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PROGRESS REPORT ON INVESTIGATIONS
OF WESTERN PHOSPHATE DEPOSITS

By R. W. Swanson, V. E. McKelvey, and R. P. Sheldon

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Trace Elements Investigations Report 246

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PROGRESS REPORT ON INVESTIGATIONS

OF WESTERN PHOSPHATE DEPOSITS*

By

R. W. Swanson, V. E. McKelvey,
and R. P. Sheldon

November 1952

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PROGRESS REPORT ON INVESTIGATIONS OF WESTERN PHOSPHATE DEPOSITS

By R. W. Swanson, V. E. McKelvey, and R. P. Sheldon

ABSTRACT

A comprehensive investigation of the western phosphate deposits, in progress since 1947, involves a study of the Phosphoria and Park City formations over an area of about 135,000 square miles in the states of Montana, Idaho, Wyoming, and Utah. It was undertaken to acquire more data on the thickness, composition and quality, structure, and distribution of the deposits--data that would help industry select deposits suitable for mining and permit estimation of reserves, evaluation of potential by-product elements, and establishment of the origin of the deposits.

Stratigraphic studies have included measurement, description, and sampling--some 9,000 channel samples--of the phosphatic and associated strata at more than 160 localities over nearly the entire field. Detailed geologic mapping of the equivalent of nearly nine 15-minute quadrangles has been completed, with three more in progress; mapping has been on a scale of 1:12,000 in areas of the thickest and richest deposits and 1:62,500 or larger in other areas. Other studies in progress include mineralogy and petrography of the rocks, geochemical studies to evaluate the marine conditions prevalent during sedimentation, and extensive paleontologic collections being used for descriptive and paleoecological studies. Most of the field work is completed, many preliminary reports are already on open file and other reports are being prepared for early publication.

The rocks in the western part of the field include 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 sandstones that grade eastward into redbeds in Wyoming and Utah. Complex structures characterized by parallel-trending tight folds and thrust faults subsequently developed in the area of the miogeosyncline, whereas simpler structures characterized by random orientation developed in the platform area.

Two black phosphatic shale members characterize the Phosphoria formation. The lower and more important is most phosphatic and thickest in southeast Idaho, and pinches out in southern Montana, central Wyoming, and eastern Utah. The upper is best developed in southwest Montana but is prominent also in western Wyoming. Chert characterizes the intervening member, and limestone and sandstone are important to the north and east. Chert and sandstone are particularly important above the upper phosphatic shale toward the north and east. The formation averages about 400 feet in thickness in its western facies and less than 300 feet in its eastern facies. The range is most marked in Utah from less than 100 feet near the Colorado line to more than 1,000 feet near and south of Salt Lake City, but westward thickening is the rule over the entire field.

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, though some high-grade beds of minable thickness occur in other parts of the field, particularly western Montana. Several valuable deposits have been discovered during this investigation, most noteworthy of which are a 6-foot bed of acid-grade rock in the Centennial Range 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 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, Wyo.

INTRODUCTION

In anticipation of increased demand for phosphate, the U. S. Geological Survey began in 1947 a comprehensive investigation of the western phosphate field (fig. 1). Most of the field investigations planned as a part of this investigation (McKelvey, 1949) are now completed. Although the results will not be fully synthesized and analyzed for some years, it seems appropriate at this time to describe what has been done and to indicate some of the important discoveries and conclusions, particularly those of economic significance.

This program has been supported in part by the Atomic Energy Commission and the Bureau of Reclamation; it is a pleasure to acknowledge their financial assistance. A large number of persons have assisted in the collection of data and many others have contributed much in the way of advice and criticism in the field. Though it is not possible to acknowledge individually the help of all these persons, their part in the program is acknowledged in the individual reports being released on various aspects of the investigation.

STATUS OF INVESTIGATIONS

Investigation of the western phosphate deposits was undertaken to acquire more data on their thickness, composition and quality, structure, and distribution--data that would help industry select deposits suitable for mining, permit estimation of reserves, evaluate the importance of potential byproduct elements, such as uranium and vanadium, and establish the origin of the deposits.

