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The Aluminum Phosphate Zone in the Peace River Area, Land-Pebble Phosphate Field, Florida

By J. B. Cathcart, 1917-
James Bachelder

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Geology and Mineralogy

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UNITED STATES DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

THE ALUMINUM PHOSPHATE ZONE IN THE PEACE RIVER AREA LAND-PEBBLE PHOSPHATE FIELD, FLORIDA*

By

J. B. Cathcart

December 1953

Trace Elements Investigations Report 394

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THE ALUMINUM PHOSPHATE ZONE IN THE PEACE RIVER AREA LAND-PEBBLE PHOSPHATE FIELD, FLORIDA

By J. B. Cathcart

ABSTRACT

The Peace River area, comprising T. 30 and 31 S., R. 24 and 25 E., contains a thicker and more persistent aluminum phosphate zone, and one that is higher in P_2O_5 and uranium content than is known elsewhere in the land-pebble phosphate district. This report has been prepared to bring together all of the information on the aluminum phosphate zone in the area where the first plant to treat this material will probably be located. The area may be divided into three physiographic units, (1) the ridge, (2) the flatwoods, and (3) the valley. Maps showing distribution and grade of the aluminum phosphate zone indicate that the zone is thin or absent in the ridge unit, thickest and most persistent, and of the best grade in P_2O_5 and uranium in the flatwoods unit, and absent or very low in grade in the valley unit. Maps of thickness and of chemical composition show that even in favorable areas there are places where the aluminum phosphate zone is missing or of questionable economic importance.

The distribution maps also show that areas of high P_2O_5 and high uranium content coincide closely. Areas containing thick aluminum phosphate material usually have high uranium and P_2O_5 contents.

It is estimated that an average of 13,000 tons per day of aluminum phosphate material might be mined from this area. This figure is based

on the probable amount of time, per year, that mining would be in favorable ground. When all mines in the area are in favorable ground, the tonnage per day might be about 23,000 tons.

Tonnages of aluminum phosphate material have been computed for about 36 percent of the area of T. 30 S., R. 25 E., and for 18 percent of the area of T. 31 S., R. 25 E. The total inferred tonnage is about 150,000,000 short tons, with an average grade of 0.012 percent U_3O_8.

INTRODUCTION

The aluminum phosphate zone (the "leached zone" of earlier reports--Altschuler and Boudreau, 1949; Staff, 1949; etc.), is characterized by the presence of aluminum phosphate minerals--wavellite, crandallite, and millisite--and commonly contains greater concentrations of uranium than the underlying rocks. This report was prepared in order to provide the Atomic Energy Commission, on whose behalf the work was done, with data on the aluminum phosphate zone in the area from which it is most likely this material will be mined first, and will be confined almost entirely to the Peace River area, which includes Tps. 30 and 31 S., Rs. 24 and 25 E., in Polk County, Florida (fig. 1). The area is generally in the eastern part of the land-pebble phosphate district, and the Peace River flows south through the eastern part of the area.

The area was chosen for the study because: (1) the aluminum phosphate zone here is thicker, richer in uranium, and more persistent than elsewhere in the district, (2) it is in this area that most of the phosphate is mined, and probably will continue to be mined for the next

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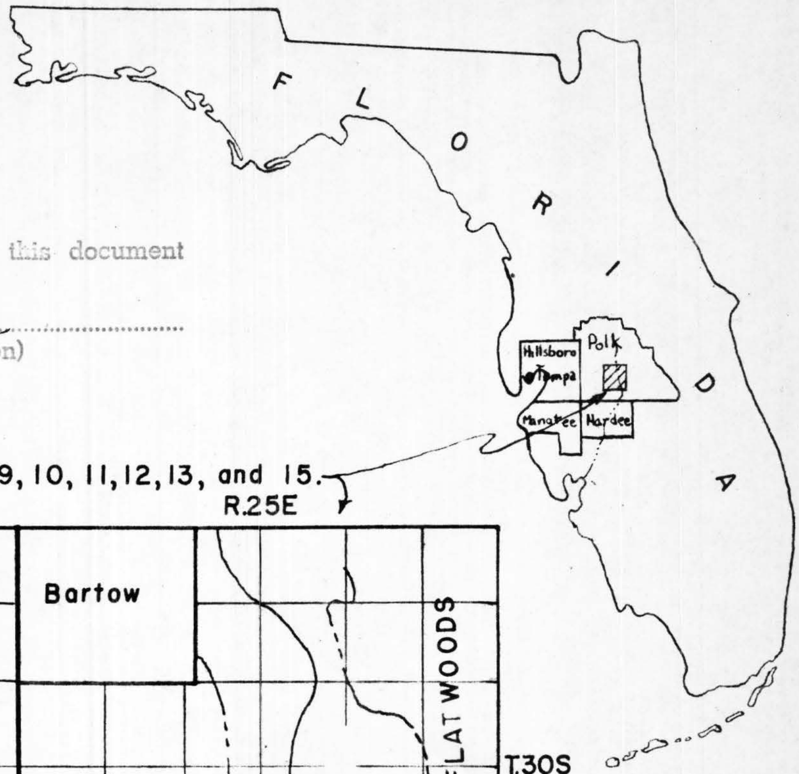

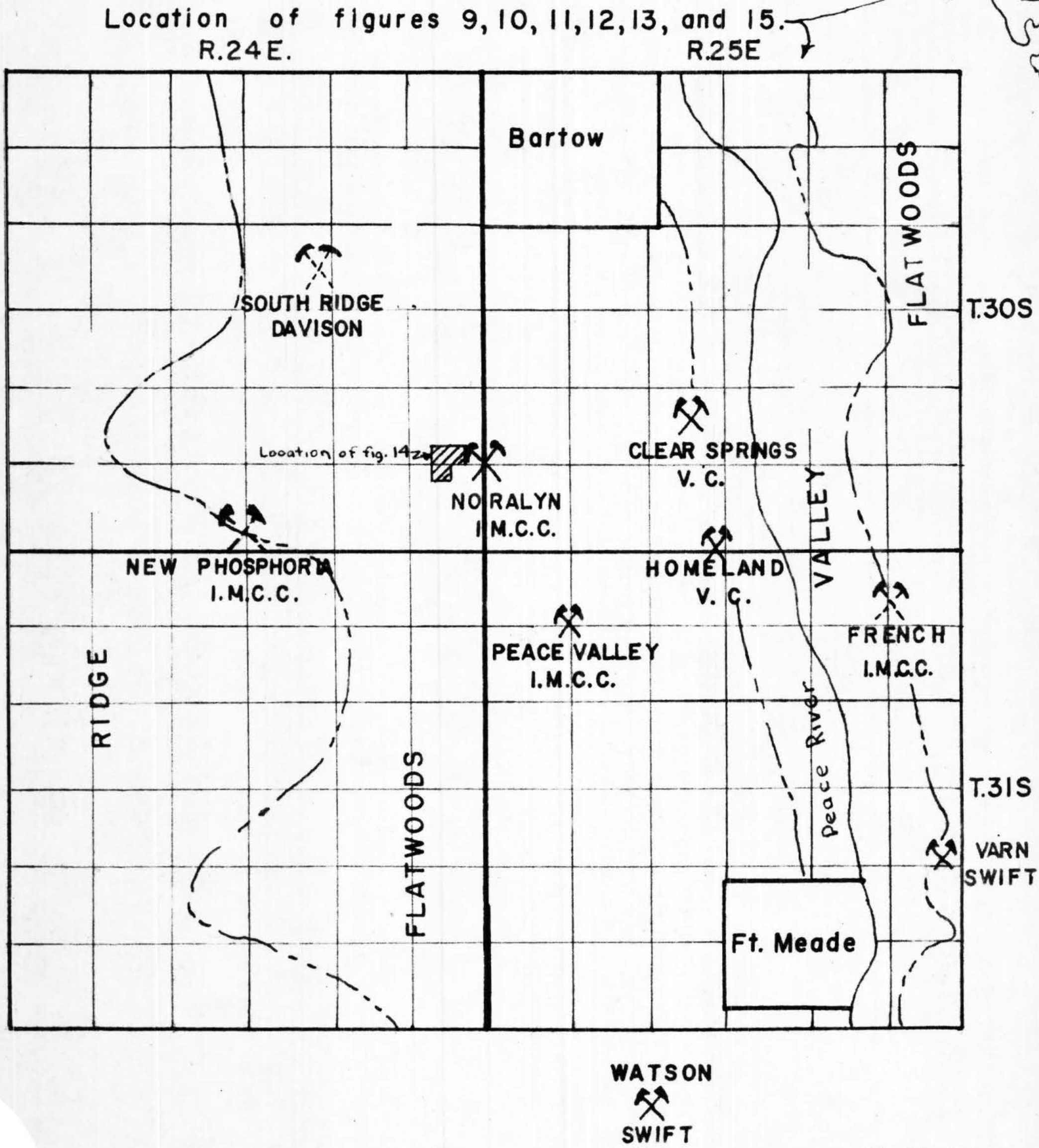

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FIGURE 1. INDEX MAP SHOWING LOCATION OF PEACE RIVER AREA, MINE LOCATIONS, AND PHYSIOGRAPHIC UNITS

decade or more, and (3) because of the active mining and prospecting in this area, it is here that we have the most complete information regarding grade and distribution of the aluminum phosphate zone. Inasmuch as any plans for mining and treating the aluminum phosphate material must depend, at least at first, on plans of the active companies to mine underlying commercial "matrix", this area must be the first to be considered.

Thanks are due to M. H. Bergendahl, L. V. Blade, W. J. Carr, and R. G. Petersen, of the Geological Survey, who have contributed directly to this investigation. The active phosphate companies have given free access to their drilling and analytical data. International Minerals and Chemical Corp., Virginia-Carolina Chemical Corp., and Swift and Co., drilling under contract to the Atomic Energy Commission, sampled and analyzed the aluminum phosphate zone. The data from the drilling form an important part of this report. Mr. Wayne Thomas, an independent contractor, allowed access to his drilling and assay data, and permitted collection of samples. Much of the data in the north half of T. 30 S., R. 25 E., east of the Peace River were collected from drilling by the Royster Guano Co.

Except as noted in the report, all analyses were made by the Geological Survey Trace Elements Washington Laboratory.

GENERAL GEOLOGY

There are three recognized formations in the land-pebble phosphate district - the middle Miocene Hawthorn formation, the Pliocene Bone Valley formation, and the Pleistocene terrace sands. Wind-blown sand, swamp deposits, and bars and flood plains of streams are generally considered to be Recent.

Figure 2 is a diagrammatic cross-section through the Peace River area, showing relations of formations, gamma-ray logs, and mining terminology.

Hawthorn formation

The Hawthorn formation is a buff, sandy, clayey limestone, containing varying amounts of phosphorite particles. The formation is exposed only in the Peace River Valley and in mining pits. The top few feet of the formation have been weathered to a gray, yellow-gray or green sandy phosphate-bearing calcareous clay. The Hawthorn formation ranges in thickness from a feather edge in northern Polk County to at least several hundred feet in Manatee and Hardee Counties. It is fossiliferous in most exposures in the area, and contains abundant casts and molds of invertebrates, shark's teeth, and manatee ribs. The Hawthorn formation is middle Miocene according to MacNeil (1947) and Cooke (1945).

Phosphate particles in the limestone are generally leaner in P_2O_5 and in uranium content than those in the overlying calcareous clay.

