UNITED STATES DEPARTMENT OF THE INTERIOR
J. A. Krug, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

Bulletin 944

CONTRIBUTIONS TO ECONOMIC GEOLOGY
1943-47

SHORT PAPERS BY

L. S. GARDNER AND A. L. ANDERSON

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PHOSPHATE DEPOSITS OF THE TETON BASIN AREA IDAHO AND WYOMING

BY

LOUIS S. GARDNER

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(Pages 1-36)

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PHOSPHATE DEPOSITS OF THE TETON BASIN AREA, IDAHO AND WYOMING

By Louis S. Gardner

ABSTRACT

Permian phosphate deposits in the mountains that border Teton Basin in southeastern Idaho and western Wyoming consist of many thin layers of phosphate rock interbedded with phosphatic siltstone, shale, limestone, and chert. Intense folding and complex faulting in the Snake River Range and Bighole Mountains on the south and west sides of the basin have caused the beds to dip steeply and to crop out in several discontinuous parallel belts that strike northwestward. The structure of the Teton Range on the east side of the basin is simple, but erosion has removed most of the phosphate rock from these mountains. The best deposits are in the shale member at the base of the Phosphoria formation, but a few good beds occur in the Rex chert member, which forms the upper part of the formation. Ten trenches were dug in the three ranges to expose the phosphate beds for sectioning and sampling, and 118 channel samples were collected for analysis.

In the Bighole Mountains 3 complete sections of the shale member include 7 to 10 beds of phosphate rock containing 30 to 78 percent of $Ca_3(PO_4)_2$ (bone phosphate of lime, or B.P.L.). The total thickness of beds in a given section ranges from 7.1 to 11.3 feet, and the average composition ranges from 49.5 to 61.7 percent of B.P.L. The beds are thin and are scattered through 30 to 35 feet of strata low in phosphate. More than half of the rock containing 50 percent or more of B.P.L., however, is concentrated near the base of the sequence and forms a deposit that is 2½ to 3 feet thick and contains about 68 percent of B.P.L.

In the Teton Range the phosphatic shale member is about 38 feet thick and includes 10 beds of phosphate rock that have a total thickness of 7.8 feet and an average B.P.L. content of 56.9 percent. The best layer is 2.8 feet thick and contains 64.5 percent of B.P.L. A complete section of the shale member in the northern part of the Snake River Range includes 5 beds of phosphate rock, which have a total thickness of 8.3 feet and an average B.P.L. content of 47.3 percent. The best bed, at the top of the member, is 1.5 feet thick and contains 70.6 percent of B.P.L.

The best deposits in the Teton Basin area are those in the Bighole Mountains. The beds are not so rich or thick as those mined in the Georgetown district of southeastern Idaho, but some of them compare favorably with deposits mined in Montana. Unlike most phosphate deposits in the Rocky Mountain region they are in an area readily accessible to railroad transportation and to coal deposits and water power. Most of the phosphate rock of the Teton Range has been destroyed by erosion, and much of the phosphate in the Snake River Range has been ruined by smearing along fault surfaces.

INTRODUCTION

Phosphate deposits have been known for many years to exist in the mountains that border Teton Basin in Teton and Bonneville Counties, Idaho, and Teton County, Wyo.[1 2] They are part of a vast phosphate field in the Rocky Mountain region of Utah, Wyoming, Idaho, and Montana; and, like most of the deposits in the field, they have not been exploited. The deposits in the Teton Basin are of particular interest, however, because they are on public lands, are reasonably accessible from railroad shipping points, and are close to coal deposits.[3 4 5] Hydroelectric power for processing the phosphate could be developed at many places nearby.

Field work to determine the location, thickness, and quality of the phosphate beds was started July 27, 1938, in the Teton Range, east of the basin, and was later extended to the Bighole Mountains and Snake River Range, west and south of the basin. Members of the field party used saddle horses and worked from camps that were moved by pack train. The field season ended October 11, 1938, when snow made geologic work in the mountains impracticable, but additional work was done in the Snake River Range in June and July 1940 as part of a project to map the Irwin quadrangle.

In order to expose fresh rock for sampling and measuring, trenches as must as 6 feet deep were dug through soil that covers the phosphate outcrops at most places. Four trenches were dug in the Snake River Range, three in the Bighole Mountains, and three in the Teton Range. (See fig. 1.) Stadia traverses were made to connect the trenches with one another and with General Land Office survey corners, and geologic features were mapped along the traverse lines. Time did not permit the mapping of the entire area underlain by phosphate rock, but a small area in each of the three mountain ranges was mapped (pls. 1, 2 and 3) to show typical occurences of the phosphate-bearing strata. The location and relative size of these areas is shown in figure 1.

G. R. Mansfield and W. W. Rubey of the Geological Survey, United States Department of the Interior, made many useful suggestions regarding the field work and gave helpful advice regarding the interpretation of the field data. Valuable field assistance was given by Arthur P. Nelson, Kenneth Preston, and Bruce Stoddard in 1938 and by John Rodgers in 1940. Sid Titensor, Herbert O. Miller, Thomas A. Lallatin, and Rex D. Vias facilitated the field work by taking care of the horses

[1] Blackwelder, Eliot, A reconnaissance of the phosphate deposits of western Wyoming: U. S. Geol. Survey Bull. 470-H, pp. 452-453, 1911.

[2] Schultz, A. R., A geologic reconnaissance for phosphate and coal in southeastern Idaho and western Wyoming: U. S. Geol. Survey Bull. 680, pp. 7-10, 1918.

[3] Idem. pp. 64-79.

[4] Woodruff, E. G., The Horseshoe Creek district of the Teton Basin coal field, Fremont County, Idaho: U. S. Geol. Survey Bull. 541-I, pp. 379-388, 1914.

[5] Mansfield, G. R., Coal in eastern Idaho: U. S. Geol. Survey Bull. 716-F, pp. 123-153, 1920.

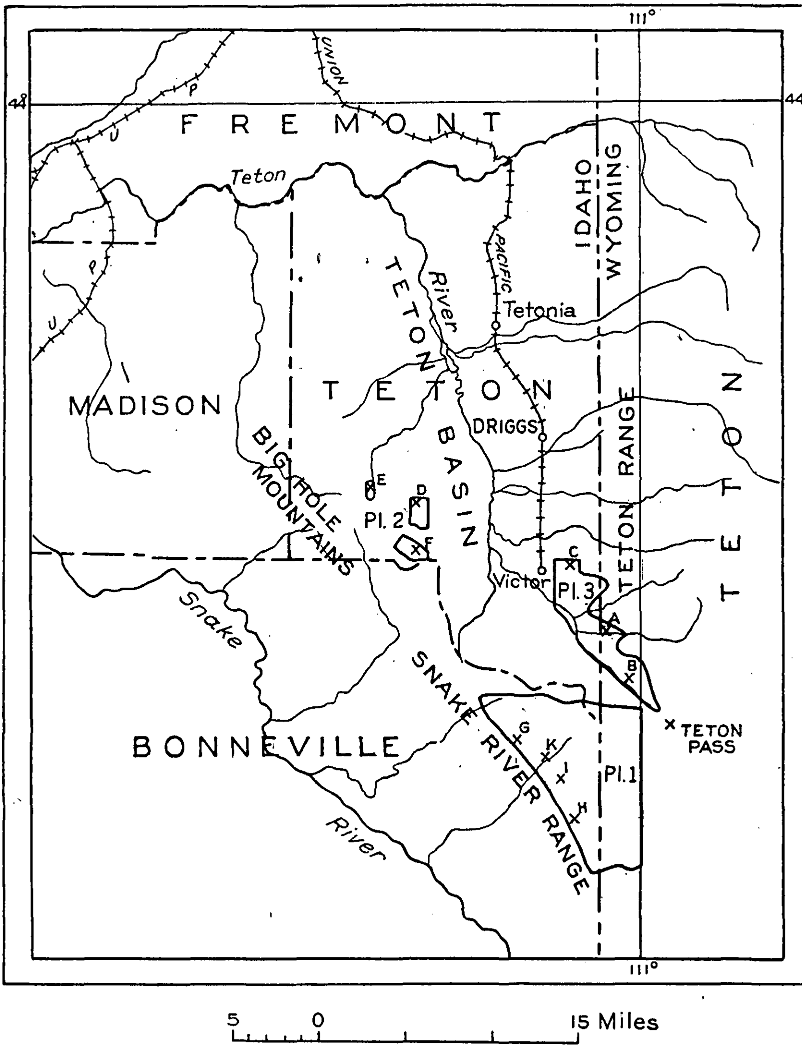

FIGURE 1.—Index map of the Teton Basin region, showing the location of the areas prospected and of the trench sections measured and sampled.

and the camps. Mr. John Cluff of Victor, Idaho, kindly guided members of the field party to several prospect pits at the western base of the Teton Range.

GEOGRAPHY

The Teton Basin is a large triangular lowland extending southeastward for about 20 miles from the east end of the vast Snake River Plains of Idaho. It lies between the Bighole Mountains and Snake River Range on the southwest and the Teton Range on the east, and it narrows from a maximum width of 10 to 12 miles at the open northern end to a blunt point a few miles south of Victor, Idaho. The floor of the basin, which is quite flat, is nearly all under cultivation. Water from many short mountain streams that enter from all sides except the north is used by many farms to irrigate forage crops, which are fed to dairy herds during the winter, and garden peas, which are supplied to canneries. The drainage of the basin gathers into the Teton River and is delivered to the Pacific Ocean by way of the Snake and Columbia Rivers.

Three sides of the basin are flanked by forest-covered mountains. The highest of these are the Tetons, which rise as long dip-slopes out of the lowlands and culminate in alpine summits that are among the most famous of all Rocky Mountain peaks for their ruggedness and scenic beauty. The Snake River Range and Bighole Mountains are also rugged but not nearly so high; they contain many heavily timbered areas and supply much of the local need for fuel and building material. All but the most inaccessible parts of the uplands serve as a summer range for herds of sheep and cattle, and the Teton and Snake River Ranges are famous game country, with hunting grounds that are well stocked with elk and deer and are easily reached over well-built trails.

The basin area is settled, but the high mountains have no permanent human inhabitants. The main towns are Driggs, Victor, and Tetonia, located on a branch line of the Union Pacific Railroad, which enters the northern end of the basin and extends as far south as Victor, Idaho. A main highway parallels the railroad to Victor, where it forks. One branch leads southeastward up Trail Creek and across Teton Pass between the Teton and Snake River Ranges to join a north-south main highway near Jackson, Wyo. The other branch leads southwestward across Pine Creek Pass between the Bighole Mountains and the Snake River Range to connect with another main highway at Swan Valley, Idaho. The altitude of Teton Pass is 8,429 feet and that of Pine Creek Pass about 6,780 feet.

Secondary roads, good only in dry weather, go to the lower parts of the main canyons that open into the basin; and good trails, built and maintained by the Forest Service or by local stockmen, lead from these roads into the high parts of the mountains. Phosphate outcrops are accessible within a short distance of the roads at a few places near the west base of the Teton Range, along Trail Creek Canyon, and west of Pine Creek Pass. Elsewhere the deposits are most easily reached from the mountain trails.

Coal has been produced in the Horseshoe Creek district of the Teton Basin coal field in the northern part of the Bighole Mountains, and several possible reservoir sites along the South Fork of Snake River have been studied by agencies of the Government. Preliminary work was being done in 1941 by the Reclamation Service at a proposed reservoir site near the mouth of Palisade Creek.

EARLIER GEOLOGIC WORK

The first extensive geologic work in the Teton Basin region was done by members[6] of the Hayden Survey in 1872-77. They did not recognize the phosphate deposits, but their reconnaissance reports were very useful to geologists when the phosphate deposits were discovered in Utah and traced into adjacent parts of Idaho and Wyoming. The first withdrawal of phosphate land was in 1908, and the Geological Survey started mapping and studying the deposits in 1909—a task that has continued, with some interruptions, to the present time.

The deposits along the west side of the Teton Mountains were described by Blackwelder[7] in one of the first reports on the western phosphate field, and many phosphate and coal localities in the Teton, Snake River, and Bighole Mountains were described by Schultz[8] in another early report. The coal deposits in the Bighole Mountains have been studied by Woodruff,[9] Mansfield,[10] and Evans.[11] Oil possibilities in parts of the Teton Basin area have been investigated by Kirkham.[12]

Reports on the phosphate deposits of the Rocky Mountains published prior to 1925 have been summarized by Condit and others.[13]

Blackwelder[14] has interpreted the post-Cretaceous history of the Teton Range and the region to the south and southeast, and Fryxell[15] and Horberg[16], have described its glacial and structural geology.

