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PEGMATITE PHOSPHATES AND THEIR PROBLEMS*

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ABSTRACT

After an introduction with a few historical comments the writer deals with the matter of nomenclature (illustrated by apatite), including brief remarks on the use of the word *isomorphism*. The pegmatite phosphates are then discussed in terms ot 70 species, presented in four tables showing their chemical compositions; the separation into four tables is based on quasi-genetic grounds. Following remarks concerned with crystal structure and crystal chemistry of the mineral phosphates, the paper is concluded with a section giving data in tabular form showing the present status of *x*-ray studies of the pegmatite phosphates, both single crystal and powder diffraction; the latter is illustrated with 60 photographs. A final Table 8 serves as an alphabetical index to Tables 2 to 7.

INTRODUCTION

As a college student of mineralogy I was greatly impressed with the large amount of space given in *Dana's Textbook* to phosphates, though actually we worked with only a half dozen of them. The majority of recognized phosphate species are found in pegmatites, and indeed in presumed magmatic ones of granitic or syenitic derivation. Unless specifically stated otherwise, all reference to pegmatites in this paper is only to the granitic type. A pegmatite is a rock characterized especially by its texture and structure, composition, and mode of occurrence. In most cases the field geologist raises no questions as to whether he is dealing with a pegmatite or not. Moreover a phosphate is a compound that can be identified readily as such by the delicate and sensitive ammonium molybdate test, which is highly satisfactory on either a macro- or microscale. Thus on the whole it is plausible to try and isolate and talk about the little corner of nature which we designate the pegmatite phosphates.

If all you know about phosphates is what you learned in your college course in mineralogy, the only ones you have probably heard of besides apatite, phosphate rock, pyromorphite, etc., are amblygonite, monazite, turquoise, vivianite, and wavellite; though there is an outside chance of

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lazulite and triphylite also. You will be disappointed if you expect my talk this afternoon to make up for the phosphate deficiencies of your otherwise liberal education, or even just the pegmatite phosphate deficiencies. I have no time to explain how unique these minerals are; for instance there is an orthorhombic phosphate (childrenite) reported to have monoclinic optics, and a monoclinic phosphate (beryllonite) with orthorhombic optics.

I first became seriously interested in the pegmatite phosphates in 1941. In those pegmatites which carry phosphates, the latter are generally rather prominent, because of their unusual appearance (colors, stain, nodular character, etc.) though they are with few exceptions distinctly minor from a quantitative point of view. Recently on looking over my old notes I was amazed to find to what effort I went to identify these minerals. Tables compiled from Larsen & Berman (U.S.G.S. Bull. 848) were my main stand-by. But even so, there were many substances I was unable to determine in a way which left me satisfied. Perhaps nowhere is the relative backwardness of the study of mineral phosphates more clearly shown than in connection with atomic structure studies. Bragg's well-known book *Atomic Structure of Minerals* of only 20 years ago listed just one such mineral, apatite. To this was devoted $1\frac{1}{4}\%$ of the space allotted to silicates (under which two sentences were given to another phosphate, xenotime).

All this has changed greatly since then. With the work on the Varuträsk pegmatite by Quensel, Mason, and others, with the appearance of the Strunz *Mineral Tables*, Volume II of *Dana's System*, and the second Hintze *Ergänzungsband*, one is easily briefed on a tremendous amount of new pegmatite phosphate data.

The pegmatite phosphates are mineralogical step-children. Being in the main of no economic importance, they are only a pain-in-the-neck to the operator or even to the average economic geologist. The mineralogist examining a pegmatite may find all the good phosphate samples in one portion of the dump. They were thrown there with disgust from a nest-like occurrence in many cases. The operator doesn't like to talk about them. One can only hope that some of the lumps will also carry good samples of the associated minerals, so that worthwhile paragenetic observations can be made. At present the study of their crystallography is in an early mature stage, but tremendous strides have been made in the last quarter century. Combination of good optical, *x*-ray, morphologic, chemical, and physical work has established beyond question the validity of quite a number of species; but many others are still in a doubtful or problematical state. To judge from published reports, one can consider thin-section work on these minerals as little more advanced than that on the silicates was at the turn of the century. Much of this should be done on sections cut from samples on whose individual minerals *x*-ray, chemical, and immersion oil studies have been made.

NOMENCLATURE

An important "human" problem in connection with the pegmatite phosphates—as indeed with all other classes of minerals—is tied in with nomenclature. It is not my purpose to discuss this in great detail, but in order to clarify some of the statements made later, it is necessary for me to indicate how I deal with this subject. For example, let us take the most common phosphate—apatite. I am no expert on this mineral group; what I have to say is to be considered only as a means of illustration to make a point.

TABLE 1. APATITES—$A_{10}(XO_4)_6Z_2$

Composition	Names	Composition	Names
1. Alkali (Alk)	*Dehrnite*	9. Lead	*Pyromorphite**
	Lewistonite		*Mimetite** (As)
2. Aluminum		10. Mangan	
3. Arsenic	*Svabite** (Pb)	11. Oxy*	Voelckerite (Mn)
	Fermorite (Sr)	12. Rare-Earth (RE)	Britholite* (Si)
4. Barium	cf. *Hedyphane* (As, Pb)	13. Silico	*Ellestadite** (S)
5. *Carbonate** (Car)	Francolite	14. Strontium	Saamite, Belovite
6. *Chlor**		15. Sulfo	*Wilkeite** (Si)
7. *Fluor**		16. Vanadium	*Vanadinite** (Pb)
8. *Hydroxyl**			

* The 12 species of Strunz (1957), who calls fluor-apatite simply apatite. The 14 species of Dana (Vol. **II**, 1951) are italicized.

Table 1 shows some members and possible members of this group. The 16 sub-divisions are of course arbitrary; the number could be increased or decreased. Calcium and phosphorus are regarded as too standard to need listing. The handy term *collophane* is omitted. Moreover the subdivisions are not clean cut; the apatites are well known scavengers so far as selection of their component elements is concerned. To a slight extent this is indicated in the table by adding the symbols of certain chemical elements in parentheses after the mineral names.

The question is, how many mineral species are we dealing with, and where will we draw the more or less arbitrary subdividing lines? *Dana's System* splits them into three series, as follows: apatites (with 4 species), pyromorphites (with 3 species), and the roughly intermediate svabites (with 2 species); in addition there are five miscellaneous species outside of these three series. The fourteen Dana species are italicized in Table 1. Strunz (*Mineralogische Tabellen*, 1957) divides the apatite group into twelve species in four series; three of these are the same as Dana, except the apatite series also includes oxy-apatite and the svabite series has but one member; the fourth series of Strunz is the silicate series with three species (ellestadite, wilkeite, and britholite), the last of which is not given species rank in Dana. Chudoba (*Hintze: Erg. II*, 461, 1955) who follows the classification of Strunz, lists 29 names introduced since the 1933 volume (4_1, p. 487) of Hintze, which had 12 names with only four of species rank. Of these 29, there are three (abukumalite, britholite, and oxyapatite) which are regarded as well-established species that are not given this rank in *Dana's System*.

Some of the 29 names listed by Chudoba which do not appear in Table 1 are significant in this connection. These include alkalioxyapatite, cerapatite, fluormanganapatite, fluoroxyapatite, manganhydroxyapatite, manganvoelckerite, strontiumarsenic apatite, yttriumapatite, calcium-pyromorphite (collieite), phosphormimetite (campylite), cuprovanadinite, barium hedyphane, calciumbariummimetite.

It seems to me these double-compound names almost give the answer to our question. It is clear that the next step may be triply-compound names such as manganhydroxyfluorapatite for a sample from the Varuträsk pegmatite (*Dana II* 883, no. 4). My simple suggestion for dealing with this subject is to have one species—*apatite*. If in a given paper one wishes to characterize a certain kind of apatite by using more than one chemical prefix; e.g., instead of fluorapatite he wishes to designate carbonate-fluorapatite, he may use this long term once, putting "Car. F apatite" in parentheses after it, to show that throughout the remainder of the paper where he uses Car. F apatite, he means carbonate-fluorapatite.

The apatites may show chemical variation in three ways: 1) in terms of the cations, A; 2) in terms of $Z=$ F, Cl, OH (and O, S?, and CO_3??); and 3) in terms of X, the ion at the center of the tetrahedral group. It is possible that the X position can be occupied in whole or part by Al, As, B, C, Ga, P, Si, S, and V. Although little seems to be known about aluminum in apatite, by heating the rare pegmatite phosphate morinite [$Ca_4Na_2Al_4(F_6O_2)(PO_4)_4 \cdot 5H_2O$] the writer has recently produced a fluorapatite that contains some 26% of Al_2O_3 and 8% of Na_2O; it seems reasonably certain that at least a part of this aluminum is in tetrahedral coordination. This apatite is stable over the range 400 to 800°; at about 800° it inverts to a whitlockite structure of the same composition, from which at about 900° corundum begins to separate.

With the composition of the apatites viewed in this broad way, it seems that the mineralogist will defeat himself if he insists on giving a non-chemical name to each of these potential apatites. His subdivisions would not only have to be arbitrary; they would approach infinity. Even the twin tetrahedra that Johannsen used for his igneous rock classification with their numerous pigeon-holes would be quite inadequate. We mineralogists are occasionally asked "How many minerals are there?" Are there 300 quartz minerals? In the case of apatite it seems to me our only chance of agreement is to say there is just one; we are not likely to settle on any other number.

It should be made perfectly clear that it is realized there may be some value in retaining certain of the non-chemical names among the apatites, and particularly those of the members of Dana's pyromorphite series; their mode of geologic occurrence as well as their high lead content separates them in distinct fashion from most other members of the group. However this is hardly essential; thus Machatschki's use of lead apatite for the phosphate member in place of pyromorphite has much to be said in its favor.

