Economic Geology of The Lakeland Quadrangle Florida

GEOLOGICAL SURVEY BULLETIN 1162-G

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

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By JAMES B. CATHCART

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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ECONOMIC GEOLOGY OF THE LAKELAND QUADRANGLE, FLORIDA

By James B. Cathcart

ABSTRACT

The Lakeland quadrangle, in west-central peninsular Florida, lies at the northern and eastern edges of the land-pebble phosphate district. Loose quartz sand of Pleistocene and Recent age covers the quadrangle; outcrops are confined to the mined areas in the southern part of the quadrangle. Most of the geology is known from drilling. Thin formations of Tertiary age dip very gently to the southeast away from the Ocala uplift and the Hillsborough high northwest of the quadrangle. The Tampa Limestone of early Miocene age, the Hawthorn Formation of middle Miocene age, and the Bone Valley Formation of Pliocene age crop out in the mining pits. Older formations including the Ocala Limestone of Eocene age, and the Suwannee Limestone of Oligocene age are known only from drilling.

The Ocala Limestone underlies all of the Lakeland quadrangle, and it is close to the surface only on the upthrown side of the Polk City fault in the northeast part of the quadrangle. The formation ranges in thickness from 160 to 265 feet and probably thickens to the south. The Ocala is overlain unconformably by the Hawthorn Formation on the east side of the Polk City fault and elsewhere by the Suwannee Limestone or the Tampa Limestone. The Suwannee Limestone ranges in thickness from 0 to 170 feet; it is thickest in the southern part of the quadrangle, and the upper surface of the formation dips to the south. The Suwannee Limestone is unconformably overlain by either the Tampa Limestone or the Hawthorn Formation. The Tampa Limestone ranges in thickness from 0 to 105 feet and is thickest over low spots on the surface of the Suwannee Limestone, but the formation tends to thicken toward the south and its upper surface dips toward the south and southwest. The Tampa forms the bedrock at the Tenoroc mine, where the Hawthorn and Bone Valley Formations are thin and is the bedrock of the drillers in the northwestern part of the quadrangle. All these pre-Hawthorn formations are limestone, but each stratigraphically higher formation contains more impurities than the one below. Only the Tampa Limestone contains phosphate and only in trace amounts.

The Hawthorn Formation consists of two parts—a calcareous lower part which ranges in thickness from 0 to about 120 feet, and a clastic upper part, which is present only in the southeastern corner of the quadrangle and ranges in thickness from 0 to 10 feet. The Hawthorn Formation thins to the north, and it is missing in the northwestern corner of the quadrangle. Phosphate nodules, mostly fine grained, brown, and amber, are present in the Hawthorn. Minable concentra-

tions are present only in calcareous clay, residual from the limestone of the formation.

The Bone Valley Formation, of Pliocene age, consists of a lower and an upper unit. The lower unit unconformably overlies the Hawthorn Formation except in the northern and eastern parts of the quadrangle where the upper unit overlies the Hawthorn Formation or the Tampa Limestone.

The lower unit of the Bone Valley Formation ranges in thickness from 0 to 35 feet and averages about 10 feet; it consists of unconsolidated sand, clayey sand, and sandy clay—all containing abundant phosphate nodules. The basal bed of the unit tends to be conglomeratic, and the lower unit is bedded, crossbedded, and shows well-developed graded bedding. The lower unit is not present in the northern and eastern thirds of the quadrangle except as scattered outliers. The lower unit pinches out to the north on the flank of the Hillsborough high. To the east, the unit was restricted by a ridge of calcareous material of the Hawthorn Formation.

The upper unit of the Bone Valley Formation is present throughout the Lakeland quadrangle except where it has been removed by erosion. The upper unit gradationally overlies the lower unit except in the northern part of the quadrangle where the distribution of the lower unit indicates that erosion after deposition removed the lower unit from a part of the area and prior to the deposition of the upper unit. The upper unit ranges in thickness from 0 to 25 feet and averages 8 feet. The unit is bedded and crossbedded gray clayey sand or sandy clay and has only traces of phosphate.

The major structural feature of the quadrangle, aside from the slight regional dip to the south, is the northwestward-striking Polk City fault. The northeast side of the fault is upthrown, and on this side of the fault both the Suwannee and Tampa Limestones are absent.

Three periods of weathering are of great importance in the concentration and origin of the phosphate deposit. The earliest formed a karst topography on the Hawthorn Formation, and a phosphate-rich residuum that formed on this surface was reworked into the base of the Bone Valley Formation. Intense lateritic weathering following the deposition of the Bone Valley Formation and prior to the deposition of sand of Pleistocene age changed the calcium phosphate mineral to aluminum phosphate minerals and montmorillonite to kaolinite. A soil profile characterized by limonite-cemented hardpan formed in the surficial sands or in the clayey sand of the upper unit of the Bone Valley Formation.

Mining for phosphate began about 1914 and has continued to the present when two mines are producing. All production has come from the calcium phosphate zone, which is characterized by abundant nodules of carbonate-fluorapatite. The zone includes mainly the lower unit of the Bone Valley Formation but also residual clay of the Hawthorn Formation and in the northern part of the quadrangle, residual clay of the Tampa Limestone.

The total measured, indicated, and inferred reserves of recoverable phosphate in the calcium phosphate zone, in the prospected area of the quadrangle, are about 138 million long tons. Unprospected areas in the rest of the quadrangle contain an unknown, but probably not a large, reserve of phosphate. The recoverable phosphate contains about 0.014 percent uranium.

The aluminum phosphate zone, formed by lateritic weathering, is characterized by aluminum phosphate minerals and kaolinite and by its light color. About 300 million long tons of this material, containing 4 percent P_2O_5 and 0.008 percent uranium, are present in the quadrangle. The material is not minable but is a potential source of phosphate, uranium, and possibly alumina.

About half a billion tons of phosphate nodules are present in the Hawthorn Formation. This material is very low grade and forms a potential phosphate resource for the future.

INTRODUCTION

The Lakeland quadrangle is in west-central peninsular Florida between lat 28°00′ and 28°15′ N. and long 81°45′ and 82°00′ W. (fig. 1) and is entirely within the northwestern part of Polk County.

The Lakeland quadrangle covers the northernmost part of the land-pebble phosphate district. The southern two-thirds of the quadrangle is underlain by deposits of phosphorite, but in the northern third and along the eastern edge of the quadrangle, patches of phosphate occur, which are probably erosional remnants of a blanket deposit that once nearly covered the quadrangle.

The land-pebble phosphate district covers almost 2,000 square miles. The phosphate deposits and their included uranium were investigated in order to determine their extent and origin. The factual data gathered during the field investigation will be reported in six bulletins, one on each of six 15-minute quadrangles. This report is the fourth of this series. Original isopach, isograde, and other subsurface maps were drawn by H. L. Jicha, Jr., L. J. Kosofsky, Louis Pavlides, R. G. Petersen, and T. E. Wayland. Assistance in the final map compilation was provided by A. M. Coleman, S. L. Houser, and L. J. McGreevy. Mine sections and drill-hole logs form the basis for much of the stratigraphic discussion. Logs and sections made by the following geologists of the U.S. Geological Survey were used in writing this report: D. C. Alverson, M. H. Bergendahl, L. V. Blade, W. J. Carr, D. F. Davidson, H. B. Dutro, F. N. Houser, H. M. Icke, K. B. Ketner, S. W. Maher, and R. H. Stewart. The work on which this report is based was done on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

Topography in the Lakeland quadrangle is flat to gently rolling. Two northward-trending narrow ridges are separated by a very flat, broad terrace or flatwoods area. The western ridge is in Tps. 27 and 28 S., R. 23 E. and reaches a maximum elevation of about 225 feet. The eastern ridge extends from the southern part of T. 26 S., R. 25 E., to the SE. cor. T. 28 S., R. 25 E. and is about 175 feet above sea level at its highest part. The flatwoods area between the ridges ranges in altitude from 100 to 125 feet (fig. 2).

The quadrangle is drained to the north by the Withlacoochee River, which empties into the Gulf of Mexico, and to the south by Saddle Creek, which empties into Lake Parker, then into the Peace River, which empties into the Gulf of Mexico. The small stream

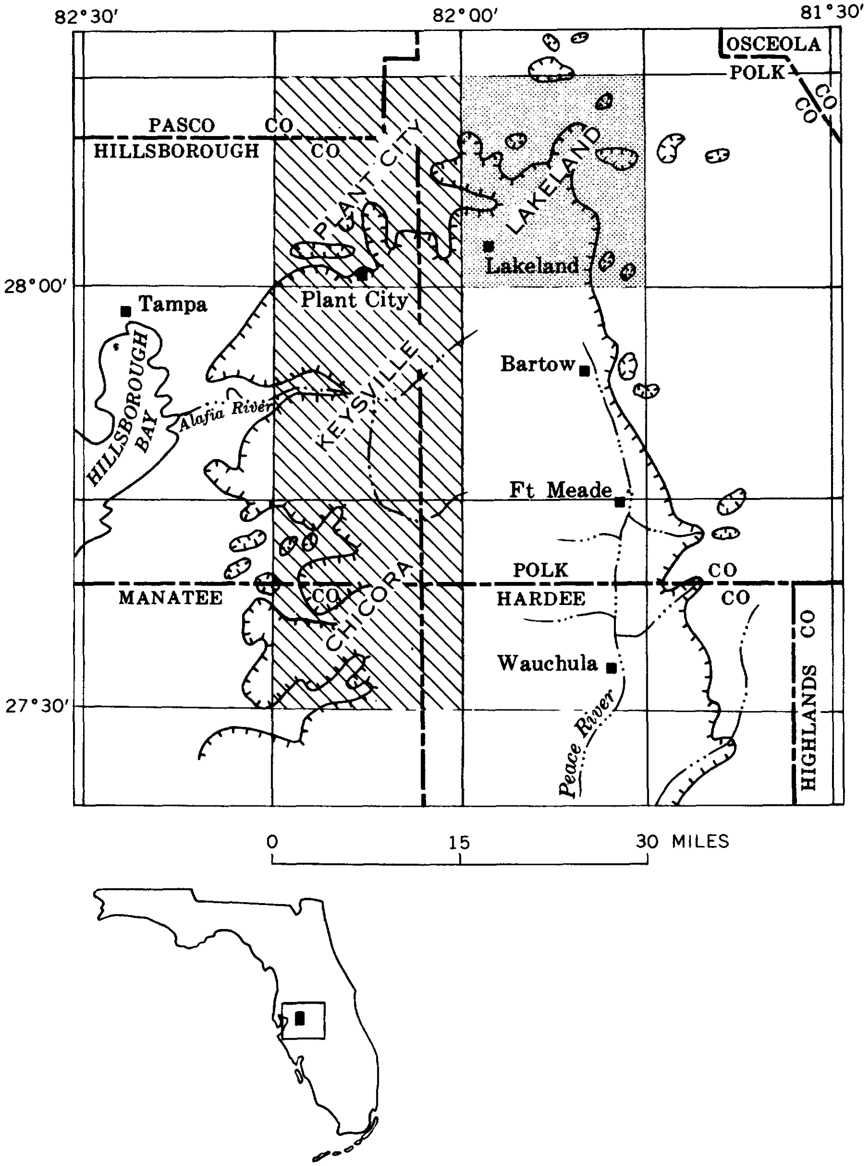


FIGURE 1.—Index map of west-central peninsular Florida, showing location of Lakeland quadrangle.

that bisects the western ridge is the headwaters of the Hillsborough River, which drains west into Tampa Bay.

PHYSIOGRAPHY

The quadrangle may be divided into three physiographic units: (1) the well-drained highlands, called the ridge area; (2) the large

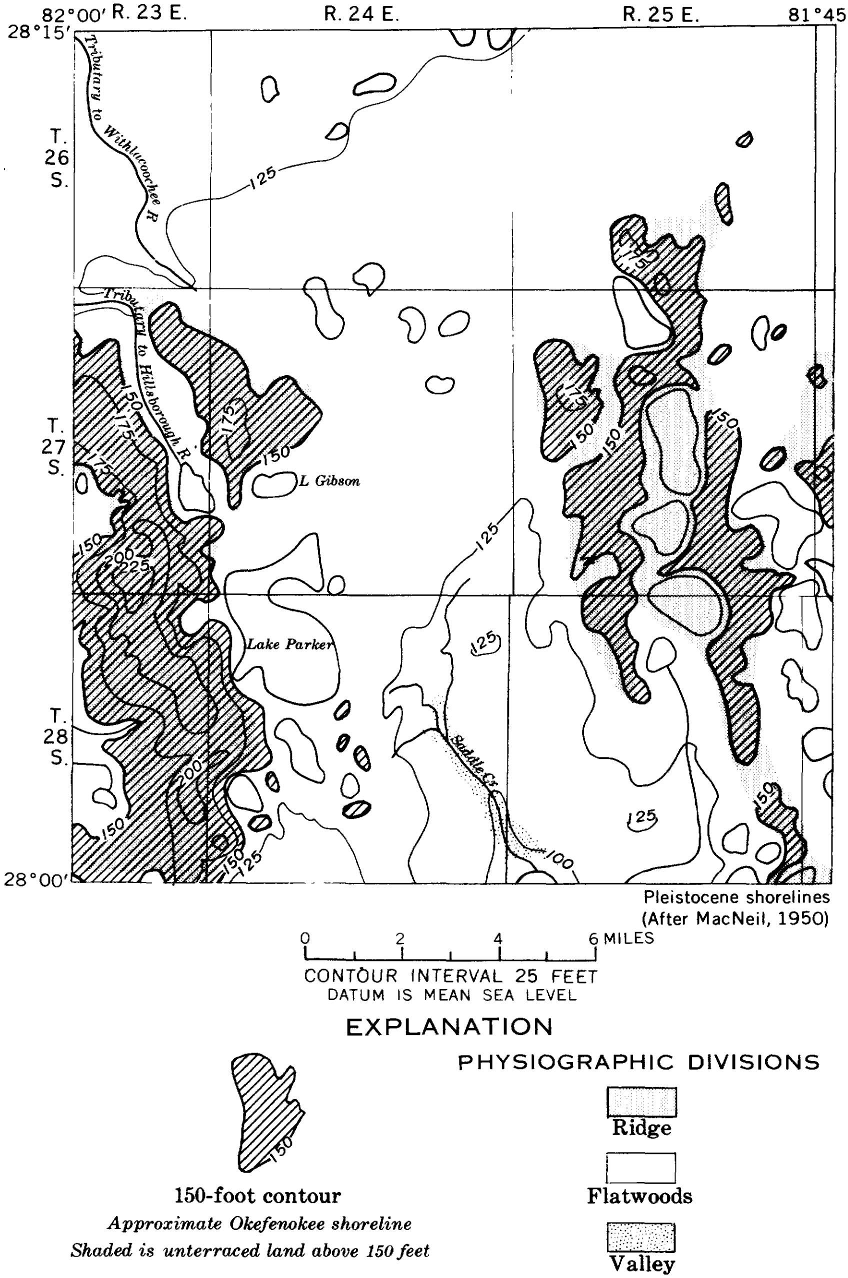


FIGURE 2.—Sketch map of topography and drainage of Lakeland quadrangle showing physiographic divisions and location of Pleistocene shorelines.

expanse of very level land called the flatwoods or the central plain; and (3) the narrow valley of Saddle Creek (fig. 2).

The valley area, which merges gradually with the flatwoods area, is restricted to a narrow strip along Saddle Creek. The creek is not well defined and flows through a swamp. The water of the stream is colored dark brown by organic material, but the stream is free of suspended detrital material.

The flatwoods area is low-lying, level, wooded, very poorly drained, and is characterized by abundant irregular swampy depressions. Streams in the flatwoods are so poorly defined that most are not shown on the maps, and they can be traced only by the swamp symbols. Common trees in the dry parts of the flatwoods are slash and longleaf pine; cypress is common in the swamps. Underbrush is wiregrass and palmetto.

The relatively high ridge area is well drained, is characterized by scrub oak, and is extensively planted with citrus trees in the Lakeland quadrangle. Many deep nearly circular sinkhole lakes are characteristic of the ridge area and are largely undrained; however, some of those at the edge of the ridge, in the high flatwoods, have external drainage.

DEFINITION OF TERMS

Local terms are used occasionally throughout the report. Because the definitions of these terms may be at variance with more commonly accepted terminology, they were defined in the report on the Keysville quadrangle (Cathcart, 1963a). For the convenience of the reader, terms used in this report are briefly defined.

Aluminum phosphate zone: Zone of aluminum phosphate minerals that originated by ground water alteration.

Leached zone: Nearly synonymous with aluminum phosphate zone, but used by some of the mining companies to indicate possibly economic material.

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

Matrix: Local term used by the mining companies to designate the economic part of the calcium phosphate zone.

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

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

BPL: Bone phosphate of lime ($Ca_3(PO_4)_2$)=percent $P_2O_5 \times 2.185$.

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

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

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

Bed clay: Plastic, generally water-saturated calcareous clay containing phosphate nodules. Residuum of the Tampa or limestone of the Hawthorn.

Overburden: Waste material above the calcium phosphate zone.

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

Hardpan: Limonite-cemented sand or clayey sand.

GENERAL GEOLOGY

The Lakeland quadrangle lies on the Gulf Coastal Plain. Thin formations of Tertiary and Quaternary age occur in the quadrangle and dip to the south at a few feet per mile off the Ocala uplift and Hillsborough high to the northwest. Loose quartz sand of Pleistocene age covers the quadrangle. The Tampa Limestone of early Miocene age crops out at the base of the pit of the Tenoroc mine (Carr and Alverson, 1959). The lower part of the Hawthorn Formation of middle Miocene age crops out at the base of the other mining pits in the area. The clastic upper part of the Hawthorn Formation is present only in the southeastern part of the quadrangle (pl. 1). The Bone Valley Formation of Pliocene age is exposed in the mining pits and was penetrated by drill holes throughout the quadrangle. Rocks older than the Tampa Limestone are known only from deep drilling—these rocks include the Suwannee Limestone of Oligocene age and the Ocala Limestone of Eocene age.

The geologic map (pl. 1) shows the distribution of the formations that underlie the loose quartz sand of the Pleistocene. Formations shown on the map include the lower and upper parts of the Hawthorn Formation and the lower and upper units of the Bone Valley Formation.

Fossiliferous limestone which forms the bedrock at the Tenoroc mine was identified as early Miocene (Carr and Alverson, 1959), and limestone or dolomite at the other mines in the quadrangle has been identified by F. S. MacNeil of the Geological Survey (oral communication, 1953) as middle Miocene in age.

Fossiliferous limestone was cored at several drill holes in 1953. Fossil lists are given by Cathcart and McGreevy (1959).

Except for these fossil localities, the formations are delineated on the basis of their lithologic characteristics. Small samples taken at 1-foot intervals during drilling were examined under a binocular microscope. Almost all of the information on which the geologic map is based is from drilling, although the mines were mapped.

ACKNOWLEDGMENTS

In an area devoid of outcrops, drilling information is of great importance in deciphering the geology. It is a pleasure to acknowledge the cooperation of the several phosphate mining companies who gave their drilling data to the Geological Survey. The American Agricultural Chemical Co., American Cyanamid Co., Coronet Phosphate Co. division of Smith-Douglas Co., Inc., Davison Chemical Co. division of W. R. Grace and Co., and International Minerals and Chemical Corp. allowed the writer to examine their files and provided maps, samples, and access to their mining pits. Mr. Wayne Thomas, consultant on phosphate lands, gave free access to his files of drilling and analytical data and checked certain aspects of the history of the mining.

The Tennessee Valley Authority drilled the government-owned tracts of land and furnished analytical data on the drill samples.

Thousands of chemical and radiometric analyses of the uranium content of the pebble and concentrate fractions of the calcium phosphate zone and of the uranium content of the aluminum phosphate zone were made in the Denver and Washington laboratories of the U.S. Geological Survey. Radiometric analyses were made by W. R. Champion, C. E. Cox, Jr., F. J. Flanagan, S. P. Furman, J. H. Goode, Jr., E. H. Humphrey, B. A. McCall, Percy Moore, and J. J. Warr, Jr. Chemical analyses were made by Haydee Alberty, M. E. Appling, I. H. Barlow, Sam Bethea, G. W. Boyes, Jr., J. W. Budinsky, G. T. Burrow, A. B. Caemmerer, C. E. Cox, Jr., Frank Cuttita, G. J. Daniels, Maryse Delevaux, David Diebler, M. E. F. Eiland, R. K. Fuyat, J. H. Goode, Jr., J. L. Green, F. S. Grimaldi, N. K. Guttag, E. H. Humphrey, Joan Hunter, Nancy Jammer, Lillie Jenkins, C. R. Johnson, H. B. Kessler, Dorothy Lee, McGee, J. W. T. Meadows, Henry Mela, Jr., R. L. Meyrowitz, R. G. Milkey, Wayne Mountjoy, Roosevelt Moore, Audrey Pietsch, I. B. Robinson, J. N. Rosholt, Jr., J. J. Rowe, Marion Schnepfe, J. P. Schuch, Leonard Shapiro, Audrey C. Smith, Joan Smith, Roberta Smith, L. Steele, C. M. Stevens, W. P. Tucker, Clarence Vaughn, James Wahlberg, and A. L. White.

STRATIGRAPHY

The stratigraphy, lithology, and mining terminology are summarized on plate 2. Exposures are limited to the mining pits where only the uppermost part of the section is exposed. Company prospect drilling penetrated only through the sand of Pleistocene age and the Bone Valley Formation, except in the northern part of the quadrangle where the prospect drill holes went through the Hawthorn Formation and bottomed on the Tampa Limestone. Formations older than the

Tampa Limestone are not exposed in the mining pits, and are known only from the few deep drill holes (table 1).

EOCENE SERIES—OCALA LIMESTONE

The Ocala Limestone of Eocene age (Vernon, 1951; Cooke, 1959) underlies but does not crop out in the Lakeland quadrangle, although it is close to the surface in the northeastern part of the quadrangle, on the upthrown side of the Polk City fault (holes D2, D3, and D9, table 1). The Ocala Limestone is unconformably overlain by the Hawthorn Formation of middle Miocene age on the east side of the fault. Elsewhere in the quadrangle, except at hole D10 (pl. 1), the Ocala Limestone is unconformably overlain by the Suwannee Limestone. At hole D10 (table 1) the Ocala Limestone is overlain by the Tampa Limestone. The stratigraphic relations are shown in figure 3.

The upper surface of the formation is from 64 to 77 feet above sea level on the east (upthrown) side of the Polk City fault, it is 55 feet below sea level on the west side of the fault in T. 27 S., and it reaches a maximum of 181 feet below sea level in T. 28 S. (table 1). Thus the surface of the formation is sloping to the south

The total thickness of the formation is known at only five drill holes in the Lakeland quadrangle (table 1), where it ranges from 160 to 265 feet. At these drill holes, the Ocala Limestone rests on the Avon Park Limestone of Eocene age. There is some suggestion that the formation thickens to the south, but erosion has modified the upper surface of the formation, and the differences in thickness represent, in part, erosional relief on the top of the formation.

The Ocala is a very pure limestone, at places containing as much as 99 percent $CaCO_3$ (Mossom, 1925, p. 69). Digestion in hydrochloric acid yields only a trace of insoluble residue—a very fine clay. The Ocala Limestone, cored at drill holes D2, D3, and D9, is a cream to light-gray soft porous granular fossiliferous limestone. Fossils from these three localities were identified by F. S. MacNeil of the Geological Survey and are listed by Cathcart and McGreevy (1959, p. 226).

OLIGOCENE SERIES—SUWANNEE LIMESTONE

The Suwannee Limestone of Oligocene age (Cooke and Mansfield, 1936, p. 71; MacNeil, 1947) does not crop out in the Lakeland quadrangle, but deep drill holes indicate that it is present only in the western and southern parts of the quadrangle, on the downthrown block of the Polk City fault (pl. 1). The upper surface of the formation is an irregular erosion surface (fig. 3). The Suwannee Limestone has been eroded from the upthrown block of the Polk City fault so that the Hawthorn Formation rests on the Ocala Limestone and from a high on the Ocala surface in the NE cor. T. 28 S., R. 23 E.

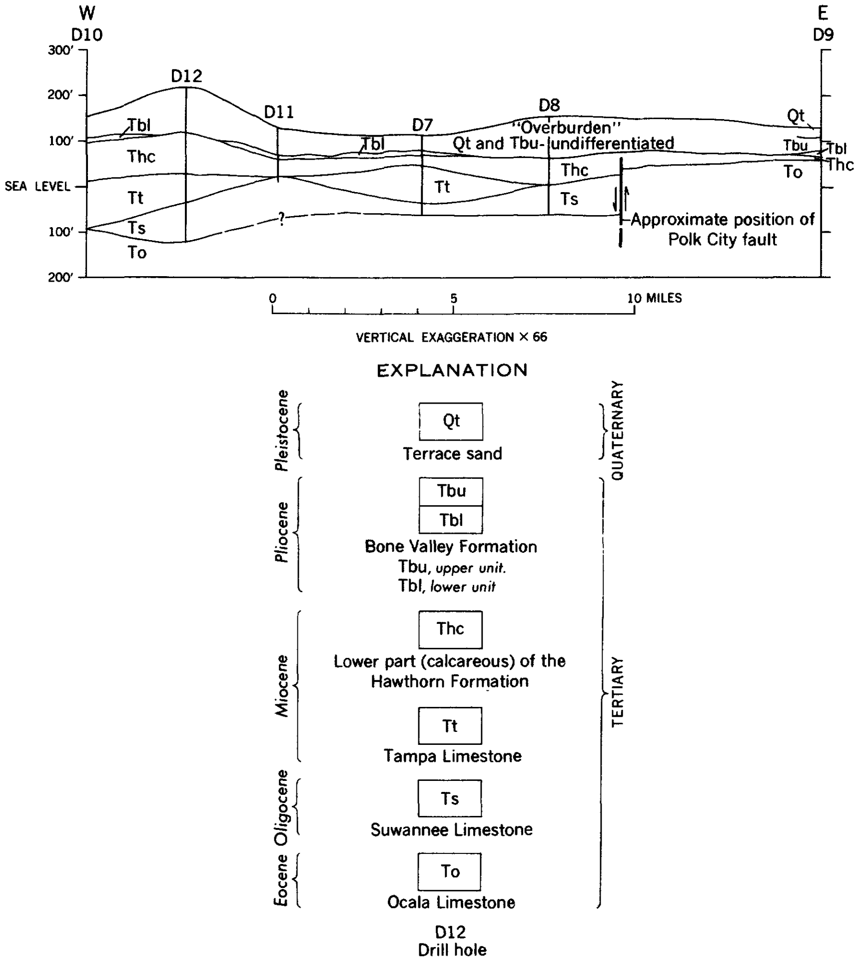


FIGURE 3.—Stratigraphic relations, Lakeland quadrangle, Florida. Location of section shown on plate 1.

(hole D10, table 1 and fig. 3), so that the Tampa Limestone rests on the Ocala Limestone.

The Suwannee ranges in thickness from 0 to 170 feet (table 1) and is thickest in the southern part of the quadrangle. The top surface of the formation is dipping to the south. In the north part of the quadrangle, the top of the formation is about 90 feet above sea level (holes D1 and D4, table 1); to the south, in T. 28 S., the top of the formation is from 5 to 34 feet below sea level (holes D12 through D15, table 1).

The Suwannee is a relatively pure limestone; it is commonly soft and granular and yellow to cream. Where close to the surface, the upper part of the formation may be silicified. The average content

TABLE 1.—*Summary of data from deep well logs, Lakeland quadrangle*

[Altitudes are feet above (+) or below (−) mean sea level; thicknesses are in feet. Leaders(..) = formation not present at drill hole; ND = no further data. Source of data: 1, Cathcart and McGreevy (1959); 2, Stratigraphy by F. S. MacNeil, U.S. Geol. Survey, from Florida Geol. Survey log; 3, Florida Geol. Survey log; 4, Cole (1941); 5, Stratigraphy by J. S. Cullison 3d, U.S. Geol. Survey]

Hole (pl. 1)	Location			Altitude of collar	Hawthorn Formation		Tampa Limestone		Suwannee Limestone		Ocala Limestone		Source of data
	Sec.	T. S.	R. E.		Thickness	Altitude	Thickness	Altitude	Thickness	Altitude	Thickness	Altitude	
D1	27	26	23	+120	..	..	18	+105	ND	+87	ND	ND	1
D2	21	26	25	+135	13	+79	..	..	..	..	ND	+64	1
D3	21	26	25	+140	10	+87	..	..	..	..	ND	+77	1
D4	1	27	23	+140	12	+111	3	+99	ND	+96	ND	ND	1
D5	11	27	24	+140	20	+121	ND	+101	ND	ND	ND	ND	1
D6	18	27	24	+150	18	+116	ND	+98	ND	ND	ND	ND	1
D7	31	27	25	+115	15	+70	95	+55	15	−40	160	−55	2
D8	34	27	25	+160	55	+65	..	..	65	+10	ND	−55	3
D9	3	27	26	+140	9	+77	..	..	..	..	ND	+68	1
D10	1	28	23	+157	85	+95	103	+10	..	..	ND	−93	4
D11	10	28	24	+130	40	+60	..	..	ND	+20	ND	ND	5
D12	17	28	24	+220	92	+120	62	+28	76	−34	166	−119	2
D13	28	28	24	+134	60	+109	60	+49	170	−11	195	−181	2
D14	27	28	24	+132	40	+92	65	+52	125	−13	265	−138	3
D15	26	28	24	+120	85	+80	..	..	105	−5	230	−110	3
D16	22	28	25	+125	[1] 8	+60	ND	+52	ND	ND	ND	ND	1
D17	25	28	25	+150	[2] 13	+83	ND	+70	ND	ND	ND	ND	1

[1] Upper part of the Hawthorn Formation, 8 ft thick.
[2] Upper part of the Hawthorn Formation, 10 ft thick, underlain by 3 ft of the calcareous lower part of the Hawthorn Formation.

of impurities (clay and silt) is 13 percent, according to Carr and Alverson (1959), but Mossom (1925) cited analyses of the Suwannee Limestone showing as much as 98 percent $CaCO_3$.

The Suwannee Limestone is unconformably overlain by the Tampa Limestone (Cooke, 1945, p. 88; Vernon, 1951, p. 67), and where the Tampa has been removed by erosion, the Suwannee is overlain by the Hawthorn Formation (holes D8 and D11, fig. 3, and table 1).

MIOCENE SERIES

TAMPA LIMESTONE

The Tampa Limestone of early Miocene age (MacNeil, 1947; Vernon, 1951) does not crop out in the Lakeland quadrangle but forms the limestone bedrock of a part of the Tenoroc pit (Carr and Alverson, 1959). It is absent from the northeastern or upthrown block of the Polk City fault, as is the Suwannee Limestone. The Tampa is also missing in two areas on the southwest or downthrown side of the fault—one in T. 28 S., R. 24 E. (hole D11, table 1)—the other in the southeast part of T. 27 S., R. 25 E. (hole D8, table 1). As shown in figure 3, both of these areas are on highs on the surface of the Suwannee Limestone. Between the highs, the Tampa almost reaches its maximum thickness in the quadrangle—95 feet at hole D7.

The Tampa Limestone, then, was deposited on the irregular eroded surface of the Suwannee Limestone and either was not deposited or was much more thinly deposited on the highs and on the east side of the Polk City fault.

The Tampa Limestone, if it was present, was eroded from the highs and from the upthrown side of the Polk City fault prior to the deposition of the Hawthorn Formation. The period of erosion was probably of local extent; drilling to the south of the land-pebble district indicates that the Tampa Limestone and the Hawthorn Formation are conformable, and Cooke (1945, p. 115) pointed out that in the northern part of the State the boundary between the two formations is gradational and indefinite.

The Tampa ranges in thickness from 0 to 105 feet. It thickens over low areas on the Suwannee surface and tends to be thicker in the southern part of the quadrangle than in the northern part (table 1)—a reflection of its deposition on the rising Ocala uplift to the north. The surface of the formation is highest in the north part of the quadrangle—about 100 feet above sea level in Tps. 26 and 27 S. (holes D1, D4, D5, and D6, table 1) and lowest in the southwest part of the quadrangle—10 feet above sea level in T. 28 S., R. 23 E. (hole D10, table 1). The formation, therefore, is probably dipping to the south and southwest, off the Ocala uplift.

The Tampa is a cream to light-gray, sandy, clayey limestone that contains a few lenticular beds of clay and sand. It contains many more impurities—particularly chert nodules, clay, fine-grained sand, and phosphatic nodules—than either the Suwannee or Ocala Limestones. In many places where the Tampa is close to the surface, as at the Tenoroc mine, it is covered by a residual mantle of greenish-gray sandy clay containing phosphate and chert nodules.

Phosphatic nodules in the Tampa Limestone are not abundant, ranging from a trace to about 20 percent by weight and averaging only about 5 percent. The nodules are white, gray, tan, and brown and are very low in P_2O_5 content. Twenty-two samples of coarse nodules (+14 mesh or pebble) from 11 drill holes were analyzed for phosphate. Their P_2O_5 content ranged from 2.03 to 6.97 percent and averaged 3.98 percent. In eight samples of soft, partly weathered limestone from eight drill holes, the P_2O_5 content ranged from 0.21 to 0.72 percent and averaged 0.32 percent. The average P_2O_5 content of these samples is almost precisely the same as the average P_2O_5 content of the Tampa Limestone (0.3 percent) as reported by Carr and Alverson (1959). Although the total number of analyzed samples is small, the ranges and averages of P_2O_5 content are very close to those reported in the Plant City quadrangle (Cathcart, 1963b). These samples probably are representative of the P_2O_5 content of the limestone and of the phosphatic nodules in the Tampa.

Fossiliferous Tampa Limestone was cored at one drill hole in the Lakeland quadrangle; fossils are listed by Cathcart and McGreevy (1959). Fossils from the Tampa Limestone at the Tenoroc mine are listed by Carr and Alverson (1959).

HAWTHORN FORMATION

The Hawthorn Formation, of middle Miocene age (Cooke, 1945; MacNeil, 1947), is divided into two parts in the Lakeland quadrangle. The lower part (calcareous) makes up almost all of the thickness of the formation and is under the entire quadrangle except for two small areas in the northwest part (pl. 1). The upper part (clayey sand) is only in the southeast part of the quadrangle; it is very thin but is so distinctive lithologically that it has been separated as a member.

The lower part of the formation crops out only along the course of Saddle Creek, and even here it is normally covered by loose quartz sand of Pleistocene and Recent age. The lower part is also exposed in the mining pits in the area, and it forms the bedrock or basement rock of the drillers at drill holes throughout most of the Lakeland quadrangle. The upper part is known only from a few drill holes in the southeastern part of the quadrangle.

LOWER PART

THICKNESS

The Hawthorn Formation in the Lakeland quadrangle ranges in thickness from 0 to about 120 feet (fig. 4) and, except in the southeastern part of the quadrangle, only the lower part is present. In the quadrangle, the greatest thickness of the lower part measured at a drill hole is 92 feet (hole D12, table 1), but at a drill hole less than half a mile south of the south boundary of the quadrangle, in sec. 33, T. 28 S., R. 24 E., a thickness of 135 feet was measured. The formation thins to the north and northeast. Two salients of thick rock trend northeast and, in the area of the Tenoroc mine, are separated by a subparallel belt where the formation is thin. In the northern third and in the southeastern corner of the quadrangle, the thickness of the lower part is no greater than about 20 feet and probably averages only about 10 feet. The formation is missing from a small area in the northeastern part of the quadrangle and from an irregular area in the southeastern part of T. 26 S., R. 23 E. (fig. 4). It has been eroded from these areas, but probably was initially thinner in the northern part of the quadrangle, as it was deposited over the rising Ocala uplift and Hillsborough high (Cathcart, 1963b). Thick and thin areas of the Hawthorn Formation do not have any relation to the surface of the Hawthorn (fig. 7), but the thicker Hawthorn rests on lows on the Tampa surface, and thinner Hawthorn is on highs on the Tampa surface (fig. 3).

UPPER CONTACT OF THE HAWTHORN FORMATION

The upper surface of the Hawthorn Formation in the Lakeland quadrangle is a karst topography, which has very abundant small irregular depressions and hills (pl. 3). There is a suggestion that a subsurface ridge is present at the western edge of the quadrangle, and a second very poorly defined ridge is at the eastern edge, although data are scattered and incomplete. The two higher areas are separated by a central plain, which is dotted with sinkholes. Altitudes in this central plain are at or close to 100 feet above sea level—the 100-foot contour is a very irregular line, which is present throughout the central plain. The lowest altitude on the central plain is 30 feet above sea level—in a sinkhole at the southern boundary of the quadrangle. Altitude at the western edge of the quadrangle reach a maximum of about 140 feet and a minimum of about 90 feet, and in the eastern part of the quadrangle, the surface of the Hawthorn is at an altitude of slightly more than 130 feet.