GEOLOGY

THE STRATIGRAPHIC COLUMN

The Teton Basin is surfaced with Quaternary and Tertiary alluvium and lava, which effectively conceal all underlying rocks; but older strata, ranging in age from pre-Cambrian to Cretaceous and including the Permian phosphate deposits, crop out in the surrounding mountains and

[6] St. John, O. H., Geological report of the Teton division: U. S. Geol. Survey Terr. 11th Ann. Rept., pp. 321-508, 1879.

[7] Blackwelder, Eliot, A reconnaissance of the phosphate deposits of western Wyoming: U. S. Geol. Survey Bull. 470-H, pp. 452-481, 1911.

[8] Schultz, A. R., A geologic reconnaissance for phosphate and coal in southeastern Idaho and western Wyoming: U. S. Geol. Survey Bull. 680, pp. 1-84, 1918.

[9] Woodruff, E. G., The Horseshoe Creek district of the Teton Basin coal field, Fremont County, Idaho: U. S. Geol. Survey Bull. 541-I, pp. 379-388, 1914.

[10] Mansfield, G. R., Coal in eastern Idaho: U. S. Geol. Survey Bull. 716-F, pp. 123-153, 1920.

[11] Evans, G. W., Preliminary report on the Horseshoe district of the Teton coal basin, southeastern Idaho: U. S. Bur. Mines Bull. 166, pp. 90-103, 1919; The Horseshoe Basin area of the Teton coal field in southeastern Idaho: Idaho Bur. Mines and Geology Pamph. 10, 1924.

[12] Kirkham, V. R. D., Petroleum possibilities of certain anticlines in southeastern Idaho: Idaho Bur. Mines and Geology Bull. 4, 1922; Geologic conditions, oil possibilities, and drilling progress in Teton County: Idaho Bur. Mines and Geology Press Bull. 15, December 1925.

[13] Condit, D. D., Finch, E. H., and Pardee, J. T., Phosphate rock in the Three Forks-Yellowstone Park region, Montana: U. S. Geol. Survey Bull. 795-G, pp. 151-166, 1927.

[14] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central western Wyoming: Jour. Geology, vol. 23, pp. 97-117, 193-217, 307-340, 1915.

[15] Fryxell, F. M., Glacial features of Jackson Hole, Wyo.: Augustana Library Pubs. No. 13, pp. 1-129, 1930.

[16] Horberg, Leland, The structural geology and physiography of the Teton Pass area, Wyoming: Augustana Library Pubs. No. 16, pp. 1-86, 1938.

presumably underlie the basin. The only formation described in this report is the Phosphoria, which contains the phosphate beds. Descriptions of the other strata, however, may be found in the report by Schultz,[17] although he did not use the formation names that are in use today. The following composite section of rock formations in the Snake River Range represents the rocks in the Bighole Mountains and Teton Range as well, because the same formations, with some differences in thickness and petrographic features, are present in all three mountain groups.

Section of Cretaceous strata on ridge between forks of Palisade Creek in sec. 18, T. 2 N., R. 46 E. Boise meridian, near northeast corner of Irwin quadrangle

[Measured by John Rodgers in 1940]

	Feet
Cretaceous:	
Upper Cretaceous:	
Frontier formation (incomplete):	
Sandstone, greenish gray, calcareous, friable, and olive-brown shale; covered interval at the top	190
Covered; upper part is probably shale, lower part is probably quartzite	50
Conglomerate and quartzite, olive brown, noncalcareous	15
Sandstone, siltstone, and shale, olive brown, calcareous	220
Covered; probably olive-brown calcareous shale and sandstone	80
Shale and sandstone, olive brown, siliceous; has discontinuous beds of gray and rusty quartzite and conglomerate at the base	90
Total Frontier formation	645
Aspen shale:	
Shale, siltstone, and sandstone, green, siliceous; has many beds of mottled gray, green, and pink porcelainite,[18] and some olive-green quartzite and siliceous sandstone	350
Shale, siltstone, and sandstone, olive green, siliceous, and many conspicuous beds of pale green and gray porcelainite	465
Shale, dark green or black, calcareous	70
Quartzite, olive green, and many beds of pale-green siliceous shale and porcelainite	270
Shale and siltstone, olive green, siliceous, with many beds of pale gray and greenish-gray sandstone and porcelainite	290
Shale and siltstone, olive green, siliceous, with some beds of sandstone and a few lenses of limestone	110
Missing because of a fault. Elsewhere beds of olive-green siliceous shale and siltstone, and some beds of white sandstone and porcelainite occupy this interval (estimate)	100
Shale and siltstone, olive green, siliceous, and some beds of sandstone. One thin bed of limestone is near the base. *Tempskya* occurs near the top	360
Total Aspen shale	2,015

[17] Schultz, A. R., A geologic reconnaissance for phosphate and coal in southeastern Idaho and western Wyoming: U. S. Geol. Survey Bull. 680, pp. 12-35, 1918.

[18] Tarr, W. A., Terminology of chemical siliceous sediments: National Research Council, Division of Geology and Geography, Report of Committee on Sedimentation, pp. 20-21, 1937-38.

Section of Cretaceous strata on ridge between forks of Palisade Creek—Continued

	Feet
Cretaceous—Continued.	
Bear River formation:	
Shale, black, nonresistant, poorly exposed; has green siliceous shale in the upper part and gray limestone in the lower part	450
Sandstone, gray, calcareous, cross-bedded	20
Siltstone and quartzite, olive green; has some beds of black shale and one thin layer of sandy limestone	200
Shale, black, nonresistant, and some bed of gray quartzite	60
Quartzite, rusty brown, thin-bedded, and some black shale	150
Total Bear River formation	880

Section of Triassic, Jurassic, and Cretaceous formations on ridge between Palisade and Trail Creeks in secs. 8, 9, and 17, T. 2 N., R. 46 E. Boise meridian, near northeast corner of Irwin quadrangle

	Feet
Cretaceous(?):	
Gannett group, Lower Cretaceous (?):	
Draney limestone:	
Limestone, dark gray, poorly exposed; weathers gray or brown; has poorly preserved fossils	70
Shale, lavender, calcareous, nonresistant, and dark-gray limestone	80
Limestone, dark gray, nonresisitant	95
Total Draney limestone	245
Bechler shale: Covered. A few small stringers of red shale and mudstone show through a red soil-covered slope	35
Peterson limestone: Limestone, dark gray, resistant; some beds are massive, some are thin-bedded; weathers white, gray, and purplish gray; contains some gastropod fossils	125
Ephraim conglomerate: Shale, red, purple, and lavender, sandy, nonresistant; many discontinuous beds of light gray resistant quartzite, conglomerate, and pebbly sandstone in the lower half; has lenticular beds of purple or lavender impure limestone and gray, thin-bedded, nodular limestone throughout the formation	535
Total Gannett group	940
Jurassic:	
Upper Jurassic:	
Stump sandstone: Sandstone or sandy limestone, brownish gray or greenish gray; has dark bluish-gray limestone near the top	140
Preuss sandstone: Sandstone, red, shaly; poorly exposed through a red sandy soil	55
Twin Creek limestone:	
Limestone, light gray, brittle; weathers to dull gray splintery and platy fragments; fossils abundant at some localities	685
Shale, red, nonresistant; very few exposures	35
Limestone, light gray; weathers to small splinters and plates; fossiliferous at some localities	250
Total Twin Creek limestone	970

Section of Triassic, Jurassic, and Cretaceous formations on ridge between Palisade and Trail Creeks—Continued

	Feet
Jurassic—Continued.	
Middle (?) Jurassic:	
Nugget sandstone: Sandstone, massive, dull reddish brown, resistant; has 6 inches of pale greenish-gray, highly calcareous sandstone at at the base	340
Triassic (?):	
Ankareh shale: Shale, deep red, nonresistant, and gray quartzite and red sandstone	550
Triassic:	
Lower Triassic:	
Thaynes limestone:	
Limestone, dull gray, sandy; weathers yellowish gray; and some gray to brown very calcareous sandstone	625
Covered; deep red soil contains fragments of red siltstone, red shaly sandstone, and gray sandy limestone	295
Limestone or calcareous sandstone, dull brown to gray; weathers dark brown	80
Total Thaynes limestone	1,000
Woodside shale: Shale and sandstone, brick red, nonresistant; poorly exposed	1,130
Dinwoody (?) formation (the equivalents of these beds are called Dinwoody in western Wyoming and Woodside in southeastern Idaho): Mudstone, dull olive green to brownish gray, thin-bedded, fine-grained; contains about equal parts of sand, clay, and calcium carbonate; has a few layers of gray, impure, resistant limestone in the lower part	760

Section of Carboniferous and Permian formations on ridge between Austin Creek and Dry Canyon in secs. 18, 19, and 20, T. 1. N., R. 46 E., Boise meridian

	Feet
Permian:	
Phosphoria formation:	
Rex chert member:	
Shale, black, phosphatic, nonresistant	4
Sandstone and quartzite, dark gray to black, massive; weathers white	19
Dolomite and limestone, gray, blue, and brown, cherty and silty, fossiliferous	78
Phosphate rock, dark gray, cherty	1
Dolomite, gray to black, silty and cherty	45
Total Rex chert member	147

Section of Carboniferous and Permian formations on ridge between Austin Creek and Dry Canyon—Continued

	Feet
Permian—Continued.	
Phosphoria formation—Continued.	
Phosphatic shale member:	
Phosphate rock, light to dark gray	1.5
Mudstone, shale, and limestone, gray to brown, phosphatic	6.3
Phosphate rock, black, incoherent	2.3
Shale and mudstone, black to brown, phosphatic	10.3
Phosphate rock, black, incoherent	1.4
Limestone or siltstone, dark gray to black, phosphatic	4.0
Phosphate rock, black	3.1
Siltstone, reddish brown, calcareous	.3
Total Phosphatic shale member	29.2
Total Phosphoria formation	176
Carboniferous:	
Pennsylvanian:	
Wells formation (probably includes beds of Carboniferous or Permian age in upper part):	
Dolomite and limestone, gray, cherty, and gray to yellow sandstone, quartzite, and siltstone	300
Quartzite and sandstone, pale yellow to brown	390
Quartzite and sandstone, white to gray	450
Total Wells formation	1,140

Section of undifferentiated Carboniferous strata on south side of Atkinson Peak in sec. 32, T. 2 N., R. 45 E. Boise meridian (unsurveyed)

[Measured by John Rodgers in 1940]

	Feet
Pennsylvanian and Mississippian:	
Undifferentiated (probably equivalent to the Amsden formation of western Wyoming): Sandstone, limestone, siltstone, breccia, and conglomerate, brown, pale yellow, and yellowish brown, nonresistant	710

Section of Brazer and Madison limestones in Hell Creek Canyon in sec. 31, T. 1 N., R. 46 E., and sec. 2, T. 1 S., R. 46 E. Boise meridian

[Measured by B. N. Moore in 1937]

	Feet
Carboniferous:	
Mississippian:	
Brazer and Madison limestones:	
Limestone, dull bluish gray, massive, and gray, thick- to thin-bedded, fine- to coarse-grained limestone; weathers to light gray surfaces that have velvety luster; resists erosion and forms cliffs. (This thickness may be excessive because some beds may be repeated by thrust faulting)	880
Limestone, gray to dark blue, thin-bedded, coarse- to fine-grained; weathers light to dark gray	280
Limestone, dark gray to black, thin-bedded, fine-grained to dense, and some lenses of light gray, fossiliferous, medium- to fine-grained limestone. Conspicuous because of its dark color and its resistance to erosion	265
Total Brazer and Madison limestones	1,425

Section of Cambrian, Ordovician, and Devonian formations on south slope of Baldy Mountain in secs. 7 and 17, T. 1 N., R. 45 E. Boise meridian (unsurveyed)

	Feet
Devonian:	
Darby formation:	
Shale, siltstone, and sandstone, yellow, purplish red, and brown, calcareous, sandy; weathers yellow, brown, dark gray, olive, and red; has some bright red partings; interbedded with a few layers of silty dolomitic limestone	210
Limestone and dolomite, dark gray to sooty black; weathers somber dark gray; interbedded with a few beds of light gray limestone, yellowish-brown siltstone, and gray to brown sandstone; has a discontinuous 5-foot bed of yellow pebbly quartzite at the base	360
	570
Ordovician:	
Upper Ordovician:	
Bighorn dolomite: Dolomite, light to dark gray, coarse- to fine-grained, massive; has some pink to gray irregular banding or mottling; weathers chalk white to gray. As much as 150 feet of red to brown sandstone, siltstone, shale, and conglomerate comprise the upper part of the formation at a few places but give way in short distances to gray massive dolomite	400
Cambrian:	
Gallatin limestone: Limestone, blue to brownish gray; has many green silty partings and yellow to brown mottled areas	145
Gros Ventre formation:	
Shale, green, nonresistant, and gray to yellowish-gray oolitic limestone and intraformational breccia; poorly exposed	240
Limestone, bluish gray, thin-bedded; has many yellow to brown irregular bands and mottled areas such as characterize Cambrian limestones in this region	80
Limestone, bluish gray, massive, coarse-grained, cliff forming; has some irregular yellow partings and mottlings	370
Total Gros Ventre formation	690
Total exposed Cambrian	835

Another Cambrian formation, the Flathead quartzite, underlies the Gros Ventre in the Teton Range but is not exposed in the Snake River Range where Gallatin and Gros Ventre strata, the oldest rocks, are in overthrust plates that rest on younger formations.