Bone Valley formation

The Bone Valley formation consists of a lower zone composed predominantly of phosphate nodules, sand, and clay, and an upper zone composed predominantly of clayey sand, with minor amounts of phosphate nodules (Altschuler, et al., 1951; Cathcart, 1950).

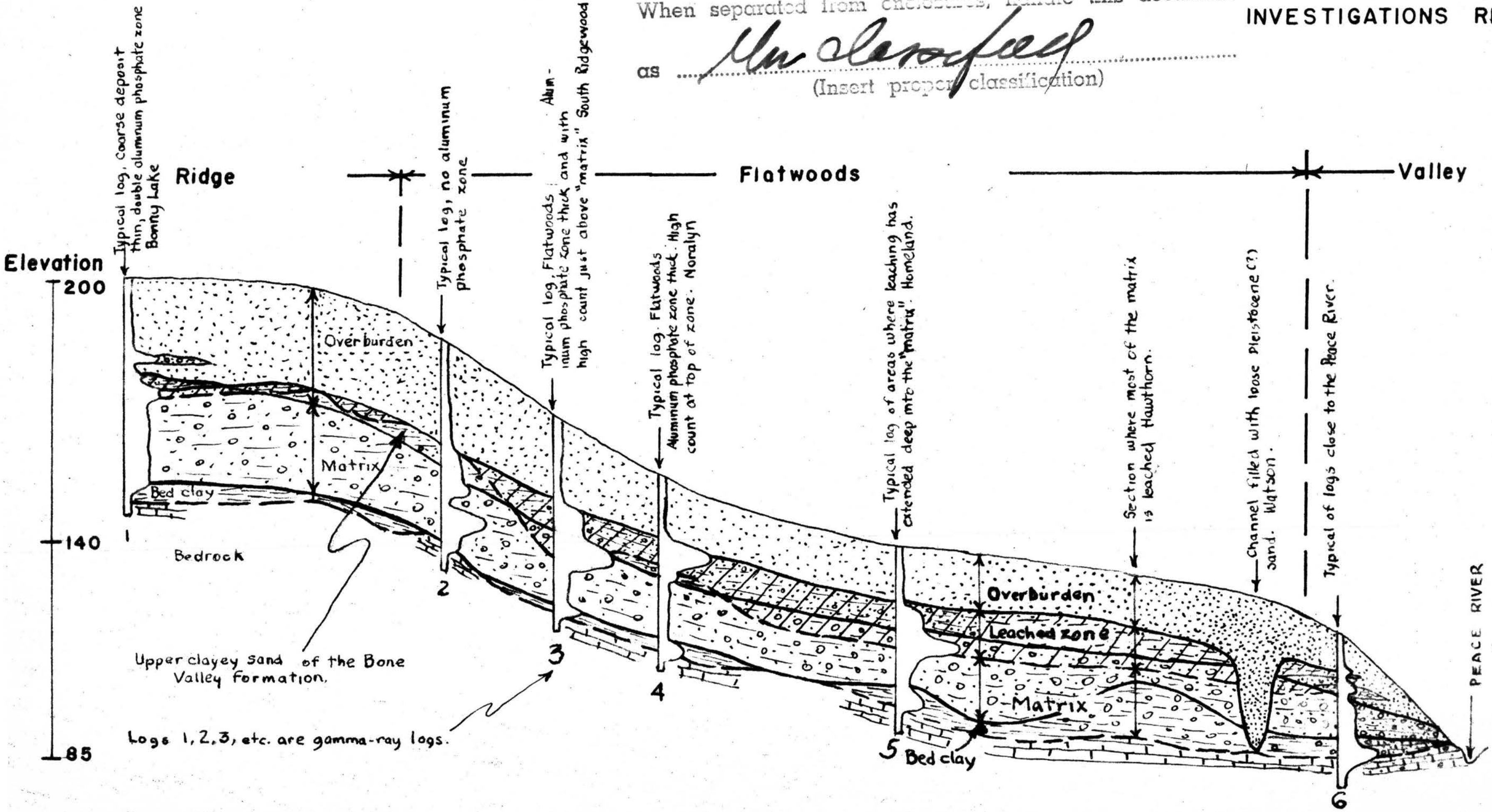

FIGURE 2. DIAGRAMMATIC CROSS SECTION OF THE PEACE RIVER AREA.

The lower zone, or phosphatic member, together with the residual mantle on the Hawthorn, comprise the "matrix", or economic phosphate deposit. This unit ranges in thickness from more than 40 feet to a feather edge. In places, (fig. 2) the "matrix" is cut out completely by sharp, narrow channel-like bodies of loose quartz sand.

In general, the material mined is composed of about equal amounts of quartz sand, slime (which is called clay in the area), and nodules of phosphate, although individual beds may vary from almost barren slime (clay) or sand to those which are composed almost entirely of phosphate nodules (table 1). The slime fraction, that fraction which passes a 150 to 200 mesh screen, is composed of clay minerals, quartz silt, and phosphate particles. Although this fraction contains between 10 and 20 percent P_2O_5, the material is so finely divided that no practical means of recovery has yet been devised.

The upper part of the Bone Valley formation ranges from a slightly clayey sand to a sandy clay, and generally contains a few phosphate nodules. The contact between the lower and upper zones of the Bone Valley formation is gradational over a few inches to as much as a foot. All of the material above the minable "matrix" is called overburden by the mining companies. The upper part ranges in thickness from as much as 50 feet to a feather edge, but probably averages about 12 to 15 feet.

Table 1.—Ratios of recoverable phosphate nodules, sand (tailings), and clay (slime) in individual strata of the matrix, land-pebble phosphate district, Florida.

Phosphate (percent)		Sand (-14 + 150 mesh)	Clay (-150 mesh)
+ 14 mesh coarse pebble	-14 + 150 mesh concentrate	(percent)	(percent)
A. 84.4	0.8	8.0	6.8
B. 1.4	54.6	38.0	6.0
C. 23.6	23.0	38.7	14.7
D. 3.0	7.3	19.7	70.0
E. 7.6	4.3	79.6	8.5

A. Bed ½ foot thick near the top of the matrix.

B. Bed 2 feet thick, in the middle of the matrix.

C. Bed 4 feet thick, at the top of the matrix.

D. Bed 2 feet thick, near the base of the matrix - so-called "barren clay bed."

E. Bed 6 feet thick, near the top of the matrix.

The Bone Valley formation has been called Pliocene by Simpson (1929) on the basis of its vertebrate fauna. There is a possibility, however, that this fauna may be upper Miocene in age._/ However, the fossils

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_/ Letter from G. G. Simpson to F. S. MacNeil, 7/3/53.

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indicate an age younger than middle Miocene (Hawthorn) for the beds in which they are found.

The calcium phosphate zone

The calcium phosphate zone is that part of the Bone Valley formation, together with the residual mantle on the Hawthorn formation which is characterized by nodules or particles of apatite. In most places this zone is the economic part of the section. Like the aluminum phosphate zone, it is not a stratigraphic unit, and may be entirely within the lower unit of the Bone Valley formation, or may be entirely residual Hawthorn, or a combination of the two.

The aluminum phosphate zone

The aluminum phosphate zone is that part of the Bone Valley formation which shows severe alteration. The alteration is generally confined to the upper part of the formation and the top of the lower part, although there may be some development of aluminum phosphate even in the basal part of the formation. The zone can be identified by some or all of the following features: vesicular-like texture, secondary cements, white color, low specific gravity, and indurated or friable character. The zone generally cuts across stratigraphy (fig. 2).

Pleistocene (?) terrace sands

The loose sands overlying the Bone Valley are probably Pleistocene, and/or Recent in age. The sands are massive, very well sorted, and are almost pure quartz, commonly with less that 5 percent clay, and about ½ percent heavy minerals. Locally, even in the surficial material, chemical analyses show as much as 0.5 percent P_2O_5, mostly in phosphate nodules. The contact between the loose sands and the Bone Valley formation is commonly gradational, but disconformable relations, i. e., channel cutting and filling, have been seen in a few places and in addition, lenses of clayey sand near the Peace River are thought to represent a floodplain deposit of Pleistocene or Recent age. Deposits of peat, muck, and windblown sand at the surface may be Recent in age.

WEATHERING AND EROSION

The writer believes that weathering and erosion have affected the phosphate deposits several times during their formation. The scope of the paper is too limited to present all the details of the weathering picture, but some aspects deserve emphasis.

A period of weathering and erosion followed the deposition of the Hawthorn formation, and the upper surface of the limestone of the Hawthorn formation is now a buried karst topography with ranges in altitude of from 40 feet to over 150 feet. Weathering processes at this time probably dissolved the more soluble calcium carbonate, leaving behind the less soluble calcium phosphate, sand, and clay.

This material is the residual Hawthorn, and is called "bed clay" by the mining companies. The "bed clay" commonly contains higher percentages of phosphate particles than the limestone. The phosphate particles of the "bed clay" contain more P_2O_5 and uranium than those in the limestone. Gamma-ray logs commonly show a peak just above the limestone, reflecting the higher uranium content of the "bed clay" (fig. 2).

Following the weathering and erosion of the Hawthorn formation, the sea advanced, at least part way, over the deeply weathered terrain, and the Bone Valley formation was deposited.

The weathering which altered the Bone Valley formation can be contrasted with that which altered the Hawthorn formation. Acid ground waters attacked the phosphate minerals, the most soluble material remaining, and altered them to aluminum phosphate minerals (Altschuler and Boudreau, 1949). Uranium presumably was concentrated at or near the base of the zone of weathering, and the line of this weathering profile is very irregular. Where only the upper part of the Bone Valley formation was weathered little or no phosphate or uranium is in the "leached zone". Where weathering was deeper and penetrated into the lower, more phosphatic part of the Bone Valley formation, both uranium and P_2O_5 contents are high. Uranium distribution is illustrated by the gamma-ray logs of figure 2. Log 2 shows only a slight rise in the upper Bone Valley, with the highest counts in the "matrix". Log 4 shows a high peak at the top of the "leached zone", with lower counts below. Logs 3 and 5 show the highest peaks at the base of the zone of leaching where the weathering penetrated the lower part of the Bone Valley formation. Typical analyses of the aluminum phosphate zone are shown on table 2.

Table 2.—Typical analyses of the aluminum phosphate zone.

		P_2O_5 percent	CaO percent	Al_2O_3 percent	U percent	Ratio P_2O_5 percent / CaO percent
Hole G-11 (Sec. 33, T. 27 S., R. 24 E.)		Analyses by Coronet Phosphate Co.				
0-3½ feet	Loose sand, "overburden"			Not analyzed		
3½-6	Sand, very slightly clayey, (upper Bone Valley)	0.7	0.3	1.7	0.001	2.3
6-12	Sand, clayey, with phosphate nodules, (lower Bone Valley, "matrix")	12.0	15.0	4.0	0.006	0.80
Hole I-12 (Sec. 26, T. 30 S., R. 25 E.)		Analyses by International Minerals & Chemical Corp.				
0-4	Loose sand, "overburden"			Not analyzed	eU ≃ 0.001	
4-6	Vesicular-like leached material (leached lower Bone Valley)	10.3	1.9	8.0	0.013	5.4
6-8½	As above with sand layers	15.8	8.7	4.3	0.017	1.8
8½-16	Sand, clayey, with soft white phosphate nodules, (leached lower Bone Valley)	23.3	25.4	5.8	0.024	0.92
16-20	Sand, clayey, abundant brown and tan phosphate nodules, (unleached lower Bone Valley)	18.7	23.9	2.0	0.009	0.78

Table 2.—Typical analyses of the aluminum phosphate zone—Continued.

