CO-34

PN-ABC-384
68819

5140

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROJECT REPORT
Colombia Investigations
(IR)CO-34

MINERALOGY AND CHEMISTRY OF PHOSPHORITE AT SARDINATA, NORTE DE SANTANDER, COLOMBIA

314-05A

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature

Prepared on behalf of the
Government of Colombia and the
Agency for International Development
U. S. Department of State

FOR USE OF THE GOVERNMENTS OF COLOMBIA AND THE UNITED STATES ONLY

1975

MINERALOGY AND CHEMISTRY OF PHOSPHORITE AT SARDINATA, NORTE DE SANTANDER, COLOMBIA

By

James B. Cathcart
U. S. Geological Survey

CONTENTS

INTRODUCTION 1

MINERALOGY 1

CHEMISTRY. 6

Phosphate 8

Organic material. 8

Calcium 9

Flourine. 9

Carbon dioxide (CO_2). 10

Magnesium 12

Acid insoluble. 15

Alumina 15

Iron. 17

TRACE ELEMENTS 20

RECOMMENDATIONS. 22

REFERENCES CITED 25

ILLUSTRATIONS

Figure 1. Scatter diagram of relations of F and CaO to P_2O_5. . . 11

2. Scatter diagram of relations of CO_2 to P_2O_5 13

3. Scatter diagram of relations of MgO and the ratio of CaO/P_2O_5. 14

4. Scatter diagram of relations of P_2O_5 and CaO to acid insoluble 16

Figure 5. Scatter diagram of relations of Al_2O_3 and P_2O_5 18

6. Scatter diagram of relations of Fe_2O_3 and P_2O_5 19

TABLES

Table 1. Mineral composition, in percent, of selected samples of phosphorite from Sardinata 4

2. Average chemical composition of phosphorite, Sardinata . . 7

3. Semiquantitative 6-step spectographic analyses, Sardinata phosphorite. 21

MINERALOGY AND CHEMISTRY OF PHOSPHORITE AT SARDINATA, NORTE DE SANTANDER, COLOMBIA

By James B. Cathcart
U.S. Geological Survey

INTRODUCTION

The phosphorite deposit at Sardinata, near Cucuta in Norte de Santander, was explored by Empreso Colombiana de Minas (ECOMINAS). Exploration data, including maps (geologic and topographic), drill hole and trench location, thickness of the phosphorite and the overburden and chemical analyses, were given to the Instituto Nacional de Investigaciones Geológico-Mineras (INGEOMINAS) to prepare reports and maps on the deposit. A series of detailed maps are being prepared by Dr. Pedro Mojica G. of INGEOMINAS to calculate reserves.

This report, on the mineralogy and chemistry of the phosphorite, was prepared using the chemical data of ECOMINAS, X-ray and thin section on mineralogy by the writer and spectrographic analyses by the U. S. Geological Survey (USGS). The work was done as part of a cooperative program between INGEOMINAS and the USGS, sponsored by the Government of Colombia and the Agency for International Development, U. S. Department of State, under PASA LA(IC) 40-71, Loan Agreement 514-L-0588.

MINERALOGY

The mineralogy of the phosphorite at Sardinata is basically simple; principal variations are due to the amount of weathering that the rock has undergone.

Where the phosphorite is covered by 8 meters or more of younger rock (overburden), the chemical analyses and mineralogic data prove that calcite is a major mineral phase. In general, where the overburden is less than 8 meters thick, calcite has been removed by weathering by acid groundwater, and where the phosphorite is at the surface (as in road cuts), acid weathering has dissolved some of the apatite. There are, then, three types of rocks which are gradational into one another.

X ray diffraction analyses show that the unweathered phosphorite contains from 40-60 percent apatite, 15-40 percent calcite, 5-15 percent quartz, and trace to minor amounts of clay, pyrite, feldspar, mica (sericite), and in some samples, trace amounts of glauconite and iron oxide. The rock is black, owing to organic material.

No clay mineral separations were made--the X-ray identification of the clay minerals is based on the major (basal) reflection and must be regarded as tentative. Some samples contain chlorite, some montmorillonite, and some a mixed-layer clay.

The X-ray data show that the apatite mineral is a carbonate fluorapatite that contains only a moderate amount of CO_3 substituting for PO_4 in the lattice. The chemical data also clearly indicate that the apatite mineral is a carbonate fluorapatite. Apatite occurs as rounded ovate, structureless pellets, some with a thin rim of contrasting color; a few distinct, nearly circular, oolitic grains; phosphatized foraminifers; and a few larger, irregular, rounded structureless nodules. The pellets range from about 0.1 to 0.6 mm in diameter, and average about 0.3 mm; nodules are as much as 1 cm in diameter. There are also a few irregular fragments of fish bones.

Quartz is present only as silt-size detrital grains; some grains within the pellets are very fine grained. No sand-size quartz was seen in the thin sections. Calcite is present as fine-grained cement and as calcitic foraminifers. Organic material, dark-reddish-brown to almost black, is present in the calcitic cement and stains and coats the phosphate pellets.

Where fresh rock grades into weathered rock, the amount of calcite decreases until the rock contains only apatite and quartz as major mineral phases; clay, sericite, orthoclase, iron oxide, and organic material are present in trace to minor amounts. Apatite in the weathered rock has the same textural form as in the fresh rock, but secondary apatite that fills cracks and pore spaces is also present in the weathered rock. Some silt-size quartz and trace amounts of feldspar are present as detrital grains in the weathered rock, and are cemented by fine-grained chertlike silica that has replaced original calcite. Foraminifers are replaced by phosphate and silica; cell walls are replaced by apatite, the body cavity is filled with silica.

The most thoroughly weathered material contains apatite and quartz and trace amounts of iron and aluminum phosphate minerals and kaolinite. Some apatite is dissolved in the acid weathering, and P_2O_5, in solution, combines with alumina of the clay minerals to form wavellite, or with iron to form cacoxenite. The original clay minerals are altered to kaolinite in this last phase of the acid weathering.

