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October 15, 1957

AEC - 89/8

Mr. Robert D. Nininger
Assistant Director for Exploration
Division of Raw Materials
U. S. Atomic Energy Commission
Washington 25, D. C.

Dear Bob:

Transmitted herewith are three copies of TEI-668, "Geology of the aluminum phosphate zone in the Lakeland Highlands area and Clark James - South Ridgewood tracts, land-pebble phosphate district, Polk County, Florida," by W. L. Emerick, June 1957.

Sincerely yours,

John H. Eric
for W. H. Bradley
Chief Geologist

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Geology and Mineralogy

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE ALUMINUM PHOSPHATE ZONE IN THE LAKELAND HIGHLANDS AREA AND CLARK JAMES - SOUTH RIDGEWOOD TRACTS, LAND-PEBBLE PHOSPHATE DISTRICT, POLK COUNTY, FLORIDA*

By

W. L. Emerick

June 1957

Trace Elements Investigations Report 668

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GEOLOGY OF THE ALUMINUM PHOSPHATE ZONE IN THE LAKELAND HIGHLANDS AREA AND CLARK JAMES - SOUTH RIDGEWOOD TRACTS, LAND-PEBBLE PHOSPHATE DISTRICT, POLK COUNTY, FLORIDA

By W. L. Emerick

ABSTRACT

The upper unit of the Bone Valley formation in the Lakeland Highlands area, T. 29 S., R. 24 E., and in the Clark James - South Ridgewood tracts, T. 30 S., R. 24 E., both in Polk County, Fla., contains an aluminum phosphate, or leached, zone that is higher in uranium than is usual in the land-pebble phosphate district. The phosphate in these two areas has nearly 1½ to 2 times as much uranium as the general average of the district. A stratigraphic sequence consisting of the Hawthorn formation of middle Miocene age, the Bone Valley formation of Pliocene age, Pleistocene terrace sands, and Recent deposits is generally present over most of the land-pebble phosphate district.

The Bone Valley formation consists of massive clay- or phosphate-cemented quartz sands in the upper part, and unconsolidated, bedded, clayey sands and phosphate pebbles in the lower part. Transgressing both parts of the formation is a purely secondary zone, called the aluminum phosphate or leached zone, that contains greater accumulations of aluminum phosphate minerals and a higher content of uranium than is found elsewhere in the formation. Owing to radioactivity differences, it is possible to separate the upper part of the formation into upper clayey sands and a lower purely

secondary zone. Three gradational types of secondary material that are texturally different--a cemented sandstone, a vesicular sandstone, and a wavellitic sand--are found in the lower secondary zone of the upper part of the formation.

Gamma-ray logs of drill holes in both areas show that the highest radioactivity is found in the aluminum phosphate zone. Isopach maps and geologic sections show variations in thickness of the aluminum phosphate zone in the report areas. There does not appear to be any relationship between thickness of the zone and uranium distribution or concentration in the zone.

Total minable indicated and inferred reserves of aluminum phosphate material in the Lakeland Highlands area amount to about 15,500,000 short tons, or about 2,600 short tons of U_3O_8. Average grade and thickness of the total reserves are about 0.017 percent U_3O_8 and 9 feet, respectively. Total minable indicated and inferred reserves of aluminum phosphate material in the Clark James - South Ridgewood tracts are about 5 times greater than in the Lakeland Highlands area. Average grade and thickness of the Clark James - South Ridgewood tracts amount to about 0.021 percent U_3O_8 and 9 feet, respectively.

INTRODUCTION

The upper part of the Bone Valley formation in the Lakeland Highlands area and Clark James - South Ridgewood tracts includes an aluminum phosphate, or leached, zone that gamma-ray logging of prospect drill holes indicates contains about 1½ to 2 times as much uranium as is typical in such deposits.

This report is based mainly on information obtained from lithologic and gamma-ray logs of drill holes in the two areas. The work was done by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

LOCATION AND GEOGRAPHY

The Lakeland Highlands area (pl. 1) lies in T. 29 S., R. 24 E., Polk County, Fla. The area is about 3½ miles southeast of the city limits of Lakeland and about 5 miles northwest of the city limits of Bartow. Highland City lies on the eastern limits of the area. Geographically, the area is a part of the rolling uplands, having elevations ranging from 105 feet to slightly more than 260 feet above mean sea level, that extend northwestward through central Florida. Closed drainage, circular marsh- and lake-filled depressions, and steep-sided sinkholes are characteristic of the area.

The Clark James - South Ridgewood tracts (pl. 2) lie in T. 30 S., R. 24 E., Polk County, Fla. Bartow, county seat of Polk County, lies 3 miles to the east. The tracts lie mostly on the east flank of a north-south trending ridge, with elevations ranging from 130 feet on the east to slightly more than 210 feet above mean sea level on the west.

ACKNOWLEDGMENTS

The writer is pleased to acknowledge the cooperation and courtesies extended by phosphate companies during the field work. Appreciation is extended to Z. S. Altschuler for discussions in the field and written communications and to various members of the Washington laboratory of the U. S. Geological Survey for the following analyses of samples: chemical analyses, under the direction of Irving May, by G. Daniels, C. Johnson, R. Smith, G. Edgington, W. Tucker, E. Campbell, and A. Sweeney; radioactivity analyses, under the direction of F. J. Flanagan, by B. A. McCall; and for X-ray determinations by G. Ashby.

GEOLOGIC ASPECTS

Land-pebble phosphate district

A stratigraphic sequence present in most of the land-pebble phosphate district includes the Hawthorn formation of middle Miocene age (MacNeil, 1947), the Bone Valley formation of Pliocene age (Simpson, 1930), Pleistocene terrace sands (Cooke, 1945; MacNeil, 1950), and Recent deposits.

The Hawthorn formation is a buff to cream, sandy, clayey, dolomitic and fossiliferous limestone containing pebbles or nodules of apatite and unconformably underlies the Bone Valley formation in most of the land-pebble phosphate district. A gray to green sandy and phosphatic residual clay, called "bedclay," ranging in thickness from less than an inch to 6 feet, usually is found at the top of the Hawthorn formation in the district.