		P_2O_5 percent	CaO percent	Al_2O_3 percent	U percent	Ratio P_2O_5 percent / CaO percent
Hole E-16 (Sec. 6, T. 31 S., R. 25 E.)		Analyses by International Minerals & Chemical Corp.				
0-8	Loose sand, "overburden"			Not analyzed		
8-10	Slightly clayey sand (leached upper Bone Valley)	2.9	1.3	7.6	0.002	2.2
10-14	Clayey sand, "vesicular", (leached lower Bone Valley)	15.5	16.8	4.5	0.013	0.92
14-20	Sand, clayey, with soft white phosphate nodules, (base of leaching)	15.1	18.6	4.1	0.018	0.81
20-30	Clayey sand, with phosphate nodules, (lower Bone Valley "matrix")	19.0	27.4	2.7	0.010	0.69

Note that the analysis of the sample from $3\frac{1}{2}$-6 feet in hole G-11 is similar to the analysis of the sample for 8-10 feet in hole E-16, and that the analyses of unleached lower Bone Valley (6-12 feet in G-11, 16-20 feet in I-12, and 20-30 feet in E-16) are all similar, and that the samples in holes I-12 and E-16 with "soft white phosphate" have the h[illegible]est uranium contents. In hole I-12 there is apparently no "upper [illegible] Valley" represented. In all of the holes, the ratio of P_2O_5/CaO [illegible]ases with depth.

MINERALOGY

The mineralogy has been described by Altschuler and Boudreau (1949), Owens, Berman, and Altschuler (1953), and Berman (1953). For further information on the mineralogy of the aluminum phosphate zone, the reader is referred to these papers.

The minerals discussed in this report are:

1. Carbonate fluorapatite $Ca_9 (PO_4, CO_3)_6 \cdot CaF_2$
   Ratio P_2O_5/CaO is 0.65
2. Wavellite $Al_3 (F,Oh)_3(PO_4)_2 \cdot 5H_2O$
3. Crandallite $CaAl_3 (PO_4)_2 (OH)_5 \cdot H_2O$
   Ratio P_2O_5/CaO is 2.53
4. Millisite $(Na,K) CaAl_6(PO_4)_4(OH)_9 \cdot 3H_2O$
   Ratio P_2O_5/CaO is 5.05
5. Kaolinite $Al_4 (OH)_8 Si_4O_{10}$
6. Montmorillonite $(Al, Mg, Fe)_4 (OH)_4 (Si,Al)_8O_{20} \cdot 8H_2O$
7. Attapulgite $Mg_5Si_8 O_{20}(OH)_2 \cdot 10H_2O$

8. Quartz SiO_2

9. Calcite $CaCO_3$

10. Dolomite Ca, Mg $(CO_3)_2$

Chemical formulae for the minerals, and the P_2O_5/CaO ratios are from Dana's System of Mineralogy (Palache, et al., 1951).

Berman (1953), in describing the mineralogy of a drill hole, points out that the deeper unaltered Hawthorn limestone contains calcite, quartz, minor apatite, and the clay minerals, either kaolinite, or montmorillonite. The Hawthorn formation consists of dolomite, attapulgite, quartz and apatite closer to the surface; the "matrix" of the Bone Valley formation is quartz, montmorillonite, and apatite; and the "overburden" is quartz and montmorillonite. This section is typical of those areas where there has been no development of aluminum phosphate minerals.

X-ray spectrometer analyses of a series of vertical channel samples, each sample representing a very limited stratigraphic interval, were made by L. V. Blade in 1952. All of the sections were taken from the surface to the base of the exposure. The following are generalizations from several sections which are believed typical of areas that have been affected by leaching, and where aluminum phosphate minerals have formed.

The loose sand at the surface contains only quartz, except near the contact with the clayey sand of the upper Bone Valley, where minor kaolinite was detected. In the clayey sand of the upper Bone Valley, in all sections whether leaching was apparent or not, kaolinite, wavellite, crandallite (called pseudowavellite in earlier reports), and possibly a minor amount of montmorillonite are present (quartz is, of course, ubiquitous, and will not be mentioned hereafter). Farther down in the section, at the top of the lower Bone Valley, the same minerals are present, but at the contact, or slightly above it, montmorillonite is the most abundant clay mineral, apatite becomes abundant and commonly crandallite is more abundant than wavellite. In the lower Bone Valley (the matrix), apatite and montmorillonite are the most abundant minerals; kaolinite and aluminum phosphate minerals are minor constituents. The bed clay contains calcite and dolomite which are not present higher in the section, in addition to apatite and montmorillonite. (Only one sample of bed clay was analyzed, and in this sample no attapulgite was identified.) The vertical distribution of the change in the ratio $\frac{P_2O_5}{CaO}$, as illustrated in table 2, corresponds with the change from aluminum phosphate minerals higher in the sections to calcium phosphate minerals lower in the section.

MODE OF OCCURRENCE AND DISTRIBUTION OF THE ALUMINUM PHOSPHATE ZONE

The aluminum phosphate zone overlies and was derived from the calcium phosphate zone (the "matrix"). The mapped area consists of three physiographic units (Fowler, et al., 1927); (1) the ridge unit, a comparatively high rolling upland, (2) the flatwoods unit, bordering the uplands, and (3) the valley unit along the Peace River, (fig. 1). The maps of distribution (figs. 9, 10, 11, 12, 13 and 15) show the following relations: (1) The aluminum phosphate zone is thin, discontinuous, or absent in the ridge area from which it presumably was removed by erosion (fig. 2). These characteristics are exemplified in secs. 3, 4, and 5, T. 31 S., R. 24 E., where the uranium and P_2O_5 contents of the zone are irregular and the zone is thin (averaging less than 2 feet, and rarely exceeding 6 feet in thickness) or absent (figs. 9, 10, 11). (2) In the flatwoods unit bordering the uplands the zone is thicker, more continuous, and higher in grade. Thickness averages about 7 feet, and ranges up to 25 feet in some places west of the Peace River. East of the Peace River, in secs. 11, 12, 13, and 14, T. 30 S., R. 25 E., the aluminum phosphate zone reaches thicknesses in excess of 50 feet. In a few, small, discontinuous areas on the flatwoods region the aluminum phosphate zone is thin or absent, or low in P_2O_5 or uranium content. Enough data have not been accumulated to explain these areas where the zone is thin or absent, but they may be due to erosion of the zone or to the fact that in local areas, because of topography or high water table, the zone was never formed. (3) Along the valley of the Peace River itself, the zone is missing, probably because it was removed by erosion. In a belt about a mile wide paralleling the river a gray clayey sand occupies the position of the aluminum phosphate zone, but this bed contains practically no P_2O_5 or uranium. It is possibly a Pleistocene floodplain deposit of the Peace River. (4) There is an area or series of areas containing very thick aluminum phosphate zone about a mile east of the Peace River and parallel to it; (5) a second area or series of areas containing thick aluminum phosphate zone is about 2 miles west of the river and only crudely subparallel to it; (6) there is a third area on the edge of the ridge unit about 6 miles west of the river, which also contains thick aluminum phozphate zone (fig. 11). Chemical distribution and variations are discussed in a following section, but it should be emphasized that generally, the areas where the zone is thickest (fig. 11) correspond with areas of high P_2O_5 and uranium content.

Relations of the aluminum phosphate zone to the calcium phosphate zone

The calcium phosphate zone or matrix underlying the aluminum phosphate zone varies in composition and character as follows: (1) In the ridge unit, the matrix contains predominantly coarse (+14 mesh) phosphate particles which are low in P_2O_5 (average about 31 percent) and are high in uranium (average about 0.015 percent). (2) In the flatwoods unit, the matrix consists predominantly of fine (-14 +150 mesh) phosphate particles which are high in P_2O_5 (average about 34 percent), and are low in uranium (average about 0.009 percent). (3) In the valley unit, the matrix thins, and the phosphate particles are the same in character as in the flatwoods unit, up to a line very close to the river (in some cases to within 300 feet or less), where coarser particles lower in P_2O_5 again predominate. (4) In the very narrow channel of the river the matrix is absent.

Thus, the most continuous, thickest, and highest grade aluminum phosphate zone occupies an area between the river and the higher ridge, and overlies "matrix" that is leaner in uranium than the "matrix" material at higher elevations.

If, as seems likely, the aluminum phosphate zone is an alteration product of the underlying matrix, it probably was developed over much of the district, and the fact that it is either absent or only sporadically present in the ridge unit may mean that it was removed subsequent to its formation, and carried away, or deposited, probably in the flatwoods unit. This would account for some of the over thickened areas in the flatwoods, away from the river, and the high grade and more or less continuous extent of the zone in this area. It may also help to explain the fact that thick and high-grade areas tend to be the same. In an undisturbed section of leached material, CaO, P_2O_5, and U are low at the top, and increase gradually to a maximum at or slightly below the contact of the aluminum phosphate zone and the calcium phosphate zone. Deposition of eroded material with high content of CaO, P_2O_5, and U, on the normal section could account for the double peaks of these oxides shown in figure 7.

CHEMICAL RELATIONS AND VARIATIONS IN THE ALUMINUM PHOSPHATE ZONE

The aluminum phosphate zone, because it is secondary, and presumably was formed by the action of acid ground waters on the phosphate deposits of the Bone Valley, has a wide range in composition. In part, at least, the range in composition depends on whether the upper, sparsely phosphatic part of the Bone Valley formation or the lower, highly phosphatic part, or both were altered by the leaching. Therefore, any attempt to present an average, or representative composition, must be qualified by stating which part of the Bone Valley is involved. A further complication is that there are areas where the Bone Valley formation is unaltered, or where altered material has been stripped off by erosion, and unaltered lower Bone Valley is overlain by later (Pleistocene?) deposits.

Table 3 shows the range in composition and the average composition of the aluminum phosphate zone for an area about 7 miles northwest of Bartow, Florida, and for the Peace River area. Although the first area is not in the Peace River Valley, the analytical results are typical of places where the aluminum phosphate zone either was not developed, or where it developed from the upper, low-phosphate part of the Bone Valley formation. In the Peace River area, both high- and low-grade samples were used in computing the ranges and averages. The low-grade samples in range columns A and B are very similar, but the high-grade samples are very different.

Table 3.--Chemical composition of the aluminum phosphate zone.

	Range (in percent)		Average (in percent)	
	A	B	A	B
P_2O_5	0.68 - 7.84	0.59 - 22.08	2.52	7.86
Al_2O_3	1.14 - 6.89	1.22 - 22.37	3.05	7.95
CaO	0.02 - 4.43	0.02 - 26.72	1.24	4.86
U_3O_8	0.000 - 0.010	0.001- 0.033	0.005	0.011

A. 27 samples north of Bartow, analyses by Coronet Phosphate Co. (Whitney, 1953).

B. 93 samples Peace River area, analyses by International Minerals and Chemical Corp. (1953).

In order to present some of the chemical relations in the aluminum phosphate zone, a statistical comparison was made of the analyses of the

93 samples from the Peace River area. The comparison is shown in table 4. Although the number of samples is perhaps too few to be statistically valid, the writer believes that the results at least indicate certain interesting trends. Further statistical work, with many more samples, is planned. Details of the analyses will be presented in a report in preparation.

The study showed that most of the samples which are low in uranium are also low in P_2O_5, and that as uranium content increases, the number of samples which are low in P_2O_5 decreases markedly. There did not seem to be any consistent relation of uranium content to CaO content, but the Al_2O_3 content seems to increase as the uranium content increases.