Table 1. Mineral composition, in percent, of selected samples of phosphorite from Sardinata. Percentages determined from chemical analyses, mineral species determined by X-ray

(Tr, trace amount; -, not present)

Trench Number	128	44	22	7	5	154	84	60	134A	73	176	180	184	203	175	143	D.H.7
Ratio CaO/P_2O_5	1.01	1.20	1.26	1.28	1.32	1.37	1.40	1.42	1.46	1.47	1.50	1.55	1.61	1.70	1.82	1.91	2.55
APATITE	55	62	75	68	82	89	78	53	80	55	80	73	73	63	63	65	48
QUARTZ	25	20	12	15	8	4	10	27	11	25	6	6	8	12	10	5	6
CALCITE	-	-	-	-	-	-	-	-	-	Tr.	3	7	10	12	18	22	38
WAVELLITE	10	9	6	7	4	Tr.	-	-	-	-	-	-	-	-	-	-	-
CACOXENITE	4	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CLAY	Tr.	Tr.	Tr.	2	1	2	5	12	3	13	5	8	3	5	3	2	2
IRON OXIDE	Tr.	Tr.	Tr.	2	1	1	2	3	2	2	1	1	1	1	1	-	-
PYRITE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Tr.	Tr.
ORGANIC	4	4	4	4	4	4	5	5	4	5	5	5	5	7	5	5	5

The mineral composition of selected samples of the phosphorite was determined from the chemical analyses after the mineral species were identified by X-ray diffraction (table 1). The data are arranged from the most severely weathered (CaO/P_2O_5 ratio of 1.01) at the left to unweathered (CaO/P_2O_5 ratio of 2.55) at the right.

The gradational nature of the weathering is clearly shown in table 1. The most thoroughly weathered material contains both wavellite and cacoxenite, which decreases in amount with decreasing effect of weathering. In addition, both clay and iron oxide minerals increase in amount as the iron and aluminum phosphate minerals decrease.

Moderately weathered rock (CaO to P_2O_5 ratios of 1.37-1.47) contains apatite and quartz as major minerals in widely different amount (compare trench 60 and 84, table 1), and minor to trace amounts of clay and iron oxide. Calcite appears in trace amounts in less weathered rocks that have CaO/P_2O_5 ratios of 1.47 and 1.50; it becomes a major mineral phase in the relatively unweathered rocks of drill hole samples, and in the freshest rock trace amounts of pyrite are present instead of iron oxide. Organic material is relatively uniform in amount, about 5 percent in most samples. The most thoroughly weathered material tends to contain slightly less organic material than less weathered rock.

Because most of the samples analyzed (172 of 222) are moderately weathered (CaO to P_2O_5 ratios from 1.32-1.50), the principal variation in the rock, as mined, will be in the ratio of apatite to quartz (table 1).

Some calcite-bearing material is present between trenches that show no calcite, demonstrating the lack of uniform leaching. Additional trenching or drilling may be necessary to precisely outline the limits of noncalcareous rock.

CHEMISTRY

The chemical composition of the phosphorite deposit at Sardinata closely reflects mineralogy and geologic history--deposition, diagenesis, and alteration by acid groundwater in the modern weathering cycle. The chemical analyses, and in particular, the ratio of percent CaO to percent P_2O_5, are indicative of the amount and severity of the weathering. Samples from drill holes taken well below the surface have ratios greater than 2.0; samples from localities where the phosphorite is under moderate overburden (8 - 12 m) have ratios that range from 1.52-1.92; samples from localities where the overburden is thin (1-7 m) have ratios that range from 1.30-1.50; and samples taken at the surface have ratios of less than 1.3.

Chemical analyses of samples were grouped according to their CaO/P_2O_5 ratios, and then arithmetically averaged (table 2). The chemical data clearly show the changes due to weathering. In the first group of samples, the very high CaO/P_2O_5 ratio and the high CO_2 content clearly show that the samples contain abundant calcite.

The first effects of weathering are indicated with data of group 2. CaO, CO_2, and MgO are reduced, while P_2O_5, acid insoluble material, iron, alumina, and fluorine are somewhat increased. The amount of calcite is sharply reduced in these samples; quartz and clay minerals are increased.

Table 2. Average chemical composition of phosphorite, Sardinata

(Chemical analysis by ECOMINAS)

	Chemical composition, in percent			
	1	2	3	4
P_2O_5	21.34	26.60	28.04	28.97
CaO	47.51	43.59	39.73	35.73
MgO	0.86	0.25	0.18	0.17
Al_2O_3	0.88	1.14	1.98	2.59
Fe_2O_3	0.40	0.47	0.94	1.13
F	2.40	3.03	3.11	3.04
CO_2	13.73	5.71	1.30	1.72
Acid Insoluble	8.90	12.99	18.86	19.26
CaO/P_2O_5	2.23	1.64	1.42	1.23
F/P_2O_5	0.112	0.114	0.111	0.104

1. 16 samples, drill holes. Unweathered. $CaO/P_2O_5 > 2.0$
2. 24 " , trenches. Slightly weathered. " 1.52 - 1.92
3. 172 " " Weathered. " 1.30 - 1.52
4. 8 " " Very weathered. " < 1.30

As an effect of increased weathering, as shown by the samples of group 3, CaO, CO_2, and MgO are further reduced, while acid insoluble material, P_2O_5, iron, and alumina increase. The rock contains only apatite, quartz, and minor amounts of clay and iron oxide.

The most severe weathering is confined to surface outcrops and is represented by the few samples of group 4. P_2O_5 is slightly higher than in group 3, but CaO is sharply reduced, and F is slightly less. Iron and alumina are higher than in group 3. The solutions have dissolved some apatite; the P_2O_5 combines with alumina and iron to form aluminum and iron phosphate minerals and calcite is removed from the system.

Phosphate--The phosphate content, as P_2O_5, ranges from 18 to 37 percent. About 95 percent of all samples analyzed range from 20-35 percent P_2O_5, and by proper mining and blending, a feed to a plant of 25-30 percent P_2O_5 should be possible.

Almost all the P_2O_5 is present in the apatite mineral; only the most weathered samples contain a small amount of the aluminum and iron phosphate minerals wavellite and cacoxenite.

The relations of P_2O_5 to the other chemical elements are shown in a series of scatter diagrams (figs. 1 to 6) and are discussed in the following pages.

Organic material--The amount of organic material is not reported in the chemical analyses but probably ranges between 3 and 7 percent. Although the amount of organic material is not large, it is a major constituent in terms of its influence. Many of the trace metals are concentrated in the

organic material; the organic material is deleterious and must be removed prior to chemical treatment.

The organic material impregnates both the groundmass and the phosphate pellets and imparts a black to dark brown color to the rock. On calcining, the entire rock is bleached to a dull white color. The type of organic material is not known, but it appears to be both carbonaceous and petroliferous.