The Bone Valley formation is an original stratigraphic unit consisting, generally, of massive clay- or phosphate-cemented quartz sands in the upper part, and unconsolidated, bedded, clayey sands and apatite pebbles in the lower part. The gradation between the two parts takes place in a zone of several inches, usually less than a foot. Transgressing both parts of the formation is a purely secondary zone containing high accumulations of aluminum phosphate minerals and a greater content of uranium than is found elsewhere in the formation. Usually, most of the secondary zone is formed in the upper part of the formation but may include the top few inches or feet of the lower part, depending upon the extent and depth attained by leaching. As a result of the leaching that formed the secondary zone, the original features of the upper part of the formation and the lower part, where affected, were changed, although these changes may not always be visible.

The upper part of the Bone Valley formation consists of massive clay- or phosphate-cemented quartz sands and includes part of the secondary aluminum phosphate zone that transgresses the upper and lower parts of the formation. By using gamma-ray logs of drill holes, it is possible to separate the upper part of the Bone Valley formation into (1) upper clayey sands containing minor amounts of aluminum phosphate minerals, and (2) a lower zone of phosphate-cemented sands, vesicular phosphate-cemented rock, and leached apatite pebbles containing abundant aluminum phosphate minerals. With a greater aluminum phosphate concentration and uranium content, the lower zone is of more economic interest than the upper clayey sands. The upper part of the formation ranges from zero to about 40 feet in thickness and averages about 6 feet in thickness (Cathcart and Davidson, 1952). Colors range through various shades of brown to white or cream. The upper part of the Bone Valley formation, called the aluminum phosphate or "leached" zone, is described further on pages 13 to 23 of this report.

The lower part of the Bone Valley formation consists of the unconsolidated, bedded, clayey sands and apatite pebbles with textures ranging from pebbly sand and phosphate to clay-size material. Thickness of the lower part ranges from less than a foot to more than 50 feet and averages about 20 feet in thickness (Cathcart and Davidson, 1952). The deposits usually have a reddish-brown color.

Unconsolidated tan to brown Pleistocene terrace sands unconformably overlie the Bone Valley formation throughout the district. Their thickness ranges from zero to about 19 feet and averages about 7 feet. The terrace sands are generally overlain or grade into relatively thin Recent sandy and carbonaceous mucks, peats, and soils near the surface.

Lakeland Highlands area

Drill core shows the Hawthorn formation underlying the Lakeland Highlands area to be a light gray to white or cream, sandy and clayey, fossiliferous and phosphatic limestone. The residual bedclay at the top of the Hawthorn formation is a brown to cream, sandy and phosphatic clay of undetermined thickness.

The total thickness of the overlying Bone Valley formation in the Lakeland Highlands area ranges from 12 to 37 feet and averages about 22 feet. Data on the lower part of the formation are meager, but in this area the lower part probably has a mixture of lean and rich zones of minable apatite pebbles, probably as a result of reworking of the formation during slumping. The thickness of the lower part in the Lakeland Highlands area is unknown.

By using gamma-ray logs obtained for some of the drill holes in sections 10 and 11 (pl. 1), the beds above the pebble apatite can be divided into (1) upper clayey sands containing only very minor amounts of aluminum phosphate minerals and with less than 0.005 percent U_3O_8, and (2) a lower zone containing abundant aluminum phosphate minerals and with more than 0.005 percent U_3O_8. The upper clayey sands range from zero to 16½ feet and average about 8½ feet in thickness; the lower zone ranges from about 6 feet to 27 feet and averages about 13 feet in thickness.

Unconsolidated quartz sands, probably of Pleistocene age, ranging in thickness from zero to about 19 feet and averaging about 3½ feet, overlie the clayey sands. In places drill holes show all of the Pleistocene sands removed by erosion, and the upper clayey sands covered by only a thin layer of Recent soil.

Clark James - South Ridgewood tracts

The Hawthorn formation in the Clark James - South Ridgewood tracts is a sandy, clayey, fossiliferous and phosphatic limestone. A grayish-white to brown "bedclay" of undetermined thickness is present at the top of the Hawthorn limestone in the area.

The karst-like surface of the Hawthorn formation in the Clark James - South Ridgewood tracts is reconstructed on the subsurface contour map (pl. 3) from the data of more than 1,500 prospect drill holes. Many sinkholes and depressions, some of which were probably formed in comparatively recent time, characterize the formation.

The overlying Bone Valley formation in the Clark James - South Ridgewood tracts ranges from about 4 feet to about 32 feet and averages about 23 feet in thickness. The lower part of the formation is a sandy and clayey deposit of apatite pebbles and nodules that ranges from about 4 to 28 feet and averages about 10 feet in thickness. The upper part of the formation in this area, in general, can also be separated by gamma-ray logs into (1) upper leached clayey sands containing very minor amounts of aluminum phosphate minerals and with less than 0.005 percent U_3O_8, and (2) a lower zone containing abundant aluminum phosphate minerals and with more than 0.005 percent U_3O_8. In the upper part of the formation the upper clayey sands range in thickness from less than an inch to about 40 feet and average about 17 feet; the lower zone ranges in thickness from about 2½ to about 28 feet and averages about 11 feet.

Unconsolidated quartz sands, probably of Pleistocene age, ranging in thickness from zero to about 15 feet and averaging about 7 feet, overlie the clayey sands. Erosion during Recent time has removed part of the sands and in the stream channels most, or all, of it has been removed, as shown on the geologic sections (pl. 2).

ALUMINUM PHOSPHATE OR "LEACHED" ZONE

Land-pebble phosphate district

The aluminum phosphate or "leached" zone in the upper part of the Bone Valley formation generally contains higher concentrations of uranium than does the rest of the formation. Although the aluminum phosphate zone is formed mostly in the upper part of the formation, it may also include the top few inches or feet of the lower part of the formation. This top few inches or feet of the lower part included in the zone consists of partly leached and whitened apatite particles of sand to cobble size that are cemented into an indurated, or semi-indurated, mass by clay and phosphate material.

Several characteristic types of secondary texture, or combinations of these, depending upon the original lithology and texture of the rock and degree of leaching, are found in the upper part of the formation. Alteration of the clayey sand and pebble apatite of the lower part of the Bone Valley formation produced an aluminum phosphate-rich vesicular type of sandstone (Altschuler, Z. S., and others, 1956, p. 498) of variable occurrence and thickness throughout the district. Alteration of the clay-cemented sand in the upper part appears to result in either a hard, cohesive, light-colored aluminum phosphate-cemented quartz sandstone, locally called "sand-rock," or a compact, unindurated wavellitic sand.