PHOSPHORIA FORMATION

General features.—The Phosphoria formation in southeastern Idaho consists of two members, a lower sequence of nonresistant black to gray phosphatic shale, brown to gray siltstone, and gray to black phosphate rock, and a much thicker upper member (Rex chert) made up of resistant cherty limestone, chert, and shale. At the type locality for the formation in the Georgetown district, about 70 miles southwest of the Teton Basin, the chert member is 240 feet thick and the phosphatic shale member is 175 feet thick,[19] but both thin to the northeast so that in the Snake River Range and the Bighole Mountains the two members are 150 to 165 and 30 to 35 feet thick, respectively.

The Phosphoria formation is considered in this paper to include all strata from the lowest bed of phosphate or dark-colored phosphatic shale to the base of the greenish-gray calcareous platy siltstone of the Dinwoody (?) formation. Some beds associated with the phosphate rock are fossiliferous, and according to G. H. Girty[20] the formation is of Permian age, corresponding to parts of the Park City and Embar formations elsewhere in Wyoming and Utah.

Rex chert member.—In the Snake River Range the Rex chert member consists mainly of cherty dolomite and limestone. It contains some layers of sandstone and shale near the top but few thick beds of chert such as characterize the member elsewhere in Idaho.[21] The sandstone and shale thicken to the north where, in the Bighole Mountains, they predominate over dolomite and limestone. Thin beds of dark-gray to black nonresistant phosphatic shale appear at the top of the member in the Snake River Range and thicken northward to form a conspicuous belt of outcrop in the Bighole Mountains very similar to that of the phosphatic shale member but about 200 feet higher in the stratigraphic section.

Phosphatic shale member.—The main zone of phosphate rock is easily located because it occurs at a definite place in the stratigraphic section—near the base of the phosphatic shale member. The phosphate beds are concealed by soil at most places, but cherty limestones of the Rex chert member on one side and sandstone, dolomite, and limestone of the Wells formation on the other form a conspicuous bracket of resistant strata that marks the limits of the phosphatic shale member. The thick sequence of Triassic red beds, which begins about 900 feet above the phosphate beds, is another useful guide to the approximate location of the deposits. Outcrops of the phosphatic shale member are commonly marked by blue-black residual soil containing fragments of phosphate rock, but the dark-colored nonresistant siltstone and shale at the top of the Rex chert member in the Bighole Mountains may be easily mistaken for the phosphatic member; and resistant cherts near the base of the member in the Teton Range may be mistaken for Rex chert beds.

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19 Richards, R. W., and Mansfield, G. R., The Bannock overthrust: Jour. Geology, vol. 20, pp. 681-687, 1912.

20 Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S Geol. Survey Prof. Paper 152, p. 78, 1927.

21 Richards, R. W., and Mansfield, G. R., op. cit., pp. 684-685.

STRUCTURE

Compressional forces, acting in a southwest-northeast direction, have bent the sedimentary rocks of the Snake River Range and Bighole Mountains into many folds, some of them wide and shallow, others narrow and deep. Similar forces have broken the strata into great plates and blocks and have shoved the plates northeastward along low-angle faults and piled them one on top of another. The main ridges, which trend northwest parallel to the axes of the major folds and the strike of the main faults, reflect the structure of the underlying rock formations and their resistance to erosion.

The Teton Range trends almost due north and shows no evidence of large-scale intense folding or complex faulting. The range has been carved from a single large fault block that had been tilted gently westward away from a great fault along the east side of the range.

The Teton Basin is believed by Mansfield[22] and Schultz[23] to be underlain by a syncline. The gentle dip slope that forms the east side of the basin and plunges beneath the alluvium cover suggests a simple structure for at least part of the basin, but the complex structure of the Bighole Mountains and Snake River Range to the southwest and south suggests that the simple structure may not persist under all of the basin; especially as some complex faults, such as those in Trail Canyon, enter the basin from the south and are hidden beneath the cover of alluvium and lava.

Deformation has aided in making the phosphate deposits accessible by enabling erosion to expose them from beneath as much as 9,000 feet of sediments. In some places the elevation was such that some parts of the deposits have been destroyed by erosion, but elsewhere large parts are preserved in synclines. Thrust faults along the horizon of the deposits have locally torn and distorted the beds, squeezing them to thin smears at some places and piling the material elsewhere.

PHOSPHATE ROCK

TERMINOLOGY

The amount of phosphate in a rock is usually reported in terms of phosphorus pentoxide (P_2O_5) or tricalcium phosphate ($Ca_3(PO_4)_2$). The latter is called "bone phosphate of lime" or "B.P.L." and equals 2.18 times the amount of P_2O_5. In this paper, rocks containing 30 percent or more of B.P.L. are called phosphate rock, and those containing less than 30 percent are called by such names as phosphatic siltstone and phosphatic shale. The limit is placed at this figure because, first, in

[22] Mansfield, G. R., Coal in eastern Idaho: U. S. Geol. Survey Bull. 716-F, p. 146, 1921.

[23] Schultz, A. R., A geologic reconnaissance for phosphate and coal in southeastern Idaho and western Wyoming: U. S. Geol. Survey Bull. 680, p. 69, 1918.

classifying phosphate lands it is the present practice of the Geological Survey to ignore beds that have less than 30 percent of B.P.L., and second, in most phosphate rock no other single constituent, such as clay, silt, sand, or carbonaceous matter, makes up as much as 30 percent of the whole.

The phosphate rocks in the Teton Basin area contain from 30 to 80.4 percent of B.P.L. They are divided in this paper into three groups—high-grade rock that has 70 percent or more of B.P.L., medium-grade rock that has 50 to 70 percent, and low-grade rock that has 30 to 50 percent. The limit for high-grade rock is placed at 70 percent of B.P.L. because (1) in the classification of phosphate lands, beds that contain less than 70 percent of B.P.L. are considered in direct ratio to their B.P.L. content, whereas beds that contain more than 70 percent are given equal consideration regardless of their quality;[24] (2) phosphate rock that has about 72 percent of B.P.L. is required in the ordinary process of making acid-phosphate fertilizer,[25] whereas, if rocks of lower grade are used, the quality must be built up by washing away the lower-grade material; and (3) in the fertilizer industry, the term "high-grade" usually is applied to phosphate rock containing 72 or 74 percent of B.P.L.

The demarcation between low- and medium-grade phosphate rock is placed at 50 percent of B.P.L. because this is a convenient point halfway between the extreme limits for these grades.

SAMPLING

The phosphate deposits in the Teton Basin area are covered at most places by many feet of hill wash and other debris. Trenches as much as 6 feet deep were dug across outcrops of the phosphatic shale member at places where the cover was thin, and samples were taken from channels about 2 inches deep and 4 inches wide cut along the bottom or side of each trench. The material was collected on a cloth, broken into small pieces, quartered down to weight 1 or 2 pounds, and then sacked and labeled. All layers that seemed to be phosphate rock were sampled either singly or in groups not more than 5 feet thick. Care was taken to insure that each sampled correctly represented all parts of a chosen interval. Many samples of rocks low in phosphate were also taken. The only rocks ignored were clean limestones, sandstones, and cherts that were obviously nonphosphatic. All but a few layers of phosphate rock exposed in the trenches were sampled, but several beds probably were missed by trenches that did not cross the entire belt of outcrop.

The phosphate beds were measured and sampled under the following conditions:

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[24] Smith, G. O., and others, The classification of the public lands: U. S. Geol. Survey Bull. 537, pp. 130-132, 1913.

[25] Miller, A. M. (statement before joint committee to investigate the adequacy and use of phosphate resources of the Unites States): 75th Cong., Public Res. 112, Hearings, p. 545, Washington, 1939.

1. Most of the samples were taken from individual beds of phosphate, but some represent two or more layers that have different B. P. L. content. These composite samples were taken because some layers of phosphate rock grade imperceptibly into adjacent strata and because phosphate layers at some places are so numerous and thin that they had to be sampled along with intervening thin layers of lower-grade rock.
2. Systematic spacing of trench sections was not possible because of the limited time available for trenching, the ruggedness of the country, and the scarcity of places where shallow trenches would uncover the phosphate beds.
3. The phosphate beds show little variation in aggregate thickness and composition in horizontal distances of as much as several miles, but at some places they have been thickened or thinned by folding and duplicated or cut out by faulting.
4. Parts of the phosphate sequence that were deposited far apart, and that therefore may differ somewhat in thickness and composition, have been brought close together in the Snake River Range and Bighole Mountains by folding and overthrust faulting. Data from one trench section may or may not be applicable to nearby outcrops that have not been sampled, depending upon whether the trench section and the nearby outcrops are on the same fold or in the same fault block.

CHEMICAL ANALYSES

The channel samples from the Bighole Mountains and Teton Range were analyzed by F. J. Gray in the Chemical Research Laboratory of the Tennessee Valley Authority. The samples from the Snake River Range, together with a few from the Bighole Mountains, were analyzed by Francis L. Schmehl in the Chemical Laboratory of the Geological Survey. The content of phosphorus pentoxide (P_2O_5) was determined for each sample from the Snake River Range, and the content of iron oxide (Fe_2O_3), alumina (Al_2O_3), vanadium oxide (V_2O_3), organic matter, and other insoluble matter was determined for the samples that had 30 percent or more of B.P.L.

FIELD IDENTIFICATION

General methods.—Most phosphate rocks may be recognized in the field by their physical properties and their reaction to a simple chemical test, but inasmuch as low-grade phosphate passes imperceptibly into siltstone and shale as the B.P.L. content diminishes, some phosphatic rocks may not be correctly identified. Most high-grade phosphate rocks are easily told from low-grade rock, but it is not always possible to distinguish between medium- and high-grade or between medium- and low-grade rocks except by chemical analyses. A study of 118 analyzed samples containing 0.2 to 80.4 percent of B.P.L. failed to show that any physical characteristic is developed in proportion to the B.P.L. content or is limited to any one grade of phosphate rock.

As the general appearance of phosphate rock is constant throughout the Rocky Mountain region, a person familiar with rock from Utah has no trouble in identifying samples from Montana. Features that have been described by geologists as characteristic of western phosphate rock are (1) presence of oolites, pisolites, or ovules; (2) surface weathering to bluish "bloom"; (3) "fetid" odor of freshly broken rock; (4) high specific gravity; and (5) dark color. In the Teton Basin area, light to medium gray fairly resistant phosphate rocks that have bluish-gray "bloom" on weathered surface and contain oolites, pisolites, or other ovules, are consistently high in B.P.L. Only in combination, however, are these features clearly indicative of high-grade phosphate; some but not all of them may be noted in medium- or low-grade rocks. On the contrary, phosphate rocks may be of high grade, though they do not show this combination of features; some are black or dark gray, many show no weathering "bloom," and most of them are nonresistant. The presence of oolites or pisolites is perhaps the best indicator of high phosphate content, but one bed that contained as much as 70.6 percent of B.P.L. showed no ovules of any kind.

Before attempting to tell which beds in a phosphatic sequence are of high, medium, or low grade, a person should study all available analyzed samples of phosphate rock from the area he is to study and then identify the rocks or collect samples with a full realization that his estimates of the B.P.L. content of some beds may be wrong by as much as 25 percent.