Calcium.--Calcium, as CaO, is a major constituent of the phosphate mineral, and is also present in the mineral calcite. In the noncalcareous samples, the CaO content varies directly with P_2O_5 content, and the correlation is strong (fig. 1). The ratio of CaO/P_2O_5 in carbonate fluorapatite ranges from 1.35 to about 1.50 and, on the scatter diagram, most of the points are grouped along the line of about a 1.4 ratio. Ratios below 1.35 indicate leaching by acid groundwater, and ratios above 1.50 indicate that some calcite is present.

Excess calcite is deleterious in chemical processing because of increased acid costs, but small amounts can be tolerated. The ratio of CaO/P_2O_5 may be as high as 1.6 before the rock will be rejected for having too much calcite.

Fluorine.--Fluorine, as F, ranges from 1.80 to 3.89 weight percent. The fluorine is almost entirely in the lattice of the apatite mineral. The ratio of F/P_2O_5 in fluorapatite is about 0.1, but in the carbonate fluorapatite, as CO_3^{-2} replaces PO_4^{-3}, an imbalance in charge results, and fluorine is added to balance the charge difference. Thus, in a carbonate fluorapatite, the ratio of F/P_2O_5 is greater than 0.1 and ranges as high

as 0.12. The scatter diagram (fig. 1) clearly shows that the fluorine content of most samples is within the range for carbonate fluorapatite, and the the average ratio of F/P_2O_5 is about 0.11. The few samples that plot above the 0.10 line (ratios less than 0.1) are leached, and a part of the P_2O_5 is present as aluminum or iron phosphate. Samples that plot below the 0.12 line (ratios greater than 0.12) contain fluorine in excess of that needed for the apatite mineral, and trace amounts of the mineral fluorite may be present. However, it is clear from the diagram that almost all of the fluorine is a part of the apatite mineral, and that the apatite mineral is a carbonate fluorapatite.

The apatite mineral is high in fluorine, and in chemical treatment of the rock, fluorine will be present in the air effluent of the chemical plant. Fluorine gases are toxic, both to plants and animals, and a chemical plant must have equipment for its removal.

Carbon dioxide (CO_2).--The CO_2 content of samples from Sardinata ranges from 0.33 to 16.31 percent. CO_2 is present both as calcite and in the apatite lattice. All samples that have CaO/P_2O_5 ratios greater than 1.55 also contain more than 4.0 percent CO_2, that is, a part of the CO_2 is present as calcite. In the samples that range from 1.30-1.50 in CaO/P_2O_5 ratios, the CO_2 should all be in the apatite lattice, and there should, therefore, be a positive correlation between CO_2 and P_2O_5--that is, an increase in P_2O_5 should be matched by an increase in CO_2. The scatter diagram (fig. 2) shows a slight positive correlation between P_2O_5 and CO_2, but the relation is not strong. The geologic history of diagenesis

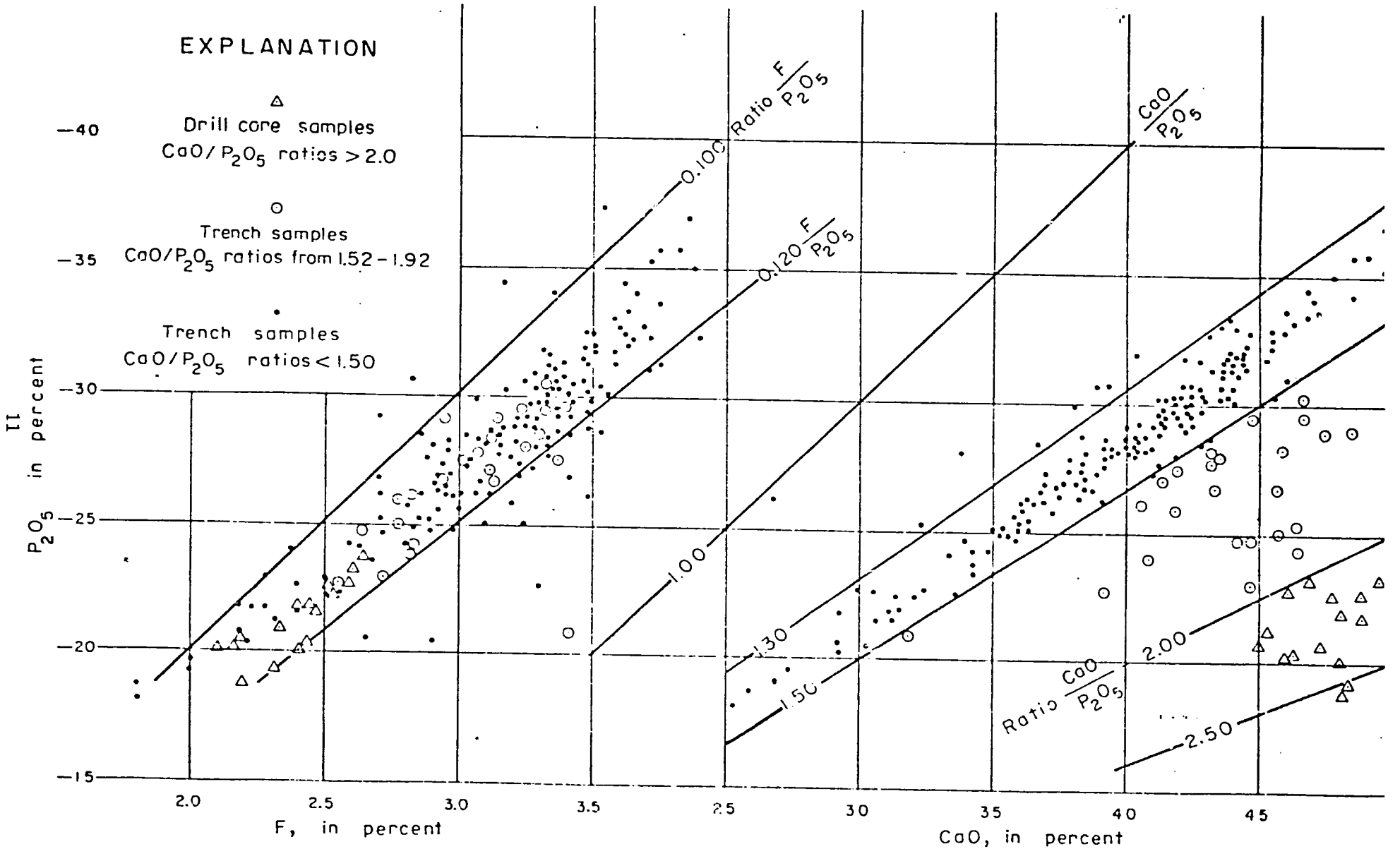

FIGURE 1. SCATTER DIAGRAM OF RELATIONS OF F AND CaO TO P_2O_5

and variable leaching after deposition has resulted in unequal addition or removal of CO_2 from the apatite. Most of the samples, however, are grouped around a line that represents a CO_2/P_2O_5 ratio of 0.04, indicating that CO_2 is present in the apatite lattice. Samples that have CaO/P_2O_5 ratios greater than 1.50 show no relation with P_2O_5 content; these samples contain some calcite, and if they were eliminated from the scatter diagram, the CO_2 to P_2O_5 correlation would be enhanced. The few samples with CaO/P_2O_5 ratios of less than 1.30 also show no relation of CO_2 to P_2O_5.