From information obtained from lithologic logs, drill cores, and mine face sections, the aluminum phosphate-cemented quartz sandstone (sandrock) type ranges from zero to more than a foot in thickness in the zone, and the wavellitic sand type attains a thickness of several feet in places over the district. The interstitial clay in the wavellitic sand is partly or completely replaced by the aluminum phosphate mineral, wavellite (Z. S. Altschuler, oral communication, 1956), and hardness in any of the types is probably due to the wavellite and to redeposited silica in the interstitial cement (Z. S. Altschuler, oral communication, 1956). Regardless of texture the materials have identical mineralogy.

The aluminum phosphate zone in the land-pebble phosphate district is characterized by the aluminum phosphate mineral, wavellite, the calcium aluminum phosphate minerals, crandallite and millisite, and the calcium phosphate mineral, apatite. Kaolinite, the iron oxides goethite and limonite (Altschuler and others, 1954, p. 204), manganese oxide or hydrate, quartz, and scattered accessory minerals that microscopically appear to be mostly ilmenite, zircon, and rutile, are other minerals found in the aluminum phosphate zone. Some or all of these minerals are present in variable amounts in the Lakeland Highlands and Clark James - South Ridgewood areas.

The aluminum phosphate zone in the Bone Valley formation was probably formed under fluctuating water table conditions by downward and laterally percolating waters. Much of the variation in thickness of the zone with its irregular bottom profile is possibly due to differences in lithology and permeability of the Bone Valley material.

It seems likely that formation of most of the aluminum phosphate zone had been completed before the end of Pliocene time, probably because of changes in drainage. The geologic sections (pl. 2) show that, in places, all of the uppermost clayey sand part of the upper Bone Valley unit, and probably some of the aluminum phosphate zone were removed by erosion before deposition of the terrace sands in Pleistocene time.

Lakeland Highlands area

In the Lakeland Highlands area the aluminum phosphate zone is predominantly a compact, unindurated, and generally massive-bedded mixture of fine- to medium-grained quartz sand, kaolinite, wavellite, and crandallite. An isopach map (fig. 1) of the aluminum phosphate zone, constructed from data obtained from gamma-ray logs of 38 drill holes, shows the approximate variations in thickness of the zone in parts of sections 10 and 11. In certain zones within this unindurated wavellitic sand, fragments of both the cemented and the vesicular type sandstones were found in drill cores. From the size of the fragments it appeared they came from a thin mass ranging from less than an inch to about 2 inches in thickness. Mine face sections elsewhere in the land-pebble phosphate district show that where the original material contained apatite, the cemented and vesicular secondary types often occur as gradational masses. The texture of the aluminum phosphate zone in the Lakeland Highlands area might suggest that the original material deposited was predominantly fine- to medium-grained quartz sands and clay with only scattered thin lenses or masses of pebbly material included within it.

Except for the quartz in sand, wavellite is the most abundant mineral in the aluminum phosphate zone of the Lakeland Highlands area, for apparently all of the apatite was replaced or carried away, and crandallite generally

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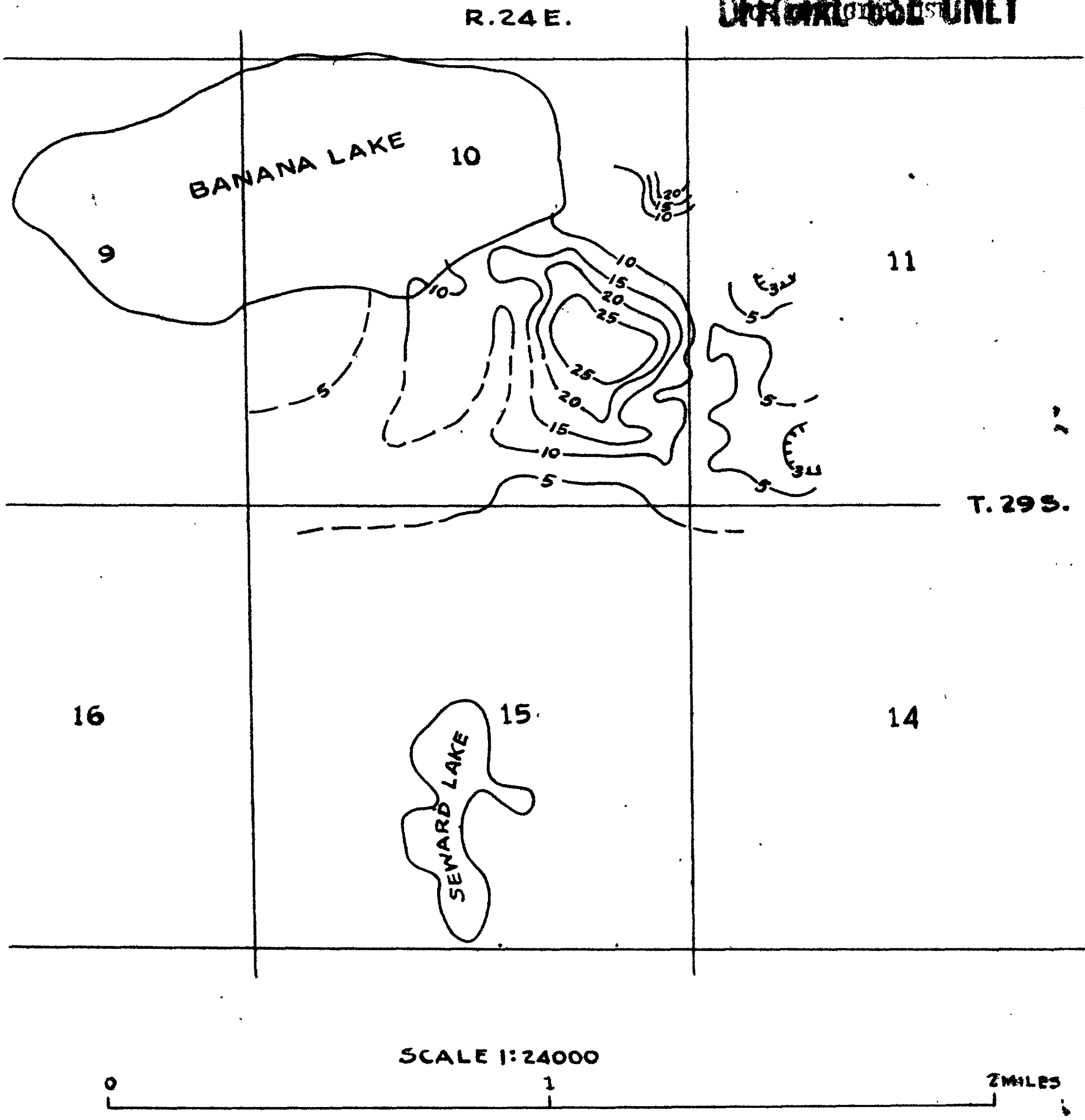

CONTOUR INTERVAL 5 FEET
DATUM IS MEAN SEA LEVEL

(HACHURES POINT TOWARD AREAS CONTAINING LESS THAN 3 FEET OF ALUMINUM PHOSPHATE MATERIAL.)