The most significant thing about this study is the P_2O_5 - U relationship, which is confirmed by other data, (figs. 9 and 10) whereas the relations of CaO and Al_2O_3 to U are not as clear cut. This may be due to the fact that these samples represent small vertical intervals from drill hole cores, whereas the maps of distribution represent the total thickness of the zone.

Table 4.--Table showing relations of P_2O_5, CaO, and Al_2O_3 to U_3O_8.

U_3O_8		P_2O_5			CaO			Al_2O_3		
Grade Range of Samples	No. of Samples	<5%	5-10%	>10%	<5%	5-10%	>10%	<5%	5-10%	>10%
<.006%	25	78%	9%	13%	83%	9%	8%	44%	56%	0
.006% to .010%	28	30%	42%	28%	66%	11%	23%	30%	60%	10%
.011% to .015%	21	10%	60%	30%	70%	5%	25%	20%	45%	35%
>.015%	26	8%	42%	50%	72%	16%	12%	12%	29%	59%

The figures within the heavy rectangle indicate the percentage of samples that fall within the intersecting vertical and horizontal catagories.

Comparison between U, P_2O_5, CaO, and Al_2O_3 percentages in the -150 mesh (slime) fraction, and the total (head) sample

Early research work on the aluminum phosphate zone showed a concentration of both uranium and phosphate in the slime fraction, and it seemed likely that a sand-slime separation method of beneficiation of the zone might be used in processing the materials. For this reason much of the analytical data on the aluminum phosphate zone is for the -150 mesh fraction. However, the latest work on this material indicates that the raw material will be treated, without any sand-slime separation. In order to make the maps of chemical distribution most useful and to utilize all available information, comparisons between -150 mesh analyses and total analyses were made to see if there was any consistent relation between them, and if a factor could be applied to the slime analysis to convert it to an approximate head analysis.

Figure 3 is a scatter diagram showing the relation of CaO in the -150 mesh fraction to CaO in the head sample. As can be seen, the scatter is extreme, but many of the samples with low CaO percentages in the -150 mesh fraction, have much lower percentages in the head samples, while many of the samples with high percentages of CaO in the -150 mesh fraction have equally high, or higher percents in the head sample. Accordingly, the numerical ratios of $\left[\frac{\text{percent CaO}(-150)}{\text{percent CaO(head)}}\right]$ were computed for 160 samples. The arithmetic average of all ratios where the CaO content in the -150 mesh fraction is less than 5.0 percent is 2.48, whereas the average ratio for those samples where the CaO content of the -150 mesh fraction is between 5.1 and 10.0 percent is 1.82. The

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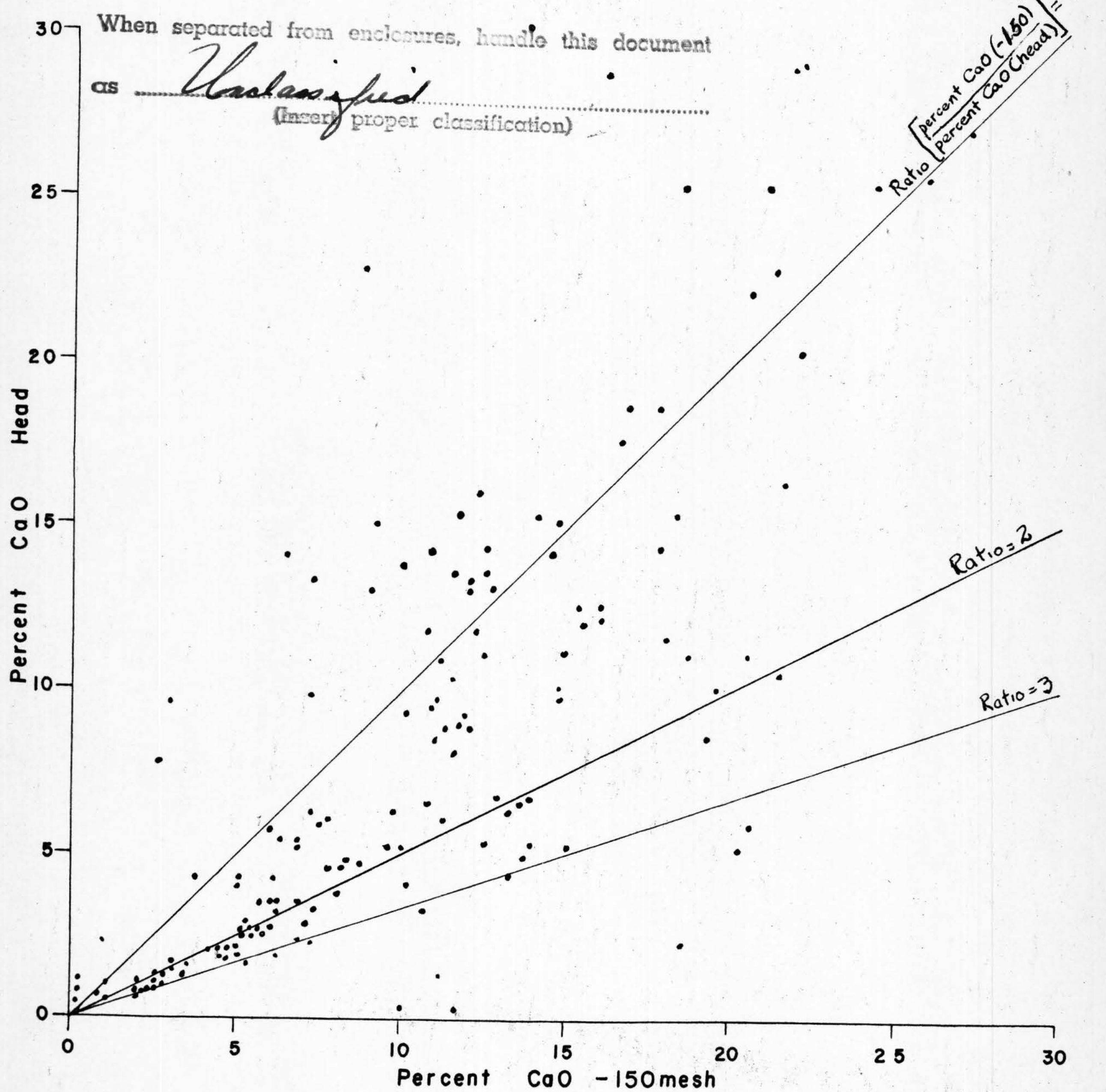

FIG. 3. DIAGRAM SHOWING RELATION OF CaO CONTENT IN THE -150 MESH FRACTION TO CaO CONTENT IN THE TOTAL (HEAD) SAMPLE OF THE ALUMINUM PHOSPHATE ZONE.

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average ratios continue to decrease as the CaO content in the -150 mesh fraction increases. Where the CaO content in the -150 mesh fraction is more than 25.0 percent the ratio is 1.1. Because of the wide scatter shown in figure 3, the map of CaO distribution (fig. 13), made, in part with the use of the above ratios, should be used and interpreted with caution.

Figures 4, 5, and 6, are scatter diagrams showing respectively the relations of P_2O_5, Al_2O_3, and U in the -150 mesh to those components in the head samples. From figure 4 the arithmetic average of the ratios of $\left[\frac{\text{percent } P_2O_5(-150)}{\text{percent } P_2O_5(\text{head})}\right]$ is 1.92. For Al_2O_3, the average ratio is 3.26, and for U, the average ratio is slightly more than 2.

Accordingly where only -150 mesh analyses were available for the aluminum phosphate zone, the analyses figures were reduced by the ratios given above. The area east of the Peace River is the only one where substantially all the data are converted. Elsewhere on the maps, only a part of the data were converted.

Vertical variations

The maps showing distribution of the chemical components of the aluminum phosphate zone were made by using the analyses or averaging analyses for the total thickness of the zone. However, as shown by detailed analyses of channel or drill hole samples, the zone is not at all uniform with depth. Because mining is by open pit methods, using large draglines, slight variations in the thickness mined may make a considerable change in the analyses of the material mined with respect to the analyses predicted from a drill hole.

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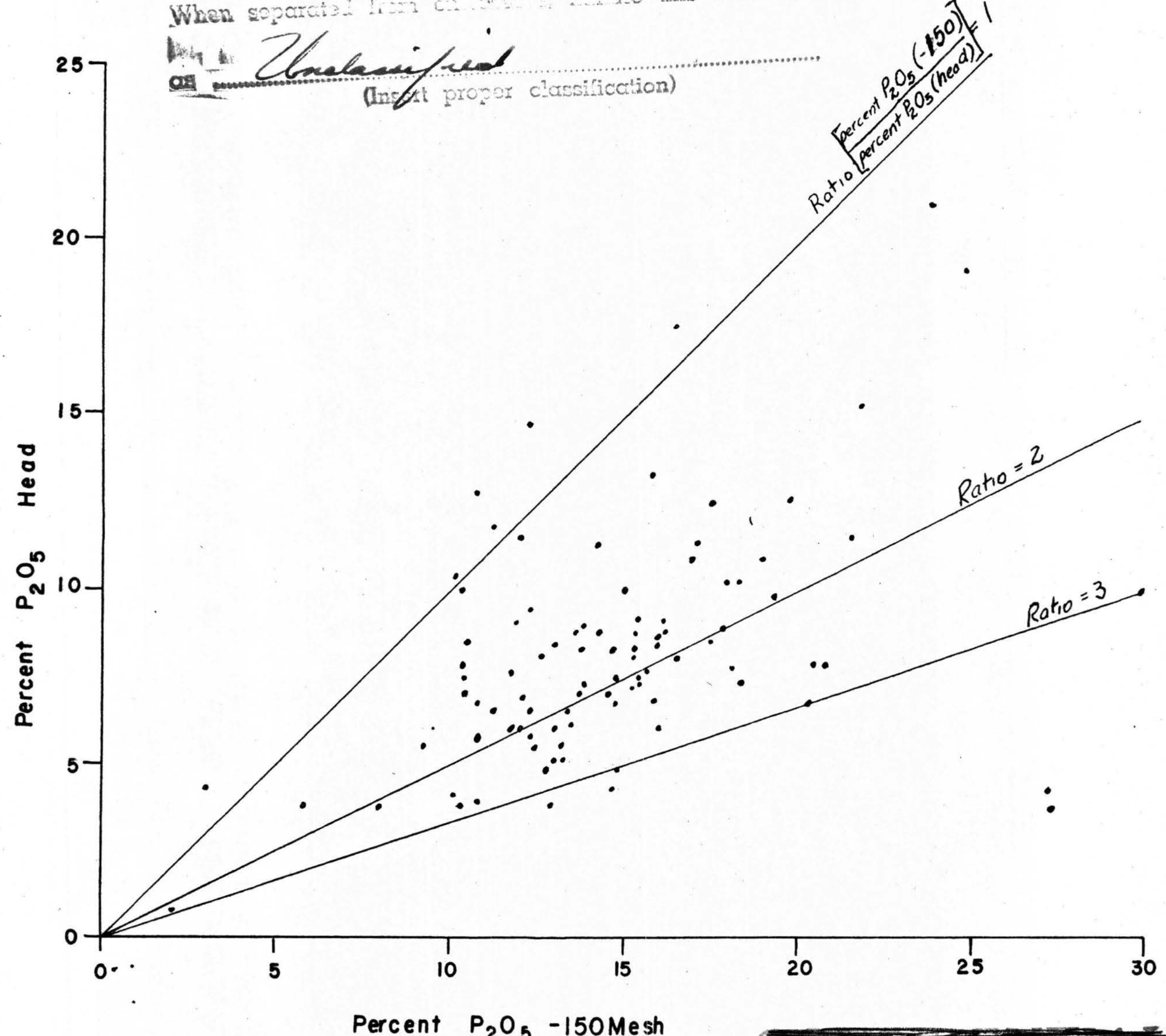