Texture.—Many descriptions of western phosphate deposits emphasize the oolitic or pisolitic texture of high-grade beds. Of 58 samples of rock from the Teton Basin area that contained 30 percent or more of B.P.L., ovules were found in 49, but radial or concentric structure characteristic of oolites could be seen in only 7 of these, even with the aid of a hand lens. In the other 42 samples the ovules appeared to be structureless pellets, although thin sections may show that many, perhaps all, of them have oolitic structure. Such pellets, ranging from one-fourth centimeter to 10 centimeters in diameter, occur in samples having as little as 8.4 percent and as much as 72.5 percent of B.P.L. Ovules were present in almost 90 percent of the samples of phosphate rock and in about 30 percent of the samples of phosphatic shale and siltstone. The pellets in some rocks have such vague outlines that they are very hard to see. This holds for some high-grade phosphate rock as well as for low-grade rock. The occurrence of oolites and structureless pellets in the samples from the Teton Basin is summarized in the following table:

Oolites and structureless pellets in phosphate rock from the Teton Basin

	High-grade phosphate rock (70-80.4 percent of B.P.L.)	Medium-grade phosphate rock (50-70 percent of B.P.L.)	Low-grade phosphate rock (30-50 percent of B.P.L.)	Phosphatic rock (0.2-30 percent of B.P.L.)
Samples showing—				
Oolites	5	2	0	0
Pellets	2	22	18	19
Neither oolites nor pellets	1	6	2	41
Total number of samples	8	30	20	60

Hydrochloric-acid test.—A convenient field test for phosphate consists in placing several drops of concentrated hydrochloric acid on a fresh surface of the rock.[26] Tests on samples from the Teton Basin area have shown that if the B.P.L. content is greater than about 40 percent, a gray, white, or orange-yellow stain will remain on the surface after the acid has evaporated; but that if the B.P.L. content is between 4 and 40 percent, a stain may or may not be formed. The mark usually appears within a few minutes after the acid is applied, but it may become visible only after the rock has dried thoroughly. The orange or yellow stains change slowly to white or gray. Incoherent black shales were least responsive to the test. In general, the higher the grade of rock the stronger the stain produced upon it, but for many rocks this was not true; for example, the stain formed on one sample containing 12 percent of B.P.L. was better than that formed on another containing 48 percent.

This test is useful but not infallible. Its efficacy depends not only on the B.P.L. content of the rocks but also on the texture and the presence of calcium carbonate. Best results appear on fine-grained, compact rocks. The acid sinks out of sight in highly permeable rocks so that the effects are somewhat obscured. The test is not reliable for calcareous rocks because the acid is weakened by reacting with calcium carbonate. All samples of phosphate rock from the Teton Basin area, no matter what their grade, were very low in $CaCO_3$; yet all effervesced slightly when treated with hydrochloric acid, probably because calcium and carbon dioxide are constituent parts of the complex phosphate compound.[27] Of 118 samples that were analyzed, only 9 were high in $CaCO_3$ and these contained only 0.2 to 18.0 percent of B.P.L.

Color.—In the Teton Basin area light colors predominate for rocks that contain the most and the least phosphate, whereas dark gray and coal black are most common for medium- and low-grade phosphate rock.

[26] Rubey, W. W. (abstract of an informal communication): Washington Acad. Sci. Jour., vol. 23, p. 402, 1933.

[27] Jacob, K. D., and others, The composition and distribution of phosphate rock with special reference to the Unites States: U. S. Dept. Agr. Tech. Bull. 364, pp. 71-76, 1933.

High-grade phosphates are generally light gray to brownish gray; medium-grade rocks are light gray to dark gray; low-grade rocks are dark gray to coal black; and phosphatic shale and siltstone are reddish brown to gray. There are no dividing lines, however, and each grade shows gray, black, and brown colors. All phosphate rocks are somber-colored and dull, although shearing in some shale has produced bright surfaces, which together with the dark color of the rock cause it to resemble coal. Samples from newly dug trenches that are moist or wet have appreciably darker colors when freshly collected than when they are examined, thoroughly dry, in the laboratory. The colors given in this report are of dry samples and are applicable only to dry rocks in natural exposures.

Specific gravity.—The specific gravity of phosphate rock that contains 69.6 to 83.9 percent of B.P.L. ranges from 2.86 to 2.95 and averages about 2.9,[28] compared with specific gravities of 2.4 to 2.8 for common shale, 2.35 to 2.87 for limestone, and 2.0 to 2.78 for sandstone.[29] High-grade phosphate rock is thus 2 to 23 percent heavier than shale, as much as 30 percent heavier than limestone, and 0.3 to 47 percent heavier than sandstone. One of the main impurities in phosphate rock is organic matter, which has a very low specific gravity. A high content of organic compounds, therefore, will greatly reduce the specific gravity of a phosphate rock; and some medium- and low-grade phosphates with notably high organic content may have lower specific gravities than common shales, limestones, or sandstones. Specific gravity is thus of doubtful value in recognizing phosphate rocks other than some of the highest grade, but it is of great value in telling coal-black heavy phosphate rock from coal or carbonaceous shale.

Fetid odor.—When struck with a hammer, hard phosphate rock, phosphatic limestone, and phosphatic chert give off a penetrating fetid odor that has been considered by many geologists to be characteristic of phosphate rock. Some have described the odor as bituminous, others as sulfurous, and still others as that of crude petroleum. Neither the intensity nor the nature of the odor, however, indicates the amount of phosphate in a rock, because some impure limestones and dolomites that contain little or no phosphate respond to this test as well as or better than some phosphate rocks.

COMPOSITION

Phosphate content.—An average section of the phosphatic shale member in the Bighole Mountains and Snake River Range consists of about 30 percent of phosphate rock and about 70 percent of brown, gray, and black siltstone, mudstone, shale, sandstone, chert, and limestone with an

[28] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S Geol. Survey Prof. Paper 152, pp. 209-210, 1927.

[29] Gillette, H. P., Handbook of rock excavation, pp. 12-13, 1916.

average B.P.L. content of less than 10 percent. About 45 percent of the phosphate rock is low grade, 40 percent medium grade, and 15 percent high grade; and the average B.P.L. content is about 50.6 percent. The beds are persistent horizontally, but they show some changes in thickness, texture, color, and hardness in trenches several miles apart, and much larger changes from one mountain range to another.

A tendency for phosphate rocks to be enriched by weathering has been observed,[30] and inasmuch as all samples from the Teton Basin area were taken from shallow trenches within the zone of weathering, the analyses may not be applicable to the parts of beds that are deeply buried. It also has been noticed[31] that mere grinding and handling of phosphate rock increases its grade by a few percent, perhaps enough to bring the B.P.L. content of processed unweathered rock up to or above that of weathered material from the same bed at the surface. The increase in grade is due to the shaking out of clay not separated in mining.

Phosphate rock in deep canyons cannot be distinguished from rock on high peaks, and samples collected from outcrops many miles apart are identical. It therefore is certain that phosphate deposits, like coal beds, maintain at depth the same general characteristics they show near the surface.

Layers of phosphate rock occur throughout the phosphatic shale sequence, but more than 50 percent of the medium- and high-grade rock is concentrated in the basal 2 to 3½ feet of the Phosphoria formation, giving this zone an average B.P.L. content of about 65 percent for the Snake River Range and Bighole Mountains together, or of about 68 percent for the Bighole Mountains alone. The best zone in the Teton Range is 2 to 9 feet above the base of the formation, is 0.7 foot to 3.6 feet thick, and contains 53.5 to 75 percent of B.P.L.

Throughout Idaho, Wyoming, and Utah, the phosphate deposits become thinner and poorer in grade to the northeast until they vanish along a line extending southeastward from near Helena, Mont., to central Wyoming and thence southward to the vicinity of the Colorado-Utah State line.[32] The deposits of the Teton Basin area are much closer to this margin than are the rich, thick deposits near Conda and Georgetown, in southeastern Idaho. Two beds of high-grade phosphate rock, each 10 feet thick, occur at Conda.[33] The lower bed, which is being mined by the Anaconda Copper Mining Co., contains 72.5 percent of B.P.L., and the upper bed contains 73.4 percent. In the George-

[30] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, p. 213, 1927.

[31] Pardee, J. T., Phosphate rock near Maxville, Philipsburg, and Avon, Mont.: U. S. Geol. Survey Bull. 847-D, p. 185, 1936.

[32] Mansfield, G. R., Phosphate deposits of the United States: Econ. Geology, vol. 35, p. 424 (map), 1940.

[33] Mansfield, G. R., Recent studies of reserves of domestic phosphate: Am. Inst. Min. Met. Eng. Tech. Pub. 1208, pp. 6-7, 1940.

town district[34] a main bed at the base of the Phosphoria formation is 6 feet 4 inches thick and contains 80.4 percent of B.P.L.; another bed, near the middle of the sequence, is 10 feet 10 inches thick and has about 74 percent; and two other beds, 6 inches and 2 feet 11 inches thick, contain 78.4 percent and 82.1 percent, respectively.

The deposits in the Bighole Mountains are about as good as those now being mined in Montana[35] and are much better than those in the Wind River Mountains of Wyoming.[36]

Iron oxide and alumina.—Acid soluble Fe_2O_3 and Al_2O_3 are undesirable in phosphate rock that is to be treated with sulfuric acid to form superphosphate, because they waste the acid and form salts which then tend to take up moisture and form a gummy product that is chemically active and therefore hard to handle. Foreign contract standards generally provided for not more than 3 to 4.5 percent of Fe_2O_3 plus Al_2O_3.[37] The following table shows the amount of undesirable iron and alumina in the various grades of phosphate rock found in the Teton Basin area.

Fe_2O_3 and Al_2O_3	High-grade rock (70-80 percent of B.P.L.)	Medium-grade rock (61-70 percent of B.P.L.)	Medium-grade rock (50-61 per cent of B.P.L.)	Low-grade rock (30-50 percent of B.P.L.)
	No. of samples	No. of samples	No. of samples	No. of samples
Less than 3 percent	7	10	4	0
3 to 4.5 percent	0	4	3	2
More than 4.5 percent	1	0	9	18

Nearly 90 percent of the phosphate rock that contains less than 61 percent of B.P.L. has objectionable amounts of iron oxide and alumina, but at least 90 percent of the rock that contains more than 61 percent of B.P.L. is free of objectionable amounts of these impurities.

Vanadium.—Analyses of 15 samples of phosphate rock from the Snake River Range showed 0.03 to 0.41 percent of V_2O_3. Two samples of high-grade phosphate contained 0.03 and 0.08 percent, and three samples of medium-grade rock contained 0.04, 0.05, and 0.14 percent of V_2O_3. Ten samples of low-grade carbonaceous phosphate rock, however, contained 0.09 to 0.41 percent and averaged 0.21 percent. These few analyses indicate that the amount of vanadium in a phosphate rock may vary with the amount of organic matter present and not with the phosphate content of the rock.

[34] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, p. 274, 1927.

[35] Pardee, J. T., Phosphate rock near Maxville, Philipsburg, and Avon, Mont.: U. S. Geol. Survey Bull. 847-D, pp. 184-185, 1936.

[36] Condit, D. D. Phosphate deposits in the Wind River Mountains, near Lander, Wyo.: U.S. Geol. Survey Bull. 764, pp. 33-34, 1924.

[37] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, p. 211, 1927.

Vanadium may become a valuable by-product in the processing of phosphate rock. It is now being recovered by the Anaconda Copper Mining Co. as a by-product from Idaho phosphate rock.[38] The phosphate deposits of the Rocky Mountains contain 10 to 20 times more V_2O_3 than do those of the eastern United States.[39]

Hydrocarbons.—Near Dillon and Dell, in southwestern Montana, Condit[40] found that some of the Permian phosphatic shales yielded on distillation 25 to 30 gallons of oil per ton. Similar shales in Idaho, Wyoming, and Utah; however, yielded little or no oil. Four samples from Palisade Creek at or near trench K, in the Snake River Range, each gave 3 gallons of oil per ton, but 3 samples from near trench B, in in the Teton Range, and a single sampled from the west side of Teton Pass yielded no oil, and 29 samples from 9 other localities in Wyoming and Idaho gave only traces.[41] Some phosphatic shales that contain as much as 30 percent of organic matter are so black and carbonaceous that they have been prospected for coal.

The phosphatic strata in the Wind River Mountains of Wyoming first became known through their content of oil,[42] and the same beds in the Dallas oil field near Lander, Wyo., have yielded oil for many years. Several geologists have cited the carbonaceous shale of the Phosphoria formation as a possible source rock for petroleum.