Magnesium--MgO in the noncalcitic phosphorite ranges from 0.06 to 0.57 percent. The MgO content of the calcitic-bearing samples is much higher, ranging from 0.13 to 2.15 percent. In the noncalcitic rock, the MgO probably is present in the apatite mineral. To test this possibility, a scatter diagram was made, plotting MgO in percent, against the ratios of CaO/P_2O_5. This diagram (fig. 3) shows that in the apatite range (1.30-1.45), there is a slight positive correlation indicating that at least a part of the MgO content is in the apatite lattice. The poor correlation may be due to the presence of small amounts of montmorillonite in some of the samples.

Magnesium, in amounts greater than about 0.5 percent MgO, can be deleterious in the production of superphosphoric acid, but the MgO content is below this limit in all but a few samples. MgO is present in large amounts only in the calcareous samples, where most of the MgO is in the lattice of the calcite. The small amounts of MgO in the noncalcareous phosphorite should not be a problem in processing the phosphate rock.

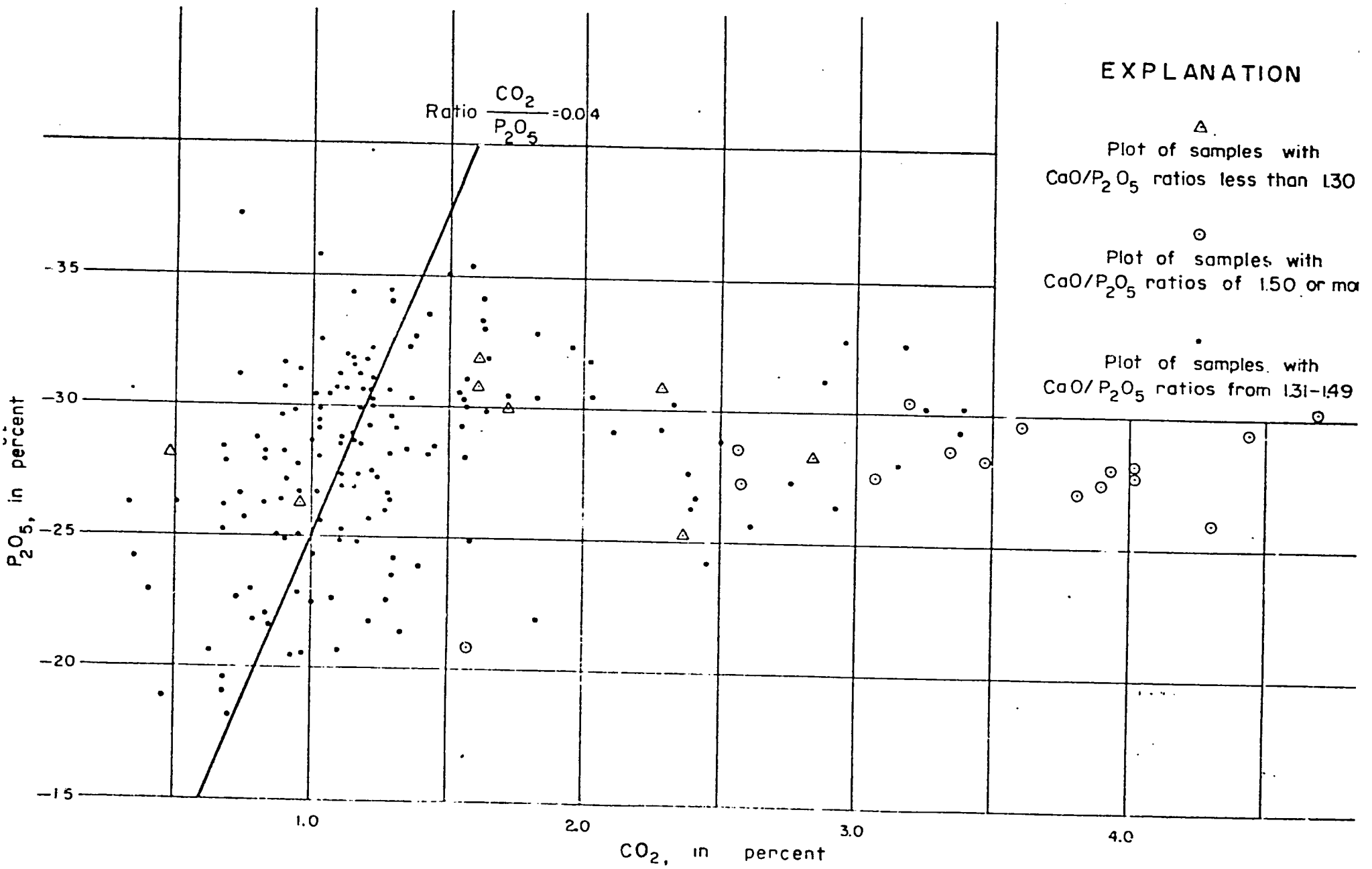

FIGURE 2. SCATTER DIAGRAM OF RELATIONS OF CO_2 TO P_2O_5

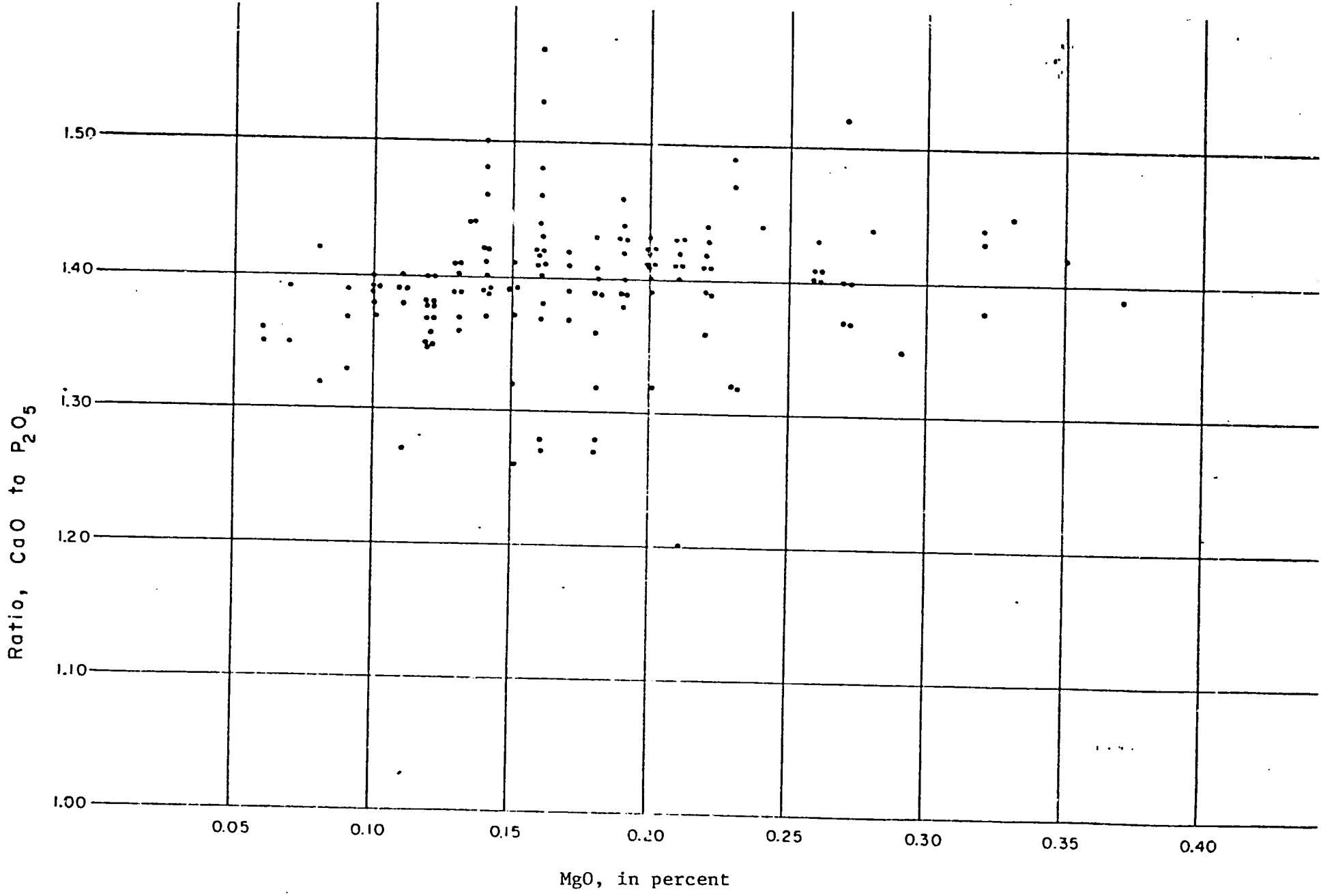

Figure 3. Scatter diagram of relations of MgO and the ratio of CaO/P_2O_5

Acid insoluble--The content of acid-insoluble material ranges from less than 5 percent to more than 40 percent and is mostly in the form of silica, as silt-size to very fine grained chertlike quartz. As the principal diluting material of the phosphorite, the