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PHOSPHATE DEPOSITS OF THE DEER CREEK-WELLS CANYON AREA CARIBOU COUNTY, IDAHO

BY

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By CHARLES DEISS

ABSTRACT

The Deer Creek-Wells Canyon phosphate area is in the Preuss Range, 15 miles by road northeast of Georgetown and 30 miles northeast of Montpelier, Idaho. (See fig. 4.) The area, which includes approximately 18 square miles in Caribou County, southeastern Idaho, was selected for geologic study in 1944 because the rocks were not excessively faulted as far as was known, the district was one to which rail transportation could be made available, and the reserves of phosphate rock were large enough to guarantee years of mining. Objectives were to make a map of the area, determine the grade and thickness of the phosphate zones, and estimate the reserves of inferred phosphate rock.

Phosphate rock and interbedded siltstones, shales, and impure limestones constitute the phosphatic shale member of the Phosphoria formation of Permian age. The phosphatic shale member, 179 to 200 feet thick, is overlain by the Rex chert member of the Phosphoria and is underlain by the Pennsylvanian Wells formation. The phosphate rock is black to brown gray and thin-bedded; it consists of collophane oolites 0.02 to 2 millimeters in diameter embedded in a matrix of extremely fine grained collophane mixed with variable amounts of silt, clay, and calcite. Much of the rock contains ovoid and irregular collophane pisolites 3 to 7 millimeters in diameter and nodules 8 to 55 millimeters in diameter.

The rocks in the area form two large synclines separated by an anticline. The western fold is the Georgetown syncline; the eastern, less faulted, is the Webster. (See pl. 5.) The phosphatic shale member of the Phosphoria formation appears as four belts—one on each limb of the synclines—which strike N. 15° to 23° E.; it is broken by four or more thrusts and by many normal faults.

Stratigraphic sections measured in 11 trenches and analyses of 202 samples (pls. 6, 7; tables 1–9) suggest that most of the phosphate rock in the member is distributed in three zones—the lower, middle, and upper phosphate zones. The lower zone contains the thickest persistent bed of high-grade rock (70 percent or more $Ca_3(PO_4)_2$ or bone phosphate of lime). The middle zone contains only medium-grade (50 to 69 percent) and low-grade (30 to 49 percent) phosphate rock. The upper zone is the thickest of the three and contains an aggregate of more high-grade rock than the lower zone, but the high-grade rock is separated by thin beds of medium- and low-grade phosphate rock and of siltstone and shale. Isolated beds of medium- and low-grade phosphate rock occur at other horizons.

Inferred reserves of phosphate rock in the area total nearly 120,000,000 tons, of which more than 27,000,000 tons are high-grade, nearly 53,000,000 tons medium-grade, and nearly 40,000,000 tons low-grade rock. The largest deposit most accessible for mining and transportation is in the east limb of the Webster syncline, 2 miles southward from Wells Canyon. The combined upper and lower zones in this locality may contain 7,300,000 tons of high-grade and 3,650,000 tons of medium-grade rock—a total reserve of almost 11,000,000 tons of inferred phosphate rock. If the ore in the middle zone and in isolated beds outside the three zones can be mined profitably, the deposit in the south part of the east limb of the Webster syncline may possibly yield 22,000,000 tons of inferred phosphate rock above the cut-off grade of 50 percent $Ca_3(PO_4)_2$.

INTRODUCTION

LOCATION OF AREA

The Deer Creek-Wells Canyon area is in southeastern Idaho, largely in the southwestern part of Caribou County (fig. 4); it lies in secs. 19–22 and 27–34, T. 9 S., R. 45 E., and in secs. 3–10 and 15–18, T. 10 S., R. 45 E., Boise meridian (pl. 5). The region is 25 to 30 miles by motor road northeast of Montpelier and 15 miles northeast of Georgetown, Idaho (fig. 4). The map area (pl. 1) is

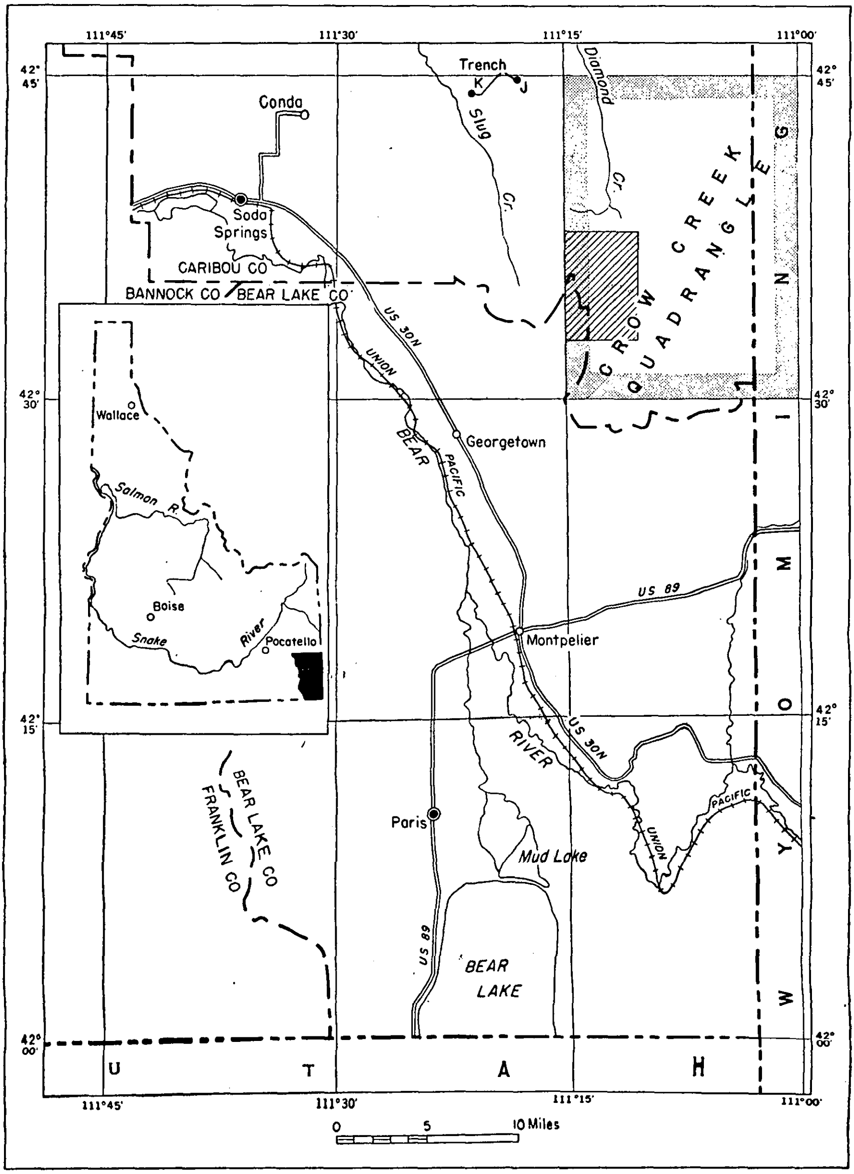

FIGURE 4.—Index map of the Deer Creek-Wells Canyon area, Caribou County, southeastern Idaho.

crossed by a dry-weather road maintained by the United States Forest Service, Department of Agriculture. The nearest railroad is the main line of the Oregon Short Line (Union Pacific system), which is 15½ miles west of the map area and half a mile west of Georgetown in Bear Lake Valley. The mapped phosphate deposits are nearly 15 miles long and are distributed in four belts. The district is covered by the published geologic and topographic maps of the Crow Creek quadrangle (Mansfield, 1927, pls. 7, 8).