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FIG. 4. DIAGRAM SHOWING RELATION OF P_2O_5 CONTENT IN THE -150 MESH FRACTION TO P_2O_5 CONTENT IN THE TOTAL (HEAD) SAMPLE OF THE ALUMINUM PHOSPHATE ZONE

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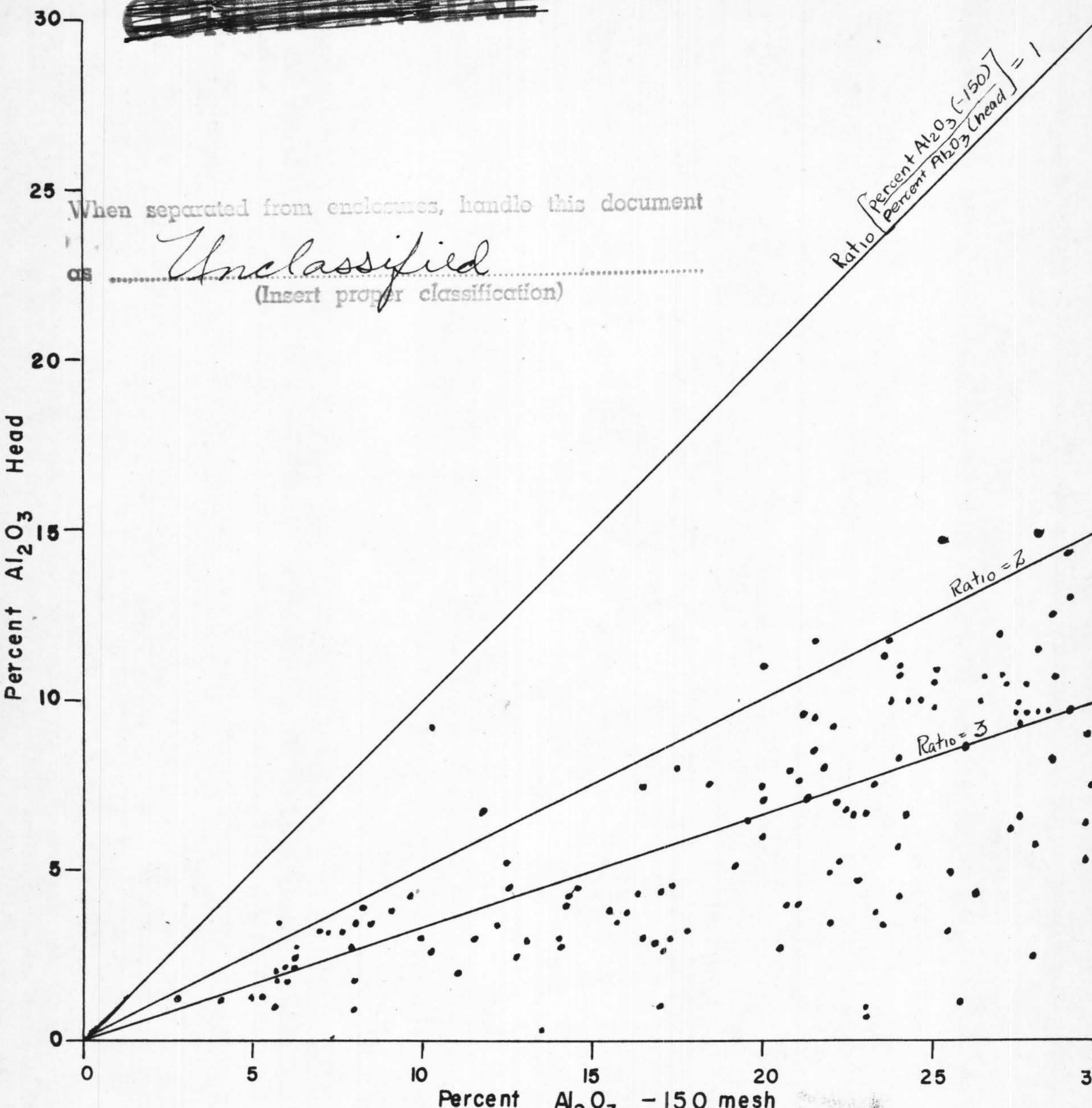

FIG. 5. DIAGRAM SHOWING RELATION OF Al_2O_3 CONTENT IN THE -150 MESH FRACTION TO Al_2O_3 CONTENT IN THE TOTAL (HEAD) SAMPLE OF THE ALUMINUM PHOSPHATE ZONE

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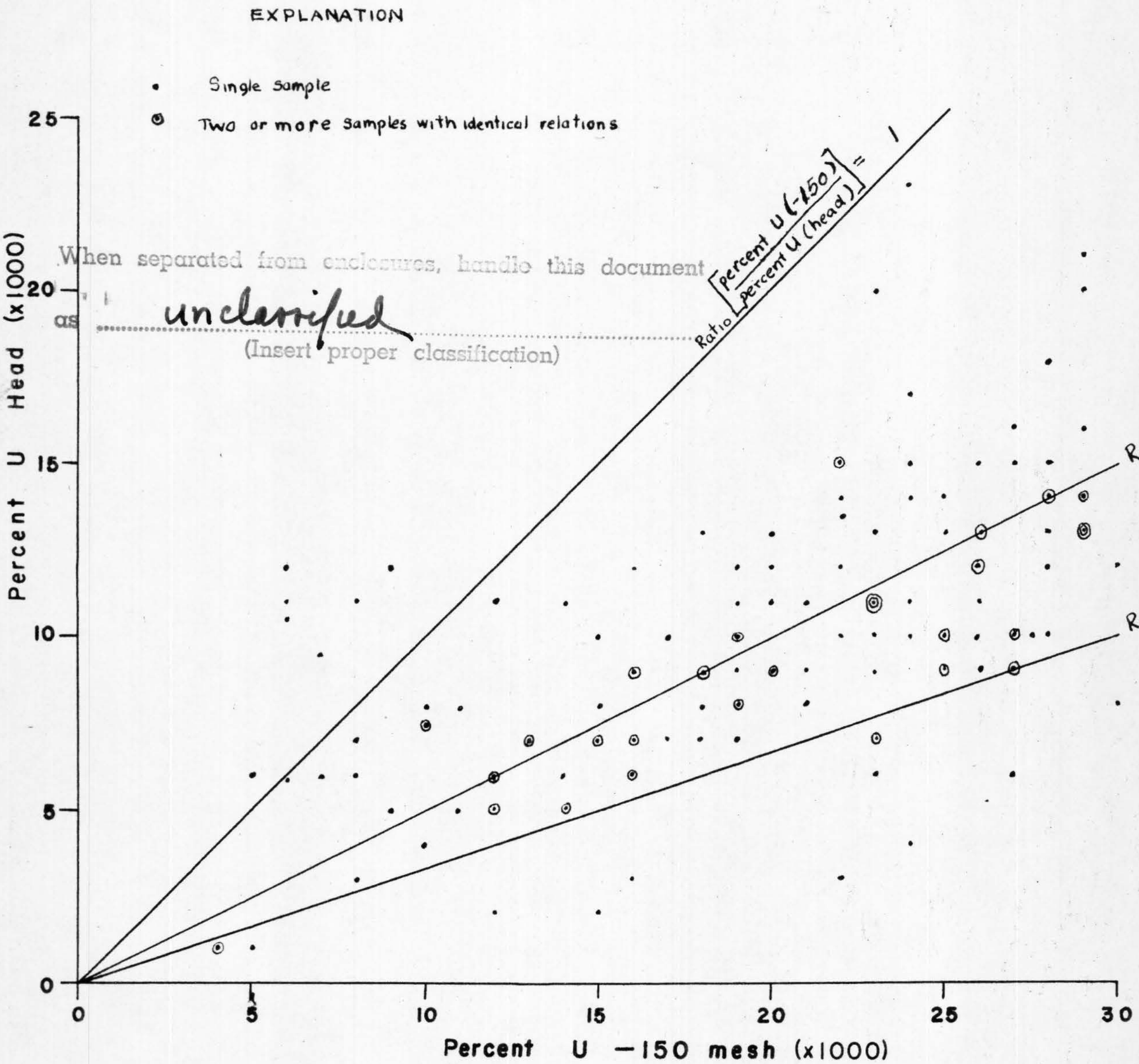

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FIG. 6. DIAGRAM SHOWING RELATION OF U CONTENT IN THE -150 MESH FRACTION TO U CONTENT IN THE TOTAL (HEAD) SAMPLE OF THE ALUMINUM PHOSPHATE ZONE.

[redacted]

Table 5 shows the variations in analyses, which might result from mining different parts of the aluminum phosphate zone. Data used are from Hole L-4, figure 7.

Table 5.—Variation in chemical analyses with depth of the aluminum phosphate zone

Interval	Average Al_2O_3 percent	Average CaO percent	Average P_2O_5 percent	Average U percent
10-22	9.4	6.1	8.6	0.008
12-22	10.2	6.8	9.4	0.009
12-16	12.9	2.9	8.4	0.013
20-22	6.3	12.1	11.5	0.006

The same variation can be seen in hole H-14, (fig. 7) and in figure 8, which shows the variations in analyses of the -150 mesh fraction from the surficial sands to the limestone of the Hawthorn formation.

Lateral variations

A series of maps have been made showing the variations in CaO, Al_2O_3, U, P_2O_5, and thickness of the aluminum phosphate zone. Most of the data used in preparing these maps are from drill holes spaced at one hole per 40 acres, but in a few areas (notably sec. 34, T. 30 S., R. 24 E.; secs. 3 and 4, T. 31 S., R. 24 E.; secs. 29, 30, 31, and 32, T. 30 S., R. 25 E.; and sec. 5, T. 31 S., R. 25 E.), the data are based on 8 or more holes per 40 acres.