The surface of the Hawthorn is similar in its topography to the present surface in a very general way—that is, two northward-trending

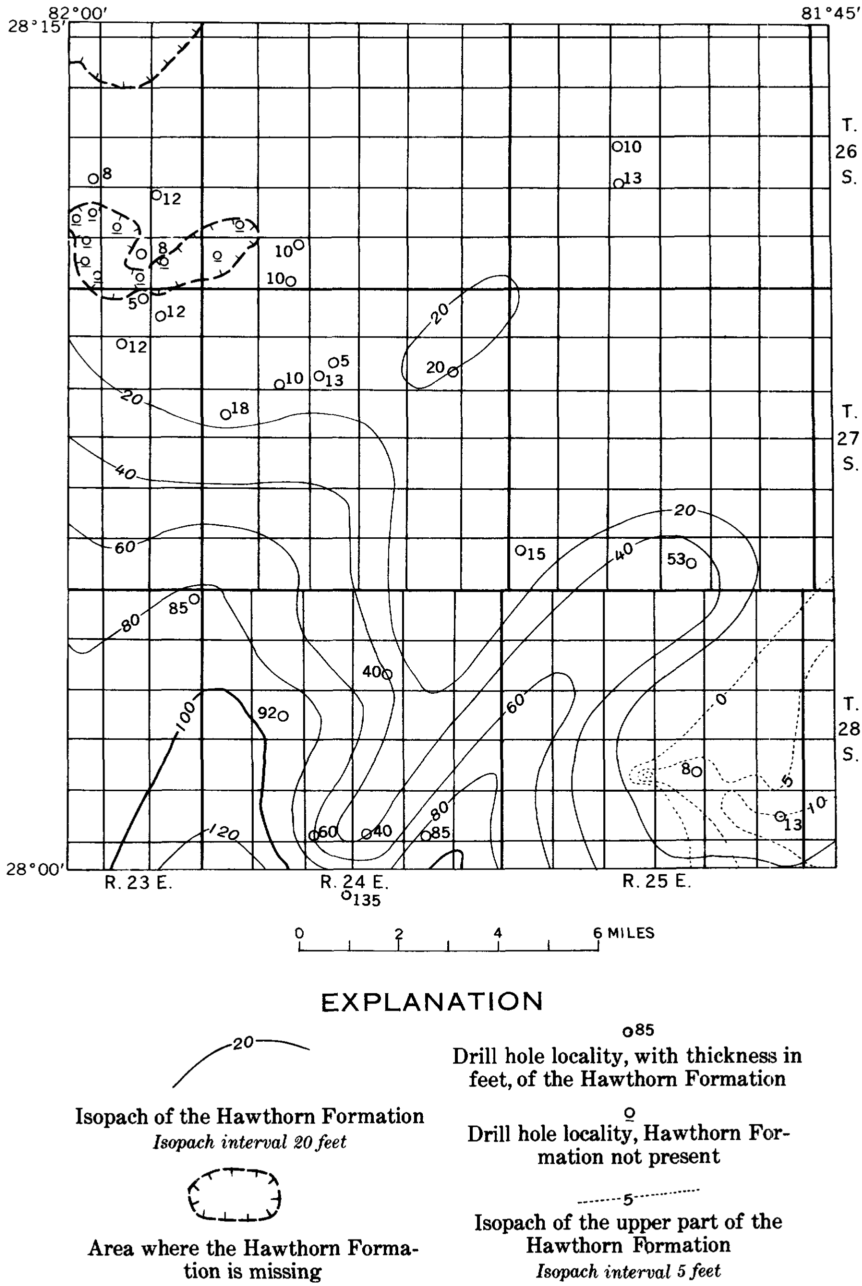


FIGURE 4.—Isopach map of the Hawthorn Formation, Lakeland quadrangle.

ridges separated by a broad central plain—but there is no similarity in detail. The surface of the Hawthorn has no through-going drainages, although there is a low troughlike area in about the position of Saddle Creek. Thus it is likely that the present surface has inherited some of its features from the Hawthorn surface; for example, the two present ridges are underlain by ridges of Hawthorn limestone.

PHYSICAL CHARACTERISTICS

The lower part of the Hawthorn Formation consists of impure limestone or dolomite at all of the mine exposures and of limestone in the deeper drill holes (table 1). Only the top few feet of the lower part is exposed in the mine pits, and here the unit consists almost entirely of residual calcareous clay or soft limestone. Mining stopped on the hard limestone, which generally is exposed only in the drainage ditches in the bottoms of the pits. The hard limestone or dolomite is cream, white, buff, or light gray, is sandy and clayey, and contains common to abundant phosphate nodules. The phosphate is very fine to medium sand size and has only traces of the granule or pebble fraction. The phosphate nodules are highly polished and are amber, tan, brown, gray, black, and white. Amber nodules are characteristic of the Hawthorn Formation, even though nodules of different colors locally are more abundant. The lower unit (phosphorite) of the Bone Valley Formation only rarely contains amber nodules and then only in the basal part of the unit. The quartz sand fraction of the Hawthorn Formation is fine to medium in most places, but it is coarse in a few localities.

Material too hard to penetrate with the hand auger was present at almost every drill locality. This material is probably limestone or dolomite of the Hawthorn Formation except at the Tenoroc mine, where it may be in the Tampa Limestone.

Hard carbonate rock may be overlain by the bedded phosphorite of the lower unit of the Bone Valley Formation, but at most places the hard material grades upward to calcareous clay—a residuum of limestone of the lower part of the Hawthorn Formation. The calcareous clay is gray, gray blue, gray green, yellow, cream, or brown and contains abundant fine- to medium-grained quartz and phosphate sand and trace amounts of phosphate pebble. Texturally, the clay and the limestone are identical. Phosphate nodules in the calcareous clay may be abundant enough and high enough in P_2O_5 to be minable. The contact between the limestone and the calcareous clay is very irregular in detail and is gradational over a few inches. Contact relations at a section at the Saddle Creek mine are shown in figure 5.

The contact between the calcareous clay and the hard limestone is extremely irregular in detail, and it is a weathering contact as indicated

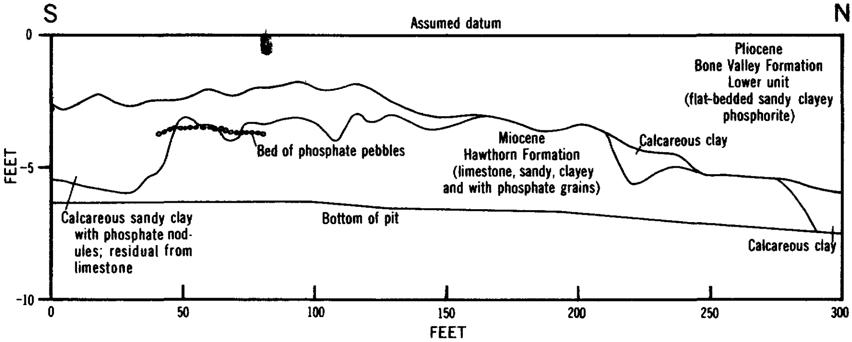


FIGURE 5.—Section of a pit wall at the Saddle Creek mine, showing the contact between residual clay and limestone, Hawthorn Formation.

by the thin bed of phosphate pebbles that was traced for about 40 feet at the southern part of the section. The bed of pebbles is present in both the limestone and the calcareous clay. The calcareous clay at this section ranges in thickness from 0 to about 3 feet. The Bone Valley Formation rests on both the limestone and the calcareous clay, and the contact between the two formations is irregular and nonconformable, but the irregularities are not nearly as large as those between the calcareous clay and the limestone.

STRATIGRAPHIC RELATIONS

The Hawthorn Formation was deposited on the eroded surface of the Tampa Limestone, and, as shown in figure 3, the Hawthorn Formation overlies the Tampa Limestone, the Suwannee Limestone, and, on the east side of the Polk City fault, the Ocala Limestone. The period of erosion was probably not very long; to the south unpublished data indicate that the Hawthorn Formation rests on the Tampa Limestone without any apparent break.

The contact between the Hawthorn and Bone Valley Formations was exposed at a few localities at the Saddle Creek and Pauway mines. At a stratigraphic section at the Saddle Creek mine (log of mine face section *R*, page G107), the contact between the formations is described as very irregular and unconformable.

A pit of the Saddle Creek mine was examined in 1956, and a sketch of the relations between the Bone Valley and Hawthorn Formations is shown in figure 6. Three feet of hard buff limestone, containing quartz grains and brown and tan fine sand-sized phosphate nodules was exposed in the ditch at the north end of the cut. The limestone is overlain by gray calcareous clay containing some fragments of limestone and fine sand-sized brown, tan, and gray phosphate nodules. The contact between the calcareous clay and the limestone is gradational and irregular. To the south, the surface of the limestone

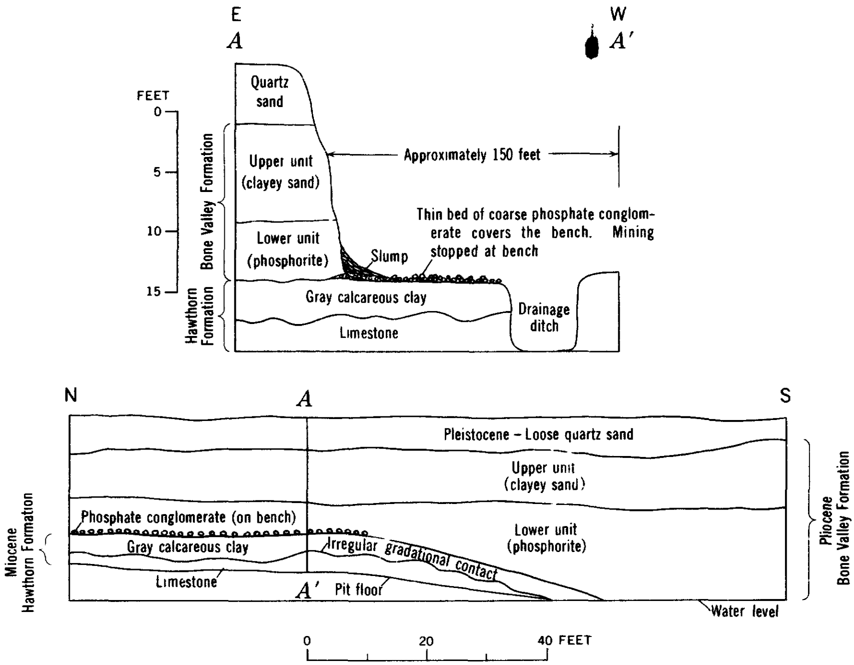


FIGURE 6.—Sketch of the Hawthorn-Bone Valley contact, Saddle Creek mine, NE¼ sec. 14, T. 28 S. R. 24 E.

drops, and at the south end of the cut, the limestone and the calcareous clay are both below water level. The phosphorite of the lower unit of the Bone Valley Formation thickens abruptly to the south, and at the south end of the section is more than twice as thick as at the north end. The contact between the gray calcareous clay of the Hawthorn Formation and the phosphorite of the lower unit of the Bone Valley Formation was covered by slumping (fig. 6), but the bench at the base of the matrix (on the top of the calcareous clay) was covered by a thin layer of very coarse brown phosphate granules and cobbles. The calcareous clay and the limestone contain only fine-grained phosphate nodules, and the phosphate gravel on the bench is probably the basal conglomerate of the Bone Valley Formation. The basal conglomerate and the abrupt thickening of the lower phosphorite of the Bone Valley indicate that the contact between the Bone Valley and the Hawthorn Formations is unconformable.

The irregular contact between the Bone Valley and Hawthorn Formations is shown on the fence diagram of the Saddle Creek mine (pl. 4). The lower unit of the Bone Valley Formation is thicker over low areas on the Hawthorn surface and thinner over Hawthorn highs.

The contact between the Bone Valley and Hawthorn Formations was seen at the Pauway mine. Here, also, the relations are unconformable. Horizontally bedded phosphorite of the Bone Valley Formation overlies an irregular surface of massive hard limestone of the Hawthorn Formation (fig. 7; section *B–B′*, pl. 5).

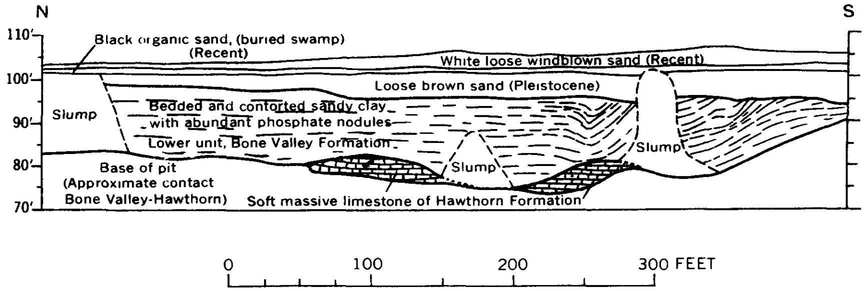


FIGURE 7.—Schematic section map of pit wall, Pauway mine, showing contorted bedding, and the irregular contacts of the Bone Valley Formation. Adapted from a planetable survey by L. V. Blade and J. B. Cathcart.

The contact was not seen at the Orange mine, which began operating after the fieldwork was completed. However, microscopic examination of core chips taken at 1-foot intervals during the drilling showed marked changes in lithology at the contact between the lower unit of the Bone Valley Formation and the residual calcareous clay of the Hawthorn Formation. At a drill hole locality in the SW¼NE¼ sec. 21, T. 27 S., R. 24 E., the Hawthorn Formation is a gray-tan calcareous clay and has minor phosphate nodules and fine to very fine to silt-sized clear angular quartz grains. Overlying the calcareous clay is the lower unit of the Bone Valley Formation, a sand of phosphate and medium- to coarse-grained rounded frosted quartz. The coarse (pebble) fraction of the phosphate is most abundant at the base of the Bone Valley Formation. The contact between the Bone Valley and Hawthorn Formations is sharp, clear, and probably nonconformable.

The contact was not seen at the Tenoroc mine because of slumping at the base of the pits, but the striking lithologic change at the contact, as seen in the drill cores from the tract (log L, p. G93), probably represents a nonconformable relation.

The contact of the Bone Valley and Hawthorn Formations is difficult to determine at some drill holes. For example, at a drill hole in the SE¼SW¼ sec. 35, T. 27 S., R. 25 E., the Bone Valley consists of interbedded gray-green and gray-blue sand, clayey sand, and sandy clay containing abundant to common nodules of phosphate. The underlying Hawthorn at this drill hole consisted of slightly calcareous blue-green sandy clay. The Hawthorn Formation contained somewhat less phosphate and somewhat more clay than the Bone Valley

Formation. The phosphate nodules in the Bone Valley Formation were coarser than those in the Hawthorn Formation, and the ratio of the pebble fraction to the concentrate fraction was greater than one in the Bone Valley and about one in the Hawthorn. The differences are slight but were noticeable enough so that the drilling foreman took two samples—one of the sandier material of the Bone Valley, the other of the clayier material of the Hawthorn.

The samples were screened, tested by flotation methods, and analyzed and proved to be significantly different. The sample from the Bone Valley had a pebble-to-concentrate ratio of 1.6; the Hawthorn sample 0.9. The total amount of recoverable phosphate was about 20 percent greater in the Bone Valley than in the Hawthorn, and the P_2O_5 content of both pebble and concentrate fractions was appreciably greater in the Bone Valley than in the Hawthorn. The analytical data are shown in table 9.

UPPER PART

A distinctive lithologic unit, which rests on limestone or calcareous clay of the Hawthorn Formation or on limestone of the Tampa, is present in the southeastern part of the quadrangle. The approximate distribution of the unit is shown on plate 1.

The unit consists of olive-green micaceous fine-grained clayey sand and minor amounts of fine sand- to granule-sized black phosphate nodules. The unit was penetrated by only nine drill holes in the Lakeland quadrangle, and no fossils were found in the unit at these localities. To the east, outside of the quadrangle boundary, fossils identified as middle(?) Miocene by F. S. MacNeil of the U.S. Geological Survey were recovered from a drill hole in the NE¼NW¼ sec. 7, T. 27 S., R. 27 E. (Cathcart and McGreevy, 1959, p. 233).

MacNeil (written communication, 1956) suggested that the unit was either late middle Miocene or early upper Miocene. He further suggested that a middle(?) Miocene age was perhaps best and indicated that the unit was probably the upper part of the Hawthorn Formation. Therefore, in this report, this clayey sand is considered to be the upper part of the Hawthorn Formation.

In the Lakeland quadrangle, the upper part of the Hawthorn Formation ranges in thickness from 0 to 10 feet and thickens to the east and to the south (fig. 4).

The upper part occurs on the east side of the eastern ridge on the Hawthorn surface (pl. 3), and in this area the Hawthorn Formation is generally thin (less than 20 feet thick, fig. 4), and most of section is included in the upper part of the formation. A typical section of the upper part is shown by the following log.

Log of drill hole A, NW¼SW¼ sec. 23, T. 28 S., R. 25 E.

[Modified from lithologic log prepared by S. W. Maher, U.S. Geol. Survey; drilled by the Tennessee Valley Authority]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, light-brown, medium-grained	3
Sand, clayey, gray	8
Sand, loose, medium- to fine-grained; brown at top, grading to white below	44
Total terrace sand	55
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, clayey to very clayey, gray	5
Miocene:	
Hawthorn Formation:	
Upper part:	
Sand, slightly clayey, olive-green, micaceous; contains minor black sand- to fine granule-sized phosphate	6
Clay, very sandy, olive-green; contains trace amounts of mica flakes. No visible phosphate	2
Lower part:	
Limestone, hard, buff, sandy; contains trace amounts of fine-grained phosphate	<1
Part of Hawthorn Formation	8+
Bottom on material too hard to penetrate.	

Stratigraphic relations of the upper part of the Hawthorn Formation are shown in figure 8. The unit is present only at holes 5 and 6; it thickens eastward, and at hole 6 the upper part of the Hawthorn Formation rests on the Tampa Limestone. The Hawthorn Formation is thin in the eastern and northern parts of the Lakeland quadrangle, and at hole 6 (fig. 8) all of the Hawthorn Formation is referable to the upper part. It is most probable that the lower part of the Hawthorn was not deposited in this area; certainly to the north this member of the formation is only a few feet thick.

PLIOCENE SERIES—BONE VALLEY FORMATION

The phosphate deposits of Florida were described by Eldridge (1893) who called the deposits of Polk and Hillsborough Counties the land-pebble phosphate. Dall (in Dall and Harris, 1892, p. 137) did not propose a formal name for the beds that include the phosphate deposits but called the material "pebble phosphate." Matson and Clapp (1909, p. 138) proposed the name Bone Valley Gravel for the phosphate deposits, and Sellards (1910, p. 33) changed the name to the Bone Valley Formation.

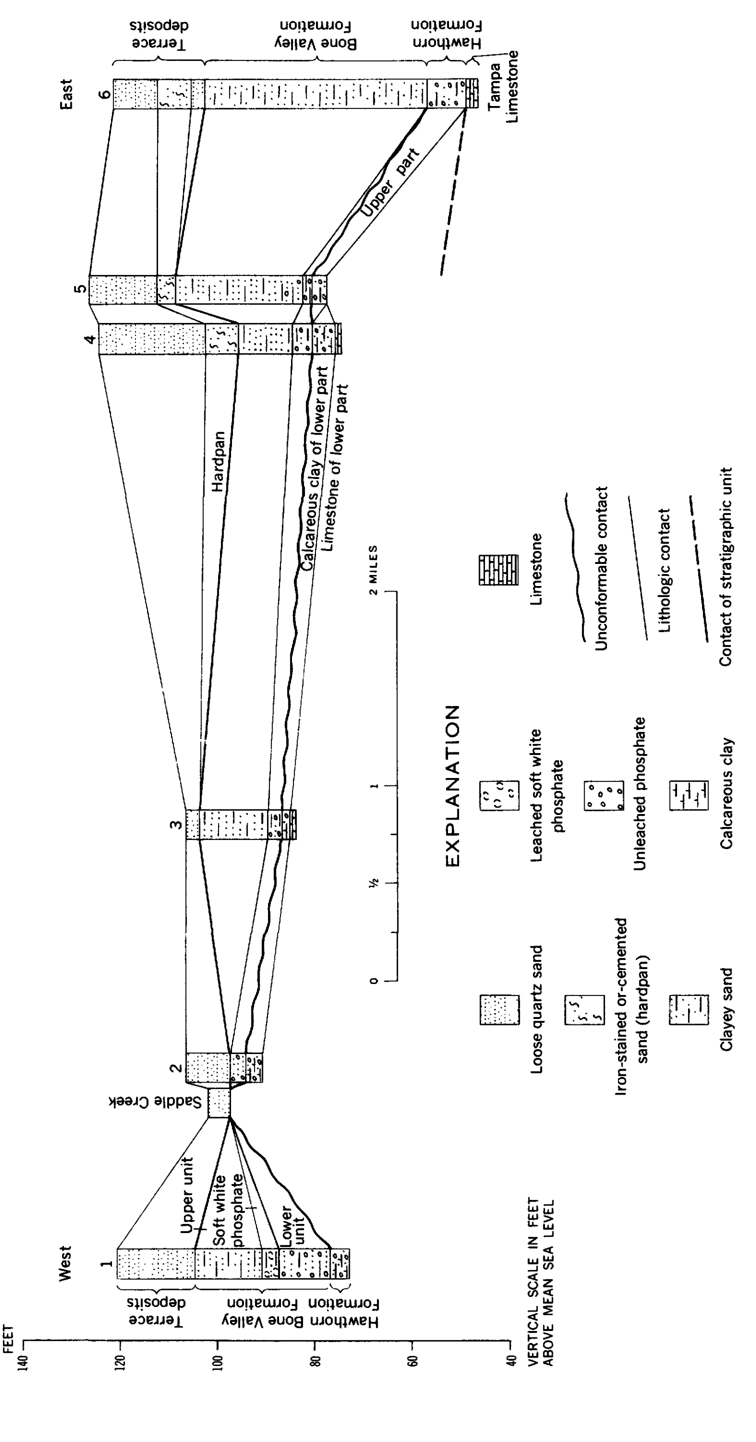


FIGURE 8.—Section, Lakeland quadrangle, showing stratigraphic relations of the upper part of the Hawthorn Formation. Location of section shown on plate 1.

As originally described, the Bone Valley was divided into a lower unit, which included all of the minable phosphate, and an upper unit of clayey sand containing only a minor amount of phosphate. Loose surficial sands were excluded from the Bone Valley, and the lower unit was described as resting unconformably on limestone or marl.

The Bone Valley Formation is divided into two units—a phosphatic lower unit and an upper unit of clayey sand. The lower unit includes most of the economic phosphate deposit, but calcareous clay, residual from the limestone of the Hawthorn Formation, that contains enough phosphate to be economic is not included in the lower unit of the Bone Valley Formation. The contact between the upper and lower units is gradational over a few inches throughout most of the quadrangle, but in the northern and eastern parts of the quadrangle, outliers of the lower unit indicate that deposition was not continuous in this area and that there was a slight erosional break between the upper and lower units of the Bone Valley Formation at the northern limit of deposition of the lower unit. The upper unit, which includes all of the clayey sand containing traces of phosphate, is overlain by loose sand of Pleistocene age.

The Bone Valley Formation is Pliocene in age. A single fossil tooth, found in the matrix at the Saddle Creek mine, was identified as *Tayassuid* cf. *Desmathysus* Matthew, an early to middle Pliocene(?) form, by Mrs. Jean Hough of the U.S. National Museum. Fossil evidence from the Keysville, Chicora, and Fort Meade quadrangles (Cathcart, 1963 a, c) also indicates a Pliocene age for the formation.

LOWER UNIT

THICKNESS AND DISTRIBUTION

The lower unit of the Bone Valley Formation is present in the southwestern two-thirds of the Lakeland quadrangle. The unit is absent from the northern tier of townships and along the eastern edge of the quadrangle (pl. 1). A few outliers are present in the northern and eastern thirds of the quadrangle. The outliers are not present very far to the north or to the east of the main extent of the formation, and the line on the map (pl. 1) showing the extent of the lower unit is probably only slightly to the south and west of the shoreline at the time of deposition.

The lower unit ranges in thickness from 0 to 35 feet and averages about 10 feet. The calcium phosphate zone (pl. 6) includes rocks of both the lower unit of the Bone Valley Formation and residual clay of the Hawthorn Formation and the isopach map does not precisely show the distribution of the lower unit. Most of the calcium phosphate zone, however, is in the Bone Valley Formation, and the map does give some idea of the distribution of the lower unit. The unit thins toward the north, and at the northern limit of the lower unit, the isopach contours are small closed 10-foot thickness lines and a few isolated 20-foot contour lines. The calcium phosphate zone thins more abruptly to the east than to the north—larger areas are underlain by 20 feet of the calcium phosphate zone, and in some areas the zone reaches 30 feet in thickness. A subsurface ridge of the Hawthorn Formation is present at about the eastern limit of the lower unit of the Bone Valley Formation, and it is likely that the Bone Valley deposition was limited by this ridge and extended east of it only during the time of the deposition of the upper unit of the Bone Valley Formation. To the north, as the sea advanced, a northward-thinning wedge of phosphorite was deposited on the gently dipping surface of the Hawthorn Formation on the central plain. The lower unit is absent along the course of Saddle Creek, where it was removed by erosion, probably in the Pleistocene or Recent Epoch.

PHYSICAL CHARACTERISTICS

The lower unit of the Bone Valley Formation is predominantly a clayey sand or a sandy clay, but beds of loose phosphate sand or fine conglomerate are common. Beds of clay, although present, are rare. The rock is soft, poorly consolidated and is light-colored—gray and white, or shades of green and blue, but some is oxidized to brown, reddish brown, or yellow.

All the beds of the lower unit contain phosphate nodules, but the rare clay beds contain so little phosphate that they are commonly called "barren clay beds" by the drillers. The phosphate nodules in the lower unit range in size from fine sand to coarse pebble. Variations in particle size can be mapped (fig. 9), but because most screened samples included both the Bone Valley and the Hawthorn, the discussion of particle size variation is included in the section of the calcium phosphate zone.

The phosphate nodules are predominantly light colored—most are white, many are light brown and tan, some are gray, a few are black, and a very few are amber. The black nodules tend to be more abundant in the basal part of the unit, although they are found throughout, and the amber nodules, found at only a few localities, are confined to the basal part of the lower unit, just above the Hawthorn Formation.

Individual beds in the lower unit are lenticular and range from phosphate or quartz sand to conglomerate to clay, but the average material, as mined, consists of nearly equal parts of recoverable phosphate nodules, quartz sand, and slime (table 2). The samples shown in table 2 are arranged, from top to bottom, from the lowest to

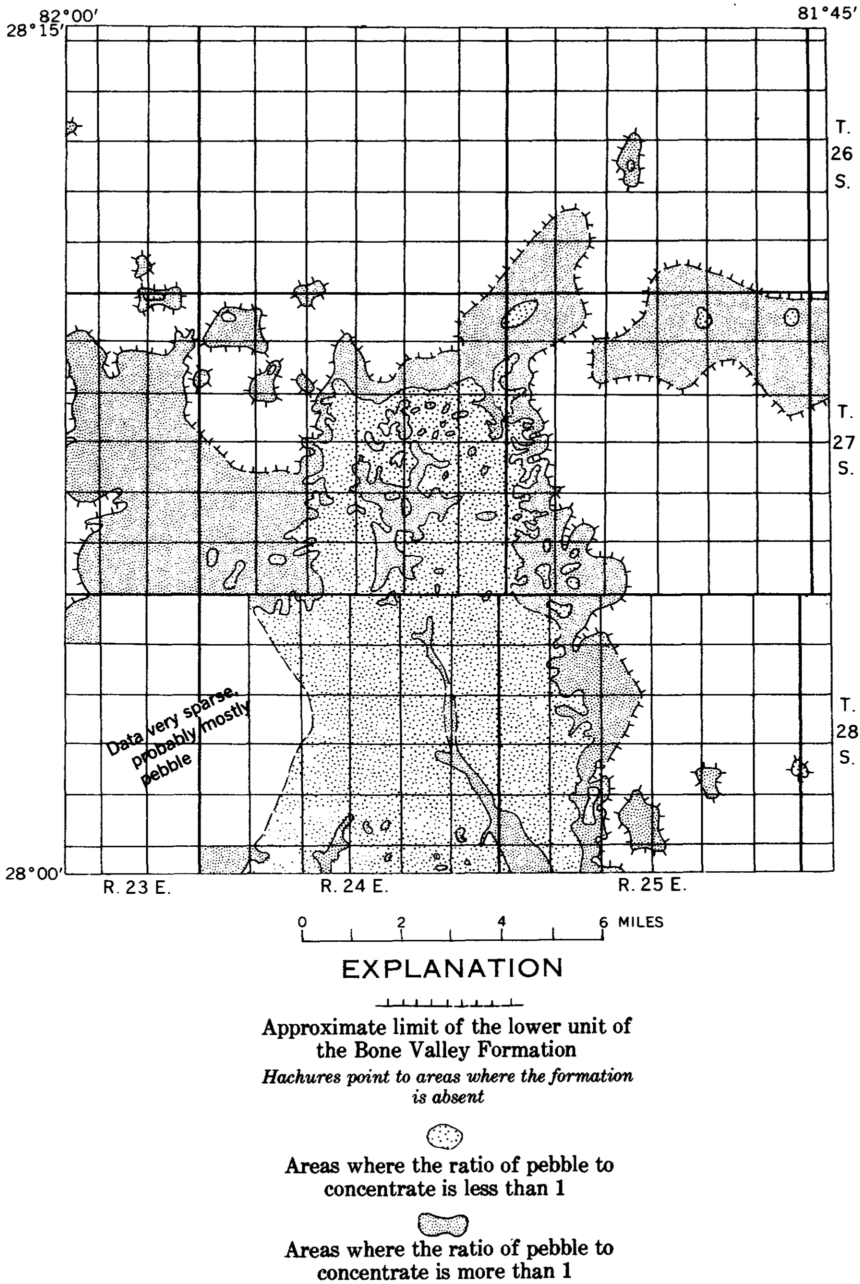


FIGURE 9.—Distribution of pebble and concentrate, calcium phosphate zone, Lakeland quadrangle.

the highest percentage of the slime fraction. The beds vary from almost pure slime (sample 921–22) to almost pure quartz sand (sample 797–60), but the average of all beds listed is about one-third slime, one-third quartz sand, and one-third recoverable phosphate.

TABLE 2.—*Screen analyses of selected individual beds of the Bone Valley Formation, Lakeland quadrangle, Florida*

Sample	Location (R. 24 E.)		Weight percent of screen fraction			
	Section	Township South	+14 mesh (pebble)	−14 +150 mesh [1] Concentrate	−14 +150 mesh [1] Tailing	−150 mesh (slime)
797–60	5	29	5.1	0.0	92.5	2.4
921–35	22	28	51.7	16.4	29.3	2.6
–33	22	28	35.5	20.1	33.4	11.0
–53	22	28	4.2	21.2	61.0	13.6
–25	22	28	56.1	12.2	14.0	17.7
797–35	5	29	13.6	36.6	31.8	18.0
–29	5	29	33.0	.0	45.4	21.6
921–56	22	28	14.5	12.3	44.3	28.9
797–16	5	29	11.7	11.0	47.1	30.2
–10	5	29	21.0	5.0	34.9	39.1
908–5	27	28	4.7	22.4	21.9	51.0
–9	27	28	3.8	5.4	10.4	80.4
921–22	22	28	0	0	1.2	98.8
Average			19.6	+12.5	36.0	31.9
Average of phosphate products (pebble plus concentrate)			32.1			

[1] This fraction was treated by flotation methods. The concentrate is phosphate, the tailing is quartz sand.

BEDDING

Bedding in the lower unit of the Bone Valley Formation is evident in the mining pits of the area, particularly at the Pauway and Saddle Creek pits, and graded bedding can be inferred from drill holes and can be seen in the pits. For example, graded bedding can be inferred from the log of drill hole B in sec. 5, T. 28 S., R. 24 E. The bottom bed of the Bone Valley Formation at this drill hole is a clayey sand with abundant phosphate that grades upward from coarse to fine. The bottom bed is overlain by a sandy clay containing phosphate. This may be one set of graded bedding. Above the clay bed is another bed of sand, the base of a second graded bedding set. This sand bed grades upward into a sandy clay bed, which is leached in the top 1 foot. The sandy clay bed is overlain by a clayey to slightly clayey sand (in the upper unit of the Bone Valley Formation), which is probably the basal bed of a third set of graded bedding. At this drill hole the upper and lower units of the Bone Valley Formation are gradational, and the contact between them is marked by the difference in the amount of phosphate nodules.

Log of drill hole B, NE¼NW¼ sec. 5, T. 28 S., R. 24 E.

[Drilled by Wayne Thomas]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, quartz, black, organic	1.0
Sand, loose, quartz, dark-brown, iron-stained	1.0
Sand, loose, quartz, tan, fine-grained	5.0
Total terrace sand	7.0
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, slightly clayey, light-gray, fine-grained at top, medium- to coarse-grained in bottom 2 ft	6.0
Sand, clayey, light-gray, medium- to coarse-grained; contains some granule-sized soft white phosphate	1.0
Lower unit:	
Clay, sandy, white; contains granule- to medium sand-sized soft white phosphate. Partially leached	1.0
Clay, sandy, light-gray; contains white and tan granule- to medium sand-sized phosphate grains. Sand fraction more abundant with depth. Grades into unit below	3.0
Sand, slightly clayey, light-tan; contains abundant sand-sized tan and gray phosphate nodules	3.0
Clay, very sandy, light-tan; contains abundant tan and white granule- to sand-sized phosphate	6.0
Sand, clayey, tan and gray; contains gray and tan sand- to granule-sized phosphate. Phosphate is coarser and more abundant with depth	5.0
Total Bone Valley Formation	25.0
Miocene:	
Hawthorn Formation:	
Lower part:	
Clay, sandy, calcareous, gray at top, grades to buff at base. Trace phosphate	3.5
Part of Hawthorn Formation	3.5

Bottom in material too hard to penetrate. Limestone.

The lithologic log of drill hole C, in sec. 15, T. 27 S., R. 24 E., also shows two sets of graded bedding in the Bone Valley Formation. The base of the lower unit of the Bone Valley Formation is a gray clayey sand containing abundant pebbles of phosphate. The phosphate nodules decrease in size upward, and the top of this bed is a very clayey sand containing only sand-sized phosphate nodules. Above this clayey bed is another bed of phosphate and quartz sand containing abundant pebble phosphate at the base. This bed grades upward into finer grained sand, and the size of the phosphate nodules decreases toward the top; it finally grades into a bed of sandy clay at the top of the lower unit of the Bone Valley. The basal bed of the upper unit of the Bone Valley Formation is also a sandy clay but is without phosphate nodules. This bed may be the leached part of the top of the lower unit. The sequence above this bed may be another set of graded bedding—clayey sand grading upward into very clayey sand.

Log of drill hole C, NE¼ SW¼ sec. 15, T. 27 S., R. 24 E., Orange Park tract

[Drilled by the American Cyanamid Co., under contract to the U.S. Atomic Energy Comm.]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, gray-tan, medium-grained	6.0
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, very clayey, dark gray-and-rust mottled	1.0
Sand, clayey, light-gray to tan, fine-grained	3.0
Sand, very clayey, white, medium-grained	1.0
Clay, sandy, grades down to white, medium-grained clayey sand	1.0
Lower unit:	
Clay, very sandy, white; contains abundant white and tan sand- to granule-sized phosphate grains	1.0
Sand, clayey at top, loose at base; contains very abundant gray, tan, and some black phosphate. Phosphate is medium sand size at top, grades downward to granule size	3.0
Sand, very clayey at top, slightly clayey at base. Abundant fine-grained tan and gray phosphate at top; granule-sized black phosphate abundant at base	4.0
Total Bone Valley Formation	16.0
Miocene:	
Hawthorn Formation:	
Clay, sandy, calcareous, gray; contains trace of very fine- to fine-grained mostly black phosphate; part of formation	0.5
Bottomed in the above material, "barren" clay.	

Thin contorted bedding in the lower unit of the Bone Valley Formation was seen at the pits of the Pauway mine in sec. 5, T. 29 S., R. 24 E. Details of the contorted bedding were mapped with a planetable and are shown in figure 7. The lower unit of the Bone Valley Formation is finely bedded—almost laminated at this particular exposure. The contorted bedding is due to sinkhole collapse, prior to the deposition of the sand of Pleistocene age. There is a sinkhole in the center of the pit west of the section shown in figure 7. The contact of the Bone Valley Formation with the underlying limestone of the Hawthorn Formation is irregular and unconformable, and the upper contact of the phosphorite with the sands of the Pleistocene is also unconformable. The upper unit of the Bone Valley Formation is missing at the exposure; loose sand rests directly on the phosphorite of the lower unit.

STRATIGRAPHIC RELATIONS

The lower unit of the Bone Valley Formation unconformably overlies the Hawthorn Formation but does not overlap it. The nature of the contact has been discussed (p. G17 and figs. 3, 5, 6, and 7). The lower unit is conformably and gradationally overlain by the upper unit throughout most of the Lakeland quadrangle. In the northern third of the quadrangle, however, the lower unit is present only as a series of disconnected outliers, and the upper unit is present as a blanket deposit. In this area, it is likely that there was a slight erosional break between the deposition of the two units, a break which is not represented in the southern part of the quadrangle.

At places in the quadrangle, at the Pauway mine for example, loose sand of Pleistocene age rests on the lower unit. Erosion prior to the deposition of the Pleistocene removed all of the upper unit and at least the uppermost part of the lower unit over a considerable area of the Pauway mine.

UPPER UNIT

The upper unit of the Bone Valley Formation is present throughout the Lakeland quadrangle except along the course of Saddle Creek and in the vicinity of the Pauway mine where it has been removed by erosion. The upper unit ranges in thickness from 0 to 25 feet and averages about 8 feet. The unit consists of clayey sand or sandy clay, and some beds are of practically pure sand. The clayey sand is gray green, blue gray, or gray, and at some of the drill-hole localities at the Tenoroc and Orange Park mines and the Lake Parker tract, a red and gray mottled clayey sand or sandy clay forms the top part of the unit. Much of the upper unit has been leached and is white, cream, or light gray; the lower part of the upper unit in the Tenoroc, Orange Park, and Lake Parker areas (the clayey sand or sandy clay under the red and gray mottled sandy clay) is light colored and is characterized by kaolinite and aluminum phosphate minerals. The red and gray mottled sandy clay is not as obviously leached as the lower material, and it is possible that it represents the lower part of the Pleistocene, or that it is leached material on which is superimposed a soil profile characterized by iron staining.

Phosphate nodules are in only the base of the upper unit, and at most localities they are soft, dull, and white and probably are in an incipient stage of leaching (Altschuler and others, 1956).

The unit is bedded and laminated and at one mine-face locality it is crossbedded. At the Pauway mine, in the SW¼ sec. 33, T. 28 S., R. 24 E., the upper unit consists of 7 feet of finely bedded and cross-bedded light-gray clayey sand and sandy clay. Thin bedding or laminations at exposures at the Saddle Creek mine are conspicuous at the base of the lower unit, and the upper part of the unit is bleached and structureless. Leaching probably bleached the material and obliterated the bedding.

The upper unit gradationally overlies the lower unit, and at most places a zone of soft white phosphate is at or close to the contact. This zone is about 2 feet thick and may be the leached part of the lower unit, a part of the upper unit, or both. The zone represents material in an incipient stage of leaching and is considered a part of the overburden by the phosphate companies; the soft white phosphate nodules cannot be economically recovered. In the northern third and along the eastern edge of the quadrangle where the lower unit is missing, the upper unit of the Bone Valley Formation overlies the Hawthorn Formation.

The upper unit is overlain by loose sand assigned to the Pleistocene. At drill holes the nature of the contact cannot be determined, and the contact is selected on the basis of the lithologic change from clayey sand to loose sand. At the mine exposures the contact is irregular in detail and is an erosional unconformity (section *C–C′*, pl. 5). At this section at the Pauway mine about 20 feet of the upper unit is in the sinkhole, but at the south end of the sink the upper unit is absent, and loose sand rests on the lower unit. Channels filled with loose sand cut out the upper unit and a part of the lower unit of the Bone Valley Formation in some areas at the Saddle Creek mine (pl. 4).