PURPOSE AND SCOPE OF FIELD WORK

The objectives of the field work in the Deer Creek-Wells Canyon area were to obtain precise data bearing on the grade and thickness of the phosphate reserves, to make a reconnaissance map of the most accessible phosphate reserves in order to determine the deposits most promising for development, to trench and sample the phosphate beds in as many places as possible in the time available, and to estimate the tonnage of inferred phosphate rock in the area at the cut-off grades of 50 and 70 percent $Ca_3(PO_4)_2$ or bone phosphate of lime.

Field work in the Deer Creek-Wells Canyon district extended from July 16 to September 17, 1944. Fourteen trenches were dug, and from eleven of them 202 channel or bench samples were taken for chemical analysis (pp. 87–92). Detailed stratigraphic sections of the Phosphoria formation exposed in the trenches were measured. In addition, a reconnaissance map of nearly 15 miles of the Phosphoria formation and adjacent Wells formation was made along four lines of outcrop (pl. 5) in order to determine the dip of the beds and the position and number of faults that may affect mining operations.

ACKNOWLEDGMENTS

V. E. McKelvey, of the Geologic Survey, spent the July 16–19 period in the field to give the writer the benefit of his experience in mapping and sampling the Phosphoria formation in southeastern Idaho. E. M. Norris, superintendent, Fertilizer Department, Anaconda Copper Mining Co., Conda, Idaho, allowed the writer to study the Conda phosphate mine and made a number of useful suggestions concerning sampling and mining problems. H. A. Curtis, technical adviser, Department of the Interior, and Eugene Callaghan, of the Geological Survey, gave valuable advice in the field concerning the location of some of the trenches. G. E. Ericksen, also, assisted the writer in the field and drafted the maps and sections in this report. Professor W. R. Lowell, Montana State University, who is studying the phosphatic shale member petrographically, contributed information concerning the mineral composition of the phosphatic rocks and, with the writer, established the correlations suggested in plates 6 and 7.

STRATIGRAPHY

GENERAL STATEMENT

The phosphate-bearing rocks of southeastern Idaho occur in the lower 179 to 200 feet of the Phosphoria formation (Richards and Mansfield, 1912, pp. 683–689). The Rex chert member of the Phosphoria overlies the phosphatic shale member of the formation (pl. 5), the Rex chert and the phosphatic shale members being shown as separate cartographic units on the geologic map and structure sections (pl. 5). The Phosphoria (Permian) is underlain by the Wells formation (Pennsylvanian), which in turn is underlain by the Brazer limestone (Mississippian), the oldest formation exposed in the area. The upper, or Rex chert, member of the Phosphoria is overlain by the Woodside shale (Boutwell, 1912, pp. 439–458), which is in turn overlain by the Thaynes group (Boutwell, 1912, pp. 439–458). The Wells, Rex, Woodside, and Thaynes units are discussed and mapped in order to make clear the geologic structure of the phosphate deposits and because they may be encountered in mining operations—in tunneling, shaft sinking, or drilling.

The youngest formations in the area are unconsolidated talus, hill wash, landslides, and stream alluvium. Of Pleistocene and Recent age, these deposits are widespread, but because they are not related to the structure of the phosphate deposits they have not been mapped.

BRAZER LIMESTONE

The Brazer limestone (Richardson, 1913, p. 407) in the map area crops out only along the axis of the Snowdrift anticline (pl. 5). The Brazer formation, of Carboniferous (Mississippian) age, was not mapped by the writer; its position on the maps and in the structure sections (pl. 5) is taken from plate 7 of Mansfield's report (1927), and the following brief description of its character is taken from a section measured by Mansfield (1927, p. 63) on the north side of Wells Canyon.

The exposed part of the Brazer limestone is 1,130 feet thick; the base of the formation is covered. The exposed lower 450 feet is gray, thick-bedded, fossiliferous limestone, the overlying 200 feet of beds is covered, and the next exposed 270 feet is white quartzite capped with 30 feet of reddish shale and quartzite. A dark-gray, crinoidal limestone, 100 feet thick, rests on the quartzite member and is overlain by 14 feet of white calcareous sandstone. The upper 46 feet of the Brazer limestone in Wells Canyon consists of light-gray, thin-bedded, fossiliferous limestone capped with 20 feet of earthy limestone that contains chert, in irregular streaks, and concretions arranged parallel to the bedding.

WELLS FORMATION

The Wells formation (Richards and Mansfield, 1912, pp. 683–684, 689–693) is Carboniferous (Pennsylvanian) in age and is named after Wells Canyon, where it is about 2,500 feet thick and exhibits three lithologic facies. The lower facies, 748 feet thick, consists mostly of pure limestone in the upper 400 feet. The middle facies, 1,700 feet thick, constitutes two-thirds of the formation and is composed of alternating units, 100 to 350 feet thick, of quartzitic sandstone and limestone. The sandstones are gray, thin-bedded, and fine- to medium-grained; in the upper half of the middle facies they weather buff and reddish tan. The upper facies, 1 foot to 75 feet thick, is a white- to buff-weathering, finely arenaceous, thick-bedded limestone that contains irregular lenses and nodules of blue-white and gray chert. This limestone crops out in many places and makes a recognizable marker bed just below the Phosphoria formation.

PHOSPHORIA FORMATION

The Phosphoria formation in the area (pl. 5) consists of the basal phosphatic shale member and the overlying Rex chert member. All the phosphate beds in the Deer Creek-Wells Canyon area are in the phosphatic shale member, which is the commercially important geologic formation in the district. It is 179 feet thick in trench I (pls. 6, 7) and may be 200 feet thick in the vicinity of trenches A and B. The three separate phosphate zones (lower, middle, and upper) are within the phosphatic shale member and should not be confused with it.