It seems probable that every working mineralogist realizes the tremendous impact that *x*-ray crystallography has had on our science for the past quarter-century and more. But sometimes it is not clear that those who like to immortalize the names of their friends have really grasped the full significance of this epochal technique. As in using the polarizing microscope, only a few tiny grains of a mineral are needed; the result is a powder diffraction pattern. While it may not be possible to deduce the structure from this, whether it is isotypous with some known substance or not can be recognized as a rule. The thesis here advocated is in effect that if two or more chemically similar minerals have the same type of structure with approximately the same dimensions, it would be valuable if this could be implied in the name given them. Let it be emphasized that the lone structure concept can be pushed too far; there would be little sense in speaking of the isotypous halite and galena in terms of some name that indicated they had like structures. In short, particularly when dealing with substances having high symmetry, the question of mutual partial or complete solid solubility becomes perhaps increasingly important. There is no attempt here to lay down hard and fast rules; only the plea that all factors be taken into account when introducing a new term.

Chudoba notes that 2142 new names have been added to the literature in the two *Ergänzungsbände* of Hintze. Of these he considers that only 597 or nearly 28% may represent what he designates as valid new species; it is my opinion that this is a somewhat liberal figure. Of the 70 pegmatite phosphate minerals listed in my Tables 2–5, Dana's 1892 *System* gave 31 and the 1951 volume has 60. The rate at which attempts were made to add names to phosphate minerals is shown in the following tabulation taken from Spencer's lists in the *Mineralogical Magazine* covering the period 1901–1955 (the superscripts show the number of compound phosphates):

Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.
13	3	18	5^1	23	6^1	28	4
14	8	19	11^2	24	12	29	13
15	5	20	14^2	25	14^1	30	16^1
16	15	21	5^1	26	11^1		
17	10^1	22	11	27	6^1	Total	169

While on this subject, I wish to make some remarks on the use of the term "isomorphism." As first employed by Mitscherlich in 1819 following his study of the alkali phosphates, this concept was based on analogous chemical composition and substantially equal interfacial angles, though shortly thereafter he added the idea of vicarious elements introduced by Fuchs in 1815. The physico-chemical term *solid solution* was first used by van't Hoff in 1890. And yet today it is often common to speak of isomorphism meaning solid solution. Thus a few years back our Journal carried an article dealing with isomorphism in the chromites. But obviously the term isomorphism as now understood in any morphologic sense is meaningless when applied to isometric substances. We should revise our use of terms to take account of the advances made in knowledge of the electronic structure of the elements, the nature of the bonds, ionic radii, and x-ray crystallography in general, and we should be careful to use the term *isomorphism* only when crystal morphology also enters into consideration. There are many examples of isomorphous relationships (including of course "analogous" chemical composition) involving little or no solid solution; and there are substances mutually soluble in the solid state which are not isomorphous. It has been known for at least 130 years that calcite and soda niter are isomorphous; it has been clear for 37 years that they are isostructural; but they show no mutual solid solution. If we employ the term *isomorphism* to mean solid solution, what will we use when we want to speak of the phenomena designated by the word *isomorphism* when no solid solution is involved? Isomorphism, isotypism,* and solid solution are terms that have respectively a

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* In America it seems to be common to prefer *isostructural* rather than *isotypous*. The two are commonly taken to have the same meaning. It might be well to speak of the apatites as being isotypous but not quite isostructural (assuming the Cl and F occupy different positions in the lattice). Similarly triphylite, lithiophosphatite (Li_3PO_4) and heterosite are isotypous, but not quite isostructural in the strictest sense.

TABLE 2. PRIMARY PHOSPHATES

	Fe″—Mn″	Al—Fe‴	Be	Other
Li	Natrophilite* Triphylites	Amblygonites		Rare Earths {Monazites Xenotime
Na	Alluaudites (Fe‴) Dickinsonites Griphite (Al) Graftonite	Bøggildite* (Sr, F)	Beryllonite	Silicon {Nagatelite Lomonosovite*
Ca				Apatites (etc.)
Other	Triplites (F, Mg) Triploidites (OH)	Lazulites (Mg, Fe″)		

* Known from only one occurrence (lomonosovite is from a syenite pegmatite).

TABLE 3. LATER PHOSPHATES*

	Fe″—Mn″	Al	Be	No Other
Li		Palermoite† (Sr, OH) Brazilianite (OH) Morinite‡ (F, OH) (Lacroixite)† Roscherite‡(Mn″, Fe″)		Lithiophosphatite†
Na	Fillowite† Fairfieldites‡ Sarcopside (F) Ludlamite‡			
Ca			Herderites (OH, F) Hurlbutite	Whitlockite Isokite (F)
Mg		Souzalite†‡ (Fe″, Fe‴, OH)		
Other	Reddingites‡ Hureaulite‡	Augelite (OH)	Moraesite†‡ (OH) Väyrynenite† (Mn, OH) Faheyite†‡ (F‴, Mn″)	
	Childrenites‡ (OH)			

* The F-phosphates spodiosite and wagnerite have not been found in pegmatites; neither have the Al phosphates berlinite, kolbeckite (Be), tavistockite, and svanbergite (or hinsdalite).

† Known from only one occurrence; souzalite is a hydrothermal alteration product of scorzalite (a ferro-lazulite).

‡ Contains H_2O.

TABLE 4. SUPERGENE PHOSPHATES*
(not known outside of pegmatites)

	Mn''—Fe'''	Mn'''—Fe'''	Zn
Li	Sicklerites*		
Ca			Scholzite†
Mg		Bermanite† (Mn'')	
Other			Phosphophyllite† (Fe'', Mn'')
No Other	Kryzhanovskite† Landesite Pseudolaueite† Salmonsite† Stewartite Xanthoxenite	Heterosites*	

* All carry H_2O (not indicated in the Table) except heterosite and sicklerite; the latter may be of epithermal origin, as may pseudolaueite, stewartite, and some others.

† Known from only one occurrence.

TABLE 5. SUPERGENE PHOSPHATES*
(known occurrences not limited to pegmatites)

	Fe'''	Al	Pb, Zn	U
Na	Wardites			
Ca		Ca Goyazite	Parahopeite (Zn)	Ca Torbernite Phosphuranylite
Fe''	Frondelites (Mn'') Vivianite (no Fe''')			
Other	Paravauxite (Mg, Mn'') Koninckite (Mn''') Leucophosphite (K)	Sr Goyazite Ce Goyazite Wavellite (OH)	Pyromorphite (Pb, Cl)	Cu Metatorbernite Cu Torbernite
No Other	Beraunite Cacoxenite Fe''' Metavariscite Fe''' Variscite	Evansite Vashegyite	Parsonsite (Pb) Hopeite (Zn)	

* All carry H_2O (not indicated in the table) except pyromorphite; only (OH) in frondelites.

morphologic, a structural, and a crystallo-chemical or physico-chemical connotation; let us keep them that way.

THE PEGMATITE PHOSPHATES

But what has all this to do with the subject of this paper? Well, just this. Considered in the standard fashion one might say that there are about 105 established phosphate species known to occur in pegmatites; these include those phosphates which are found in pegmatites which have been subjected to more or less minor alterations under supergene conditions, but they omit the names of many very doubtful or unsatisfactorily described species. On the other hand, if we throw out what may be regarded in terms of the principles already covered as unnecessary or nonessential names, this number is reduced by 35, and thus amounts to only 70 species. Thus decreased by one third, it is more readily possible to make some remarks having in view the forest as a whole in spite of all the trees that are present.

Phosphorus is the eleventh most abundant element (after titanium and hydrogen) by weight in the earth's crust. It is estimated that at least 95% of the phosphorus in igneous rocks (mostly in those of the basaltic clan) is in the ubiquitous apatite. While this is perhaps the commonest phosphate mineral in granitic pegmatites, it is likely that in this environment both triphylites and amblygonites occur in greater amounts. Quantitatively speaking, it is known that pegmatites constitute an insignificant part of the lithosphere, and phosphates comprise a trivial volume of the great mass of pegmatites.

The large number of individual phosphate minerals occurring in certain pegmatites, as well as the rarity of many of them (at least seventeen are at present reported from only one locality) has been a drawback to their study. The beginner is overwhelmed; he hardly knows where to start. As late as 1930 the great Russian pegmatite mineralogist A. E. Fersman shuddered at this subject. At that time he dealt with only 35 phosphates, yet when he discussed the role of phosphorus in pegmatites he limited himself to a brief one-sentence paragraph concluding with the statement "the history of phosphorus is of the greatest interest and needs special investigation." Twenty-three of these phosphates were included in his hypercritical stage *G;* five were under more intense conditions, and seven under less intense.

The geologist interested in the origin of a given rock type, such as a granite pegmatite, would not select for genetic study some common accessory group of minerals occurring in this rock, with the expectation that his results would be of much significance from the larger point of view. Thus from the study of phosphates one could hardly hope to conclude much of a definitive nature as regards the broad question of the origin of pegmatites. But one is bound to fill in something on the natural history of a rock, even from the study of a "trace mineral" category. The large number of phosphate species simply points up the relatively limited range of stability of any one phosphate in general. Many of them can be considered as delicate indicators of the particular conditions present at the time of their formation. While dealing in general with much less than one per cent of the pegmatite mass, we may be working with a score or more of minerals all told. Thus as primary ones give way to secondary and even tertiary species—and possibly to supergene ones—we have conditions in existence of more or less temporary approximate equilibrium for one or another phosphate.

But let us proceed from the general to the specific. In Tables 2–5 my seventy phosphate species have been arranged in a fairly arbitrary but crudely genetic set of four divisons. These include what have been designated 1) primary, 2) later, and 3) supergene, the latter split into two categories depending on whether the known occurrences are limited to pegmatites or not; obviously as phosphate study proceeds, some or all of those listed in Table 4 will be transferred to Table 5.

Phosphates occur in any of the shells of zoned pegmatites, but those with important amounts generally carry most of the phosphate in an intermediate zone or a replacement unit. The 18 phosphates designated as primary (listed in Table 2) are those which typically occur in pegmatites in more or less large masses (exceptions are noted later). These are commonly in crudely spherical or ellipsoidal masses with a fringe of alteration product as a border. They generally seem to be somewhat corroded single crystals, not uncommonly of giant dimensions; they often have the appearance of nodules.