The two major aspects of the field investigations have been stratigraphic studies and geologic mapping. The stratigraphic studies have

FIGURE 1. INDEX MAP OF THE WESTERN PHOSPHATE FIELD SHOWING LIMITS OF THE PHOSPHORIA, PARK CITY, AND EMBAR FORMATIONS (DASHED LINE) AND THEIR PHOSPHATE DEPOSITS (SOLID LINE).

included measurement, description, and sampling of the phosphatic and associated beds over nearly the entire field. In the more important parts of the field Phosphoria strata have been measured and sampled at intervals of 3 to 6 miles; in the marginal areas the interval between localities has been of the order of 10 to 20 miles.

About 9,000 channel samples have been collected from more than 160 localities during the course of this work (figs. 2, 3, 4, and 5). The analytical data are being prepared for publication, but as a stop-gap measure the data on about 8,500 samples have been placed on open file (McKelvey and others, 1953 a, b, c; Swanson and others, 1951, 1953; Sheldon and others, 1951; O'Malley and others, 1953; Smith and others, 1953; and Cheney and others, 1952). These data are not adequate, of course, for the appraisal of individual deposits--such was not their purpose--but they do serve to show the areas in which the best deposits lie and, through the stratigraphic correlation they make possible, they permit the estimation of reserves over large areas.

Though the mapping program has been restricted to a relatively small part of the total field, a considerable total area has been mapped in connection with these and other Geological Survey investigations (fig. 6). In southeastern Idaho, where the classic studies of Mansfield and other early Survey workers (See particularly Gale and Richards, 1910; Richards and Mansfield, 1912; and Mansfield, 1927.) had already established the distribution and gross structural features of the rocks, mapping has consisted of topographic and geologic mapping, on a scale of 1:12,000, of the Aspen Range--Dry Ridge area, in which some of the thickest, richest, and most accessible phosphate deposits of the western field are located. The topographic mapping of this 450-square-mile area is completed and maps of

FIGURE 6. STATUS OF GEOLOGIC MAPPING BY THE U. S. GEOLOGICAL SURVEY (1:250,000 OR LARGER) IN QUADRANGLES CONTAINING PERMIAN PHOSPHATE DEPOSITS

most of the area have been published; geologic mapping has been completed over about a third of the area and preliminary maps of two $7\frac{1}{2}$ -minute quadrangles have been placed on open file (Cressman, 1952; and Gulbrandsen and others, 1952).

The Soda Springs 15-minute quadrangle, bounding the Aspen Range--Dry Ridge area on the southwest, contains some of the structure necessary to an adequate understanding of the area being mapped in detail. About two-thirds of the quadrangle was mapped on a scale of 1:48,000 before the work had to be recessed in favor of more pressing investigations related to the national emergency. A report on the work done to date is in preparation.

In southwestern Montana, where only broad-scale reconnaissance had been undertaken in most areas previously, several areas totalling more than 1,400 square miles have been mapped on a scale of 1:62,500 or larger. These areas include the west half of the Willis 30-minute quadrangle west of Dillon and part of the east half south of Dillon; a small part of the Dell 30-minute quadrangle near Lima; more than three-fourths of the Lyon 30-minute quadrangle west of Yellowstone Park; and parts of the Virginia City and Eldridge 30-minute quadrangles northwest of the Park. Part of the Lyon quadrangle in the Centennial Range along the Idaho-Montana border, in which rich phosphate deposits have been found, has also been mapped on a scale of 1:12,000. Geologic maps of some of these areas have already been placed on open file (Kennedy, 1949; Lowell, 1950, 1953; Swanson, 1951; and Myers, 1952) and others will be released shortly.

Geologic mapping has also been undertaken in Montana, Wyoming, and Utah in connection with other Survey investigations, chiefly oil and gas. As is readily seen from figure 6, the recent and earlier mapping combine to give coverage over nearly half of the quadrangles that contain phosphate in the western field.

Several other studies are being carried on as a part of these investigations. The mineralogy and petrography of the rocks are being studied in some detail to establish the mineral identities and properties of the components of western phosphate rock and to supplement the field description of strata sampled at various localities. Geochemical studies have been directed chiefly toward an evaluation of the marine conditions that probably prevailed while the Phosphoria sediments were accumulating (Krauskopf, 1952). Paleontologic collections have been made from most of the localities measured and sampled on the sampling program. These extensive collections are being used for both descriptive paleontological and paleoecological studies.

Preliminary reports on the various aspects of these investigations are being prepared and released as rapidly as possible. Most of the data on stratigraphy are being prepared for release as Geological Survey Circulars. Geologic maps accompanied usually by brief texts are being prepared for publication in either the Quadrangle Map series or the Mineral Investigations Field Studies series. Most reports are placed on open file as soon as prepared in order to release the information to the public. In addition to the studies described above, tables and maps showing ownership of all lands in which Permian phosphatic rocks are exposed are in preparation for release as Circulars.

