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# SELECTED ANNOTATED BIBLIOGRAPHY OF THE GEOLOGY OF URANIFEROUS PHOSPHORITES IN THE UNITED STATES*

By

Diane Curtis

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Trace Elements Investigations Report 532

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by Diane Curtis

## INTRODUCTION

The presence of uranium in phosphatic materials has been known since the investigations of Strutt_/ in 1908 when he observed that phosphates

_/ Strutt, Hon. R. J., 1908, On the accumulation of helium in geological time: Proc. Roy. Soc. London, vol. 81, Ser. A, p. 272-277.

have a higher radioactivity than many other rocks in the earth's crust. The fact remained of scientific interest only, however, until World War II when uranium became important as a source of nuclear energy.

Although much work has been done on the geology of uranium-bearing phosphates, most of the reports that have been written are classified and unpublished. The references in this bibliography represent nearly all of the reports pertaining to uranium in domestic phosphorites that were publicly available as of May 31, 1955.

## Domestic phosphates

There are six important geologic types of phosphate in the United States: 1) apatite deposits of igneous origin; 2) residual deposits; 3) phosphatized rock; 4) river-pebble deposits; 5) guano; and 6) marine phosphorites.

Apatite is a constituent of many igneous and metamorphic rocks, but has been mined for phosphate in the United States, only from the titanium-apatite deposits of Nelson County, Virginia (Ref. no. 20). So far as is known no uranium analyses of this rock have been made. According to Davidson_/, the uranium content of samples of apatite from foreign countries ranges from less than 0.001 to 0.03 percent.

_/ Davidson, C. F., and Atkin, D., 1953, On the occurrence of uranium in phosphate rock: in Origine des gisements de phosphates de chaux: Cong. Geol. Internat., Comptes rendus de la 19th session, Alger 1952, Section XI, Fascicule XI, p. 26.

Residual deposits are formed by the concentration of phosphate derived from the weathering of marine phosphatic limestones. The brown phosphate rock deposits of Tennessee are an example. The brown rock occurs in the belt of outcrop of the limestones of the Nashville group of the upper part of the Ordovician system, along the northern and western edges of the central basin of Tennessee. The brown rock contains practically no uranium.

Deposits of phosphatized rock are formed by the solution of phosphatic materials from overlying sedimentary rocks and redeposition in, or replacement of, the underlying rock, usually limestone. Examples of phosphate deposits of this type are afforded by the white-rock deposits around the central basin of Tennessee and by the belt of hard-rock deposits in the Alachua formation in northwestern Florida. The uranium content of these deposits is generally low.

River pebble deposits are alluvial deposits and occur as bars and banks in present-day stream channels and neighboring lowlands. Deposits of this type are in Florida and South Carolina and were derived by reworking of marine phosphorites. The uranium content of river pebble deposits is comparable to the uranium content of the material from which they were derived.

Deposits of guano, the excrement of birds and animals, have been reported from the bat caves of Texas and New Mexico. The deposits are rich in phosphate but are limited as a commercial source of fertilizer because of their very small size. A few tons have been mined from the New Mexico deposits. As far as is known, guano contains practically no uranium.

Marine phosphorites are characteristically thin, but probably represent all the products deposited during long periods of geologic time. Phosphorites of this type are believed to be precipitated on shelving margins of large oceanic basins. All of the marine phosphorites that have been analyzed chemically contain from 0.005 to 0.03 percent uranium.

The land-pebble phosphate deposits of Florida and the deposits in the western phosphate field represent the most important concentrations of marine phosphorites in the United States.

The land pebble district of Florida is in the west-central peninsular part of the state. The phosphate deposits are mostly in the Bone Valley formation which is considered by most writers to be of Pliocene age. Some of the phosphate mined, however, is a residual part of the underlying Hawthorn formation of middle Miocene age. The high-grade phosphate that is mined is locally termed "matrix". Phosphate is mined only from the deposits in the northern half of the district, although there are some lower-grade phosphate deposits in the southern half.

The lower part of the Bone Valley formation is composed of quartz sand, clay, and phosphate nodules. The upper part of the formation is a clayey sand with sparse phosphate nodules. In some areas of the land-pebble district the upper part and the top of the lower part of the Bone Valley have been altered by acid ground waters. These altered sections which reflect the original rock type are known as the "leached" zone, and are erratically distributed in the northern part of the land-pebble district. The "leached" zone apparently does not extend into the southern part of the district.

The $P_2O_5$ content of the phosphate nodules in the matrix ranges from 30 to 36 percent, and the uranium content ranges from 0.005 to 0.02 percent. Generally, the uranium content of the phosphorite increases as the phosphate content increases, although there are exceptions. For example, the "leached" zone has a higher uranium content and a lower $P_2O_5$ content than the matrix.

The most important phosphate deposits in the western field are found in the phosphatic shale member of the Permian Phosphoria formation. The Phosphoria formation and its stratigraphic equivalents crop out in Idaho, Montana, Wyoming, and Utah and have an eastern and a western facies.

The western facies is part of the folded Cordilleran miogeosyncline and is characterized by black shales, cherts, carbonaceous mudstones, and rich, black phosphorites. The eastern platform facies has a predominance of carbonate rocks, with interbedded layers of chert, sand, limestone, and weakly phosphatic rock.

The $P_2O_5$ content of the mineable beds of the Phosphoria rarely exceeds 32 percent. The uranium content of the phosphorite ranges from 0.01 to 0.02 percent and seems to increase in a general way with an increase in phosphate. The $P_2O_5$ content seems to increase westward, and the uranium also appears to be more abundant in the eastern part of the geosynclinal facies.

Phosphate deposits of the marine platform type are found associated with limestones, glauconitic sands, and black shales. Examples of this type are: the blue-rock phosphate of Tennessee which is an unaltered part of the Hardin sandstone member of the Chattanooga shale_/;

_/ Smith, R. W., and Whitlatch, G. I., 1940, The phosphate resources of Tennessee: Tennessee Dept. Cons., Div. Geology Bull. 48. 444 p.

phosphatic Permian limestones in central Texas; phosphate deposits in the Cason shale in the vicinity of Batesville, Arkansas_/; and

_/ Waggaman, W. H., 1912, A report on the natural phosphates of Tennessee, Kentucky, and Arkansas: U. S. Bureau of Soils Bull. 81, 36 p.

phosphatic nodules in black shales in Kansas and Oklahoma.

It has been suggested that the uranium in marine phosphorites substitutes for calcium in the phosphate mineral which is a fluorapatite (Ref. no. 11, p. 28, 29), although some uranium appears to be associated with the clay minerals and organic material. Most authors agree that the uranium is of syngenetic origin, probably being derived from the sea water and removed from it by precipitation by organic or inorganic substances. The theory is supported by the fact that the uranium content of marine phosphorites is higher than that of continental phosphate deposits. With some exceptions, the uranium content increases as the phosphate content increases. Uranium is not abundant in calcareous phosphorites. Local factors, such as the grain size of the matrix may also influence the amount of uranium deposited.

The marine phosphate deposits of the United States represent a large, low-grade reserve of uranium. In 1952, the Atomic Energy Commission announced that the Blockson Chemical Co., near Joliet, Illinois, would be the first to extract uranium from phosphate rock. Since then, plants in Texas City, Texas and in Florida have started to produce uranium as a by-product in the manufacture of wet-process phosphoric acid.

## EXPLANATION OF THE BIBLIOGRAPHY AND INDEX MAP

The bibliography is primarily an annotated list of published and open-file reports pertaining to the geology of uraniferous phosphorites, although a few general papers on the geology of domestic phosphate deposits have been included. The references are numbered and are listed alphabetically by author.

The annotations of the reports express only the ideas of their authors. Occasionally, however, information has been added for clarification, and this is included in brackets. Where the author's summary or abstract is used in lieu of an annotation, and where an entire article is quoted, the author's name appears at the end of the quotation.

A finding list, by subject, author, and area, is included as an index at the end of the report.

The localities mentioned in the references are shown on the index to localities and the index map, figure 1. (See p. 75, 76.) Each locality or general area has been assigned a specific number on the map and this key number enclosed in brackets, for example [Map No. 1], has been inserted in the text of the bibliography after the citations of references applying to that locality.

## ACKNOWLEDGMENTS

This report concerns work done on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission. The author wishes to thank James B. Cathcart and Robert W. Schnabel of the U.S. Geological Survey for their helpful suggestions.

1. Altschuler, Z. S., 1953, Southeast phosphate mineralogic and petrologic studies: in Search for and geology of radioactive deposits, Semiannual progress report, December 1, 1952 to May 31, 1953: U. S. Geol. Survey Rept. TEI-330, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, p. 171-176. [Map Nos. 1 and 2.]