relation of acid-insoluble material to P_2O_5 and CaO should be inverse and strong, and the scatter diagram (fig. 4) clearly indicate that this is true. Samples that contain calcite (ratios of $CaO/P_2O_5 > 1.52$) fall away from the excellent correlation line of P_2O_5 with acid insoluble, and fall in lower P_2O_5 groups in the diagram of CaO with acid insoluble. For example, the acid-insoluble content of the calcitic samples ranges from 5 to 15 percent, and they contain from 20-25 percent P_2O_5, whereas noncalcitic samples that contain less than 15 percent acid insoluble contain more than 30 percent P_2O_5.

Lateral variation in acid-insoluble content may be extreme. For example, the sample from trench 133 contained 44 percent acid insoluble, and that from trench 212, 150 m northwest, contained only 3.8 percent insoluble, and trench 132, 75 m east, contained 24 percent. There does not seem to be any regional trend in the acid-insoluble content, although some areas are relatively low (less than 15 percent). About 10 percent of the samples analyzed contained more than 30 percent acid insoluble, and 66 percent contained less than 20 percent acid insoluble. It should be possible to mine at several localities, and blend rock of differing acid-insoluble content to achieve a uniform feed to a processing plant.

Alumina--Alumina as Al_2O_3 ranges from 0.29 to 4.38 percent; alumina is present in the clay minerals, montmorillonite, chlorite, and illite; in the most weathered material, the clay mineral kaolinite is also present.