It should be emphasized that many of the minerals listed in this table occur in some pegmatites as a later formation. For example, what is now known as ferro-dickinsonite (arrojadite) was described by Headden in 1891 from a Black Hills pegmatite; here it occurred in large masses carrying cassiterite, and was obviously primary. Mangan-dickinsonite may be in part primary at Branchville, Conn., but at Poland, Me. it occurs as later crystals lining vugs. Similarly amblygonite, while often primary, is well known also as small crystals lining vugs. Quensel puts alluaudite in his supergene stage at Varuträsk; nevertheless, in some of its occurrences it is definitely a primary mineral. Apatite may be found in any of the zones of a pegmatite, in a replacement unit, or as needles shooting across vugs. In order to avoid repetition, no species is listed in more than one of the tables. It should also be recognized that probably rarely some phosphates listed in Table 3 may occur in small amounts in a given deposit as a primary mineral. The really typical primary phosphate minerals of the pegmatites are those shown in the first column of Table 2 (less natrophilite, known only from Branchville) plus amblygonite, and the rare-earth phosphates. Of course apatite is also commonly primary, but it and all of the others of Table 2 not specifically mentioned here do not occur as relatively large masses so typical of the characteristic primary phosphates.

It should be emphasized that the so-called primary phosphates listed in Table 2 are not limited to the original minerals of the various zones. Thus Shainin considered that at Branchville the manganese phosphates occur in one of three replacement units; in fact the smallest one, the cleavelandite-spodumene unit. Natrophilite is regarded as primary here because of its close association with mangan-triphylite; fillowite is placed in Table 3 because of its close association with reddingite. Beryllonite is included in Table 2 (rather than Table 3) since it is recognized by Volborth as being the first beryllium phosphate to be formed at Viitaniemi, Finland, where it occurs in a replacement unit; hydrothermal action altered part of it to hurlbutite, and part of the latter to herderite. Ferrolazulite (scorzalite) has been found in the wall zone of a Black Hills pegmatite.

Table 3 lists 20 "later" phosphates; these are commonly considered to be of hydrothermal origin, but since many of those given in Table 2 may also be of this origin, the term is not applied. In certain deposits some of these are considered to be hydrothermal alteration products of one or more of the phosphates of Table 2. An attempt was made to separate the hydrous phosphates from the others, but this did not seem to yield results of genetic significance; accordingly a footnote is used in Tables 3 and 4 to set off the hydrous phosphates. It is probable that the hydrous minerals of Table 3 are in general lower-temperature, and therefore later, than those lacking water. Those phosphates which contain ferric iron (unless it proxies for aluminum) are excluded from Table 3; this has been shown by Mason to have real genetic significance. However vivianite (Table 5) normally lacks this cation, and the alluaudites (Table 2) always carry it.

Tables 4 and 5 contain those phosphates regarded as commonly supergene. However, some of the eleven minerals in Table 4 (see the footnote) may certainly be of epithermal origin. These are included in this table because of their ferric iron content; it is thus admitted that the heading for this table is used loosely. It is also true that vivianite, frondelites, wavellite, and probably others of the 21 given in Table 5 may be of epithermal origin. It is of course very difficult or impossible to draw a sharp line between epithermal and supergene; Quensel puts it at 100° C., though 50° C. is a more common figure. But even if some arbitrary definite temperature is set, our state of knowledge is insufficient to place all these phosphates on the proper side of the boundary line. If one should choose to split the post-primary and non-supergene pegmatite phosphates into two categories: 1) hypo- and mesothermal, and 2) epithermal, it is certain that the latter would contain a number of species here put in Tables 4 and 5.

PHOSPHATE STRUCTURES AND CRYSTAL CHEMISTRY

Structures among the phosphates are in some cases analogous to those of the silicates and other minerals, but the structural work on phosphates has never had a Bragg. Nesophosphates (that is, orthophosphates, island structures) seem to be by far the most common; volume II of *Dana's System* is practically all in terms of orthophosphates. Sorophosphates (that is, pyrophosphates, group or doublet structures), cyclophosphates (tetrametaphosphates, four-ring structures), and inophosphates (tetrametaphosphates, single chain structures) are known, but not among minerals. These condensed phosphates are relatively unstable; in solution they hydrolyze readily to orthophosphates.

Phyllophosphates and tektophosphates in which phosphorus is the only tetrahedral cation are non-existent in nature.* Since phosphorus in oxygen salts has a valence of $+5$ and is in tetrahedral coordination, the phosphates are by definition anisodesmic; each P—O bond has an average charge of 5/4. In short, the oxygens are held more tightly to the phosphorus (and less tightly to the other cations) in phosphates than is true for silicates; thus the phosphates are in general softer than the silicates, because of the relatively weaker oxygen-cation bonds in the former. If two PO_4 groups are joined through a common oxygen, this ion would on the average (assuming regular non-resonating tetrahedra) have two bonds each of electrostatic charge 5/4; in short an excess charge of 1/2. It is to be noted that the sorophosphate $Mg_2P_2O_7$ (isotypous with thortveitite) has highly distorted PO_4 tetrahedra, and the PO_4 chains in rubidium metaphosphate ($RbPO_3$) are spirals; in short polymorphism in the phosphates is very different from that in the silicates.

On the other hand, a PO_4 group can share one or more of its oxygens with an AlO_4 group, or in general with any tetrahedral group in which the central cation has a charge of 3 or less. Cations of this nature known to occur in tetrahedral coordination include beryllium, boron, aluminum and gallium. Thus when these metals are present in phosphates, structures of the sheet or framework type are possible. An example of the former is the monoclinic herderite [$Ca(BeP)(O_4F)$], isotypous with dato-

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* The rings of six or ten PO_4 tetrahedra in the orthorhombic modifications of P_2O_5 are united into net or framework structures quite different from those in the silicates.

lite [$Ca(BSi)(O_4OH)$], which has infinite sheets of alternating BO_3OH and SiO_4 tetrahedra parallel (100); these are linked tightly by calcium in 8 coordination. Representative of the latter are orthorhombic hurlbutite ($CaBe_2P_2O_8$), isotypous with danburite ($CaB_2Si_2O_8$) and also the pseudo-orthorhombic feldspar paracelsian ($BaAl_2Si_2O_8$); and rhombohedral berlinite ($AlPO_4$), isotypous with quartz; ($AlPO_4$ also has phases corresponding to tridymite and cristobalite). In addition the monoclinic beryllonite ($NaBePO_4$) is homeotypous with trimerite [$(Ca,Mn)BeSiO_4$], which may be a framework structure. It should be noted that in the well-known layer structure seen in the torbernites and metatorbernites, the sheets contain not only PO_4 groups, but also UO_6 groups; in short here the PO_4 groups exist as islands.

Examples of nesophosphate-nesosilicate isotypous pairs include xenotime-zircon, monazite-huttonite, triphylite (also sicklerite, heterosite, lithiophosphatite, and nearly natrophilite)-olivine, libethenite-andalusite, and isokite-sphene. Phosphorus may also replace some of the silicon of silicates, and *vice versa;* the apatites, most abundant of phosphates and those on which most structural work has been done, are examples of the latter, as is kolbeckite; representative of the former are viséite (analcime structure), erikite, nagatelite, and the recently described pegmatite mineral lomonosovite.

Other mineral phosphates whose structures have been determined include ludamite, monetite, vivianite, and possibly whitlockite. Additional structures are known among the closely-related arsenates; these include berzeliite (garnet structure; cf. griphite), scorodite (variscite is isotypous), brandtite, and pharmacosiderite. Strunz (1957, p. 56) has hematolite isotypous with the rare As silicate dixenite. Less commonly phosphate-sulfate isotypous pairs have been recognized. These include brushite/churchite-gypsum and the goyazites*-alunites; the svanbergites† contain equal amounts of the two; i.e., they are phosphate-sulfates. Combinations are known of phosphate with borate (luenebergite, seamanite), carbonate (bradleyite), and nitrate (likasite). With the possible exception of the borates, these seem to be analogous to double salts. Sincosite may be a meta-autunite with vanadium in place of uranium.

In summary it is clear that a fair start on the elucidation of phosphate structures has been made, but that a tremendous amount of work remains to be done. The discussion in this section has not been limited to the pegmatite phosphates.

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* Dana (II 831) calls these the plumbogummites. The group was formerly known as the hamlinites, but the latter mineral has been shown to be goyazite. The name *plumbogummite* is quite unsatisfactory, since the mineral is not gummite (*Am. Mineral.* **41**, 1956, 539–568).

† The writer uses this term to include the four phosphates of the beudantite group.

TABLE 6. CRYSTALLOGRAPHY OF THE PEGMATITE* PHOSPHATES

Triclinic System (with $c<a<b$); space group $P\bar{1}$

a/b	c/b	a_0 α	b_0 β	c_0 γ	Strongest line (Å)	Name
0.684	0.515	6.97	10.19	5.25	9.6	Gordonite
		101°34′	111°12′	96°55′	9.93	(laueite)
					—	(paravauxite)
0.729	0.708	5.19	7.12	5.04	4.62	Amblygonite
		112°03′	97°50′	68°08′	3.14	(fremontite)
					2.97	(montebrasite)
					3.29	(tavorite)
0.764	0.702	5.77	7.55	5.30	—	Parahopeite
		93°18′	91°55′	91°19′		
0.880	0.834	5.78	6.57	5.48	3.22	Fairfieldite
		102°05′	108°43′	90°05′	3.14(6.34)	(messelite)