PHOSPHATIC SHALE MEMBER

The phosphatic shale member consists of brown, gray, and green fissile and chunky shales interbedded with siltstones or mudstones and beds of finely to coarsely oolitic phosphate rock. Irregularly distributed throughout the member are elliptical and irregular nodules of limestone that range from half an inch to 18 inches in thickness and from 1 inch to 60 inches in long diameter. Many of the siltstones and some of the phosphate rocks are calcareous. The limestone nodules probably were precipitated by ground water after the other rocks were deposited. Most of the shales and siltstones and the limestone nodules are more or less phosphatic and are strongly fetid when broken. Blebs and irregular small masses of bituminous matter occur in some of the phosphate beds. Only one persistent limestone bed is reported from the phosphatic shale member. This bed, known as the "Cap lime" in southeastern Idaho and northeastern Utah, is 19 inches thick, and within the map area (pl. 5) is present only in trench I (pl. 6). The soft phosphatic shale member weathers more rapidly than either the Rex chert member or the Wells formation; consequently, the phosphatic shale member is covered with soil, hill wash, landslides, alluvium, or talus from the Rex chert member or the Wells formation throughout most of the district.

Detailed lithologic descriptions of each rock unit in the phosphatic shale member of the Phosphoria formation are given in the following complete stratigraphic section, measured in trench I from 6,980 to 7,050 feet in altitude (pl. 5). Trench I is on the north side of Deer Creek Valley on the ridge in the middle of the S½SW¼ sec. 34, T. 9 S., R. 45 E. Complete analyses for each sample in this section are given in table 9.

Stratigraphic section of phosphatic shale member, Phosphoria formation, trench I, Deer Creek-Wells Canyon area, Idaho

	Ft.	in.
Rex chert.		
Phosphatic shale member:		
74. Phosphate rock: One bed, black, finely to medium coarsely oolitic, nodular, calcareous, and fossiliferous. Contains *Omphalotrochus* sp. and a large, finely costate productid. *Sample 57*	0	4
73. Shale, brown and brown-gray, fissile and platy-bedded, calcareous, finely micaceous, and very finely arenaceous	3	7
72. Shale, mudstone, and limestone:[1] Alternating 11- to 15-inch units of calcareous mudstone, which grades laterally into argillaceous limestone, and interbedded argillaceous tan and gray shales. Much spheroidal weathering	4	9
71. Shale and limestone, tan brown in lower part, gray in upper third. A few intercalated 2- to 4-inch limestone beds. Spheroidal weathering obscures bedding	6	8
70. Limestone or mudstone: Buff-gray, hard, argillaceous limestone or very calcareous mudstone. Lower bed 12 inches, middle bed 4 inches, upper bed 12 inches thick	2	4
69. Siltstone or shale, buff and tan, silty, soft but tough, chunky-bedded. Upper 26 inches more massive and very thick bedded. A 1- to 3-inch bed (lens?) of limestone 27 inches below top and a 4-inch zone of oolitic phosphatic shale approximately 20 inches above base of unit	5	2
68. Phosphate rock, black, medium coarsely oolitic, brittle. Contains many spherical and ovoid, finely and medium coarsely oolitic, phosphatic nodules 0.3 inch to 1.5 inches in long diameter. Some nodules concentrically banded. *Sample 56*	0	10

[1] Petrographic study by W. R. Lowell indicates that the limestones in the phosphatic shale member of the Phosphoria formation are strongly silty or argillaceous. Probably none of the rocks called "limestone" in this section and in the columnar sections (pls. 6, 7) contain as much as 55 percent calcite.

Stratigraphic section of phosphatic shale member, Phosphoria formation, trench I, Deer Creek-Wells Canyon area, Idaho—Continued

Phosphatic shale member—Continued	*Ft.*	*in.*
67. Phosphate rock and shale: Lower 7 inches very thick bedded, black-gray, coarsely oolitic phosphate rock that dries light gray. Upper 9 inches thin-bedded, platy, medium coarsely and coarsely oolitic phosphate rock and a few thin partings of phosphatic shale. Upper 1.5 to 2 inches fissile phosphate rock. *Sample 55*	1	4
66. Siltstone, pale buff-tan, earthy, phosphatic, thick-bedded, soft but massive. Thin-bedded in lower 2 to 2½ inches. *Sample 54*	0	10
65. Limestone, blue- to dark-gray, finely and medium coarsely crystalline, hard, thick-bedded, fossiliferous. Contains many large pelecypods and some brachiopods	0	11
64. Phosphate rock and shale: Black and dark-gray, medium to very coarsely oolitic, hard phosphate rock in beds 0.6 inch to 2.5 inches thick alternating with brown-gray, hard, chunky to platy-bedded shale in 1- to 3-inch units. A 5-inch zone (not sampled) of black-gray, hard, finely crystalline, elliptical nodules of limestone 4 inches above base of unit. Much dirt between beds. Oolites as much as 1.5 millimeters in diameter and, at top of unit, nodules as much as 20 millimeters in diameter. *Sample 53*	2	4
63. Phosphate rock and shale: Lower 9 inches black, hard, finely oolitic, brittle, irregularly bedded phosphate rock overlain by 8 inches of coarsely oolitic, thick-bedded phosphate rock. Next a 0.7- to 1-inch bed of tan shale and at top a 2-inch bed of coarsely oolitic phosphate rock that weathers black gray. *Sample 52*	1	8
62. Shale and phosphate rock: Brown, argillaceous, phosphatic, chunky-bedded shale and interbedded phosphate rock 0.2 to 0.8 inch thick. Upper 6 inches black-gray, hard, finely oolitic, slightly nodular, impure phosphate rock. Buff-tan siltstone occurs from 7 to 12 inches below top. *Sample 51*	1	9
61. Phosphate rock, black, thick-bedded, coarsely oolitic, in beds 1 inch to 4 inches thick. Weathers pale gray. Oolites 0.1 millimeter to 2 millimeters in diameter; some phosphatic nodules as much as 5 millimeters in diameter. *Sample 50*	1	1

Stratigraphic section of phosphatic shale member, Phosphoria formation, trench I, Deer Creek-Wells Canyon area, Idaho—Continued