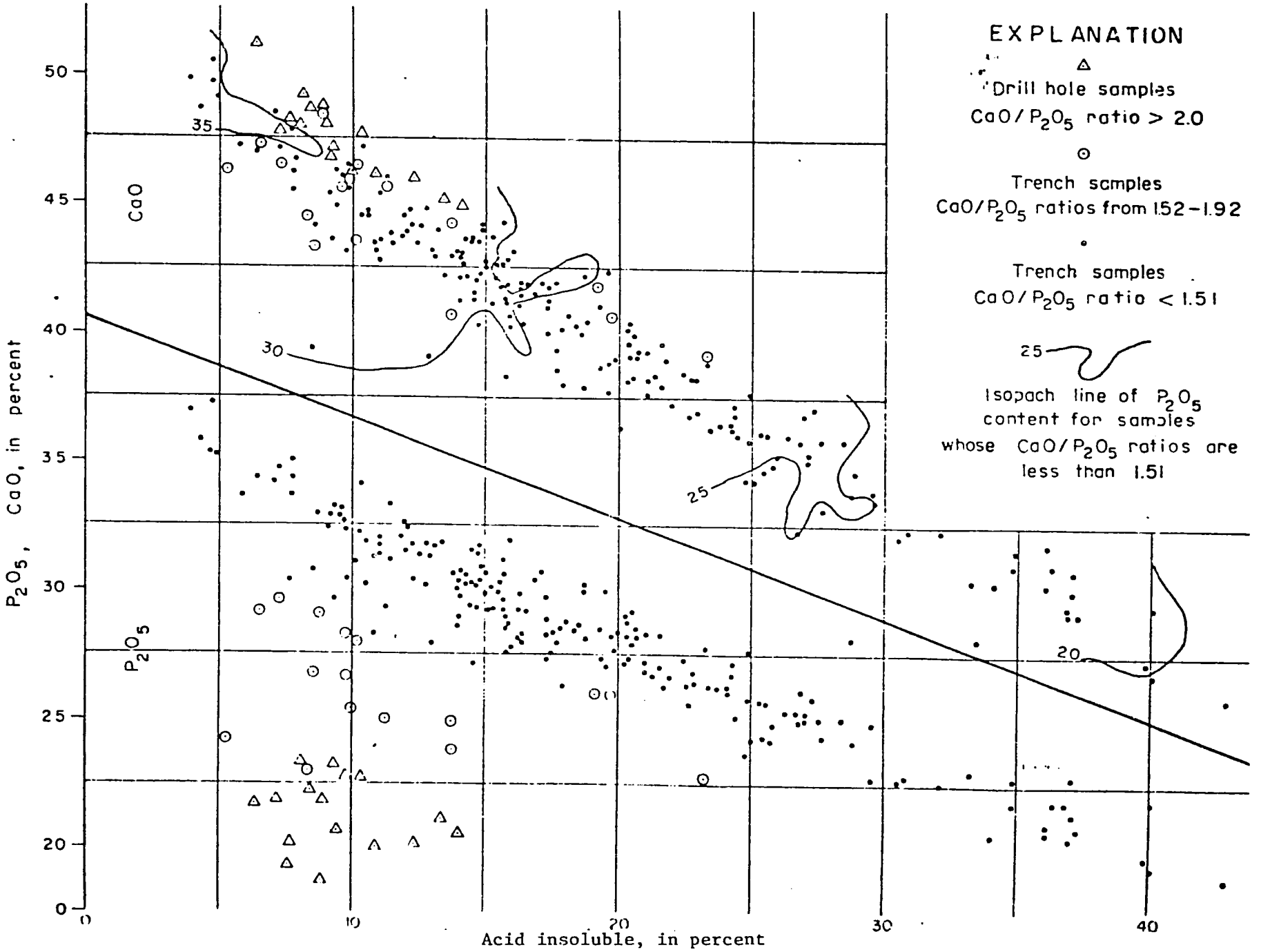

Figure 4. Scatter diagram of relations of P_2O_5 and CaO to acid insoluble

Some wavellite (aluminum phosphate) is present in trace to minor amounts in the most thoroughly weathered material. The scatter diagram (fig. 5) of relation of Al_2O_3 and P_2O_5 shows a slight negative correlation. When clay minerals are more abundant, phosphate minerals are less abundant.

Alumina is deleterious in chemical processing because it ties up P_2O_5 as insoluble aluminum phosphate, but the content is low in the phosphorite from Sardinata; only 2 percent of the samples contain more than 4 percent Al_2O_3, and almost 70 percent of the samples contain from 1 to 3 percent Al_2O_3.

Iron.-- Iron, as Fe_2O_3, ranges from 0.30 to 2.87 percent. In unweathered samples from drill cores, the iron is present as pyrite. Pyrite is altered to iron oxide (limonite) in the moderately weathered samples and in the leached, surficial samples iron is combined with P_2O_5 to form the secondary iron phosphate mineral cacoxenite.

Iron is diluting material, and is, therefore, in inverse relation to P_2O_5content, as indicated in the scatter diagram (fig. 6). The inverse relation is not strong. Samples from drill cores and from trenches cut where the rock contains some calcite are all very low in iron, and therefore, show no relation with P_2O_5.

Iron is not desirable in the manufacture of chemical fertilizers because it ties up P_2O_5 as insoluble iron phosphate. The iron content of Sardinata phosphorite is low, and the total content of Fe_2O_3 plus Al_2O_3 (called I and A in the fertilizer business) is below the maximum limit of 5 percent.