Monoclinic System (with $c<a$ for ratios)

a/b	c/b	a_0	b_0	c_0	β	Space group	Strongest line	Name
.171	.118	7.17	60.8	10.41	109–32	—	10.05	Stewartite
.232	.193	8.55	36.90	7.13	97–41	15–$C2/c$?	7.00	Moraesite
.541	.894	5.29	9.77	8.73	90–36	11–$P2_1/m$	2.78	Clinostrengite
.545	.894	5.16	9.47	8.47	90±	11–$P2_1/m$	2.72	Clinovariscite
.727	.330	10.47	14.40	4.75	102–49	14–$P2_1/a$?	3.42, 2.84	Väyrynenite
.751	.350	10.08	13.43	4.70	104–30	12—$C2/m$	6.59	Vivianite
.767	.533	8.87	11.57	6.17	99–12	14–$P2_1/c$	2.86, 3.50	Graftonite
							—	(magniophilite)
.838	.529	5.34	10.09	8.46	90–40	—	—	Kolbeckite*
.859	.745	7.51	8.75	6.52	121–28	15–$C2/c$	3.18	Isokite
.868	.518	10.93	12.59	6.52	97–59	15–$I2_1/a$	2.72	Hagendorfite
							2.71	((hühnerkobelite)
.880	.511	11.03	12.53	6.40	97–34	15–$I2_1/a$	2.72	Alluaudite
							2.73	(varulite)
.885	.509	9.46	10.69	5.45	105–28	11–$P2_1/m$	2.95	Morinite
.896	.512	—	—	—	105–32	—	2.95	Jezekite
.916	.740	12.26	13.38	9.90	108–04	14–$P2_1/a$	2.92	Triploidite
.921	.739	12.12	13.16	9.73	108–18	14–$P2_1/a$	2.93	Wolfeite
.951	.770	11.92	12.53	9.65	108–07	14–$P2_1/a$	2.95	Wagnerite*
.963	.919	6.74	7.00	6.43	104–36	14–$P2_1/n$	3.07	Cheralite
.964	.919	6.79	7.04	6.47	104–24	14–$P2_1/n$	3.05	Monazite
.977	.975	7.15	7.32	7.14	119–00	14–$P2_1/n$	3.25	Scorzalite
.983	.981	7.12	7.24	7.10	118–55	14–$P2_1/n$	3.23	Lazulite
						14–$P2_1/n$	3.36	(barbosalite)
1.014	1.009	9.73	9.60	9.69	102–16	14–$P2_1/n$	6.78	Leucophosphite
1.110	.700	11.19	10.08	7.06	97–22	14–$P2_1/n$	5.04	Brazilianite
1.275	.625	9.82	7.70	4.81	90–06	14–$P2_1/a$	3.11	Herderite
1.364	1.285	9.57	7.45	10.16	104–40	—	9.93	Pseudolaueite
1.645	.635	13.13	7.98	5.07	112–27	12–$C2/m$	3.33	Augelite
1.767	.500	5.24	10.48	18.52	107–35	14–$P2_1/c$	3.16	Bøggildite
1.807	1.047	8.16	7.79	14.08	90–00	14–$P2_1/n$	2.81	Beryllonite
1.862	1.553	12.05	6.47	10.05	105–42	12–$I2/m$	2.87	Triplite
1.864	1.552	12.02	6.45	10.01	108±	12–$I2/m$	2.87?	Zwieselite
1.910	1.042	17.42	9.12	9.50	96–40	13–$P2/c$	3.14	Hureaulite
							2.85, etc.	(salmonsite?)
2.065	2.014	10.25	5.09	10.51	120–15	14–$P2_1/c$	2.83	Phosphophyllite
2.247	1.989	10.45	4.65	9.25	100–30	14–$P2_1/a$	2.55	Ludlamite
2.462	1.650	16.68	10.11	24.89	105–41	15–$C2/c$	3.02	Dickinsonite
2.484	1.657	16.60	10.02	24.89	105–50	15–$C2/c$	3.04	Arrojadite
3.998	3.734	20.59	5.15	19.23	94–06	15–$C2/c$	10.30	Beraunite
			Data lacking					
							3.14 etc.	Kryzhanovskite
							2.91	Lacroixite?
							—	Lomonosovite?
							—	Nagatelite
							3.22	Parsonsite
							9.59	Roscherite
							2.69	Souzalite?
							(Syst. not known)	Xanthoxenite?

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* Including *ca.* 7 hydrothermal species marked with an asterisk.

TABLE 6 (*continued*)

Orthorhombic System (with $c<a<b$ for ratios)

a/b	c/b	a_0	b_0	c_0	Space group	Strongest line (Å)	Name
.455	.329	6.26	8.94	19.65	—	9.59	Bermanite
.555	.403	9.62	17.34	6.99	62-*Pcmn*	8.40	Wavellite
.580	.275	18.36	5.04	10.64	62-*Pmcn*	2.85	Hopeite
.580	.452	10.36	4.68	6.01	62-*Pnam*	2.53	Triphylite
						2.53	(lithiophilite)
.587	.467	10.24	4.78	6.01	62-*Pnam*	3.01, 2.53	Sicklerite (Mn)
.589	.475	10.11	4.80	5.95	62-*Pnam*	2.95, 2.49	Sicklerite (Fe)
.601	.492	9.70	4.77	5.83	62-*Pnam*	2.45	Heterosite
						2.45?	(purpurite)
.601	.472	10.54	4.98	6.33	62-*Pnam*	2.60	Natrophilite
						3.98	(lithiophosphatite)
.730	.463	7.31	15.79	11.53	71-*Immm*	3.11	Palermoite
.772	2.98	17.14	22.19	6.61	51-*Pbmm*	8.59	Scholzite
.775	.514	10.45	13.49	6.93	41-*Bba2*	2.82	Eosphorite
.777	.517	10.38	13.36	6.91	41-*Bba2*	2.81	Childrenite
.812	.306	13.76	16.94	5.19	20-$B22_12$	3.31	Rockbridgeite
.817	.306	13.89	17.01	5.21	20-$B22_12$	3.16	Frondelite
.896	1.559	6.17	6.89	10.74	57-*Pbcm*	2.81	Chlor-Spodiosite*
.910	.790	15.85	17.42	13.76	63-*Bmmb*	7.83	Phosphuranylite
.915	.783	16.01	17.5	13.7	63-*Bmmb*	7.95	Renardite
.939	.864	9.41	10.02	8.66	53-*Pmna*	3.18	Phosphoferrite
.941	.864	9.49	10.07	8.70	53-*Pmna*	3.20	Reddingite
.942	.888	8.29	8.80	7.81	47-*Pmmm*	3.67	Hurlbutite
.970	.863	9.87	9.57	8.52	61-*Pcab*	4.29	Variscite
.979	.860	10.08	9.87	8.67	61-*Pcab*	4.36	Strengite
		Data Lacking				—	Koninckite?
						—	Tavistockite*

Tetragonal System

c/a	a	c	Space group	Strongest line (Å)	Name
0.877	6.89	6.04	141-$I4/amd$	3.42	Xenotime
1.239	6.96	8.62	129-$P4/nmm$	3.61	Metatorbernite
2.650	7.32	19.4	92-$P4_12_12$	4.85	Cyrilovite
2.682	7.04	18.88	92-$P4_12_12$	4.74	Wardite
2.904	7.06	20.5	139-$I4/mmm$	3.69, 10.3	Torbernite
2.953	7.00	20.67	139-$I4/mmm$	3.46	Autunite

Hexagonal System

0.71–0.74	9.4±	6.9±	176-$P6_3/m$	2.80	Apatite
0.735	9.97	7.33	176-$P6_3/m$	2.92	Pyromorphite
1.325	7.92	10.5	—	3.35	Cacoxenite
1.697	9.43	16.0	—	5.72	Faheyite
2.217	4.93	10.94	152-$P3_1/2$	3.32	Berlinite*
2.308	6.99	16.13	160-$R3m$	2.92	Crandallite
2.346	6.96	16.33	—	2.92	Koivinite
2.370	6.98	16.54	166-$R\bar{3}m$	2.97	Goyazite
2.410	6.97	16.8	166-$R\bar{3}m$	2.98	Svanbergite*
2.448	6.76	16.55	—	2.92?	Florencite
2.535?	—	—	—	2.98?	Hinsdalite*
2.841	15.25	43.32	148-$R\bar{3}$	2.80	Fillowite
3.57	10.32	36.9	161-$R3c$	2.85	Whitlockite

Isometric System

a_0	Space group	Strongest line (Å)	Name
12.28	230-$Ia3d$?	2.74	Griphite

CONCLUDING REMARKS

Data showing the present status of x-ray studies of the pegmatite phosphates are presented in Tables 6 (single crystal) and 7 (powder diffraction). Table 8 is an alphabetical index to Tables 2 to 7.