PHOSPHATE DEPOSITS

SNAKE RIVER RANGE

The rugged mountains that are known as the Salt River and Wyoming Ranges in western Wyoming continue northwestward beyond the Grand Canyon of Snake River and there are called the Snake River Range. The high central belt and the southwestern flank of this range consist of a disorderly pile of Paleozoic formations comprising several thrust plates, which have moved northeastward along faults that dip parallel to the strata or cut them at low angles. The faults have southwest dips of 20° to 60° along the northeast margins of the plates where Paleozoic rocks have moved over and against younger strata; but farther west, where the same faults are exposed in deep canyons, they are nearly flat or dip only 5° to 10° SW. The northeastern part of the range consists of two belts of closely folded and complexly faulted Mesozoic strata and one belt of overturned Mesozoic and Paleozoic rocks that include the Phosphoria formation.

[38] Rubey, W. W., Vanadiniferous shales in the Phosphoria Formation, Wyoming and Idaho: (abstract) Ec. Geol. vol. 38, p. 87, 1943.

[39] Jacob, K. D., and others, The composition and distribution of phosphate rock with special reference to the United States: U. S. Dept. Agr. Tech. Bull. 364, p. 22, 1933.

[40] Condit, D. D., Oil shale in western Montana, southeastern Idaho, and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 711–B, p. 15, 1919.

[41] Idem, pp. 31-32.

[42] Condit, D. D., Phosphate deposits in the Wind River Mountains, near Lander, Wyo.: U. S. Geol. Survey Bull. 764, p. 35, 1924.

In the part of the Snake River Range that is near the Teton Basin (see pl. 1) the phosphate-bearing beds crop out in three narrow belts. Two of them lie along or close to overthrust faults, and the third is in the belt of overturned strata that form the high mountain ridge southwest of Trail Creek Canyon. A small undisturbed remnant of the Phosphoria formation capped by Mesozoic strata lies in a broad, shallow syncline on the divide between Palisade Lake and Austin Canyon west of the three main belts. The following section of the phosphatic shale member was measured and sampled in trench H at this place.

Complete section of phosphatic shale member of Phosphoria formation in trench H, on ridge between Austin Creek and Dry Canyon in NE¼ sec. 19, T. 1 N., R. 46 E. Boise meridian, Idaho

	Thickness (feet)	P_2O_5 (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Sample No.
Rex chert member.				
Phosphatic shale member:				
Phosphate rock, light to dark gray; contains many yellow to white bladed crystals in a black, matrix giving a feltlike texture	1.5	32.3	70.6	H-16
Mudstone, dark brown, thick-bedded	1.8			
Shale and mudstone, black to dark brownish gray, phosphatic; contains scattered pellets as much as 5 mm. in diameter	2.5	10.8	23.6	H-14
Limestone, light gray	.9			
Limestone, dark gray to black, massive, phosphatic	1.1			
Phosphate rock, black, thin-bedded; has a 6-inch bed of black soft pellets	2.3	18.0	39.3	H-11
Mudstone, brown, thick-bedded	2.2			
Mudstone or shale, black, calcareous, phosphatic; contains some black soft pellets	2.8	3.9	8.4	H-9
Mudstone or shale, sooty black, calcareous, phosphatic	3.1	10.7	23.4	H-8
Shale, black, incoherent, phosphatic; contains thin layers of tiny black soft pellets	2.2	12.7	27.7	H-7
Phosphate rock, black; contains many black pellets as much as 4 mm. in diameter	1.4	16.0	34.9	H-6
Limestone or siltstone, dark gray to black, massive, phosphatic	2.2	3.6	7.8	H-5
Siltstone, dull gray to black, phosphatic; contains some thin layers of phosphate rocks that have pellets as much as 2 mm. in diameter	1.8	9.3	20.2	H-4
Phosphate rock, black, massive; made up of black pellets as much as 1 mm. in diameter	.9	15.9	34.7	H-3
Phosphate rock, dark gray to black, coherent	2.2	24.1	52.7	H-2
Siltstone, reddish brown, calcareous	.3			
Total phosphatic shale member	29.2			
Wells formation.				

Chemical analyses of samples from trench H

[F. L. Schmehl, analyst]

Sample No.	P_2O_5 (percent)	Fe_2O_3 (percent)	Al_2O_3 (percent)	V_2O_3 (percent)	Organic matter (percent)	Insoluble, including organic matter (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Thickness (feet)
H-16	32.3	2.0	5.4	.03	2.5	11.0	70.6	1.5
H-14	10.8						23.6	2.5
H-11	18.0	2.1	4.4	.41	24.9	44.2	39.3	2.3
H-9	3.9						8.4	2.8
H-8	10.7						23.4	3.1
H-7	12.7						27.7	2.2
H-6	16.0	2.9	6.9	.26	19.8	38.8	34.9	1.4
H-5	3.6						7.8	2.2
H-4	9.3						20.2	1.8
H-3	15.9	1.3	4.0	.09	20.4	44.6	34.7	.9
H-2	24.1	1.1	6.3	.04	7.6	29.2	52.7	2.2

The phosphatic zone in the Snake River Range was trenched and sampled at three places close to major faults. (See plate 1.) Trenches G and I were on mountain peaks where the thickness of the phosphatic member was about normal, and trench K was in the bottom of a deep canyon where the thickness was almost four times greater than normal. In each of these trenches the general tenor of phosphate rock was much lower than in the nearby trench H, where the section was unaffected by faulting, and samples of the best appearing phosphate rock from the disturbed sections were consistently 10 to 30 percent lower in B.P.L. than samples of similar rock from the undisturbed section. The reason for this is not known.

The discontinuous nature of the phosphate outcrops and the complex pattern of folds, overthrusts, and other faults in the Snake River Range are shown on plate 1. This pattern probably continues northward into parts of the Bighole Mountains.

Section of faulted phosphatic shale strata in Trench G, on Thompson Peak near center of west half of sec. 27, T. 2 N., R. 45 E. Boise meridian, Idaho (unsurveyed)

	Thickness (feet)	P_2O_5 (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Sample No.
Fault.				
Phosphatic shale member of Phosphoria formation:				
Limestone or siltstone, light brown	5.0			
Siltstone and shale, dark brownish gray to black, phosphatic	5.0	5.0	10.8	G-11
Mudstone, light brownish gray to black	9.1			
Shale, black, calcareous, phosphatic	.9	7.6	16.6	G-9
Siltstone, shale, and limestone, dark gray, phosphatic	2.0	2.9	6.4	G-8
Mudstone, light brown, calcareous	1.9			
Siltstone, black, very calcareous, phosphatic	2.4	8.2	17.9	G-6
Shale, black, phosphatic; contains many small black pellets	1.0	13.7	29.8	G-5
Phosphate rock, black, thin-bedded; made up of black pellets that average less than 1 mm. in diameter	4.0	14.4	31.4	G-4
Limestone, light gray, brittle	1.7			
Phosphate rock, black, incoherent; contains small black pellets	2.0	18.6	40.6	G-2
Siltstone, darh brownish gray, highly calcareous, phosphatic	4.3	4.6	10.1	G-1
Total phosphatic shale member	39.3			
Wells formation: Limestone, light gray.				

Chemical analyses of samples from trench G

[F. L. Schmehl, analyst]

Sample No.	P_2O_5 (percent)	Fe_2O_3 (percent)	Al_2O_3 (percent)	V_2O_3 (percent)	Organic matter (percent)	Insoluble, including organic matter (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Thickness (feet)
G-11	5.0						10.8	5.0
G-9	7.6						16.6	.9
G-8	2.9						6.4	2.0
G-6	8.2						17.9	2
G-5	13.7						29.8	1.0
G-4	14.4	4.2	3.3	.24	19.8	43.0	31.4	4.0
G-2	18.6	2.4	7.2	.10	15.0	39.5	40.6	2.0
G-1	4.6						10.1	4.3

Section of faulted phosphatic shale member in trench I, near top of Palisade Peak, in SW¼ sec. 6, T. 1 N., R. 46 E. Boise meridian, Idaho

	Thickness (feet)	P_2O_5 (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Sample No.
Limestone, light gray.				
Phosphatic shale member of Phosphoria formation:				
Phosphate rock, black, thin-bedded; contains many small black soft pellets	2.3	15.7	34.2	I-12
Siltstone, dark brown, calcareous	.5	------	------	------
Phosphate rock, dark brown to black, thin-bedded; contains many black pellets less than 1 mm. in diameter	2.4	18.4	40.2	I-10
Mudstone, calcareous; has several thin black layers of phosphatic shale	1.4	------	------	------
Siltstone, black to dark brown, friable, phosphatic; made up of black soft pellets less than 1 mm. in diameter	3.4	12.5	27.2	I-8
Mudstone, dark brown, thin-bedded, calcareous	1.5	------	------	------
Siltstone, dark gray to brownish gray, incoherent	1.8	13.4	29.3	I-6
Mudstone, brown, calcareous, thin-bedded, coherent	9	------	------	------
Phosphate rock, dark brownish gray, coherent; has thin layers of brown mudstone	1.5	21.8	47.7	I-4
Mudstone, dark brown, calcareous, thin-bedded	3.5	------	------	------
Phosphate rock, dark brown to black, incoherent; contains scattered small black pellets about ½ mm. in diameter	1.0	15.7	34.3	I-2
Phosphate rock, dark gray to black; some layers are dense and cherty; others have black hard pellets as much as 10 mm. in diameter	2.1	27.8	60.7	I-1
Total phosphatic shale member	22.3			
Wells formation: Limestone and quartzite.				

Chemical analyses of samples from trench I

[F. L. Schmehl, analyst]

Sample No.	P_2O_5 (percent)	Fe_2O_3 (percent)	Al_2O_3 (percent)	V_2O_5 (percent)	Organic matter (percent)	Insoluble, including organic matter (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Thickness (feet)
I-12	15.7	1.8	4.5	.38	14.2	29.7	34.2	2.3
I-10	18.4	2.3	4.9	.33	15.1	31.5	40.2	2.4
I-8	12.5	------	------	------	------	------	27.2	3.4
I-6	13.4	------	------	------	------	------	29.3	1.8
I-4	21.8	3.2	9.8	.09	8.4	21.3	47.7	1.5
I-2	15.7	2.6	8.5	.11	7.7	40.4	34.3	1
I-1	27.8	.95		.05	1.8	15.6	60.7	2.1

Section of faulted phosphatic shale strata in trench K, on south bank of Palisade Creek in the NE ¼ of sec. 35, T. 1 N., R. 46 E. Boise meridian, Idaho (unsurveyed)

	Thickness (feet)	P_2O_5 (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Sample No.
Wells formation: Sandstone and quartzite (vertical beds).				
Phosphatic shale member of Phosphoria formation:[1]				
Limestone, light gray, impure	1.2	------	------	------
Shale, black, phosphatic; like sample No. K-2	.6	------	------	------
Mudstone, grayish brown, calcareous	1.0	------	------	------
Shale, black to brown, somewhat calcareous, phosphatic	.8	------	------	------
Shale, black, phosphatic; like sample No. K-2	.9	------	------	------
Shale, black, coherent, phosphatic	.8	------	------	------
Shale, black, phosphatic, crushed; contains lenses of dark-gray limestone	1.6	------	------	------
Shale, black, coherent, phosphatic, calcareous	.7	------	------	------
Shale, black, phosphatic; like sample No. K-2	1.0	------	------	------
Mudstone, grayish brown, calcareous	1.8	------	------	------
Shale, black to brown, phosphatic, calcareous	1.6	------	------	------
Limestone, light gray, nonresistant, shaly	2.0	------	------	------
Mudstone, grayish brown, calcareous	3.1	------	------	------
Limestone, dark gray, massive; has black phosphatic shale partings	1.1	------	------	------
Shale, black, coherent, phosphatic; like sample No. K-33	2.3	------	------	------

[1] The strata are vertical and lie between faults, so that it is not known which is the stratigraphic top of the sequence.