PLEISTOCENE SERIES—TERRACE SAND

Loose quartz sand, from 0 to 58 feet thick, overlies the Bone Valley Formation throughout almost all of the Lakeland quadrangle. MacNeil (1950, p. 99) recognized four shorelines in the Pleistocene of Florida—at 150, 100, 30, and 10 feet above present sea level. These shorelines are regarded by him as inland limits of marine transgressions. Only the 150-foot shoreline, the Okeefenokee, is represented in the Lakeland quadrangle. The 100-foot contour line is present along Saddle Creek, however at this locality it does not represent a shoreline but is merely a contour along the creek.

The sand of the Pleistocene is thickest in the areas of the surface ridges, where it ranges from 15 to about 50 feet and is very thin or absent in the swampy lowland areas, particularly in the swamps of Saddle Creek.

The sand is well sorted and consists of fine- to medium-grained quartz. The quartz grains are clear or milky and are commonly stained black or brown with organic material or iron oxide. Hardpan, sand cemented by iron oxide (limonite), is only sparingly present and then only at higher elevations. The hardpan is found commonly at the contact between the loose sand of the Pleistocene and the clayey sand of the upper unit of the Bone Valley Formation.

Windblown sand of Recent age is known to be present, but at most places it has not been separated from the sand of the Pleistocene; therefore, all the loose sand, from the contact with the clayey sand of the Bone Valley to the surface of the ground, is assigned arbitrarily to the Pleistocene.

Analytical and screen data on the sand of the Pleistocene are not abundant, but the sand was sampled at one mine-face section at the Saddle Creek mine. The samples were screened and the screen fractions were analyzed for uranium and P_2O_5. Analytical results are shown in table 3.

The +14 mesh fraction (pebble) is virtually absent from these samples and the slime (−150 mesh) fraction is present only in very small amounts. Most of the slime fraction is probably very fine sand or silt; there is very little clay in these samples. The slime fraction, however, does increase downward. The medium sand fraction (−14+35 mesh) is very abundant in the top sample and decreases downward; the fine sand fraction (−35+150 mesh) increases as the medium sand decreases. These samples, then, although well sorted, are finer grained with increasing depth from the surface.

Uranium is virtually absent from all samples analyzed—only 0.000 percent was reported for each analysis. The P_2O_5 content of the

TABLE 3.—*Screen data and chemical analyses, Pleistocene and Recent deposits, Saddle Creek mine, NE¼NE¼ sec. 34, T. 28 S., R. 24 E.*

[Leaders (----)=sample not analyzed. Chemical analyses by M. E. F. Eiland and N. K. Guttag, U.S. Geol. Survey. See p. G107, mine face section R, for lithologic log]

Lot and sample	Depth (in feet) below surface	Screen and chemical analyses, in percent									
		+14 mesh			−14+35 mesh			−35+150 mesh			−150 mesh [1]
		Weight	U	P_2O_5	Weight	U	P_2O_5	Weight	U	P_2O_5	Weight
794-18	0-7	0.0	------	------	71.3	0.000	------	24.0	0.000	0.6	4.7
17	7-10	.4	0.000	1.7	59.5	.000	------	34.8	.000	.7	5.3
16	10-14	0	------	------	34.2	.000	0.5	59.8	.000	.6	6.0
15	14-16	0	------	------	33.3	.000	.7	57.5	.000	.6	9.2
14	16-20	0	------	------	22.3	.000	------	69.2	.000	------	8.5

[1] Sample of −150 mesh fraction not saved; no chemical analyses.

samples is less than 1.0 percent, except for one sample of +14 mesh material that was 1.7 percent.

RECENT SERIES

Deposits of windblown sand and swamp muck at the surface are probably Recent. These deposits have not been separated from the Pleistocene deposits, except for the swamp muck at the Saddle Creek mine (pl. 4), which ranges in thickness from 0 to about 5 feet. At places at the Tenoroc and Pauway mines, the surface at the mining pits consisted of about 2 feet of white well-sorted and probably windblown sand. This was in contact with a black highly organic sand, from 1 to 2 feet thick, which probably represents an ancient swamp (pl. 5). The loose, surficial sand here is probably Recent.

River-pebble deposits—bars along the present streams of coarse phosphate nodules and quartz sand derived from the calcium phosphate zone—are not known in the Lakeland quadrangle; however, they may occur in small amounts along Saddle Creek.

STRUCTURE

Structure in the Lakeland quadrangle is basically simple; the beds dip to the south, away from the Ocala uplift. The dips are so slight (a few feet per mile) and exposures are so poor that details of the structure could not be delineated. Table 1, however, shows that the formation tops are lower in altitude in the southern part of the quadrangle than in the northern part, indicating a general southerly dip, and the formations thicken to the south. Figure 3 shows that the erosional relief on the top of each formation is large enough to obscure minor structural relief, and deep drill holes are not abundant enough to demonstrate any minor folding similar to that in the Keysville and Plant City quadrangles to the west (Cathcart, 1963 a, b). However, such minor folding is probably present.

The major structural feature in the Lakeland quadrangle is the Polk City fault. This fault is entirely in the subsurface and was first found in 1953 by drilling. It was noted that in two of the lines of drill holes the Ocala Limestone was very close to the surface and occupied an upthrown fault block (Cathcart and McGreevy, 1959). The dip of the fault is not known. The fault strikes northwest, as indicated on the geologic map (pl. 1) and probably extends northwest to join the fault shown by Carr and Alverson (1959). Drilling data indicate that the fault extends perhaps 20 miles southeast beyond the boundary of the Lakeland quadrangle, to about T. 30 S., R. 28 E. On the upthrown block, limestone of the Hawthorn Formation rests directly on the Ocala Limestone. The Suwannee Limestone and the Tampa Limestone are missing, and the Hawthorn Formation is very thin. Although precise data are lacking, there is probably about 100 feet of stratigraphic displacement along the fault.

MINERALOGY

The mineralogy of the rocks in the land-pebble phosphate district is different in the weathered and unweathered parts of the section. The unweathered sections of the Bone Valley Formation consist of quartz, phosphate nodules, and clay. The clay mineral is montmorillonite (Altschuler, and others, 1956). The phosphate nodules are carbonate-fluorapatite (Altschuler and others, 1958), containing varying amounts of impurities, the most common of which are quartz grains, clay, and calcite.

The Hawthorn Formation, when it is unweathered, is an impure limestone containing montmorillonite clay, quartz sand, and phosphate nodules. The phosphate nodules are pellets of carbonate-fluorapatite that generally have impurities, the most common of which is calcite but containing some clay and quartz grains. The clay mineral attapulgite has been reported in the Hawthorn Formation (Berman, 1953).

A small percentage of heavy minerals is in all the beds of the section. Opaque minerals, the most common of which is ilmenite, are most abundant, but tourmaline, zircon, rutile, and garnet are almost everywhere present in small amounts.

The mineralogy of the weathered section is considerably different. The aluminum phosphate zone typically contains crandallite (calcium aluminum phosphate) and wavellite (aluminum phosphate), and kaolinite is the dominant clay mineral. The distribution of the minerals in the aluminum phosphate and the top of the calcium phosphate zone is shown in the following sections taken at the Tenoroc and Saddle Creek mines. Samples were screened at 200 mesh to eliminate most of the quartz grains, and the —200 mesh fraction was analysed in the X-ray diffractometer. The trace of the X-ray diffractometer was interpreted by the writer and L. V. Blade of the Geological Survey. The clay minerals in the phosphate district were identified by Z. S. Altschuler of the Geological Survey (written communication. 1952).

Log of mine face section D, Saddle Creek mine, SE¼SE¼ sec. 15, T. 28 S., R. 24 E.

[Minerals are listed in approximate order of decreasing abundance. Query indicates uncertain identification. The numbered beds are the same as in table 5]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
20. Sand, loose, gray at top, white and tan at base	6.4

Log of mine face section D, Saddle Creek mine, SE¼SE¼ sec. 15, T. 28 S., R. 24 E.—Continued

	Thickness (feet)
Pliocene:	
Bone Valley Formation:	
Upper unit:	
19. Sand, slightly clayey, tan	2.1
Major: quartz.	
Minor: kaolinite, wavellite, crandallite, goethite?	
18. Sand, slightly clayey, iron-cemented (hardpan)	3.5
Major: quartz.	
Minor: kaolinite, wavellite, crandallite, goethite?	
17. Sand, clayey, iron-stained	.8
Major: quartz, kaolinite, wavellite.	
Minor: crandallite.	
16. Sand, clayey, tan	2.0
Major: kaolinite, crandallite, wavellite, quartz.	
15. Clay, sandy, and clayey laminated sand	1.1
Major: kaolinite, crandallite, wavellite, quartz.	
Minor: montmorillonite (trace).	
14. Sand, slightly clayey, tan; with patches of white loose sand	1.6
Major: quartz, kaolinite.	
Minor: crandallite, wavellite, trace montmorillonite.	
13. Sand, clayey, tan	2.0
Major: kaolinite, crandallite.	
Minor: quartz, wavellite, trace montmorillonite.	
13a. Sand, loose, quartz. At water table. Bed is persistent laterally in the pit (not sampled)	.2
12. Sand, clayey, tan	1.2
Major: kaolinite, crandallite.	
Minor: quartz, wavellite, trace montmorillonite.	
11. Clay, sandy, gray, trace white phosphate	1.7
Major: kaolinite, crandallite, quartz.	
Minor: wavellite, montmorillonite, apatite.	
Lower unit:	
10. Sand, clayey, gray-tan; contains gray and tan phosphate and phosphatized limestone fragments	.9
Major: apatite, millisite?	
Minor: montmorillonite, wavellite, crandallite, trace kaolinite.	
7, 8, 9. Sand, clayey, gray-tan; contains gray and tan, sand- and granule-sized phosphate nodules, and white phosphatized limestone fragments. Phosphate is more abundant with depth, and contains progressively less clay from top to bottom. (Three samples taken of this unit.)	3.9
Miocene:	
Hawthorn Formation:	
Lower part:	
6, 5. Clay, calcareous, sandy, gray; contains abundant fine to medium sand-sized brown, gray, and white phosphate nodules	1.3

Log of mine face section D, Saddle Creek mine SE¼SE¼ sec. 15, T. 28 S., R. 24 E.—Continued

	Thickness (feet)
Miocene—Continued	
Hawthorn Formation—Continued	
Lower part—Continued	
4, 3. Clay, calcareous, sandy, gray and brown; contains abundant fine sand-sized phosphate nodules	2.0
2. Limestone, dolomitic, soft, sandy and clayey, yellow-brown. Some fine sand-sized phosphate nodules. Exposed thickness	1.2
1. Clay, calcareous, sandy, yellow-brown; with fine sand-sized brown, white, gray, phosphate nodules. Residual from limestone, but exposed under the limestone above and due to laterally moving ground water	1.8

Bottom of the pit is in hard limestone, like sample 2.

Log of mine face section E at the Tenoroc mine, SW¼NE¼ sec. 35, T. 27 S., R. 24 E.

[The numbered beds are the same as in table 4]

	Thickness (feet)
Recent:	
Swamp deposit:	
19. Sand, black, highly organic (swamp muck)	1.0
Pleistocene:	
Terrace deposits:	
18. Sand, loose, quartz, gray and brown	2.0
Pliocene:	
Bone Valley Formation:	
Upper unit:	
16, 17. Sand, clayey, brown and gray (two samples)	3.8
Major: kaolinite, quartz.	
Minor: crandallite, wavellite, montmorillonite.	
15. Sand, clayey, gray	2.5
Major: kaolinite, crandallite.	
Minor: quartz, wavellite.	
14. Clay, sandy, light-gray	.9
Major: kaolinite, crandallite, quartz.	
Minor: wavellite, trace apatite.	
13. Clay, sandy, blue-gray	2.1
Major: kaolinite, crandallite, quartz.	
Minor: wavellite, montmorillonite, trace apatite.	
12. Sand, clayey, blue-gray	2.1
Major: quartz, kaolinite, montmorillonite.	
Minor: crandallite, trace wavellite and apatite.	
11. Clay, sandy, blue-gray	.5
Major: quartz, montmorillonite, kaolinite.	
Minor: crandallite, apatite, wavellite.	
Lower unit:	
10. Sand, slightly clayey, light-gray; contains abundant gray, coarse granule-sized phosphate nodules	.9
Major: apatite, montmorillonite, kaolinite.	
Minor: crandallite, wavellite, quartz.	

Log of mine face section E at the Tenoroc mine, SW¼NE¼ sec. 35, T. 27 S., R. 24 E.—Continued

	Thickness (feet)
Pliocene—Continued	
Bone Valley Formation—Continued	
Lower unit—Continued	
9. Sand, slightly clayey, brown; contains very abundant sand-sized brown phosphate and minor amounts of fine granule-sized phosphate	2.0
8. Sand, clayey, yellow-green; contains granule-sized brown and gray phosphate, some sand-sized	.5
7. Sand, clayey, gray. Phosphate is coarse granule size at top, sand size at base	1.4
5, 6. Clay, sandy, light-gray; contains abundant gray sand- and granule-sized phosphate. White clay balls (weathered limestone?) scattered throughout	2.7
Miocene:	
Hawthorn Formation:	
Lower part:	
4. Clay, sandy, calcareous, gray-brown; contains abundant fine sand-sized brown phosphate	1.5
2, 3. Clay, sandy, calcareous, gray-brown; contains trace amounts of phosphate nodules. Has irregular, subparallel and crudely horizontal crusts of phosphatized material	1.5
1. Limestone, gray-brown, clayey; trace fine phosphate	.5
Bottom of pit is in hard limestone.	

The mineral distribution is very similar in the two sections. At the Saddle Creek mine section, the principal clay mineral in the leached upper unit of the Bone Valley Formation is kaolinite. Montmorillonite is in the bottom part of the upper unit, but only in trace amounts except in the bottom sample (11). In sample 10, the top sample of the lower unit of the Bone Valley Formation, however, montmorillonite is the major clay mineral and kaolinite is present only in trace amounts. In the upper part of the leached section (samples 17–19), wavellite is more abundant than crandallite, but in the bottom part of the upper unit (samples 11–16), crandallite is more abundant than wavellite. In the bottom sample of the upper unit (11) a small amount of apatite is present, and in sample 10, the top of the lower unit, apatite is the most abundant phosphate mineral; millisite?, a calcium aluminum phosphate, is also present, and crandallite and wavellite are minor constituents. Some questionable goethite is present in samples 18 and 19, the iron-stained and cemented samples.

There are some minor differences in mineral distribution at the section in the Tenoroc mine. Crandallite is more abundant than wavellite throughout the leached upper unit of the Bone Valley Formation, and millisite and goethite are not present in the section. Except for these differences, the two sections are nearly identical.

The mineral distribution in these sections, which are typical of the leached sections throughout the quadrangle, is probably due to downward leaching by acidic ground waters.

SPECTROGRAPHIC ANALYSES

Semiquantitative spectrographic analyses of channel samples from the Tenoroc and Saddle Creek mines are reported, in tables 4 and 5, within limits differing by a factor of 10 (that is, 0.01–0.1 percent, 0.001–0.01 percent, and so on). The standard sensitivities for the elements determined by the semiquantitative method are shown in table 6.

DISTRIBUTION OF MAJOR ELEMENTS

Phosphorus is low or very low in the hard dolomite, it is a major constituent (> 10 percent) in the matrix and bedclay samples and is one or two orders of magnitude lower in the upper unit of the Bone Valley Formation than in the lower unit. Magnesium is a major constituent only in the hard dolomite. It ranges from 1 to 10 percent in the lower bedclay samples, is low (0.1–1 percent) in both units of the Bone Valley Formation, and is very low (0.01–0.1 percent) in the sand of Pleistocene age. Calcium is high (1–10 percent) in the bedrock and in part of the matrix, is a major constituent in the rest of the matrix, and is uniformly low (0.1–1 percent) in the upper unit of the Bone Valley Formation and in the sand of Pleistocene age. Sodium ranges from 0.1 to 1 percent in the bedrock, bedclay, and matrix, is an order of magnitude lower in the upper unit of the Bone Valley Formation, and is below the limit of detection in the loose surficial sand and in the upper part of the upper unit of the Bone Valley Formation. Silicon is a major constituent (>10 percent) in all the samples except in those of bedrock and in one sample of the matrix (8, table 4) where it ranges from 1 to 10 percent. Aluminum is a major constituent in the clayey sand of the upper unit of the Bone Valley Formation—ranging from 1 to 10 percent in the matrix and bedclay; but it is low (0.1–1 percent) in the bedrock and sand of the Pleistocene. Iron is low (0.1–1 percent) in most samples; however, it ranges from 1 to 10 percent in the swamp muck (sample 19, table 4), in the basal bedclay samples, and in the samples at the contact of the aluminum phosphate zone and the matrix. Barium content ranges from 0.01 to 0.1 percent in all samples from the Bone Valley and Hawthorn Formations, except that it is an order of magnitude higher in two samples (10 and 11, table 4) from the matrix-aluminum phosphate zone contact at the Tenoroc

TABLE 4.—*Semiquantitative spectrographic analyses of channel samples from the Tenoroc mine*

[Analysts: K. A. Valentine and H. W. Worthing, U.S. Geol. Survey]

Sample	Lab. No.	Percent					
		More than 10	1-10	0.1-1.0	0.01-0.1	0.001-0.01	0.0001-0.001
19	97081	Si	Fe	Al Ca P Ti	Mg B Cu Mn Zr	La Ni Cr Sn V Ga Ba Mo Y	Sr Ag
18	97080	Si		Fe Al Ca P	Mg Cu Mn B Ti Zr	Ni Cr Ba Ga V Sn Sr	
17	97079	Si	Al	Fe Ca P Mg Ti	Mn B Cu Ba Cr Sr	Ni V Ga La Y Zr Sn Mo Pb	Yb
16	97078	Al Si		Fe Ca P Mg Ti	Na B Mn Cr Cu Ni Sr Ba V	Zr Ga La Y Pb Mo Sn	Be Yb
15	97077	Al Si		Fe Ca P Mg Ti	Ba Sr B Mn Cr Cu Zr	Ni V Ga La Y Pb Sn Mo Sc	Yb Be
14	97076	Al Si		Fe P Ca Mg Ti	Na Ba Sr B Cr Cu Mn V	Ga Zr Ni La Y Pb Sc	Mo Be Yb
13	97075	Al Si		Fe Ca P Mg Ti	Ba Na Sr B Cr Cu Mn V	Zr Ga Ni La Y Pb Sn Sc	Mo Yb Be
12	97074	Al Si	Ca Fe	P Mg Ti	Ba Na V B Cr Mn Sr Cu Ni Zr	Ga La Y Sc Pb Sn Mo	Yb Be
11	97073	Al Si	Ca P Fe	Mg Ba Ti	Na Sr V Mn B Cr Cu Ni Zr	Ga La Y Pb Sn Sc	Mo Yb Be
10	97072	Al P Si	Ca	Fe Mg Ba Na Ti	Sr Y V Mn B Cr Zr Cu La Ni	Ga Yb Sc Pb Mo Sn	Be
9	97071	Ca P Si	Al	Fe Na Mg	Sr Mn Ti B Ba Cr Cu Y	Ni V La Ga Zr Mo Sn Pb Yb Sc	Be Ag
8	97070	Ca P	Si Al	Fe Na Mg	Ti Sr Cr V B Cu Ba Mn Ni Y	Ga La Mo Zr Sc Sn Pb	Yb Be
7	97069	Ca P Si	Al	Fe Mg Na	Ni Sr Ti Mn V B Cr Cu Ba Y	Co Cd Zr La Mo Sn Pb	Yb Ag Be
6	97068	P Si	Ca Al	Fe Mg Na	V Mn Ti Ni Sr B Ba Cr Cu	Y Ga Cd Zr La Mo Sn Pb	Yb Be
5	97067	Si	P Ca Al	Fe Mg Na	Ba Sr Ti V B Cu Mn Ni Cr	Y Zr Ga La Sn Mo Pb	Yb Ag
4	97066	P Si	Ca Al	Fe Na Mg	V Sr B Ba Cu Mn Ti Ni Cr	Zr Y Co Cd Ga Sn La Mo Pb	Yb Ag Be
3	97065	Ca P Si	Al	Fe Na Mg	Y Sr Ti Mn Ba Cu B Cr Ni	Zr Cd Y Ga La Sn Mo Pb	Yb Ag Be
2	97064	Ca P Si	Al Mg Fe	Na	V Sr Ba Mn Ni Ti B Co Cr Cu	Cd Y Ga La Sn Zr Mo Pb	Yb Be Ag
1	97064	Mg	Ca Si P	Al Fe Na	Ce La V B Ba Cu Mn Ni Sr Cd	Cr Ti Y Pb Sc Zr	Mo Yb

TABLE 5.—*Semiquantitative spectrographic analyses of channel samples from the Saddle Creek mine*

[Analysts: K. A. Valentine and H. W. Worthing, U.S. Geol. Survey]

Sample	Lab. No.	Percent					
		More than 10	1-10	0.1-1.0	0.01-0.1	0.001-0.01	0.0001-0.001
20	97101	Si		Fe Ca Al P	Cu Ti B Zr Mg Mn	Ni Ba Sn Cr Sr V Mo	Yb
19	97100	Si		Ca P Fe Al Ti	Cu B Mg Zr	Mn Ni Ba Cr Sn Sr Ga Mo Pb V Y	Yb
18	97099	Si	Al	Ca P Fe Ti	Zr B Mg Cu Sr	Ba Ni Cr Ga Mn Pb Sn Y V	Yb
17	97098	Si		Al Fe Ca P	Mg Ti B Mn Cu	Ba Cr Zr V La Ga Sn Y Mo	Sr Ag Yb
16	97097	Si	Al	P Ca Fe Mg	Ti Ba Cr B Cu Mn	V Ga Ni Y Zr La Sr Pb Mo	Ag Yb Be
15	97096	Al Si	P	Ca Fe Mg Ti	Ba Cr Zr B Cu Mn V	Ga Ni Y La Pb Sr	Mo Yb Ag Be
14	97095	Si	Al Fe	Ca P	Cu Mg Mn B Ti	Ba Cr Ni V La Sn Ga Zr Mo	Sr Yb
13	97094	Si	Al	Ca P Fe Mg	Ti Ba B Cr Zr	Cu Mn V Ga La Y Sr Pb Sc	Yb Be
12	97093	Si	Al	Ca P Fe Mg	Ti Ba Cr Cu B Mn	V Y Ga La Sr Zr Mo Pb Sc	Yb Be
11	97092	Si	Al	P Ca Fe Mg	Ti Na B Ba V Cu Mn Cr	Zr Ga Ni Sn Pb Y Sc Sr	Mo Be Yb
10	97091	Al P Si	Ca Fe	Mg B Na Ti	V Ba Cr Zr Mn Y La Ni	Cu Ga Sr Sn Sc Mo Pb Yb	Be
9	97090	P Si	Ca Al	Fe Mg Na Ti	Ba Cr Y B V Mn Zr Cu	Ni Sr Ga Sn La Yb Pb Mo Sc	Be Ag
8	97089	P Si	Ca Al	Fe Mg Na	Ba Ti Cr B Cu Mn V Y	Ni Sr La Zr Ga Sn Pb Mo Sc	Yb Ag Be
7	97088	P Si	Ca Al	Fe Na Mg	Ba Cr Ti B Cu Mn Sr V Y	Ni Zr Ga La Pb Sc	Yb Ag Be
6	97087	Ca P Si	Al	Fe Mg Na	Cr Ti Ba V B Mn Y Co Cu Ni Zr	Sr Ga Sn Mo Pb	Yb Ag Be
5	97086	Ca P Si	Al	Fe Mg Na	Ba Ti Cr Mn B V Y Cu Ni	Sr La Zr Ga Sn Mo Pb	Yb Ag Be
4	97085	P	Ca Si Al Mg	Fe Na	Mn Cr B Ti V	Cu Ni Y Ba La Sr Ga Zr Mo Pb	Yb Ag Be
3	97084	P Si	Ca Mg Al Fe	Na	Cr Mn Ti B V Ni Ba Co Cu Y	Sr Ga Zr La Sn Mo Pb Yb	Ag Be
2	97083	Mg	Ca Si	P Fe Al Na	Ti Cr B Ba Cu	Mn Ni V Sr Sn Zr Ga Y Mo	Yb
1	97082	P	Mg Ca Si	Al Fe Na	Mn Cr Cu B Ba	Ni Ti Sr Sn V Y Ga Zr Mo Pb	Yb Ag

mine. The sand of Pleistocene age ranges from 0.001 to 0.01 percent barium. Strontium ranges from 0.01 to 0.1 percent in all samples of the Hawthorn and Bone Valley Formations at the Tenoroc mine, whereas the loose surficial sand and the swamp muck contain from 0.001 to 0.01 percent. Samples from the Saddle Creek mine contain an order of magnitude less strontium than the samples at the Tenoroc mine.

TABLE 6.—*Standard sensitivities for the elements determined by the semiquantitative method*

[As revised July 1952 by U.S. Geol. Survey Washington Laboratory. It is possible to detect some elements below the values listed, as the standard reference plates were prepared on the basis of the 10-percent increments]

Element	Percent	Element	Percent	Element	Percent
Ag	0.0001	Hg	0.1	Sb	0.01
Al	.0001	In	.001	Sc	.001
As	.1	Ir	.1	Si	.0001
Au	.01	K [1]	.01 (1.0)	Sm	.1
B	.001	La	.01	Sn	.01
Ba	.0001	Li [1]	.0001 (0.1)	Sr	.01
Be	.0001	Lu	.01	Ta	.1
Bi	.001	Mg	.0001	Tb	.01
Ca	.001	Mo	.001	Te	.1
Cd	.01	Mn	.001	Th	.1
Ce	.1	Na [1]	.001 (0.1)	Ti	.001
Co	.01	Nb	.01	Tl	.1
Cr	.001	Nd	.01	Tm	.01
Cs [1]	.1 (1.0)	Ni	.01	U	.1
Cu	.001	Os	.1	V	.01
Dy	.01	P	.1	W	.1
Eu	.01	Pb	.01	Y	.001
Er	.01	Pd	.01	Yb	.0001
F [2]	.1	Pr	.01	Zn	.01
Fe	.001	Pt	.01	Zr	.001
Ga	.01	Rb [1]	.01 (10.0)		
Gd	.01	Re	.1		
Ge	.001	Rh	.01		
Hf	.1	Ru	.01		

[1] A second exposure is required for the high sensitivity noted.
[2] A third exposure is required for the fluorine estimate.

DISTRIBUTION OF METALS

Chromium, titanium, vanadium, lead, copper, gallium, nickel, manganese, tin, molybdenum, beryllium, and silver are present in trace amounts. They tend to be an order of magnitude lower in the hard bedrock and the loose surficial sand than in the Bone Valley Formation. Zirconium is somewhat higher (0.01–0.1 percent) in the bedrock and the loose sand than in the Bone Valley Formation (0.001–0.01 percent). Cobalt is present in a few samples and is below the limit of detection in the rest.

The rare earths, cesium and cadmium, are somewhat higher in the dolomite than in the rest of the section. Scandium is higher in the Bone Valley Formation than in the rest of the section. Lanthanum, yttrium, and ytterbium are present in trace amounts and are concentrated very slightly in the top sample of the matrix—the zone of soft white phosphate.

Boron is present in trace amounts but is not concentrated in any sample.

The mineralogical distribution of the trace elements is not definitely known. The rare earths vanadium, strontium, and barium may be associated with the apatite mineral; zirconium and titanium may be in detrital zircon and ilmenite, and gallium, chromium, and nickel may be associated with clay minerals (McKelvey and others, 1951).

WEATHERING AND EROSION

Weathering has altered the rocks of the land-pebble phosphate district several times. The earliest periods of weathering are recognized in the unconformities between the Ocala and Suwannee Limestones, between the Suwannee and Tampa Limestones, and between the Tampa Limestone and the Hawthorn Formation (fig. 3). The products from each of these weathering periods may have been reworked into the next higher formation, as indicated by the fact that each younger formation has more total clastic material (silt, sand, and clay) than the immediately underlying older formation. Thus, the Hawthorn Formation contains more clastic material than the Tampa Limestone, the Tampa contains more than the Suwannee, and the Suwannee contains more than the Ocala, which is a nearly pure limestone.

At least three periods of weathering affected the phosphatic sedimentary rocks and are of considerable significance in the formation of the economic phosphate deposit. The earliest of these periods of weathering and erosion came at the close of Hawthorn time. Weathering was largely chemical, as indicated by the karst topography developed on the upper surface of the formation (pl. 3). The restricted distribution of the clastic upper part of the formation and the probability that it was originally much more extensive (Cathcart, 1963c), however, indicates that this member was removed by erosion from all but the southeastern part of the Lakeland quadrangle.

The chemical weathering of the Hawthorn Formation produced a residual mantle that was probably very similar to the present bed clay—that is, a calcareous clayey sand or sandy clay containing abundant sand-sized phosphate nodules.

The phosphatic lower unit of the Bone Valley Formation was deposited following this period of erosion. Phosphate was precipitated, limestone fragments were phosphatized, and the phosphate in the residual mantle was enriched, sorted, and concentrated. The basal bed of the Bone Valley Formation filled low spots on the surface of the Hawthorn Formation.

Deposition of the lower unit was succeeded, without interruption, by the upper unit—except in the northern part of the quadrangle where, after the maximum advance of the early Bone Valley sea, there was a slight withdrawal, and the thin deposit of phosphorite at the northern limit of the sea was eroded, leaving scattered outliers. The deposit of loose sand at the base of the upper unit at the Orange Park tract may represent the shoreline of the late Bone Valley sea at this time. After this period of erosion, which was short, the sea readvanced and covered all of the Lakeland quadrangle.

Following the deposition of the upper unit of the Bone Valley Formation, a period of weathering altered the upper unit and the top part of the lower unit. The calcium phosphate minerals were altered to aluminum phosphate and the montmorillonite clay to kaolinite—forming the aluminum phosphate zone. Erosion following the weathering stripped the aluminum phosphate zone from much of the area of the Pauway mine (pl. 5) and from parts of the Saddle Creek mine (pl. 4). At these mines, loose sand, probably of Pleistocene age, rests on the lower unit, and at the Pauway mine as much as 20 feet of the upper unit is preserved in a sinkhole. At the Saddle Creek mine, lenses of reworked material derived from the Bone Valley Formation are in the loose sand of the Pleistocene.

The alteration of the phosphate and the clay minerals was probably by acidic ground waters percolating downward through the unconsolidated, permeable material. Alteration of the limestone of the Hawthorn to residual calcareous clay possibly occurred during this and subsequent weathering cycles. The distribution of the residual clay is related to the present surface, and deeply buried limestones do not have a mantle of residual material. Residual clay formed during the pre-Bone Valley weathering cycle may have been preserved at some places, as for example, part of the calcareous clay at the Saddle Creek mine (fig. 5).

Hardpan, limonite-stained and cemented sand, and clayey sand, was formed after the deposition of the loose sand. The material is part of a soil profile typified by the acidic Leon soil (Fowler and others, 1927). The hardpan is related to the present surface—it may be in the loose sand or superimposed on the underlying leached clayey sand, depending on the thickness of the loose sand. Another soil profile, in an early stage of development and younger than the Leon soil profile, is described by Hunt and Hunt (1957).

ECONOMIC GEOLOGY

Phosphate is the only mineral product mined in the Lakeland quadrangle, although surficial sands and clayey sands have been mined for local use as road metal. Phosphate deposits underlie about two-thirds of the area of the quadrangle but are not present in the northern and eastern parts (pl. 1). Mining for phosphate has been carried on at several locations in the quadrangle since about 1914, and in 1962, two phosphate mines, Tenoroc and Orange Park, were in operation.

HISTORY OF MINING

The earliest record of phosphate mining is that of the Lakeland Phosphate Co., which was organized in 1913. They mined from 1914

(Sellards, 1914) until about 1918 in the SW¼ sec. 26, T. 28 S., R. 23 E., and the NW¼ sec. 35, T. 28 S., R. 23 E. The mined-out areas are open lakes, indicating that mining was hydraulic.

About 1920 this company was taken over by the Southern Phosphate Co. who mined in the southeast part of T. 28 S., R. 23 E., from sometime in the 1920's to October 1945. They mined, by dragline, only for pebble fraction until about the middle 1930's, after which they mined for both the pebble and flotation fractions.

The Southern Phosphate Co. also mined at the Pauway mine in the southern part of the Lakeland quadrangle. The first mining was in the NW¼ SE¼ and the SW¼ NE¼ sec. 33, T. 28 S., R. 24 E., in 1925 and 1926. Later mining was to the south, in the Bartow quadrangle, but mining in sec. 33 in the NW¼ was carried on in 1946 by Davison Chemical Co., which took over the Southern Phosphate Co. in that year. Mining in the Pauway area was going on in 1960 but was south of the boundary of the Lakeland quadrangle. Early mining was by hydraulic methods and was for the pebble fraction only; later mining was by dragline for the overburden, but hydraulic monitors were used to move the ore; the latest mining was by dragline, and the flotation fraction was recovered in a table plant and in flotation cells. Washer debris from the early operation has been in part remined.

The American Cyanamid Co. operated their Saddle Creek mine in T. 28 S., R. 24 E., from 1942 to 1957, after which they moved to the Orange Park mine. The Saddle Creek area was mined with draglines; both pebble and flotation concentrates were recovered. The Orange Park mine in T. 27 S., R. 24 E. started operating in April 1957 and was still active in 1962. Mining is by large draglines, flotation cells are used, and Dorrclones are used for primary desliming.

Coronet Phosphate Co. began operation of their Tenoroc mine, T. 27 S., R. 24 E., in 1951, and the mine was still in operation in 1962. Mining is for flotation concentrate and pebble; draglines are used to mine the overburden and the phosphate rock.

River pebble, as such, has never been mined in the Lakeland quadrangle, but some of the phosphate rock mined close to Saddle Creek may have been river pebble. All production, however, is classed as land pebble.

CALCIUM PHOSPHATE ZONE

The calcium phosphate zone is a zone of unconsolidated sand, clayey sand, and sandy clay containing abundant nodules of calcium phosphate. The zone contains enough phosphate so that it is at least potentially economic and includes, but is not necessarily equivalent to, the economic phosphate deposit—the matrix.

720-869 O—64——4

The calcium phosphate zone is economic where it contains a minimum of 500 tons per acre-foot of recoverable phosphate nodules with at least 66 percent BPL. The overburden overlying the deposit must be less than a certain maximum thickness. The ratio of overburden to matrix is expressed as the ratio of cubic yards moved per ton of product recovered and should be less than 25:1. The digging depth of the draglines is about 65 feet, and if the total thickness of overburden plus matrix is more than 65 feet it is necessary to remove part of the overburden, then put the dragline on the bench thus created to mine the rest of the material, an added mining expense. Iron and alumina are deleterious in the making of fertilizers, so if the total content of iron and alumina (I and A) is too high, the material is uneconomic. The upper limit is not fixed, but material with more than 5 percent I and A is not being mined.

STRATIGRAPHIC RELATIONS

The calcium phosphate zone is not a stratigraphic unit but may include the lower unit of the Bone Valley Formation, residual clay of the Hawthorn Formation, and even residual clay of the Tampa Limestone. The matrix includes the lower unit of the Bone Valley Formation and residual clay of the Hawthorn, but residual clay of the Tampa Limestone is nowhere considered a part of the matrix because of the very low P_2O_5 content of the phosphate nodules (table 7).

Stratigraphic relations of the economic calcium phosphate zone are diagrammatically shown in figure 10. All drill holes shown in figure 10 were abandoned in calcareous clay with only traces of phosphate nodules—a part of the calcium phosphate zone but too low in phosphate nodules to be called matrix.

At hole 1 all the Bone Valley Formation has been altered to form the aluminum phosphate zone, and the calcium phosphate zone and the matrix are entirely within the Hawthorn Formation.

At hole 2 the calcium phosphate zone includes both the lower unit of the Bone Valley Formation and residual clay of the Hawthorn. The matrix at this hole includes both the Bone Valley and Hawthorn Formations, but the top bed of the lower unit of the Bone Valley Formation is leached and is not a part of the calcium phosphate zone. The bed immediately underlying the leached bed of the lower unit is also excluded from the matrix, although it contains fresh shiny highly polished black and brown phosphate nodules. This bed is not visibly leached, but the phosphate nodules are so sparse that the company decided that the bed was not minable, and it was analyzed by the company as a part of the leached zone. This is an example of a bed in the uppermost part of the calcium phosphate zone that is included in the leached zone (normally a part of the aluminum phosphate zone) because it is unminable.

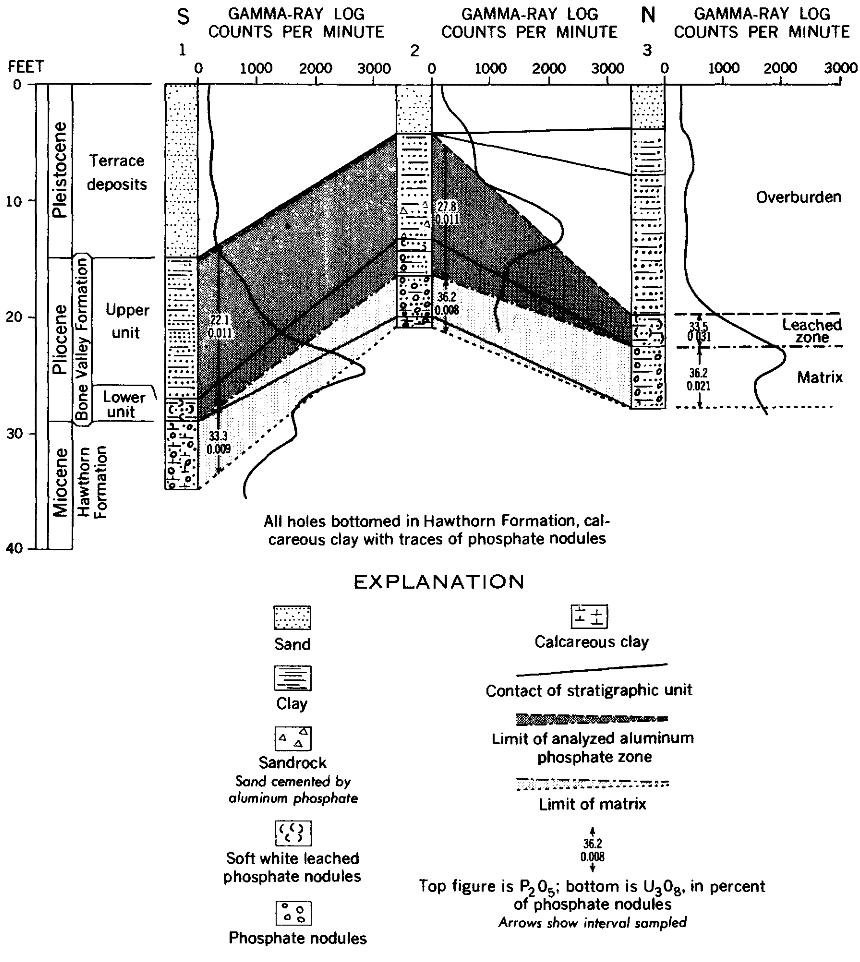


FIGURE 10.—Diagrammatic section, showing relations of stratigraphy and economic geology, Lakeland quadrangle.