Phosphatic shale member—Continued	*Ft.*	*in.*
60. Phosphate rock, bluish-black, finely oolitic, hard, brittle, shiny on fresh fracture, in irregular beds 0.1 to 0.6 inch thick, averaging 0.3 inch. Stained rusty brown on many joint faces. ***Sample 49***	2	0
59. Phosphate rock, limestone nodules, and shale: Black, platy-bedded, medium coarsely oolitic, shaly phosphate rock in beds 0.1 to 0.6 inch thick. Some shale partings. Within unit, limestone concretions as much as 25 inches thick and 32 to 34 inches long. Limestone seemingly has thrust beds of shale and phosphate rock apart till now they bend smoothly around concretions in prominent folds. ***Sample 48***	2	6
58. Phosphate rock, brown and brown-black, finely to slightly and medium coarsely oolitic, shaly, in beds 0.05 to 0.4 inch thick. Banded brown and black. Composition fairly uniform throughout. ***Sample 47***	3	6
57. Shale, phosphate rock, and limestone: Brown- and brown black-banded, soft, finely oolitic shale in 0.01- to 0.3-inch beds. Two beds in middle part are 1 inch and 1.7 inches thick; some contain a few medium-sized oolites. Four inches above base, zone of 7.5-inch elliptical nodules of limestone; 30 inches above base, 3- to 3.5-inch zone of nodular limestone (neither sampled). Upper half of unit shaly phosphate rock. ***Sample 46***	3	9
56. Siltstone and shale: Dull brown-gray, slightly calcareous, earthy, chunky-bedded siltstone in lower 14 inches, overlain by 5 to 6 inches of gray, siliceous, tough shale. Upper 10 inches brown, fissile, chunky shale. ***Sample 45***	2	6
55. Shale and phosphate rock: Brown, platy-bedded shale like that in upper three-fourths of unit 54 but slightly more phosphatic. At base, 1.2- to 1.5-inch bed of black-brown, nodular, very finely oolitic phosphate rock. Nodules subangular and 0.5 to 1 inch in diameter. ***Sample 44***	1	9

Stratigraphic section of phosphatic shale member, Phosphoria formation, trench I, Deer Creek-Wells Canyon area, Idaho—Continued

Phosphatic shale member—Continued	*Ft.*	*in.*
54. Shale, brown, fissile in lower 6 to 7 inches, chunky to platy in upper part. Limestone nodule 10 inches in diameter 13 inches above base (not sampled). Upper three-fourths of unit contains some finely oolitic phosphatic shale in two 4-inch units. ***Sample 43***	4	3
53. Phosphate rock, bluish black-gray and brown-gray, finely oolitic, extremely nodular, and irregularly bedded. Nodules 1 inch to 1.6 inches long, irregular in shape, and hard. Rock unconsolidated between nodules. ***Sample 42***	0	11
52. Shale and siltstone: Brown-gray, finely micaceous, phosphatic, fissile shale in lower third; massive, thick-bedded, spheroidally weathered siltstone in upper two-thirds. ***Sample 41***	1	5
51. Phosphate rock, brown, fissile, chunky, very finely oolitic. Contains thin stringerlike lenses of medium-sized oolites. ***Sample 40***	0	6
50. Shale, greenish-gray, phosphatic. Upper 6 to 8 inches brown, lumpy-bedded, finely micaceous. Upper 1 inch to 3 inches very finely oolitic in some beds. Occasional 0.5- to 1-inch lenses of limestone. ***Sample 39***	2	5
49. Limestone: Two beds, blue-gray, finely crystalline, hard, slightly silty. Scattered phosphatic oolites	1	0
48. Shale and siltstone: Gray-brown, micaceous, finely arenaceous, fissile shale in lower 9 inches; brown-gray, hard, thick-bedded siltstone in upper 8 inches. Siltstone slightly calcareous in upper 2 to 4 inches. Few *Chonetes*(?) sp. ***Sample 38***	1	4
47. Phosphate rock and shale: Lower half thin, alternating beds of medium coarsely oolitic phosphate rock and finely oolitic shale. One- to two-inch bed of limestone in middle. Upper half black, coarsely oolitic phosphate rock in beds 0.2 inch to 2.5 inches thick. Upper 1 inch of unit fissile. ***Sample 37***	1	10
46. Shale, brown-gray, fissile, and in part chunky-bedded. Finely micaceous in lower part, finely oolitic in upper. Grades uniformly upward from micaceous shale into browner phosphatic shale. ***Sample 36***	2	3

Stratigraphic section of phosphatic shale member, Phosphoria formation, trench I, Deer Creek-Wells Canyon area, Idaho—Continued

Phosphatic shale member—Continued	Ft.	in.
45. Shale and phosphate rock: Interbedded brown, finely oolitic shale in beds 0.01 to 0.4 inch thick and lenses of medium- and medium coarse-grained oolitic phosphate rock 0.05 to 0.3 inch thick. All shale and phosphate rock intimately interbedded, but phosphate rock more abundant in upper half of unit. ***Sample 35***	1	6
44. Shale, gray-brown, micaceous, slightly phosphatic, strongly weathered spheroidally in lower 6 to 7 inches. Upper 25 to 26 inches dark-brown, micaceous, soft, uniformly bedded, fissile to slightly chunky shale that becomes very finely oolitic in upper 5 to 8 inches. ***Sample 34***	2	9
43. Phosphate rock and shale: Three 2- to 3-inch units of coarsely oolitic, soft, lenticular-bedded phosphate rock and three interbedded 1.5- to 5-inch units of brown and black, finely to medium coarsely oolitic shale. Middle 4 to 5 inches of entire unit contains many 0.5- to 1.1-inch nodules of gray and black, finely to medium coarsely oolitic phosphate rock. ***Sample 33***	1	6
42. Phosphate rock and shale: Lower 5 inches black and brown, nodular, phosphatic shale composed of very fine oolites with a few scattered large ones. Next 4 inches chunky phosphatic shale. Upper 6 inches coarsely oolitic, soft phosphate rock in thick, irregular beds and some interbedded wavy-banded, finely oolitic shale. ***Sample 32***	1	3
41. Shale or siltstone, dull-gray, micaceous, siliceous, slightly phosphatic, strongly weathered spheroidally. Some centers of concentric weathering hard and dense. Overlying 14 to 15 inches more even bedded and less micaceous; upper surface knobby. Upper 4 to 6 inches brown-gray, finely oolitic and argillaceous shale (not sampled). Contains *Nucula*(?) sp. and *Lingulella*(?) sp. ***Sample 31***	7	4
40. Shale and phosphate nodules: Black, siliceous, fine-grained, very hard, extremely nodular bedded, phosphatic shale and hard, rounded, black phosphate nodules 0.3 inch to 2.5 inches in diameter. All stained bright orange, yellow, or tan. ***Sample 30***	1	3

Stratigraphic section of phosphatic shale member, Phosphoria formation, trench I, Deer Creek-Wells Canyon area, Idaho—Continued