Section of faulted phosphatic shale strata in trench K—Continued

	Thickness (feet)	P_2O_5 (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Sample No.
Shale, black, phosphatic; like sample No. K-2	1.7			
Limestone, light gray, resistant	2.1			
Shale, black, phosphatic; like sample No. K-2	.8			
Limestone, light gray, resistant	1.3			
Shale and mudstone, coal-black, phosphatic, coherent; contains scattered black, pellets	3.1	10.1	22.1	K-33
Limestone, light gray, resistant	1.1			
Shale, black, phosphatic; like sample No. K-2	.4			
Limestone, light gray, resistant	2.7			
Shale, black, phosphatic; like sample No. K-2	4.0			
Limestone, dark gray, argillaceous; contains several thin seams of black phosphatic shale	12.8			
Limestone, dark gray, massive	.5			
Shale, black, phosphatic; like sample No. K-2	.5			
Limestone, dark gray, argillaceous	2.9			
Shale, black, calcareous, phosphatic; made up of black soft pellets less than 1 mm. in diameter	2.4	7.8	16.9	K-24
Limestone, dark gray, argillaceous	.5			
Shale, black, phosphatic; like sample No. K-2	1.7			
Limestone, dark gray, argillaceous	.5			
Shale, black, phosphatic; like sample No. K-2	.3			
Limestone, dark gray, argillaceous	1.1			
Shale, black, phosphatic; like sample No. K-2	1.0			
Mudstone, grayish brown, calcareous	5.6			
Shale and mudstone, black, calcareous, phosphatic; contains scattered black pellets as much as 3 mm. in diameter	4.0			
Limestone, dark gray, argillaceous	1.3			
Shale, black, phosphatic; contains black pellets; like sample No. K-10	.3			
Shale, coal-black, coherent, phosphatic, calcareous; contains scattered black pellets as much as 2 mm. in diameter	1.4	4.8	10.5	K-13
Shale, black; contains many black soft pellets as much as 1 mm. in diameter	2.3	8.6	18.7	K-12
Limestone, dark gray, argillaceous; has seams of black phosphatic shale	2.3			
Shale, black, phosphatic, calcareous; contains many black soft pellets as much as 1 mm. in diameter	2.3	7.1	15.6	K-10
Shale and mudstone, black, coherent, phosphatic	3.3	3.0	6.6	K-9
Limestone, dark gray, massive	1.2			
Shale, black, phosphatic; contains several small lenses of dark gray limestone; has many black soft pellets as much as 1 mm. in diameter	4.8	6.1	13.3	K-7
Shale, black, phosphatic, and phosphatic mudstone that contains scattered black pellets	3.4	7.2	15.8	K-6
Limestone, dark gray, massive	.8			
Shale, coal black, coherent, phosphatic; contains scattered black pellets; like sample No. K-33	4.4			
Limestone, dark gray, massive	1.5			
Shale, black, phosphatic; contains many tiny soft black pellets	1.2	9.0	19.6	K-2
Total phosphatic shale member	102.0			
Wells formation: Limestone, light to dark gray; has many thin layers and partings of slicken-sided black shale (vertical beds).				

Summary of trench sections in northern part of the Snake River Range

	Trench H (complete and undisturbed section of phosphatic shale member)	Trench G (adjacent to a fault)	Trench I (adjacent to a fault)	Trench K (straddled by a fault)
Thickness of section feet	29.2	39.3	22.3	102
Number of beds of phosphate rock	5	3	6	[1]9
Thickness of phosphate rock feet	8.3	7.0	11.1	[1]24.9
Average content of B.P.L. in the phosphate rock percent	47.3	33.8	41.5	[1]14.4
Thickness of the best bed of phosphate rock feet	1.5	2.0	2.1	[1]3.1
Content of B.P.L. in the best bed of phosphate rock percent	70.6	40.6	60.7	[1]22.1

[1] No phosphate rock was found in this section. The figures are for beds that appeared to be phosphate rock but actually were phosphatic shale and siltstone.

BIGHOLE MOUNTAINS

The Bighole Mountains are the northern extension of the Snake River Range. They consist of Mesozoic and Paleozoic strata, including the Phosphoria formation, and are flanked on the east, west, and north by Tertiary and Quarternary lava flows. The strata are complexly folded and faulted, so that phosphate beds in the southeastern part of the mountains crop out in several discontinuous belts that strike about N. 40° W., parallel to the trend of the range, and that dip 25° to 50°, generally to the southwest. Each outcrop belt consists of two narrow bands of dark-colored nonresistant phosphate-bearing strata separated by a wide band of resistant limestone, dolomite, and sandstone (Rex chert member). The phosphatic beds in the lower band are far richer than those in the upper and represent the phosphatic shale member of the Phosphoria formation. The upper beds are equivalent to the thin phosphatic siltstone and shale at the top of the Rex chert member in the Snake River Range.

Three trenches were dug in the Bighole Mountains. Trenches D and E cross the upper and the lower group of phosphatic beds, but trench F crosses only the lower or main group. The locations of the trenches are shown on plate 2, which, however, shows but little of the geology in the vicinity of the sections. A more nearly complete geologic map of this part of the Bighole Mountains has been published by Mansfield.[43]

Complete section of Phosphoria formation in trench D, on Mahogany Ridge in NW¼ sec. 22, T. 4 N., R. 44 E. Boise meridian, Idaho

	Thickness (feet)	P_2O_5 (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Sample No.
Dinwoody (?) formation.				
Phosphoria formation:				
Rex chert member:				
Upper trench:				
Sandstone, dull gray, quartzitic, coarse-grained; weathers brown	9.0			
Shale, dull gray, siliceous, phosphatic; weathers light gray (sample from a 5-foot interval near the middle)	28.0	5.5	12.0	D-33
Phosphate rock, black coherent; made up of tiny pellets; like sample No. 29	1.1			
Shale, dark brown, weathered	1.7			
Shale, dark brown to black, incoherent, phosphatic	2.9	4.4	9.6	D-30
Phosphate rock, black and gray mottled; weathers dark brownish gray; made up of tiny black pellets ⅛ mm. or less in diameter	1.2	30.8	67.3	D-29
Mudstone, dull brown, calcareous	4.2			
	48.1			
Resistant interval:				
Limestone, dull gray, siliceous	27.0			
Limestone, gray; becomes cherty near the top; weathers hackly	45.0			
Sandstone, dull brown, argillaceous, brittle	20.5			
Limestone, dull gray, tough; weathers white	21.0			
Covered with soil containing angular limestone fragments	16.2			
Total Rex chert member	177.8			

[43] Mansfield, G. R., Coal in eastern Idaho: U. S. Geol. Survey Bull. 716-F, pl. 15, 1920.

Complete section of Phosphoria formation in trench D, on Mahogany Ridge—Con.

	Thickness (feet)	P_2O_5 (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Sample No.
Phosphoria formation—Continued.				
Phosphatic shale member:				
Lower trench:				
Mudstone, olive brown, coherent	4.0	----------	----------	--------
Phosphate rock, dull gray to brown; made up of black hard pellets about ½ mm. in diameter	.3	32.0	69.9	D-21
Mudstone, olive drab, incoherent	.4	----------	----------	--------
Phosphate rock, black, shaly; contains scattered small black pellets	1.9	18.9	41.3	D-19
Sandstone, dull brown, argillaceous, resistant	5.3	----------	----------	--------
Mudstone, dull brown to black, thin-bedded	4.2	----------	----------	--------
Shale, black, phosphatic; contains some small black pellets	1.0	12.6	27.4	D-16
Shale, dull brown, incoherent	.9	----------	----------	
Phosphate rock, sooty black; contains many black soft pellets as much as 2 mm. in diameter	1.1	25.0	54.6	D-14
Shale, black to brown, phosphatic, incoherent	.7	----------	----------	--------
Siltstone, black, brittle, massive, calcareous	.8	1.4	3.1	D-12
Phosphate rock, black, shaly; contains many black soft pellets as much as 2 mm. in diameter	1.5	18.8	41.1	D-11
Phosphate rock, black, shaly, smutty; contains some black soft pellets as much as 2 mm. in diameter	1.1	15.2	33.2	D-10
Sand, white, loose; made up of fine- to medium-sized grains of chert and quartz	.2	----------	----------	--------
Phosphate rock, black, smutty; like sample No. 10	.2	----------	----------	--------
Phosphate rock, black, shaly, incoherent; contains black pellets as much as 5 mm. in diameter	.8	19.2	41.9	D-7
Phosphate rock, dark brownish gray, friable; contains many black soft pellets as much as 4 mm. in diameter	.6	23.7	51.8	D-6
Phosphate rock, black, brittle; contains some black pellets as much as 3 mm. in diameter	.8	33.2	72.5	D-5
Mudstone, dull brownish gray, calcareous; like sample No. 2	.5	----------	----------	--------
Phosphate rock, black massive, brittle	1.3	27.2	59.4	D-3
Mudstone, dull brownish gray, calcareous	1.4	.4	.8	D-2
Phosphate rock, dark gray, hard; weathers bluish gray	1.9	31.2	68.1	D-1
Total phosphatic shale member	30.9			
Total Phosphoria formation	208.7			
Wells formation: Limestone, dolomite, and sandstone.				

Chemical analyses of samples from trench D

[Samples D-6, D-16, and D-30 analyzed by F. L. Schmehl; others by F. J. Gray]

Sample No.	P_2O_5 (percent)	CaO (percent)	Fe_2O_3 (percent)	Al_2O_3 (percent)	Ignition loss (percent)	Insoluble (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Thickness (feet)
D-1	31.2	45.8	.9	.5	3.5	12.3	68.1	1.9
D-2	.4	25.5	1.1	.7	38.2	16.4	.8	1.4
D-3	27.2	45.6	.5	.6	1.3	3.2	59.4	1.3
D-5	33.2	49.2	.5	.3	5.4	2.5	72.5	.8
D-6[1]	23.7	--------	1.9	4.0	----------	[2]29.3	51.8	.6
D-7	19.2	30.3	1.9	3.2	14.8	21.0	41.9	.8
D-10	15.2	23.7	2.0	3.1	19.0	26.3	33.2	1.1
D-11	18.8	28.5	1.5	3.7	14.5	25.3	41.1	1.5
D-12	1.4	25.8	1.0	.5	40.4	13.1	3.1	.8
D-14	25.0	37.4	1.1	2.2	12.9	13.3	54.6	1.1
D-16	12.6	--------	--------	--------	----------	----------	27.4	1.0
D-19	18.9	29.4	1.8	3.1	15.7	21.9	41.3	1.9
D-21	32.0	48.3	1.0	1.1	5.3	3.5	69.9	.3
D-29	30.8	45.6	1.1	2.0	5.3	7.2	67.3	1.2
D-30	4.4	--------	--------	--------	----------	----------	9.6	2.9
D-33	5.5	8.4	2.6	2.1	5.9	70.9	12.0	[3]5.0

[1] Contains 0.14 percent of V_2O_3.
[2] Insoluble plus organic matter.
[3] Only 5 feet of this 28-foot bed was sampled.

Complete section of the Phosphoria formation in trench E, 1 mile north of Elk Flat in NE¼ sec. 18, T. 4 N., R. 44 E. Boise meridian, Idaho