At hole 3 the calcium phosphate zone includes all of the lower unit of the Bone Valley Formation, plus an unknown thickness of calcareous clay of the Hawthorn Formation in which the hole was bottomed. The matrix, however, is confined entirely to the lower unit of the Bone Valley Formation, and all of the lower unit is a part of the matrix. Leaching stopped at about the stratigraphic contact between the upper and lower units.

The matrix, at most drill holes, does not include as great a thickness of beds as does the calcium phosphate zone. The top part of the calcium phosphate zone is generally leached and is very low grade. For example, at holes 1 and 2 (fig. 10), the phosphate particles in the leached material contain less than 30 percent P_2O_5, far too low to be economic. At hole 3 the phosphate particles in the leached material contain enough P_2O_5 to be economic, but they are too sparse to be mined. The lower part of the calcium phosphate zone (the calcareous clay of the Hawthorn) contains too few phosphate particles to be economic. All holes shown in figure 10 bottomed in calcareous clay, called "lean matrix" by the drilling foreman. This material is a part of the calcium phosphate zone but contains only traces of phosphate particles, and is not minable.

The following two drill logs illustrate the relations between economic geology and stratigraphy.

Log of drill hole F in the SE¼NW¼ sec. 21, T. 27 S., R. 24 E.

[Drilled by the American Cyanamid Co.]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, gray-white, tan at base	33
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, clayey, tan. Quartz grains are coarse	2
Clay, sandy, gray; contains some fine-grained to granule-sized soft white phosphate nodules that are more abundant toward base	4
Lower unit:	
Sand, very slightly clayey, tan; contains very abundant medium- to coarse-grained sand-sized white and tan phosphate	3
Clay, sandy, gray-tan; contains abundant tan, white, and some black, granule- to coarse sand-sized phosphate	2
Total Bone Valley Formation	11
Miocene:	
Hawthorn Formation:	
Clay, calcareous, sandy, cream to light gray. Trace of very fine grained sand-sized phosphate and some very fine grained clear quartz sand	1
Part of Hawthorn Formation	1

Hole abandoned in calcareous clay with trace of phosphate.

Log of drill hole G in the SE¼NW¼ sec. 5, T. 28 S., R. 24 E.

[Drilled by Wayne Thomas]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, white at top; brown, iron stained at base	2
Sand, iron-cemented, dark-brown	1
Sand, loose, brown, fine- to coarse-grained	4
Total terrace sand	7
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, clayey; grades to very clayey at base, white and light-gray. Trace of soft white phosphate at base	7
Sand, clayey, light-brown; contains minor soft white phosphate	1
Lower unit:	
Sand, clayey, light-brown; contains abundant soft white phosphate, granule to medium-grained sand size	1
Sand, clayey, brown and gray; contains white and tan granule-to sand-sized phosphate nodules	2
Sand, loose; of quartz and tan and white phosphate. Trace granule-sized phosphate nodules	2
Sand, very clayey, light-gray; contains abundant white and some brown granule- and sand-sized phosphate nodules	4
Total Bone Valley Formation	17
Miocene:	
Hawthorn Formation—lower part:	
Clay, sandy, brown, calcareous; contains abundant sand-sized brown and some white phosphate nodules	2
Limestone, sandy, buff, soft; contains trace amounts of fine- to very fine-grained phosphate nodules	1
Part of Hawthorn Formation	3

Bottom in material too hard to penetrate.

Two samples from drill hole F in sec. 21, T. 27 S., R 24 E., were analyzed by American Cyanamid Co. chemists under contract with the U.S. Atomic Energy Commission. The top sample included all the upper unit of the Bone Valley Formation; it contained 8.6 percent P_2O_5, 6.4 percent CaO, 7.5 percent Al_2O_3, and 0.014 percent U. The analysis indicated that the sample contained a mixture of calcium phosphate and aluminum phosphate minerals, and probably most of the calcium phosphate was in the bottom bed of the upper unit, in the zone containing the soft white phosphate nodules. The bottom sample included the two beds of the lower unit of the Bone Valley Formation and contained 18 percent P_2O_5 and 0.012 percent U, or more than twice as much phosphate as the upper unit and slightly less uranium. The calcareous clay of the Hawthorn Formation contained so little visible phosphate that it was not analyzed. The analytical data at this drill hole indicate that here the upper unit of the Bone Valley Formation is the aluminum phosphate zone and the lower unit is the matrix. The calcareous clay is a part of the calcium phosphate zone but, because of the very low tonnage of recoverable phosphate grains, is excluded from the matrix.

The log of drill hole G in sec. 5, T. 28 S., R. 24 E., shows a somewhat different relation and one that is generally typical in the Lakeland quadrangle. The aluminum phosphate zone includes the top bed of the upper unit of the Bone Valley Formation and the zone of soft white phosphate. This zone is equally divided between the upper and the lower units of the formation—thus, the aluminum phosphate zone includes the uppermost bed of the lower unit of the Bone Valley Formation plus all of the upper unit. The calcium phosphate zone and the economic phosphate deposit (matrix) are equivalent at this drill hole. The lower three beds of the phosphorite unit of the Bone Valley and all of the calcareous clay, residual from the limestone of the Hawthorn Formation, are considered to be a part of the matrix. The soft limestone of the Hawthorn Formation is not considered a part of the calcium phosphate zone.

THICKNESS AND DISTRIBUTION

The calcium phosphate zone underlies almost all the Lakeland quadrangle, except along the courses of the modern streams. The zone is economic only in the southwestern two-thirds of the quadrangle, however, in the area underlain by the lower phosphorite unit of the Bone Valley Formation. The distribution is shown on plate 6, the isopach map of the zone. The calcium phosphate zone is not shown outside of the area underlain by the lower unit of the Bone Valley. There are two reasons for this—first, the zone is less than 10 feet thick over much of this area, and second, the zone is so low in tonnage of phosphate nodules that the drilling stopped before the total thickness of the zone had been penetrated. Drilling is widely scattered in this area, because no economic material was found in the wildcat drilling, and no additional holes were necessary to block out ore. Wildcat drilling penetrated as much as 15 feet of residuum of the Tampa Limestone or the Hawthorn Formation at a few scattered localities, but analyses of the phosphatic material from these drill holes showed that they contained so little P_2O_5 that the material could not be mined in the foreseeable future. For this reason, the material is not considered a part of the calcium phosphate zone—a potentially economic material.

The calcium phosphate zone ranges in thickness from 0 to between 40 and 50 feet and probably averages about 15 feet. Plate 6 shows a 40-foot isopach line in sec. 32, T. 28 S., R. 24 E.

A thick calcium phosphate zone tends to fill low spots on the Hawthorn surface, and the zone tends to be thin where it overlies highs on the Hawthorn surface, but the relation is not well developed in the Lakeland quadrangle. Detailed maps (fig. 11 and pl. 4) of the Lakeland Phosphate and Saddle Creek mines show the relation much better than the regional maps.

RELATIONS TO THE OVERBURDEN

The overburden is all the material from the surface of the ground to the matrix and, therefore, includes the loose sand of Pleistocene age, the clayey sand of the upper unit of the Bone Valley Formation, and the aluminum phosphate zone. The isopach map of the overburden (pl. 7) was made from company data, using this definition.

The overburden ranges in thickness from slightly less than 10 feet to about 90 feet. It is thickest in the eastern and western parts of the quadrangle—underlying the ridges, where there are large areas underlain by 50 feet or more of overburden. In the central plain the overburden thickness is irregular—the isopach lines form small irregular closed contours of 10-, 20-, and 30-foot thicknesses. The most persistent thin area is along the course of Saddle Creek, where the material has been removed by erosion.

The calcium phosphate zone is thin and irregular in distribution on the ridges and is thickest and most persistent under the central plain. In a very general way, the thicknesses of the overburden and the calcium phosphate zone form an inverse relation. The areas of thickest overburden are underlain by thin calcium phosphate zone, and the areas of thin overburden tend to be underlain by a calcium phosphate zone that is thick and persistent.

PHOSPHATE NODULES

The phosphate nodules of the calcium phosphate zone range in size from silt (<0.05 mm) to cobble (>64 mm). In the plants and in the treatment of the prospecting samples, however, the nodules are separated into two sizes—the pebble (-25 mm $+1$ mm) and the concentrate (-1 mm $+0.1$ mm). Because there is very little quartz

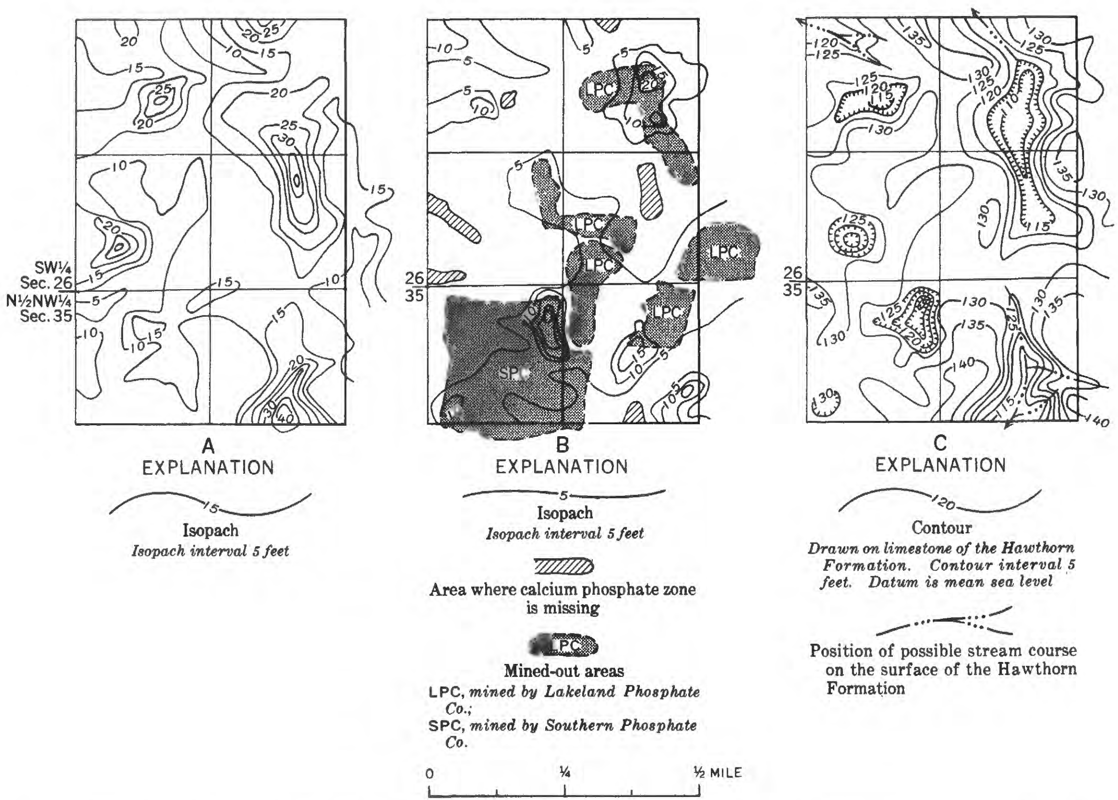


FIGURE 11.—*A*, Isopach map of the overburden; *B*, isopach map of the calcium phosphate zone; and *C*, paleotopographic map of the surface of the Hawthorn Formation, in parts of secs. 26 and 35, T. 28 S., R. 23 E.

that is greater than 1 mm in size, the pebble fraction is a phosphate product and is separated by simple screening. The concentrate is separated from the quartz sand by screening and flotation. All analytical data are reported in terms of these two fractions; the chemical analyses and the tonnage data are for the separated phosphate fractions.

The phosphate nodules in the lower unit of the Bone Valley Formation, the Hawthorn Formation, and the Tampa Limestone are varied in BPL content and in amount, expressed as tons per acre-foot. Tons per acre-foot is used to express the abundance of phosphate because prospect data always include thickness and tons per acre of phosphate nodules, from which tons per acre-foot can be computed. Other types of data regarding abundance, such as percentage of phosphate nodules, are seldom given and generally cannot be computed from the prospect data. Table 7 shows the variations in tonnage and grade of the pebble fraction of the three formations and, for comparison, the data for the concentrate fraction of the Bone Valley Formation. Data on the concentrate fractions of the Hawthorn and Tampa were not available.

TABLE 7.—*Comparison of BPL content and tons per acre-foot of phosphate nodules of the Bone Valley Formation, the Hawthorn Formation, and the Tampa Limestone*

[Analyses by company chemists]

	Percent BPL [1]		Tons per acre-foot	
	Range	Average	Range	Average
Bone Valley Formation (several hundred samples):				
Pebble	60–79	71.0	100–500	230
Concentrate	72–80	76.0	150–740	350
Hawthorn Formation (several hundred samples):				
Pebble	16–78	51.0	15–250	50
Tampa Limestone: [2]				
Pebble A (22 samples)	2–7	4.0	35–400	130
Pebble B (8 samples)	0.2–0.7	.3	250–870	470

[1] BPL=percent $P_2O_5 \times 2.185$.
[2] Pebble samples from the Tampa Limestone were divided into two groups on the basis of their BPL content.

The concentrate fraction of the Bone Valley Formation has the highest phosphate content of any group shown. The pebble fraction of the Bone Valley is almost as high, except that some samples were quite low in BPL. The pebble fraction of the Hawthorn Formation contains, on the average, very low BPL, but some samples are high in BPL, almost as high as the highest samples in the Bone Valley. All the samples of the Tampa Limestone are low in BPL—lower by far than any other samples on the table. The samples from group B probably are composed of fragments of limestone containing only a trace of P_2O_5. The samples from group A probably are phosphate nodules, but they, too, are extremely low in phosphate content.

The tonnage of the phosphate particles is highest in the Bone Valley Formation and lowest in the Hawthorn Formation. The highest tonnage of particles is for the B group of the Tampa Limestone, and these samples are probably not phosphate nodules.

These data on tonnage and grade can be used to help determine the stratigraphic position of analyzed samples from company drill holes that are called by the driller "clay, or sand, with phosphate rock." Samples high in BPL are from either the Bone Valley or the Hawthorn; samples containing from 10 to about 60 percent BPL are probably from the Hawthorn; samples containing less than about 10 percent BPL are almost surely in the Tampa Limestone.

SIZE VARIATION

Variation in phosphate particle size, computed as the ratio of tons per acre of the pebble fraction to tons per acre of the concentrate fraction, is mappable in the land-pebble district and is related to the present topography (Cathcart and Davidson, 1952, fig. 1). Davidson (1952, p. 13) pointed out that coarse phosphate was on Hawthorn highs and fine phosphate was on Hawthorn lows.

Figure 9 shows the distribution of pebble and concentrate in the Lakeland quadrangle. Two types of phosphate are distinguished on the map—predominantly coarse (pebble) and predominantly fine (concentrate). The lines that separate coarse phosphate from fine have a ratio of 1:1 pebble to concentrate.

In general, coarse phosphate predominates in the phosphorite underlying the western ridge and at the edge of the phosphorite deposit on the flanks of the eastern ridge. Fine phosphate predominates in the phosphorite underlying the central plain. A narrow strip along Saddle Creek, in the middle of the fine phosphate, is coarse grained, and a very irregular area in T. 27 S., R. 24 E., is also characterized by coarse phosphate.

The phosphorite deposit ends at the eastern ridge except for scattered patches, most of which are characterized by coarse phosphate. The edges of the deposit, particularly to the north and east, are also characterized by coarse phosphate—possibly because they represent the approximate shoreline of the Bone Valley sea. Remnants of the lower unit north and east may represent erosional outliers of the lower unit of the Bone Valley Formation originally characterized by coarse material.

The coarse phosphate along Saddle Creek and along the small unnamed creek in secs. 28 and 33, T. 28 S., R. 24 E., may be due to the removal of fines by erosion by the streams (river pebble) or by preferential leaching of the finer material by acidic ground water flowing toward the stream. The diminution of P_2O_5 content at or close to the streams points to the latter as the more probable cause.

The "topography" of the top of the Hawthorn Formation (pl. 3) follows the gross surface topography. In the flatwoods areas, altitudes are generally below 100 feet, whereas at both the north and south ends of the western ridge they reach 140 feet and on the eastern ridge 130 feet. On the Hawthorn surface, therefore, highs are generally characterized by coarse phosphate and lows by fine phosphate.

ANALYTICAL DATA

The analytical data are confined to the chemical analyses of the separated fractions of the calcium phosphate zone—the pebble, concentrate, and slime. In 1952 and 1953 the companies drilled three areas under contract to the U.S. Atomic Energy Commission. One hole per 40-acre block was drilled, and a single sample, representing the economic part of the calcium phosphate zone, was taken at each drill hole. Most of the samples represent phosphatic material from the Bone Valley and from the Hawthorn. The data are probably representative of the chemical composition of the separated parts of the calcium phosphate zone in the Lakeland quadrangle. The chemical data are summarized on table 8.

TABLE 8.—*Analytical data, calcium phosphate zone, Lakeland quadrangle*

[NA, no analysis reported. Analytical data by American Cyanamid Co. and Coronet Phosphate Co., under contract to the U.S. Atomic Energy Comm.]

Number of drill holes	Location	Fraction (mesh size)	Chemical analyses, average, (in percent)				Ratio $U:P_2O_5$ (average)
			P_2O_5	I and A[1]	Acid insoluble	U	
90	Park and Orange tracts, T. 27 S., R. 24 E.	+20	33.9	2.39	7.20	0.012	1:2820
		−20+150[2]	35.0	2.28	4.24	.010	1:3500
		−150	19.8	12.85	32.57	.011	1:1800
		Head[3]	23.1			.008	
39	Tenoroc mine, T. 27 S., Rs. 24 and 25 E.	+24	31.8	2.33	8.14	.015	1:2120
		−24+150[2]	35.2	1.83	1.88	.010	1:3520
		−150	14.7	NA	42.69	.011	1:1340
		Head[3]	12.1			.006	
27	Lake Parker tract, T. 28 S., R. 24 E.	+24	32.2	3.31	9.67	.015	1:2150
		−24+150[2]	31.4	2.01	2.30	.012	1:2620
		−150	16.8	NA	39.55	.010	1:1680
		Head[3]	12.6			.006	

[1] Percent $Fe_2O_3+Al_2O_3$.
[2] Concentrate fraction—quartz sand removed by flotation.
[3] Calculated, assuming that the sand tailing contained 2 percent P_2O_5 and 0.002 percent U.

In general, the coarse phosphate fraction of the calcium phosphate zone (+20 or +24 mesh) contains less P_2O_5 and more U than the fine phosphate fraction (−20+150 mesh), as is characteristic of the land-pebble phosphate district (Cathcart, 1956). At the Lake Parker tract, however, the coarse phosphate fraction contains more P_2O_5 than the fine fraction. The content of acid insoluble and total iron and alumina is low in the concentrate fraction from the Lake Parker tract, indicating that the low P_2O_5 content of this fraction is due to some other diluent, probably calcite. High calcite content is characteristic of the phosphate of the Hawthorn Formation, and the fact that the pebble fraction is higher in P_2O_5 content than the concentrate fraction at the Lake Parker tract may be because the calcium phosphate zone at this tract is mostly in the Hawthorn Formation.

The iron and alumina content of the phosphate products is low and is nearly uniform at all tracts, although the concentrate fractions generally contain slightly less iron and alumina than the pebble fractions. The iron and alumina content of the slime fraction was reported only from the Park and Orange tract where it is very high because of the concentration of clay minerals.

The acid insoluble content is similar at all tracts—higher in the coarse than in the fine fraction and very high in the slime fraction; very fine grained quartz sand and silt are concentrated in the slime fraction, accounting for the high insoluble content.

The uranium-to-phosphate ratio is highest in the slime fraction, lowest in the concentrate fraction. Concentrate-sized nodules tend to be simple, and those in the Hawthorn Formation are mostly primary nodules. Pebble-sized nodules are complex and generally several generations of the phosphate mineral cement finer phosphate nodules, and these compound nodules are then recemented into still larger and more complex nodules. This may be because of continued reworking in more than one cycle of sedimentation as suggested by Altschuler, Clarke, and Young (1958). Thus, the coarser nodules have considerably higher uranium-to-phosphate ratios than the finer nodules because of enrichment in uranium relative to P_2O_5 during several exposures to sea water or simply because of longer exposure to sea water because of their larger size. The slime fraction, which has a very high uranium-to-phosphate ratio was also enriched in uranium, relative to its P_2O_5 content. For comparison, table 13 shows the extremely high uranium-to-phosphate ratios in the aluminum phosphate zone, which has been secondarily enriched in uranium.

PHOSPHATE CONTENT

The P_2O_5 content of the phosphate nodules of the calcium phosphate zone varies with nodule size and with stratigraphy. Ratios of pebble to concentrate are different in the Hawthorn and Bone Valley Formations. Data from a typical drill hole in which both formations were analyzed are shown in table 9.

The pebble fraction in the Bone Valley Formation is almost twice as abundant as in the Hawthorn Formation, but the concentrate fractions are nearly equal in the two formations (table 9). The pebble-to-concentrate ratio in the Bone Valley Formation is about

TABLE 9.—*Analytical data, pebble and concentrate samples of the Bone Valley and Hawthorn Formations, from a drill hole in the SE¼ SW¼ sec. 35, T. 27 S., R. 25 E.*

	Tons per acre-foot	Analytical data, in percent					
		P_2O_5	I and A[1]	Acid insoluble	CaO[2]	F[3]	Remainder[4]
Bone Valley, pebble	214	32.63	1.28	13.68	45.6	3.3	3.5
Hawthorn, pebble	137	30.59	1.30	11.11	42.7	3.1	11.2
Bone Valley, concentrate	130	36.01	1.83	3.49	50.4	3.6	3.7
Hawthorn, concentrate	149	33.45	1.40	3.94	46.7	3.3	11.2

[1] I and A = total percent $Fe_2O_3 + Al_2O_3$.
[2] Calculated by multiplying the P_2O_5 by 1.4—the ratio of CaO to P_2O_5 in carbonate-fluorapatite.
[3] Calculated by dividing the P_2O_5 by 10—the ratio of F to P_2O_5 is 1:10 in fluorapatite.
[4] Remainder is amount needed to make 100 percent. Most of the remainder is probably calcium carbonate.

1.6; whereas in the Hawthorn it is only about 0.9. The P_2O_5 content of both the pebble and concentrate fractions is higher in the Bone Valley than in the Hawthorn. The total iron and alumina contents are about the same in all fractions, and the acid insoluble contents are much higher in the two pebble fractions than in the concentrate fractions.

The contents of CaO and F as shown in table 9 were calculated from the known contents of P_2O_5 on the assumption that the phosphate mineral is a carbonate fluorapatite. The ratio of CaO to P_2O_5 in this mineral is about 1.4, and the fluorine content is about one-tenth that of the P_2O_5 content. The remainder, the percent necessary to make 100 percent, is about three times as high in both fractions of the Hawthorn as in the Bone Valley. Much of the remainder may be calcium carbonate, although trace elements may make up 1 or 2 percent of this amount. The phosphate nodules in the Hawthorn Formation contain more calcite than do the nodules of the Bone Valley Formation.

The bed clay, residual calcareous clay of the Hawthorn Formation, is a part of the calcium phosphate zone throughout the Lakeland quadrangle. At most drill holes only one sample was taken of the calcium phosphate zone, which includes both the Bone Valley and Hawthorn Formations. At the Saddle Creek tract, however, the bed clay, where it contained sufficient visible phosphate nodules, was sampled and analyzed separately from the rest of the zone. At 63 drill holes in this tract the calcium phosphate zone was sampled in two or more beds; the bottom bed was described by the driller as bed clay, the upper bed or beds as matrix. Coarse (+3/64 inch) and fine (−3/64+1/32 inch) pebble fractions were split from each sample and were analyzed for their BPL content. It is not possible to compare the concentrate fractions because generally both samples were combined to make a single flotation test. The ranges and averages for the P_2O_5 content of the pebble fractions from the Bone Valley and Hawthorn Formations are compared in table 10.

TABLE 10.—*Comparison of P_2O_5 content of pebble samples from the bed clay and matrix, Saddle Creek tract*

[Analyses, in percent, by American Cyanamid Co., published with permission]

Sample	+3/64 inch (coarse pebble)		−3/64 inch +1/32 inch (fine pebble)	
	Range	Average	Range	Average
Matrix (Bone Valley)	29.0–37.3	33.1	27.9–36.3	32.4
Bed clay (Hawthorn)	10.6–29.3	22.6	9.2–35.6	24.1
Difference [1]	2.8–21.5	10.5	0.6–23.7	8.3

[1] This is the difference in P_2O_5 content between samples of the Bone Valley and the Hawthorn Formations at the same drill hole.

The entry in the stub column of table 10 termed "difference" refers to the difference in P_2O_5 content of the pebble fraction of the Bone Valley and Hawthorn Formations at the same drill hole, and it should be emphasized that the matrix sample directly overlies the bed-clay sample at each drill hole locality, and that at every drill hole the phosphate content of the pebble fractions of the Bone Valley Formation was higher than that of the Hawthorn Formation. In the matrix the P_2O_5 content is somewhat higher in the coarse pebble fraction than in the fine pebble fraction, but in the bed clay the reverse is true.

The fine pebble fraction of the matrix has a higher content of insoluble residue than the coarse pebble fraction. The acid-insoluble residue is mostly silica and presumably quartz sand. There is little or no quartz sand coarser than $+3/64$ inch in the matrix, but there is some in the $-3/64+1/32$ inch fraction. In the bed clay, however, the content of insoluble residue is about the same in both pebble fractions. Quartz grains are evidently somewhat finer in the bed clay than in the matrix.

The pebble phosphate fraction of the bed clay contains enough P_2O_5 at some localities to be economic, and at some places, the concentrate fraction may also be high in phosphate content.

URANIUM CONTENT AND DISTRIBUTION

Uranium is present in the phosphate products—the pebble and the concentrate—and in the slime fraction of the calcium phosphate zone. As noted earlier, the pebble fraction contains more uranium than the concentrate fraction (table 8), and the maps of distribution of uranium confirm this generalization (pls. 8 and 9).

The uranium analyses on which plates 8 and 9 are based were made by the U.S. Geological Survey. All analyses of the pebble fraction from a drill hole were arithmetically averaged, and this average number was used for contouring. The same procedure was used for the concentrate fraction. The distribution of uranium in the two fractions is similar. Both fractions are low in uranium—less than 0.010 percent—at or close to the modern streams. Areas underlain by phosphate nodules containing higher amounts of uranium are represented by very irregular closed isopleths. The pattern of distribution of uranium as shown on the two maps is broadly similar, but the uranium content of the pebble is considerably higher than the uranium content of the concentrate. The highest uranium content of the pebble fraction is about 0.045 percent, at a hole in the NE¼ sec. 14, T. 28 S., R. 24 E., and the highest content of uranium in the concentrate fraction (about 0.030 percent) is at two drill holes—one in the SW¼NW¼ sec. 4, T. 28 S., R. 24 E., the other in the SE¼SE¼ sec. 30, T. 27 S., R. 25 E.

The 0.010-percent uranium contour on the pebble isopleth (pl. 8) follows the stream course of Saddle Creek, but on the concentrate isopleth (pl. 9), very broad areas are underlain by phosphate nodules containing less than 0.010 percent uranium. No area on the pebble map is underlain by phosphate containing less than 0.005 percent uranium, but on the concentrate map, a small area in the NW¼ sec. 21, T. 27 S., R. 24 E., is underlain by phosphate containing less than 0.005 percent uranium.

Although the pebble fraction generally contains from 0.005 to 0.010 percent more uranium than the concentrate fraction, in a few places the two fractions contain equal amounts of uranium, and at one drill hole, in the SW¼SW¼ sec. 21, T. 26 S., R. 24 E., the pebble fraction contained 0.010 percent uranium; the concentrate fraction 0.015 percent.

Except for the lowering of the uranium content at the modern streams, which may be due to leaching of uranium from the phosphate nodules by acidic waters (Cathcart, 1963 a, b), no regional trends are apparent.

The vertical, or stratigraphic, distribution of uranium in the phosphate products (pebble and concentrate) and in the slime fraction is shown in figure 12. The Hawthorn Formation (samples 5 and 6) is high in slime, and the pebble-to-concentrate ratio is very low, about 0.2. The lower unit of the Bone Valley Formation (samples 7–10) contains varying amounts of pebble, concentrate, and slime, ranging from a slightly clayey sand containing abundant coarse phosphate (sample 10) to a slightly sandy clay containing only minor phosphate (sample 9). The upper unit of the Bone Valley Formation (sample 11) is a very sandy clay with no phosphate.

The uranium content of the pebble and concentrate follow identical patterns—generally decreasing from top to bottom—and in every sample the pebble contains more uranium than the concentrate. Uranium in the slime fraction is low in sample 11, reaches a maximum in sample 10, and is variable, but low, in the rest of the samples. The bottom two samples (6 and 5), from the Hawthorn Formation, contain the lowest amounts of uranium in the section.

The distribution pattern indicates that uranium, leached from the upper part of the section, was concentrated in the loose phosphate and quartz sand (sample 10) because of the relatively impermeable clay bed (sample 9) or because of the original difference in uranium content or, most probably, both. The uranium content of all fractions increases slightly in sample 8 and generally decreases toward the bottom of the section; the samples from the Hawthorn Formation generally contain less uranium than the average of the samples from the Bone Valley Formation.

ACID INSOLUBLE CONTENT

Phosphate nodules in the lower unit of the Bone Valley Formation consist of carbonate fluorapatite and acid insoluble material—principally quartz, and samples of phosphate nodules show a strong inverse correlation between percent BPL and percent acid insoluble material (Cathcart, 1963a, p. 51). Samples of pebble phosphate from calcareous clay of the lower part of the Hawthorn Formation consist of a mixture of carbonate fluorapatite, acid insoluble material, and some other acid soluble material, probably calcite, and samples of pebble from the Hawthorn show little or no correlation between percent BPL and percent acid insoluble material.

ALUMINUM PHOSPHATE ZONE

The aluminum phosphate zone is a zone of ground water alteration formed by downward-percolating acidic water. The zone is not a stratigraphic unit but may include all of the upper unit of the Bone Valley Formation, only the upper part of the upper unit, or the upper unit plus the top part of the lower unit of the Bone Valley. The physical and chemical characteristics of the zone vary with the part of the section that has been altered. Typically, it is a white, light-gray, tan, or gray-green clayey sand containing no visible phosphate except near the base, and in some areas the base of the zone is characterized by lumps, fragments, or beds of sandrock. According to Altschuler, Clarke, and Young (1958), the most completely leached part of the zone is characterized by the aluminum phosphate mineral wavellite, the less weathered parts by calcium aluminum phosphate minerals, and the unweathered part by the calcium phosphate mineral carbonate fluorapatite. The principal clay mineral in the weathered parts is kaolinite, whereas montmorillonite is characteristic of the unweathered parts. The zone is high in uranium, which typically is concentrated in the finest (slime) fraction.

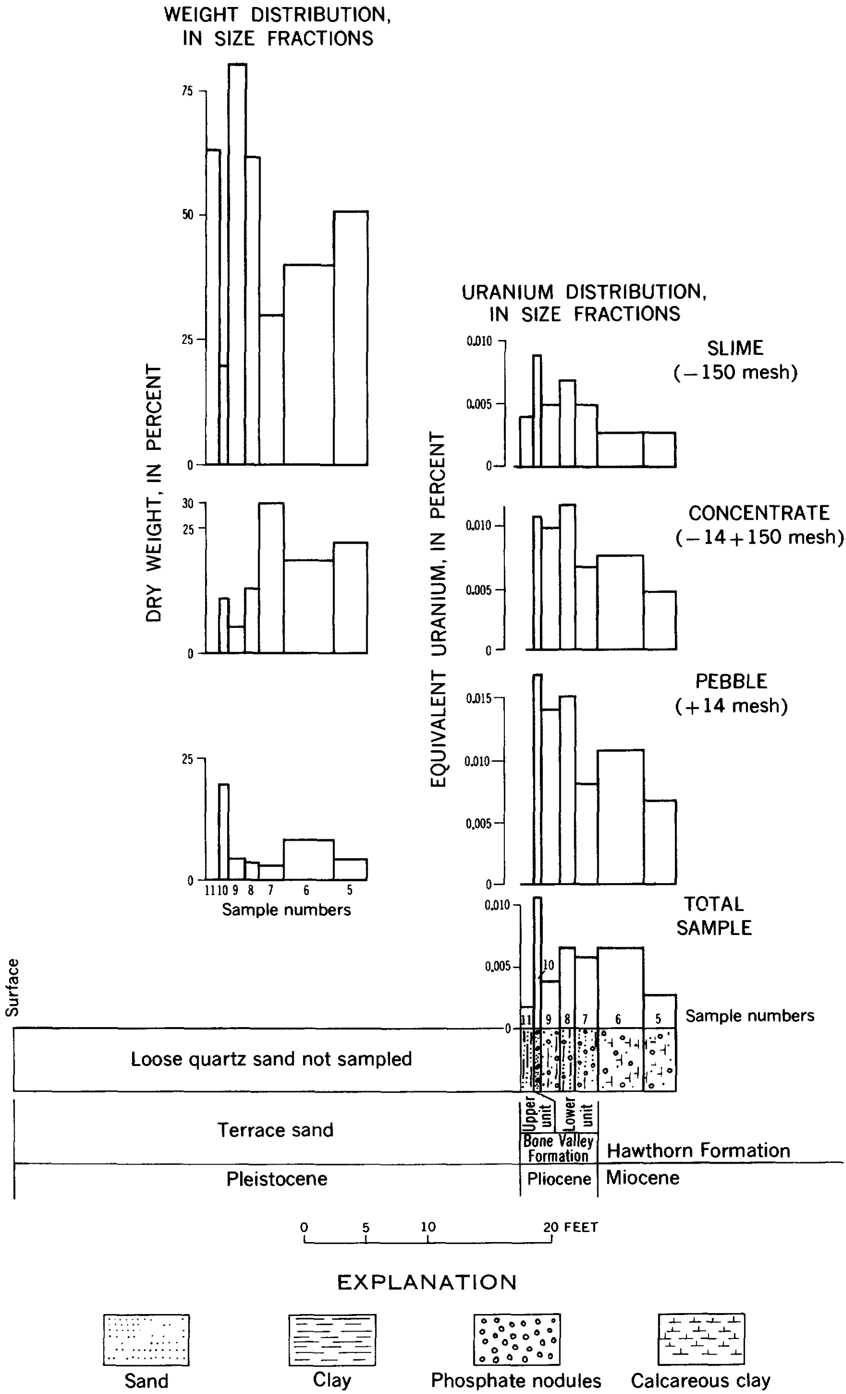


FIGURE 12.—Section, Saddle Creek mine, SW¼NW¼ sec. 27, T. 28 S., R. 24 E., showing uranium content and distribution of pebble, concentrate, and slime. Modified from stratigraphic section by F. N. Houser. Uranium analyses by G. T. Burrow, S. P. Furman, and Wayne Mountjoy, U.S. Geological Survey.

Screen data and uranium analyses for a section of the aluminum phosphate zone that includes the upper unit of the Bone Valley Formation are given in table 11. The table illustrates the effects of thorough leaching on a section of clayey sand of the upper unit. The original material probably did not contain very much phosphate typical of the upper unit. The upper unit contains practically no coarse pebble. The basal bed (sample 921–12) contained 0.9 percent, by weight, of the pebble fraction. The sharp increase in the amount of pebble in the next lower sample (921–11), in the top bed of the phosphoritic lower unit of the Bone Valley, and in the top part of the calcium phosphate zone indicates that at this locality the stratigraphic contact between the upper and lower units of the Bone Valley Formation and the weathering contact between the aluminum phosphate and calcium phosphate zones is at the same horizon. The highest uranium content is in the pebble fraction of the basal bed of the upper unit, and the higher beds in the section are very low in uranium content, much lower than in unweathered sections. Uranium, leached from the upper beds, has been concentrated in the pebble fraction of the basal part of the weathered zone. Both the weight percent and the uranium content of the slime fraction increase gradually toward the base of the aluminum phosphate zone. Almost all of the uranium is concentrated in the slime fraction of the zone, except in the basal sample where there is appreciable uranium in the pebble and coarse-sand fractions. The concentrate fraction is not present in any of the samples of the aluminum phosphate zone, but it is very abundant in sample 921–11 from the top of the lower unit of the Bone Valley. The −35+150-fraction consists of quartz sand, except for the sample of the calcium phosphate zone that contains abundant sand-sized phosphate grains.

TABLE 11.—*Screen data and uranium analyses of screen fractions, upper unit of the Bone Valley Formation, Saddle Creek mine, NE¼NW¼ sec. 22, T. 28 S., R. 24 E.*

[Analyses by F. S. Grimaldi, U.S. Geol. Survey. Sample 921-16 is sand of Pleistocene age, samples 921-15 to 921-12 are from the upper unit of the Bone Valley Formation and represent the aluminum phosphate zone, and sample 921-11 is the top bed of the lower unit of the Bone Valley and is in the calcium phosphate zone]

Sample	Depth (in feet) below surface	Screen and analytical data, in percent											
		+14 (pebble)			−14+35 (sand)			−35+150 [1]			−150 (slime)		
		Weight	U	Lab. No.	Weight	U	Lab. No.	Weight	U	Lab. No.	Weight	U	Lab No.
921-16	4-8	0.4	0.001	27688	14.9	0.000	27689	67.5	0.000	27690	17.2	0.001	27691
15	8-13	0	-----	------	6.7	.002	27683	68.8	.000	27684	24.5	.003	27685
14	13-18	0	-----	------	26.0	.000	27678	47.9	.000	27679	26.0	.002	27680
13	18-23	.4	.002	27672	9.7	.000	27673	62.7	.000	27674	27.2	.005	27675
12	23-27.5	.9	.019	27666	7.8	.005	27667	59.8	.001	27668	31.4	.007	27669
11	27.5-30.5	9.4	.012	27659	10.3	.009	27660	31.0 18.2	.003 .009	27664 27663	31.1	.011	27662

[1] Sand tailings, except for sample 921-11 where top figures are tailings and bottom are concentrate; only this sample had a concentrate fraction.