TABLE 7. PEGMATITE* PHOSPHATE POWDER DIFFRACTION DATA

Strongest lines			Name	Photograph	Locality	Crystal system	*a/b* (*c/a* in dimetric)
1.85/10	1.82/10	3.14/10	Kryzhanovskite	—		M	—
2.45/10	2.91/9	1.58/8	Heterosite	1A	Grafton, N.H.	O	0.601
			(Purpurite)	—			
2.49/10	2.95/10	5.01/9	Sicklerite (Fe)	—		O	0.589
2.53/10	3.01/10−	4.32/9+	Sicklerite (Mn)	1B	Black Hills	O	0.587
2.53/10	3.01/9	1.75/8+	Lithiophilite	cf. 1C		O	0.580?
2.53/10	3.02/9+	2.49/9	Triphylite	1C	Rochester, N.H.	O	0.580
2.55/10	2.77/9	3.96/8	Ludlamite	1D	Palermo, N.H.	M	2.247
2.60/10	2.87/9	4.05/7	Natrophilite	1E	Branchville	O	0.601
2.69/10	3.79/8?	5.35/7?	Souzalite	—		M?	—
2.71/10	2.53/6	6.26/5	Hühnerkobelite	cf. 1F	Hühnerkobel	M	0.87?
2.72/10	3.05/8	6.26/7	Alluaudite	1F	Chanteloube	M	0.880
2.72/10	6.28/7	2.54/5	Hagendorfite	cf. 1F	Hagendorf	M	0.868
2.73/10	2.54/9	3.49/7	Varulite	cf. 1F	Varuträsk	M	0.87?
2.74/10	3.07/5	2.99/4	Griphite	1G	Black Hills	I	1.00
2.78/10	4.34/9	4.68/8	Clinostrengite	1H	Bavaria	M	0.541
2.80/10	2.70/7	1.90/6	Apatite	1J	Saxony	H	0.71–0.74
2.80/10	3.00/7	2.54/6	Fillowite	1K	Branchville	R	2.841
2.81/10	1.52/8	5.19/7	Childrenite	cf. 2B		O	0.777
2.81/10	3.62/9	2.27/6	Beryllonite	2A	Stoneham, Me.	M	1.807
2.82/10	5.22/7	4.39/7	Eosphorite	2B	Branchville	O	0.775
2.83/10	9.00/8	4.43/7	Phosphophyllite	—	Bavaria	M	2.065
2.84/10	3.42/10	2.64/9	Väyrynenite	—		M	0.727
2.85/10	2.58/8	3.16/7	Whitlockite	2C	Palermo	R	3.57
2.85/10	9.1/9	4.56/7	Hopeite	2D	Rhodesia	O	0.580
2.85/10	9.4/10	3.16/10	Salmonsite	2E	Pala	M?	1.91?
2.86/10	3.50/10−	2.72/8	Graftonite	2F	Grafton	M	0.767
2.87/10	3.05/9	3.26/7	Triplite	2G	Bohemia	M	1.862
2.87/10	3.05/9	3.26/7	Zwieselite	cf. 2G		M	1.864
2.92/10	1.52/9	1.49/9	Pyromorphite	2H	Nassau, Ger.	H	0.735
2.92/10	1.88/7	1.28/7	Koivinite	—	———	R	2.346
2.92/10	2.15/8	1.89/7	Crandallite	2J	Fairfield	R	2.308
2.92/10	3.09/10−	3.19/8	Triploidite	2K	Branchville	M	0.916
2.93/10	3.09/9	3.18/8	Wolfeite	cf. 2K		M	0.921
2.95/10	2.49/10	5.01/9	Sicklerite (Fe)	cf. 1B		O	0.589
2.95/10	2.83/9	3.26/8	Wagnerite*	3A	Norway	M	0.951
2.95/10	3.47/9	1.79/9	Morinite	3B	France	M	0.885
2.95/10	3.47/9	1.79/9	Jezekite	cf. 3B		M	0.896
2.97/10	2.20/8	1.89/7	Goyazite	cf. 3C	New Hampshire	R	2.370
2.97/10	5.70/8	3.45/6	Plumbogummite	3C		R	—
2.97/10	4.68/9	3.22/6	Montebrasite	3D	Black Hills	Tr	0.73?
2.98/10	2.22/6	5.75/4	Svanbergite*	cf. 3C		R	2.410
3.01/10	2.81/8	3.49/7	Vashegyite	—	Nevada	—	—
3.01/10	2.53/10	4.32/10−	Sicklerite (Mn)	1B	Black Hills	O	0.587
3.02/10	2.72/9	1.77/6	Dickinsonite	3E	Poland, Me.	M	2.462
3.04/10	2.70/9	3.21/7	Arrojadite	cf. 3E		M	2.484
3.05/10	3.26/6	2.85/4	Monazite	3F	New Mexico	M	0.964
3.07/10	2.86/?	3.26/?	Cheralite	cf. 3F		M	0.963
3.11/10	2.85/6	2.20/5+	Herderite	3G	Auburn	M	1.275
3.11/10	4.38/9	2.44/8	Palermoite	—		O	0.730
3.14/10	1.85/10	1.82/10	Kryzhanovskite	—		M	—
3.14/10	2.87/7	3.72/6	Messelite	3H	Hesse	Tr	0.88?
3.14/10	2.98/8	8.01/7	Hureaulite	3J	Branchville	M	1.910
3.14 10	4.62/9	2.95/8	Natromontebrasite	cf. 3D		Tr	0.73?
3.16/10	1.59/7	3.56/6	Frondelite	3K	Brazil	O	0.817

* Including three hydrothermal phosphates (marked with an asterisk) not known from pegmatites.

TABLE 7 (*continued*)

Strongest lines			Name	Photograph	Locality	Crystal system	a/b (c/a in dimetric)
3.16/10	2.85/10	9.42/10	Salmonsite	2E	Pala	M?	1.91?
3.16/10	3.89/9	3.96/8	Bøggildite	—		M	1.767
3.18/10	3.02/8	2.63/7	Isokite	4A	Bohemia	M	0.859
3.18/10	4.97/7	4.25/6	Phosphoferrite	4B	Bavaria	O	0.939
3.20/10	2.62/8	3.15/7	Landesite	4C	Poland, Me.	cf.	reddingite
3.20/10	5.01/6	2.74/6	Reddingite	cf. 4B		O	0.941
3.22/10	3.01/8	6.33/7	Fairfieldite	4D	Branchville	Tr	0.880
3.22/10	3.38/9	4.13/8	Parsonsite	—		M	—
3.23/10	4.72/7	3.14/7	Lazulite	4E	Death Valley	M	0.983
3.25/10	3.20/9	3.15/5	Scorzalite	cf. 4E		M	0.977
3.29/10	3.05/9	4.99/5	Tavorite	4F	Brazil	Tr	0.73?
3.31/10	3.20/9	1.60/7	Rockbridgeite (Zn)	4G	Portugal	O	0.812
3.32/10	4.27/4	3.97/3?	Berlinite*	—		R	2.217
3.33/10	3.51/9½	4.72/8	Augelite	4H	Black Hills	M	1.645
3.35/10	12.0/3	4.27/3	Cacoxenite	4J	Arkansas	H	1.325
3.36/10	3.31/8	4.84/6	Barbosalite	4K	Brazil	M	0.98?
3.42/10	1.76/9	0.807/7	Xenotime	5A	Norway	Te	0.877
3.42/10	2.84/10	2.64/9−	Väyrynenite	—		M	0.727
3.46/8	2.16/6	3.23/3	Autunite†	—		Te	2.953
3.51/10	3.90/7	2.81/7	Sarcopside	5B	New Hampshire	—	—
3.61/10	8.57/9	3.42/7	Metatorbernite	5C	Unknown	Te	1.239
3.67/10	3.03/9	2.78/9	Hurlbutite	5D	New Hampshire	O	0.942
3.69/10	1.56/8	1.64/7	Torbernite†	—		Te	2.904
3.98/10	3.79/10−	2.67/8+	Lithiophosphatite	5E	Synthetic	O	0.60?
4.36/10	5.47/9	3.10/8	Strengite	5F	Bavaria	O	0.979
4.62/10	3.15/9+	2.96/9	Amblygonite	cf. 3D		Tr	0.729
4.74/10	2.99/7	2.59/7	Wardite	5G	Black Hills	Te	2.682
4.85/10	3.19/8	2.66/8	Cyrilovite	5H	Brazil	Te	2.650
5.04/10	2.98/8	2.73/8	Brazilianite	5J	Brazil	M	1.110
5.72/10	7.28/9	3.24/6	Faheyite	5K	Brazil	H	1.697
6.34/10	3.17/10	3.02/8	Messelite	3H	Hesse	Tr	0.880?
6.59/10	6.84/5	3.19/5	Vivianite	6A	Colorado	M	0.751
6.78/10	5.96/9	3.06/7	Leucophosphite	6B	Brazil	M	1.014
7.00/10	3.28/9	4.24/6	Moraesite	6C	Brazil	M	0.232
7.83/10	3.97/9	5.83/8	Phosphuranylite	—		O	0.910
7.95/10	3.11/9	2.88/8	Renardite	—		O	0.915
8.40/10	3.60/8	3.48/8	Meta-autunite	cf. 5C	Australia	Te	1.24?
8.10/10	3.20/9	3.44/9−	Wavellite	6D	Arkansas	O	0.555
8.59/10	2.79/9	4.23/7	Scholzite	6E	Bavaria	O	0.772
9.42/10	3.16/10	2.85/10	Salmonsite	2E	Pala	M?	1.91?
9.59/10	5.08/8	2.90/8	Bermanite	6F	Arizona	O	0.455
9.59/10	5.93/9	3.17/9	Roscherite	6G	Rumford, Me.	M	—
9.6/10	6.37/8	4.80/7	Gordonite	cf. 6H	Utah	Tr	0.684
9.93/10	3.28/6	4.92/5	Laueite	6H	Bavaria	Tr	0.684?
9.93/10?	3.28/6?	4.92/5?	Paravauxite	cf. 6H		Tr	0.684?
9.93/10	5.87/7	3.47/4	Pseudolaueite	6J	Bavaria	M	1.364
10.1/10	4.38/7−	6.70/5	Stewartite	—		M	0.171
10.3/10	4.94/9	3.58/9	Torbernite	—	Synthetic	Te	2.904
10.3/10	3.07/8	4.81/7	Beraunite	6K	Arkansas	M	3.998
10.5/10	7.20/7	2.90/7	Vashegyite	—		—	—

† When fully hydrated, shows strong lines at d=*ca.* 10.0 and 5.0 Å.

TABLE 8. INDEX TO THE PEGMATITE* PHOSPHATES

No.	Name	Strongest line Å	Crystal system	a/b† (c/a in dimetric)	Occur. (Table No.)
1	Alluaudite	2.72	M	0.880	2
2	Amblygonite	4.62	Tr	0.729	2
3	Apatite	2.80	H	0.71 to 0.74	2
13*a*	Arrojadite	3.04	M	2.484	2
4	Augelite	3.33	M	1.645	3
58*a*	Autunite	3.46	Te	2.953	5
66*a*	Avelinoite		(Same as cyrilovite)		
32*a*	Barbosalite	3.36	M	0.98?	2
5	Beraunite	10.30	M	3.998	5
*	Berlinite	3.32	R	2.217	3
6	Bermanite	9.59	O	0.455	4
7	Beryllonite	2.81	M	1.807	2
8	Bøggildite	3.16	M	1.767	2
9	Brazilianite	5.04	M	1.110	3
10	Cocoxenite	3.35	H	1.325	5
38*a*	Cheralite	3.07	M	0.963	2
11	Childrenite	2.81	O	0.777	3
12*a*	Clinostrengite	2.78	M	0.541	5
12	Clinovariscite	2.72	M	0.545	5
19*a*	Crandallite	2.92	R	2.308	5
66*a*	Cyrilovite	4.85	Te	2.650	5
13	Dickinsonite	3.02	M	2.462	2
11*a*	Eosphorite	2.82	O	0.775	3
14	Evansite	—	—	—	5
15	Faheyite	5.72	H	1.697	3
16	Fairfieldite	3.22	Tr	0.880	3
17	Fillowite	2.80	R	2.841	3
19*b*	Florencite	2.92?	R	2.448	5
2*b*	Fremontite	(Same as natromontebrasite)			
18	Frondelite	3.16	O	0.817	5
45*a*	Gordonite	9.6?	Tr	0.684	5
19	Goyazite	2.97	R	2.370	5
20	Graftonite	2.86, 3.50	M	0.767	2
21	Griphite	2.74	I	1.00	2
1*a*	Hagendorfite	2.72	M	0.868	2
19	Hamlinite		(Same as Sr goyazite)		
22	Herderite	3.11	M	1.275	3

* Including some seven phosphates (marked by an asterisk) which are known from hydrothermal deposits, but not from pegmatites.