Phosphatic shale member—Continued	*Ft.*	*in.*
39. Shale and phosphate rock: Bright-brown and black, coarsely and medium coarsely oolitic, thick-bedded, slightly chunky- and concretionary-bedded phosphatic shale. Contains much orange-red limonite(?) stain and partings in upper three-fourths. Lower 2 inches coarsely oolitic, black-brown phosphate rock. ***Sample 29***	0	8
38. Shale and limestone: Black, fissile, intensely sheared phosphatic shale. Very finely oolitic in upper half, to medium coarsely oolitic in lower half. Contains a 1- to 2-inch zone of nodular limestone 5 inches below top. ***Sample 28***	1	5
37. Limestone, argillaceous, lenticular. Pinches out in walls of trench	0	4
36. Shale, limestone, and phosphate rock: Brown, finely oolitic, banded, slightly calcareous shale and four to five lenticular beds of argillaceous limestone 0.4 to 1 inch thick. Lower 4 to 6 inches soft, black, medium coarsely oolitic phosphate rock. ***Sample 27***	3	4
35. Shale, phosphate rock, and limestone: Lower 15 to 16 inches black-brown and black, finely oolitic shale interbedded in upper third with 0.05- to 0.3-inch beds of medium coarsely oolitic, shaly phosphate rock. Upper 9 inches black, medium coarsely and in part coarsely oolitic, platy-bedded phosphate rock with many partings of phosphatic shale. Dark-gray, nodular limestone from 9 to 10.5 inches below top. ***Sample 26***	2	1
34. Shale and limestone: Black-brown and black-gray, finely micaceous, calcareous, chunky- to smooth-bedded phosphatic shale, many beds with stringers of finely oolitic shale. Several 0.2- to 3.5-inch zones of blue-gray, finely crystalline to argillaceous limestone in flat, elliptical nodules intercalated 8 to 15 inches apart in shale. Many joint planes covered with white calcite 1.2 to 20 millimeters thick. ***Sample 25***	3	8
33. Siltstone and limestone: Argillaceous, dull-gray, finely crystalline, thick-bedded limestone, grading from calcareous siltstone in lower fourth to argillaceous limestone in upper part. Similar to unit 30	2	11
32. Shale, brown, slightly phosphatic, very calcareous. Contains poorly preserved *Grammysia* sp. and *Chonetes* sp. ***Sample 24***	1	10

Stratigraphic section of phosphatic shale member, Phosphoria formation, trench I, Deer Creek-Wells Canyon area, Idaho—Continued

Phosphatic shale member—Continued	Ft.	in.
31. Shale, green-black, fissile, phosphatic, soft but somewhat tough. Some beds slightly oolitic. Middle 2 inches contains secondary white calcite on bedding and joint faces. ***Sample 23***	2	1
30. Limestone and siltstone: Dull-gray, finely crystalline, thick-bedded, fossiliferous limestone that grades down into calcareous siltstone. In upper 6 inches and 14 to 20 inches below top many individuals of *Nucula* sp., *Chonetes* sp., *Ambocoelia arcuata*(?), and *Lingula*(?) sp. One individual of *Orbiculoidea* sp. found in upper 2 inches	2	3
29. Shale, dull green-gray, argillaceous, carbonaceous, finely micaceous. Some beds very finely oolitic. Grades up into pale gray-brown siltstone. ***Sample 22***	1	3
28. Limestone, pale brown-gray and pale tan-brown, fetid, argillaceous, thick-bedded, earthy, soft. Contains *Chonetes* sp. 5 to 7 inches above base of unit. Upper 30 inches more calcareous and harder, composed of only 3 or 4 thick beds. Lower bed 17 inches thick. ***Sample 21***	4	4
27. Shale or siltstone, greenish-gray and brown-gray, slightly phosphatic, finely micaceous, platy-bedded, stained tan on some joint and bedding faces, slightly weathered spheroidally in lower half. Upper 8 inches hard and in beds as much as 2 inches thick. Upper bed tan brown, earthy. ***Sample 20***	4	3
26. Limestone: One lenticular bed, steel-gray, finely crystalline, hard	0	6
25. Shale: Lower 27 inches gray and black gray, very slightly phosphatic, finely micaceous, hard, spheroidally weathered into concentrically banded, hard, ovoid nodules as much as 15 inches in diameter and 6 inches thick. Upper 36 inches irregularly banded brown and gray, finely micaceous, tough, weathered spheroidally 16 to 28 inches below top. ***Sample 19***	5	3
24. Shale, like that in unit 22. Some beds irregularly weathered spheroidally. ***Sample 18***	4	6
23. Limestone, black-gray, finely crystalline, hard, dense. Weathered zone, 2 to 6 inches thick, of brown-gray, calcareous, thinly and concentrically bedded shale	1	2

Stratigraphic section of phosphatic shale member, Phosphoria formation, trench I, Deer Creek-Wells Canyon area, Idaho—Continued

Phosphatic shale member—Continued	Ft.	in.
22. Shale and limestone: Dark greenish-gray, argillaceous, phosphatic shale. Many streaks or brown beds calcareous. Irregularly interbedded are lenses of blue-gray, finely crystalline limestone 1 inch to 1.2 inches thick and 4 to 19 inches long. Upper 2 inches of unit brown, fissile to platy calcareous shale. ***Sample 17***	3	5
21. Limestone nodules, blue-gray, flatly elliptical, 1 inch to 14 inches thick	1	2
20. Shale and limestone: Brown and dark-gray, hard, finely micaceous shale. Many beds calcareous; upper 21 inches more micaceous, calcareous, phosphatic, and weathered spheroidally. Contains many flat, lenticular beds of tan, silty limestone as much as 0.7 inch thick. ***Sample 16***	4	4
19. Limestone: One nodular bed, dark blue-gray, finely crystalline, fetid. Weathers brown and earthy	1	
18. Shale, black-gray and brown, argillacous, finely micaceous, phosphatic. Interbedded in upper third with tan, calcareous, earthy beds 0.1 to 0.4 inch thick. ***Sample 15***	2	5
17. Shaly phosphate rock, lumpy and poorly bedded, mashed, nodular. Nodules 0.3 inch to 1.7 inches in diameter. Upper 3 to 5 inches strongly calcareous (contains secondary amorphous calcite). ***Sample 14***	1	3
16. Phosphate rock and shale: Black and black-brown, fissile to thick-bedded (as much as 1.5 inches), finely to very coarsely oolitic phosphate rock. Contains shale partings 0.01 to 0.2 inch thick. Increasingly silty upward in section. Oolites 0.1 millimeter to 1.25 millimeters in diameter. ***Sample 13***	1	6
15. Phosphate rock and shale: Lower 3 inches bluish-black, lumpy, finely and medium coarsely oolitic phosphate rock overlain by 10 to 11 inches of coarsely oolitic, soft, thick-bedded, pure phosphate rock. Upper 20 inches interbedded, black, coarsely oolitic phosphate rock in 0.2- to 1.9-inch beds and irregular beds of brown and black-brown, finely and medium coarsely oolitic phosphatic shale. Most shale beds in middle third of unit. Oolites 0.15 millimeter to 3 millimeters in diameter. ***Sample 12***	2	10