An example of a leached section that includes only the upper part of the upper unit of the Bone Valley Formation is given in the log of a drill hole in the NE¼NW¼ sec. 26, T. 28 S., R. 24 E. (drill hole H), and in table 12, which shows the analytical and screen data.

TABLE 12.—*Screen data, uranium analyses, and uranium distribution, aluminum phosphate zone, drill hole in the NE¼NW¼ sec. 26, T. 28 S., R. 24 E.*

[Leaders (--) = no analysis. Chemical analyses by Dorothy Lee, Maryse Delevaux, Roberta Smith, and W. P. Tucker; radiometric analyses by B. A. McCall and J. H. Goode, Jr., U.S. Geol. Survey]

Laboratory No.	Screen fraction (mesh size)	Weight percent	Percent			Distribution of uranium in screen fractions (percent)
			eU	U	P_2O_5	
Top sample: 9 to 14 ft below surface						
100678	+14 (pebble)	0.8	0.009	--	--	1.7
100679	−14+35 (feed)	10.1	.001	--	--	2.3
100680	−35+150 (sand)	55.5	.001	--	--	12.5
100681	−150 (slime)	33.6	.009	0.011	11.1	83.5
	Head (calculated)	100.0	.004	--	--	100.0
Bottom sample: 14 to 24 ft below surface						
100673	+14 (pebble)	0.8	0.013	--	--	3.0
100674	−14+35 (feed)	2.6	.004	--	--	3.0
100675	−35+150 (sand)	56.8	.003	--	--	48.7
100676	−150 (slime)	39.7	.004	0.005	7.7	45.3
	Head (calculated)	100.0	.0035	--	--	100.0

Log of drill hole H in the NE¼NW¼ sec. 26, T. 28 S., R. 24 E.

[Drilling by the American Cyanamid Co., adapted from lithologic log by H. B. Dutro, U.S. Geol. Survey]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, quartz, gray at top, grading to tan	2
Sand, loose, quartz, dark-brown, grading to tan	3
Sand, loose, gray-white	1
Sand, dark-brown, with iron-cemented lumps	3
Total terrace sand	9
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, clayey, light-gray	3
Clay, sandy, light-gray	2
Clay, very sandy, light grayish-white; contains trace amounts of soft white phosphate	6
Sand, clayey, light blue-gray; no visible phosphate	4
Lower unit:	
Clay, very sandy, blue-gray; contains abundant brown and tan sand and granule-sized phosphate nodules	2
Total Bone Valley Formation	17

Log of drill hole H in the NE¼NW¼ sec. 26, T. 28 S., R. 24 E.—Continued

	Thickness (feet)
Miocene:	
Hawthorn Formation—lower part:	
Clay, sandy, buff-yellow, calcareous; contains ninor brown and white fine sand-size phosphate nodules	3
Part of Hawthorn Formation	3

Bottom in material too hard to penetrate—limestone.

At drill hole *H*, soft white leached phosphate was in about the middle of the upper unit of the Bone Valley Formation, but none was seen in the basal bed of the upper unit—which was not visibly altered by weathering but appeared to be fresh. Two samples of the upper unit were screened and analyzed (table 12). The top sample included the upper two beds, the bottom sample included the lower two beds. In the top sample, about 84 percent of the total uranium was in the slime fraction, which contained 0.011 percent uranium and 11.1 percent P_2O_5, whereas the sand fractions (−14+35 and −35+150 mesh) contained about 15 percent of the total uranium, but only 0.001 percent equivalent uranium. This is typical of the uranium distribution in thoroughly leached samples. The bottom sample included the soft white phosphate bed as well as the unleached lowest bed of the upper unit, but the uranium in this sample is about equally divided between the fine sand (−35+150 mesh) fraction and the slime fraction, and both of these fractions contain about the same amount of uranium. There is no apparent concentration of uranium in the slime fraction. It is probable, therefore, that leaching reached only to the base of the unit of soft white phosphate, and that the bottom 4 feet of the upper unit of the Bone Valley Formation is unleached. Economically, because of mining problems, the entire upper unit would have to be included as a part of the aluminum phosphate zone if the zone was mined in this area.

An example of leaching extending downward to the top of the Hawthorn Formation is the drill hole in the NE¼SW¼ sec. 21, T. 27 S., R. 24 E. (hole 1, fig. 10). At this drill hole the analyzed aluminum phosphate zone extended from the base of the loose sand of the Pleistocene to the top of the residual calcareous clay of the Hawthorn Formation. All the Bone Valley Formation was altered by leaching; the lower unit at this drill hole is the zone of soft white phosphate, and the calcium phosphate zone is entirely within the Hawthorn Formation.

At a drill hole in sec. 22, T. 27 S., R. 24 E. (hole 2, fig. 10), leaching extended down into the top of the lower unit of the Bone Valley Formation, and the high peak of radiation on the gamma-ray log breaks off sharply at the base of the leached lower unit. The high peak of radiation corresponds to the basal bed of the upper unit, a clayey sand with abundant sandrock, plus the top bed of the lower unit, a clayey sand with abundant soft white phosphate. The matrix, as determined by the phosphate company, however, begins 2 feet below the zone of leaching.

The aluminum phosphate zone at this drill hole includes all the upper unit of the Bone Valley and the top leached part of the lower unit. The calcium phosphate zone includes all the rest of the lower unit plus the calcareous clay of the Hawthorn Formation. The top part of the unleached lower unit, however, is not a part of the matrix and was included, by the company, in its leached zone. Thus, at this drill hole, the leached zone includes all the aluminum phosphate zone plus the top uneconomic part of the calcium phosphate zone. This mixture of material is reflected in the analyses of the zone. The pebble fraction contained 27.8 percent P_2O_5 and 29.5 percent CaO—mostly calcium phosphate but containing some aluminum phosphate minerals. The slime fraction, however, contained 10.2 percent P_2O_5, but only 1.5 percent CaO and is mostly aluminum phosphate minerals.

THICKNESS AND DISTRIBUTION

The aluminum phosphate zone probably underlies almost all the Lakeland quadrangle, except along the course of Saddle Creek, but data are not available for the northern, eastern, and southwestern parts of the quadrangle. The distribution of the zone is shown on plate 10. The zone is thin (less than 3 ft thick) in the northern third of the quadrangle and under the two areas of the ridge province (in the eastern part of the quadrangle and from the city of Lakeland to the northwest). The zone is thickest and most persistent in the flatwoods area between the two ridges, but even here it reaches a maximum of only about 20 feet—in the SE¼NE¼ sec. 11, T. 27 S., R. 24 E. Throughout much of the area the zone ranges in thickness from 3 to 5 feet and probably averages about 7 feet.

ANALYTICAL DATA

Analytical data for the aluminum phosphate zone in the Lakeland quadrangle are summarized in table 13. A single sample that represents the total thickness of the zone was taken at each drill hole. Drilling and analytical work was done in 1953 by the American Cyanamid Co. and Coronet Phosphate Co., under contract to the U.S. Atomic Energy Commission. All the analyses in the table are weighted averages of the number of samples and represent very large tonnages.

The pebble fraction (+20 or +24 mesh) is only a very small part of the total rock, the sand fraction (−20 or −24+150 mesh) makes up more than two-thirds of the weight of the rock at the Lake Parker and Tenoroc tracts and somewhat more than half of the rock at the Orange and Park tracts. The remainder of the rock is in the slime (—150 mesh) fraction, which is significantly more abundant at the Orange and Park tracts than at the Lake Parker or Orange tracts.

TABLE 13.—*Summary of screen data and chemical analyses, aluminum phosphate zone, Lakeland quadrangle*

[Analyses by American Cyanamid Co. and Coronet Phosphate Co., published with permission]

Number of samples	Screen data		Chemical analyses, in percent					Ratios	
	Size	Weight percent	P_2O_5	CaO	U	Al_2O_3	Fe_2O_3	$CaO:P_2O_5$	$U:P_2O_5$
Lake Parker tract, T. 27 S., R. 24 E.; T. 28 S., R. 24 E.									
27	+24	1.1	13.09	3.97	0.009	11.50	0.56	0.303	1:1450
	+150	68.4	.72	.08	.0001	.56	.26	.111	----------
	−150	30.5	6.10	3.64	.012	8.28	.71	.597	1:510
	Head	100.0	2.52	1.24	.004	3.05	.40	.492	1:630
Tenoroc mine, T. 27 S., R. 24 E.; T. 27 S., R. 25 E.; T. 28 S., R. 24 E.									
39	+24	0.7	11.99	5.88	0.005	8.42	0.80	0.490	1:2390
	+150	72.1	.52	.37	.0001	.41	.31	.712	----------
	−150	27.2	5.42	3.65	.009	6.94	.86	.673	1:600
	Head	100.0	1.93	1.30	.0025	2.28	.46	.674	1:770
Orange tract, T. 27 S., R. 24 E.									
57	+20	1.5	26.02	28.03	0.015	8.29	0.69	1.077	1:1630
	+150	56.7	2.25	2.08	.002	.78	.36	.924	1:1130
	−150	41.8	8.66	6.26	.017	11.10	1.22	.723	1:510
	Head	100.0	5.29	4.23	.008	5.17	.72	.800	1:660
Park tract, T. 27 S., R. 24 E.									
33	+20	3.2	31.84	34.09	0.016	8.11	0.91	1.071	1:1990
	+150	52.0	3.85	3.94	.003	.94	.41	1.023	1:1280
	−150	44.8	14.63	14.05	.018	11.64	1.89	.960	1:810
	Head	100.0	9.58	9.44	.010	5.97	1.09	.985	1:960

The pebble fraction at each of the tracts contains the most P_2O_5 and CaO; at the Orange and Park tracts, the P_2O_5 and CaO contents of this fraction are more than twice as high as at the Lake Parker and Tenoroc tracts. Uranium is highest in the slime fraction at all tracts and, again, is much higher at the Orange and Park tracts than at the Lake Parker and Tenoroc tracts. The percentage of Al_2O_3 is highest in the pebble fraction at the Lake Parker and Tenoroc tracts but is highest in the slime fraction at the Orange and Park tracts. Fe_2O_3 is uniformly low but is most abundant in the slime fraction and is higher in all fractions at the Orange and Park tracts than at the Tenoroc and Lake Parker tracts.

The ratio of CaO to P_2O_5, a measure of the intensity of leaching, is considerably lower in the Tenoroc and Lake Parker tracts than at the Orange and Park tracts, and the very high uranium to P_2O_5 ratios, particularly in the slime and the head samples, is indicative of the redistribution of uranium in the aluminum phosphate zone.

As indicated by the chemical data, leaching was greater at the Tenoroc and Lake Parker tracts than at the Orange and Park tracts—probably because the lower content of slime, including clay, at the Lake Parker and Tenoroc tracts resulted in greater permeability of the rocks.

Additional analytical and screen data for the aluminum phosphate zone, at the Saddle Creek tract where the zone was sampled in short vertical intervals from top to bottom, are shown in table 14. At most drill localities, the bottom samples of the aluminum phosphate zone contained considerably more uranium than the top samples. To show this contrast, an average was taken of 19 bottom samples and of the 32 top samples from 19 drill holes.

TABLE 14.—*Summary of screen data and uranium analyses, aluminum phosphate zone, Saddle Creek tract*

Screen data		Uranium analyses, in percent	Distribution of uranium in size fractions, in percent
Size	Weight percent		
Top samples (averaged)			
+14	0.6	0.005	1
−14+35	11.4	<.001	2
−35+150	56.8	<.001	13
−150	31.2	.006	84
Head	100.0	.002	100
Bottom samples (averaged)			
+14	4.8	0.019	9
−14+35	10.0	.008	8
−35+150	56.5	.004	23
−150	28.7	.021	60
Head	100.0	.010	100

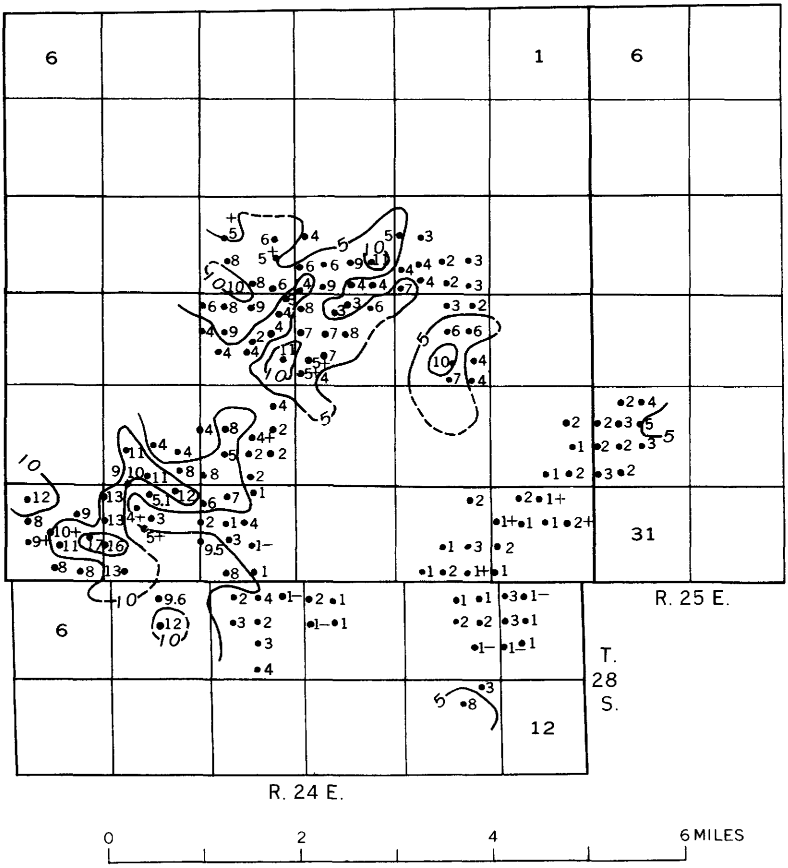
The differences in the samples are striking. The screen data are very similar, except that the bottom samples contain considerably more +14 mesh (pebble) and somewhat less of the slime fraction than the top samples. In these thoroughly leached samples, the coarse phosphate fraction has been removed by the leaching from the top samples, and phosphate nodules are not abundant in the upper unit of the Bone Valley Formation except in the basal part. In the top samples, the sand fractions (−14+150 mesh) contain no uranium and, probably, little or no phosphate. In the bottom samples, however, the sand fractions contain some uranium—appreciably more in the coarser fraction than in the finer. It is probable that there is some phosphate in these fractions, although no flotation concentrate was obtained. The phosphate is soft and white, and this type of phosphate normally gives little or no flotation concentrate. The pebble and slime fractions of the bottom samples contain almost four times as much uranium as those of the top samples.

Virtually all the uranium in the top samples is in the slime fraction. The fine sand fraction contains 13 percent of the total uranium, but the uranium content of this fraction ranged from less than 0.001 to 0.002 percent, and averaged 0.0005 percent. In the bottom samples, however, only about 60 percent of the total uranium is in the slime fraction, and a considerable amount is in the fine sand (−35+150 mesh) fraction. The pebble fraction contains about 9 percent of the uranium. Thus, the distribution of the uranium is considerably different in the two parts of the aluminum phosphate zone.

The areal distribution of uranium in the aluminum phosphate zone is shown on plate 11. The uranium content of the zone is less than 0.005 percent along the stream courses. Large areas are underlain by aluminum phosphate zone containing from 0.005 to 0.010 percent uranium, but areas where the zone contains as much as 0.015 percent uranium are small, and the iospleths form rounded randomly distributed "hill-like" highs. The highest contour on the map is the 0.025 percent uranium contour, in the SE¼SE¼ sec. 15, T. 27 S., R. 24 E., in the SE¼NE¼ sec. 31, T. 27 S., R. 24 E., and in the NE¼ NE¼ sec. 33, T. 28 S., R. 24 E. Other highs may be present but could not be defined with the information available. Each of the areas was defined by a single drill hole in which the uranium content of the aluminum phosphate zone was between 0.025 and 0.030 percent.

The areal distribution of phosphate in the aluminum phosphate zone is shown in figure 13. The P_2O_5 content of the zone ranges from 1 to 17 percent. Through most of the area the range in phosphate content is from 1 to 5 percent, but there are large areas underlain by aluminum phosphate zone containing from 5 to 10 percent P_2O_5; a few small area contain from 10 to 15 percent, and one small area (defined by a single drill hole) contained 17 percent P_2O_5. Areas underlain by aluminum phosphate zone high in phosphate content correspond closely to those areas where the uranium content is high (compare fig. 13 and pl. 11). For example, the areas containing 0.025 percent uranium in secs. 15 and 31, T. 27 S., R. 24 E., contain 10 and 15 percent P_2O_5, and all of the areas where the aluminum phosphate zone contains more than 10 percent P_2O_5 also contain between 0.010 and 0.020 percent uranium. Obviously, the uranium and phosphate contents of the zone have a positive correlation.

The slight positive correlation between uranium and phosphate in the aluminum phosphate zone is indicated by the scatter diagram (fig. 14) showing the relation between P_2O_5 and U_3O_8 in the slime fraction of the aluminum phosphate zone. The slime fraction was



EXPLANATION

5

Isopleth

Showing percent P_2O_5. Isopleth interval 5 percent

• 4

Location of drill hole

Number is percent P_2O_5 in the aluminum phosphate zone, to the nearest 1 percent. + indicates actual analysis is higher than shown, − indicates that analysis is lower than shown, that is, 5+ includes values between 5.01 and 5.49; 5− includes values between 4.51 and 4.99

FIGURE 13.—Isopleth map of P_2O_5 content of the aluminum phosphate zone in parts of Tps. 27 and 28 S., Rs. 24 and 25 E.

chosen to show this relation because both uranium and phosphate are concentrated in it and in higher contents. For example, no head sample contained more than 0.030 percent U_3O_8 or more than 17 percent P_2O_5, and a large number of the slime samples contain more than these amounts.

The relations between CaO and U_3O_8 in the slime fraction of the aluminum phosphate zone are shown in figure 14. The diagram shows, at best, a very slight positive correlation between these two elements, but the correlation is not as strong as that between uranium and phosphate.

The relation between uranium and the ratio of CaO to P_2O_5 in the slime fraction of the aluminum phosphate zone is shown in figure 14. The diagram indicates that there is no correlation and that most of the samples plot between the lines representing carbonate fluorapatite and crandallite. Very few of the samples contain abundant wavellite; most are a mixture of crandallite and varying amounts of carbonate fluorapatite, and some are a mixture of crandallite and wavellite.

It is obvious from a comparison of the scatter diagrams and the maps of phosphate and uranium distribution for the aluminum phosphate zone that uranium is closely related to phosphate. The distribution of uranium and phosphate in the aluminum phosphate zone is, however, complex, as indicated by figure 14. The higher uranium assays (those above 0.030 percent) all fall above the CaO to P_2O_5 ratio for crandallite—uranium evidently is concentrated in the calcium phosphate or calcium aluminum phosphate minerals rather than the aluminum phosphate mineral. The absence of any correlation of uranium with the ratio of CaO to P_2O_5, however, probably is indicative of the variation in the amount or intensity of leaching and in the original amounts of apatite and uranium in the section. The samples on which the diagram is based are of the total thickness of the leached zone and include, therefore, the thoroughly leached upper part of the section and the very slightly leached basal part, just above the matrix.

LEACHING

Although it is difficult to determine quantitatively the amount of leaching that has gone on at a given locality, a semiquantitative estimate can be made from the ratios of percent CaO to percent P_2O_5 for the total thickness of the aluminum phosphate zone. Altschuler, Jaffe, and Cuttita (1956) have shown that leaching first produces calcium aluminum phosphate mineral (crandallite) containing varying amounts of apatite, and when the leaching goes to completion, the final product is the aluminum phosphate mineral—wavellite. Carbonate fluorapatite has a CaO to P_2O_5 ratio of about

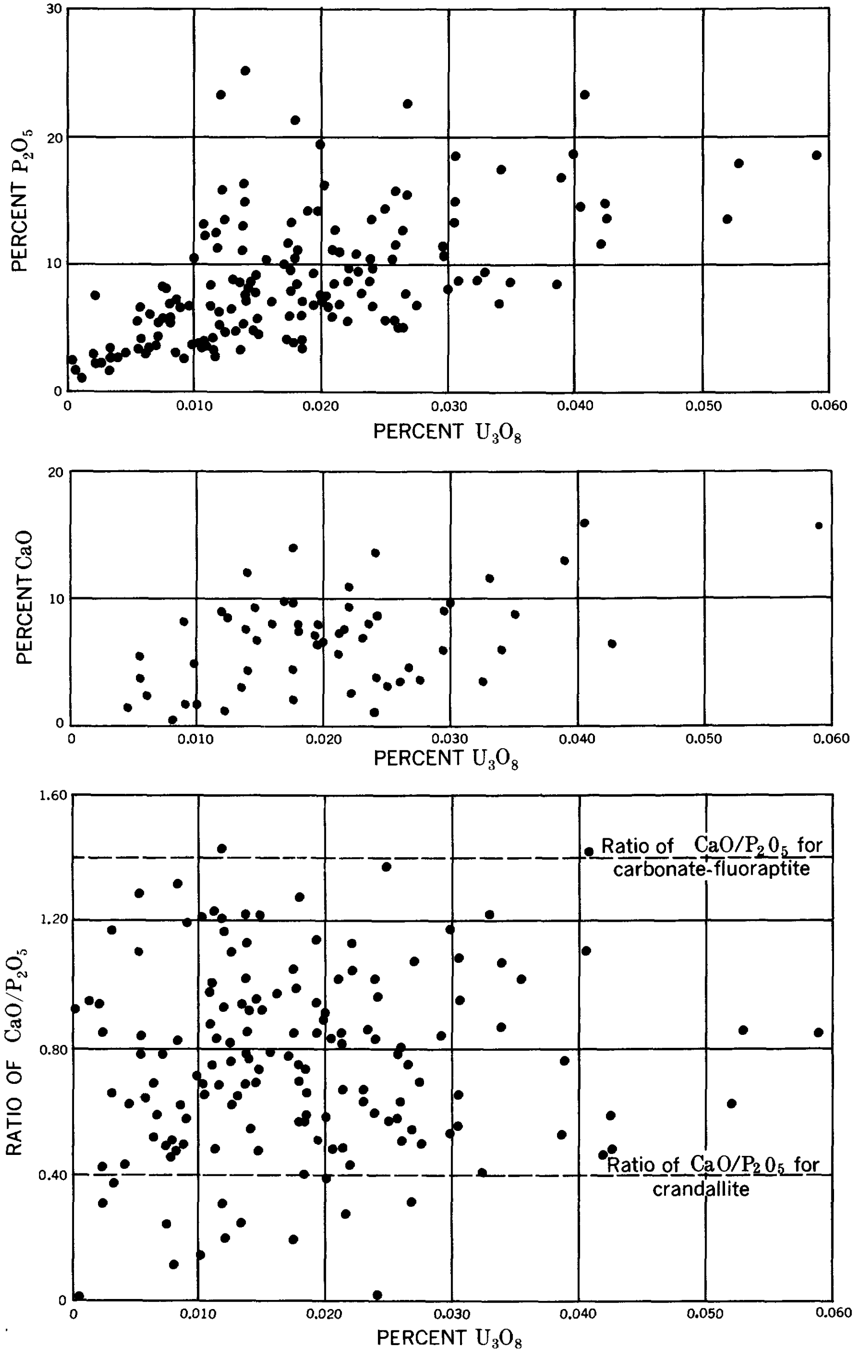


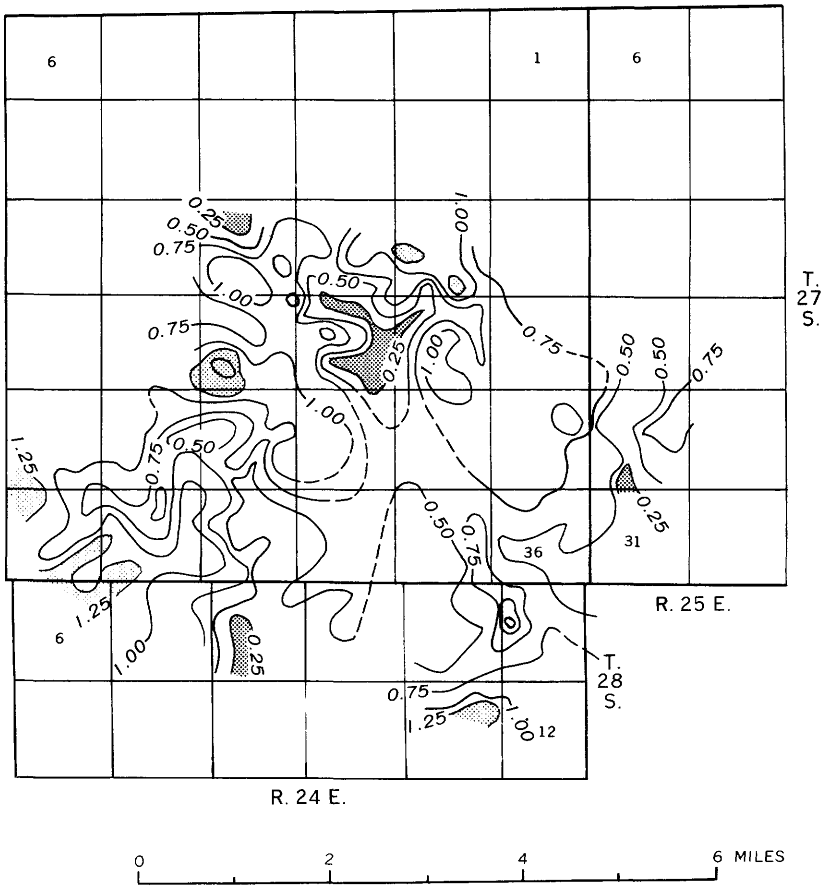
FIGURE 14.—Scatter diagrams, slime fraction of the aluminum phosphate zone, showing relations of U_3O_8 to P_2O_5 and CaO, and the ratio of CaO to P_2O_5.

1.4, crandallite about 0.4, and wavellite has no CaO. Unleached phosphate nodules are known to contain varying amounts of calcite; these nodules, then, have CaO to P_2O_5 ratios in excess of 1.4 (Cathcart and McGreevy, 1959).

An isopleth map of the CaO to P_2O_5 ratio for the aluminum phosphate zone should give some sort of semiquantitative picture of the leaching. There are certain dangers in interpreting such a map. For example, it is known that leaching is by downward-moving acidic ground water. The upper part of the section is the most thoroughly leached, and the amount of leaching diminishes to nothing at the base of the section. Therefore, if only the bottom part of the zone is sampled, the CaO to P_2O_5 ratio will be much higher than if the entire zone is sampled. Figure 15 is an isopleth map of the CaO to P_2O_5 ratios for the entire thickness of the aluminum phosphate zone. The zone was sampled from the contact of the sand of Pleistocene age at the top to the contact with the phosphorite of the lower unit of the Bone Valley at the base. A single sample was taken at each drill hole; analyses are by the company laboratories.

The map (fig. 15) indicates that there is considerable variation in the ratios and probably, then, in the intensity of the leaching in this part of the Lakeland quadrangle. There are only two small areas where the ratio is 1.4 or greater: in the SW¼ sec. 21, T. 27 S., R. 24 E., and in the SE¼ sec. 31, T. 27 S., R. 24 E. Material having a ratio above 1.00 might be considered as slightly leached, ratios from 0.50 to 1.00 are moderately leached, and ratios less than 0.50 might be considered thoroughly leached.

A comparison of the iosgrade map of P_2O_5 content (fig. 13) with the ratio map (fig. 15) shows a rough matching of high areas. For example, even where the phosphate content of the zone is very low, as in sec. 1, T. 28 S., R. 24 E., the small high on the ratio map corresponds to the highest phosphate content in the section (3 percent). The rough correspondence of these two maps indicates either a considerable difference in the original P_2O_5 content of the material, or that phosphate as well as calcium has been leached from the section. Phosphate that is leached combines with alumina to form insoluble aluminum phosphate minerals, however, and is not removed from the section. It is likely, then, that the ratio of CaO to P_2O_5 does give some indication of the amount of leaching and that the variation in P_2O_5 content reflects original differences in the composition of the upper unit of the Bone Valley Formation. Thus, probably there was originally much less phosphate in the upper unit of the Bone Valley Formation in the eastern part of the area than in the western part.



EXPLANATION

——— 1.50 — — —

Isopleth

Showing ratio of percent CaO *to percent* P_2O_5. *Dashed where inferred. Isopleth interval 0.25 units*

Area where ratio is 0.25 or less

Contains mostly aluminum phosphate minerals

Area where ratio is 1.25 or more

Contains mostly calcium phosphate minerals

FIGURE 15.—Isopleth map of the ratio of percent CaO to percent P_2O_5, aluminum phosphate zone, in parts of Tps. 27 and 28 S., Rs. 24 and 25 E.

TONNAGE CALCULATIONS

CALCIUM PHOSPHATE ZONE

The area of the Lakeland quadrangle is about 165,000 acres. Prospecting, at the rate of at least one drill hole per 40-acre tract, has covered slightly more than 47,000 acres, or about 28 percent of the area of the quadrangle. Most of the prospecting is in the southern two-thirds of the quadrangle. The Bone Valley Formation, and most of the possibly economic calcium phosphate zone, is absent from the eastern and northern parts of the quadrangle (pl. 1). Total measured, indicated, and inferred reserves of recoverable phosphate rock in the quadrangle are 62.7 million long tons of the pebble fraction and 75.2 million long tons of the concentrate fraction. Data on the unprospected areas in the northern and eastern parts of the quadrangle are sparse, but it is known that the calcium phosphate zone in these areas consists of the clastic upper part and the calcareous lower part of the Hawthorn Formation. The P_2O_5 content of the two parts is known to be low, and tonnages of phosphate nodules are small; therefore, the unprospected areas probably will not contain large tonnages of minable reserves.

The figures for reserves represent the potentially minable phosphate in the quadrangle. The phosphate content of these reserves should be in excess of 65 percent BPL (29.7 percent P_2O_5).

Uranium analyses were made of samples of the pebble fraction from 1,728 drill holes and of the concentrate fraction from 918 drill holes. Uranium analyses were made of as many as 10 samples from each drill hole; the average drill hole had 4 pebble and 2 concentrate samples. The average uranium content for the pebble fraction is about 0.015 percent; for the concentrate fraction about 0.013 percent. The pebble fraction, then, contains more than 9,200 long tons of uranium; the concentrate fraction almost 9,500 long tons, or a total of 18,700 long tons of uranium are present in the recoverable phosphate products of the calcium phosphate zone in the Lakeland quadrangle.

ALUMINUM PHOSPHATE ZONE

Of the total area of the Lakeland quadrangle, about 30,000 acres (slightly less than one-fifth) is underlain by an aluminum phosphate zone that is more than 3 feet thick and that has a content of more than 0.005 percent U_3O_8 (pls. 10 and 11). The rest of the quadrangle, although it may be underlain by aluminum phosphate zone material, is not considered in the following computations, because it is too thin or too low in grade to be potentially economic. The formulas used in computing tonnages are discussed by Cathcart and McGreevy (1959, p. 266).

Company prospecting, at a spacing of one hole per 40-acre block, covered about 6,000 acres. A single sample of the aluminum phosphate zone was taken at each drill hole in this program. The drilling developed 52 million long tons of aluminum phosphate material with an average content of 0.006 percent uranium, and 4.7 percent P_2O_5. Gamma-ray logs were made of an additional 98 drill holes which represent about 2,000 acres, with a spacing of one or two drill holes per 40 acres. This drilling showed an additional 20 million long tons of material containing an average equivalent uranium content of about 0.008 percent, and by analogy with the known aluminum phosphate zone, this material may contain about 5 percent P_2O_5.

The isopach and isograde maps of the aluminum phosphate zone indicate that there are an additional 22,000 acres underlain by the potentially economic aluminum phosphate zone. If this material averages 7 feet in thickness, almost 240 million long tons of aluminum phosphate zone are present. This material is estimated from the uranium isograde map (pl. 11) to contain about 0.007 percent uranium and, by analogy with known areas, about 4 percent P_2O_5. These data are summarized in table 15.

TABLE 15.—*Reserves, inferred and potential, of aluminum phosphate zone, Lakeland quadrangle*

Class of reserves	Source of data	Number of drill holes	Number of acres	Total long tons (millions)	eU (percent)	U (long tons)	P_2O_5 (Percent)	P_2O_5 (Long tons)
Inferred	Prospecting and analysis.	156	6,240	52	[1] 0.006	3,100	4.7	2,450,000
Do	Prospecting gamma logs only.	98	2,080	20	.008	1,600	5.0	1,000,000
Potential	Isopach and isograde maps.		22,000	240	.007	16,800	4.0	9,600,000
Total			30,000±	312	.007	21,500	4.2	13,000,000

[1] Percent U, by chemical analysis.

PHOSPHATE RESOURCES OF THE HAWTHORN FORMATION

Abundant phosphate nodules are present in the Hawthorn Formation, but the nodules are low in P_2O_5 content and are sparser in amount than in the Bone Valley Formation. The Hawthorn Formation averages about 35 feet in thickness in the Lakeland quadrangle (fig. 4), and from rather sparse analytical data, the pebble fraction of the formation contains from 10 to 70 percent BPL and averages about 45 percent. Based on the few samples that have been analyzed, the pebble fraction is present in amounts that average about 50 tons per acre-foot. Data on the concentrate fraction are completely lacking, but observation of the core samples indicates that this fraction is more abundant than the pebble fraction, and the total recoverable phosphate is estimated to be about 150 tons per acre-foot.

The average thickness has been estimated to be 35 feet, but the beds are not uniformly phosphatic, and the total amount of recoverable phosphate is estimated to be 3,000 tons per acre.

Almost the entire Lakeland quadrangle is known to be underlain by the Hawthorn Formation; if the total area underlain by the Hawthorn Formation is about 160,000 acres, then about half a billion long tons (5×10^8) of phosphate nodules with an average content of about 45 percent BPL are in the quadrangle.

MINE AND TRACT DESCRIPTIONS

Phosphate has been mined at the following mines in the Lakeland quadrangle: the mine of the Lakeland Phosphate Co., Sangully, Pauway, Saddle Creek, Orange Park, and Tenoroc. Mine names are those of the companies; the tract names are in part those of the companies but in part are those of the writer. Information on the different mines and tracts varies widely. At some, information is plentiful; elsewhere, very little or no information is available.

LAKELAND PHOSPHATE CO. MINE

The mine of the Lakeland Phosphate Co., which operated from 1914 to 1918, comprised several small pits in the SW¼ sec. 26 and the NW¼ sec. 35, T. 28 S., R. 23 E. Mining was by hydraulic methods and only for the pebble fraction. Most of the mined area is now covered by a debris dam from the mining of the Sangully mine by the Southern Phosphate Co.

The mined areas are under water or are covered; nothing is exposed at the surface. The only information now available is a prospect map which shows the thicknesses of the overburden and the matrix, and the tonnage and grade of the pebble fraction.

The information from the prospect map was used to make the isopach maps (fig. 11), and the total thickness of the overburden and matrix subtracted from the surface altitude gives the elevation of the "basement," which is assumed to be the top of the lower part of the Hawthorn Formation.

The surface of the Hawthorn (fig. 11*C*) is karst topography, and altitudes range from about 110 to about 140 feet above sea level. There are three possible stream courses on this surface—two at the north end of the map area, flowing northwest and one in the southern part of the map area, flowing south.

The calcium phosphate zone (fig. 11*B*) ranges in thickness from 0 to about 25 feet and averages about 10 feet. The zone was deposited on the Hawthorn surface and fills low spots on the surface. At every place on the map where the calcium phosphate zone is 10 feet or more in thickness it overlies a low spot, either a sinkhole or one of the possible stream valleys on the Hawthorn surface. The calcium phosphate zone is thick in the NE. cor. NW¼NW¼ sec. 35, over a deep sinkhole, and in the NW. cor. NW¼SW¼ sec. 26, the 10-foot-thick calcium phosphate zone overlies the possible small stream on the Hawthorn surface. The calcium phosphate zone is missing at several small places in the area—over sinkholes or the courses of the possible streams on the Hawthorn surface—which are characterized by greater than average thicknesses of overburden (fig. 11*A*). The lithology of the overburden is not known, but from the adjacent Sangully mine it is known that the overburden consists of loose sand of Pleistocene age and clayey sand of the upper unit of the Bone Valley Formation.

The formation of sinkholes occurred at several times. Some sinkholes, for example those in the NE cor. NW¼NW¼ sec. 35 (fig. 11*C*), are filled with the calcium phosphate zone (compare figs. 11 *B* and *C*). Because most of the calcium phosphate zone is in the lower unit of the Bone Valley Formation, this sinkhole collapsed prior to the deposition of the lower unit of the Bone Valley. The sinkhole in the SW¼SW¼ sec. 26 (fig. 11*C*), however, is in an area where the calcium phosphate zone is thin, but the overburden (fig. 11*A*) is thickened over this sinkhole. This sink formed after the deposition of the lower unit of the Bone Valley Formation. Because the character of the overburden is not known at this mine, it is not possible to say whether this sink is filled with clayey sand of the upper unit of the Bone Valley Formation, or with loose sand of Pleistocene age, but elsewhere sinks are filled with the upper unit of Bone Valley (Pauway mine, p. G121; pl. 5), and sinks filled with sand of Pleistocene age have been described in the Keysville quadrangle (Cathcart, 1963a). The absence of the Bone Valley along the stream courses on the Hawthorn surface may be the result of erosion in the pre-Pleistocene.