REVIEW OF GEOLOGY OF THE WESTERN PHOSPHATE FIELD

Geologic setting and structure

The most important phosphates in the western field are part of the marine Phosphoria formation of Permian age and its partial stratigraphic equivalent in Utah, the Park City formation. These formations were

deposited over an area of some 135,000 square miles in Montana, Idaho, Wyoming, Utah, and Nevada. The rocks in the western part of this area are part of the Paleozoic Cordilleran miogeosyncline (Kay, 1947), a pile of sediments 20,000 to 40,000 feet or more in thickness that accumulated along the margin of the stable continental platform (figs. 1,7). Rocks of comparable age that accumulated on the platform are only a few hundred to a few thousand feet thick.

The facies of the Phosphoria and associated formations in the miogeosynclinal zone differ from those on the platform. The rocks in the miogeosynclinal zone are generally finer-grained and thicker than their platform equivalents. Dark shales and cherts are more abundant in the miogeosyncline. Redbeds are almost wholly restricted to the platform. One of the most conspicuous differences between the two zones lies in the vertical continuity of sedimentation. Unconformities are much more abundant and prominent on the platform than in the miogeosynclinal zone.

Differences in the geologic structure of the eastern and western part of the field are even more pronounced. The structure in the miogeosynclinal zone is complex. The folds are tight, overturned and mashed in many places, generally trend north, and broken by numerous overthrust and normal faults of both large and small displacement. On the other hand the structure on the platform in the eastern part of the field, where the phosphate beds are thin and of low quality, is relatively simple. The folds are broad, of diverse orientation, and unbroken by faults over large areas.

The phosphate beds now occur in all attitudes from flat to vertical or sharply overturned and range in location from small remnants on the tops of high mountain ranges to deposits buried at great depth beneath overlying Mesozoic strata and in some places, as the Snake River plains southwest of

Yellowstone Park, beneath unknown thicknesses of continental deposits and volcanic rocks. Maps showing distribution of outcrops, therefore, (figs. 2 to 5) present a very broken and irregular pattern and point to the great diversity of environments under which mining enterprises must be prepared to operate.

Stratigraphy of the Phosphoria formation

The Phosphoria formation may be roughly divided into a miogeosynclinal facies and a platform facies, prominent in the western and eastern parts of the field respectively (fig. 7). Many problems remain to be solved in the correlation of component parts of these facies over the field but, primarily as the result of Sheldon's work in the Jackson Hole, Wyo., area, correlation of the gross units has been established (fig. 8).

The miogeosynclinal facies is best known near its eastern limits in the Bear River region of southeastern Idaho, westernmost Wyoming, and north-central Utah. There the Phosphoria formation consists of a lower, phosphatic shale member, 150 to 200 feet thick; overlain by the Rex chert or cherty limestone member of comparable thickness; and in most places capped by an upper shale member, 25 to 75 feet thick, which also contains some phosphatic beds. The Phosphoria formation in this area is composed of three principal constituents or mixtures thereof--phosphate rock, carbonaceous mudstone, and chert. Carbonate rock is a minor constituent. In the Bear River region the Phosphoria overlies limestone of the Wells formation. Whether or not these beds are Pennsylvanian age, as formerly thought (Mansfield, 1927, p. 71), or Permian, as seems to be the case in Utah (Baker and Williams, 1940), is not yet known.

The Park City formation in the Wasatch mountains in Utah consists of a lower carbonate member, 650 feet thick, of Leonard age that may correspond to the upper part of the Wells formation in Idaho; a middle shale member, 200 feet thick, that corresponds to the phosphatic shale member of the Phosphoria formation; and an upper cherty-carbonate member, 900 feet thick, that corresponds to the Rex member. Carbonate rocks are more prominent in the geosynclinal facies in Utah than in Idaho and phosphatic rocks are less abundant, and generally thin and lean besides. The lower member overlies the Pennsylvanian Weber sandstone or quartzite.

The Phosphoria formation is not well known to the west; but, judged from sections in the Goshute Range, eastern Nevada, and the Sublette Mountains, Cassia County, Idaho, its thickness increases markedly, and black carbonaceous mudstone and chert become the dominant rock types.