This is a summary of mineralogic and petrologic studies made of southeast phosphates during the period August 1952 to May 1953.

A petrologic study of sections from a mine face at Homeland, Florida where the aluminum phosphate zone (leached zone) transgresses the original stratigraphy, indicates that the following succession of minerals prevails according to the degree of alteration of the rock. The minerals are listed in order from the base to the top of the section: (1) montmorillonite and apatite in the unaltered area; (2) pseudowavellite, kaolinite, apatite, and montmorillonite where alteration is first observed; (3) pseudowavellite and montmorillonite near the top in areas of more intense alteration; and (4) wavellite at the top of the section. Quartz, which is abundant in all samples, increases regularly from the base to the top.

The uranium content of the sections is enriched by supergene processes at the base of the pseudowavellite-apatite zone (See (2) above)

The origin of the surface sands and the source of the uranium are two major problems in the leached zone of the land pebble district. Field evidence indicates either a residual or depositional origin for the surface sands. In either case, the uranium in the leached zone could be a concentrated product of a once thicker section of slightly phosphatic, clayey quartz sand.

DC

2. Altschuler, Z. S., Jaffe, E. B., and Cuttitta, F., The aluminum phosphate zone of the Bone Valley formation and its uranium deposits (abstract): Contribution to the International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, August 1955, Session C.- Role of Nuclear Energy. (in press). [Map No. 1.]

The Pliocene Bone Valley formation which contains most of the "Land Pebble" phosphates, occurs in west-central Florida east of the Tampa Bay region, unconformably overlying the lower and middle Miocene Hawthorn formation and covered by a surface mantle of quartz sands. It contains graded-bedded pebbly and clayey phosphatic sands in its lower two-thirds, which are mined, and a less phosphatic, massive-bedded, clayey sand, approximately 8 to 10 feet thick, in its upper third, which is discarded.

The upper part of the Bone Valley formation has been leached, altered to aluminum phosphates, and enriched in uranium in a widespread, though discontinuous zone which underlies several hundred square miles of the Peace and Alafia drainage basins and averages about 6 to 7 feet in thickness. The areal patterns of thickness and of tonnage and grade distribution for $P_2O_5$ and uranium of the aluminum phosphate zone conform strikingly to the topography of the river valleys.

The alteration of the Bone Valley formation was caused by weathering and ground water, and the vertical changes through the aluminum phosphate zone show a progressive variation in mineralogy and texture. In typical sections carbonate-fluorapatite still prevails at the base, incipiently leached and altered. In the middle of the zone the calcium-aluminum phosphates crandallite and millisite are found, and at the top, the aluminum phosphate wavellite predominates. The changes have been brought about by phosphatization of clay and by alumina alteration of apatite.

Much apatite and clay have been leached and replaced in the aluminum phosphate zone and its rock is generally white, friable, and highly porous; however, its character has been greatly influenced by the primary Bone Valley petrography. Thus where graded-bedded, pebbly rock is altered, coarse, frequently graded, vesicularity results; where massive clayey sand is altered, fine porosity prevails and aluminum phosphates are more common.

The uranium content of unaltered rock of the lower Bone Valley is approximately 0.008 percent; its $P_2O_5$ content is about 15 percent. Unaltered rock of the upper Bone Valley contains much less uranium and $P_2O_5$. By contrast, a well-developed section of aluminum phosphate zone has typically 0.012 percent uranium and approximately 8 to 10 percent $P_2O_5$. Within the aluminum phosphate zone, uranium increases as calcium does and more calcic phosphates are more uraniferous. In addition supergene processes have caused a subzone of basal enrichment in the aluminum phosphate zone in which individual apatite specimens contain as much as 0.X percent uranium. Except for a single trace occurrence of autunite, no uranium minerals have been found in the Bone Valley formation.

The aluminum phosphate zone is a potentially valuable resource of uranium, phosphate, and alumina, particularly as it must be stripped to mine the underlying apatite deposits and its rock can be readily beneficiated by removal of quartz, the major diluent.

Z. S. Altschuler and others

3. Anonymous, 1950, Uranium found in Florida phosphate limited to certain deposits: Eng. Min. Jour., vol. 151, no. 8, p. 93. [Map Nos. 1 and 5.]

This article is a resumé of a paper presented by J. B. Cathcart (U. S. Geol. Survey) at the meeting of the Industrial Division of the AIME in Tampa, November 1949. The entire article, except for introductory material follows:

Land-pebble phosphate, hard-rock phosphate, and river-pebble phosphate are the three types of phosphatic rock found in Florida. Mr. Cathcart's report is concerned primarily with the land-pebble deposits, the only type which contains the uranium. The most productive part of the land-pebble district is in Polk and Hillsborough Counties, in the west-central part of Florida.

In the two counties named, which contain the high-grade part of the land-pebble phosphate district, uranium occurs principally in the Bone Valley formation. Fresh unweathered Hawthorn formation has little or no uranium, but leached Hawthorn, rich in $P_2O_5$, contains a small amount of uranium. The Pleistocene sands have no uranium except where they contain reworked phosphatic material from the Bone Valley formation.

South of the high-grade district, in Manatee and Hardee Counties, the Bone Valley, Hawthorn, and Pleistocene formations contain only very minor amounts of uranium.

The uranium in the land-pebble deposits was probably syngenetic in origin. The uranium seems to be associated with the phosphate.

Two types of rocks in the land-pebble phosphate district contain the uranium. First is the rock composed of sand, clay, and abundant phosphate nodules, termed "matrix". Uranium is present in nodules as proved by analyses of samples from which everything but the phosphate nodules have been removed. In this case it is possible that the uranium takes the place of the calcium in the phosphate mineral. Uranium is also present in the clay fraction (slime). Certain rocks which are composed of clay-sized particles and are white and kaolin-like and highly phosphatic, also contain small amounts of uranium. Green "matrix" clays, however, contain almost no phosphate, and little or no uranium.

Anonymous

4. Barnes, V. E., 1954, Phosphorite in eastern Llano Uplift of central Texas: Univ. of Texas, Bur. Econ. Geol., Rept. of Inv. No. 23, 9 p. [Map No. 22.]

A radioactive deposit of phosphorite, estimated to be 11 feet thick, is exposed about 1 1/2 miles south of Marble Falls, Burnet County, Texas, in a road-material pit on the eastern side of an outlier of Carboniferous age. The deposit consists of interbedded phosphate rock and limestone with phosphatic nodules. Stratigraphically the deposit lies above shale typical of that in the Barnett formation of Mississippian age, and beneath spiculitic limestone at the base of the Pennsylvanian Marble Falls formation. Other thin phosphate zones are known in the Llano Uplift, all of which are abnormally radioactive.

The phosphorite is composed mostly of well-rounded grains between 0.1 and 0.6 mm. in diameter. Most of the grains are oölitic, a few appear to be structureless pellets, and others are portions of organisms.

Phosphatic nodules are found in limestone beds, the lower of which is highly fossiliferous in places. Brachiopods are most abundant, and gastropods, cephalopods, and corals are common. The upper limestone beds are less fossiliferous and contain fewer phosphate nodules.

The phosphatic nodules in the limestone are a pale to dark yellowish-brown color on the fresher surfaces, and a dark yellowish-orange where weathered.

Chemical analysis of a sample of the bed from 3 inches to 5 feet above the base of the deposit showed a $P_2O_5$ content of 13.92 percent, and a chemical analysis of the bed from 5 to 8 1/2 feet above the base showed a $P_2O_5$ content of 15.18 percent. The phosphorite is estimated to contain about 0.017 percent $U_3O_8$ (by comparison, using a Geiger counter and an analyzed sample of phosphate rock known to contain 0.029 percent $U_3O_8$). /Analysis of a sample of phosphorite from the same area by the U. S. Geological Survey shows 0.006 percent equivalent uranium./

The deposit is estimated to contain 5,000 tons of phosphorite. An additional 35,000 tons of phosphorite may be present in an outlier to the northeast, although no abnormal radioactivity was noted there. These deposits are of low grade, small tonnage, and have a questionable commercial value.

DC

5. Bergendahl, M. H., 1953, Wavellite spherulites in the Bone Valley formation of central Florida: (abstract) Nuclear Science Abstracts, vol. 7, no. 11, p. 375-376. [Map. No. 1.]

Megascopic spherulitic aggregates of wavellite have recently been found in the Florida land-pebble phosphate field. Petrographic studies were made to establish the identity of the mineral. Chemical and spectrographic data revealed the spherulites to be practically pure wavellite, and the remainder is composed of phosphatic cement partly altered to wavellite. The origin of wavellite is considered to be secondary, a replacement of apatite which has undergone ground-water leaching. [A chemical analysis made by the U.S. Geological Survey of the wavellite shows 0.003 percent uranium.]