THICKNESS OF ALUMINUM PHOSPHATE ZONE BASED ON GAMMA-RAY LOGS

FIGURE 1 .-ISOPACH MAP OF ALUMINUM PHOSPHATE ZONE, LAKELAND HIGHLANDS AREA, POLK COUNTY, FLORIDA.

is present only in trace amounts. The wavellite occurs sparingly in the clayey sands and abundantly in the lower material of the upper part of the Bone Valley formation, where it has probably replaced all or nearly all of the clay minerals. Wavellite was recognized microscopically as single euhedral, colorless, bladed crystals, or as groups of delicate rosettes, fibrous masses, and as single long ribbon-like crystals. X-ray examination was required to establish the presence of any crandallite. Both wavellite and crandallite were identified by X-ray analyses of samples taken from the aluminum phosphate zone (tables 1 and 2).

Colors of the aluminum phosphate zone in the Lakeland Highlands area are imparted mostly by iron oxides, either as a coating on quartz grains, or as a stain or impregnation of the clayey material. The range of color is from light tan to dark brown, depending upon the amount of iron oxide present. Several drill cores in the area showed pronounced light and dark layering in parts of the altered zone, owing to very thin, alternating layers of iron-impregnated clay and silty sand. Where unstained, material of the aluminum phosphate zone is white to cream color.

Clark James - South Ridgewood tracts

All three types of secondary material--phosphate-cemented sandstone, vesicular sandstone, and wavellitic sands--were found in drill cores from the aluminum phosphate zone of the Clark James - South Ridgewood tracts. Lithologic logs classified the lower secondary zone as "sandrock," a local mining term here including both the cemented and vesicular sandstone types. The two types occur together in the secondary zone. These two types were

Table 1.--Chemical and X-ray analyses of the aluminum phosphate zone in a core drill hole of the Lakeland Highlands area, Polk County, Florida.

Sample no.	Sample interval (Depth below surface)	Constituents in percent						X-ray diffraction spectrometer identification*
		P_2O_5	Fe_2O_3 1/	Al_2O_3	CaO	U	eU	
	0" to 5'0" (no core)							
18	5'0" to 6'2"	1.8	2.10	18.2	0.70	.002	.001	
19	6'2" to 7'0"	2.6	2.23	12.1	0.90	.003	.002	
20	7'0" to 7'11"	2.6	1.79	10.0	0.71	.003	.002	
21	7'11" to 8'10"	2.4	1.64	10.0	0.53	.002	.002	A kaolin mineral
22	8'10" to 9'8"	1.7	1.78	11.8	0.17	.002	.003	
23	9'8" to 10'10"	1.4	1.94	11.2	0.45	.002	.002	
24	10'10" to 11'11"	13.5	5.14	20.4	0.68	.011	.012	Wavellite, a kaolin mineral and crandallite
25	11'11" to 13'1"	7.1	3.60	11.9	0.23	.005	.005	Wavellite, a kaolin mineral and a trace of crandallite

1/ Total iron

* Quartz identified in all samples

Analysts: Chemical - I. May, G. Edgington, W. Tucker, E. Campbell, A. Sweeney
Radioactivity - F. J. Flanagan, B. A. McCall
X-ray - G. Ashby

Table 1.--Chemical and X-ray analyses of the aluminum phosphate zone in a core drill hole of the Lakeland Highlands area, Polk County, Florida.--Continued

Sample no.	Sample interval (Depth below surface)	Constituents in percent						X-ray diffraction spectrometer identification*
		P_2O_5	Fe_2O_3[1/]	Al_2O_3	CaO	U	eU	
26	13'1" to 13'11"	3.3	1.46	8.4	0.11	.003	.004	Wavellite and a kaolin mineral
27	13'11" to 15'3"	7.5	3.50	11.5	0.45	.008	.008	Wavellite, a kaolin mineral and a trace of crandallite
28	15'3" to 16'10"	14.3	7.78	15.8	0.23	.018	.016	Wavellite
29	16'10" to 18'2"	9.5	8.16	13.7	0.54	.016	.017	Wavellite and a trace of crandallite

Table 2.--Results of chemical and X-ray analyses on selected samples from various depths in 5 core drill holes, Lakeland Highlands area, Polk County, Florida.

Hole	Sample no.	Depth of sample from surface	Constituents in percent P_2O_5	Fe_2O_3 1/	Al_2O_3	CaO	U	eU	X-ray diffraction spectrometer identification*
A	1 2/	15'3"	5.7	3.62	10.5	0.11	.006	.006	Wavellite, a kaolin mineral and a trace of crandallite
	2 2/	19'0"	14.0	12.40	15.4	0.11	.020	.018	Wavellite
B	3 3/	22'0"	0.7	0.82	9.3	0.28	.002	.002	A kaolin mineral
	4 2/	23'6" to 23'9"	8.2	5.40	13.3	1.52	.027	.024	A kaolin mineral
C	5 2/	15'9"	10.7	1.99	15.0	0.79	.010	.012	Wavellite, traces of crandallite and a kaolin mineral
	6 2/	20'0" to 22'0"	5.7	0.95	7.2	0.45	.006	.006	Wavellite, and a trace of crandallite

1/ Total iron

2/ Lower aluminum phosphate zone

3/ Sample from upper clayey sands of aluminum phosphate zone

* Quartz identified in all samples

Analysts: Chemical - I. May, G. Edgington, W. Tucker, E. Campbell, A. Sweeney
Radioactivity - F. J. Flanagan, B. A. McCall
X-ray - G. Ashby