In the Beaverhead County region, southwestern Montana, the Phosphoria formation consists of five units, provisionally termed members A, B, C, D, and E, from oldest to youngest (Klepper, 1950). Member A, which overlies quartzite of the Pennsylvanian Quadrant formation, is 20 to 380 feet thick and consists predominantly of carbonate rocks. It is probably equivalent to the upper part of the Wells formation in southeastern Idaho and perhaps to the lower member of the Park City formation in Utah. Member B, 5 to 70 feet in thickness, consists of phosphate rock and carbonaceous mudstone; it is probably the equivalent of the phosphatic shale member in Idaho. Member C, 100 to 250 feet thick, is composed mainly of carbonate and cherty carbonate rocks; it is probably the equivalent of the Rex chert. Member D, 50 to 80 feet thick, is mainly carbonaceous mudstone and phosphatic mudstone; it is probably equivalent, at least in part, to the upper shale. Member E, 100 to 150 feet thick, is mainly chert and sandstone; it may have no counterpart in southeastern Idaho.

The platform facies borders the geosynclinal facies on the east and north. It ranges in total thickness from about 100 to nearly 400 feet. The formation becomes progressively less phosphatic eastward and northward and carbonate rocks and sandstone make up an increasing proportion of the formation. In central Wyoming, eastern Utah, and south-central Montana the Phosphoria beds tongue out into redbeds of the Opeche and Spearfish formations (Condit, 1924; Thomas, 1934; Thomas and Krueger, 1946; Tourtelot, 1952). The A, B, and C members become progressively thinner and disappear to the north and particularly to the northeast in Montana. At least the upper part of the Wells formation in Idaho and the lower member of the Park City formation in Utah disappear eastward. In Wyoming the Phosphoria and Park City rest directly on the Pennsylvanian Tensleep and Weber sandstones respectively. Some of this "disappearance", particularly the Wells-Tensleep transition in Wyoming and the A member-Quadrant formation transition in Montana is apparently due in large part to facies changes in lithology that confuse the detailed correlation of beds or groups of beds.

REGIONAL VARIATIONS IN THICKNESS AND QUALITY OF PHOSPHATE ROCK

Now that most of the analytical work on recently collected samples is complete, the regional variations in thickness and quality of phosphate rock in the western field can be indicated fairly reliably. This is done by means of iso-grade and iso-grade-thickness lines on figures 9, 10, 11, and 12. Attention is called to the fact that the thickness indicated on these maps represents the total thickness of all layers containing more than the stated amount of P_2O_5 , and therefore is not necessarily minable thickness. As a general rule, however, the total thickness of minable layers of a given P_2O_5 content increases as the total thickness of all layers of that quality in the whole formation increases.

FIGURE 9. TOTAL PHOSPHATE (IN FEET TIMES PERCENT P_2O_5) IN PHOSPHATIC PORTIONS OF PHOSPHORIA AND PARK CITY FORMATIONS.

FIGURE 10. TOTAL THICKNESS (IN FEET) OF ROCKS IN THE PHOSPHORIA AND PARK CITY FORMATIONS CONTAINING MORE THAN 31 PERCENT P_2O_5

FIGURE 11. TOTAL THICKNESS (IN FEET) OF ROCKS IN THE PHOSPHORIA
AND PARK CITY FORMATIONS CONTAINING MORE THAN 25
PERCENT P_2O_5

FIGURE 12. TOTAL THICKNESS (IN FEET) OF ROCKS IN THE PHOSPHORIA AND PARK CITY FORMATIONS CONTAINING MORE THAN 18 PERCENT P_2O_5

The data synthesized on these maps show clearly that the greatest volume of P_2O_5 as well as the greatest thickness of beds containing more than any given P_2O_5 content is in the Bear River region of southeastern Idaho and adjacent parts of Wyoming and Utah. Other parts of the field, particularly western Montana, contain minable thicknesses of both acid-grade and furnace-grade rock (i.e. 31 and 25 percent P_2O_5 respectively). Minalbe beds of both qualities possibly may be found elsewhere but the chances of finding such deposits outside the limit of the 3-foot or 5-foot isopachs on the maps are small.

NEWLY DISCOVERED DEPOSITS

The field reconnaissance of recent years has disclosed the presence of the Phosphoria at numerous localities where it was unknown previously. In addition, several valuable deposits have been discovered through mapping and sampling.