Stratigraphic section of phosphatic shale member, Phosphoria formation, trench I, Deer Creek-Wells Canyon area, Idaho—Continued

Phosphatic shale member—Continued	*Ft.*	*in.*
14. Phosphate rock and shale: Lower 10 inches black and in part brown-streaked, finely and medium coarsely oolitic shale that is slickensided across many beds, overlain by 5 inches of black, soft, coarsely oolitic phosphate rock. Next 7 to 8 inches black and brown, finely and medium coarsely oolitic shale interbedded with medium-grained oolitic lenses of phosphate rock that contains many 0.4- to 0.7-inch nodules. Upper 1 inch brown shale. ***Sample 11***	1	11
13. Shale and siltstone: Lower 19 to 20 inches brownish-gray, micaceous, phosphatic shale like upper half of unit 12 but more finely micaceous and strongly weathered spheroidally. Upper 17 to 18 inches dark green-gray and brown, thick-bedded, very calcareous siltstone that contains large oolites. Upper surface flaggy. Occasional small individual of *Nucula* sp. ***Sample 10***	3	1
12. Shale and mudstone: Lower 3 to 4 inches brown and black-gray, irregularly mottled, hard, tough, slightly phosphatic and calcareous mudstone. Upper 29 to 30 inches dark gray-brown and black greenish-gray, fissile, massive, finely oolitic and micaceous, tough shale that is slightly grayer and more micaceous upward in section. ***Sample 9***	2	9
11. Siltstone and limestone: Drab brown-gray calcareous siltstone or silty limestone in two beds: lower, 23 to 24 inches; upper, 6 inches, grading up into dark green-gray siltstone. Beds cut by 0.5- to 1-millimeter vein of white secondary calcite. Limestone weathers to siltstone	2	6
10. Phosphate rock and shale, like that in unit 9 but faint bluish black to black gray. Upper third harder and thicker-bedded (0.4 inch to 2 inches); contains scattered blebs of black, fine-grained collophane. Many beds appear finely and some medium finely oolitic. Oolites 0.05 to 1.5 millimeters in diameter. ***Sample 8***	2	8

Stratigraphic section of phosphatic shale member, Phosphoria formation, trench I, Deer Creek-Wells Canyon area, Idaho—Continued

	Ft.	in.
Phosphatic shale member—Continued		
9. Shale, phosphate rock, and limestone: Brown-gray, finely oolitic, micaceous, phosphatic shale. In lower third of shale is horizon of large limestone nodules 4 to 6 inches thick and 18 to 24 inches in diameter. Limestone drab brown gray, finely crystalline, silty, phosphatic, showing shale partly replaced by calcite. Lower 2 inches chocolate-brown siltstone. Upper 2 to 3 inches contains rounded nodules of fine and medium-sized black oolites. Many beds of shaly phosphate rock contain stringers of fine and medium-sized oolites. *Sample 7*	3	6
8. Phosphate rock and shale: Black-gray, fissile, hard, siliceous(?) phosphate rock. Contains 0.02- to 0.05-inch stringers or lenticular layers of fine oolites. Lower 15 inches brownish dark-gray shale. Zone of argillaceous limestone concretions 10 to 12 inches in long diameter 15 to 19 inches above base. Overlying 35 inches platy-bedded, finely micaceous, massive phosphate rock in beds 0.1 inch to 1.4 inches thick. Upper 36 inches slightly fissile to thinly platy shale. *Sample 6*	7	7
7. Limestone and shale: Lower 14 inches one bed dull-gray, medium finely and finely crystalline and black-gray, finely crystalline limestone, overlain by 1 inch to 2.5 inches of black-gray shale. Next 3 to 4 inches black, hard, argillaceous limestone, overlain by 4 to 4.5 inches greenish black-gray shale. Upper 11 to 12 inches one lenticular bed similar to lower 14-inch bed	2	11
6. Shale and limestone, dark greenish-gray. Thin- and platy-bedded in upper 29 inches; tough, brittle, fissile, in beds 0.1 to 0.5 inch thick in upper 2 inches; thicker-bedded in middle, where shale is slightly weathered spheroidally. Lower 6 inches black-green and brown-gray, very hard, argillaceous limestone that contains black, irregularly shaped, 0.1- to 0.3-inch phosphatic nodules. Locally this 6-inch unit grades into gray argillaceous limestone. *Sample 5*	3	0

Stratigraphic section of phosphatic shale member, Phosphoria formation, trench I, Deer Creek-Wells Canyon area, Idaho—Continued

Phosphatic shale member—Continued	*Ft.*	*in.*
5. Limestone ("Cap lime"), lead-gray altering to brown-gray, finely crystalline, hard, probably argillaceous, fetid, phosphatic, thick-bedded (lower, 4 to 4.5 inches; upper, 14 to 15 inches), very fossiliferous. Contains collophane oolites as much as 2 millimeters in diameter and pisolites as much as 10 millimeters in diameter	1	7
4. Phosphate rock and shale: Lower 1 inch to 1.3 inches black, medium coarsely to coarsely oolitic, phosphate rock in 0.1- to 0.2-inch beds. Next 2.7 inches dense, hard, siliceous, finely oolitic phosphate rock in two beds. Overlying 4 inches soft, coarsely oolitic and finely pisolitic, chunky-bedded phosphate rock. Upper 1.5 to 1.7 inches brown and black-gray, mottled, finely micaceous, slightly fissile, phosphatic shale. ***Sample 4***	0	10
3. Phosphate rock: Black, medium coarsely and coarsely oolitic, in beds 0.1 inch to 1.5 inches thick, averaging 0.3 inch. Lower 3 to 4 inches slightly fissile and wavy-bedded. Some thin beds finely and medium finely oolitic. Oolites 0.15 millimeter to 1.5 millimeters in diameter, averaging 0.7 millimeter. ***Sample 3***	3	3
2. Phosphate rock, black, generally thick-bedded to medium coarsely oolitic. Oolites 0.2 to 1 millimeter in diameter, averaging 0.5 millimeter. Beds average 0.5 inch in thickness in lower 2 inches and as much as 6 inches in middle and upper parts. Unit is basal part of lower phosphate zone. ***Sample 2***	1	6
1. Shale and phosphate rock: Lower 0.9 inch to 1.5 inches chocolate-brown, black-streaked, argillaceous shale and irregular areas of fine oolites. Middle 3 to 4 inches black and brown, slightly argillaceous, finely oolitic, phosphatic shale. Upper 1.5 to 2.5 inches black, medium and finely oolitic phosphate rock. This unit lies on tan-brown mudstone that is only 3 to 5 inches thick and in turn rests on silty limestone that is base of Phosphoria formation here. ***Sample 1***		7
Total thickness of phosphatic shale member	178	8

Wells formation.