The areas mined by the Lakeland Phosphate Co. generally are areas where the overburden is thin (less than 20 ft thick in most places) and are not necessarily those areas where the calcium phosphate zone is thickest. For example, the thick calcium phosphate zone in the NE cor. NW¼NW¼ sec. 35 was not mined by the Lakeland Phosphate Co. However, in 1936 this area was mined by the Southern Phosphate Co. as a part of their Sangully mine. Generally, areas underlain by less than 5 feet of calcium phosphate zone or by more than 20 feet of overburden were not mined. It is apparent that the ratio of overburden to matrix was much lower in the early hydraulic mining than in the more recent mining.

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SANGULLY MINE

The Sangully mine of the Southern Phosphate Co. is in secs. 25, 26, 35, and 36, T. 28 S., R. 23 E., and in secs. 1 and 2, T. 29 S., R. 23 E. Although the land in T. 29 S. is in the Bartow quadrangle, the entire tract will be discussed in this report.

Mining began sometime in the late 1920's; until about the mid-1930's mined material was pumped to a washer plant in the SE¼SE¼ sec. 26, T. 28 S., R. 23 E. Sometime in the middle or late 1930's the plant was relocated in the SE. cor. sec. 36, T. 28 S., R. 23 E., and a flotation section (table plant) was added. Mining then continued, in the southern half of the tract, until late in 1945 when the area was abandoned. Early mining was by hydraulic methods and as late as 1938 some of the overburden was removed hydraulically, but all the later mining was by dragline. Some of the washer debris was treated again to recover the fine-grained phosphate discarded in the earlier processing. The mined-out land was sold—by either the Southern Phosphate Co. or its successor, Davison Chemical Co.—to private individuals.

About 1920, Southern Phosphate Co. took over the Lakeland Phosphate Co., which had been mining in the Sangully area. Mining in the Sangully area by Southern Phosphate Co., however, apparently did not start immediately.

The only information is the company's prospect map of the tract. Early prospecting, in 1920, was for the pebble fraction only, and a single sample was taken of the calcium phosphate zone. Later prospecting included, at many holes, a top and a bottom matrix sample; about one-third of the holes drilled at this time had a zone of barren (nonphosphatic) material between the top and bottom samples. Again, only the pebble data are shown on the map, although flotation-size phosphate was recovered in the plant.

The overburden dumps at the Sangully mine were examined in 1951 to determine the amount of aluminum phosphate zone present. A sandy clay or clayey sand was at the top of the overburden dumps, and one sample was taken of this material (the aluminum phosphate zone), from the SE¼SW¼ sec. 36, T. 28 S., R. 23 E. The sample contained about 54 percent, by weight, of −150 mesh material, and this material contained 0.004 percent uranium.

At a few places on the prospect map, there is some information on the overburden. In the northern third of the tract (secs. 25 and 26, T. 28 S., R. 23 E.), there are scattered drill holes that penetrated 1 or 2 feet of "hard sandrock" in the bottom half of the overburden. In the central part of the tract (secs. 35 and 36, T. 28 S., R. 23 E.), as much as 11 feet of "kaolin" was penetrated toward the base of the overburden. The sample of the overburden dump was taken in this area. There are scattered individual drill holes in this area that found thin (1–2 ft) beds of "hard sandrock." In secs. 1 and 2, T. 29 S., R. 23 E., the southern third of the tract, there are several areas, each including several drill holes, where as much as 11 feet of hard "sandrock" was penetrated. Again, this material is in the bottom part of the overburden.

A very few scattered drill holes in the central part of the tract penetrated 1–2 feet of "hard iron rock," and at the northernmost part of the tract, one drill hole passed through 11 feet of hardpan. The iron rock and the hardpan are in the top part of the overburden.

Very little data are available on the stratigraphy of the Sangully mine. The notation on the prospect maps of "sandrock" in the northern and southern thirds of the mined area, however, indicates that the clayey sands of the upper unit of the Bone Valley are rather thoroughly leached in these areas. The fact that the sandrock is always in the bottom half of the overburden indicates that at least half of the overburden thickness is clayey sand, probably of the upper unit of the Bone Valley Formation. The middle third of the tract, that part which contained the beds of "kaolin" in the bottom half of the overburden, is characterized by a sandy clay or clay in the upper unit of the Bone Valley. The one sample that was taken in this area contained a high percentage of slime fraction (54 percent) and indicates that this material, which forms the basal half of the overburden, is a sandy clay. The higher clay content of this part of the upper unit made the rock much less permeable, leaching was not as effective, and the sandrock beds were not formed.

It can be deduced from the available evidence that the loose, surficial sand of Pleistocene age ranges from a few feet to perhaps 20 feet in thickness (about half of the total overburden).

The upper unit of the Bone Valley Formation ranges in thickness from 0 to as much as 20 feet. The upper unit is present over most of the area, but there are a few drill holes which penetrated only 1 or 2 feet of total overburden; loose sands are known to cover the area, and it is likely that these drill holes where the overburden is very thin probably did not penetrate any of the upper unit of the Bone Valley Formation. The upper unit ranges from a clayey sand, altered to sandrock (quartz sand cemented by aluminum phosphate minerals) at the southern end of the tract, through a sandy clay or clay in the middle part of the tract, and to a clayey sand, with some sandrock in the northern third. It is likely, also, that the more abundant sandrock indicates that the upper unit at these places originally contained more phosphate than in the areas where the sandrock is less abundant or absent.

The lower unit of the Bone Valley Formation is probably present over most of the tract and ranges in thickness from 0 to about 20 feet. The analytical data, particularly the high pebble percentages at some of the drill holes, indicate that the unit contains some pebble conglomerates. Probably much of the calcium phosphate zone is in the lower unit of the Bone Valley Formation, but some may be in residual clays of the Hawthorn Formation.

Little is known of the so-called bedrock or bedclay at the tract. The later prospecting probably continued to bedrock, and it is believed that the entire tract is underlain by the Hawthorn Formation. Certainly a part of the matrix is referable to the Hawthorn Formation. At some of the drill holes where two matrix samples were taken, the bottom sample is low in phosphate content and is almost devoid of the pebble fraction, in contrast to the top sample which is high in phosphate and contains very abundant phosphate nodules larger than 14-mesh size. At these localities the bottom sample may be referable to the Hawthorn Formation.

Table 16 shows the distribution, in percentage, of the tonnage and BPL content of the top and bottom samples of all the drill holes where more than a single sample was taken. The tonnage figures are the tons per acre-foot, as computed by the writer from the company data.

TABLE 16.—*Distribution of tonnage and BPL content in pebble fraction, Sangully mine*

[100 samples from drill holes that had 2 beds sampled]

Number of samples		
Top	*Bottom*	*BPL content (percent)*
3	4	<60
0	4	60.0–64.9
8	27	65.0–69.9
51	35	70.0–74.9
37	30	75.0–79.9
1	0	80.0+
		Tons per acre-foot
9	27	<100
15	25	101–200
42	21	201–300
23	22	301–400
10	4	401–500
1	1	>500

The table clearly shows that the top samples are higher in BPL content and in tonnage than are the bottom samples, although most samples are probably economic, and many of the bottom samples are as high in both tonnage and grade as are the top samples. It is not possible to tell from tonnage and grade data alone if a sample should be placed in the Bone Valley Formation or the Hawthorn

Formation, but some of the bottom samples are probably referable to the Hawthorn Formation. Also, the top samples average about twice the thickness of the bottom samples, and even if all the bottom samples are in the Hawthorn Formation, about two-thirds of the total calcium phosphate zone is in the Bone Valley Formation.

The aluminum phosphate zone is probably present through most of the tract, but very little is known of its thickness or grade. The more clayey parts of the section (the middle part of the tract) are probably lower in uranium and phosphate content than the northern and southern parts—which are characterized by abundant sandrock—and the highest uranium content and thickest parts of the aluminum phosphate zone are in the southern third of the tract.

As in the mine of the Lakeland Phosphate Co., the calcium phosphate zone tends to be thickest over lows on the Hawthorn surface, particularly over sinkholes. The Hawthorn surface in the area of the Sangully mine is a karst topography.

ORANGE PARK MINE

The Orange Park mine of the American Cyanamid Co. consists of two tracts of land—Orange and Park—northeast of Lakeland in Polk County. The Orange tract consists of land in secs. 8–10, 14–17, 21–23, and 28, T. 27 S., R. 24 E.; the plant is located in sec. 16, T. 27 S., R. 24 E. The Park tract consists of land in secs. 29–33, T. 27 S., R. 24 E., and sec. 5, T. 28 S., R. 24 E. The company started mining in the Orange tract in 1957, and in 1962 they were operating two 18-cubic-yard draglines 5 days a week.

In 1954, the company drilled 57 holes at the Orange tract and 33 holes at the Park tract, under contract to the U.S. Atomic Energy Commission. One sample each of the aluminum phosphate zone and the calcium phosphate zone were taken at each drill location and were analyzed by the company; average results are shown in tables 8 and 13. The holes are spaced one in each 40-acre tract, to cover most of the property owned by the company.

Small chip samples of the core, taken at 1-foot intervals at each drill hole, were examined under the binocular microscope by the writer. No fossils were found during the drilling; all stratigraphic interpretations are based on lithology.

STRATIGRAPHY

Stratigraphy, as interpreted from lithology, is shown by the isometric fence diagram (pl. 12) of drill holes in the Orange tract. The stratigraphy is generally uniform—all holes bottomed in calcareous clay or soft limestone, assigned to the Hawthorn Formation, and all holes passed through both units of the Bone Valley Formation. The surface is blanketed by loose quartz sand assigned to the Pleistocene.

HAWTHORN FORMATION

Only the lower part of the Hawthorn Formation is present at the Orange Park mine. It consists of cream, light-gray, white, or buff, calcareous sandy clay or clayey sand. At a few holes, soft impure white limestone or marl was recovered in the drilling. Most drill holes bottomed in the calcareous clay; a few bottomed on material too hard to penetrate with the hand auger, presumed to be limestone of the Hawthorn Formation. At the few holes where soft limestone was recovered, calcareous clay gradationally overlies the limestone; this clay is believed to be residual from the limestone. The sand fraction of the clay consists of very fine to fine-grained quartz, and black, brown, tan, gray, and a minor amount of white and amber phosphate grains. Phosphate of granule size (the pebble fraction) is present at only a few drill holes and is minor in amount. The calcareous clay, a part of the calcium phosphate zone, ranges from 0 to 6 feet in thickness and averages about 3 feet. At most drill holes the calcareous clay forms the bottom part of the calcium phosphate zone; at a few, it represents all of the calcium phosphate zone (hole F–6, sec. 21, pl. 12).

HAWTHORN-BONE VALLEY CONTACT

At most drill holes in the Orange Park area, the contact between sedimentary rocks assigned to the Hawthorn Formation and those assigned to the lower unit of the Bone Valley Formation is marked by a conspicuous lithologic change from the underlying white or cream calcareous clay to a gray or gray-green slightly clayey or loose sand. The contact is also marked by a change in grain size of the sand fraction, from fine or very fine in the underlying material to coarse in the overlying. The phosphate particles in the underlying calcareous clay are fine to very fine grained and are dominantly black; those in the overlying sand are coarse sand to granule size and are light in color—tan, white, or light gray. Typical contact relations are shown in the following log of drill hole I, sec. 28, T. 27 S., R. 24 E. This contact is found throughout the tract and is so striking at most drill holes that it is believed to be the contact between the Hawthorn and Bone Valley Formations.

Log of drill hole I in the NW¼SE¼ sec. 28, T. 27 S., R. 24 E.

[Drilled by the American Cyanamid Co., under contract to the U.S. Atomic Energy Comm.]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, fine- to medium-grained	18.0

Log of drill hole I in the NW¼SE¼ sec. 28, T. 27 S., R. 24 E.—Continued

	Thickness (feet)
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, clayey, brown at top, grading to cream and gray at base	18.0
Clay, gray, silty and sandy; contains lumps of aluminum phosphate cemented sand (sandrock)	3.0
Lower unit:	
Sand, clayey; contains abundant tan and white, medium-grained, soft phosphate nodules (leached)	2.5
Clay, sandy, gray; contains white and tan, granule- to medium sand-sized phosphate nodules	1.5
Sand, quartz and phosphate, trace clay. Phosphate is coarse sand and granule size, and is tan and white, with some black (driftrock)	2.0
Total Bone Valley Formation	27.0
Miocene:	
Hawthorn Formation:	
Clay, white to light-gray, sandy, calcareous. Black, tan, and white, sand- and some granule-sized phosphate	6.5
Clay, slightly sandy, gray and brown, very calcareous. Trace of fine to very fine grained phosphate	<0.1
Part of Hawthorn Formation	6.5+
Bottom in barren calcareous clay.	

The contact is difficult to locate at some drill holes. For example, at a hole in the SE¼NW¼ sec. 32, T. 27 S., R. 24 E., the top of the lower unit of the Bone Valley Formation is a light-gray clayey sand containing abundant white, black, and brown granule- to medium sand-sized phosphate nodules. The bottom 1 foot of the core was a cream, sandy, calcareous clay, with a trace of fine-grained phosphate nodules, assigned to the Hawthorn Formation. The Bone Valley grades downward by an increase in clay content and a decrease in the amount of phosphate, and a change in color to the calcareous clay. Because the cuttings are mixed in the drilling, the actual contact is very difficult to select.

BONE VALLEY FORMATION—LOWER UNIT

The lower unit of the Bone Valley Formation is present throughout the Orange Park tract. Only one drill hole, which was abandoned at 50 feet, did not penetrate the lower unit; cuttings from the bottom of the drill hole were loose sand. The lower unit is represented at some drill holes by the soft white phosphate bed (for example, hole K–11, sec. 22, pl. 12), where all of the unit has been leached, but at most holes only the top part of the unit has been altered to form the zone of soft white phosphate. The unit ranges in thickness from 1 to 12 feet and averages about 5 feet. The unit is relatively uniform in thickness throughout the tract, although there is some suggestion of a westward thickening (pl. 12).

The unit generally consists of clayey sand or sandy clay in the top half and sand or slightly clayey sand in the bottom. Individual beds, however, are lenticular, and many drill holes show a reverse sequence (fig. 16).

At about one-third of the drill holes in the tract, a sand or fine-grained conglomerate of phosphate and quartz containing only a trace of clay rests directly on the calcareous clay of the Hawthorn Formation.

The lower unit is dominantly gray or gray green but is also tan and gray brown and contains abundant coarse sand- to granule-sized phosphate nodules that are predominantly white and light tan and some brown, a minor amount of gray, and a trace of black.

The unit is bedded and individual beds are lenticular. The mining pit has not been mapped, but graded bedding can be inferred from the logs of some of the drill holes (for example, drill hole C, sec. 15, T. 27 S., R. 24 E. p. G28).

ZONE OF SOFT WHITE PHOSPHATE

The contact between the upper and lower units of the Bone Valley Formation is gradational through the soft white phosphate zone, which is a white, cream, or light-gray clayey sand or sandy clay, ranging in thickness from 0 to 5 feet and averaging about 2 feet. The zone was penetrated at most drill holes in the tract. It may be entirely within the lower unit, as at hole E–2, sec. 22 (pl. 12) where it comprises all the lower unit of the Bone Valley Formation; it may be entirely within the upper unit, as at hole F, sec. 21, T. 27 S., R. 24 E. (p. G46); or, as is most common, it may be in both the upper and lower units, as at hole J, sec. 14, T. 27 S., R. 24 E. (p. G84), where it consists of the bottom bed of the upper unit and the top bed of the lower unit. The division between the upper and lower units is based on the amount of phosphate nodules present; the lower unit everywhere contains abundant phosphate grains. Wherever the zone of soft white phosphate is absent, the basal part of the upper unit consists of a bed of relatively impermeable sandy clay that restricted the downward movement of the acidic ground water that formed the zone.

BONE VALLEY FORMATION—UPPER UNIT

The upper unit of the Bone Valley Formation was penetrated in all drill holes. It is a clayey sand or sandy clay throughout the tract except at four drill holes in sec. 14—E–4, F–8, I–8, and K–3 (pl. 12) where the lower part of the upper unit is a loose to very slightly

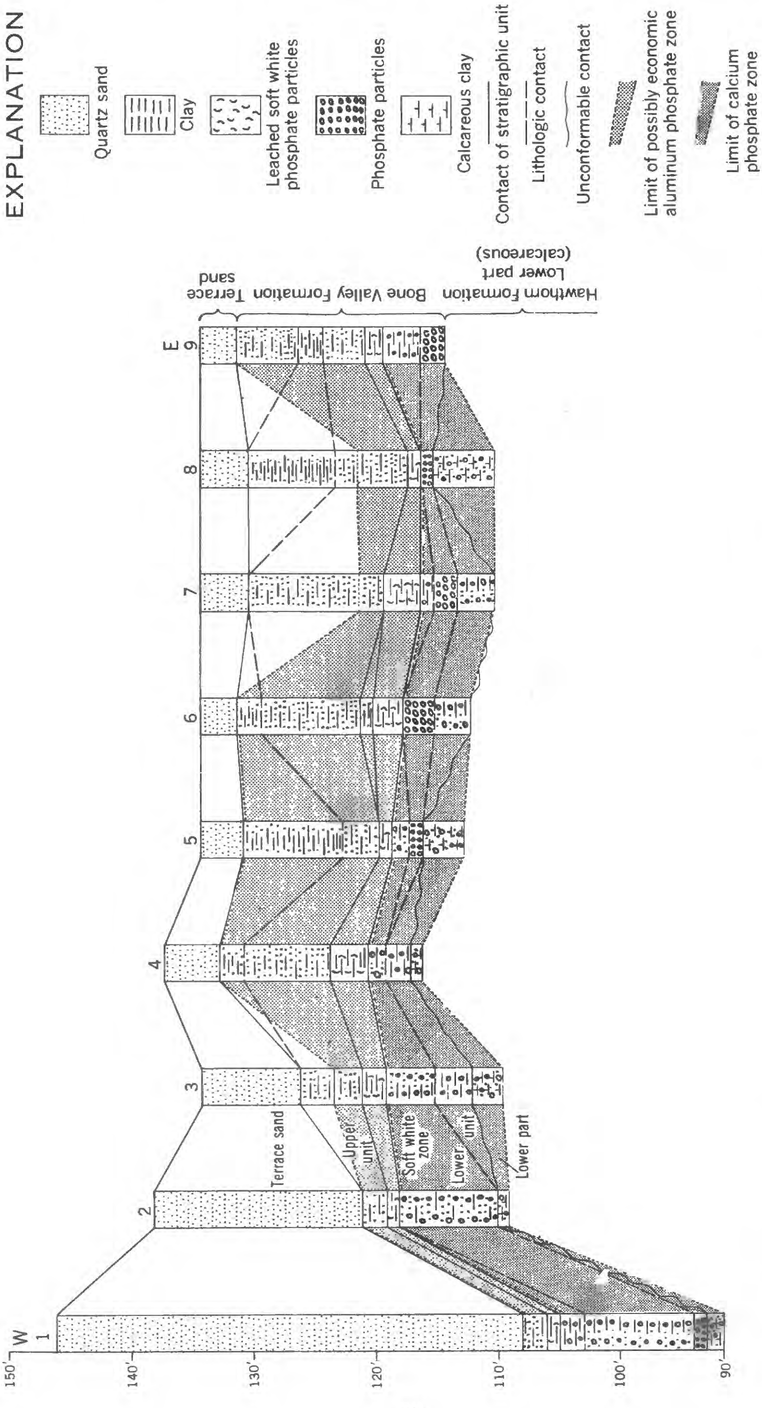

FIGURE 16.—Section, Orange Park mine, showing relations of stratigraphy and economic geology. Horizontal not to scale. Location of section shown on plate 1.

clayey sand. In the upper part, the unit is brown gray, tan gray, or red and gray mottled; toward the base it is light gray, cream, or white. Except at the four drill holes previously mentioned, where loose sand underlies sandy clay or clayey sand, there is no suggestion of zoning or uniform lithologic succession in the upper unit. The beds of clayey sand and sandy clay are lenticular and may be at either the top or the base of the unit (fig. 16). The log of drill hole C, sec. 15, T. 27 S., R. 24 E. (p. G28) is an example of a very clayey section in the upper unit, and the more clayey parts are at the base of the unit. The log of drill hole J, sec. 14, T. 27 S., R. 24 E., which follows, is an example of a very sandy section of the upper unit, and loose or slightly clayey sand form the basal part of the unit.

Log of drill hole J in the SE¼SW¼ sec. 14, T. 27 S., R. 24 E., Orange Park tract

[Drilled by the American Cyanamid Co., under contract to the U.S. Atomic Energy Comm.]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, gray and brown	4
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, clayey, mottled dark-gray and red	3
Sand, clayey, tan-gray, with red streaks	3
Clay, very sandy, tan-cream	7
Sand, slightly clayey, tan-gray	2
Sand, loose, tan-gray, medium-grained	5
Sand, slightly clayey, cream; contains granule- to coarse sand-sized soft white phosphate grains	2
Lower unit:	
Sand, slightly clayey, cream-gray; contains abundant sand-sized soft white phosphate grains (leached)	1
Sand, clayey, gray; contains abundant tan and hard-white, coarse sand- to granule-sized phosphate nodules	4
Sand, trace clay, light-gray; contains tan and white medium to coarse sand- and granule-sized phosphate nodules	2
Total Bone Valley Formation	29
Miocene:	
Hawthorn Formation:	
Clay, sandy, calcareous; contains abundant fine sand-sized black and white phosphate nodules, minor granules	1
Limestone, sandy and clayey, buff-cream; contains trace amounts of white and black sand- and granule-sized phosphate	<1
Part of Hawthorn Formation	1+

Bottom in material too hard to penetrate.

The upper unit ranges in thickness from 1 to 20 feet and averages about 10 feet. The unit is very thin at the western edge of the tract (pl. 12) and is relatively uniform in thickness throughout the rest of the tract, although the thickest parts are at the eastern edge. The eastward thickening of the unit is also shown in figure 16. The upper unit is very thin at holes 1 and 2, thickens rapidly at holes 3 and 4, and is nearly uniform in thickness from hole 4 through hole 9, the remainder of the section.

The contact of the upper unit with the sand of Pleistocene age is selected at the upper limit of clayey sand. All the loose sand above the clayey sand is classed as Pleistocene.

TERRACE SAND

Loose quartz sand blanketing the surface is assigned to the Pleistocene. The loose sand ranges in thickness from 3 to about 50 feet and averages about 22 feet. One drill hole, abandoned at 50 feet, was still in loose sand assigned to the Pleistocene. The loose sand thickens westward and is thickest in the area under the ridge province (fig. 16 and pl. 12).

ECONOMIC GEOLOGY

Both the calcium phosphate zone (including the economic phosphate deposit) and the potentially economic aluminum phosphate zone are present at all the holes that were drilled in the Orange and Park tracts in 1954, with one exception—a hole which was abandoned at 50 feet in loose sand.

CALCIUM PHOSPHATE ZONE

The calcium phosphate zone at the Orange Park mine ranges in thickness from 4 to 16 feet and averages about 7.5 feet. In the southern part of the area (in the Park tract) the zone averages 9 feet in thickness; in the northern part (the Orange tract) it averages about 6.5 feet in thickness.

The calcium phosphate zone includes rocks of both the Hawthorn and Bone Valley Formations at almost every drill hole, but at a few it is confined to one or the other. These relations are shown in figure 17; the calcium phosphate zone is entirely within the Hawthorn Formation at hole A, is divided about equally between the Hawthorn and Bone Valley Formations at hole B, and is entirely within the Bone Valley Formation at hole C.

Figure 16 shows the typical distribution of the calcium phosphate zone throughout most of the tract. The lower unit of the Bone Valley Formation makes up most of the calcium phosphate zone at all holes except 5 and 8; at holes 6, 7, and 9 the entire calcium phosphate zone is in the lower unit of the Bone Valley Formation. The zone of soft white phosphate, although it is a part of the lower

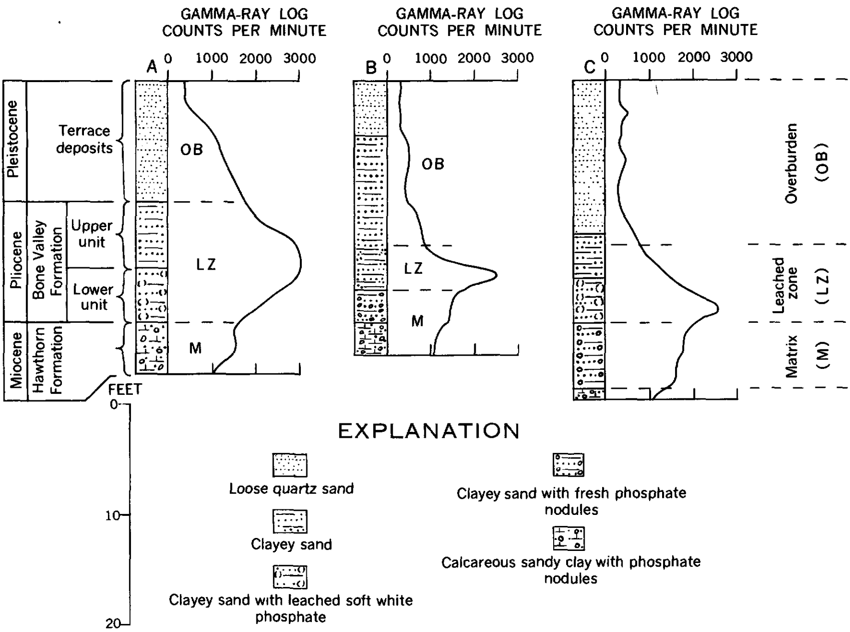

Figure 17.—Typical drill hole and gamma logs, Orange Park tract. Location of drill holes shown on plate 1.

unit, is excluded from the calcium phosphate zone. The radioactivity, as indicated by the gamma logs in figure 17, reaches a maximum in the aluminum phosphate zone at or close to the contact with the calcium phosphate zone and is higher in the part of the calcium phosphate zone assigned to the Bone Valley Formation than in the part assigned to the Hawthorn Formation.

Single samples of the calcium phosphate zone were taken in the drilling in 1954, and differences in phosphate content and grade of phosphate particles between the Bone Valley and Hawthorn could not be determined. However, examination of the cored material indicated some qualitative differences. The phosphate particles are generally finer grained in the Hawthorn Formation than in the Bone Valley Formation and are not as abundant. Company drilling at 16 holes per 40-acre block was completed sometime before the drilling under the Atomic Energy Commission contract. In the earlier drilling, at least two samples of the calcium phosphate zone were taken at each drill hole. Lithologic logs recorded by the drilling foreman were used to determine the Hawthorn-Bone Valley contact. In one section where the contact could be selected with some degree of certainty, one sample each of the Bone Valley and Hawthorn parts of the calcium phosphate zone was collected from 35 drill holes. An average of the analyses of these samples is shown in table 17.

TABLE 17.—*Comparison of tonnage and grade of phosphate nodules from the Bone Valley and Hawthorn Formations in a part of the Orange Park tract*

[Average of analyses, by American Cyanamid Co., of one sample each (+14-mesh fraction) of the Bone Valley and Hawthorn Formations from 35 drill holes]

	Tons per acre-foot		Grade (percent P_2O_5)	
	Range	Average	Range	Average
Bone Valley Formation	125–375	220	31.1–36.4	33.8
Hawthorn Formation	25–300	110	16.0–33.9	26.7

The data in table 17 show that the coarse phosphate particles are lower in P_2O_5 content and in tonnage in the Hawthorn Formation than in the Bone Valley Formation. Note that the highest tonnage and highest grade samples of pebble from the Hawthorn are well above the lowest tonnage and grade samples of pebble from the Bone Valley. Tonnage and grade of phosphate particles, then, cannot always be used to differentiate the Bone Valley from the Hawthorn, even though the average tonnage and grade in the Hawthorn is much less than in the Bone Valley.

ALUMINUM PHOSPHATE ZONE

The aluminum phosphate zone at the Orange Park mine ranges in thickness from 1.5 to 23.5 feet and averages about 6.5 feet. Like the calcium phosphate zone, the aluminum phosphate zone is thicker in the southern part of the area (in the Park tract), where it averages 9 feet in thickness, than in the northern part (the Orange tract), where it averages about 5.5 feet.

The aluminum phosphate zone is not a stratigraphic unit but may consist of a part of the upper unit of the Bone Valley Formation, all of the upper unit, or of the upper and a part or all of the lower unit of the Bone Valley Formation. Figure 17 shows, by means of typical drill logs, some of the possible variations. At hole A, the aluminum phosphate zone (or leached zone) consists of all the upper unit plus all the lower unit of the Bone Valley Formation. At this hole the lower unit has been leached to form the zone of soft white phosphate, which is excluded from the matrix by the company. At hole B, the leached zone consists of only the basal one-third of the upper unit of the Bone Valley Formation and is the part of the section where the radioactivity log reaches a maximum.

At hole C (fig. 17), the leached zone consists of nearly all of the upper unit plus the top half of the lower unit of the Bone Valley Formation, and again, includes the high peak of radioactivity.

The high peak of radioactivity is at the base of the zone of leaching at drill holes B and C, and the peak is sharp, whereas at hole A the peak is much wider and is somewhat above the base of leaching.

Figure 16 also shows the distribution of the leached or aluminum phosphate zone. In this section, the zone of soft white phosphate is present at each drill hole, and it is put into the aluminum phosphate zone in every locality. The soft white zone is thinnest at the westernmost drill hole, is somewhat thicker to the east, and is thin again in the easternmost part of the section.

The aluminum phosphate zone is thinnest in the western part of the section—at holes 1 and 2—it is thick in the east—at holes 3 through 6—then is thin at holes 7 and 8, and thick again at hole 9 (fig. 16).

TENOROC MINE

The Tenoroc mine of the Coronet Phosphate Co., Division of Smith-Douglas, Inc., is in secs. 25–27, 34, 35, and 36, T. 27 S., R. 24 E., secs. 1 and 2, T. 28 S., R. 24 E., and sec. 30, T. 27 S., R. 25 E., Polk County, northeast of Lakeland, Fla. (pl. 1). The washer and flotation plant is located in sec. 26, T. 27 S., R. 24 E. Mining started in 1951 in sec. 25, T. 27 S., R. 24 E., and the mine and plant were operating in 1962.

In 1953, the company drilled 39 holes under contract to the U.S. Atomic Energy Commission. In an area of about 2,000 acres, the holes were drilled at a spacing of one in each 40 acres. One sample each of the aluminum phosphate zone and the calcium phosphate zone were taken at each drill hole and were analyzed by the company. Weighted averages of the analytical results are shown in tables 8 and 13. Small chip samples, taken at 1-foot intervals from each drill hole, were examined under the binocular microscope. Stratigraphic interpretations are based on the lithology as determined from these samples, and the discussion that follows is based on this drilling plus a few mine samples.

STRATIGRAPHY

Stratigraphy, based on lithology, is shown in figure 18. The stratigraphy is relatively simple and grossly uniform, but individual beds are lenticular and cannot be traced for great distances. The beds shown in figure 18 are lumped into those which are dominantly sandy and those which are dominantly clayey; only a few individual beds of sand or clay are shown (hole 5). All drill holes were completed in calcareous clay containing phosphate nodules (bedclay) assigned to the Hawthorn Formation, or were completed in limestone (bedrock) either of the Hawthorn Formation or the Tampa Limestone, and all holes passed through both the upper and the lower units of the Bone Valley Formation. The surface is covered with loose sand, assigned to the Pleistocene.

TAMPA LIMESTONE

The Tampa Limestone is known to be present at the Tenoroc mine from fossils collected from limestone fragments in the spoil banks at

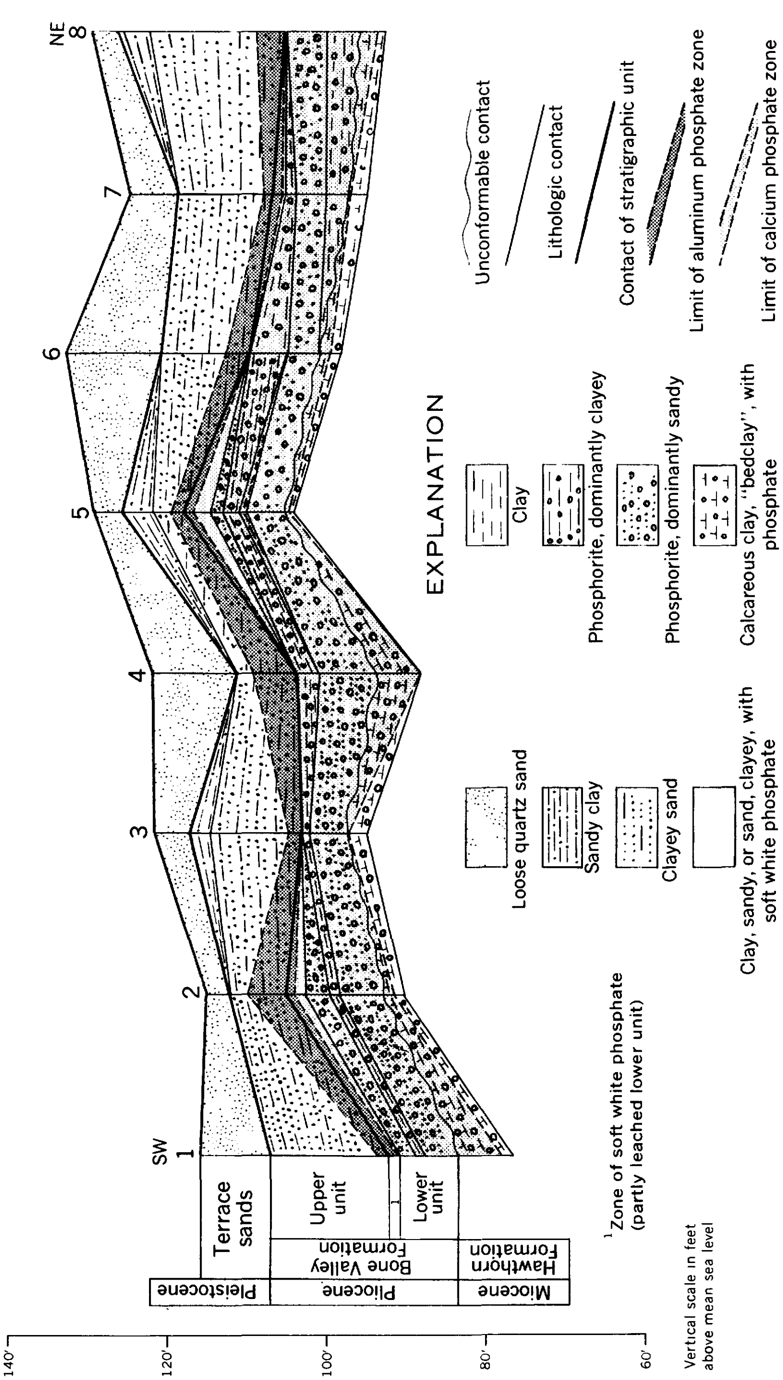

Figure 18.—Section, Tenoroc mine, showing relations of stratigraphy and economic geology. Horizontal not to scale. Location of drill holes shown on plate 1.

the mine (Carr and Alverson, 1959). The Tampa Limestone may form the "bedrock" of the drillers over much of the tract, but fossil evidence is lacking, and details are not available.

The Tampa Limestone is light brown or tan, hard, slightly sandy to sandy and contains sparse to very sparse brown fine-grained phosphate nodules. Fossils from the Tampa Limestone at the Tenoroc mine are listed by Carr and Alverson (1959). The thickness of the Tampa Limestone in the area of the Tenoroc mine is not known; all drill holes were completed in calcareous clay of the Hawthorn Formation, or in hard limestone, possibly referable to the Tampa.

HAWTHORN FORMATION

The Hawthorn Formation is present throughout the area of the Tenoroc mine, but only the calcareous lower part is represented. Contact relations of the Hawthorn Formation with the underlying Tampa Limestone are not known; drilling did not penetrate into the Tampa, and the contact was not seen in the mine pits. The calcareous clay containing common to abundant phosphate nodules, the bedclay, is assigned to the Hawthorn Formation because of the abundance of phosphate. The Tampa Limestone contains only trace amounts of phosphate, and the calcareous bedclay which is a residuum of limestone, probably represents the Hawthorn Formation.

The Hawthorn Formation in the area of the Tenoroc mine is very thin, ranging in thickness from a few feet to about 20 feet (fig. 4).

The formation consists of light-gray, tan, buff, white, cream, or yellow calcareous sandy clay containing common to very abundant nodules of phosphate. The quartz sand fraction is fine to very fine grained. Most drill holes were completed in material too hard to penetrate, probably limestone of either Hawthorn or Tampa, but a few drill holes penetrated white, light-gray, or cream marl or soft limestone containing fine-grained quartz sand and phosphate nodules.

The phosphate nodules of the calcareous clay of the Hawthorn Formation are abundant enough so that the material is a part of the calcium phosphate zone and may be a part of the matrix. The phosphate is black, amber, brown, white, and tan. The black and amber phosphate particles are more characteristic of the Hawthorn Formation than of the Bone Valley Formation or the Tampa Limestone. Although black and amber nodules are not necessarily more abundant than brown, white, or tan nodules in the Hawthorn Formation, the Tampa Limestone only rarely contains any black or amber nodules, and the Bone Valley Formation contains only minor amounts of black and amber nodules, and only in the bottom part of the formation. The phosphate nodules are of fine to very fine sand size, but some granule-size phosphate is in the Hawthorn Formation at most drill hole localities.

The lower part of the Hawthorn Formation in the area of the Tenoroc mine is seen only in the bottom of the mine pits and is seldom exposed for more than a few feet. The lower part is mostly residual calcareous clay and is massive and has no obvious bedding. The calcareous clay in drill holes was from 1 to 6 feet thick and averaged about 3 feet. Hard limestone, either of the Tampa or of the Hawthorn, is found only as blocks and fragments on the spoil banks, and occasionally the top of the limestone is exposed as the bottom surface of the pit.

BONE VALLEY-HAWTHORN CONTACT

The contact between the Bone Valley and the Hawthorn Formations is difficult to see in the mine pits, as it is close to the bottom of the pit and at most places is covered by slumping of the overlying unconsolidated sediments. The nature of the contact, however, can be seen in the drill cores. At about one-third of the drill holes, the contact is marked by a very sharp lithologic change: from massive white or cream calcareous clay or marl containing fine-grained black and amber phosphate—assigned to the Hawthorn Formation—to bedded gray loose to very slightly clayey sand composed of quartz and black, brown, tan, and white phosphate of sand and granule size—assigned to lower unit of the Bone Valley Formation. The quartz sand fraction of the Hawthorn Formation is fine to very fine grained, clear, and subangular to angular, whereas the quartz fraction of the Bone Valley Formation is medium grained, frosted, and subrounded to rounded. The phosphate grains, in most places, are distinctly coarser in the Bone Valley than in the Hawthorn, and the carbonate fraction of the Hawthorn is very abundant, whereas carbonate is absent in the Bone Valley Formation except as a part of the phosphate nodules.