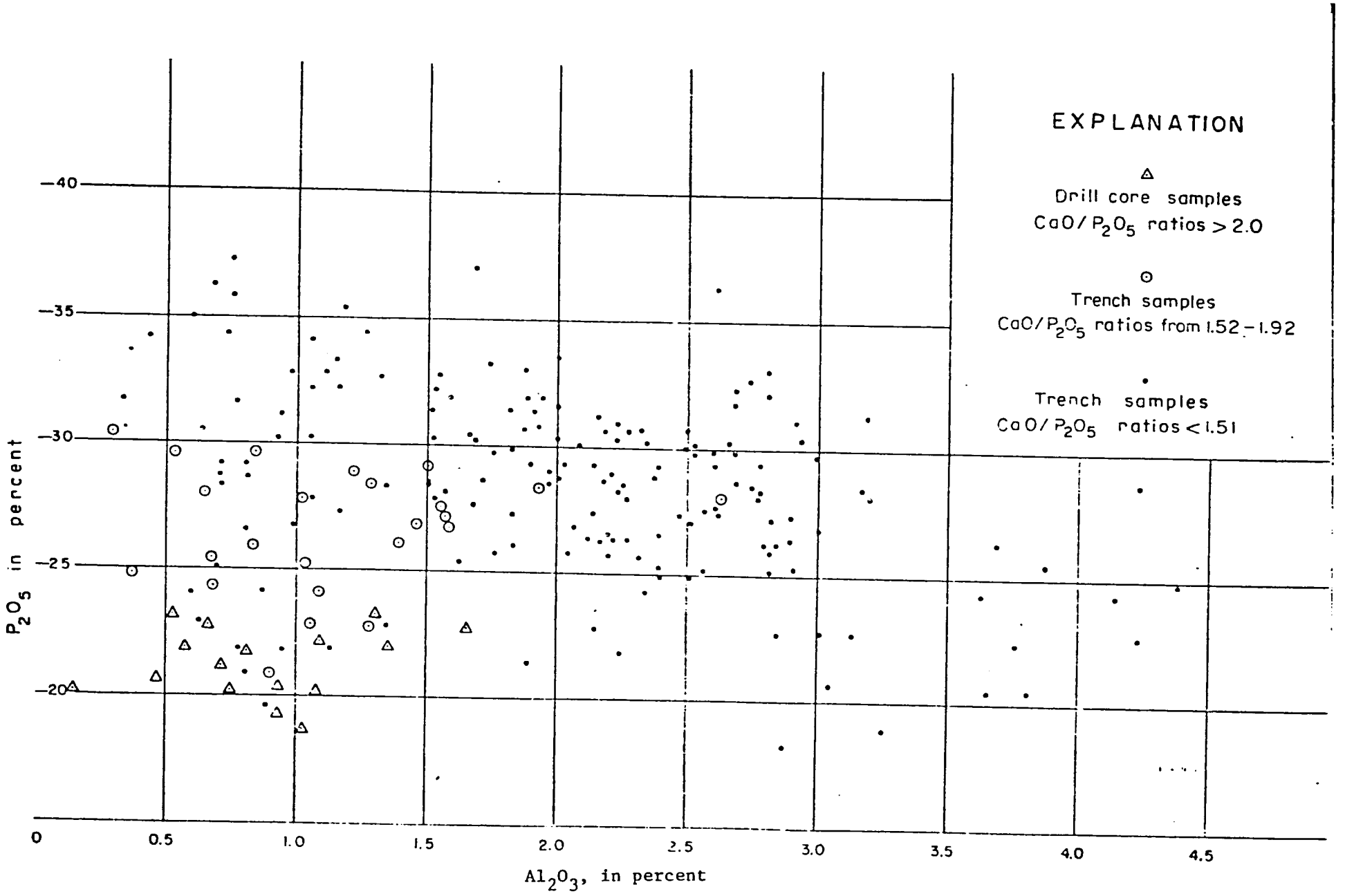

Figure 5. Scatter diagram of relations of Al_2O_3 and P_2O_5 .

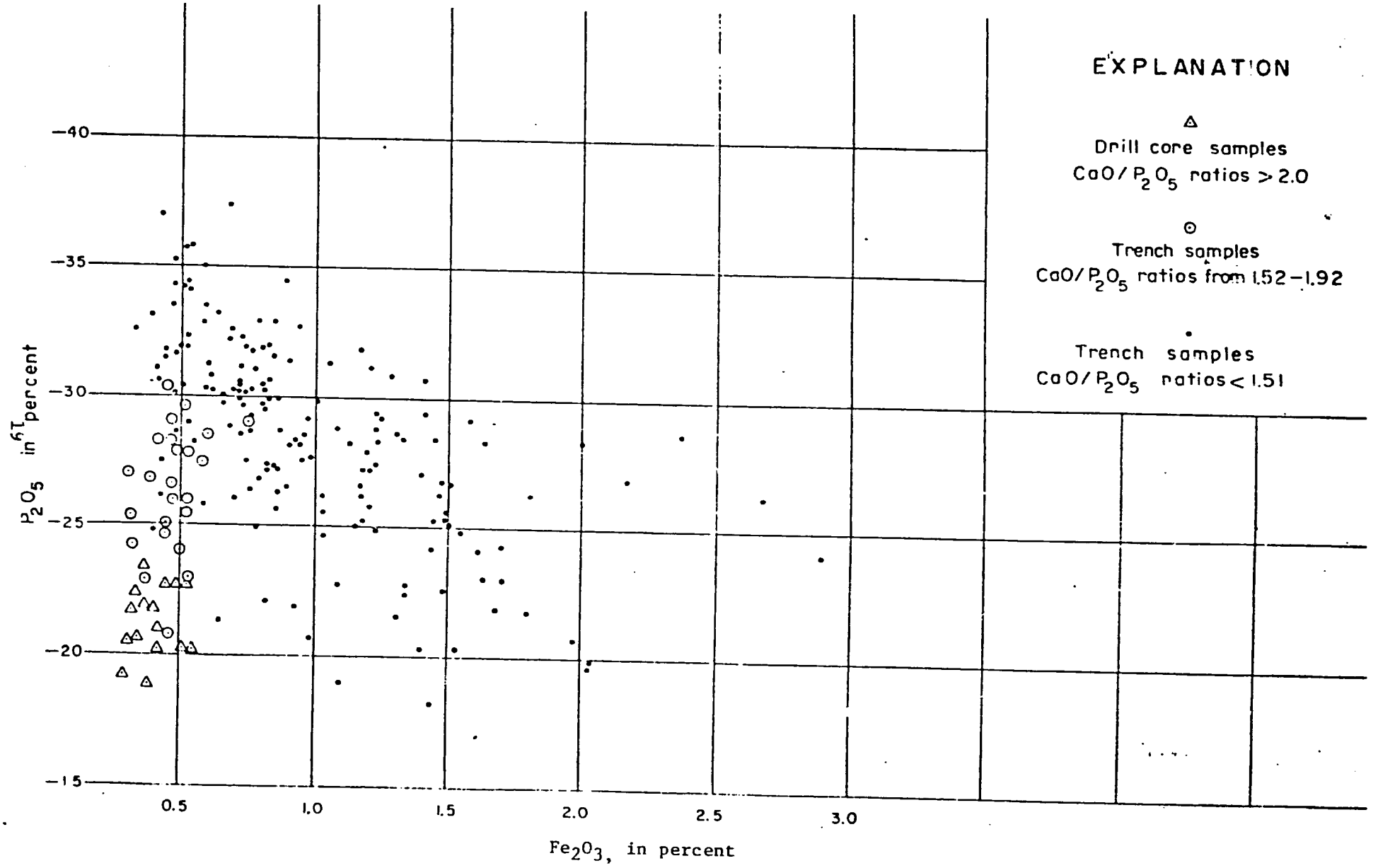

Figure 6. Scatter diagram of relations of Fe_2O_3 and P_2O_5

TRACE ELEMENTS

Semiquantitative spectrographic analyses made by the U. S. Geological Survey laboratory in Denver of 4 samples from Sardinata (table 3) show that the elements Ca, P, Al, Fe, Mg, and Si are present in amounts that are consistent with the oxide analyses of these elements discussed previously. Sodium and MgO may substitute for calcium in the apatite lattice; both are present in trace amounts--about 0.1 percent. Potassium is below the limit of detection in all samples. The rare earth elements (La, Ce, Y, Yb, Nd, Gd, Dy, and Er) are associated with apatite--scandium also may follow the rare earths. The amounts of rare earth and scandium in these rocks is about the same as in phosphate of the Phosphoria Formation of the western U.S. (Gulbrandsen, 1966), and in the phosphorite of the Pesca area (Cathcart and Zambrano, 1973).

Strontium undoubtedly substitutes for calcium in the apatite and is somewhat higher than in the Conejera deposit. The origin of the Sardinata rock, weathered from a calcareous phosphorite, may account for the slightly greater content of stontium.