Table 2.--Results of chemical and X-ray analyses on selected samples from various depths in 5 core drill holes, Lakeland Highlands area, Polk County, Florida.--Continued

Hole	Sample no.	Depth of sample from surface	Constituents in percent						X-ray diffraction spectrometer identification*
			P_2O_5	Fe_2O_3 1/	Al_2O_3	CaO	U	eU	
D	7 3/	17'0" to 18'9"	1.5	1.32	9.0	0.11	.001	.002	A kaolin mineral and a trace of wavellite
D	8 2/	23'0"	3.6	5.40	5.6	0.11	.005	.005	Traces of kaolin mineral and wavellite
D	9 2/	28'0"	10.4	2.96	12.0	0.11	.013	.012	Wavellite
D	10 2/	30'0"	14.5	10.40	16.5	0.62	.018	.016	Wavellite
E	11 3/	6'0" ±	2.9	2.13	10.2	0.73	.002	.002	Trace of a kaolin mineral
E	12 2/	18'2" ±	2.9	0.85	7.1	0.23	.002	.002	Traces of wavellite and a kaolin mineral
E	13 2/	19'2" to 20'0"	8.3	11.00	11.3	0.23	.009	.009	Wavellite
E	14 2/	20'6" ±	10.2	6.24	11.8	0.79	.011	.010	Wavellite and crandallite
E	15 2/	22'3"	9.6	7.98	8.9	0.68	.017	.016	Wavellite and crandallite
E	16 2/	22'9" to 23'0"	12.4	9.30	12.9	1.12	.016	.017	Wavellite and crandallite
E	17 2/	25'0" ±	14.0	3.75	14.4	0.11	.020	.022	Wavellite

also observed in a groundmass of clayey, wavellitic sands, where they must have been present as thin, isolated layers. Lithologic logs indicate that variable thicknesses of the secondary cemented and vesicular sandstones were encountered above the pebble apatite beds in the drill holes. The thickness of these secondary masses ranged from about 2½ feet to about 28 feet and averaged about 11 feet.

All of the vesicular sandstone fragments in drill core samples from the Clark James - South Ridgewood tracts were harder and heavier than the usual white, lightweight variety exposed in cuts or mine faces elsewhere in the district. Much of the hardness of both the cemented sandstone and the vesicular sandstone in this area is probably imparted to the rock by the wavellite in the cement, and probably also by redeposited silica (Z. S. Altschuler, oral communication, 1956).

Geologic sections on plate 2 show the variations in thickness of the lower aluminum phosphate zone and the upper clayey sands. An isopach map of the aluminum phosphate zone (pl. 4), constructed from data obtained from the gamma-ray logs of 135 drill holes (pl. 2), also shows the variations in thickness of the zone in the area. The geologic sections and isopach map show that the altered zone, in places, changes rapidly in a horizontal direction from a thickness of several feet to less than a foot. For example, on the western half of geologic section G-G' (pl. 2) and in the same area on the southern end of geologic section H-H', the gamma-ray log of drill hole XY shows a thickness of about 29 feet of aluminum phosphate material. However, the zone appears to thin out rapidly to the south, for the gamma-ray log of drill hole XZ, about 750 feet south in section 22, indicates only about 0.1 foot of aluminum phosphate zone. About 750 feet east of drill hole XZ, the aluminum phosphate zone again becomes several feet thick, possibly because of more favorable lithology and permeability of the original material.

URANIUM DISTRIBUTION IN THE ALUMINUM PHOSPHATE ZONE

Lakeland Highlands area

Lithologic logs, supplemented by gamma-ray logs, of drill holes in sections 10 and 11 of the Lakeland Highlands area show that the highest radioactivity is in the aluminum phosphate zone. An isograde map (fig. 2) of the aluminum phosphate zone, constructed from radioactivity data obtained from gamma-ray logs of 38 drill holes, shows the approximate distribution or concentration of uranium in the zone in parts of sections 10 and 11. Comparison of corresponding intervals on gamma-ray logs and X-ray analyses indicates that maximum peaks on the gamma-ray logs are in altered material containing the aluminum phosphate mineral, wavellite, and the calcium-aluminum phosphate mineral, crandallite. Normally, uranium preferably associates with apatite, but when apatite has been entirely removed the uranium is enriched in crandallite (Altschuler, Z. S., and other, 1956, p. 500). In this area X-ray determinations of aluminum phosphate zone samples from several holes (tables 1 and 2) show wavellite to be predominant and crandallite in only trace amounts. The X-ray determinations also indicate that calcium phosphate (apatite) is not present in the samples. Regardless of the predominance of wavellite in the samples, the trace amounts of the more calcic crandallite, according to Altschuler and