The log of drill hole K, sec. 36, is a typical example of this type of contact relation.

Log of drill hole K in the NW¼SW¼ sec. 36, T. 27 S., R. 24 E.

[Drilled by the Coronet Phosphate Co., under contract to the U.S. Atomic Energy Comm.]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, fine- to medium-grained, gray at top, white at base	4
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Clay, very sandy, medium-grained—gray and rust mottled	1
Sand, clayey, medium-grained, light-gray	3
Sand, clayey, fine-grained, light-gray; trace of soft white phosphate nodules	1

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Log of drill hole K in the NW¼SW¼ sec. 36, T. 27 S., R. 24 E.—Continued

	Thickness (feet)
Pliocene—Continued	
Bone Valley Formation—Continued	
Lower unit:	
Clay, sandy, light-brown. Sand fraction is white phosphate and minor quartz. Some granule-sized white phosphate	1
Sand, of very abundant medium-grained to granule-sized white phosphate and sand-sized quartz. Trace clay	5
Total Bone Valley Formation	11
Miocene:	
Hawthorn Formation—lower part:	
Clay, sandy, buff, calcareous; contains abundant sand-sized and some granule-sized white phosphate	2
Clay, sandy, calcareous, buff; contains minor fine-grained amber phosphate nodules	1
Part of Hawthorn Formation	3
Bottom in limestone too hard to penetrate with hand auger.	

A second type of contact relation is illustrated by the following log of drill hole L. At this hole a gray clayey sand containing abundant black, brown, amber, and white phosphate nodules rests on white calcareous clay containing fine-grained black phosphate nodules. This drill hole is typical of about one-third of the holes drilled and, again, the lithologic change is clear but is not quite as sharp as the change in lithology at drill hole K. The contact is more difficult to see at drill hole L because the calcareous clay is a part of the calcium phosphate zone and at many drill holes contains enough phosphate to be a part of the matrix. However, there is more and coarser phosphate, the quartz sand fraction is more abundant and coarser, and the clay fraction is less abundant in the Bone Valley Formation than in the Hawthorn Formation. In addition, there is a marked difference in the carbonate content between the two formations.

Log of drill hole L in the SE¼SW¼ sec. 35, T. 27 S., R. 24 E.

[Drilled by Coronet Phosphate Co., under contract to the U.S. Atomic Energy Comm.]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, gray to white, fine- to medium-grained	3.5

Log of drill hole L in the SE¼SW¼ sec. 35, T. 27 S., R. 24 E.—Continued

	Thickness (feet)
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Clay, very sandy, red- and gray-mottled	2.0
Sand, clayey, gray; some rust mottling	4.0
Clay, sandy, red- and gray-mottled; sand fraction is fine-grained	4.0
Sand, very slightly clayey to loose, white, fine-grained	2.5
Sand, clayey, white; trace of soft white phosphate	1.0
Clay, sandy, gray; contains some fine-grained white phosphate	1.0
Lower unit:	
Sand, clayey, white, tan, and rust; contains abundant white and tan, sand- to granule-sized phosphate	3.0
Clay, very sandy, brown; contains abundant white and brown sand-sized phosphate nodules. Black phosphate nodules in the basal foot of the unit	6.0
Sand, clayey, light-gray, fine-grained; contains abundant black, brown, amber, and white sand-sized phosphate nodules	4.0
Total Bone Valley Formation	27.5
Miocene:	
Hawthorn Formation—lower part:	
Clay, sandy, calcareous, white; contains trace of fine-grained black phosphate nodules	1.5

Bottomed in limestone too hard to penetrate with the hand auger.

In the remaining drill holes, the contact is more difficult to determine. The lower unit of the Bone Valley Formation, which is a light-gray or tan clayey sand or sandy clay containing abundant medium- to fine-grained varicolored phosphate nodules, rests on the lower part of the Hawthorn Formation which is a tan to cream or white calcareous sandy clay containing abundant fine-grained varicolored phosphate nodules. Both the lower unit of the Bone Valley Formation and the calcareous clay—residual from the Hawthorn Formation—are a part of the matrix; both contain abundant phosphate, which is, perhaps, slightly coarser in the Bone Valley; and both contain approximately the same quartz sand to clay ratio. The only real difference is in the carbonate content—it is very abundant in the calcareous clay of the Hawthorn and is virtually absent, except for small amounts tied up in the phosphate nodules, in the Bone Valley. Drill hole M, sec. 25, illustrates this kind of contact relation. Other company drill hole data, used in the preparation of the various isopach maps, give only the total thickness of the overburden and the matrix, and in most of the area the matrix contains rocks of both the Hawthorn and Bone Valley Formations. Thus, the contact of the Hawthorn and the Bone Valley is within the matrix unit.

Log of drill hole M in the SE¼NE¼ sec. 25, T. 27 S., R. 24 E.

[Drilled by the Coronet Phosphate Co., under contract to the U.S. Atomic Energy Comm.]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, fine- to medium-grained	8
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, clayey, tan, gray, and rust	10
Sand, clayey, white	2
Lower unit:	
Sand, very clayey, white to light-gray; contains abundant white, sand- to fine granule-sized phosphate nodules	4
Clay, sandy, very fine grained, gray; contains white and some black phosphate nodules	1
Sand, very clayey, gray (tan in bottom foot), medium- to fine-grained; contains white and some black phosphate	3
Total Bone Valley Formation	20
Miocene:	
Hawthorn Formation—lower part:	
Clay, sandy, tan to cream, calcareous; contains fine-grained white, black, and brown phosphate nodules	4
Clay, cream, very calcareous, sandy; contains minor amounts of black and tan fine sand-sized phosphate nodules and trace amounts of granule-sized phosphate	2
Part of Hawthorn Formation	6

Bottom in material too hard to penetrate with the hand auger.

BONE VALLEY FORMATION—LOWER UNIT

The lower unit of the Bone Valley Formation is present at every hole drilled during the 1953 drilling program. The lower unit ranges in thickness from 3 to 22 feet and averages about 9½ feet; it is a sandy clay, a clayey sand, or a loose to very slightly clayey sand. Beds of loose sand are commonly at the bottom of the unit, and beds of clay are very rare. Individual beds are lenticular, as shown in figure 18, and although the bottom half of the lower unit is commonly sandy (as at holes 1–6, fig. 18), it also contains beds that are dominantly clay (holes 7 and 8, fig. 18). The lower unit is mostly light gray or white, but tan, gray-green, or yellow beds are common, and brown or rust-brown beds are present. Abundant phosphate nodules are characteristic of all the beds of the lower unit of the Bone Valley Formation. The nodules range in size from fine-grained sand to fine-grained granule, and the finer sizes (the concentrate fraction) are the most common. The phosphate nodules are varicolored; in order of abundance, white, brown, and tan are most common. Gray nodules are at a few drill holes; amber nodules are only in the basal part of the lower unit, and black nodules, although present throughout the lower unit, are most common in the bottom half.

Bedding was observed at the mine pits and can be inferred from the drill logs (log L, p. G92, and fig. 32). Graded bedding was not observed in the Bone Valley Formation. A sand of phosphorite and quartz is commonly at the base of the formation, and this sand is possibly the equivalent of the basal conglomerate noted at other areas. The sand contains coarse quartz and some granule-size phosphate; at places it is a fine-grained sandy conglomerate or conglomeratic sand.

The contact between the upper and lower units of the Bone Valley Formation is gradational over a few inches to about 2 feet and is marked by the abrupt diminution in the number of phosphate nodules from abundant in the lower unit to traces in the upper. The contact zone at the Tenoroc mine has been partly leached and is the so-called soft white phosphate zone (fig. 18). Although the zone stratigraphically may be a part of the lower unit, it generally is not put into the economic phosphate zone. The logs of drill holes K, L, and M (p. G91) illustrate the contact relations. Sparse phosphate nodules are present only in the bottom 1 or 2 feet of the upper unit.

BONE VALLEY FORMATION—UPPER UNIT

The upper unit of the Bone Valley Formation is a gray, tan, and brown, clayey to slightly clayey sand. In the Tenoroc area, red and gray mottled sandy clay commonly is present as beds a few feet thick at the top of the unit (fig. 18, and logs of drill holes K and L, p. G91 and G92). The upper unit contains only trace amounts of visible phosphate and then only at the base of the unit. The phosphate nodules are dull, white, and soft and may form the upper part of the zone of soft white phosphate. The phosphate in the upper unit is clay size and is one of the aluminum phosphate minerals. Leaching has been so thorough that the phosphate nodules are gone except at the base of the unit, and even here they have been partly altered.

The upper unit is present at all drill holes in the Tenoroc area and ranges in thickness from 5 to 25 feet and averages about 11½ feet.

TERRACE SAND

Loose quartz sand covers the entire surface over the Tenoroc mine. The sand, which ranges in thickness from 2 to 12 feet and averages about 6 feet, is dark gray or black, has organic material in the top part, and is leached to a white or light gray at depth. The sand is assigned to the Pleistocene, although in the mine pits a zone of black, highly organic sand—which probably represents an ancient swamp zone—is overlain by 1 or 2 feet of gray to white sand that is probably Recent windblown sand. No attempt has been made to differentiate the sand of Recent and Pleistocene ages.

ECONOMIC GEOLOGY

The calcium phosphate and the aluminum phosphate zones, both potentially economic, are present at every drill location in the Tenoroc area.

CALCIUM PHOSPHATE ZONE

The calcium phosphate zone at the Tenoroc mine consists of the lower unit of the Bone Valley Formation and the bed clay, a calcareous clay residual from the Hawthorn Formation. The relations between stratigraphy and economic geology are shown in figure 18. The calcium phosphate zone at hole 1, for example, is about equally divided between the Bone Valley and Hawthorn Formations, whereas at hole 5, only the bottom foot of the calcium phosphate zone is assigned to the Hawthorn Formation. At all the drill holes in the section most of the calcium phosphate zone is in the Bone Valley Formation, and at several holes (3, 5, and 7)—although the calcium phosphate zone consists of both Bone Valley and Hawthorn—the matrix (the economic part of the zone) is entirely within the Bone Valley Formation. The part of the calcium phosphate zone in the Bone Valley Formation is dominantly sandy, the part in the Hawthorn is dominantly clayey.

The zone of soft white phosphate is genetically a part of the calcium phosphate zone. At some drill holes, however, the soft white zone is economically considered as a part of the aluminum phosphate zone, and at every drill hole where it is present, at least the top part of the zone is considered to be a part of the aluminum phosphate zone. Leaching has so softened and altered the nodules of phosphate in this zone that they cannot be economically recovered, and the zone of soft white phosphate is considered to be a part of the leached, or aluminum phosphate zone.

Analytical data on the calcium phosphate zone are summarized in table 8. The concentrate fraction of the zone is more abundant than the pebble fraction and is higher in phosphate content and lower in uranium content. Figure 9, which illustrates the distribution of the pebble and concentrate in the calcium phosphate zone, shows that in the area of the Tenoroc mine the concentrate fraction is dominant; pebble is more abundant than concentrate at only a few isolated drill localities.

The total Fe_2O_3 plus Al_2O_3 content of the pebble fraction is slightly higher than that of the concentrate fraction, and the content of insoluble residue of the pebble fraction is significantly higher than the insoluble content of the concentrate fraction. Evidently the lower phosphate content of the coarser nodules is due to the higher percentage of insoluble residue (probably mostly quartz) in this fraction.

ALUMINUM PHOSPHATE ZONE

The aluminum phosphate zone at the Tenoroc mine consists of about the lower half of the clayey sand of the upper unit of the Bone Valley Formation plus, at most drill holes, the soft white phosphate zone—the partly leached upper 1 or 2 feet of the lower unit of the Bone Valley. Based on the 39 holes drilled in 1953, the aluminum phosphate zone ranges in thickness from 1½ to 12 feet and averages about 4 feet. The aluminum phosphate zone, called the leached zone in the company logs, is that part of the section which was cut out for analysis by the company. It is the zone immediately above the economic phosphate deposit, and the top of the analyzed section was selected on the basis of the rise in radioactivity in the lower part of the clayey sand, as shown by the gamma logs.

Analytical data for the screened fractions of the aluminum phosphate zone are summarized in table 13. Both phosphate and uranium contents of the zone are low, averaging, for the head samples, 1.93 and about 0.003 percent, respectively. These data indicate that the zone has been thoroughly leached and that the clayey sand that was leached probably contained very small amounts of phosphate nodules.

The map of uranium distribution in the aluminum phosphate zone (pl. 11) shows that only one area (in the SE¼SW¼ sec. 25, T. 27 S., R. 24 E.) contains as much as 0.010 percent uranium; throughout most of the tract only the 0.005 percent contour line is present. The map of P_2O_5 distribution (fig. 13) shows that only one small area in the SE¼NW¼ sec. 30, T. 27 S., R. 25 E., contains as much as 5 percent P_2O_5. Thus, although the aluminum phosphate zone is present throughout the tract, it is too low in both phosphate and uranium content to be economic.

LAKE PARKER TRACT

The Lake Parker tract of the Coronet Phosphate Co. is in secs. 21, 28, and 33, T. 27 S., R. 24 E., and secs. 3 and 4, T. 28 S., R. 24 E., in Polk County, Fla. The tract comprises almost 1,300 acres and has not been mined.

In 1953, the company drilled 27 holes, under contract to the U.S. Atomic Energy Commission, at a spacing of 1 hole per 40-acre block. One sample of the aluminum phosphate zone and one sample of the calcium phosphate zone were taken at each drill hole. Samples were analyzed by company chemists, and the averaged results are shown in tables 8 and 13.

Small chip samples were taken at 1-foot intervals at each drill hole and were examined under the binocular microscope. Stratigraphic interpretations were based on the lithology as determined from these samples. No fossils were found during the drilling. The surface is covered by a blanket of loose sand, assigned to the Pleistocene.

STRATIGRAPHY

Stratigraphic relations and the relation of stratigraphy to economic geology are shown in figure 19. Stratigraphy is basically simple, although individual beds are lenticular. All holes were completed in material too hard to penetrate with the hand auger,

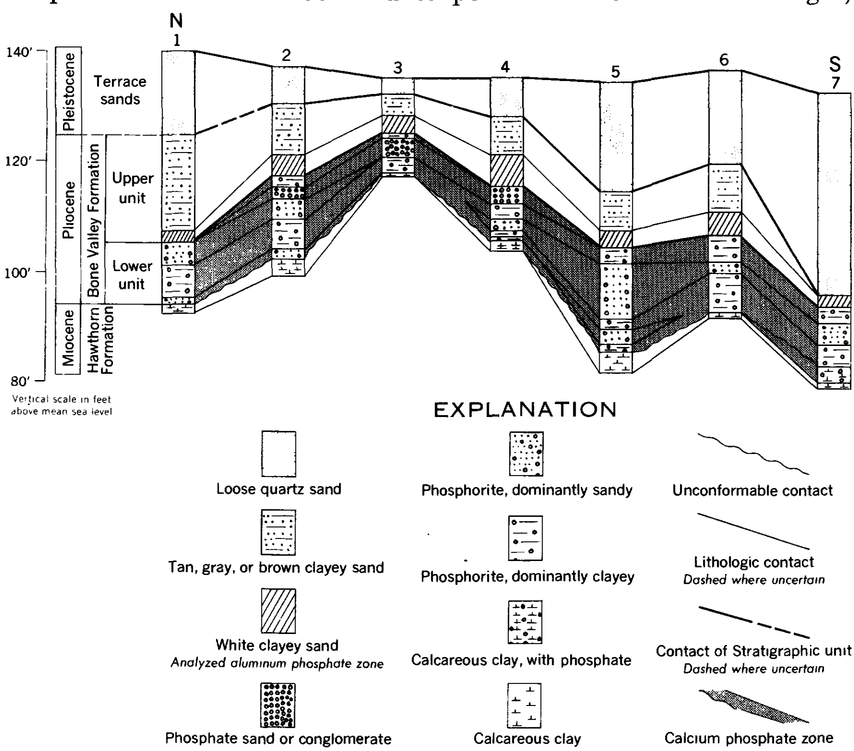

FIGURE 19.—Section, Lake Parker tract, Coronet Phosphate Co. Horizontal not to scale. Location of drill holes shown on plate 1.

probably limestone of the Hawthorn Formation. Calcareous clay, residual from limestone was penetrated by all drill holes but one where the Bone Valley Formation rested on hard limestone. Bedded phosphorite of the lower unit of the Bone Valley Formation and clayey sand of the upper unit were penetrated by all drill holes; surficial loose sand, assigned to the Pleistocene, covers the Lake Parker tract.

HAWTHORN FORMATION

Only the lower calcareous member of the Hawthorn Formation is present at the Lake Parker tract, and only the top few feet of the member was penetrated by the drill. Drilling stopped at material too hard to penetrate with the hand auger, probably limestone of the Hawthorn Formation. The calcareous clay that was cored is probably residual from the underlying limestone. Most of the clay is white, cream, or gray, but shades of yellow, brown, and green were also noted. The clay contains very fine to fine-grained quartz sand or silt, and a minor to abundant amount of fine sand-size black, brown, white, and amber phosphate nodules. There are only trace amounts of the pebble phosphate fraction. The clay ranges in thickness from 0 to 6.5 feet and averages about 2 feet. The calcareous clay is a part of the calcium phosphate zone, and in about half of the drill holes it contains enough phosphate to be economic. The possibly economic part of the calcareous clay ranges in thickness from 0 to 6 feet and averages about 1 foot.

HAWTHORN-BONE VALLEY CONTACT

The contact between the Hawthorn and Bone Valley Formations has not been seen at the Lake Parker tract, but the unconformable nature of the contact can be inferred from the drill cores. At most drill holes the contact is marked by a change in lithology—from the underlying massive calcareous sandy or silty clay of the Hawthorn to sandy clay, clayey sand, or sand, containing very abundant phosphate of the Bone Valley. There are, then, changes in the size and the amount of both the phosphate nodules and the quartz grains, changes in the sand-to-clay ratios, changes in carbonate content, and changes in the color of the sedimentary rocks. The rocks of the lower unit of the Bone Valley Formation are bedded, but in the rocks of the Hawthorn Formation no bedding has been observed or can be inferred from the cores. The logs of the two drill holes that follow show two extremes. At drill hole N, the lithologic break between the Bone Valley and Hawthorn Formations is sharp and clear, whereas at drill hole O, the difference is only in the relative amounts of phosphate nodules and carbonate. In both holes however, a lithologic contact can be selected. Bedded sand, clayey sand, and sandy clay of the Bone Valley Formation rested on hard limestone at only one locality.

Log of drill hole N in the SW¼SE¼ sec. 4, T. 28 S., R. 24 E.

[Drilled by Coronet Phosphate Co., under contract to the U.S. Atomic Energy Comm.]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, quartz, medium-grained	10.5
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, very slightly clayey, gray-brown, medium- to coarse-grained	2.0
Clay, sandy, gray-tan	1.0
Sand, very clayey, gray-tan	2.0
Sand, clayey, gray-tan	1.5
Clay, sandy, light-gray; contains minor amounts of soft white phosphate	1.0
Lower unit:	
Clay, sandy, gray-green; contains abundant white and tan phosphate	1.0
Sand, clayey, gray-green; contains white and tan sand- to granule-sized phosphate nodules	3.0
Clay, sandy, white; contains white, sand-sized phosphate	2.0
Clay, green; contains white phosphate, and some quartz grains in bottom half	2.0
Sand, dark-gray, of quartz and black phosphate. Trace clay	4.0
Total Bone Valley Formation	19.5
Miocene:	
Hawthorn Formation—lower part:	
Clay, sandy, calcareous, cream and rust; contains fine-grained sand-sized black phosphate	2.0
Clay, sandy, calcareous, brown; contains trace amounts of fine-grained phosphate	1.5
Part of Hawthorn Formation	3.5

Bottom in limestone too hard to penetrate with the hand auger.

Log of drill hole O in the SE¼NW¼ sec. 33, T. 27 S., R. 24 E.

[Drilled by Coronet Phosphate Co., under contract to the U.S. Atomic Energy Comm.]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, brown, fine- to medium-grained	3.5
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, very slightly clayey, dark gray-brown	2.5

Log of drill hole O in the SE¼NW¼ sec. 33, T. 27 S., R. 24 E.—Continued

	Thickness (feet)
Pliocene—Continued	
Bone Valley Formation—Continued	
Lower unit:	
Clay, sandy, green and tan; contains white and black sand- to fine granule-sized phosphate nodules	.5
Sand, clayey, tan; contains abundant white fine sand-sized and minor fine granule-sized phosphate	1.0
Clay, sandy, to very sandy in the bottom half, light-tan; contains tan, brown, white, and minor black, fine- to very fine-grained phosphate, trace granule size	2.0
Clay, tan to brown, sandy; contains abundant fine-grained white phosphate nodules	2.0
Total Bone Valley Formation	8.0
Miocene:	
Hawthorn Formation—lower part:	
Clay, calcareous, sandy, white to cream; contains fine-grained, brown, and some white phosphate	1.0
Bottom in limestone too hard to penetrate.	

BONE VALLEY FORMATION—LOWER UNIT

The lower unit of the Bone Valley Formation at the Lake Parker tract consists of gray-green, brown, and white sandy clay and gray or greenish-gray clayey sand. Beds of sand and clay are not common, but a few drill holes penetrated beds of phosphatic sand or fine conglomerate (fig. 19). The beds are lenticular and individual drill holes may be predominantly sandy, as hole 5, or clayey, as holes 4 and 6, figure 19. The lower unit of the Bone Valley Formation commonly consists of gray clayey sand or sandy clay at the top and is greenish gray and more clayey in the bottom part.

All the beds of the lower unit contain abundant phosphate nodules. The fine (concentrate size) phosphate nodules are more abundant than the coarser (pebble size) nodules. The distribution of pebble and concentrate is shown in figure 9. The concentrate fraction is more abundant than the pebble fraction throughout the tract, except at the western and eastern edges. Only a few drill holes penetrated the calcium phosphate zone that contained more pebble than concentrate. The pebble fraction tends to be more abundant toward the base of the lower phosphorite unit, except for the thin beds of phosphate sand or conglomerate shown at the top of the section at holes 2, 3, and 4, figure 19.

The phosphate nodules are predominantly white and black, but brown nodules are abundant, and tan, amber, and gray nodules are also present. Amber nodules are characteristically in the lower part of the unit, and black nodules, at about half of the drill holes, are present only in the basal part of the unit.

The lower unit of the Bone Valley Formation is entirely within the calcium phosphate zone and makes up most of the calcium phosphate zone throughout the tract. The unit ranges in thickness from 5 to 21 feet and averages 12 feet in the 27 holes drilled in 1953.

The contact between the upper and the lower units of the Bone Valley Formation is gradational and conformable and is marked by the trace amounts of phosphate nodules in the upper unit, as compared with the abundant nodules in the lower unit. In addition, the upper unit contains considerably less clay than does the lower unit.

The phosphoritic lower unit of the Bone Valley Formation is bedded and shows graded bedding at a few drill holes. Bedding and graded bedding must be inferred from the drill hole logs. The log of drill hole P is a good example of graded bedding in the lower unit of the Bone Valley Formation. The bottom bed of the Bone Valley Formation (bed 2) is the base of a set of graded beds, which included beds 2 and 3. Beds 4 and 5 form a second set of graded beds, and beds 6 and 7 form a possible third set. In each set the bottom bed is a sand or clayey sand containing abundant coarse phosphate in the bottom part of the bed. In each set there is an upward increase in the amount of clay, the phosphate fraction is finer grained in the top bed of each set, and, generally, the quartz sand fraction is finer grained at the top of each set of graded beds.

Log of drill hole P in the NW¼NE¼ sec. 33, T. 27 S., R. 24 E.

[Drilled by the Coronet Phosphate Co., under contract to the U.S. Atomic Energy Comm.]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
10. Sand, tan, loose, fine- to medium-grained	7.0
Pliocene:	
Bone Valley Formation:	
Upper unit:	
9. Sand, slightly clayey, tan	7.0
8. Sand, clayey, tan to white	6.0
Lower unit:	
7. Sand, very clayey, cream; contains abundant fine-grained white phosphate nodules	1.0
6. Sand, clayey; contains abundant black and white and some brown fine-grained phosphate, and abundant brown granule-sized phosphate at the base of the bed	2.0
5. Clay, slightly sandy, olive-green; contains sparse fine-grained phosphate	3.0
4. Sand, clayey, green-gray; contains black and white sand-sized and a little fine granule-sized phosphate	2.0
3. Clay, sandy, white, grading downward to clayey sand. Contains sand-sized white and black phosphate	1.0
2. Sand, slightly clayey; contains abundant granule-sized and sparse sand-sized phosphate	1.0
Total Bone Valley Formation	23.0

Log of drill hole P in the NW¼NE¼ sec. 33, T. 27 S., R. 24 E.—Continued

	Thickness (feet)
Miocene:	
Hawthorn Formation—lower part:	
1. Clay, sandy, calcareous, brown and cream; contains sparse black and tan, fine-grained phosphate	1.5

Bottom in material too hard to penetrate, probably limestone of the Hawthorn Formation.

BONE VALLEY FORMATION—UPPER UNIT

The upper unit of the Bone Valley Formation is present throughout the Lake Parker tract. It is a gray, light-gray, or white, clayey to slightly clayey sand ranging in thickness from 2 to 18.5 feet and averaging about 8.5 feet in the 27 holes drilled in 1953. Gray-brown to reddish-gray sandy clay is present at a few drill holes and is generally near the top of the unit. Loose or very slightly clayey sand is present in the middle of the unit at a few drill holes. Phosphate nodules are present only in the bottom 1 or 2 feet of the unit and are soft, dull, and white. The entire unit has been thoroughly leached.

The base of the upper unit is taken to be the base of the analyzed aluminum phosphate zone, as shown in figure 19. This may be in error, slightly, because the bottom 1 or 2 feet of the leached material contains white phosphate nodules and may belong to the lower unit of the Bone Valley Formation. The leached white phosphate cannot be recovered economically, however, and it should, therefore, be put into the aluninum phosphate zone rather than the calcium phosphate zone.

TERRACE SAND

Loose quartz sand that blankets the surface is assigned to the Pleistocene. This sand, which ranges in thickness from 3 to 37 feet and averages about 11½ feet, is fine to medium grained and is mostly gray, white, or brown. Hardpan, the iron-cemented sand, was not penetrated by any of the drill holes, although the surficial sand is stained brown by iron oxide at some localities.

ECONOMIC GEOLOGY

The calcium phosphate zone, which includes the economic phosphate deposit, and the aluminum phosphate zone, which includes some possibly economic phosphate, are both present at all drill holes in the Lake Parker tract. Relations of the two zones are graphically shown in figure 19.

CALCIUM PHOSPHATE ZONE

The calcium phosphate zone at the Lake Parker tract consists, in large part, of the lower unit of the Bone Valley Formation, but some calcareous clay of the Hawthorn Formation is present at every drill hole locality but one. The zone ranges in thickness from 7½ to 25 feet and averages about 14 feet, but the matrix, the economic part, ranges in thickness from 6 to 22½ feet and averages about 13 feet. It has already been noted that the lower unit of the Bone Valley Formation averages 12 feet in thickness. Therefore, only about 1 foot of the average matrix thickness is assigned to calcareous clay of the Hawthorn Formation.

The zone of soft white phosphate, which marks the contact between the calcium phosphate zone and the overlying aluminum phosphate zone at most places throughout the quadrangle, is not prominent at the Lake Parker tract. The basal 1 or 2 feet of the clayey sand of the aluminum phosphate zone does contain some soft white phosphate, but the amount of phosphate is so small that it was not possible to separate a distinct zone that was characterized by soft white phosphate.

The calcium phosphate zone is thickest over low areas on the Hawthorn surface and thinnest over highs on this surface. For example, as shown in figure 19, the thinnest calcium phosphate zone is at hole 3, where the Hawthorn surface is topographically highest, and the zone thickens both to the north and to the south toward low areas. The maximum thickness of calcium phosphate zone material in the section is at hole 5, overlying a depression on the Hawthorn surface.

Average analytical data for the calcium phosphate zone at the Lake Parker tract are given in table 8. The pebble fraction is lower in P_2O_5 and higher in uranium content than the concentrate fraction, and the content of acid insoluble (probably mostly quartz) is significantly higher in the pebble fraction than in the concentrate fraction, but the total $Fe_2O_3+Al_2O_3$ (I and A) are only slightly higher in the pebble fraction. It seems likely that grains of quartz sand and silt make up the principal diluent in the pebble fraction.

ALUMINUM PHOSPHATE ZONE

The aluminum phosphate zone is present throughout the tract and includes all the upper unit of the Bone Valley Formation. The leaching that formed the zone was by downward-moving acidic groundwater; the upper part of the clayey sand, therefore, is more thoroughly leached than the lower part and contains less uranium and phosphate than the lower part. The uranium content of the zone was of particular interest at the time of drilling, and the section of core cut out for analysis was determined by high radioactivity on gamma-ray logs. Thus, at most drill holes, only the bottom part of the aluminum phosphate zone was cut out from the core for analysis. At each drill hole, the bottom of the aluminum phosphate zone was taken as the top of the economic phosphate deposit, as determined by the company. The analyzed aluminum phosphate zone ranges in thickness from

1.5 to 13 feet and averages about 4 feet, and the clayey sand of the upper unit averages about 8.5 feet in thickness.

A top and bottom sample of the aluminum phosphate zone, representing all of the clayey sand between them, were taken at only one drill hole—in the NE¼NW¼ sec. 4, T. 28 S., R. 24 E. The bottom sample corresponded to the high peak of radioactivity on the gamma log, and the top sample was of the rest of the clayey sand to the contact with the overlying loose quartz sand. Analytical data are summarized in table 18.

TABLE 18.—*Analytical data, aluminum phosphate zone, NE¼NW¼ sec. 4 T. 28 S., R. 24 E.*

[Leaders (....) =below limit of detection, taken as 0.0 percent. Analyses by Coronet Phosphate Co. chemists, under contract to the U.S. Atomic Energy Comm. Pebble=+20 mesh; sand=−20+150 mesh; slime=−150 mesh; head=computed from pebble, sand, and slime fractions. From 0 to 17 ft below surface is loose quartz sand, not sampled; from 30 to 44 ft is calcium phosphate zone]

Fraction	Weight percent	Chemical analyses, in percent					
		P_2O_5	CaO	Insoluble	Al_2O_3	Fe_2O_3	U
Top sample; 17-26 ft below surface							
Pebble	0.3	2.55	1.01	92.42	2.18	0.42	0.0001
Sand	70.4	.33	----	98.13	.28	.18	----
Slime	29.3	6.79	3.36	64.74	14.62	.40	.010
Head	100.0	2.23	.90	88.24	4.48	.25	.002
Bottom sample; 26-30 ft below surface							
Pebble	0.5	14.18	8.52	56.57	11.96	0.68	0.047
Sand	62.4	.80	2.77	96.63	.85	.17	.001
Slime	37.1	5.08	1.50	72.81	12.50	.28	.022
Head	100.0	2.45	2.33	87.61	5.22	.21	.010

The top sample is more thoroughly leached, has less CaO and uranium, and slightly less P_2O_5 than the bottom sample; both have about the same Al_2O_3 content. The P_2O_5 content, originally as apatite (calcium phosphate), is dissolved and combines with alumina to form the relatively insoluble aluminum or calcium aluminum phosphate minerals. Uranium, however, is not taken up by the aluminum phosphate minerals but does combine with the calcium phosphate minerals. It is removed from the coarser fractions of the top sample, is concentrated to some degree in the slime fraction of the top sample, and is highly concentrated in the pebble and slime fractions of the lower sample.

SADDLE CREEK MINE

The Saddle Creek mine of the American Cyanamid Co. is in secs. 10, 11, 14, 15, 22–27, and 34–36, T. 28 S., R. 24 E., and sec. 31, T. 28 S., R. 25 E., east of Lakeland, Polk County, Fla. Mining, which was by large draglines, began in 1942 and continued until 1957. Mined material was pumped to a washer and flotation plant located in sec. 26, T. 28 S., R. 24 E.

STRATIGRAPHY

General stratigraphy and stratigraphic relations at the Saddle Creek mine are shown on a fence diagram (pl. 4). Most of the information on which the diagram is based is from lithologic logs of company drilling; additional information is from study of stratigraphic sections at the mine, which were used to interpret the company logs.

The fence diagram shows the general stratigraphy at the Saddle Creek mine. All drill holes were completed in calcareous clay or limestone of the Hawthorn Formation, and all holes passed through the Bone Valley Formation and unconsolidated sand of Pleistocene age. The irregular contact between the Hawthorn Formation and the lower unit of the Bone Valley Formation is clearly shown in the diagram, and the section between holes C16 and H16, sec. 22, shows this irregular contact particularly well. The thickening of the lower unit of the Bone Valley Formation over low areas on the Hawthorn Formation is also well shown. Swamp deposits, probably of Recent age, are shown at the surface at a few localities, but windblown sands, also of Recent age, were not distinguished. The beds are lenticular, and both units of the Bone Valley Formation are thin bedded or laminated. These details are not shown in the fence diagram, but are illustrated in the detailed stratigraphic sections taken in the mine.

Mine face section Q, NE¼NE¼ sec. 34, T. 28 S., R. 24 E., Saddle Creek mine

[Modified from lithologic log by H. M. Icke and R. H. Stewart. Sample Nos. refer to samples in table 3, p. G31]

	Thickness (feet)
Recent:	
Sand deposit:	
Sand, loose, quartz, white. Top foot gray with organic material. Contact with unit below is irregular (sample 794–18)	7.0
Pleistocene:	
Terrace deposit:	
Sand, loose, brown, darker at top. The top is an old erosion surface (sample 794–17)	3.0
Sand, loose, dark-brown, lighter at top (sample 794–16)	4.0
Sand, loose, brown (sample 794–15)	2.0
Sand, loose, black (sample 794–14)	4.0
Total terrace deposit	13.0
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, clayey, light-gray-green and some brown mottling	1.5
Sand, clayey, light-gray-green	5.0
Sand, clayey, gray-green	4.0
Sand, clayey, gray-green, leached and partly indurated, and very thin bedded. Bedding is horizontal	1.5
Sand, slightly clayey, light-gray, trace white phosphate, increasing toward base	7.5

Mine face section Q, NE¼NE¼ sec. 34, T. 28 S., R. 24 E., Saddle Creek mine—Con.

	Thickness (feet)
Pliocene—Continued	
Bone Valley Formation—Continued	
Lower unit:	
Sand, clayey, light-gray; contains white phosphate pebble	1.0
Sand, clayey, gray-green; contains sand- to granule-sized tan and white phosphate nodules. A lenticular gray-green to white very sandy clay bed with tan and white phosphate nodules interfingers with the clayey sand here	1.0
Sand, clayey, gray-green; contains abundant tan and white sand- to granule-sized phosphate nodules	2.0
Sand, clayey, gray-green to buff; contains phosphate sand and pebble	0.3
Sand, clayey gray; contains very abundant sand-sized black phosphate, and some granules	2.5
Sand, clayey, gray-green; contains abundant sand- and granule-sized black phosphate nodules	2.0
Part of Bone Valley Formation	28.3
Bottom of pit.	

Mine face section R, NW¼SE¼ sec. 27, T. 28 S., R. 24 E., Saddle Creek mine

[Adapted from section by F. N. Houser]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, quartz	24.0
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, slightly clayey, light-tan, very fine grained, leached	1.2
Lower unit:	
Sand, slightly clayey, of gray and tan phosphate and quartz. Minor gray granule-sized phosphate	1.2
Sand, slightly clayey, of gray and tan phosphate and quartz. Contains abundant gray granule-sized phosphate	1.2
Sand, slightly clayey, of brown and black phosphate, and medium-grained quartz. Contains some gray phosphate granules	1.6
Sand, clayey, gray, and brown-gray mottled; contains black, gray, and brown sand-sized phosphate. Minor gray granule-sized phosphate nodules	.7
Total Bone Valley Formation	5.9
Unconformity. Irregular contact varying as much as 8 ft vertically over short distances horizontally.	
Miocene:	
Hawthorn Formation:	
Lower part:	
Clay, very calcareous, soft, very light-yellow-gray, sandy. Sand fraction consists of fine-grained quartz and brown, gray, and black phosphate. Trace amounts of gray phosphate granules	3.7
Part of Hawthorn Formation	3.7
Base of pit.	

720-869 O—64——8

At mine face section Q, a loose sand, probably of Recent age, rests on the irregular surface of sand of Pleistocene age. The top of the sand of Pleistocene age is an erosional surface. Both units of the Bone Valley Formation are broken down into many individual beds, some of which are laminated, and the bedding is horizontal. The lenticular nature of the beds is also noted.

In the log of mine face section R, the irregular and unconformable contact between the lower unit of the Bone Valley Formation and the underlying Hawthorn Formation is indicated.

HAWTHORN FORMATION

The Hawthorn Formation at the Saddle Creek mine consists of sandy, clayey, and phosphatic limestone or marl and sandy calcareous clay, residual from the limestone. Both lithologic units are in the lower part of the formation and contain fine sand- to granule-size brown, gray, and black phosphate nodules, and the sand-size nodules are most abundant. The limestone is soft, very light yellowish gray, and is probably dolomitic. At most localities only 1–5 feet is exposed in the ditches in the middle of the pits, and these exposures are several feet below the lowest exposure of the phosphorite of the Bone Valley Formation. The contact, therefore, is almost everywhere covered by slumping at the bottom of the pit.

Soft limestone or marl was sampled at three localities at the Saddle Creek mine. Samples were wet screened, the sand fraction was treated by flotation to obtain a phosphate concentrate, and the samples were analyzed for uranium by the Geological Survey. Results are shown in table 19.

The screen data in table 19 show a very high average content of the pebble (+14 mesh) fraction. This fraction is very low in uranium content and consists of fragments of impure limestone containing some phosphate grains. The concentrate fraction of all three samples is higher in uranium content than any of the other fractions. Probably this fraction is phosphate grains. The slime fraction (−150 mesh) contains practically no uranium. These samples were not analyzed for P_2O_5, but company prospect samples of similar material were screened, and the pebble fraction was analyzed for P_2O_5. These samples were taken at the base of the drill holes, just above the hard limestone (bedrock), and they probably represent the salt limestone or marl. Eleven samples of the pebble fraction ranged from 2.3 to 11.7 percent P_2O_5 and averaged 7.0 percent. The acid insoluble content was not particularly high, and these samples are probably impure slightly phosphatic limestone.