M. H. Bergendahl

6. Cathcart, J. B., 1950, Notes on the land-pebble phosphate deposits of Florida; in Snyder, F. G., (edited by), Symposium on mineral resources of the southeastern United States, 1949 proceedings: The University of Tennessee Press, Knoxville, p. 132-151. [Map Nos. 1 and 5.]

The phosphate deposits in Florida are of three types: (1) the land-pebble deposits, which are of marine origin and of Pliocene age, such as those in the Bone Valley formation; (2) hardrock deposits, which are of continental origin and are formed as replacement bodies in earlier limestone, and as fluvial concentrations in Pliocene stream channels; (3) and river-pebble phosphate of continental origin, which is found as bars and on flood plains along present streams. The report is concerned mainly with the land-pebble type deposits.

The phosphorites contain small quantities of uranium, which probably is in the phosphate mineral (a fluorapatite).

It is suggested that the source of the uranium was sea water. This supposition is supported by the fact that the marine Bone Valley formation has a higher uranium content than the continental hardrock.

The marine Bone Valley formation has a higher uranium content, and possibly accumulated more slowly than the underlying marine Hawthorn formation. This fact suggests that the longer the time of exposure of the phosphate nodules to the sea water, the greater their uranium content.

DC

7. Cathcart, J. B., 1953, Economic geology, land-pebble phosphate district (Florida); in Geologic investigations of radioactive deposits, Semiannual progress report, June 1 to November 30, 1953: U. S. Geol. Survey Rept. TEI-390, issued by U. S. Atomic Energy Comm., Tech. Inf. Service, Oak Ridge, p. 175. [Map No. 1.]

The Peace River area, Florida, may be divided into three physiographic units: (1) the ridge, (2) the flatwoods, and (3) the valley and floodplain of the river. The aluminum phosphate zone is thickest, most continuous, and highest in $P_2O_5$ and U in the flatwoods region, and is thin and discontinuous, or absent in the ridge area, and is absent in the floodplain and valley of the Peace River. Analytical data indicate that areas of high $P_2O_5$ and high U generally correspond, and in general these high areas correspond with the thicker sections. However, detailed drilling has shown the extreme lateral variations in both thickness and analyses, from possibly mineable to unmineable areas in as little as 200 feet. It seems likely that very detailed drilling will be necessary prior to mining in order to predict feeds for a plant, and that some surge capacity and mixing facilities will be necessary to maintain a uniform feed.

J. B. Cathcart

This is a slightly edited but otherwise essentially complete text of this reference.

8. Cathcart, J. B., 1954, Drilling of airborne radioactivity anomalies in Florida, Georgia, and South Carolina: U. S. Geol. Survey Open-file Rept. [Map Nos. 3, 6, 7, 8, 9, and 10]

Areas of abnormal radioactivity, as recorded by airborne surveys in Florida, in general were proved by drilling to be underlain, at shallow depths, by uranium-bearing phosphatic rocks. In Marion County, Florida, drilling within the area of anomalous radioactivity showed aluminum phosphate material very close to the surface; check holes drilled outside the areas of anomalous radioactivity showed thick, barren quartz sand at the surface. However, several areas of anomalous radioactivity were drilled and checked with a scintillation counter without finding any anomalous radioactivity. In the area near Olustee Creek, in Union County, Florida, and in the Steinhatchee area, the reason anomalous radioactivity was not found may be that the anomalous areas, as shown on county road maps, are misplotted. County roads in both cases are shown cutting across the edges of the anomalous areas, and if the line enclosing the area of anomalous radioactivity were moved only a short distance, the roads would be out of the areas and would be blank as the drilling indicated.

In Clay and Manatee Counties, Florida, and in the Altamaha River drainage in Georgia, the anomalies were very slight, only about twice background, and reasons for finding no anomalous radioactivity on the ground are not known.

In general, therefore, it would seem that anomalies which are greater than about twice background indicate the presence of uranium-bearing phosphatic rocks at or near the surface, while those anomalies which are only about twice background may or may not indicate the presence of phosphate rock.

J. B. Cathcart

9. Cathcart, J. B., Distribution and occurrence of uranium in the calcium phosphate zone of the land-pebble phosphate district of Florida (abstract): Contribution to the International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, August 1955, Session C - Role of Nuclear Energy. (in press). /Map No. 1./

The land-pebble phosphate district of Florida in west central peninsular Florida, covers an area of more than 1000 square miles, mostly in Polk and Hillsborough Counties. Lower grade phosphate deposits also occur to the south.

The Tampa formation of lower Miocene age is exposed only in the northernmost part of the area, where the Hawthorn formation of middle Miocene age thins to a feather edge. The Hawthorn formation contains minor to trace amounts of phosphate particles, and where the carbonate has been removed by weathering, the residual concentration of phosphate particles and quartz sand is called "bedclay", and may form a part of the matrix. The uranium content of the bedclay averages about 0.005 percent.

The Bone Valley formation of Pliocene age has been leached by acid-groundwaters, forming a zone characterized by aluminum phosphate minerals. This zone, locally called the "leached" zone, commonly contains between 0.010 and 0.015 percent uranium.

The matrix, or calcium phosphate zone, comprising the lower phosphorite part of the Bone Valley formation, and the upper residual part of the Hawthorn formation, consists essentially of equal parts of quartz sand, phosphate particles (+ 150 mesh), and "slime" (-150 mesh). The central area of the Bone Valley formation contains predominantly coarse (+ 14 mesh) phosphate and the surrounding areas contain predominantly fine (-14 +150 mesh) phosphate. The analysis of many thousands of samples has shown that the coarser phosphate particles are higher in uranium and lower in $P_2O_5$ content than the finer material. Uranium content of the coarser material (pebble) averages between 0.010 and 0.020 percent, and the $P_2O_5$ content averages about 31.5 percent. The uranium content of the finer materials (concentrates) is commonly between 0.005 and 0.015 percent, and the $P_2O_5$ content averages about 34 percent. A direct relation between $P_2O_5$ content and U content is present, however, within a size fraction: in pebble samples of the same size, the U content tends to increase as the $P_2O_5$ increases.

The uranium content of the quartz sand fraction of the matrix is less than 0.001 percent, and the slime fraction of the matrix usually contains small amounts of uranium, averaging less than 0.005 percent, although some samples very high in $P_2O_5$ content have a higher uranium content.

It is believed that the uranium is syngenetic, and was absorbed by the phosphate particles as they formed on the sea floor. This might account for the observed higher uranium content of the coarser materials, as they were probably exposed for longer periods of time to the action of sea water than were the smaller particles.

J. B. Cathcart

10. Cathcart, J. B., and others, 1953, The geology of the Florida land-pebble phosphate deposits: in Origine des gisements de phosphates de chaux; Cong. Geol. Internat., Comptes rendus de la 19th session, Alger, 1952; Section XI, Fascicule XI, p. 77-91. See p. 77. /Map No. 1/

The land-pebble phosphate district is on the Gulf Coastal Plain of Florida. The phosphate deposits are in the Bone Valley formation, dated Pliocene by most writers. These strata overlie the Miocene Hawthorn formation, and are overlain by unconsolidated sands 3 to 20 feet thick.

The mineable phosphate deposits, called "matrix" in the district, range from a featheredge to about 50 feet in thickness and consist of phosphatic pellets and nodules, quartz sand, and montmorillonitic clay in about equal proportions. Locally the matrix displays cross-bedding and horizontal laminations, but elsewhere it is structureless. The phosphorite particles, composed largely of carbonate-fluorapatite, range in diameter from less than 0.1 mm. to about 60 cm. and in $P_2O_5$ content from 30 to 60 percent. Coarse-pebble deposits, containing 30 to 34 percent $P_2O_5$, are found mainly on basement highs: and fine-pebble deposits, containing 32 to 36 percent $P_2O_5$ are found in basement lows. Deposits in the northern part of the field contain more phosphate particles and their $P_2O_5$ content is higher than those in the southern part.

The upper part of the phosphatic strata is leached to an advanced degree and consists of quartz sand and clay-sized particles of pseudowavellite and wavellite. The leached zone ranges in thickness from a featheredge to 60 feet.

The origin of the land-pebble deposits is incompletely known. Possible modes of origin are a residuum of Miocene age, or a reworked residuum of Pliocene or Quaternary age.

J. B. Cathcart

11. Davidson, C. F., and Atkin, D., 1953, On the occurrence of uranium in phosphate rocks: in Origine des gisements de phosphates de chaux: Cong. Geol. Internat., Comptes rendus de la 19th session, Alger 1952, Section XI, Fascicule XI, p. 13-31. See p. 29.