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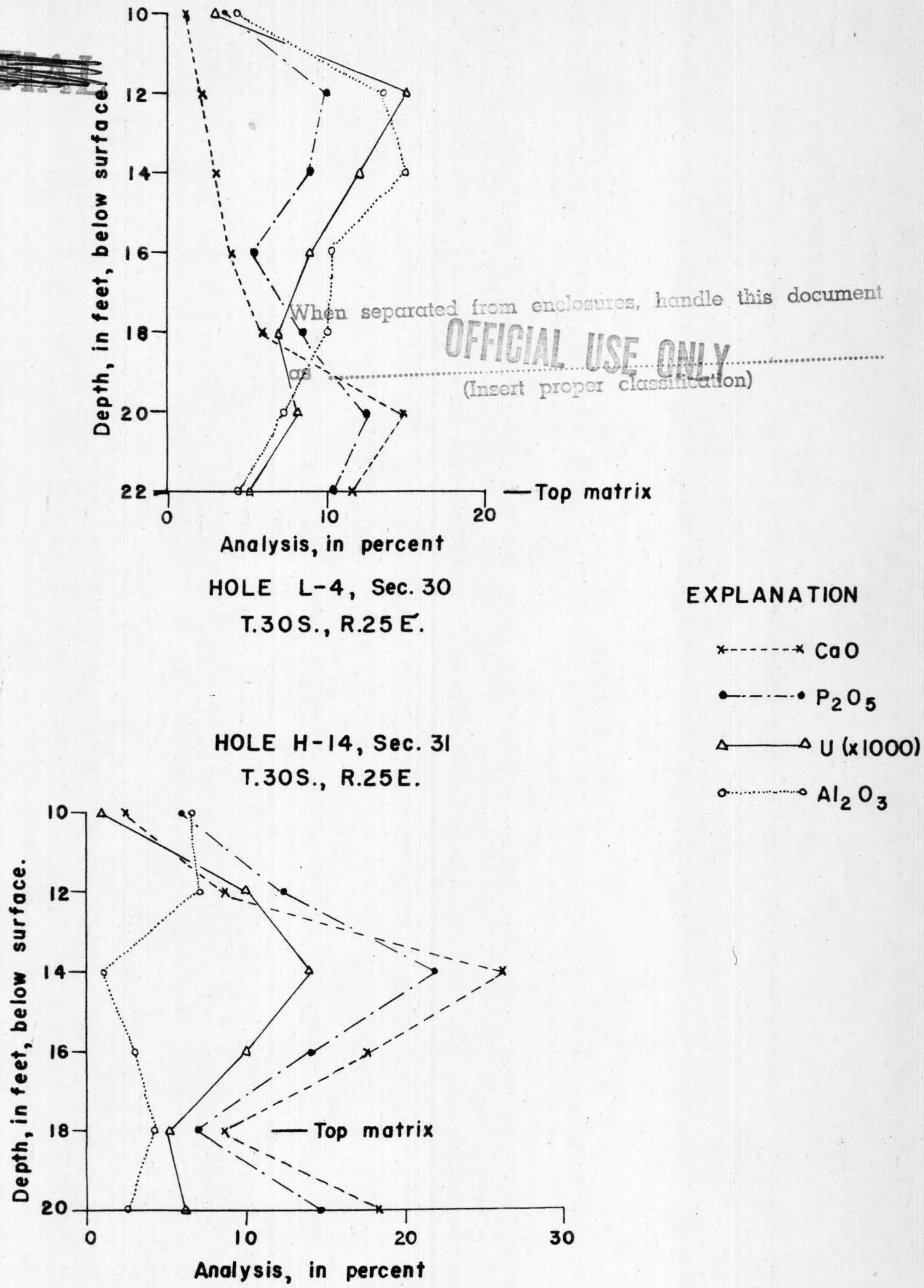

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FIG. 7. DIAGRAM SHOWING VERTICAL VARIATIONS IN ANALYSES, HEAD SAMPLE

Samples from drill cores

Analyses by International Minerals and Chemical Corp.

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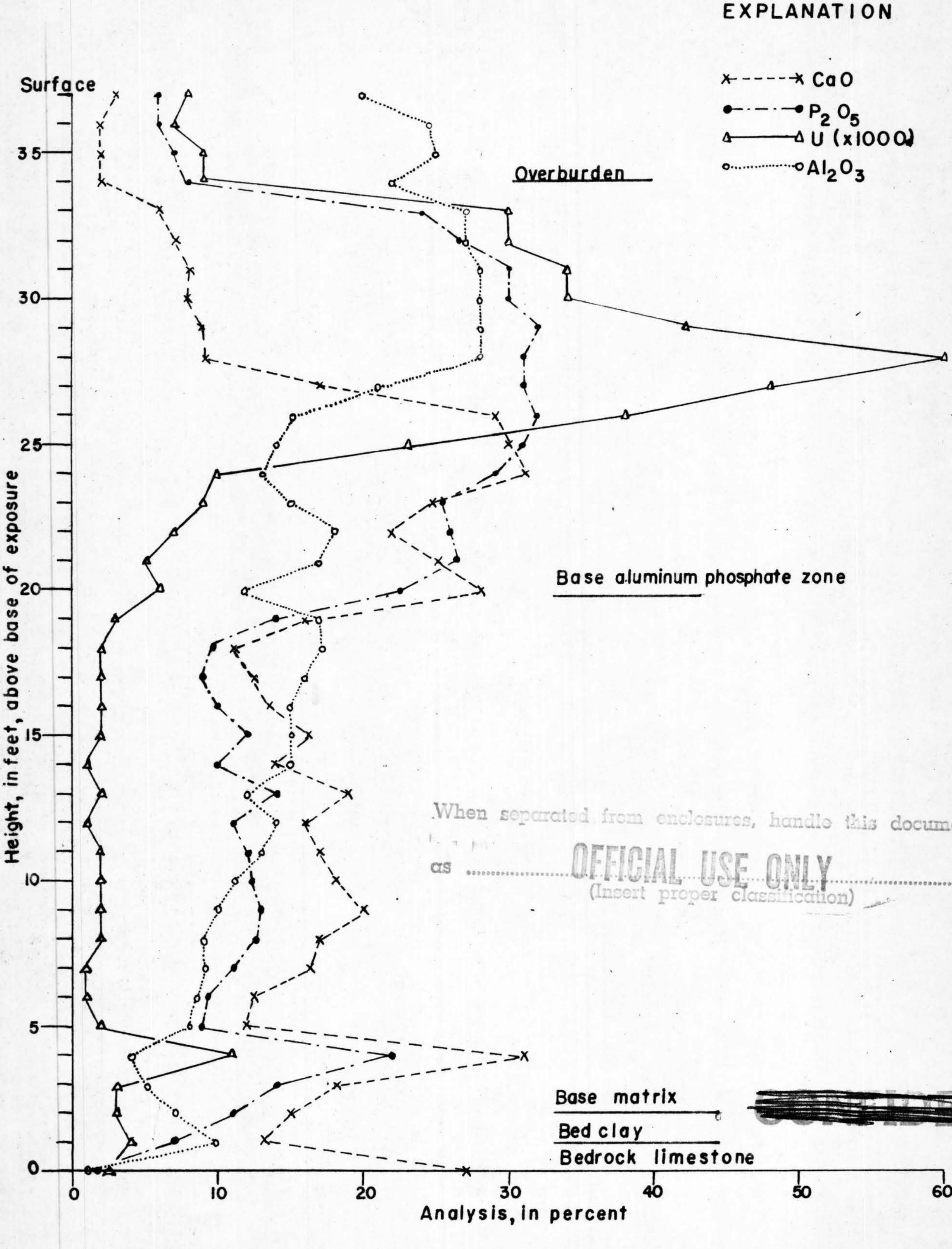

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FIG. 8. DIAGRAM SHOWING VERTICAL VARIATIONS IN ANALYSES, —150 MESH SAMPLES
Mine face section, Homeland mine.

The maps showing distribution of U and P_2O_5 are very similar. (See figs. 9 and 10.) Areas of high P_2O_5 content coincide closely with areas of high U content, and areas of low P_2O_5 content coincide with areas of low U content. This would indicate that gamma-ray logs, which give a measure of radioactivity, may be used to suggest the general range of P_2O_5 content as well as uranium content. This relation is also shown graphically on the favorability map (fig. 15). However, there are rather large areas (sec. 1, T. 31 S., R. 25 E.), where the U content and P_2O_5 content do not coincide. Therefore, this relationship should be used with caution.

There is also a general relationship between thickness and grade; areas underlain by the thicker parts of the aluminum phosphate zone tend to coincide with the areas containing higher-grade U and P_2O_5. (Compare fig. 11 with figs. 9 and 10.) Areas underlain by the thinner parts of the zone also coincide with low grade areas, particularly along the Peace River, but this can be explained as being due to the erosion of the aluminum phosphate zone by the river and the deposition, in its place, of non-phosphatic clayey sands of the floodplain. The map of Al_2O_3 distribution (fig. 12) shows that areas of medium content of Al_2O_3 extend along and across the Peace River in areas of low P_2O_5, CaO, and U content. This relationship might indicate an area of non-phosphatic clayey sands. There is, however, a belt of high Al_2O_3 patches in the west parts of T. 30 S. and T. 31 S., which is roughly similar to the belts of high P_2O_5 and U patches in west parts of T. 30 S. and T. 31 S.

The map of distribution of CaO (fig. 13) is somewhat different than the maps of U, P_2O_5 and Al_2O_3 distribution in that areas of high and medium CaO content are rather small, and throughout most of the area the CaO content is low. However, areas of high CaO content coincide very generally, with areas of high P_2O_5 and U content, although the areas of high CaO tend to be smaller in size. It is also true that some patches of highest U content correspond to patches of lowest CaO content.

In general, the distribution maps show large areas of fairly uniform grade aluminum phosphate zone, and also show that high U and P_2O_5 content go together, with generally high CaO content, although the last component is somewhat more irregular in distribution. However, these maps were made up from rather widespread data, and therefore, figure 14 was prepared in order to determine whether more closely spaced data would show similar patterns of distribution.

The distribution of P_2O_5, U, CaO, and Al_2O_3 is much more erratic in the closely spaced holes in figure 14 than would have been predicted from the favorability map (fig. 15). Each of the holes represents about two days of mining, and an examination of figure 14 shows that there would be marked variations in feed to a plant, and that these variations would be almost daily, particularly in the portion of the diagram represented by holes 7 through 12. The change in the character of the material is also significant. In the areas represented by holes 3 to 6 and 13 to 75, the material is high in Al_2O_3 and low in CaO, indicating the presence of aluminum phosphate minerals, while in the area represented by holes 7 to 12, the material is high and variable in CaO and P_2O_5 and low in Al_2O_3, indicating the presence of calcium phosphate or calcium aluminum phosphate minerals.

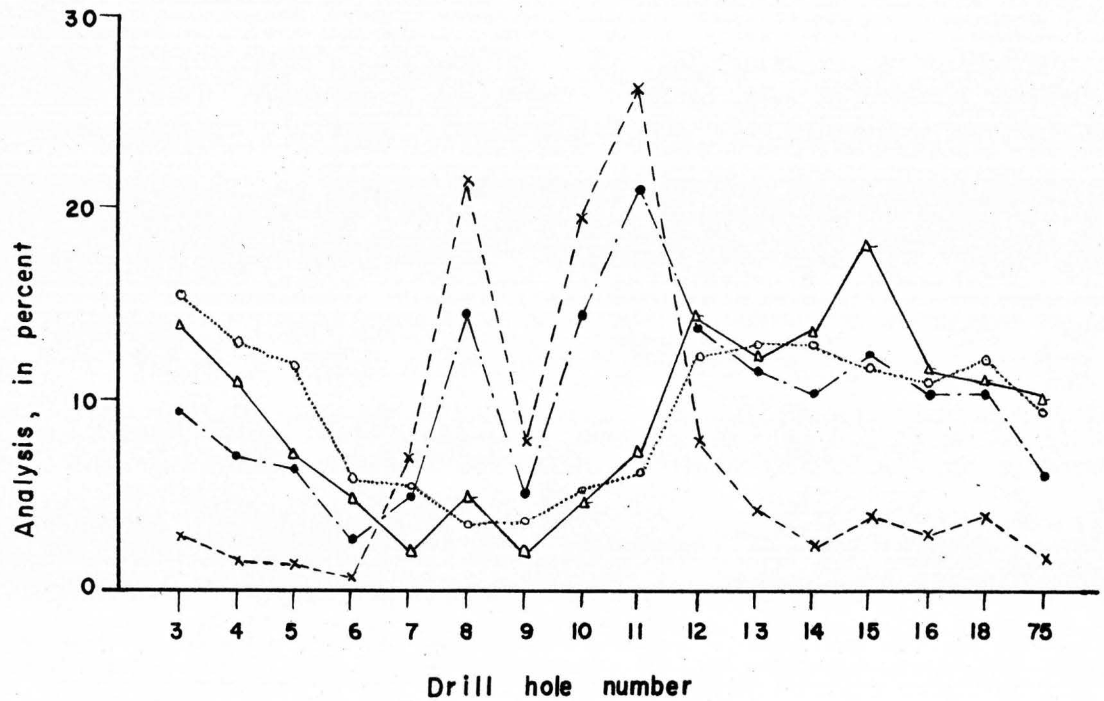
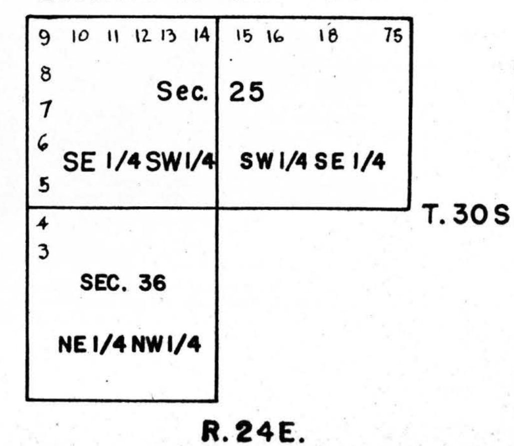


FIGURE 14. DIAGRAM SHOWING LATERAL VARIATIONS IN CaO, P_2O_5, U, AND Al_2O_3 IN THE ALUMINUM PHOSPHATE ZONE.