	Thickness (feet)	P_2O_5 (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Sample No.
Dinwoody (?) formation.				
Phosphoria formation:				
Rex chert member:				
Upper trench:				
Sandstone, yellowish brown, cherty	7.0			
Shale, gray	6.0			
Sandstone, yellowish brown, cherty	1.8			
Shale, light gray, phosphatic, brittle	3.2	5.7	12.4	E-32
Sandstone, yellowish brown, cherty	7.0			
Phosphate rock, dull gray to black, fine-grained, brittle	.8	24.6	53.7	E-30
Sandstone, yellowish brown, cherty	2.3			
Quartzite, dark gray, fine-grained, tough	.3	1.1	2.4	E-28
Sandstone, yellowish brown, cherty	2.1			
Chert, gray	.6			
	31.1			
Resistant strata:				
Sandstone, dark brown, cherty, resistant	83.0			
Dolomite and limestone, light gray; contains many small chert nodules	52.0			
Total Rex chert member	166.1			
Phosphatic shale member:				
Lower trench:				
Shale, brown, calcareous, somewhat siliceous	18.1			
Phosphate rock, black, massive; made up of black pellets as much as 1 mm. in diameter	.8	30.2	66.0	E-25
Sandstone, yellowish brown, slightly calcareous	.9			
Shale, brown to black, phosphatic, incoherent	.3	12.5	27.3	E-23
Sandstone, yellowish brown, fine-grained, slightly calcareous	.2			
Siltstone, dull gray to black, phosphatic	1.8	10.2	22.3	E-21
Phosphate rock, black; consists of black soft pellets as much as 2 mm. in diameter	.1	20.9	45.7	E-20
Limestone, dull gray, phosphatic, silty; some thin beds contain pellets as much as 1 mm. in diameter	1.0	8.2	17.9	E-19
Limestone, gray, nearly pure	.2			
Limestone, dull gray, silty, phosphatic	.5	5.6	12.2	E-17
Phosphate rock, black, massive; composed of tightly packed black soft pellets as much as 2 mm. in diameter	.3	23.5	51.3	E-16
Limestone, dull gray, silty, phosphatic	.5	4.9	10.7	E-15
Phosphate rock, black; composed of tightly packed black soft pellets	1.0	23.4	51.1	E-14
Limestone, dull gray, silty, phosphatic; has thin layers of black pellets as much as 2 mm. in diameter	.3	7.3	15.9	E-13
Phosphate rock, black, incoherent; contains many black soft pellets as much as 4 mm. in diameter	.8	19.5	42.6	E-12
Shale, black, incoherent, phosphatic; contains some flat pellets	.2	13.0	28.4	E-11
Limestone, light gray	.3			
Phosphate rock, black, shaly, nonresistant; contains some black pellets as much as 3 mm. in diameter	.6	15.4	33.6	E-9
Limestone, light gray	.1			
Phosphate rock, gray to black, shaly; contains black pellets as much as 3 mm. in diameter	.5	29.8	65.0	E-7
Chert, light gray	.1			
Phosphate rock, dull gray, incoherent; contains scattered oolites, pellets and angular fragments of phosphate	.8	33.2	72.5	E-5
Phosphate rock, dark gray, coherent; contains oolites, pellets and angular fragments of phosphate	.7	34.3	74.9	E-4
Shale, black to brown, phosphatic; contains a few black pellets	.3	11.4	24.9	E-3
Shale, dark brown to black, incoherent, phosphatic	.3	8.4	18.3	E-2
Phosphate rock, dark gray; contains a few pisolites as much as 10 mm. in diameter	1.5	35.7	78.0	E-1
Total phosphatic shale member	32.2			
Total Phosphoria formation	198.3			
Wells formation: Limestone, dolomite, and sandstone.				

Chemical analysis of samples from trench E

[Samples E-4 and E-12 analyzed by F. L. Schmehl; others by F. J. Gray]

Sample No.	P_2O_5 (percent)	CaO (percent)	Fe_2O_3 (percent)	Al_2O_3 (percent)	Ignition loss (percent)	Insoluble (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Thickness (feet)
E-1	35.7	52.2	.4	.6	2.9	2.9	78.0	1.5
E-2	8.4	13.6	3.8	5.8	12.3	52.7	18.3	.3
E-3	11.4	18.5	2.5	5.0	19.7	37.5	24.9	.3
E-4[1]	34.3	49.0	.5	.7	3.6	5.3	74.9	.7
E-5	33.2	48.8	.3	.3	5.8	4.5	72.5	.8
E-7	29.8	43.8	1.3	1.4	8.7	6.7	65.0	.5
E-9	15.4	25.5	1.6	3.4	20.9	26.1	33.6	.6
E-11	13.0	21.7	2.1	3.2	19.7	31.6	28.4	.2
E-12[2]	19.5	29.9	1.6	3.1	15.0	22.3	42.6	.8
E-13	7.3	25.1	1.9	1.8	27.6	23.0	15.9	.3
E-14	23.4	35.6	1.3	2.3	13.4	14.3	51.1	1.0
E-15	4.9	29.6	.4	.6	40.8	5.8	10.7	.5
E-16	23.5	36.9	.6	2.4	14.3	11.1	51.3	.3
E-17	5.6	31.2	.4	.4	40.7	4.0	12.2	.5
E-19	8.2	26.7	1.5	1.5	26.4	23.2	17.9	1.0
E-20	20.9	33.5	1.5	2.8	15.2	16.3	45.7	.1
E-21	10.2	16.9	2.8	3.9	14.8	45.5	22.3	1.8
E-23	12.5	19.6	2.9	5.4	15.2	36.9	27.3	.3
E-25	30.2	44.5	1.3	1.8	5.5	6.9	66.0	.8
E-28	1.1	3.2	2.6	.4	1.8	89.7	2.4	.3
E-30	24.6	36.8	2.3	4.5	6.3	19.3	53.7	.8
E-32	5.7	8.8	3.5	6.2	6.8	65.3	12.4	3.2

[1] Contains 0.89 percent of V_2O_3.
[2] Contains 0.12 percent of V_2O_3.

Complete section of phosphatic shale member of Phosphoria formation in trench F, on ridge southwest of Potterson Creek in NW¼ sec. 34, T. 4 N., R. 44 E. Boise meridian, Idaho

	Thickness (feet)	P_2O_5 (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Sample No.
Rex chert member.				
Phosphatic shale member:				
Sandstone or siltstone, pale gray to pale yellow	2.7			
Phosphate rock, black, hard; weathers brownish gray; made up of black, pellets ½ to 2 mm. in diameter	.1	24.3	53.1	F-19
Siltstone, gray to yellow, friable	5.7			
Phosphate rock, dull brown to black, smutty; consists of black soft pellets ¼ to 1 mm. in diameter	2.0	20.8	45.4	F-17
Sandstone or siltstone, pale gray to yellow, argillaceous, friable	8.4			
Siltstone, dull brownish gray, coherent; weathers black	.4	.8	1.7	F-15
Siltstone, dull gray, calcareous; weathers buff	.6			
Siltstone, black to brown, phosphatic; contains some small black pellets	2.1	10.5	22.9	F-13
Phosphate rock, black to dark gray; contains some black pellets as much as 2 mm. in diameter	2.7	14.2	31.0	F-12
Phosphate rock, dull brownish gray; contains scattered dark gray pellets as much as 10 mm. in diameter	2.6	23.5	51.3	F-11
Siltstone, dull brown to black, smutty, highly calcareous	2.2	.1	.2	F-10
Phosphate rock, dull brown; contains pellets as much as 5 mm. in diameter	1.0	24.0	52.4	F-9
Phosphate rock, black, thin-bedded; contains oolites as much as 3 mm. and pellets as much as 10 mm. in diameter	1.2	36.3	79.3	F-8
Phosphate rock, dark gray, resistant; contains many oolites as much as ½ mm. in diameter; also some white to pale yellow weathered crystals	1.1	28.9	63.1	F-7
Total phosphatic shale member	32.8			
Wells formation: Limestone, sandstone, and chert.				

Chemical analyses of samples from trench F

[F. J. Gray, analyst]

Sample No.	P_2O_5 (percent)	CaO (percent)	Fe_2O_3 (percent)	Al_2O_3 (percent)	Ignition loss (percent)	Insoluble (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Thickness (feet)
F-7	28.9	41.8	1.0	.8	2.4	20.7	63.1	1.1
F-8	36.3	52.0	.8	.5	3.3	1.8	79.3	1.2
F-9	24.0	35.1	1.9	4.2	6.3	21.7	52.4	1.0
F-10	.1	23.7	1.1	.7	36.7	21.1	.2	2.2
F-11	23.5	34.4	1.9	3.7	8.5	20.6	51.3	2.6
F-12	14.2	21.9	2.5	4.8	14.5	34.7	31.0	2.7
F-13	10.5	16.0	3.5	5.1	13.1	46.3	22.9	2.1
F-15	.8	3.0	4.4	5.1	8.3	77.2	1.7	.4
F-17	20.8	30.6	2.1	4.0	8.3	26.8	45.4	2.0
F-19	24.3	35.6	1.9	3.6	5.4	21.4	53.1	.1

Summary of trench sections in the Bighole Mountains

	Trench D (complete section of Phosphoria formation)	Trench E (complete section of Phosphoria formation)	Trench F (phosphatic shale member only)
Thickness of section...feet..	[1]30.9	[1]32.2	[2]32.8
Number of beds of phosphate rock...	[1]10	[1]10	[2]7
Thickness of phosphate rock...feet..	[1]11.3	[1]7.1	[2]10.7
Average content of B.P.L. in the phosphate rock...percent..	[1]51.8	[1]61.7	[2]49.5
Thickness of best bed of phosphate rock..feet..	[3]1.9	1.5	[4]3.3
Content of B.P.L. in the best bed of phosphate rock...percent..	[3]68.1	78.0	[4]71.5

[1] Does not include beds of phosphate rock that were found in the Rex chert member.
[2] Rex chert member was not sectioned.
[3] The bed of highest grade contains 72.5 percent of B.P.L. but is only 0.8 foot thick.
[4] Consist of two adjacent beds represented by samples F-7 and F-8.

TETON RANGE

The remarkably high and rugged Teton Range differs from the Snake River Range and Bighole Mountains in having relatively simple structure. Pre-Cambrian gneiss, schist, and granite form the high eastern and central parts of the range; and Paleozoic sedimentary formations, which overlie the crystalline rocks, form long dip slopes on the relatively gentle west flank. Mountain streams have furrowed the dip slope at close intervals and have formed westward-sloping ridges and spurs separated by narrow canyons. All Phosphoria strata except remnants of cherty beds that lie near the base of the formation have been eroded at most places. The remnants now cap the lower ends of some ridges, and, inasmuch as exposures generally are poor, one may easily mistake the cherty beds for the Rex chert member and assume from fragments of phosphate rock in the soil that the phosphatic shale member is present in its entirety, whereas only the few inches of phosphate rock that underlie the cherty beds remain. (See pl. 3.)

Some of the main spurs, however, have backbones of phosphatic shale and phosphate rock that overlie the cherty layers; but dense thickets of aspen trees and brush growing on a heavy blanket of rocky hill wash nearly everywhere effectively conceal these remnants. Trench C, dug on one of the spurs, exposed 4.3 feet of broken phosphate rock containing 74.23 percent of B. P. L. This is the best bed of phosphate found in the entire Teton Valley area, but it is only a small isolated patch where the phosphate content may have been increased by leaching and the thickness by slope wash or creep.

Incomplete section of phosphatic shale member of Phosphoria formation in trench C, at west base of the Teton Range about 3 miles northeast of Victor, Idaho, in lot 4, sec. 6, T. 3 N., R. 46 E. Boise meridian, Idaho

	Thickness (feet)	P_2O_5 (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Sample No.
Soil and coarse hill wash.	3 to 5			
Chert, light gray, brittle; mixed with soil and fragments of phosphate rock	1.1	6.7	14.6	C-2
Phosphate rock, light greenish gray, weathered; made up of hard oolites as much as 2 mm. in diameter	1.9	34.3	74.9	C-3
Phosphate rock, light gray, hard; made up of oolites as much as 3 mm. in diameter and flattened pellets as much as 10 mm. wide and 3 mm. thick	1.7	36.8	80.4	C-4
Phosphate rock, gray to almost white, very hard and tough; made up of white oolites and pellets as much as 3 mm. in diameter in a dense gray groundmass	.7	26.3	57.4	C-5
Chert, blue gray, brittle	6.0	-------	-------	-------

Chemical analyses of samples from trench C

[F. J. Gray, analyst]

Sample No.	P_2O_5 (percent)	CaO (percent)	Fe_2O_3 (percent)	Al_2O_3 (percent)	Ignition loss (percent)	Insoluble (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Thickness (feet)
C-2	6.7	9.9	4.4	1.9	1.2	74.8	14.6	1.1
C-3	34.3	48.2	1.3	1.7	2.6	5.2	74.9	1.9
C-4	36.8	50.9	.9	.8	2.1	3.5	80.4	1.7
C-5	26.3	36.7	4.6	.6	1.8	27.3	57.4	.7

The dip slope along the west flank of the Teton Range is terminated on the south by two folds that trend northwestward across the south end of the Teton block. They change the strike and increase the dip of the strata so that the entire thickness of the Phosphoria formation appears between Moose and Game Creeks and forms a poorly exposed but easily traced belt of outcrop that zigzags southeastward across spurs and valleys toward Teton Pass. Formations as young as the Jurassic Twin Creek limestone are present in the ridge north of Trail Creek. (See pl. 3.) Several prospect tunnels and pits, now abandoned, have been dug into the black phosphatic shale by persons seeking coal. One of these, located on the north side of Moose Creek, was enlarged to form trench A, and it furnished the following section of the phosphatic beds:

Incomplete section of phosphatic shale member of Phosphoria formation in trench A, a few hundred feet north of Moose Creek on unserveyed land in Teton County, Wyo., about three-eights of a mile east of milepost 179 on Idaho-Wyoming boundary