It has been known since the investigations of Strutt over forty years ago that phosphorites, apatite crystals, and fossil bones are richer in uranium than the average rocks of the earth's crust. In the present study a quantitative examination has been made of the uranium content in commercial phosphate rocks from North Africa, America /Florida, South Carolina/, various localities in Europe, and the Oceanic Islands. A considerable range of values has been found, the Ocean Island phosphorites possessing a low radioactivity and the phosphate rocks of marine deposition showing high uranium, especially where the carbonate content is low. Fossil bones and apatite crystals also contain a little uranium, the highest value found being 0.55 percent $eU_3O_8$ in a Middle Old Red Sandstone fossil fish from Sutherland /Great Britain/. Aluminum phosphates, such as variscite and turquoise, may display a significant radioactivity. It is concluded that, at least in most instances, the uranium is present in the apatite of the phosphorite of bone as a proxy for calcium, and that it is derived principally from percolating waters. Where the apatite or phosphorite is of a porous nature the substitution has usually proceeded uniformly throughout the mass; where it is compact or impervious replacement is concentrated towards the edges.

C. F. Davidson and D. Atkin

12. Dietz, R. S., Emery, K. O., and Shepard, F. P., 1942, Phosphorite deposits on the sea floor off southern California: Geol. Soc. America Bull., vol. 53, no. 6, p. 815-848. [Map No. 24.]

Submarine phosphorite deposits are found off the coast of Southern California from Monterey Bay south to the Gulf of California. Samples of phosphorite were collected from the sea bottom, as well as from the tops and sides of offshore banks. The deposits are found in Miocene to Recent sediments, but no positive identification of the age of the strata could be made.

The mode of occurrence of the phosphorite varies in forms ranging from thin, flat slabs to nodular masses. It also is found as coatings on hard compact rock, as fillings in porous rock, and as a cement of fragments of darker phosphorite and other rocks.

The nodules are generally hard, dense, have smooth glazed surfaces and a fresh appearance. Their surface consists of a thin discolored layer of phosphorite or of manganese oxide. Freshly broken surfaces are usually light to dark brown in color. Collophane is the principal mineral form of the phosphate. Francolite (?) is sometimes associated with the collophane. The majority of the nodules are irregularly layered, many are conglomeratic, and nearly all the phosphorite is somewhat oölitic. Many nodules enclose foreign material such as foraminiferal tests, grains of clastic minerals, and glauconite.

Six samples were analyzed chemically and have an average of 28.15 percent $P_2O_5$, 44.91 percent CaO, and 3.11 percent F. Insoluble residues comprised from 6 to 30 percent of the samples; the fine fraction consisted dominantly of amorphous silica and carbonaceous material; the coarse fraction consisted of glauconite, mineral grains, carbonaceous particles, and siliceous animal remains.

That the phosphorite was deposited essentially <u>in situ</u> is suggested by the following facts: the one-sided mammilary surfaces formed by growth layers on many nodules; the large size of many of the nodules, and their lack of abrasion; the close resemblance of the sediment enclosed in the nodules with the surrounding sediment; and the nondepositional environment [probably meaning the paucity of clastic sediments being deposited at present] which prevails on the south California sea floor.

The authors conclude that the nodules were deposited on the present banks, shelves and canyon walls during Quaternary time, and that previously an abundance of Miocene foraminifera had been eroded or weathered out of Miocene formations and concentrated on surfaces on which the phosphorite deposition gradually took place.

DC

Note: This paper has been included as it is a valuable discussion of present day phosphorites and their mode of origin. The data on the radioactivity of the nodules is given in a later paper by Emery and Dietz (Ref. no. 13).

13. Emery, K. O., and Dietz, R. S., 1950, Submarine phosphorite deposits off California and Mexico: California Jour. Mines and Geology, vol. 46, no. 1, p. 7-17. [Map No. 24.]

Samples of phosphorite were taken from submarine areas off the coast of southern California. The sea sediments are Miocene to Recent in age.

The Beta-radioactivity of 10 nodules from areas off the coast of California ranged from 41 to 65 counts per minute per gram with a background of 22 counts per minute.

DC

Note: This paper is essentially a resumé of the paper by Dietz, Emery, and Shepard (Ref. no. 12) with the addition of data on the radioactivity of some of the nodules.

14. Gould, H. R., 1953, Phosphate studies in the eastern Gulf of Mexico; in Search for and geology of radioactive deposits, Semiannual progress report, December 1, 1952 to May 31, 1953: U. S. Geol. Survey Rept. TEI-330, issued by U. S. Atomic Energy Comm., Tech. Inf. Service, Oak Ridge, p. 176-180. [Map No. 4.]

The purpose of the investigations of the phosphorite deposits in the eastern Gulf of Mexico was to determine the areal distribution, quality, source and mode of formation of the phosphatic sediments.

Preliminary results show that the continental shelf between Tarpon Springs and Fort Meyers, Florida, consists of an inshore zone of 20 miles of shelf and an outer zone of 100 miles off the shelf area.

The inshore zone is characterized by detrital sands composed chiefly of quartz. Generally, only traces of phosphorite were found in this zone. Visual comparison with chemically analyzed samples indicate that samples from this zone have a $P_2O_5$ content of less than 0.50 percent and a uranium content of less than 0.0001 percent. However, a few of the samples analyzed chemically have maximum contents of 13.4 percent $P_2O_5$ and 0.004 percent uranium.

Almost no phosphorite was detected in the offshore zone, which is characterized by calcareous sands of organic origin. These sediments have a $P_2O_5$ content of less than 0.15 percent and a uranium content of less than 0.0001 percent.

The features of the phosphorite in the two zones suggest that it is of detrital origin, being supplied by rivers draining peninsular phosphate deposits and by adjacent phosphatic beaches.

DC

15. Harris, R. A., Davidson, D. F., and Arnold, B. P., 1954, Bibliography of the geology of the western phosphate field: U.S. Geol. Survey Bull. 1018, 89 p. [Map No. 23]

This bibliography lists publications, prior to September 1952, on the geology of phosphates in Alberta and British Columbia, Colorado, Idaho, Montana, Utah, and Wyoming, with a section on the mineralogy and chemical composition of phosphorites in other regions. The section on areal geology includes only the publications that describe the geology of the area containing the Phosphoria formation of Permian age or its partial stratigraphic equivalents, the Park City and Embar formations. The sections on stratigraphy, regional structure, and other mineral deposits and fuels contain references to publications describing those aspects of areas within the western phosphate field as a whole. Entries are liberally cross indexed.

16. Jacob, K. D., Hill, W. L., Marshall, H. L., and Reynolds, D. S., 1933, The composition and distribution of phosphate rock with special reference to the United States: U. S. Dept. of Agriculture Tech. Bull. No. 364, 90 p. /Map Nos. 1, 5, 11, 17, 18, 19, and 23./

A brief review of the phosphate deposits and the production and reserves of phosphate rock in the United States is given. The flotation process of concentrating low-grade phosphate ores is discussed with reference to its value in the conservation of the phosphate deposits in the southeastern part of the United States.

The results of an analytical study of 46 samples of mineral calcium phosphates representing nearly all of the more important domestic types and sources of this material are presented. Data are also given on the composition of 11 samples of bone ash, apatites, and foreign phosphate rocks, and on the percentages of fluorine and phosphoric acid in a large number of additional samples from deposits throughout the world.

Phosphoric acid, lime, alumina, iron, silica, carbon dioxide, fluorine, and, in most samples, sulphate are the predominating constituents of domestic phosphate rock. Magnesium, titanium, sodium, potassium, manganese, chromium, copper, zinc, arsenic, chlorine, and iodine are present in nearly all samples, but only in comparatively small quantities. Small percentages of vanadium are also present in many samples.

Phosphate rock from continental deposits usually contains 3 to 4 percent of fluorine, whereas that from insular deposits contains smaller quantities. As a general rule, the fluorine-phosphoric acid ratios in a particular type of rock are approximately constant. Although fresh bones are very low in fluorine, fossil bones frequently contain high percentages of this element. Evidence is presented to show that the fluorine in phosphate rock and fossil bones originates principally from contact of the phosphates with fluorine-bearing waters, and that, to a certain extent, there is a rough correlation between the fluorine content and the geological age of these materials.