† With $c<a<b$.

TABLE 8—(*continued*)

No.	Name	Strongest line Å	Crystal system	*a*/*b*† (*c*/*a* in dimetric)	Occur. (Table No.)
23	Heterosite	2.45	O	0.601	4
*	Hinsdalite	2.98?	R	2.535	3
24	Hopeite	2.85	O	0.580	5
1*b*	Hühnerkobelite	2.71	M	0.87?	2
25	Hureaulite	3.14	M	1.910	3
26	Hurlbutite	3.67	O	0.942	3
27	Isokite	3.18	M	0.859	3
40*a*	Jezekite	2.95	M	0.896	3
19*b*	Koivinite	2.92	R	2.346	5
*	Kolbeckite	—	M	0.838	3
28	Koninckite	—	O?	—	5
29	Kryzhanovskite	3.14, 1.85, 1.82	M	—	4
30	Lacroixite	2.91	M?	—	3
31	Landesite	3.20	(cf. reddingite)		4
45*b*	Laueite	9.93	Tr	0.684?	5
32	Lazulite	3.23	M	0.983	2
33	Leucophosphite	6.78	M	1.014	5
59*a*	Lithiophilite	2.53	O	0.580?	2
34	Lithiophosphatite	3.98	O	0.60?	3
35	Lomonosovite	—	M?	—	2
36	Ludlamite	2.55	M	2.247	3
20*a*	Magniophilite	2.86?	M?	0.767?	2
1*c*	Mangan-alluaudite	2.71?	M	0.880?	2
16*a*	Messelite	3.14(6.34)	Tr	0.880?	3
37*a*	Meta-autunite	8.40	(See metatorbernite)		
12*a*	Metastrengite		(See clinostrengite)		
37	Metatorbernite	3.61	Te	1.239	5
12	Metavariscite (Fe‴)		(See clinovariscite)		
38	Monazite	3.05	M	0.964	2
2*a*	Montebrasite	2.97	Tr	0.73?	2
39	Moraesite	7.00	M	0.232	3
40	Morinite	2.95	M	0.885	3
41	Nagatelite	—	M	—	2
2*b*	Natromontebrasite	3.14	Tr	0.73?	2
42	Natrophilite	2.60	O	0.601	2
16*a*	Neomesselite		(See messelite)		
43	Palermoite	3.11	O	0.730	3
44	Parahopeite	—	Tr	0.764	5
45	Paravauxite (Mn″Fe‴)	9.93?	Tr	0.684?	5
46	Parsonsite	3.22	M	—	5

TABLE 8—(*continued*)

No.	Name	Strongest line Å	Crystal system	a/b† (c/a in dimetric)	Occur. (Table No.)
50*a*	Phosphoferrite	3.18	O	0.939	3
47	Phosphophyllite	2.83	M	2.065	4
48	Phosphuranylite	7.83	O	0.910	5
49	Pseudolaueite	9.93	M	1.364	4
23*a*	Purpurite	2.45?	O	0.601?	4
3*a*	Pyromorphite	2.92	H	0.735	5
50	Reddingite	3.20	O	0.941	3
48*a*	Renardite	7.95	O	0.915	5
18*a*	Rockbridgeite (Zn)	3.31	O	0.812	5
51	Roscherite	9.59	M	—	3
52	Salmonsite	9.42, 3.16, 2.85	M?	1.91?	4
53	Sarcopside	3.51	—	—	3
54	Scholzite	8.59	O	0.772	4
32*b*	Scorzalite	3.25	M	0.977	2
55	Sicklerite (Mn)	3.01, 2.53	O	0.587	4
55*a*	Sicklerite (Fe)	2.95, 2.49	O	0.589	4
56	Souzalite	2.69	M?	—	3
*	Spodiosite	2.81?	O	0.896	3
57	Stewartite	10.05	M	0.171	4
62*a*	Strengite	4.36	O	0.979	5
*	Svanbergite	2.98	R	2.410	3
*	Tavistockite	—	O	—	3
2*c*	Tavorite	3.29	Tr	0.73?	2
58	Torbernite	3.69, 10.3	Te	2.904	5
59	Triphylite	2.53	O	0.580	2
60	Triplite	2.87	M	1.862	2
61	Triploidite	2.92	M	0.916	2
62	Variscite	4.29	O	0.970	5
1*d*	Varulite	2.73	M	0.87?	2
63	Vashegyite	3.01, 10.5	(Same as evansite?)		5
64	Väyrynenite	3.42, 2.84	M	0.727	3
65	Vivianite	6.59	M	0.751	5
*	Wagnerite	2.95	M	0.951	3
66	Wardite	4.74	Te	2.682	5
67	Wavellite	8.40	O	0.555	5
68	Whitlockite	2.85	R	3.57	3
61*a*	Wolfeite	2.93	M	0.921	2
69	Xanthoxenite	—	—	—	4
70	Xenotime	3.42	Te	0.877	2
60*a*	Zwieselite	2.87?	M	1.864	2

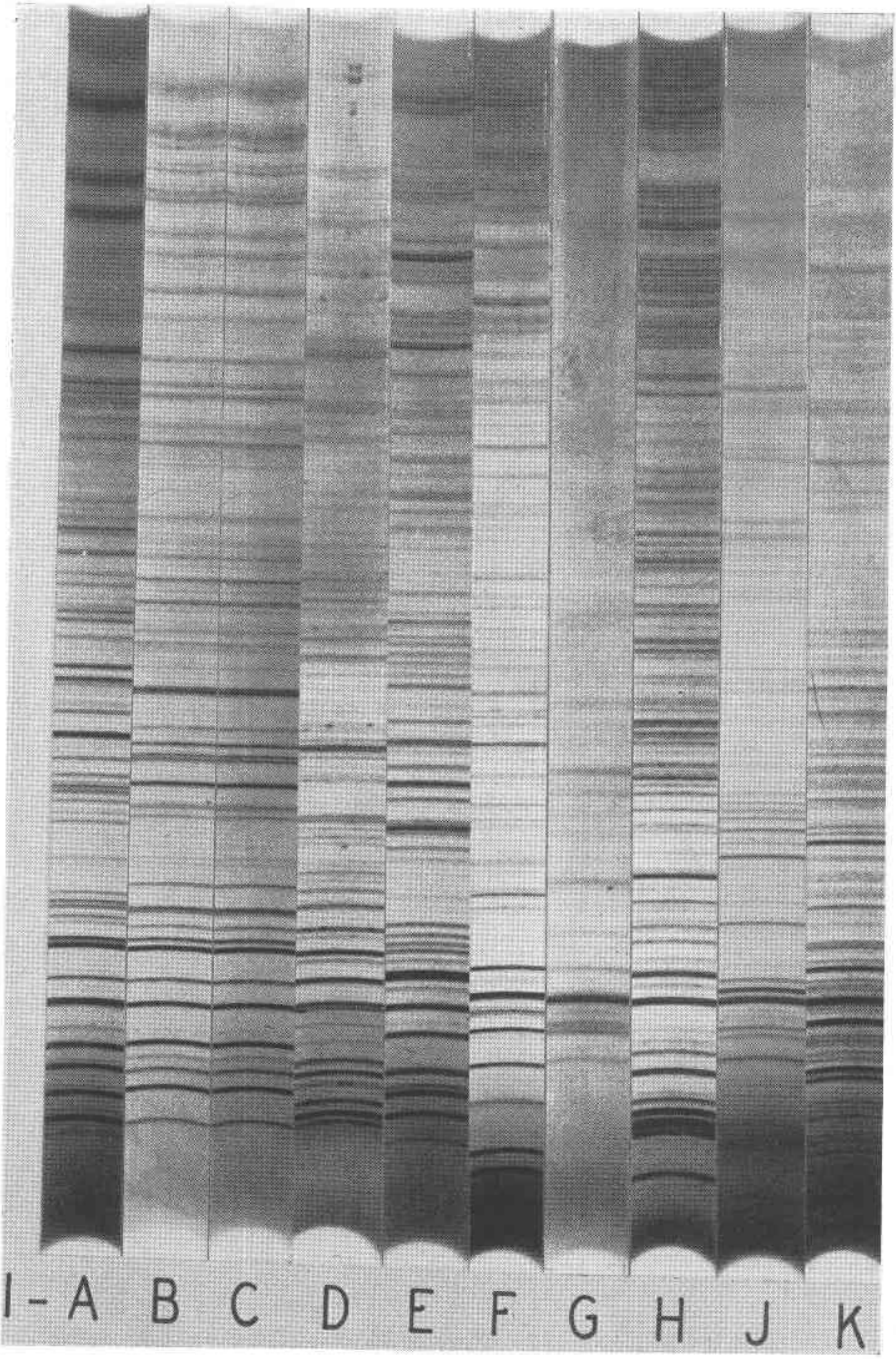

FIG. 1. *X*-ray diffraction patterns for phosphates whose strongest line corresponds to *d* of 2.45 to 2.80 Å.