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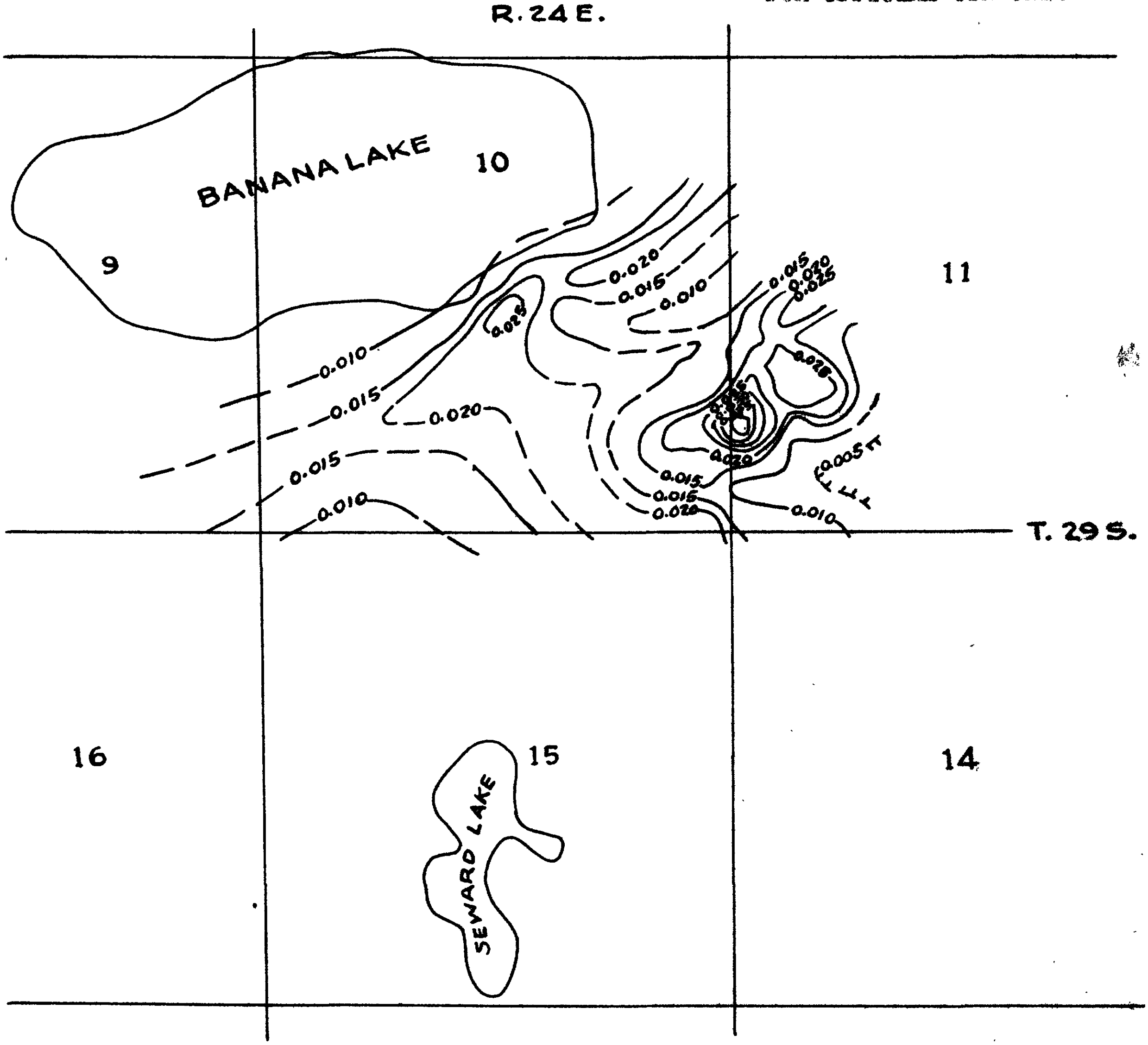

SCALE 1:24000

0 1 2 MILES

CONTOUR INTERVAL = 0.005 PER CENT U_3O_8

(HACHURES POINT TOWARD AREAS CONTAINING LESS THAN 0.005 PER CENT U_3O_8)

RADIOACTIVITY VALUES BASED ON DATA FROM GAMMA-RAY LOGS

FIGURE 2. -ISOGRADE MAP OF URANIUM CONTENT, ALUMINUM PHOSPHATE ZONE, LAKELAND HIGHLANDS AREA, POLK COUNTY, FLORIDA.

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and others (1956, p. 500), would account for most of the total uranium. Where only wavellite is reported there is still the possibility of undetected traces of crandallite or millisite, or association of the uranium with iron. For example, in sample 10 of Hole D, table 2.

Figure 3 shows graphically the distribution of U_3O_8, P_2O_5, Al_2O_3, CaO, and Fe_2O_3 in the same drill hole represented by table 1 (p. 18). In general, the Fe_2O_3 appears to parallel the P_2O_5 and U_3O_8 over all grade ranges. It is unknown whether there is a definite linking here of iron and uranium as found in the Clark James - South Ridgewood tracts (Altschuler and others, 1954, p. 204). There does not seem to be a great deal of parallelism between Al_2O_3, P_2O_5, and U_3O_8 until the U_3O_8 content reaches 0.005 percent or until the aluminum phosphate zone is reached. P_2O_5 and U_3O_8 parallel each other closely in both the clayey sands and the lower aluminum phosphate zone. The Al_2O_3 in the upper clayey sands of the aluminum phosphate zone is probably all in the kaolinite, as indicated by the X-ray analyses (table 1), but in the lower zone it is probably contained mostly in crandallite, and in lesser amounts in wavellite and an unidentified clay mineral. At the bottom of the aluminum phosphate zone, adjacent to unaltered apatite pebbles, there is an increase in CaO and P_2O_5 and a decrease in Al_2O_3, Fe_2O_3, and U_3O_8. From microscopic studies of other samples, the chemical and X-ray analyses of the aluminum phosphate zone in this hole are considered to be typical of the aluminum phosphate zone in the drilled parts of sections 10 and 11.