The commercial types and grades of domestic phosphate rocks contain approximately the following percentages of minor constituents - $MgO$, 0.0 to 0.5; $TiO_2$, 0.02 to 0.15; $Na_2O$, 0.1 to 0.8; $K_2O$, 0.05 to 0.65; $MnO$, traces to 0.3; $Cr_2O_3$, 0.00 to 0.15; $V_2O_3$, 0.00 to 0.40; $CuO$, $<$ 0.0005 to 0.01; $ZnO$, $<$ 0.0005 to 0.025; $As_2O_3$, 0.001 to 0.015; and $Cl$, 0.00 to 0.10. The iodine content ranges from approximately 1 to 130 parts per million.

Pyrite is a common constituent of Tennessee blue rock and phosphatic limestone, South Carolina land rock, and rock from Cokeville, Wyo.

The organic matter isolated from phosphate rock carries high percentages of nitrogen and sulphur, and the ash of this material is rich in iron.

In comparison with the other types of domestic phosphate rock, Tennessee brown-rock phosphate is characterized by the presence of high percentages of aluminum, iron, and manganese, and by the absence of vanadium. It usually contains more potassium than sodium, whereas the reverse is the rule with the other types.

Tennessee blue-rock phosphate is similar to Tennessee brown rock in that it is comparatively high in iron. It is also high in acid-soluble sulphate, but its outstanding characteristic is its high content of acid-insoluble sulphide, principally pyrite.

Florida land-pebble phosphate has no outstanding chemical characteristic. The percentages of fluorine in the different commercial grades of this material are, however, approximately constant, whereas in the other types of phosphate rock the fluorine content varies, as a general rule, directly with the phosphoric acid.

Florida hard-rock phosphate is characterized by its comparatively high content of iodine, and low content of sulphate and chlorine.

In general, the phosphates from deposits in the Rocky Mountain States are comparatively high in chromium and vanadium, and low in iodine. Certain samples, notably those from deposits at Conda, Idaho, and Cokeville, Wyo., are exceptionally high in organic carbon and organic sulphur, whereas rock from the Garrison, Mont. deposit is low in organic carbon and in total sulphur.

In comparison with phosphate rock, Florida waste-pond phosphate is low in phosphoric acid and exceptionally high in silica and alumina. The composition of Florida soft phosphate varies considerably with different samples.

Nearly all of the elements present in phosphate rock occur also in bone ash.

Analyses of the mechanical fractions separated from samples of ground phosphate rock and from Florida soft and waste-pond phosphates showed that, as a general rule, the phosphoric acid, calcium, and fluorine concentrate somewhat in the "sand" and "silt" fractions, whereas the alumina and silica concentrate to a marked extent in the "clay" and colloid fractions, particularly the latter.

Phosphate rock does not contain significant quantities of phosphoric acid soluble in neutral ammonium citrate solution, and less than 30 percent of the total phosphoric acid is soluble in 2 percent citric acid solution. The percentages of phosphoric acid dissolved by these reagents from a particular sample of phosphate increase with increase in the fineness of the particles.

The principal phosphatic component of phosphate rock from continental deposits is fluorapatite, which is present almost entirely in the submicrocrystalline condition. Hydroxyfluorapatite is an important constituent of rock from insular deposits. The available data indicate that domestic phosphate rock may contain small quantities of carbonate apatite and hydroxyapatite.

K. D. Jacob and others

Note: This paper has been included as it is of general interest, although it does not discuss uranium.

17. Ketner, K. B., 1955, A bibliography of phosphate deposits in southeastern United States: U. S. Geol. Survey Open-file Rept., 18 p. [Map Nos. 1, 5, and 11.]

The bibliography includes references to phosphate deposits in South Carolina, Georgia, Alabama, and Florida published before 1954. Although the bibliography is not exhaustive, the references are reasonably complete for the field of geology. Only those works on technology and statistics of production that contain geologic data are included. For more complete coverage of non-geologic topics related to phosphate deposits the reader is referred to publications such as those of the American Institute of Mining and Metallurgical Engineers and the U. S. Bureau of Mines.

Following the bibliography is a general subject index in which numbers refer to entries in the bibliography.

K. B. Ketner

18. McKelvey, V. E., Uranium in phosphate rock (abstract): Contribution to the International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, August 1955, Session C - Role of Nuclear Energy. (in press)

Marine phosphorites commonly contain 0.005 to 0.03 percent uranium. The uranium content increases roughly with increasing phosphate content but is generally low in rocks that contain more than a few percent $CO_2$. Aluminum phosphate deposits that have been derived from the weathering of marine phosphorites and phosphatic nodules in some marine black shale formations contain similar amounts of uranium. Most of the uranium in these materials does not occur as a separate mineral phase but substitutes for calcium in carbonate fluorapatite or crandallite. A few occurrences of tyuyamunite and torbernite have been reported from highly weathered marine phosphorites, however, and these and other secondary uranium minerals, such as carnotite and autunite, are not uncommon in fossil bones and teeth that have been exposed to uranium-bearing solutions after burial. Because the marine phosphorites are of wide extent they contain large tonnages of uranium, some of which can be recovered, under favorable conditions, as a by-product of the manufacture of triple super phosphate.

V. E. McKelvey

19. McKelvey, V. E., and Carswell, L. D., Uranium in the Phosphoria formation (abstract): Contribution to the International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, August 1955, Session C - Role of Nuclear Energy. (in press). [Map No. 23.]

The Phosphoria formation of Permian age and its close stratigraphic correlatives consist of two overlapping couplets, each composed of a lower carbonaceous, phosphatic unit, overlain by a cherty or carbonatic unit. Phosphate deposits are found in the Phosphoria formation over an area of about 135,000 square miles in Montana, Idaho, Utah, and Nevada, but the richest deposits are confined to a central area in eastern Idaho and adjacent parts of Montana, Wyoming, and Utah. Nearly all the phosphatic beds are uraniferous but their uranium content ranges from about 0.001 to 0.065 percent. Although some highly phosphatic beds are only weakly uraniferous, the phosphate beds that are more than 3 feet in thickness and that contain more than 31 percent $P_2O_5$ generally contain 0.01 to 0.02 percent uranium. Most of the differences in uranium content of the phosphate rocks cannot be correlated with other observable differences in their physical or chemical properties. As a rule, however, beds composed of pellets and oölites are more uraniferous than those composed of fish scales, brachiopod shells, and other organic remains; and highly weathered phosphate beds contain less uranium than their unweathered equivalents.

Most of the uranium seems to occur in carbonate fluorapatite, where it probably substitutes for calcium, but tyuyamunite has been discovered in one area where the rocks are highly weathered.

V. E. McKelvey and L. D. Carswell

20. McKelvey, V. E., Cathcart, J. B., Altschuler, Z. S., Swanson, R. W., and Buck, K. L., 1953, Domestic phosphate deposits; in Soil and fertilizer phosphorous in crop nutrition: vol. IV of Agronomy, Academic Press Inc., p. 347-376. [Map Nos. 1, 5, 11, 12, 17, 18, 19, 20, and 23.]

There are six important geologic types of phosphate deposits in the United States. They are apatite deposits of igneous origin, residual phosphorites, marine phosphorites, river-pebble deposits, phosphatized rock, and guano. The characteristics of each type are discussed and representative chemical analyses are given.

Concentrations of one type or another are found in 30 of the states, although only some of the states - Pennsylvania, Virginia, North Carolina, South Carolina, Georgia, Alabama, Florida, Tennessee, Kentucky, Arkansas, Idaho, Wyoming, Utah, and Montana - have produced phosphate rock.

At present, the only production is from the land-pebble district and the hard-rock field of Florida, the brown-rock field of Tennessee, and from the Permian phosphorite deposits in Idaho, Montana, Wyoming, and Utah. Future production is likely to be limited to these fields.

The authors discuss the types of phosphate deposits found throughout the United States, and estimate the total reserves of mineable phosphate to be about 5 billion tons of rock containing about 1.5 billion tons of $P_2O_5$. Additional lower-grade reserves total nearly 50 billion tons of rock containing 12 billion tons of $P_2O_5$.

DC

Note: This paper has been included as it is of general interest, although it does not discuss uranium.

21. McKelvey, V. E., and Nelson, J. M., 1950, Characteristics of marine uranium-bearing sedimentary rocks: Econ. Geol., vol. 45, No. 1, p. 35-53. [Map Nos. 1, 21, and 23.]

All marine phosphorites tested up to the time of writing the report contain from less than 0.01 to 0.02 percent uranium. The Permian Phosphoria formation in the west and the Pliocene Bone Valley formation in Florida represent the largest deposits of this type in the United States.

Uranium is also found as a constituent of phosphatic nodules from shales; the uranium content of the nodules is higher, generally, than that of the surrounding shale. Such uraniferous phosphatic nodules are found in the shale at the top of the Checkerboard limestone member of the Coffeyville formation and in the Fort Scott limestone of Oklahoma; and in the Hushpuckney and Stark shales of Kansas.