Location of drill holes



The discussion above is the most pessimistic interpretation. Alternatively, since this is a right angle traverse, there may be a continuous and uniform aluminum phosphate zone from holes 3 - 7, extending to, and including holes 12 - 75. However, even if this is not so, there are still two patches, each representing about one week of mining of relatively homogeneous, low-calcium material, separated by a patch of high-calcium, low-uranium material.

An examination of the maps of distribution (figs. 9, 10, 12, and 13) indicates that the area of figure 14 would be medium-grade in uranium (0.005 to 0.015 percent), variable grade Al_2O_3, medium-grade P_2O_5, and generally low-grade CaO. However, the detailed picture shows that only about two-thirds of the area falls into the above pattern, the remaining third being low in uranium (less than 0.005 percent) and Al_2O_3, and variable in P_2O_5 and CaO.

The preceding discussion indicated that variations in chemical analysis of the aluminum phosphate zone can be significant between samples spaced at 200 feet. Accordingly, two mines were sampled on 50 foot centers to determine the analytical variation between very closely spaced samples. Fifteen samples were taken at the Peace Valley mine, in sec. 8, T. 31 S., R. 25 E. The samples were taken at 50 foot intervals on the south face of a long east-west pit. A single sample of the entire thickness of the aluminum phosphate zone was taken at each locality. The overburden thickness was uniform, ranging from 6 to 9 feet, but the aluminum phosphate zone was much more irregular, ranging from 2 to 8 feet in thickness. No regular changes in thickness were noted in this section.

The analytical variations are plotted in figure 16. The close correspondence in the shapes of the lines of P_2O_5 and uranium is noteworthy. The peaks and troughs of the lines match very closely. The uranium content falls below 0.005 percent in only one sample, no. 12, but is 0.006 percent in holes 1, 3, 6, and 15. P_2O_5 falls below 6.0 percent in samples 1, 3, 6, 12, and 15, therefore all of these samples are of questionable economic value. Al_2O_3 content is uniformly high; falling below 10 percent only in samples 3, 6, and 11. CaO is very low in samples 1 through 9, and in samples 10 through 15 is strongly variable.

Twenty-one samples were taken at the Varn mine, in sec. 30, T. 31 S., R. 26 E. Samples 1-5 were on the north face of the pit and samples 6-21 were on the east face of the pit, making this a right angle section. The aluminum phosphate zone ranges from 11 to 13 feet in thickness on the north face and the north end of the east face and thins to a minimum of 2 feet at the south end of the east face. The overburden is thickest at the south end of the east face, and thins northward as the aluminum phosphate zone thickens.

Analytical variations are plotted in figure 17. The uranium content is higher and more uniform than at the Peace Valley mine. Only one sample, 21, falls below 0.010 percent. Also, although there is a fair correspondence between P_2O_5 and uranium contents, it is not as close as the correspondence shown in figure 16. The section from sample 1 through 15 is quite uniform, containing low CaO, high uranium, medium P_2O_5 (from 6 to 10 percent), and medium to high Al_2O_3 (from 8 to about 13 percent). In samples 16-21, as the section of aluminum phosphate material becomes thinner, the

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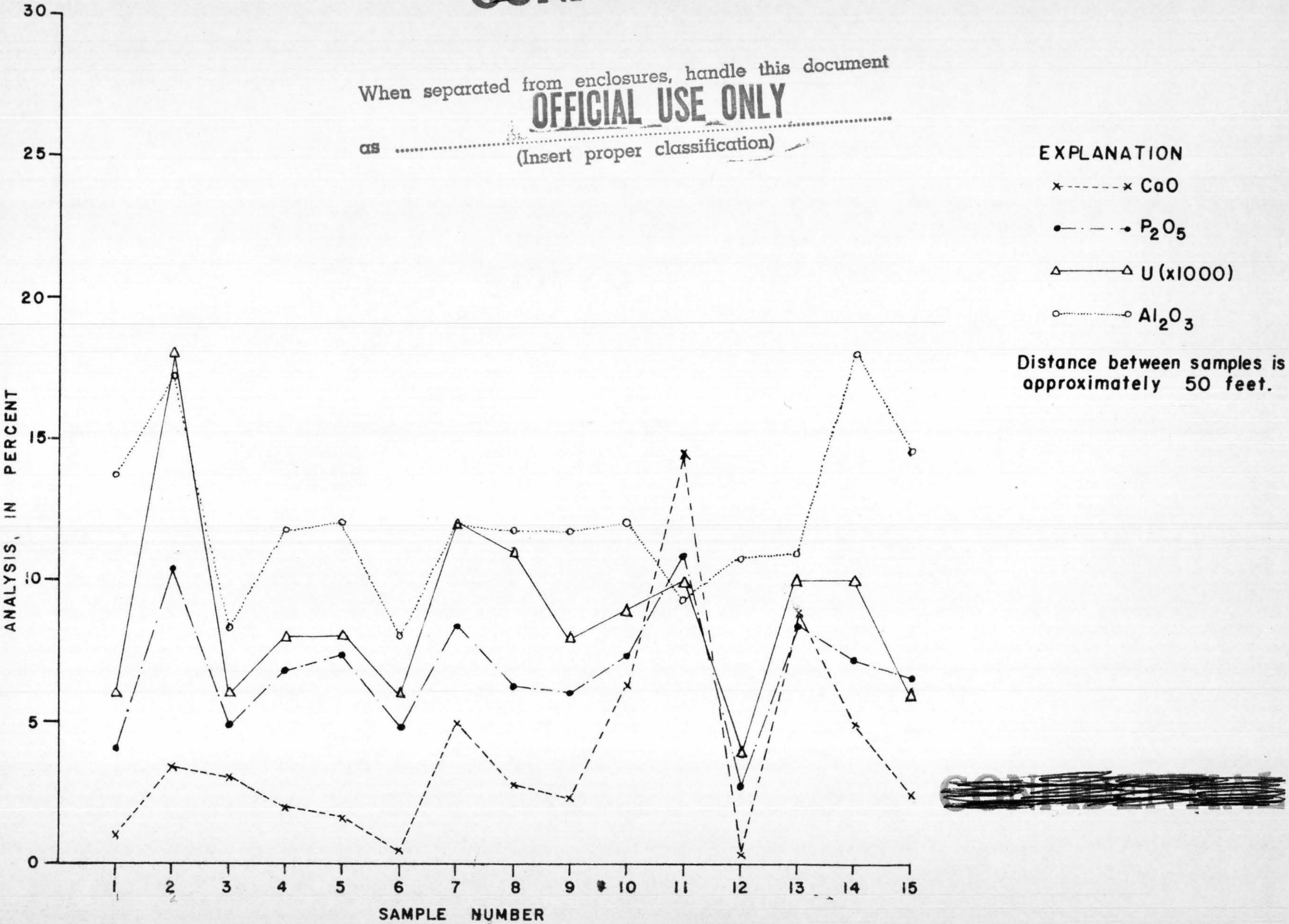

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FIG. 16. DIAGRAM SHOWING VARIATIONS IN ANALYSIS, CLOSELY SPACED SAMPLES, PEACE VALLEY MINE.
N 1/2 OF NE 1/4, SEC. 8, T. 31 S., R. 25 E.

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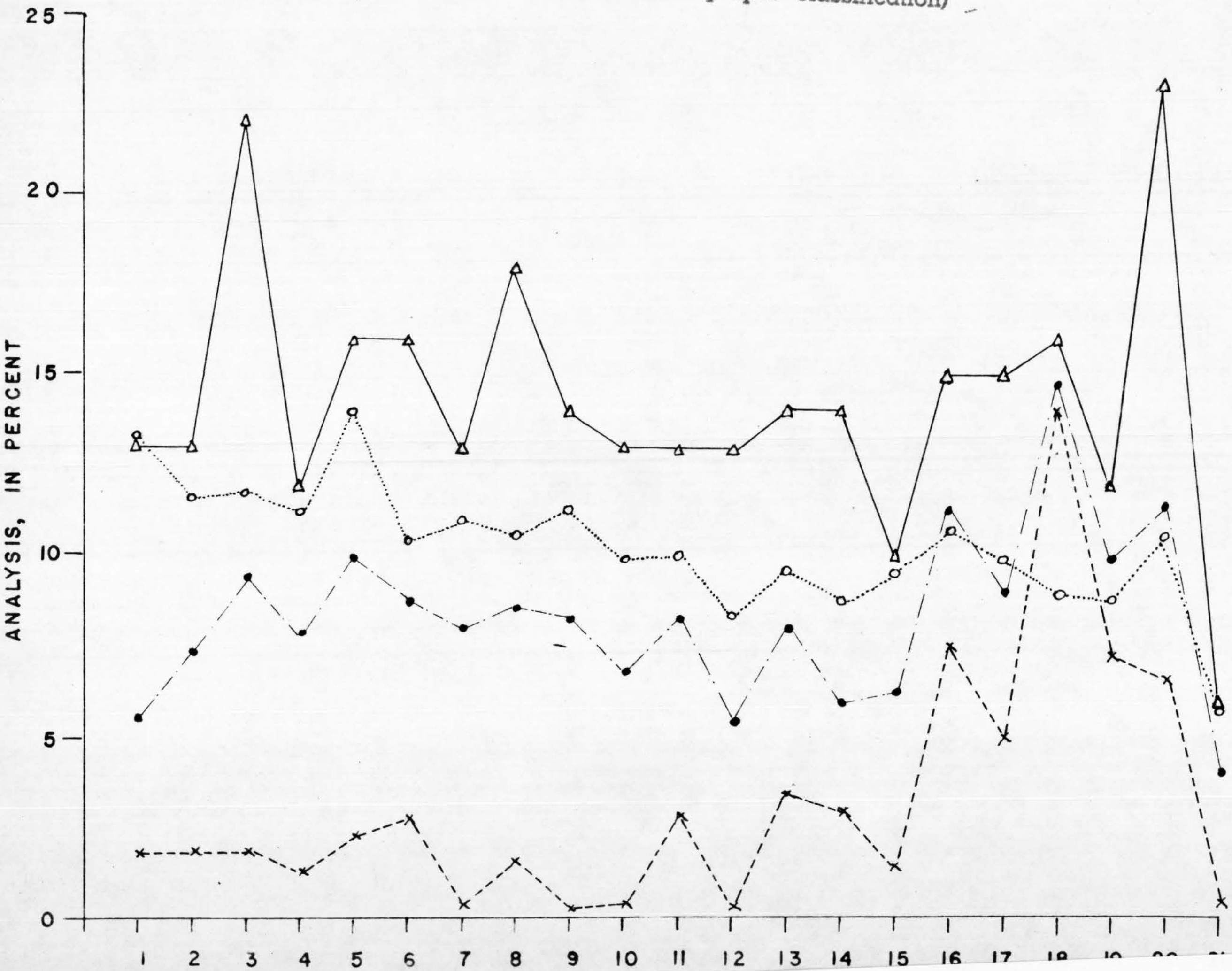

EXPLANATION

CaO

P_2O_5

U (x1000)

Al_2O_3

Distance between samples is approximately 50 feet, except that between 6 and 7, the distance is about 300 feet.