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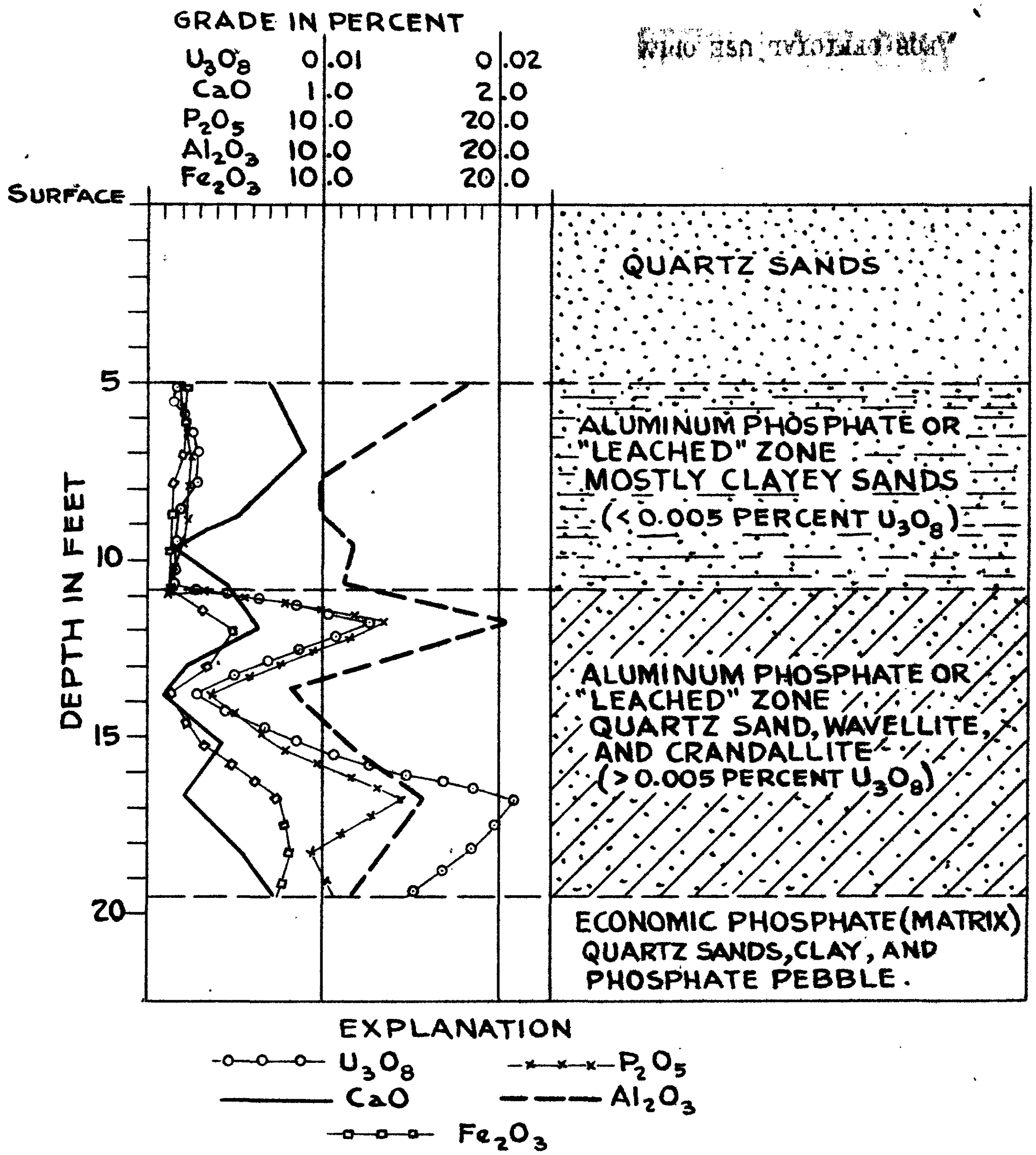

FIGURE 3.- GRAPHIC REPRESENTATION OF U_3O_8, P_2O_5, Al_2O_3, CaO, AND Fe_2O_3 DISTRIBUTION IN THE ALUMINUM PHOSPHATE ZONE OF A CORE DRILL HOLE, LAKELAND HIGHLANDS AREA, POLK CO., FLORIDA.

Manganese occurs in this area near the base of the aluminum phosphate zone, but apparently no relationship exists between it and uranium (Z. S. Altschuler, oral communication, 1956).

Conclusions based on studies of gamma-ray logs, mineralogy, chemical analyses, and X-ray determinations, and normal associations make it appear that the uranium in the aluminum phosphate zone in the Lakeland Highlands area is mostly associated with crandallite, and to a lesser extent with wavellite and possibly iron oxides.

Clark James - South Ridgewood tracts

A correlation of 25 drill hole gamma-ray and lithologic logs in the Clark James - South Ridgewood tracts indicated that the highest peaks of radioactivity in the aluminum phosphate zone were concentrated generally near the base of the zone, where leached apatite pebbles were present, and to a lesser extent higher in the zone where leached apatite pebbles were absent and only aluminum phosphate minerals were present. Altschuler and others (1956, p. 498) found that uranium concentration increased in the leached apatite pebbles at the basal part of the zone and decreased upward in the section. They reasoned that continued leaching in the upper parts of the zone caused the uranium to be removed and carried downward for re-deposition and concentration in parts of the zone with less advanced stages of leaching. The leached apatite pebbles grade upward into a "sandrock."

Altschuler and others (1954, pp. 203, 204) found that a great deal of the uranium in the Clark James - South Ridgewood tracts is associated with the iron oxides, goethite and limonite; that the iron-stained or -impregnated apatite is uraniferous; and that the uranium parallels iron more closely than it does phosphorus or calcium. Although oxides of iron are common within the Bone Valley formation, this is apparently the first definite linking of uranium and iron in the land-pebble district.

Incrustations of manganese oxide, or hydrate, in a thin band near the base of the aluminum phosphate zone, usually coincide with peak zones of radioactivity on gamma-ray logs. The occurrence of manganese in this part of the section appears to be a coincidence of deposition and no relation exists between it and the uranium (Z. S. Altschuler, oral communication, 1956).

Three gamma-ray and lithologic logs (pl. 5) illustrate the irregularity of uranium distribution and concentration in the Bone Valley formation of the Clark James - South Ridgewood tracts. The highest peak on the gamma-ray curve of Hole A occurs in the lower zone about 2 feet above the base of the upper part of the formation. A lithologic log of Hole A indicates leached apatite pebbles in the lower part of the aluminum phosphate zone, and probably most of the uranium in this part of the zone is associated with the leached apatite pebbles as a substitution for some of the calcium in the apatite structure (Altschuler, Z. S., Jaffee, E. B., Cuttitta, F., 1956, p. 500). Higher in the aluminum phosphate zone where the apatite has been entirely removed, the uranium associates mostly with crandallite and only to a minor extent with wavellite (Altschuler, Z. S., and others, 1956, p. 500). In this hole, then, most of the total uranium is probably associated with apatite and trace amounts of crandallite and in a very minor way with wavellite.

Hole B illustrates high uranium concentration near the top of the lower part of the Bone Valley formation (matrix) below the aluminum phosphate zone. In this hole the gamma-ray log shows radioactivity decreasing upward through a thin lower aluminum phosphate zone, and although wavellite is present in the zone most of the total uranium in the hole, as indicated by the high peak of the curve, appears to be associated with apatite pebbles. Although not clearly shown by the lithologic log, it is probable that the apatite pebble interval is leached deeper than the log indicates.

Hole C illustrates a thick aluminum phosphate zone containing wavellite, and probably crandallite. As no leached apatite pebble interval is indicated on the lithologic log, the uranium is probably associated mostly with crandallite, and only to a lesser degree with the wavellite.

An isograde map of the aluminum phosphate zone (pl. 6), based on data from 135 gamma-ray logs, illustrates the variable distribution of uranium in the tracts. A comparison of the isograde and isopach (pl. 4) maps indicates that there is no apparent relationship between thickness of the aluminum phosphate zone and uranium distribution or concentration.