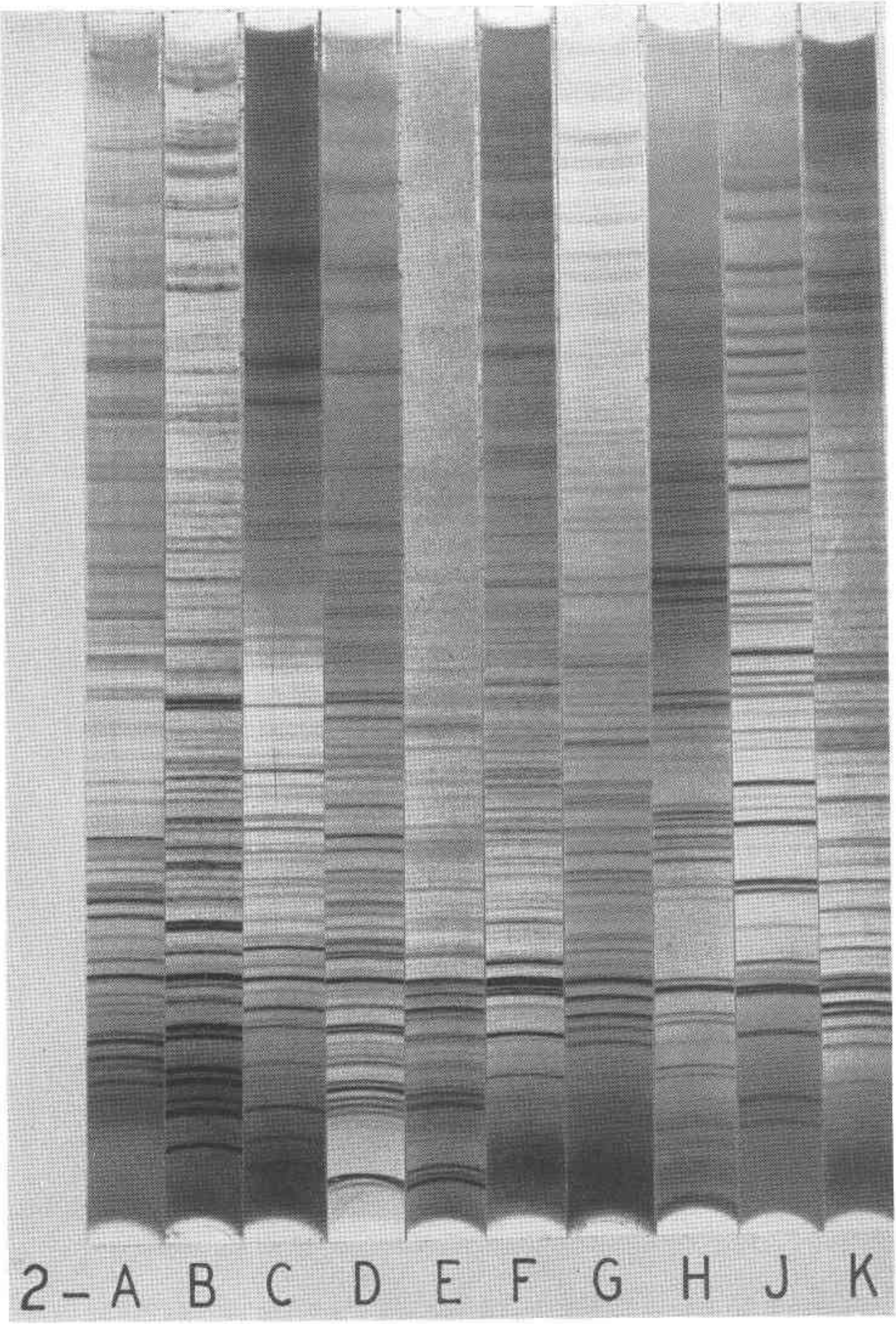

FIG. 2. *X*-ray diffraction patterns for phosphates whose strongest line corresponds to *d* of 2.81 to 2.92 Å.

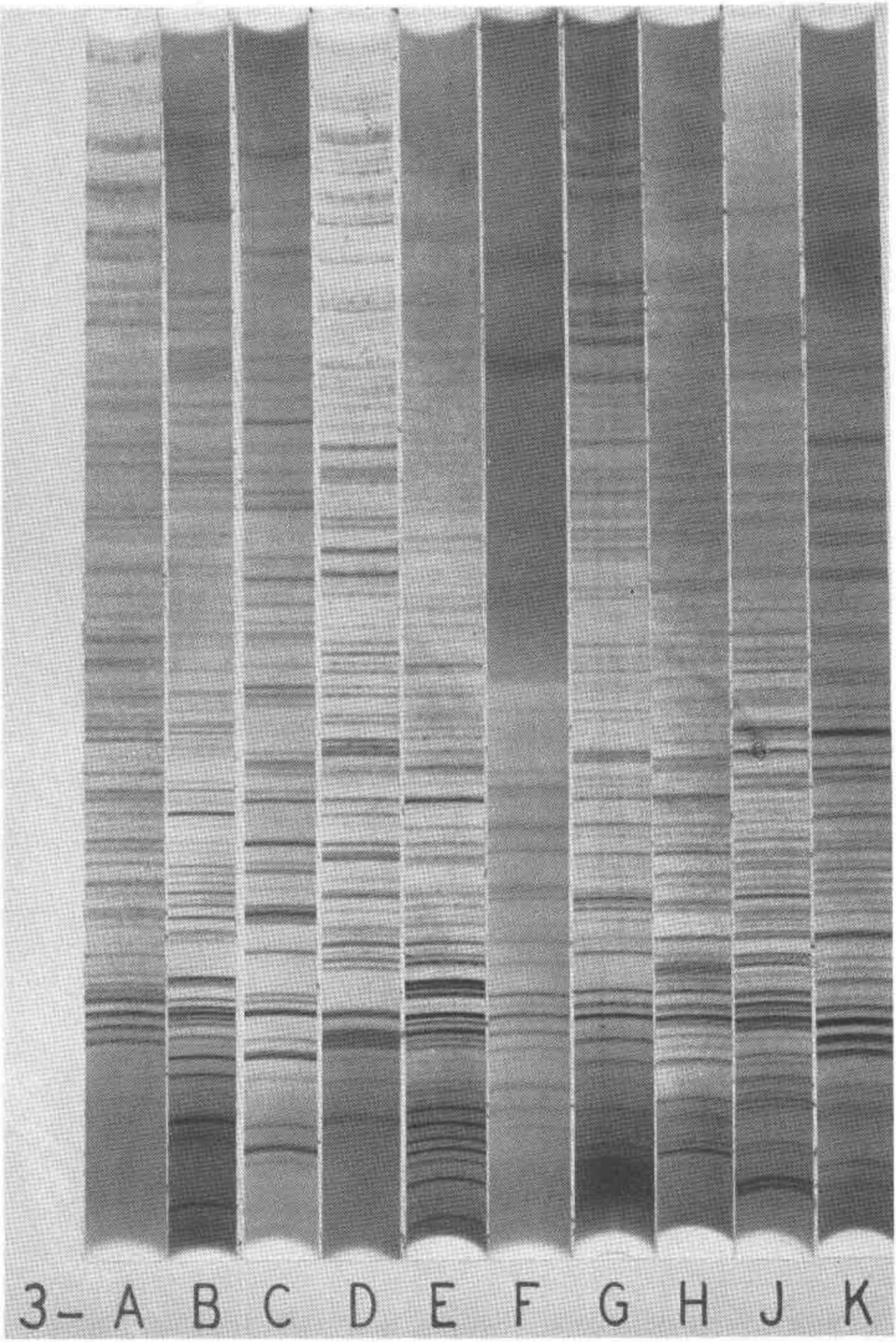

FIG. 3. *X*-ray diffraction patterns for phosphates whose strongest line corresponds to *d* of 2.95 to 3.16 Å.

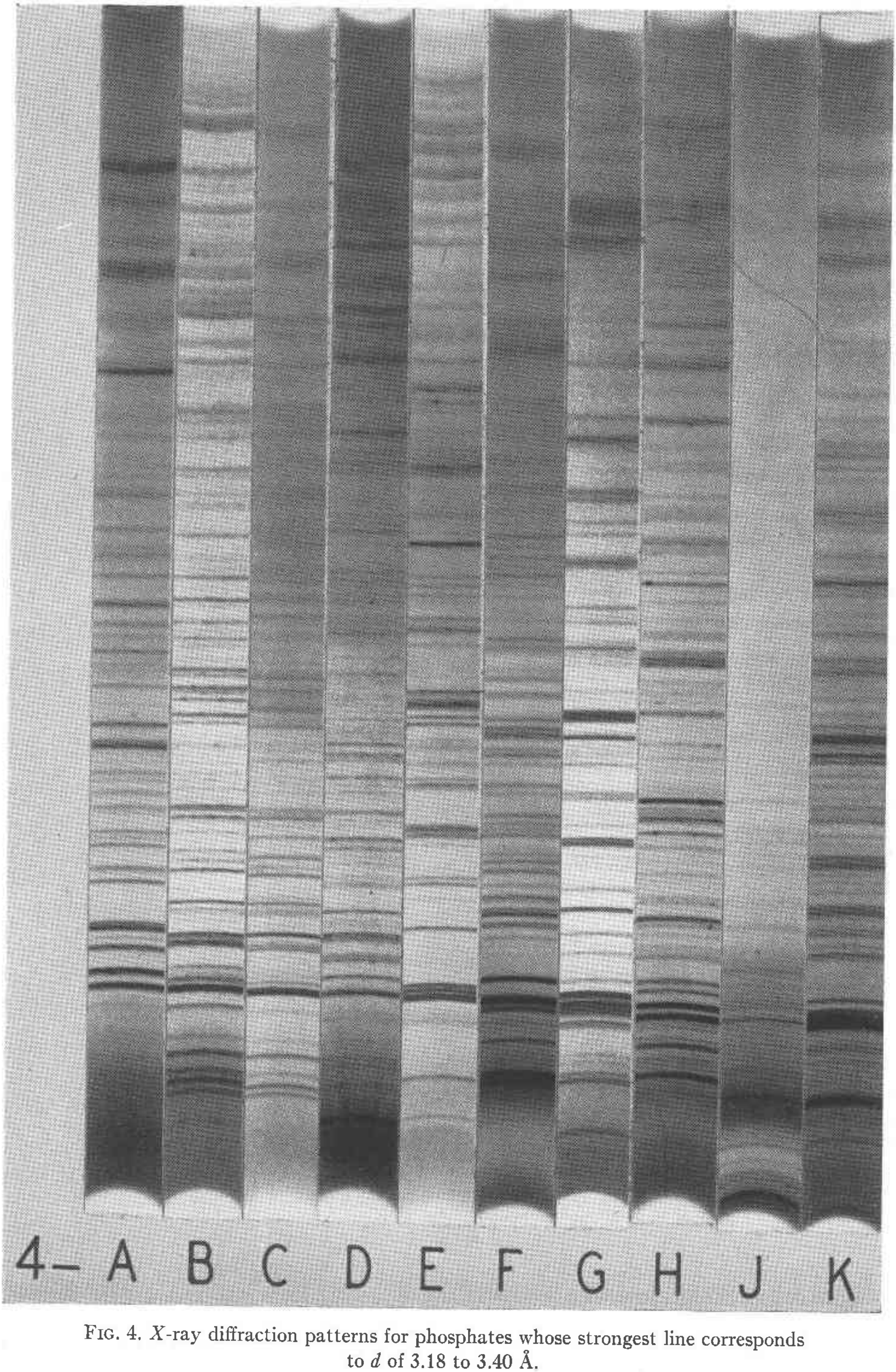

FIG. 4. *X*-ray diffraction patterns for phosphates whose strongest line corresponds to *d* of 3.18 to 3.40 Å.