In general, the uranium content of the phosphorite increases as the phosphate content increases, although there are numerous exceptions in this country. The uranium is believed to be in the phosphate mineral which is a fluorapatite.

Local factors may influence the amount of uranium deposited. In the Bone Valley formation in Florida, for example, analyses of samples suggest that there is a higher uranium concentration in the phosphorites with a clay-size matrix than in those with a sandy matrix. The uranium content of phosphorite beds may also vary with the thickness of a given formation, depending on whether or not the uranium-bearing materials cause the increase in thickness or are diluted by increased amounts of non-uraniferous materials.

Phosphorite formations are characteristically thin, perhaps representing the entire depositional products of long periods of time.

The uranium in phosphorite is of syngenetic origin, probably being derived from sea water, and removed from it either by direct precipitation as an inorganic uranium salt, or by selection by organisms or substances for which it has an affinity.

Assuming that the uranium is precipitated and fixed in the sediments in the various ways described, its concentration will result from conditions that lead to the concentration of substances, such as phosphate or organic matter, which may have removed the uranium from solution. In any case, deposition in a marine basin in which the environment does not favor influx of large amounts of clastics or precipitation of large amounts of carbonate, is a basic set of important conditions. The controlling height of the adjacent land masses, the dimensions and configuration of the basin of deposition, and the climate, all play a part in the development of such an environment.

The authors believe that relatively thin beds of phosphorite, such as those described, are likely to contain significant amounts of uranium, and that they merit prospecting.

DC

22. McKelvey, V. E., Swanson, R. W., and Sheldon, R. P., 1953, The Permian phosphorite deposits of western United States; in Origine des gisements de phosphates de chaux; Cong. Geol. Internat., Comptes rendus de la 19th session, Alger 1952, Section XI, Fascicule XI, p. 46-64. [Map No. 23.]

The Permian Phosphoria formation and its stratigraphic equivalents comprise about 135,000 square miles of marine sediments in Idaho, Montana, Wyoming, and Utah. There are two facies of the formation - that in the west being part of the folded Cordilleran miogeosyncline, that in the east being a platform facies. The western facies is characterized by black shales, cherts, carbonaceous mudstones, and rich black phosphorites. The eastern facies has a predominance of carbonate rocks, with interbedded layers of chert, sand, limestone, and weakly phosphatic rock.

The phosphorites of the Phosphoria formation are a colloform carbonate-fluorapatite mixed with detrital silicates and other material. Minor amounts of more than 35 metals including uranium are found in the Phosphoria formation. Uranium and the rare earths are more abundant in the phosphorites than in other rocks of the Phosphoria formation. The uranium probably occurs in the carbonate-fluorapatite mineral. Most of the metals are not abundant in calcareous phosphorites; in fact, uranium appears to decrease in the phosphorites as the $CO_2$ content rises to as much as 4 percent.

The grade of mineable phosphate beds is usually not more than 32 percent $P_2O_5$. The $P_2O_5$ content seems to increase westward to about the center of the geosynclinal facies, as does the amount of carbonaceous matter and the quality of the phosphate rock. The carbonate content, the size of the phosphorite particles, and the grain size of the clastic material, however, all decrease to the west. Some of the minor metals, such as uranium and vanadium, are more abundant in the geosynclinal facies in the west, than in the eastern platform facies.

The composition and facies changes of the phosphorite are indicative of marine deposition controlled mainly by pH, $CO_2$ content, temperature and depth. The presence of animal life, such as phytoplankton is also a contributing factor in the deposition of the phosphorite. The authors present an excellent discussion of the theory of the origin of the deposits, which is similar to, but modified from that proposed by Kazakov.

DC

23. McKeown, F. A., and Klemic, Harry, 1953, Reconnaissance for radioactive materials in northeastern United States during 1952: U. S. Geol. Survey Rept. TEI-317 A., issued by U. S. Atomic Energy Comm., Tech. Inf. Service, Oak Ridge, 68 p. [Map Nos. 13 through 16.]

The geology and radioactivity of magnetite-apatite mines and prospects which are not significant as possible sources of radioactive elements, are presented in table form. A few of the deposits, however, have a possible potential as sources of radioactive elements and warrant detailed description; some of these are described below.

The Mineville group of magnetite mines is in the Mineville district, near Mineville, Essex County, New York. The Miller, Old Bed, and "21"-Bonanza-Joker, are three faulted parts of one complexly folded ore bed in the Mineville group. The ore is massive and granular; apatite is a constituent of the gangue in rich as well as lean ore. The Old Bed is the richest ore body and contains the highest percentage of phosphorous (1 to 1.25 percent). Granular high-grade ore generally contains the least amount of apatite and other gangue minerals. Medium to fine grained ore (magnetite grains less than about 2 millimeters across) contains radioactive fluorapatite-rich layers and stringer, as well as disseminated fluorapatite.

Chemical analysis of a sample of hand-picked apatite grains shows a uranium content of 0.018 percent and a thorium content of 0.04 percent. The amount of radioactivity of various samples (ore, rock, etc.) seems to be a function of the amount, as estimated visually, of red- or flesh-colored apatite present in the sample.

The Canfield phosphate mine is about 2 miles west of Dover, Morris County, New Jersey. The ore is a granular aggregate of magnetite and greenish-gray apatite, with quartz, feldspar, and biotite the minor constituents. The mine was originally explored for magnetite, but the high apatite content of 35 percent made the ore worthless for smelting for iron, and the mine was abandoned. Among the rocks on the dump, those with the highest apatite content are also the most radioactive. Monazite is also present in small amounts and is radioactive.

The rocks of the Rutgers Mine, Clinton County, New York, and the Mulligan Quarry, Hunterdon County, New Jersey, also have some apatite, but the geology is described only briefly in this report.

DC

24. Mansfield, G. R., 1927, Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, 207 p. [Map No. 23]

The principal mineral resource of southeastern Idaho is phosphate rock, which occurs at two horizons, upper Mississippian and Permian, but only the Permian rock has much commercial value. This rock is characterized chiefly by its oölitic texture and generally dark color and by its odor when freshly broken, which resembles that of crude petroleum. It is a bedded deposit of marine origin and will have to be mined in the same manner as coal.

The phosphate rock is really a mixture or "solid solution" of several phosphatic minerals, but the chemical composition is approximately that of tricalcium phosphate, $Ca_3(PO_4)_2$. There are numerous accessory constituents, among which vanadium is noteworthy. Some tendency has been noted toward enrichment by weathering.

The western phosphate reserve now includes 2,269,055 acres, of which 664,911 acres is in Idaho. The Idaho portion comprises 268,299 acres formally classified as phosphate land and hence released from any form of phosphate withdrawal and 396,612 acres unclassified and still remaining withdrawn. There are in addition some privately owned lands. The government-owned phosphate land is classified and made available for exploitation under regulations which are specified. Not all the reserved land has yet been examined, but 52 townships in Idaho and 6 townships in Wyoming, which are regarded as phosphate bearing, are described in this paper in some detail, and estimates of their tonnages are furnished, together with revised estimates of tonnage for other parts of the western field. The estimates thus far available for Idaho alone indicate a reserve of about 5,000,000,000 tons of high-grade phosphate rock.

The history of the western phosphate industry is briefly sketched, including an account of the litigation, its settlement, and the subsequent laws affecting phosphate lands. The producing companies are briefly described and information is given regarding the production, marketing, and utilization of the rock, together with a statement about processes of manufacture of phosphate and of phosphorous.

G. R. Mansfield

Note: This reference has been included as it is of general interest, although it does not discuss uranium. The summary was taken from Chapter VII - Mineral Resources. Other chapters in the paper deal with the geography, stratigraphy, structure, historical geology, and broader problems of the region in southeastern Idaho.

25. Mansfield, G. R., 1940, Phosphate deposits of the United States: Econ. Geol., vol. 35, no. 3, p. 405-429. /Map Nos. 1, 5, 11, 12, 17, 18, 19, 20, and 23./

A variety of types of phosphate deposits, representing a wide range in geologic age, are found in the United States. Guanos containing from 4.00 to 32 percent $P_2O_5$ have been reported chiefly from Texas and New Mexico, where they are locally of some commercial importance. Phosphatic marls of both Cretaceous and Tertiary age are found in the sedimentary rocks of the eastern Coastal Plain; the $P_2O_5$ content is low, ranging from less than 1 percent to 4.5 percent. Low grade phosphatic limestones are widely distributed in both the eastern and western parts of the United States and range in age from Paleozoic to Tertiary. Apatite is a constituent of many igneous and metamorphic rocks, but is rarely found in commercial concentrations. The only apatite produced in the United States is from the titanium-apatite deposits in Nelson County, Virginia. Phosphate rock in North Carolina, Georgia, and Alabama fields is of low grade and has not been explored extensively. Medium-grade phosphate rock deposits are found in South Carolina and were among the largest producers in the world before the exploitation of the Florida and Tennessee fields. Some phosphate has been produced from the brown phosphate deposits in Kentucky, and from the phosphate deposits in the Cason shale of Ordovician age in Arkansas. The most important deposits of phosphate rock are found in Florida, Tennessee, and the western field.