Of the trace metals reported in the spectrographic analyses, Ag, Cr, Cu, Pb, Mo, Ni, V and Zn are probably associated with organic matter (Krauskopf, 1955; Gulbrandsen, 1966). This possibility is supported by the fact that the phosphorite from Conejera, which is very low in organic material, is also somewhat lower in all of these trace metals (Cathcart and Zambrano, 1973).

Manganese, barium, beryllium, zirconium, and gallium do not seem to be related either to the apatite mineral or to the organic phase.

Table 3. Semiquantitative 6--step spectrographic analysis, Sardinata phosphorite (Harriet G. Neiman, analyst, USGS, Denver. G = Greater than 10%; N = not detected, L = detected, but below limit of determination).

	IGM-10791 D127999	IGM-10798 D123003	C131-72 D159418	C 132 - 72 D159419
		IN PERCENT		
Fe	0.5	0.7	3.	0.5
Mg	0.1	0.15	0.1	0.1
Ca	G	G	G	G
Ti	0.3	0.2	0.1	0.02
Si	5.	5.	7.	3.
Al	0.7	1.	3.	0.7
Na	0.07	0.15	0.07	0.2
K	N	N	N	N
P	G	G	G	G
		IN PARTS PER MILLION		
Mn	15	15	20	15
Ag	0.5	0.7	1.0	1.5
Ba	1000	700	2000	10 000
Be	N	N	2	N
Cr	300	200	200	200
Cu	50	30	15	15
La	300	300	150	200
Mo	N	N	N	10
Ni	20	50	20	50
Pb	N	N	10	N
Sc	20	15	15	10
Sr	2000	2000	2000	3000
V	200	200	150	150
Y	500	500	200	500
Zn	N	200	N	N
Zr	20	50	50	20
Ce	N	N	N	200
Ga	N	N	7	N
Yb	20	20	15	15
Nd	200	150	100	100
Gd	N	N	N	L
Dy	N	N	L	N
Er	N	N	N	L
P_2O_5	31.84	30.0	25.0	32.9

Manganese is quite low, owing probably to the reducing conditions of deposition of the organic-rich phosphorite.

Gallium is probably associated with aluminum in the clay minerals. This association is indicated by the fact that gallium is above the limit of detection only in the sample with the highest alumina content.

Beryllium and zirconium are probably present as a beryllium mineral and in zircon, both in amounts too small to be detected by X-ray.

The barium content is fairly high--considerably higher than in rocks from Conejera. Barium may be present as the mineral barite, but in amounts too low to be detected by X-ray.

No elements are present that should cause problems in plant growth or in chemical processing. As a matter of fact some elements necessary in trace amounts for plant growth are present (Cu, Mo, etc.).

RECOMMENDATIONS

Although many trenches have been cut and a few holes drilled in the Sardinata deposit, some additional drilling and trenching should be done to determine the extent of the weathering. For example, Dr. Francisco Zambrano (written communication) reports that a small mine at Sardinata ran into calcareous rock 30-40 meters from the road cut, even though samples at the outcrop, about 150 meters from the road, contained no calcite. From the outcrop to the road cut, the dip is gentle, the overburden is less than 4 meters,

and the total section should be weathered. Evidently leaching is erratic, and unweathered material is present, at random, in the area thought to be leached. One line of closely spaced holes should be drilled, say from trench 126 or 127 (at the outcrop) to trench 137 or 137A at the road (a distance 125-150 meters) to determine, approximately, the ratio of weathered to unweathered rock. From the above, a refined estimate of tonnages can be made.

A contract will be negotiated with the Tennessee Valley Authority for research work on removing silica and organic material from the Sardinata phosphorite to produce a product high in P_2O_5, with less than about 4 percent silica, and with less than 1 percent total organic material.

Silica can be removed in several ways, as follows:

1. Grinding, screening, and desliming, followed by froth flotation. The tonnage amenable to open-pit mining at Sardinata, and which is also low in calcite, probably is not sufficient to support a flotation plant, and remaining reserves will be calcitic. No flotation testing should be done on Sardinata rock.

2. Scrubbing at a high-pulp density, followed by screening to remove slimes. A preliminary test indicates the method is promising. The concentrate (coarse fraction) was lower in silica and organic than the head fraction while the slime (fine fraction) was higher in silica and organic material. More research is needed to determine materials balances, and amount of P_2O_5 in the slime fraction. Several samples from that part of the deposit amenable to open pit mining should be taken and composited to make a representative sample.

3. Grinding, then calcining at elevated temperature, followed by immediate quenching. The friable chertlike silica may fracture in this situation, and wet screening may result in a reduction in silica in the coarse fraction. No testing has been done on this method.

4. Grinding of dry material followed by air elutriation as suggested by Hignett (letter, Jan. 1973), may reduce silica content in one of two ways: a) if both silica and phosphate are reduced to the same size in the grinding, air elutriation would separate silica because of its lower specific gravity; b) if the phosphate fraction is ground to a finer size than the silica, because the phosphate is softer, then air elutriation may concentrate the phosphate in the finer-grained fraction.

The possibility of pipeline transport of the phosphate to the Magdalena River has been suggested. It is possible that this transport would result in a differential sizing of the phosphate and silica, and wet screening at the pipeline terminus may result in a concentration of the phosphate either in the coarse size (silica breaks down because it is more friable than the phosphate) or in the fine sizes (phosphate breaks down because it is softer than the silica.)

Additional drilling of the deeper parts of the deposit should eventually be done to determine the extent and the structure of the phosphorite in the subsurface. The deeper rock is calcite-rich and will have to be mined by underground methods, and processed to remove calcite as well as silica.

Research on method of removal of calcite should be started as soon as possible. Calcite can be removed by froth flotation, or by calcining followed by quenching. This work should be done in Colombia, perhaps by means of research contracts with universities or within INGEOMINAS. There are many areas of calcareous phosphorites in Colombia, and calcite will have to be removed before chemical fertilizers can be made from these rocks; thus, an economic method to remove calcite will have a large impact on the development of a fertilizer industry in Colombia.

REFERENCES CITED

Cathcart, J. B., and Zambrano O., F., 1973, Mineralogy, petrology, and chemistry of phosphorite from the Conejera Area, Boyacá, Colombia: U. S. Geol. Survey Proj. Rept. (IR)CO-28.

Gulbrandsen, R. A., 1966, Chemical composition of phosphorite of the Phosphoria Formation: Geochim. et Cosmochim. Acta, v. 30, p. 769-778.

Krauskopf, K. B., 1955, Sedimentary deposits of rare metals: Econ. Geol., 50th Anniversary Vol. p. 411-463.