The newly discovered lines of outcrop are mainly in southwestern Montana, part of which had not been mapped previously and part of which, mainly in the Phillipsburg area, had been mapped prior to the discovery of phosphate in the western field. Altogether about 250 miles of outcrop of the Phosphoria formation are shown on figure 2 that were unknown or unrecorded previously.

Many of these new discoveries were made as a result of the Geological Survey program but the results of other geological work, particularly by the Montana Bureau of Mines and Geology is included. Because many of these newly reported lines of outcrop have not been adequately explored by the Geological Survey, the value of deposits contained in them is not yet known. Lying as they do in areas of complex structure, many of them probably will be

too crushed and broken to be minable. Deposits in the vicinity of Maxville, Elliston, and Anaconda at the north end of the field, however, deserve further exploration for both acid-grade and furnace-grade rock. Those between Dillon and Anaconda may contain furnace-grade rock.

One of the most promising deposits found thus far is in the Centennial Range along the Montana-Idaho state line. Phosphate deposits were first reported in this area by Condit, Finch, and Pardee (1928), but its potentialities were not recognized until recent sampling and mapping showed the presence of large reserves--perhaps 50 million tons or more--of phosphate rock averaging 4 to 6 feet in thickness and containing about 31 percent P_2O_5 . The best of these deposits crop out along the crest of the range, which is nearly inaccessible from the north, but as they dip 12° to 20° southward they could be entered from the southern toe of the range by cross-cuts of 1 to 2 miles in length, the portals of which would be less than 25 miles from the railroad at Trude siding between West Yellowstone and Idaho Falls.

Another important deposit was discovered in 1951 in the Caribou Range of Idaho, sec. 31, T. 1S, R. 45 E., 3 or 4 miles south of the Snake River Palisades dam site. Preliminary analyses of samples from this deposit indicate an average grade of about 33 percent P_2O_5 over a thickness of about 12 feet--the largest thickness of such quality rock known anywhere in the country. Details of the way the complicated structure in this area affects the deposit have not been determined, but it appears that a considerable tonnage may be anticipated above entry level. The rocks where sampled dip steeply.

In western Wyoming, about 15 miles northeast of Cokeville, a 12-foot bed of phosphate containing only 22 percent P_2O_5 and occurring at the top contact of the formation was discovered in 1952. Reconnaissance of the adjoining

area indicates that the deposit is of rather limited areal extent, but the deposit is noteworthy for both the thickness and the quality of phosphate at this stratigraphic horizon.

One of the most significant developments in mining in the western field has been the initiation of strip-mining techniques by the San Francisco Chemical Company at Montpelier, Idaho, and Leere, Wyo., and by the Simplot Company at Fort Hall, Idaho. Because of the complex structure and steep dips in the Bear River region, deposits of attitude suitable for strip-mining are the exception rather than the rule, but both private companies and Geological Survey parties have found a number of strippable deposits of sufficient volume to support mining operations for some years. All of these are on private land or on land already under lease. The largest of the new discoveries are along the western margin of the Trail syncline, near Soda Springs, and along the east limb of the Webster syncline south of Wells Canyon.

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PART II

DISTRIBUTION AND QUALITY OF URANIFEROUS PHOSPHATE ROCKS

The distribution of uranium in the rocks of the Phosphoria formation is shown in figures 13 and 14. Figure 13 shows the maximum uranium content at each locality sampled, regardless of stratigraphic position or thickness. Because any uranium produced from the Phosphoria will be as a byproduct of phosphate we have shown in figure 14 the maximum uranium content in phosphate beds of acid-grade and minable thickness.

Both maps bring out the fact that the uranium contents of 0.01 percent or more are restricted to the Bear River region of southeastern Idaho and to parts of western Montana.

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FIGURE 14. AVERAGE URANIUM CONTENT OF MINABLE PHOSPHATE DEPOSITS
(MINIMUM THICKNESS, 3 FEET; MINIMUM GRADE, 30 PERCENT P_2O_5)

PHOSPHORIA FORMATION OUTCROPS IN MONTANA AND LOCALITIES SAMPLED FOR PHOSPHATE

10 0 40 MILES

PHOSPHORIA FORMATION OUTCROPS IN IDAHO AND
LOCALITIES SAMPLED FOR PHOSPHATE

PHOSPHORIA AND PARK CITY FORMATION OUTCROPS IN UTAH AND LOCALITIES SAMPLED FOR PHOSPHATE

10 0 40 MILES