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analytical variations become more extreme; P_2O_5 ranging from 4.0 to 14.8 percent, CaO from 0.4 to 14.0 percent, U from 0.006 to 0.023 percent, with only Al_2O_3 remaining relatively uniform.

The conditions indicated by these closely spaced holes may also have general significance. They are in an area generally favorable for the aluminum phosphate zone, and it seems reasonable that similar variations will be found in other generally favorable areas.

RELATIONS OF GEOLOGIC FEATURES TO UTILIZATION OF THE ALUMINUM PHOSPHATE ZONE

A number of factors must be considered in discussing the economics of the aluminum phosphate zone. These factors can be divided, for purposes of this discussion, into those that directly affect the economics and those that indirectly affect the processing, or the final product. The direct factors are (1) thickness of waste material (overburden) above the zone, which must be less than an unknown maximum, (2) thickness of the zone, which must be above a given minimum, and (3) phosphate and uranium content in percent, which must be above a given minimum. If any one or combination of these factors are below the minimum limit, the zone is uneconomic.

The indirect factors are: (1) High CaO content which may make processing costs higher, and (2) high Al_2O_3 content which may make the final product less desirable. In those areas where the percentage of Al_2O_3 and CaO are too large the economic value of the zone may be questionable.

Another indirect factor which may become important in the future, is whether or not economic phosphate deposits underlie the aluminum phosphate zone. At present all mining of the zone must be integrated with the mining plans of the phosphate companies for the "matrix". A few scattered holes, in outlying areas indicate that a good aluminum phosphate zone is present in some parts of the land-pebble area where there is no underlying economic "matrix". Future prospecting may reveal more of those areas.

In the area of the Peace River drainage, the factor of excess overburden thickness has not been considered, inasmuch as overburden is thin enough in this area so that all of it is minable for matrix. It is, therefore, favorable for mining the aluminum phosphate zone.

The factor of thickness of the aluminum phosphate zone is important. All of the active phosphate companies consider three feet as the minimum thickness that can be economically mined with the large equipment currently used. Therefore the three foot isopach line has been used as a cutoff on figure 15 (favorability diagram). Any change in this factor, either raising or lowering the limit, would change only the details in the position of the line, for instance raising the limit to 4 feet would move the line away from the Peace River, and would add a few more isolated unfavorable patches in otherwise favorable areas.

The cutoff value of contained P_2O_5 has been arbitrarily placed at 6 percent, principally because some large areas contain less that 6 percent P_2O_5, and other large areas contain between 6 and 12 percent P_2O_5. Raising the limit would have about the same effect as raising thickness and uranium percent, i. e., it would tend to move the line away from the Peace River.

A limit of 0.005 percent uranium as a cutoff has been chosen because most of the samples which were above this value had high contents of uranium in the slime fraction. The U content of the slime fraction is about 0.015 percent and ranges up to 0.030 percent where head assays range from 0.005 to 0.010 percent U. These amounts of uranium in the slime fraction might be high enough to be economic if a sand-slime separation process is used in treating the material. Raising the cutoff value to 0.010 percent would make the unfavorable area much larger (fig. 9) by moving the cutoff line up to a mile further away from the Peace River.

It is interesting to note the very close similarity of unfavorable and favorable areas defined by each of the factors. An area paralleling the Peace River and about a mile in width is unfavorable with respect to all factors, and the actual lines for each factor correspond very closely. In the west two-thirds of T. 31 S., R. 24 E., small areas of favorable ground for one factor are generally not favorable for one or both of the other, resulting in a large area of generally unfavorable ground. This area is on the edge of the ridge unit and the line between favorable and unfavorable ground probably coincides fairly closely with the line dividing the ridge unit from the flatwoods unit. Generally, except for small patches, the area of the flatwoods unit contains favorable aluminum phosphate zone, and there is another favorable area to the east of the Peace River. The favorable area extends at least several miles south of the mapped area.

More data on the area to the south will be available sometime in the near future and will be discussed in a report now being prepared on the aluminum phosphate zone of the entire land-pebble district.

No cutoff grades for CaO and Al_2O_3 have been chosen, as too little is known about how they affect the economics and process technology, and their effects on the final product.

MINING PLANS

Mining of the aluminum phosphate zone in the Peace River area must be carried on at the time the underlying "matrix" is mined by the phosphate companies. Accordingly the mining plans of the phosphate companies are of importance in planning any exploitation of the aluminum phosphate zone. Three companies, International Minerals and Chemical Corp., Virginia-Carolina Chemical Corp., and Swift and Company are active at present in the area under discussion, and a fourth, Davison Chemical Corp. will start mining in 1955 or 1956.

International Minerals and Chemical Corp. operates the Noralyn and Peace Valley mines, both in areas that are favorable, and will move to one or two other areas if present plans are carried out. The Noralyn Mine will be in operation for many years, and as much as 7,000 tons per day of aluminum phosphate zone material will be mined. However, there will probably be short periods of time when no economic aluminum phosphate zone material will be produced. Plans for the Peace Valley Mine are somewhat less certain. Mining may continue for a number of years, but eventually will be moved east of the Peace River to the French area. As long as this company mines at Peace Valley, production of aluminum phosphate material might be as much as 7,000 tons per day, in favorable areas, but would be subject to the same variations in production as the Noralyn Mine. Production from the French area may be expected to be somewhat different, depending on precisely where the mining is carried on. The favorability map indicates that as mining approaches the Peace River, there will be periods when little or no aluminum phosphate material will be produced. Mining away from the river, however, might be expected to be in favorable ground, and perhaps 5,000 to 10,000 tons per day could be expected, again however, with short periods of time of little or no production.

Mining plans of this company for the New Phosphoria area indicate that eventually a large-scale operation may be started here, as a replacement for the Achan mine, outside the area under discussion. Inasmuch as the area where mining probably will start (secs. 3 and 4, T. 31 S., R. 24 E.), is unfavorable, only a sporadic production of aluminum phosphate material can be expected; therefore, this mine is omitted from the production table.

Virginia-Carolina Chemical Corp. operates two mines, Clear Springs and Homeland, both adjacent to the Peace River, almost on the line separating favorable and unfavorable areas. When mining in favorable ground, which would be about half-time, the two areas might produce up to 10,000 tons per day of aluminum phosphate zone material. Mining is expected to continue in this area for 10 years or more.

Swift and Company operate two mines, Varn and Watson, in the area. The Varn Mine is close to the Peace River, where conditions are the same as at the Clear Springs and Homeland Mines. Production from this mine, when in favorable ground might be as much as 1,500 - 2,000 tons per day; the lower tonnage is due to the much smaller operation. The Watson Mine is just south of the map area in secs. 4, 5, 8, 9, 15, and 16, T. 32 S., R. 25 E. Production may be as much as 3,000 tons per day in favorable areas. Present plans are that Swift will operate in these areas for 10 - 15 years.

Davison Chemical Corp. will move into the South Ridgewood area in secs. 10 and 15, T. 30 S., R. 24 E., in 1955 or 1956. Although only thickness data are shown on the maps, a few analyses and many gamma-ray logs indicate that this area is favorable, with only local small areas of unfavorable ground. Production from this area might be about 4,000 tons per day.

Production data are summarized in table 6.

Table 6.--Possible daily production of the aluminum phosphate zone.

		Possible average production short tons per day		Possible time (months/year) mining at average production	
Company	Mine	Current	Future	Current	Future
IMCC	Peace Valley	5,000		7-8	
	French		5,000		5-6 1/
	Noralyn	7,000	7,000	7-8	
V. C.	Clear Springs	4,000	4,000	5-6 1/	
	Homeland	4,000	4,000	5-6 1/	
Swift	Varn	1,000	1,000	5-6 1/	
	Watson	2,000	3,000	7-8	
Davison	South Ridgewood		4,000	8-9	
Total		23,000	28,000	7	

1/ When mining near Peace River there probably will be no production; this is assumed to be about half time.

As indicated in table 6, the average production time for aluminum phosphate zone might be 7 months per year, or possibly about 13,000 tons per day. It is possible, of course, that all of the mines might be in unfavorable ground at the same time, resulting in little or no production. However, indications are that mines in the favorable areas (Peace Valley, Noralyn, Watson, and later South Ridgewood) would be out of production for only a few days at a time, and during observations in the mining areas over a several year period there was no time when all of the mines in this area were in unfavorable ground. Therefore, it seems likely that the minimum production will be on the order of 5,000 tons per day. The maximum production, on the other hand might be about 23,000 tons per day, as there have been many occasions when all six mines in the area have been observed mining in favorable ground.

Because of the possible daily variations in tonnage and grade, plant design must consider large surge capacity and blending facilities. In addition, as pointed out by the writer and others (Cathcart, 1951; Cathcart and others, 1953), substantial tonnages of favorable aluminum phosphate zone are present in the overburden dumps of mined out areas. This material could be removed, according to company engineers, at a reasonable cost. Inasmuch as production could be spotty, it may be important to consider production from the overburden dumps as a standby operation.

TONNAGE AND GRADE OF THE ALUMINUM PHOSPHATE ZONE

Table 7 summarizes data on tonnage and grade for part of the area discussed. Data for the remainder of the area have not been computed as yet. These data have been computed from all possible sources, but most have come from gamma-ray logs, and are therefore, not precise. Because of the very large tonnages present, even if these figures merely show an order of magnitude, enough material is present for many years of mining. If 13,000 tons per day are mined (table 6 and discussion, manuscript p. 51), the yearly production will be 4 million tons. The tonnage shown in table 7, therefore, represents more than 35 years of production from these two townships. However, tonnages have been computed for only a small part of the total area, and considerably larger tonnages probably will be developed in these townships, possibly two or three times as large as shown.

Table 7.—Tonnage and grade summary, aluminum phosphate zone,

T. 30 S., R. 25 E., T. 31 S., R. 25 E.

	Percent of area computed 1/	Average thickness of zone (feet)	Average eU_3O_8 (percent)	Tons aluminum phosphate material (in millions of tons) Inferred	Tons aluminum phosphate material (in millions of tons) Indicated	Tons U_3O_8 Inferred	Tons U_3O_8 Indicated
T. 30 S., R. 25 E.	36	$7\frac{1}{2}$	0.012	56	44	7500	4970
T. 31 S., R. 25 E.	18	8	0.011	21	30	2355	3079
Totals				77	74	9855	8049

1/ Tonnages were computed only for 40 acre tracts with at least one drill hole.

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