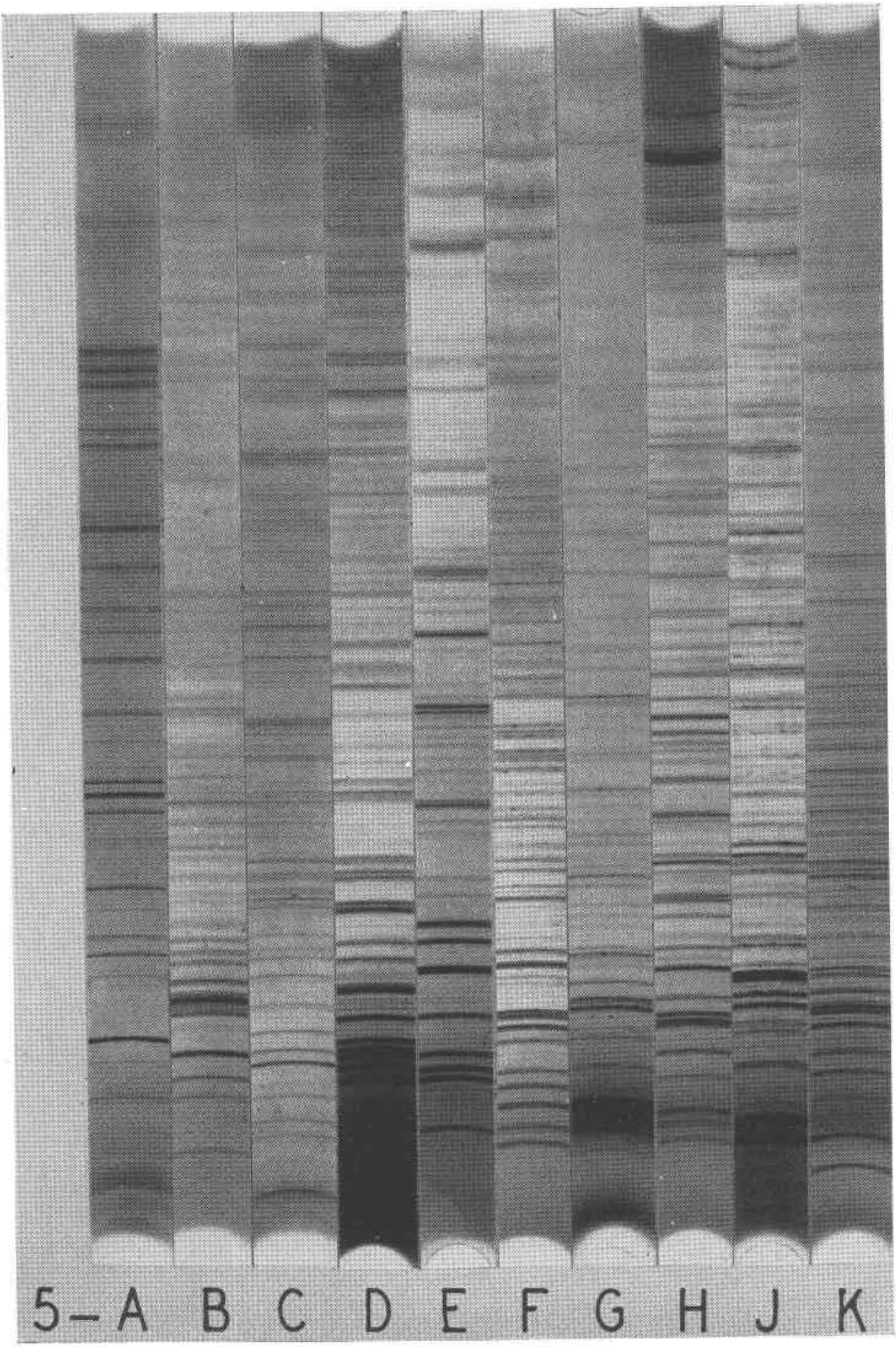

FIG. 5. X-ray diffraction patterns for phosphates whose strongest line corresponds to d of 3.4 to 6.0 Å.

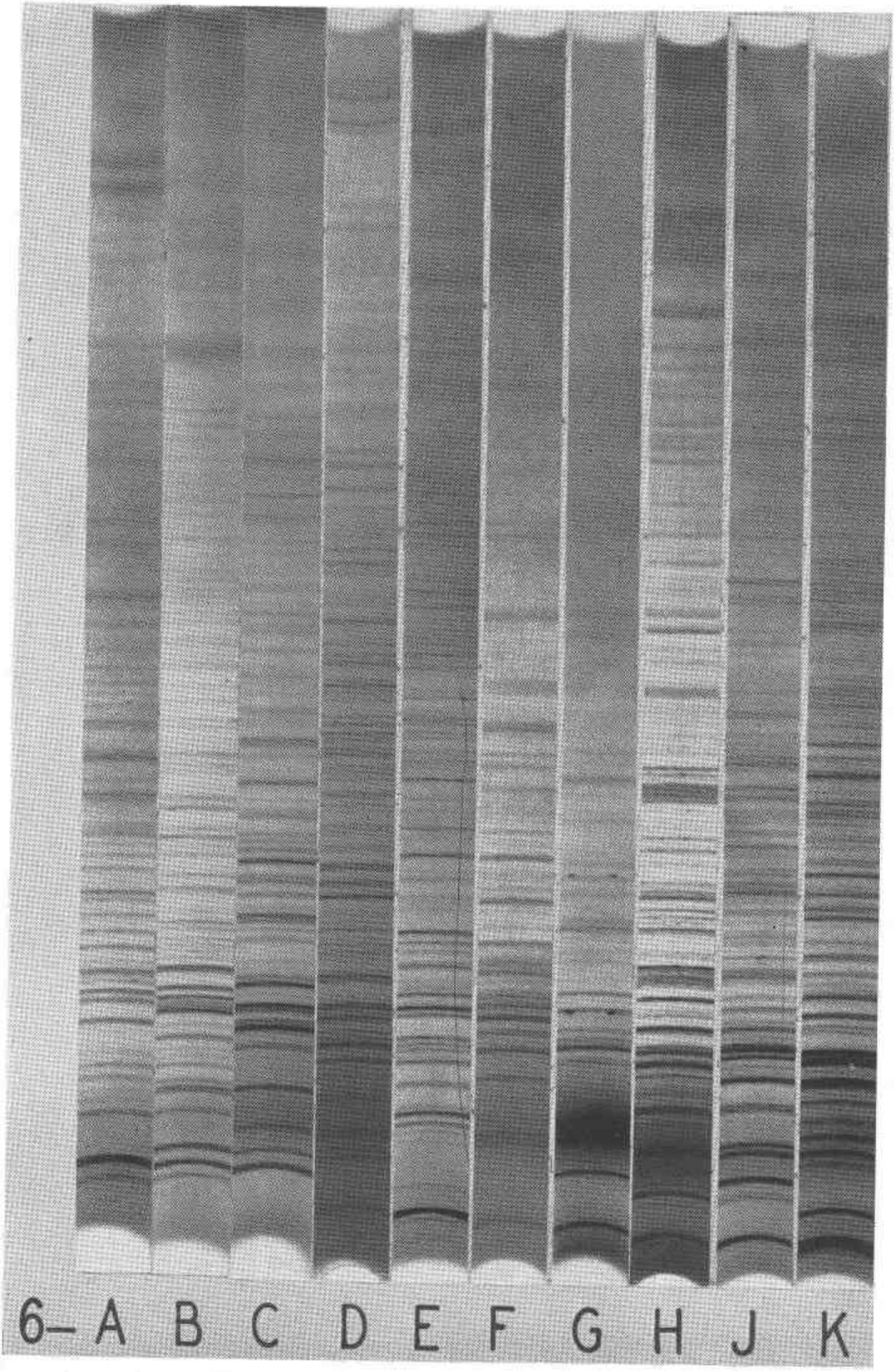

FIG. 6. X-ray diffraction patterns for phosphates whose strongest line corresponds to d of 6.5 to 10.5 Å.

In Table 6 the order of listing is that of increasing *a/b* ratio (*c/a* in the dimetric) by crystal systems; for this purpose it is assumed that $c<a<b$. However the actual values of *a*, *b*, and *c* shown are those generally given in the literature. The next-to-the-last column in this table serves as an index to Table 7.

Table 7 lists the pegmatite phosphates in order of increasing spacing value of the most intense powder diffraction line; spacing values for the next two lines (in decreasing order of intensity) are also given. Figures 1 to 6 referred to in the fifth column (which serves as an index to these patterns) are reproductions of those films which were available in suitable quality. All photographs are approximately natural size for a 114 mm. diameter camera; all were made with iron radiation using a manganese filter; the stronger β lines generally appear. The photographs in the figures should not be used for comparing relative intensities of lines of greatly differing spacing values, since in some cases during the photographic reproduction process an effort was made to overprint zones of weak lines and suppress those of heavy lines. The last two columns of the table serve as an index to Table 6.

Table 8 constitutes an alphabetical index to Tables 2 to 7. The writer's 70 phosphates are each given a number. Thus amblygonite is no. 2; the other members of this series are shown as 2*a*, montebrasite; 2*b*, natromontebrasite (fremontite); and 2*c*, tavorite. The third column serves as an index to Table 7, the fourth and fifth columns to Table 6, and the last column to Tables 2 to 5.

This attempt to summarize certain data dealing with the pegmatite phosphates has nothing of a definitive nature. Besides ordinary mistakes of the clerical sort, there are certainly errors of both omission and commission. In some cases it has been necessary to take a positive stand, even though the data hardly warranted this. I will be greatly pleased to be corrected, argued with, and otherwise man-handled. Should enough such material accumulate to warrant it, I will be delighted to publish it with suitable acknowledgments.

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