	Thickness (feet)	P_2O_5 (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Sample No.
Rex chert member: Sandstone, bluish gray, thick-bedded, calcareous	2.5			
Phosphatic shale member:				
Siltstone, dark-gray, thin-bedded, slightly calcareous; weathers light brown	1.3	1.7	3.7	A-19
Mudstone, light gray; weathers dull yellowish brown	.4			
Chert, black, in layers as much as 2 inches thick separated by black shale partings	.8			
Siltstone, dark gray to black with dark bluish tint, phosphatic	.5	5.9	12.9	A-16
Sandstone, gray to yellowish brown, friable	.3			
Shale, dull gray, sandy, brittle	.3			
Shale, dull reddish brown to purple; weathered	.3			
Phosphate rock, light gray, resistant; contains many oolites and pellets as much as 2 mm. in diameter	.7	26.7	58.3	A-12
Phosphate rock, light gray, nonresistant; contains many black to gray pellets as much as 1 mm. in diameter; grades laterally into bed No. 12	.5	31.3	68.3	A-11
Sandstone, dull reddish brown, thin-bedded, friable	.1			
Sandstone, light reddish brown, fine-grained, hard, calcareous, earthy	2.5	1.6	3.5	A-9
Sand, white, loose, calcareous; made up of coarse angular chert and quartz fragments	.2			
Chert, black, brittle, in beds 1 to 7 inches thick separated by partings of black shale and dull red siltstone	2.9			
Siltstone, dark brown, thin-bedded, phosphatic	.4	6.8	14.8	A-6
Siltstone, brown to black, friable, phosphatic, slightly calcareous	.3	2.7	5.9	A-5
Chert, bluish gray, brittle	.1			
Shale, dark brown to black, phosphatic, slightly calcareous, crumpled	.3	4.3	9.4	A-3
Phosphate rock, light gray; contains many dark gray pellets as much as 1 mm. in diameter	.2	31.5	68.8	A-2
Phosphate rock, reddish brown; contains many flat pellets as much as 3 mm. wide and 1 mm. thick	.6	23.4	51.1	A-1
Chert, light to dark bluish gray	9.0			
Total phosphatic shale member	21.7			
Wells formation.				

Chemical analyses of samples from trench A

[F. J. Gray, analyst]

Sample No.	P_2O_5 (percent)	CaO (percent)	Fe_2O_3 (percent)	Al_2O_3 (percent)	Ignition loss (percent)	Insoluble (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Thickness (feet)
A-1	23.4	35.1	7.3	4.7	6.5	15.4	51.1	.6
A-2	31.5	47.9	1.3	1.3	5.8	2.8	68.8	.2
A-3	4.3	9.7	4.6	7.6	12.6	54.2	9.4	.3
A-5	2.7	8.1	3.0	4.4	12.1	63.2	5.9	.3
A-6	6.8	11.0	2.1	2.9	8.0	66.2	14.8	.4
A-9	1.6	30.1	.6	.5	42.8	4.9	3.5	2.5
A-11	31.3	48.4	.6	.9	5.8	4.6	68.3	.5
A-12	26.7	40.7	.4	.3	5.1	20.6	58.3	.7
A-16	5.9	11.9	3.5	4.7	9.8	59.1	12.9	.5
A-19	1.7	3.0	2.1	8.2	3.8	78.1	3.7	1.3

Teton Pass marks the south end of the Teton Mountains and affords the only direct route of travel by automobile across the range. Trail Canyon, which drains northwestward from the pass, has been eroded along a complex fault zone. Strata ranging in age from Carboniferous to Jurassic crop out on the northeast side of the canyon; Upper Cretaceous rocks are exposed in the bottom; and Paleozoic rocks form the mountain slope to the southwest. The fault zone separates the Snake River Range to the southwest from the Teton Range to the north.

The Phosphoria formation crops out for several miles along the north side of Trail Creek Canyon where the steep southwest limb of an anticline or monocline forms the canyon wall. Dips are steep, and at some places the beds are overturned. Trench B, which exposes the entire phosphatic member, was dug in Talbot Canyon, a tributary to Trail Canyon, at a place where coal prospectors had uncovered some beds of phosphate.

Complete section of phosphatic shale member of Phosphoria formation in trench B, on unsurveyed land in Teton County, Wyo., about a third of a mile up Talbot Canyon and about 2 miles southeast of place where Teton Pass Highway crosses Idaho-Wyoming boundary

	Thickness (feet)	P_2O_5 (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Sample No.
Rex chert member: Chert, dull gray, brittle	4+	-------	-------	-------
Phosphatic shale member:				
Shale, pale lavender brown, nonresistant, crumpled	3.7	-------	-------	-------
Phosphate rock, dark bluish gray, hard; contains some vague pellets in a dense groundmass	2.3	29.3	64.0	B-35
Phosphate rock, bluish gray, nonresistant; some lenses and layers made up of closely packed black pellets as much as 1 mm. in diameter	.5	30.7	67.0	B-34
Shale and mudstone, light gray, sandy	1.3	-------	-------	-------
Sandstone, light gray, fine-grained, resistant	.7	-------	-------	-------
Shale, bluish gray to brown	1.1	-------	-------	-------
Chert, light to dark gray; weathers brown	.5	-------	-------	-------
Sand, white, loose; made up of coarse angular chert fragments	.8	-------	-------	-------
Phosphate rock, dark bluish gray, massive, brittle; contains some vague pellets in a dense groundmass	.4	25.2	55.0	B-28
Sand and gravel, white, loose; made up of angular chert fragments	.6	-------	-------	-------
Quartzite, dark gray, in layers ½ inch to 2 inches thick	1.5	-------	-------	-------
Sandstone, gray, thin-bedded, brittle, resistent	1.7	-------	-------	-------
Mudstone, dull gray, sandy, nonresistant	0.5	-------	-------	-------
Sandstone, pale yellowish gray, massive, resistant	1.0	-------	-------	-------
Shale, dark greenish gray, sandy	.8	-------	-------	-------
Sandstone, dull gray, resistant	.4	-------	-------	-------
Siltstone, dark gray, friable, shaly, nodular	1.9	1.4	3.1	B-20
Siltstone, dull brownish gray, concretionary, resistant, phosphatic	2.3	3.4	7.4	B-19
Siltstone, dull brownish gray, friable, phosphatic	.9	4.4	9.6	B-18
Phosphate rock, black, massive; made up of closely packed black pellets as much as 1 mm. in diameter	.7	29.0	63.3	B-17
Siltstone, dark gray, brittle, phosphatic; weathers brownish gray	1.2	3.7	8.1	B-16
Siltstone, black to gray, thin-bedded, phosphatic	2.1	3.3	7.3	B-15
Shale, dark gray to black, soft, phosphatic; with many stringers of gray to white sandstone	1.6	5.3	11.6	B-14
Shale, dark gray to brownish gray, soft, calcareous, phosphatic	.5	3.9	8.5	B-13
Phosphate rock, black, nonresistant; contains some small vague black pellets as much as 1 mm. in diameter	.5	30.7	67.0	B-12
Phosphate rock, brown to black, nonresistant, shaly	.5	27.9	60.9	B-11
Phosphate rock, dark bluish gray, silty, resistant; weathers brownish gray and forms the top of a ledge	1.7	21.6	47.2	B-10
Chert, brownish gray; forms a conspicuous ledge	2.2	-------	-------	-------
Phosphate rock, dark gray; weathers brownish gray; has one thin seam of small black pellets	.7	14.1	30.8	B-8
Chert, dark gray, brittle, resistant	.3	-------	-------	-------
Siltstone, dark brownish gray, thin-bedded, phosphatic; has thin seams of small black pellets	.3	7.8	17.0	B-6
Phosphate rock, dark gray; made up of closely packed black pellets as much as 1 mm. in diameter	.2	30.8	67.1	B-5
Chert, reddish brown, rotten, sandy	1.7	-------	-------	-------
Phosphate rock, dark gray, resistant contains many small black pellets	.3	26.9	58.7	B-3
Chert, dark gray, crumbly	.7	-------	-------	-------
Chert, dark gray, calcareous, brittle, resistant	.3	-------	-------	-------
Total phosphatic shale member	38.4			
Wells formation: Limestone and sandstone.				

Chemical analyses of samples from trench B

[F. J. Gray, analyst]

Sample No.	P_2O_5 (percent)	CaO (percent)	Fe_2O_3 (percent)	Al_2O_3 (percent)	Ignition loss (percent)	Insoluble (percent)	$Ca_3(PO_4)_2$ (B.P.L.) (percent)	Thickness (feet)
B-3	26.9	39.1	1.8	1.1	4.7	17.8	58.7	.3
B-5	30.8	45.7	.8	2.3	5.5	5.5	67.1	.2
B-6	7.8	12.5	5.0	7.8	8.7	51.9	17.0	.3
B-8	14.1	20.7	3.0	5.2	6.2	44.3	30.8	.7
B-10	21.6	34.2	1.1	2.6	8.4	22.2	47.2	1.7
B-11	27.9	40.8	2.0	2.5	8.8	9.9	60.9	.5
B-12	30.7	45.4	1.3	1.4	7.5	5.0	67.0	.5
B-13	3.9	9.6	2.8	4.8	18.0	53.5	8.5	.5
B-14	5.3	7.5	3.3	1.9	8.9	71.8	11.6	1.6
B-15	3.3	5.7	2.6	1.5	5.9	78.6	7.3	2.1
B-16	3.7	5.7	1.6	1.6	5.1	81.2	8.1	1.2
B-17	29.0	43.6	1.3	1.5	9.0	6.3	63.3	.7
B-18	4.4	25.2	1.9	2.1	32.0	19.5	9.6	.9
B-19	3.4	5.2	3.9	3.6	7.2	75.2	7.4	2.3
B-20	1.4	5.4	4.4	6.2	14.4	62.5	3.1	1.9
B-28	25.2	37.7	1.7	3.2	4.0	21.4	55.0	.4
B-34	30.7	45.3	1.2	2.2	3.7	8.4	67.0	.5
B-35	29.3	44.2	1.1	1.2	4.2	12.6	64.0	2.3

Summary of trench sections in the Teton Range

	Trench C (incomplete section of phosphatic shale member)	Trench A (incomplete section of phosphatic shale member)	Trench B (complete section of phosphatic shale member)
Thickness of section..................feet..	5.4	21.7	38.4
Number of beds of phosphate rock..........	13	4	10
Thickness of phosphate rock..........feet..	14.3	1.9	7.8
Average content of B.P.L. in the phosphate rock..........................percent..	[1]74.2	60.2	56.9
Thickness of the best bed of phosphate rock............................feet..	[1] [2]3.6	.2	[3]2.8
Content of B.P.L. in the best bed of phosphate rock..........................percent..	[1] [2]77.4	68.8	[3]64.5

[1] The B.P.L. content of these beds probably has been increased by leaching, and the apparent thickness may have been increased by soil creep.
[2] Two adjacent beds of phosphate rock represented by samples C-3 and C-4.
[3] Two adjacent beds of phosphate rock represented by samples B-34 and B-35.

RESERVES

The best deposits of phosphate in the Teton Basin area are in the Bighole Mountains, where the beds are thicker, of higher grade, and less eroded than those in the Tetons, and are less broken by faults than those in the Snake River Range. Inasmuch as the beds crop out on high mountain ridges, large parts of the deposits lie above the natural drainage level. Not enough work has been done in these mountains, however, to make possible a worthwhile estimate of available phosphate.

Overthrusts have ruined much of the phosphate rock in the northern part of the Snake River Range by destroying the continuity of high-grade beds and by mixing worthless material with the phosphate rock. The weak phosphatic beds were favored zones along which the overthrust blocks could easily move. At some places the beds were eliminated or smeared to mere streaks, and elsewhere they were piled in disorderly heaps as much as five times thicker than normal. At places where the main faults missed these beds, as in Siddoway Fork, a tributary to Elk Creek, the sequence was greatly distorted by minor faults. It is therefore impossible to predict the underground extent, thickness, or composition of the phosphate beds that have been affected by the overthrusts.

Some of the main spurs along the west flank of the Teton Range are capped with small areas of phosphatic shale and phosphate rock, and south of Game Creek the Phosphoria formation in its entire thickness crops out in a belt that extends as far as Teton Pass. Elsewhere in the range all Phosphoria strata except remnants of cherty beds that lie near the base of the formation have been eroded.

Sections of the phosphatic sequence in eight of the trenches in the Teton Basin area are shown on plate 4. The thickness, richness, and stratigraphic position of the beds of phosphate and phosphatic rock are diagrammatically represented.

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