The principal types of phosphate rock in Florida are the land pebble, hard rock, soft rock, and river pebble. The land pebble phosphate is in the marine Bone Valley formation of Pliocene age and is the most important commercial deposit of the four types mentioned. The hard rock deposits are in the Alachua formation of Pliocene age and are residual deposits. Soft rock is finely divided phosphatic material and is present in small amounts in both the land pebble and hard rock fields. River pebble phosphate, mostly of Recent age, occurs as bars and banks in stream channels and neighboring lowlands.

The Tennessee phosphates occur in the western part of the central basin of the state and in valleys of the western part of the Highland Rim surrounding the basin. The phosphates are of three types: brown, blue, and white rock. Brown rock phosphates are residual deposits, derived from phosphatic limestone formations of Ordovician age, and are at present the most important commercially. The blue rock is an unaltered portion of the Hardin sandstone member of the Chattanooga shale of basal Mississippian or Upper Devonian age. The white rock deposits are secondary deposits formed by solution of phosphatic minerals in the overlying blue rock, and by redeposition in openings in the underlying limestone.

The phosphate deposits in the phosphatic shale member of the Permian Phosphoria formation in Idaho, Montana, Wyoming, and Utah comprise the commercial deposits of the western field.

The geology, and mining and prospecting methods of the deposits mentioned are discussed briefly, and reserves are given for most of the fields.

DC

Note: This paper has been included as it is of general interest, although it does not discuss uranium.

26. Moxham, R. M., 1954, Airborne radioactivity surveys for phosphate in Florida: U. S. Geol. Survey Circ. 230, 4 p., 9 figs. /Map Nos. 1, 3, 5, 6, 7, 8, and 9./

Airborne radioactivity surveys totaling 5,600 traverse miles were made in 10 areas in Florida, which were thought to be geologically favorable for deposits of uraniferous phosphate. Abnormal radioactivity was recorded in 8 of the 10 areas surveyed. The anomalies are located in Bradford, Clay, Columbia, DeSoto, Dixie, Lake, Marion, Orange, Sumter, Taylor, and Union Counties. /Airborne radioactivity survey maps of all the areas covered are included in the Circular./

Two of the anomalies were investigated briefly on the ground. One resulted from a deposit of river-pebble phosphate in the Peace River valley; the river-pebble samples contain an average of 0.013 percent equivalent uranium. The other anomaly resulted from outcrops of leached phosphatic rock containing as much as 0.016 percent equivalent uranium. Several anomalies in other areas were recorded at or near localities where phosphate deposits have been reported.

At least two of the airborne radioactivity anomalies described above have been caused by deposits of uraniferous phosphatic materials. Most of the other anomalies were detected in areas in or near which phosphate has been reported, so it would appear that the anomalies are in some manner related to uranium associated with phosphatic materials. However, it should be pointed out that, at nearly every locality at which phosphate has been reported, the material is said to be covered by as much as 50 feet of overburden. If radioactive source rocks of the tenor with which we are dealing are covered by more than 1 foot of inert overburden, the radiation intensity should be reduced to an undetectable level at the 500-foot flight level. So, if the anomalies described above are to be attributed to phosphatic materials, we must assume that (1) the deposits are at or near the surface of the ground or (2) radioactive materials are being transported to the surface from buried deposits.

The results of the surveys indicate that the phosphate deposits of Florida contain sufficient uranium to be detected by airborne radioactivity detection equipment provided there is some surface expression of the deposits. The significance of the radioactivity anomalies in the areas of buried phosphate deposits cannot be ascertained until adequate exploration work is undertaken.

R. M. Moxham

27. Nininger, R. D., 1954, Minerals for atomic energy: D. Van Nostrand Co., Inc., New York, Toronto, London, 367 p. See p. 73-74. [Map Nos. 1, 5, 17, 18, 19, 21, and 23.]

Uranium occurs in marine phosphorites of the western Phosphoria formation and the Bone Valley formation in Florida, and in phosphatic nodules of black shales in Oklahoma and Kansas. The uranium in these marine phosphates is of syngenetic origin. Non-marine phosphorites, such as those in Tennessee, and the Florida hard-rock phosphates, are not appreciably uraniferous.

Uranium-bearing phosphorites range in age from Paleozoic to Pliocene and all seem to be equally favorable for uranium. Generally, the beds with the highest $P_2O_5$ content are likely to have the highest uranium content, although there are some exceptions. The uranium appears to be primarily in the phosphate mineral which is a fluorapatite, although some uranium is probably associated with the clay minerals and organic material.

The central Florida phosphate deposits provided the first uranium production from phosphates in 1952. The Bone Valley formation of Pliocene age is the most uraniferous. The underlying Hawthorn formation of Miocene age has a lower $P_2O_5$ and uranium content than the Bone Valley formation.

The Permian Phosphoria formation which crops out in Idaho, Montana, Wyoming and Utah, is appreciably uraniferous. The uranium content varies from one area to another, increasing, for example, westward from Wyoming into Idaho and decreasing westward in Montana. The northwest phosphates contain a variety of minor metals other than uranium.

DC

28. Runnels, R. T., Schleicher, J. A., and Van Nortwick, H. S., 1953, Composition of some uranium-bearing phosphate nodules from Kansas shales: State Geol. Survey of Kansas Bull. 102, Part 3, p. 93-104. [Map No. 21.]

This report discusses samples of uranium-bearing phosphate nodules taken from seven different shale beds of Pennsylvanian age in Kansas. There are 11 localities in all, in Wyandotte, Labette, Linn, Crawford, Douglas, and Wilson counties. The shales examined are listed below, in ascending order, and some are described briefly.

Shale from the Cherokee group - A black, fissile shale a few feet above the Mulky coal and below the Fort Scott limestone. Round to oval phosphate concretions are abundant throughout.

Little Osage shale member of the Fort Scott limestone.

Anna shale member of the Pawnee limestone - The shale occurs just below the Myrick Station limestone member. The phosphate nodules have a high purity (34 percent $P_2O_5$) and a high uranium value (0.02 percent $U_3O_8$).

Lake Neosha shale member of the Altamont limestone.

Shale of the Pleasonton group - The shale has a consistent black, fissile, bituminous facies. The top 18 feet is barren of nodules in contrast to the underlying 10 feet (and possibly more) which contains abundant nodules. The phosphatic nodules of this group differ slightly from those in other groups in that many of these have a core of iron sulfide.

Muncie Creek shale member of the Iola limestone - Some nodules from this shale have very high contents of $P_2O_5$ (37.00 percent) and $U_3O_8$ (0.03 percent). There is evidence (not given) that these nodules have been reworked, probably being redeposited during final deposition and initial compaction of the shale.

Heebner shale member of the Oread limestone - This is a persistent black shale occurring between the Plattsmouth and Leavenworth limestone members. The nodules are generally well-formed and numerous. According to the author the phosphate content is fairly high (32 percent $P_2O_5$), although the uranium content is not anomalous (0.017 percent $U_3O_8$).

The average composition of the phosphatic nodules is 30.2 percent $P_2O_5$, 0.017 percent $U_3O_8$, and 3.2 percent F. The mineral form has tentatively been identified as a carbonate-bearing fluorapatite, chemically between fluorapatite and dahlite. The x-ray diffraction patterns suggest a single-carbonate-fluorapatite mineral, but the sedimentary origin of the nodules points to the possibility of the presence of dahlite.

The phosphate nodules may be a potential fertilizer source as their phosphate content is comparable to that of commercial rock phosphate. The potential future value of the uranium is unknown.

DC

29. Russell, W. L., 1944, The total gamma ray activity of sedimentary rocks as determined by Geiger counter determinations: Geophysics, vol. 9, no. 2, p. 180-216. [Map Nos. 20 and 21.]

This report presents, in table form, the radioactivity of 510 samples of sedimentary rocks including shales, limestones, sandstones, and dolomites. Phosphatic material is not included as such, but results are given for formations in Arkansas, Kansas and Oklahoma, that contain phosphatic nodules. The reference has been included for this reason, as few results of radioactivity determinations made on these rocks have been published.