REX CHERT MEMBER

In contrast to the lower and thinner phosphatic shale member, the Rex chert member of the Phosphoria formation ranges from 240 to 450 feet in thickness, consists of three lithologic units, and generally is well exposed. The basal unit, 25 to 35 feet thick, consists of interbedded siliceous limestone, shale, and smooth-bedded chert in beds 1 inch to 10 inches thick. This unit rests on the upper 4- to 8.5-inch phosphate bed of the phosphatic shale member in trenches A, B, G, H, and I (pl. 7). The middle unit of the Rex chert member is composed of 30 to 50 feet of massive, thick- and irregular-bedded, reddish-tan chert that forms prominent ledges. Talus and float of this kind of chert generally cover the lower unit of the Rex and the upper part of the phosphatic shale member. The upper 175 to 350 feet of the Rex chert is composed of tan and dark-gray cherty shales that break down to small angular fragments. Some of the shale in the upper part of the Rex chert is similar to that in the overlying Woodside shale. The Woodside-Rex contact, therefore, is difficult to determine in most localities. The thickness of the Rex chert was not measured; the thicknesses given for the member are taken from Mansfield (1927, p. 78) and from computations made from the geologic map (pl. 5).

WOODSIDE SHALE

The Woodside shale, Lower Triassic in age, is 1,000 or more feet thick and rests on the Rex chert member of the Phosphoria formation. It was not mapped by the writer except in part of the Georgetown syncline (pl. 5). The following brief description of the Woodside shale in southeastern Idaho is given by Mansfield (1927, p. 86):

> * * * the formation as a whole is characterized by olive-drab platy shales, with alternating thin beds of brownish-gray limestones that have locally a faint purplish tint. The shales are siliceous and calcareous, so that they are hard and ring under the hammer. They weather into rusty brown, yellowish, or even black fragments that on breaking show the characteristic olive-drab color, and they commonly contain dendrites. The limestones on weathering preserve the purplish-gray or brownish-gray color and assume a sort of velvety surface.

The lower part of the Woodside in the map area is maroon and green-tan, brittle, siliceous shale.

THAYNES GROUP

Rocks of the Thaynes group (Triassic) occur in the Deer Creek-Wells Canyon area only as isolated outcrops in the Georgetown syncline (pl. 5) and were not mapped by the writer. The position of the Thaynes group on the map and in the structure sections (pl. 5) was adapted from Mansfield's map (1927, pl. 7) of the Crow Creek quadrangle. The following description of the Thaynes group in southeastern Idaho also is taken from Mansfield (1927, p. 88):

The lithology of the Thaynes is similar to that of the Woodside in many respects, but some differences should be noted. The more shaly parts of the group have in general the same olive-drab color and weathering features that are noted in the beds of the Woodside, but locally * * * they are lighter colored and more sandy. Elsewhere for almost 200 feet above the base, the rocks are more clayey and have a well-defined grayish color that differs from the yellowish and greenish tints of the Woodside. This feature is helpful as an indicator where the *Meekoceras* zone is not well developed. The middle portion of the Thaynes contains at many places thin, platy beds of sandy and calcareous shale, in which the individual plates are large and smooth and might almost be used for roofing material.

The limestones are more prominent in the Thaynes than in the Woodside. They form ledges that in many places are conspicuous and make rougher slopes than those developed on the Woodside. The limestones contain much clay and sand and turn dark on weathering, so that they then resemble dark-brownish sandstones except along fresh fractures.

UNCONSOLIDATED SEDIMENTS

The youngest rocks in the map area are unconsolidated soils, hill wash, landslides, talus, and alluvium. These unconsolidated sediments probably are both Pleistocene and Recent in age. Because much of the bedrock is covered with such sediments, an accurate areal geologic map could not be made in the time available. It is particularly unfortunate that the unconsolidated materials cover the phosphatic shale member throughout the map area and that this overburden prevents uniform spacing of trenches for sampling the phosphate deposits and thereby prevents the obtaining of reliable information concerning the uniformity of thickness and grade.

GEOLOGIC STRUCTURE

GENERAL STATEMENT

The rocks in the area (pl. 5) form three large folds. The troughlike western and eastern folds are referred to as the Georgetown and Webster synclines. Between the two synclines the rocks are folded into an arch called the Snowdrift anticline. The formations on the sides or limbs of these major folds are secondarily flexed and are broken locally by thrust and normal faults (pl. 5). Although numerous faults are indicated on the map and structure sections, there are doubtless many other faults that may affect the phosphate beds but are concealed by unconsolidated sediments. If the Bannock overthrust (Richards and Mansfield, 1912) is present in the area, it probably is below all the other structures and therefore would not affect mining.

FOLDS

GEORGETOWN SYNCLINE

The Georgetown syncline, 40 miles long, has an estimated northward pitch of 200 feet to the mile, slightly less than 4 percent (Mansfield, 1927, p. 143). Within the map area, the Georgetown syncline is a complex synclinorium composed of minor folds on the east limb and of overturned isoclinal folds on the west limb (pl. 5, secs. *A–F*). The synclinorium also is overturned to the east and is broken by several thrust faults and many normal faults.

The geologic structure is economically significant because the phosphate beds and the other soft rocks in the phosphatic shale member were mashed and broken in many places between the massive competent chert and limestone of the Rex and Wells units. The structure sections (pl. 5) and map (pl. 5) probably do not show forcefully enough the amount and intensity of folding to which the rocks in the Georgetown syncline were subjected. Unmashed or unbroken blocks of phosphate rock probably are not present on the west limb between Deer Creek Mountain and the southern end of the Deer Creek-Wells Canyon area (pl. 5). The east limb dips more gently, is less broken by faults, and is more favorable for further exploration than any part of the west limb. Between the fault in the South Fork Deer Creek and the fault in Deer Creek, the rocks appear less disturbed than in any other part of the Georgetown syncline (pl. 5).

SNOWDRIFT ANTICLINE

Between the Georgetown and Webster synclines (pl. 5) is the Snowdrift anticline, a tightly folded arch that is slightly overturned eastward. The oldest rocks exposed in the area crop out along the axis of this fold. The Snowdrift anticline is known to be 55 miles in length (Mansfield, 1927, p. 141), although only 5 miles of it lies within the map area (pl. 5). The limbs of the Snowdrift anticline are the east and west limbs of the Georgetown and Webster synclines, respectively (pl. 5, secs. *E–E′*, *F–F′*).