The soft limestone is overlain by "bedclay" in about half of the holes drilled in the mine area and by the lower unit of the Bone Valley Formation in the other half. Pebble samples from the bedclay

TABLE 19.—*Screen data and uranium analyses, soft limestone of the Hawthorn Formation, Saddle Creek mine*

[Radiometric analyses by J. J. Warr, Jr., Emma H. Humphrey, and B. A. McCall]

Fraction (mesh size)	Sample 794-40			Sample 794-49			Sample 921-50		
	Percent of dry weight	Lab. No.	Percent eU	Percent of dry weight	Lab. No.	Percent eU	Percent of dry weight	Lab. No.	Percent eU
+14 (pebble)	54.6	32064	0.002	52.5	34028	0.003	33.7	32621	0.001
−14+35 (feed)	8.7	32065	.005	7.4	34029	.003	6.6	32622	.002
−35+150 (concentrate)	5.9	32068	.005	7.5	34032	.008	6.6	32625	.004
−35+150 (tailing)	7.9	32069	.002	6.5	34033	.002	17.2	32626	.001
−150 (slime)	22.9	32067	<.001	26.1	34031	.001	35.9	32624	.001
Head	100.0	32063	.002	100.0	34027	.001	100.0	32620	.002

immediately above the limestone contain from 15 to 19 percent more P_2O_5 than pebble samples from the limestone, and the pebble samples from the lower unit of the Bone Valley Formation, where it directly overlies the limestone, contain from 21 to 25 percent more P_2O_5 than the pebble samples from the limestone.

Samples of the soft limestone were taken at nine additional locations but were not screened. The head sample was analyzed for uranium content, which ranged from 0.001 to 0.003 percent and averaged 0.002 percent—about the same as the head samples in table 19.

The limestone bed rock of the Hawthorn Formation contains only very minor amounts of uranium, and the uranium is present only in the phosphate nodules of the formation.

The bed clay, a residual calcareous sandy clay, is, like the soft limestone, light yellowish gray, but it is also described as brown, blue gray, and greenish gray. It contains brown, tan, gray, and black sand- and some granule-size phosphate nodules. The bed clay gradationally overlies the soft limestone or, at some localities, is apparently interbedded with the limestone—probably the result of lateral leaching. For example, at a mine face section in the NE¼NE¼ sec. 22, T. 28 S., R. 24 E., a sample of massive tan sandy calcareous clay containing abundant tan phosphate nodules was taken at the bottom of a drainage ditch and is noted to be well within the solid Hawthorn. The contact between the bed clay and the underlying limestone is a weathering contact. At a mine section, taken in the SE¼ sec. 27, T. 28 S., R. 24 E., it is noted that coarse phosphate nodules "straddle" the contact between the hard limestone and the overlying calcareous clay, being partly in the calcareous clay and partly in the limestone.

Table 20 shows the screen and analytical data for three samples of bed clay taken at the Saddle Creek mine.

Screen data show the high percentage of slime (−150 mesh) in these samples—almost twice as high as in the soft limestone samples in table 19. The pebble fraction is much lower in weight percent

TABLE 20.—*Screen data and uranium analyses, calcareous clay (bedclay) of the Hawthorn Formation, Saddle Creek mine*

[Radiometric analyses by S. P. Furman]

Fraction (mesh size)	Sample 794-57			Sample 794-58			Sample 794-64		
	Percent of dry weight	Lab. No.	Percent eU	Percent of dry weight	Lab. No.	Percent eU	Percent of dry weight	Lab. No.	Percent eU
+14 (pebble)	8.0	60292	0.009	11.1	60299	0.003	24.5	60341	0.004
−14+35 (feed)	6.0	60293	.007	10.6	60300	.003	10.2	60342	.007
−35+150 (concentrate)	13.9	60296	.006	11.9	60303	.007	8.6	60345	.007
−35+150 (tailing)	15.3	60297	.001	4.3	60304	.001	15.6	60346	.002
−150 (slime)	56.8	60295	.002	62.1	60302	<.001	41.1	60344	.002
Head	100.0	60291	.001	100.0	60298	.003	100.0	60340	.003

than the pebble fraction of the limestone, but sample 794–64 of bed clay approaches sample 921–50 of the limestone in the amount of the pebble fraction, emphasizing the gradational nature of the two rock types. The uranium content is highest in the pebble fraction of sample 794–57 (table 20), and in this sample the weight percent of the pebble fraction is the lowest of the three samples. The concentrate samples of the bed clay contain about the same amount of uranium as the concentrate samples of the limestone. As in the limestone samples, the slime fraction of bed clay is very low in uranium content. The concentrate fractions and the pebble fraction of sample 794–57 are probably phosphate nodules; the rest of the fractions are probably mixtures of phosphate, sand, clay, and carbonate.

None of these bed clay samples were analyzed for phosphate, but company drill holes in the Saddle Creek tract were drilled to hard bedrock, and many of the holes passed through bed clay, which was sampled, screened, and analyzed. Bed clay samples overlie the hard limestone and are overlain by the economic phosphate deposit—the matrix.

P_2O_5 analyses of the pebble fraction of the bed clay are summarized on table 10, page G56. The pebble fraction is generally low in phosphate content, and the finer pebble fraction contains slightly more phosphate than the coarse pebble fraction. The pebble fraction of the bed clay contains much less phosphate than the pebble fraction of the lower unit of the Bone Valley Formation, which immediately overlies it. Most of the samples from the Bone Valley are economic—only the highest grade samples of the bed clay are economic. The highest phosphate content samples of the bed clay are higher in P_2O_5 than the lowest phosphate content samples from the Bone Valley.

The calcareous clay (bed clay) is thin, ranging in thickness from 0 to about 7 feet and averaging about 3 feet. Only the upper surface of the limestone is exposed at most places, and drill holes stopped on contact with the hard material. The isopach map of the Hawthorn

Formation (fig. 4) however, indicates that the formation ranges in thickness from 20 to about 100 feet in T. 28 S., Rs. 24 and 25 E. (Saddle Creek area), and drill hole D15 (table 1) that is at the Saddle Creek plant penetrated 85 feet of limestone of the Hawthorn Formation.

The contact between the Bone Valley and the Hawthorn Formations is irregular in detail and is unconformable. The irregular contact is shown in the fence diagram (pl. 4) and is indicated on the log of mine face section R (p. G107). The sketch of the contact relations in sec. 14, T. 28 S., R. 24 E. (fig. 6), shows that at this pit the contact was unconformable.

BONE VALLEY FORMATION—LOWER UNIT

The lower unit of the Bone Valley Formation is a clayey sand or sandy clay that is blue, blue-green, gray-green, or gray, bedded or laminated, and contains abundant brown, gray, tan, and black, sand- to coarse granule-size phosphate nodules. Individual beds in the lower unit are lenticular, many are thin-bedded or laminated. Beds of sand containing minor amounts of clay and very abundant phosphate are common, particularly near the base of the unit, where they may form a basal conglomerate. As graphically shown on plate 4, the lower unit thickens over lows on the Hawthorn surface and is thin on highs on the Hawthorn. The unit is present throughout the tract, except where it has been removed along the course of Saddle Creek; here the Hawthorn Formation is present under the loose sand of Pleistocene age.

The lower unit of the Bone Valley Formation ranges in thickness from 0 to about 25 feet and averages about 10 feet. The contact between the upper and lower units of the Bone Valley Formation is conformable and gradational.

BONE VALLEY FORMATION—UPPER UNIT

The upper unit of the Bone Valley Formation consists of gray-green to blue-green clayey sand with only traces of phosphate (generally altered to soft white nodules) at the base of the unit. At mine face sections, the basal part of the unit is almost always described as thin bedded alternate beds of clay and sand. The color of the unit is lighter toward the top, grading to a tan or light gray at the contact with the overlying sand of Pleistocene age. Bedding becomes obscure toward the top of the unit, possibly as the result of leaching. Downward movement of ground water through the very porous beds would remove at least some of the clay fraction, making the bedding obscure. The bedding is virtually horizontal. The upper unit ranges in thickness from 0 to about 20 feet and is somewhat thicker and more persistent in the western part of the tract (pl. 4). The unit has been thinned or removed by erosion along the course of pre-Pleistocene streams. Several channels that cut out the upper unit are shown in the fence diagram (pl. 4); for example, at holes G6, sec. 27, and D4–E4, sec. 36.

TERRACE SAND

Loose quartz sand, which blankets the surface at the Saddle Creek mine, is assigned to the Pleistocene, although sand of probable Recent age is known to be present. (See log of mine face section Q, p. G106.) At almost every drill hole and mine face section the loose sand was lumped as a single unit, and there is no way to divide it into Pleistocene and Recent. The sand is from 0 to 58 feet thick and is thickest on the ridge in the western part of the tract. In the eastern part of the tract, in the swampy area of Saddle Creek, the sand is only a few feet thick, or is absent, as at hole F6, sec. 36, where swamp muck overlies the lower unit of the Bone Valley Formation, and at holes I14, and J14, sec. 35, where the clayey sand of the upper unit of the Bone Valley is covered by a veneer of sand that is so thin it cannot be shown at the scale of the map (pl. 4).

Hardpan, iron-cemented sand, is not abundant but is present at a few drill holes in the western higher part of the tract. The hardpan is generally at the contact of the sand and the clayey sand of the Bone Valley Formation but is entirely within the sand at drill holes M16, sec. 22, and K6, sec. 27 (pl. 4). It is likely that the hardpan is superimposed on both the sand and the clayey sand at most localities, thus obscuring the contact between the Pliocene and Pleistocene. At hole M11, sec. 35 (pl. 4), the hardpan almost certainly is covering the contact. Drill logs, however, are not detailed enough to prove this.

The contact of the loose sand and the underlying clayey sand of the Bone Valley is irregular and disconformable. At several localities in the tract, Pleistocene or pre-Pleistocene streams have cut down through the upper unit of the Bone Valley Formation, and loose sand of the Pleistocene is resting on the lower phosphorite of the Bone Valley; at some of these channels the lower unit of the Bone Valley is appreciably thinned. At two of the channel locations, A14, sec. 35 and E4, sec. 36 (pl. 4), lenses of reworked sandy clay of the upper unit and phosphate of the lower unit of the Bone Valley are incorporated in the loose sand, indicating erosion and redeposition of material from the Bone Valley.

RECENT DEPOSITS

Organic swamp deposits, called muck in the driller's logs, are at the surface at several drill holes. The deposits are thin, reaching a maximum of 5 feet at hole O14, sec. 34 (pl. 4). Recent sand deposits have not been differentiated from the sand of Pleistocene age.

ECONOMIC GEOLOGY

CALCIUM PHOSPHATE ZONE

The calcium phosphate zone at the Saddle Creek mine ranges in thickness from 0 to about 29 feet and averages about 12 feet. The zone is mostly in the lower unit of the Bone Valley Formation, but some calcareous clay of the Hawthorn Formation is included in the calcium phosphate zone at about half of the drill hole localities in the area, and at a few holes most of the calcium phosphate zone is in the Hawthorn Formation. For example, in the drill hole log that follows, the calcium phosphate zone is 9 feet thick, and only the top 2.5 feet is in the Bone Valley Formation. However, only this top bed was considered to be economic (matrix) by the company.

Log of drill hole S in the NE¼SW¼ sec. 36, T. 28 S., R. 24 E.

[Adapted from driller's lithologic log]

	Thickness (feet)
Pleistocene and/or Recent:	
Terrace deposit:	
Sand, loose, mixed with organic mud (swamp muck)	3.0
Pliocene:	
Bone Valley Formation—lower unit:	
Clay, very sandy, white; contains abundant sand-sized and some granule-sized white phosphate nodules	2.5
Miocene:	
Hawthorn Formation—lower part:	
Clay, calcareous, white, sandy; contains minor phosphate; part only	6.5
Bottom in soft marl or limestone.	

Coarse phosphate nodules (pebble or +14 mesh fraction) are higher in P_2O_5 content and are about twice as abundant in the lower unit of the Bone Valley Formation as in the residual clay of the Hawthorn Formation. At most drill holes the feed fractions from the Bone Valley and Hawthorn Formations were combined and a single concentrate was produced, but at the few drill holes where samples from the two formations were treated individually, the tonnage of the concentrate fractions was about the same and the fine phosphate from the Bone Valley Formation contained only slightly more P_2O_5 than the fine phosphate from the Hawthorn Formation.

Screen data and uranium analyses from a typical drill hole are given in table 21. The pebble fraction is about half as abundant in the calcareous clay as it is in the Bone Valley, and the concentrate fraction is slightly more abundant in the Hawthorn than in the Bone Valley. The uranium content of the pebble, concentrate, and slime (−150 mesh) fractions is lower in the Hawthorn than in the Bone Valley. All fractions of the top sample of the calcium phosphate zone (sample 10) contain the highest amounts of uranium in the section. In the top sample, the phosphate nodules are light gray, but in the rest of the section they are brown, gray, tan, and black. The uranium content of the fractions of sample 11 (the aluminum phosphate zone) is low, and it is likely that the high uranium content of the fractions of sample 10 is due to slight enrichment by downward-moving ground water. Sample 10 is probably representative of the start of leaching, but the leaching has not progressed far enough for the bed to be put into the aluminum phosphate zone. At many drill localities, however, the top bed of the lower unit of the Bone Valley Formation contains phosphate nodules that are so low in P_2O_5 content that the material is considered uneconomic, and the bed is included in the aluminum phosphate zone or the overburden by the company. The material is described as white sandy clay or clayey sand containing white phosphate nodules and some white sandrock nodules. The pebble fraction of 16 samples of this material was analyzed; these samples contained 12.5–31.1 percent P_2O_5, 14–30 percent acid insoluble, and 5.3–8.8 percent Al_2O_3. In contrast, in the same drill holes, a pebble fraction from the material immediately underlying these samples contained 30.9–36.2 percent P_2O_5, 4–8 percent acid insoluble, and 0.5–2.4 percent Al_2O_3. Generally, the contrast in analytical data between the two beds is very striking, but the changes are also completely gradational.

TABLE 21.—*Screen data and uranium analyses, calcium phosphate zone, SW¼NW¼ sec. 27, T. 28 S., R. 24 E., Saddle Creek mine*

[Radiometric analyses by S. P. Furman. All samples are in lot 908. Sample 11 is clayey sand, leached upper unit, Bone Valley Formation. Aluminum phosphate zone. Samples 10–6 are phosphorite, lower unit, Bone Valley Formation. Sample 5 is calcareous clay, residual from the Hawthorn Formation. Calcium phosphate zone. From 0.0 (surface) to 41.0, loose sand of Pleistocene age, and at 53.8 ft, hard limestone of the Hawthorn Formation]

Sample	Laboratory No.	Depth below surface (feet)	Screen and analytical data, in percent											
			Head	+14 (pebble)		−14+35 (feed)		−35+150 (concentrate)		−35+150 (tailings)		−150 (slime)	
			eU	Weight	eU	Weight	eU	Weight	eU	Weight	eU	Weight	eU
11	59561–59565	41.0–42.2	0.002	0.0	------	1.6	0.008	0.0	------	35.0	0.002	63.4	0.004
10	59554–59560	42.2–42.9	.012	19.3	0.017	21.2	.012	11.2	0.011	28.6	.004	19.7	.009
9	59547–59553	42.9–44.2	.004	3.8	.014	3.1	.010	5.4	.010	7.3	.003	80.4	.005
8	59540–59546	44.2–45.5	.007	3.1	.015	4.5	.011	13.3	.012	16.3	.002	62.7	.007
7	59553–59538	45.5–47.3	.006	2.8	.008	15.3	.006	30.0	.007	21.6	.002	30.3	.005
6	59526–59532	47.3–51.3	.007	8.1	.011	11.2	.009	18.2	.008	22.5	.001	40.0	.003
5	59519–59525	51.3–53.8	.003	4.7	.007	7.1	.006	22.4	.005	14.8	.002	51.0	.003

The calcium phosphate zone is somewhat thicker than the matrix. The matrix is almost entirely within the lower unit of the Bone Valley Formation, although some calcareous clay of the Hawthorn was mined. At many drill holes, the top bed of the lower unit of the Bone Valley Formation is partly leached, lowering the phosphate content of the nodules so that they are uneconomic. This transition bed between the calcium phosphate and aluminum phosphate zones is the so-called soft white phosphate unit.

ALUMINUM PHOSPHATE ZONE

The aluminum phosphate zone is present throughout the area of the Saddle Creek mine except along Saddle Creek, where it has been removed by erosion. Throughout most of the area, the zone is low in both uranium and phosphate content, but individual small areas may contain high uranium and phosphate contents. An example of high phosphate content in the zone is in the analysis of a sample from a drill hole in the SW¼NE¼ sec. 11, T. 28 S., R. 24 E. Data are shown in table 22.

TABLE 22.—*Screen and analytical data, aluminum phosphate zone, drill hole in the SW¼NE¼ sec. 11, T. 28 S., R. 24 E., Saddle Creek mine*

[Analytical data by American Cyanamid Co., under contract to the U.S. Atomic Energy Comm.]

Screen fraction (mesh size)	Percent of dry weight	Chemical analyses, in percent					Distribution in screen sizes (percent)				
		P_2O_5	Al_2O_3	CaO	Fe_2O_3	U	P_2O_5	Al_2O_3	CaO	Fe_2O_3	U
+20 (pebble)	3.1	32.22	1.46	43.96	0.52	0.020	12.0	1.0	12.4	0.7	8.8
−20+150 (sand)	50.0	3.58	.34	3.10	.22	.003	21.4	3.9	14.2	5.1	22.1
−150 (slime)	46.9	11.84	8.93	17.07	4.37	.010	66.6	95.1	73.4	94.2	69.1
Head (calculated)	100.0	8.34	4.40	10.92	2.18	.007					

A single sample of the total aluminum phosphate zone was analyzed. The sample was 5 feet thick and included all material from the base of the loose sand to the top of the economic phosphate. The highest phosphate, uranium, and calcium contents occur in the +20 mesh fraction—the pebble. The lithologic log of the drill hole shows that visible phosphate occurs only in the lower half of the aluminum phosphate zone, and that phosphate nodules are abundant only in the basal foot of the zone. Analyses show that the pebble fraction is calcium phosphate and has a high uranium content. All the elements analyzed are concentrated in the slime (−150 mesh) fraction. Almost all the iron and aluminum are in the slime, and about two-thirds of the calcium, uranium, and phosphate are in this fraction. This represents a leached section, and the leaching extended downward through the entire upper unit of the Bone Valley Formation and into the top part of the lower unit.

Leaching that formed the aluminum phosphate zone was by downward-moving acidic ground water. In a thoroughly leached section, uranium should be moved downward from the top part of the section and concentrated at the water table, either at the base of the upper unit of the Bone Valley or in the top of the lower unit. An example of the uranium distribution in a thoroughly leached section is shown in table 23. Only the basal 3 feet of the clayey sand (sample 28) and perhaps the clayey sand having white phosphate (sample 27), could be considered as a possibly economic aluminum phosphate zone. Sample 27 is a part of the calcium phosphate zone, and it may be a part of the matrix—if not, it would be included in the overburden by the company, and would then be, economically, a part of the aluminum phosphate zone.

TABLE 23.—*Screen data and uranium analyses, aluminum phosphate zone, NE¼NW¼ sec. 22, T. 28 S., R. 24 E.*

[F. S. Grimaldi, analyst. All samples are in lot 921. From 0 (surface) to 12 ft, loose quartz sand, assigned to the Pleistocene, not sampled]

Sample No.	Depth (feet) below surface	Screen and analytical data, in percent											
		+14 mesh			−14+35 mesh			−35+150 mesh			−150 mesh		
		Weight	U	Lab. No.	Weight	U	Lab. No.	Weight	U	Lab. No.	Weight	U	Lab. No.
32	12–15	--------	------	------	5.5	0.000	28206	59.1	0.000	28207	35.4	0.002	28208
31	15–15.5	--------	------	------	5.0	.000	28201	64.2	.000	28202	30.8	.002	28203
30	15.5–19.5	--------	------	------	13.0	.000	28196	57.5	.000	28197	29.5	.004	28198
29	19.5–23.5	--------	------	------	5.8	.000	28191	70.0	.000	28192	24.2	.002	28193
28	23.5–26.5	4.8	0.032	28185	13.0	.001	28186	68.2	.003	28187	14.0	.025	28188
27	26.5–27.5	15.0	.011	28178	11.8	.007	28179	18.1	.003	28183	36.6	.018	28181
					Concentrate (−35 +150 mesh) (sample 27)			18.5	.005	28182	--------	------	------

Samples 29–32 are gray-green clayey sand, except that the top part of the top sample is light gray tan. Sample 29 is also thin bedded. Sample 28, which is partly indurated, has the highest uranium content in the section. Samples 29–32 are virtually devoid of uranium—which has been concentrated in sample 28 at the base of the upper unit of the Bone Valley Formation. Sample 27, the top sample of the lower unit of the Bone Valley, has high uranium only in the slime fraction—the pebble and concentrate fractions of this sample contain about average, or slightly less than average, amounts of uranium. It is probable that uranium has been leached from the top beds of this section and concentrated at the base of the section, particularly in the pebble and slime fractions.

Leaching does not everywhere extend down into the lower unit of the Bone Valley Formation, but may affect only the top part of the upper unit as shown in the following log of drill hole T and in the screen and chemical analyses of the aluminum phosphate zone cored at this hole (table 24).

Log of drill hole T, SW¼SE¼ sec. 23, T. 28 S., R. 24 E., Saddle Creek mine

[Drilled by American Cyanamid Co., logged by H. B. Dutro. Analytical data shown in table 24]

	Thickness (feet)
Pleistocene:	
Terrace sand:	
Sand, loose, gray, with organic material at top	2.0
Sand, loose, dark-brown, tan at base	2.0
Total terrace sand	4.0
Pliocene:	
Bone Valley Formation:	
Upper unit:	
Sand, clayey, gray	2.5
Sand, clayey, stiff, light-gray, some red streaks in top foot. Leached. (Sample 906–249)	5.0
Clay, very sandy, light-gray and yellow-brown. Trace of soft white phosphate nodules in the section 13–14 ft below surface. Leached. (Sample 906–253)	3.5
Sand, clayey, pale-blue-gray mottled with yellow brown; contains minor white and tan phosphate nodules. Unleached. (Sample 906–248)	13.0
Clay, very sandy, yellow; contains less than 5 percent white phosphate nodules. Not sampled	2.5
Lower unit:	
Clay, sandy, or sand, clayey, blue-gray. Contains abundant (about 30 percent) tan, and some white, sand- to granule-sized phosphate nodules (ratio of pebble to concentrate is 0.4)	6.0
Total Bone Valley Formation	32.5

Bottom in cream, sandy, calcareous clay, with a trace of phosphate nodules—residual Hawthorn.

Table 24 shows the analytical and screen data. The top sample is virtually devoid of uranium, and all of the uranium in the sample is in the slime fraction. The P_2O_5 content of the slime fraction is very low. The middle sample (906–253) contains somewhat more uranium and phosphate, and almost all the uranium is in the slime fraction. The bottom sample (906–248), although it has a relatively high uranium content in the pebble fraction, shows no particular enrichment in the slime fraction, and the sample contains less uranium and phosphate in the slime fraction than the average for the slime fraction of the calcium phosphate zone. Somewhat less than half of the total uranium is in the slime fraction. The bottom sample probably represents an unleached section of the upper unit of the Bone Valley Formation.

The distribution of the aluminum phosphate and the calcium phosphate zones is shown in the isopach maps (pls. 6 and 10) and on

TABLE 24.—*Analytical and screen data, upper unit, Bone Valley Formation, hole T, sec. 23, T. 28 S., R 24 E.*

[Leaders (..) = not analyzed. Chemical analyses by Dorothy Lee, Maryse Delevaux, Roberta Smith, and W. P. Tucker; radiometric analyses by B. A. McCall and Julius Goode]

Sample	Laboratory No.	Screen size	Weight percent	Chemical analyses, in percent			Radiometric analyses, percent eU
				U	Al_2O_3	P_2O_5	
906-249	....	+14 (pebble)	0.0	....	....	....	....
	100669	−14+35 (feed)	8.4	....	....	....	<0.001
	100670	−35+150 (sand)	65.5	....	....	....	<.001
	100671	−150 (slime)	26.1	0.002	25.0	1.2	.002
906-253	100688	+14 (pebble)	.5	....	....	....	.007
	100689	−14+35 (feed)	8.6	....	....	....	<.001
	100690	−35+150 (sand)	47.7	....	....	....	<.001
	100691	−150 (slime)	43.1	.005	21.1	5.1	.004
906-248	100664	+14 (pebble)	1.7	....	....	....	.014
	100665	−14+35 (feed)	6.4	....	....	....	.002
	100666	−35+150 (sand)	57.0	....	....	....	.002
	100667	−150 (slime)	34.9	.004	20.1	7.5	.004

the fence diagram (pl. 4). The clayey sand of the upper unit of the Bone Valley Formation is relatively uniform in thickness throughout the mine area, except for a slight thinning to the east (pl. 4), but the "sandrock" found at the base of the aluminum phosphate zone is thicker and more persistent in the western part of the area (pl. 4). The aluminum phosphate zone thins toward the west (pl. 4) on the ridge that extends northwestward from the city of Lakeland.

The calcium phosphate zone thins somewhat from west to east (pl. 4) and is thickest over low spots on the Hawthorn surface. The isopach map shows that the zone is absent along Saddle Creek and in the rest of the area is present as a blanket deposit. Irregular areas are underlain by 10-foot thicknesses of the calcium phosphate zone, and small rounded areas are underlain by 20-foot thicknesses.

PAUWAY MINE

The Pauway mine of the Davison Chemical Co. is in secs. 28, 29, 31–33, and 34, T. 28 S., R. 24 E., and secs. 3–6, T. 29 S., R. 24 E., Polk County, Fla. The mine is in the southern part of the Lakeland quadrangle and in the northern part of the Bartow quadrangle to the south. The mine was first operated by the Southern Phosphate Co. in the mid-1920's, and from 1946 to 1961 by the Davison Chemical Co. The mine was first operated by hydraulic methods for the pebble fraction. Later, both pebble and concentrate were recovered, and the area was mined by a combination of hydraulic methods (for the matrix) and draglines (which stripped the overburden). This area was the last in the land-pebble district to use hydraulic methods. In 1960, the mine operated with draglines and recovered both pebble and concentrate. It is reported that washer debris from the early pebble mining was segregated and later remined for its fine-grained phosphate.

The southern part of the area mined (in the Bartow quadrangle) included Banana Lake, which was mined by the company in the late 1950's.

STRATIGRAPHY

The stratigraphy at the Pauway mine was determined from the mine exposures. Hard limestone or dolomite of the Hawthorn Formation was exposed at the bottom of the mining pits and the surface of this limestone is extremely irregular in detail; the result of solution and repeated sinkhole collapse. Both the lower and upper units of the Bone Valley Formation are present; these units are bedded, and the bedding is contorted at many places due to the collapse of sinkholes. Sand of Pleistocene age and windblown sand and swamp deposits, probably of Recent age, cover the surface. The disconformable relations between these deposits and the underlying Bone Valley Formation can be seen clearly at the mine pits. Stratigraphic relations are shown on the fence diagram of a part of the mine area (pl. 5).

HAWTHORN FORMATION

The calcareous lower unit of the Hawthorn Formation is the bedrock at all of the mine pits in the Pauway area. The Hawthorn is a massive white, buff, or cream sandy and clayey limesone or dolomite. The sand fraction consists of medium- to fine-grained quartz and amber, brown, tan, and some black and white fine-grained highly polished phosphate nodules. Amber and brown nodules are the most common and are characteristic of the unit. Coarse-grained phosphate, the pebble fraction, is common but generally in trace amounts. Calcareous sandy clay, residual from the limestone, covers much of the area. The clay is gray, gray blue, gray green, tan, and brown, water saturated, plastic, and contains abundant fine-grained phosphate nodules. The contact of the clay with the underlying limestone is irregular in detail and is gradational over such short distances (about 1 cm) that it appears sharp and distinct. The texture of the calcareous clay is identical with that of the underlying limestone. At many places the bed clay contains enough phosphate that it is considered a part of the matrix.

HAWTHORN-BONE VALLEY CONTACT

The contact between the Hawthorn and Bone Valley Formations is unconformable. At many places in the Pauway mine the contact was between horizontally bedded phosphorite of the lower unit of the Bone Valley and hard massive limestone of the Hawthorn (section *B–B′*, pl. 5). The contact is irregular in detail and is very sharp. At many places, drilling data indicate that the contact is between the calcareous bed clay of the Hawthorn and the phosphorite of the lower unit of the Bone Valley, but even in drill holes the lithologic contrast between the two formations is clear. The lower unit of the Bone Valley Formation contains abundant coarse pebble phosphate in a clayey sand or sandy clay; the calcareous bed clay of the Hawthorn Formation contains dominantly fine grained phosphate and much more clay.

BONE VALLEY FORMATION

The Bone Valley Formation is throughout the area of the Pauway mine. Although both the lower and upper units are present, the upper unit has been eroded from large parts of the area, and the lower unit was not reached in a few mining pits where sinkholes are filled with the upper unit (section *C–C′*, pl. 5), although it may be present at depth. The lower unit is also missing along the small stream that drains Lake Hollingsworth.

The lower unit ranges in thickness from 0 to about 35 feet and averages about 15 feet. Two lenticular lithologic units are distinguished on the isometric fence diagram of the mine—a sandy clay and a pebbly sand or clayey sand. The lower unit may consist entirely of the sandy clay (as at hole C15, pl. 5), or interbedded sandy clay and pebbly sand (hole M10). The pebbly sand may be at the top (hole G14) or at the bottom (hole J9) of the lower unit of the Bone Valley Formation. The lenticular nature of the beds in the lower unit of the Bone Valley Formation is shown in section *C–C′*, (pl. 5) particularly in the difference in the lithology of the unit at the north and south ends of the section.

The lower unit of the Bone Valley Formation at the Pauway mine is characteristically a blue-green, gray-green, or gray-blue sandy clay or clayey sand, but beds of clay, sand, or conglomerate are commonly present. The unit contains abundant phosphate nodules, ranging in size from coarse granule to fine sand. The coarse nodules (the pebble fraction) tend to be light colored—white, gray, or tan, but some black and brown phosphate pebbles are present. The fine nodules (the concentrate fraction) tend to be dark—brown nodules are the most abundant, but tan, gray, white and black nodules are also found. The unit is thinly bedded; some of the clay beds are laminated. Crossbedding was noted at a few places, and contorted bedding in the lower unit was conspicuous at or around the sinkholes (section *C–C′*, pl. 5). Barren clay beds (middle bed of the lower unit at the north end of section *C–C′*) are common in the drilling records of the tract. The drilling foreman commonly sampled a top matrix, then noted a barren clay bed, and then sampled a bottom matrix.

The log of mine face section U is typical of the lower unit of the Bone Valley Formation at the Pauway mine.

The Bone Valley Formation at this locality is horizontally bedded, and the lowest bed rests directly on the hard limestone of the Hawthorn Formation. The contact is sharp and is irregular in detail. There is as much as 2–3 feet of relief on the limestone, and the flat-bedded unconsolidated phosphorite rests unconformably on the irregular surface of the Hawthorn. The upper unit of the Bone Valley Formation is missing at this locality. The top foot of the lower unit has been leached and is not considered to be a part of the matrix.

The upper unit of the Bone Valley Formation ranges in thickness from 0 to about 20 feet and averages about 5 feet. As shown in the fence diagram (pl. 5) the unit has been eroded from much of the southern part of sec. 5, but the unit is at least 20 feet thick in the sinkhole in the NW¼NE¼ sec 5, T. 29 S., R. 24 E. (section *C–C'*). At this locality, at least 20 feet of the upper unit was removed by erosion prior to the deposition of the surficial sands.

The upper unit is a gray-green or blue-gray clayey sand or sandy clay, which is bleached white at most localities. The upper unit is thin bedded and is crossbedded at one locality, but bedding was destroyed by leaching, and the unit is massive or the bedding is obscure at most localities (section *C–C'*, pl. 5). The unit contains only a trace of phosphate nodules that are most prominent at the base, and at most places the phosphate is soft, dull, and white, evidence of leaching.

Log of mine face section U, NW¼NE¼ sec. 5, T. 29 S., R. 24 E.

[Modified from lithologic log by J. B. Cathcart and Louis Pavlides]

	Thickness (feet)
Recent or Pleistocene:	
Swamp deposit:	
Sand, black, highly organic and including muck	1.0
Windblown(?) deposit:	
Sand, loose, white	1.2
Total Recent or Pleistocene	2.2
Pleistocene:	
Terrace deposits:	
Sand, dark-brown to brown, iron-stained and cemented (hardpan)	3.6
Sand, dark-gray, fine-grained, loose	2.5
Total Pleistocene	6.1
Pliocene:	
Bone Valley Formation—lower unit:	
Clay, sandy, light-green and tan; contains white, soft, leached phosphate nodules. (Leached lower unit.)	1.0
Sand, clayey, tan, mottled with white. The white mottling becomes more abundant toward the top. Very abundant white, gray, and tan phosphate pebble, and in the top 1 foot, black pebble is prominent	2.5

Log of mine face section U, NW¼NE¼ sec. 5, T. 29 S., R. 24 E.—Continued

	Thickness (feet)
Pliocene—Continued	
Bone Valley Formation—lower unit—Continued	
Sand, tan, clayey, fine-grained; contains abundant tan fine-grained phosphate, and coarse-grained black phosphate nodules	1. 5
Sand, tan, clayey, fine-grained; contains abundant tan and white sand-sized phosphate, and white phosphate granules	1. 5
Clay, sandy, mottled gray and white; contains abundant white and tan pebble phosphate	. 5
Clay, sandy, gray and tan mottled; contains very abundant fine-grained brown phosphate grains	3. 0
Total Bone Valley Formation	10. 0
Miocene:	
Hawthorn Formation—lower part:	
Limestone, sandy and clayey, white to buff; contains abundant fine-grained and some fine granule-sized amber phosphate	1. 8
Clay, sandy, calcareous, mottled gray and tan, thinly bedded. Sand beds are highly phosphatic; clay beds contain minor amounts of phosphate	. 6
Limestone, sandy and clayey, white to buff; contains minor coarse to fine sand-sized phosphate, mostly amber, but with some gray	3. 2
Total Hawthorn Formation exposed	5. 6

The contact between the Bone Valley Formation and the sand of Pleistocene age is nonconformable. Over much of the area of the Pauway mine, the upper unit of the Bone Valley Formation is missing, and sand of Pleistocene age is in contact with the lower unit. Section *C–C′*, plate 5, shows a rubble zone consisting of fragments of phosphate nodules, rounded fragments of aluminum phosphate cemented sand, and quartz pebbles at the base of the loose sand of Pleistocene age. An angular discordance between the loose sand of Pleistocene age and the lower unit of the Bone Valley Formation is shown on figure 7. Sinkhole collapse probably caused the contorted bedding in the phosphorite, and the surface of the phosphorite was planed off prior to the deposition of the loose sand. These data indicate that there was an erosional interval after the deposition of the Bone Valley Formation, and prior to the deposition of the loose sand.

TERRACE SAND

Loose quartz sand at the surface covers all the Pauway mine area. This sand is assigned to the Pleistocene, although as shown in sections *B–B′* and *C–C′*, plate 5, some of the surficial sand is of Recent age. On the fence diagram (pl. 5), the loose sand ranges in thickness from 5 to 24 feet and averages about 15 feet and is thinner in the north and west parts of the diagram than in the south and east. The thicknesses are typical of the area of the Pauway mine.

RECENT DEPOSITS

Windblown sand at the surface and black organic muck deposits at or near the surface are probably Recent. These deposits can be separated at the mine faces (pl. 5) but, except for muck, were not distinguished at most of the drill holes. The deposits seldom are more than 2 or 3 feet thick.

ECONOMIC GEOLOGY

The calcium phosphate zone and the aluminum phosphate zone are both present over much of the Pauway area, but both potentially economic units have been removed at some localities by erosion, and at some sink holes, drilling and mining penetrated only into the aluminum phosphate zone. At these areas the calcium phosphate zone probably is present, but was dropped below the economic depth to which mining can be carried.

CALCIUM PHOSPHATE ZONE

The calcium phosphate zone at the Pauway mine includes both the lower unit of the Bone Valley Formation and the residual calcareous clay of the Hawthorn Formation, but most of the material is in the Bone Valley Formation, and at many mine sections and drill holes, phosphorite of the Bone Valley Formation rests on limestone of the Hawthorn Formation. The zone ranges from 0 to about 40 feet in thickness and probably averages about 17 feet, and, because the phosphorite of the Bone Valley averages 15 feet in thickness, only 2 feet of the average thickness can be assigned to the Hawthorn Formation.

Much of the phosphate in the Bone Valley is coarse grained and is white, although tan, gray, brown, and black phosphate nodules are present. Concentrate-size phosphate nodules tend to be brown, but the other colors are also found. The Hawthorn part of the zone contains dominantly fine-grained amber and brown phosphate, but sparse black and white pebble-size nodules are also found.

The thicker parts of the calcium phosphate zone overlie and fill depressions on the surface of the Hawthorn Formation, as in the SE¼ sec. 29, T. 28 S., R. 24 E., and in sec. 32, T. 28 S., R. 24 E. The zone is absent along the small creek that drains Lake Hollingsworth.

ALUMINUM PHOSPHATE ZONE

The aluminum phosphate zone at the Pauway mine is erratic in distribution, and is absent over large areas, having been removed by erosion (fig. 35). The zone ranges in thickness from 0 to about 15

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feet and averages about 5 feet. Over most of the area, the zone is low in uranium content, averaging only about 0.005 percent U. The P_2O_5 content of the zone is not known, but is thought to be low, because of its low uranium content. The zone probably is not minable at the Pauway mine, although a few small areas are underlain by high-grade material. For example, in section A–A′ (fig. 35) high uranium content in the aluminum phosphate zone is confined to the bottom foot of the zone at hole O–½ 4½, but at holes O–5–½ and N–½ 6½, the high uranium part of the zone is in the top foot of the zone, and at hole N–½ 7, none of the zone is high grade. At the rest of the holes in the section, loose sand of Pleistocene age rests on the lower unit.

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