DC

30. Swanson, R. W., McKelvey, V. E., and Sheldon, R. P., 1953, Progress report on investigations of western phosphate deposits: U. S. Geol. Survey Circ. 297, 16 p. [Map No. 23.]

A comprehensive investigation of the western phosphate deposits has been in progress since 1947. Most of the field work is now completed but final reports will not be completed for some years. The scope of the investigations and preliminary conclusions, however, are summarized in this report.

The principal phosphate deposits are found in the Phosphoria and Park City formations over an area of about 135,000 square miles in Montana, Idaho, Wyoming, and Utah. The rocks composing these formations in the western part of the field are chiefly dark phosphatic shales and cherts that were deposited near the margin of the Paleozoic Cordilleran miogeosyncline; those to the east are thinner, were deposited on the stable continental platform, and include conspicuous limestones and sandstone that grade eastward into redbeds in Wyoming and Utah. Complex structures characterized by parallel-trending tight folds and thrust faults were developed subsequently in the area of the miogeosyncline, whereas simpler structures characterized by random orientation were developed in the platform area.

Two black phosphatic shale members characterize the Phosphoria formation. The lower, and more important, of these members is thickest and most phosphatic in southeast Idaho and pinches out in southern Montana, central Wyoming, and eastern Utah. The upper member is best developed in southwestern Montana but is prominent also in western Wyoming. Chert characterizes the intervening member, but limestone and sandstone are important constituents to the north and east. Also toward the north and east, chert and sandstone above the upper phosphatic shale are important.

The Bear River region of southeastern Idaho and adjacent parts of Wyoming and Utah contains the greatest total amount of phosphate as well as the thickest beds of high-grade phosphate, although some high-grade beds of mineable thickness occur in other parts of the field, particularly in western Montana. Several valuable deposits were discovered during this investigation, most noteworthy of which are a 6-foot bed of acid-grade rock in the Centennial Mountains at the Montana-Idaho State line, a 12-foot bed of 33 percent $P_2O_5$ rock in the Caribou Range, Idaho, several strippable deposits of acid- and furnace-grade rock in southeastern Idaho, and a 12-foot bed of 20 percent $P_2O_5$ rock at the top of the formation north of Cokeville, Wyoming.

R. W. Swanson and others

Note: This reference has been included as it is of general interest, although it does not discuss uranium.

31. Thompson, M. E., 1953, Distribution of uranium in rich phosphate beds of the Phosphoria formation: U. S. Geol. Survey Bull. 988-D, p. 45-67. /Map No. 23./

Five sets of "close" samples were analyzed radiometrically for uranium, and chemically for $P_2O_5$, CaO, organic matter and loss on ignition. A Rosiwal analysis was made of thin sections of one set of samples. The results of the analyses have been plotted on graphs and on scatter diagrams, and coefficients of correlation are given for uranium with CaO, $P_2O_5$, organic matter, and loss on ignition. Preliminary studies indicate that the concentration of uranium in these samples of phosphate rock is not due wholly to phosphate content but may depend in part on organic matter or on other components. The correlations of uranium with $P_2O_5$ are poor in the groups of samples with smaller amounts of uranium but are good in the groups of samples containing more uranium.

M. E. Thompson

32. Thompson, M. E., 1954, Further studies of the distribution of uranium in rich phosphate beds of the Phosphoria formation: U. S. Geol. Survey Bull. 1009-D, p. 107-123. /Map No. 23./

Rock from the Phosphoria formation is pelletal, rather than oölitic, and is generally dark brown to black in color. The phosphatic material is chiefly pelletal phosphate of the carbonate-fluorapatite type.

The five sets of "close" samples (narrow and contiguous samples across a lithologic unit) from Idaho, Wyoming, and Utah, which are described in the preceding article by this author, (Ref. no. 31) were also analyzed chemically for F and $CO_2$ in an effort to determine if there was any correlation between these constituents and equivalent U and $P_2O_5$. The formula used for the coefficient of correlation is that given by Snedecor_/.

_/ Snedecor, G. W., 1946, Statistical methods applied to experiments in agriculture and biology, Iowa State College Press, p. 138.

The samples with a high percent of equivalent uranium show much better correlation of equivalent uranium with $P_2O_5$ than do the samples with a low percent of equivalent uranium. The samples that show good correlation of equivalent uranium with $P_2O_5$, show better correlation of $CO_2$ with $P_2O_5$. Very good correlations were found between F, $CO_2$ and $P_2O_5$ in several of the samples.

The size of the phosphorite pellets was measured in the thin sections of two sets of samples. This was done in an effort to determine whether or not the size of the pellets in phosphate rock might have a direct relation to the amount of uranium present. Cumulative curves and frequency histograms were plotted from the size measurements obtained. On comparison of these with the uranium concentration for each sample, no significant correlation could be found between size of phosphorite pellets and amount of uranium.

DC

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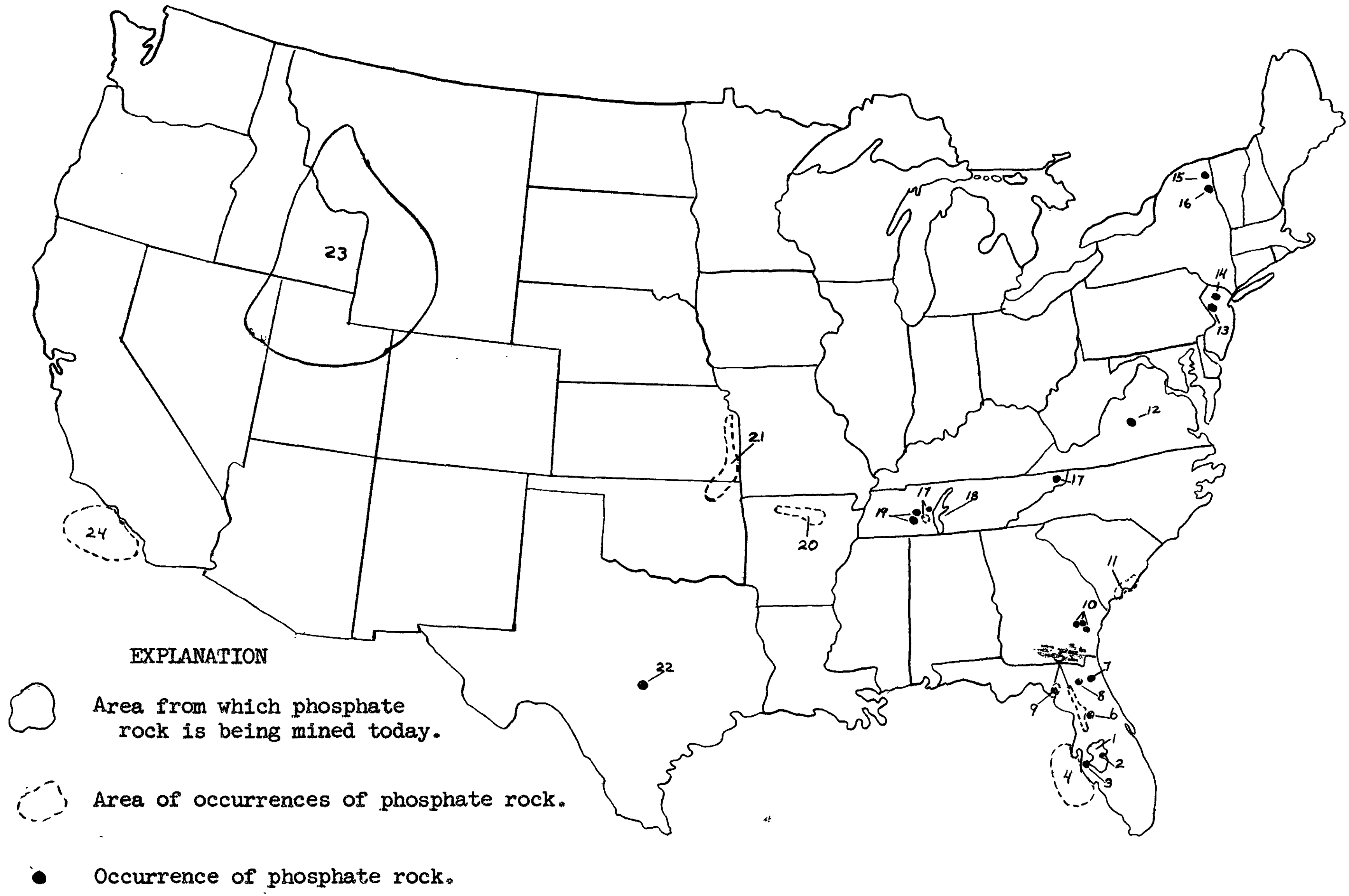


Figure 1. Index map of localities of uraniferous phosphorites.

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