The grade of uranium in the aluminum phosphate zone of the Clark James - South Ridgewood tracts ranges from 0.007 percent to 0.051 percent U_3O_8, and averages 0.021 percent U_3O_8. This is almost twice the average grade of 0.012 percent U_3O_8 found in the aluminum phosphate zone of the land-pebble phosphate district. The gamma-ray logs showed that an aluminum phosphate zone was absent in 6 of the 135 holes.

Based on information from gamma-ray logs, lithologic logs, and the results of earlier studies, the uranium in the Clark James - South Ridgewood tracts appears to be associated in varying degrees with leached apatite pebbles, crandallite, wavellite, and iron oxides.

RESERVES

Estimation of U_3O_8 reserves for the Lakeland Highlands area is based on 40-acre tracts. Indicated tonnage is based on 3 or more holes per 40-acre tract; areas with less than 3 holes per 40-acre tract were calculated as inferred tonnage. Grade figures resulting from the calculations were based on chemical assays or gamma-ray logs. A thickness cut-off at 3 feet and a grade cut-off at 0.005 percent U_3O_8 was used for minable uraniferous aluminum phosphate material. No reserves were estimated for areas without sample or drilling data.

Based on gamma-ray logs and chemical assays, indicated reserves in the Lakeland Highlands area range from 5 to 16 feet in thickness and from 0.015 percent to 0.022 percent U_3O_8. Average thickness and grade are $10\frac{1}{2}$ feet and 0.018 percent U_3O_8, respectively. Inferred reserves of aluminum phosphate material in the Lakeland Highlands area range from $3\frac{1}{2}$ to $18\frac{1}{2}$ feet in thickness and from 0.006 percent to 0.041 percent in U_3O_8. Average thickness and grade are 7 feet and 0.016 percent U_3O_8, respectively.

Indicated and inferred reserves of aluminum phosphate material in the Lakeland Highlands area are given in tables 3 and 4 respectively. Total minable indicated and inferred reserves of aluminum phosphate material for the holes shown on plate 1 amount to about 15,500,000 short tons, or about 2,600 short tons of U_3O_8. Average grade of the total indicated and inferred reserves is about 0.017 percent U_3O_8, and the average thickness is about 9 feet.

The reserve area in sections 10 and 11 of the Lakeland Highlands is based partly on gamma-ray logs and partly on chemical assays, whereas the data for isolated holes along rights-of-way are based entirely on chemical assay.

An area northwest of Crews Lake in sections 21 and 22 of the Lakeland Highlands area (plate 1) would possibly develop, with additional drilling, into a reserve area of better-than-average grade though of insufficient thickness for economical mining; an area northeast and east of Crews Lake in section 23 would probably develop into an area of above-average grade and thickness with additional drilling. The area between Seward Lake and Highland City in sections 14 and 15 (pl. 1) is unexplored but appears to be favorable ground for aluminum phosphate material.

Total minable indicated and inferred reserves of aluminum phosphate material in the Clark James - South Ridgewood tracts have been covered elsewhere in unpublished reports (J. B. Cathcart, written communication, 1955). The reserves are about five times greater than in the Lakeland Highlands area under existing information. Based on gamma-ray logs and chemical assays, the indicated and inferred reserves of aluminum phosphate

Table 3.--Indicated reserves by 40-acre tracts, aluminum phosphate zone, Lakeland Highland area, Polk County, Florida

Location	Thickness aluminum phosphate zone (in feet)	Aluminum phosphate material (short tons)	Percent U_3O_8	Short tons U_3O_8
	10	780,800	.016 2/	125.00
	15	1,171,200	.018 2/	211.00
Sec. 10, T. 29 S., R. 24 E.	16	1,249,280	.019 2/	237.00
	11	858,880	.019 1/	163.00
	11½	897,920	.019 2/	171.00
	5	390,400	.015 1/	59.00
Sec. 11, T. 29 S., R. 24 E.	5	390,400	.022 1/	86.00
	Total tonnage	5,738,880		1,051.00
Thickness and grade				
Average	10½		.018	
Range	5'-16'		.015 - .022	

1/ Chemical assay

2/ Gamma-ray unit

Table 4.--Inferred reserves by 40-acre tracts, aluminum phosphate zone, Lakeland Highland area, Polk County, Florida

Location	Thickness aluminum phosphate zone (in feet)	Aluminum phosphate material (short tons)	Percent U_3O_8	Short tons U_3O_8
Sec. 9, T. 29 S., R. 24 E.	8	624,640	.017 1/	106.00
	5½	429,440	.010 1/	43.00
	18½	1,444,480	.013 2/	188.00
Sec. 10, T. 29 S., R. 24 E.	8	624,640	.009 1/	56.00
	9½	741,760	.009 2/	67.00
	12	936,960	.020 2/	187.00
Sec. 14. T. 29 S., R. 24 E.	8	624,640	.018 1/	112.00
	7	546,560	.008 1/	44.00
Sec. 15, T. 29 S., R. 24 E.	6	468,480	.041 1/	192.00
	6½	507,520	.006 1/	30.00

1/ Chemical assay

2/ Gamma-ray unit

Table 4.--Inferred reserves by 40-acre tracts, aluminum phosphate zone, Lakeland Highland area, Polk County, Florida.--Continued

Location	Thickness aluminum phosphate zone (in feet)	Aluminum phosphate material (short tons)	Percent U_3O_8	Short tons U_3O_8
Sec. 16, T. 29 S., R. 24 E.	6	468,480	.006 1/	28.00
	6½	507,520	.007 1/	36.00
Sec. 21, T. 29 S., R. 24 E.	4	312,320	.023 1/	72.00
Sec. 22, T. 29 S., R. 24 E.	4	312,320	.007 1/	22.00
	4½	351,360	.020 1/	70.00
Sec. 23, T. 29 S., R. 24 E.	8	624,640	.037 1/	231.00
	3½	273,280	.018 1/	49.00
Total tonnage		9,799,040		1,534.00
Thickness and grade				
Average	7		.016	
Range	3½ - 18½		.006-.041	

material in the Clark James - South Ridgewood tracts range from zero to about 18½ feet in thickness, and from about 0.007 percent to 0.051 percent U_3O_8. Average thickness and grade amount to about 9 feet and 0.021 percent U_3O_8, respectively.

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