WEBSTER SYNCLINE

The eastern part of the map area contains another large fold known as the Webster syncline (Mansfield, 1927, pp. 139–140). It is relatively broad and open and therefore unlike the Georgetown syncline, in which the phosphate beds are either deeply buried or broken and mashed. The rocks on the west limb of the Webster syncline dip much more steeply than those on the east limb but are not overturned or much broken (pl. 5, secs. *E–E′* to *J–J′*). The Phosphoria formation in the syncline has been almost completely cut away by erosion in

Wells Canyon. The phosphatic shale member and the upper part of the Wells formation on the west limb of the syncline are much covered with hill wash and landslides, and the phosphatic shale member may be thinner and more broken by faults than is indicated on plate 5. The east limb dips gently toward the west and is broken by several transverse normal faults. Mansfield (1927, p. 140) states that the syncline pitches northward at the rate of 350 feet per mile, but south of Wells Canyon it seems to pitch slightly southward. The Webster syncline from Wells Canyon southward for nearly 2 miles is probably the most promising part of the area for intensive prospecting and sampling with a view to economic development.

Springs emerge in and south of Wells Canyon at the contact of the Rex chert and phosphatic shale members, the latter being the aquifer. The water is caught on the west limb of the syncline at altitudes as high as 8,200 feet on the east side of Snowdrift Mountain, where the phosphatic shale member crops out nearly 1,000 feet higher than it does on the east limb. The springs indicate that the phosphatic shale member is saturated below the drainage level in the canyons (average altitude, 7,250 feet), and the possibility of excessive water in a mine in this part of the Webster syncline should be considered before the deposit is exploited.

FAULTS

GENERAL DISCUSSION

Two kinds of faults, thrust and normal, break the rocks in the limbs of the folds and partly determine the position of the phosphate rock and its accessibility for mining. The thrusts were formed when the rocks were being folded and are nearly parallel to the trend of the folds. The normal faults formed much later, when the compressive stresses subsided, and are either oblique or perpendicular to the trend of the folds. Both types are significant economically because they may cut out, thin, or displace the phosphate rocks.

In the Conda mine, 7 miles northeast of Soda Springs, Idaho (fig. 4), small faults with displacements of only 5 to 10 feet increase the costs of mining to a serious extent and reduce the grade of the phosphate rock within the fault zone; also, numerous small faults occur on each side of large faults throughout a zone 50 to 100 feet wide. Because much ore is lost in such fault zones, it is very important in mining phosphate rock to ascertain the geologic structure in advance.

The phosphate beds generally do not exhibit breccia zones, but the limestone in the Wells formation and, in places, the Rex chert member of the Phosphoria formation is slightly brecciated. The three or four thrusts and the many normal faults that were mapped (pl. 5) were recognized largely in the exposed beds of the competent Rex chert or the Wells formation limestone. The phosphatic shale member of the Phosphoria formation is mostly covered by unconsolidated sediments. As it is composed of weak shales that were unable to carry the stresses of mountain building, more faults probably occur in the phosphatic shale member than in the stronger rocks above and below it.

THRUST FAULTS

The rocks in the Georgetown syncline are broken by at least four thrusts, two on the east limb and two on the west limb. The thrusts on the east limb dip east, and those on the west limb dip west. No thrust faults were recognized in the Webster syncline.

On the east limb of the Georgetown syncline, from a quarter of a mile to more than half a mile south of the South Fork Deer Creek (pl. 5), the upper limestone of the Wells formation is thrust westward upon the Rex chert member of the Phosphoria formation. The fault cuts out the phosphatic shale member. Approximately a mile north of Black Dugway, as the road cut in the Phosphoria formation at the foot of the hill in Deer Creek Canyon is called locally, the rocks are cut by another eastward-dipping thrust, along which sandstones of the upper middle part of the Wells formation were thrust westward against the Rex chert and phosphatic shale members of the Phosphoria and the upper limestone of the Wells.

Extending along the east side of Deer Creek Mountain and from there southwestward across the main divide and into an unnamed gulch is a pair of branching, westward-dipping thrusts (pl. 5, sec. *E–E′*). The relationships of the formations in this area are obscured by hill wash and talus. Along the east fault the phosphatic shale member of the Phosphoria was thrust against the Rex chert member, which was partly cut out. Along the west fault the Wells formation was thrust against the phosphatic shale member (pl. 5). Because these are high-angle thrusts and because they are in the overturned limb of the syncline, the fault planes are almost parallel with the bedding. Whether the Rex chert and phosphatic shale members are thinned by faulting or by squeezing in the limbs of the folds is impossible to determine because the beds are so intensely folded.

NORMAL FAULTS

Normal faults are much more numerous, but generally smaller, than thrust faults in the Deer Creek-Wells Canyon area. The trend of the normal faults is nearly at right angles to the strike of the beds (pl. 5), but four conspicuous exceptions to this trend may be noted: one on the west limb of the Webster syncline and three on the east limb of the Georgetown syncline.

The west limb of the Georgetown syncline, south of Deer Creek Mountain, probably contains more small normal faults than any other part of the area. Because these faults are numerous and closely spaced, the phosphate beds are probably much shattered and displaced. This part of the area is therefore the least promising for development as a source of phosphate. The east limb of the Georgetown syncline (pl. 5) is broken by at least four or five transverse normal faults; three of them offset the entire phosphatic shale member of the Phosphoria formation. The phosphatic shale member was offset 200 feet or more to the west along the south side of one of the three faults in the South Fork Deer Creek. This fault seems to be a normal dip-slip type of displacement. The largest normal fault on the east limb of the Georgetown syncline is probably the one at Black Dugway (pl. 5, sec. *D–D'*). Along the east side of this fault the beds were displaced more than 400 feet to the south. The fault seemingly extends northward and merges with the axis of a minor anticline developed in the Woodside shale. Approximately a mile north of Black Dugway are two other normal faults; unlike most of the others in the map area, they are slightly oblique or subparallel to the strike of the beds. Because these two oblique or strike faults are close to a thrust, the phosphate beds are probably much broken in that locality.

Judging from the evidence of faulting shown on the map (pl. 5), perhaps only two parts of the Georgetown syncline show much promise for prospecting. The first part is between half a mile and 1½ miles north of Deer Creek Mountain. The other is between the South Fork Deer Creek and a point at trench B, more than half a mile north of Black Dugway (pl. 5).

The Webster syncline is faulted in at least three places on the west limb and three to five places on the east limb (pl. 5). The movement on all the faults, except the one at the switch-back in the road south of the South Fork Deer Creek, appears to be dip-slip. The movement on the fault at the switch-back is oblique-slip. Because overburden above the Webster syncline obscures the contacts of the phosphatic shale member of the Phosphoria formation and covers the fault traces, the position of the fault planes and the type and amount of displacement must be inferred. Although the amount of displacement is not known precisely, the phosphatic shale member appears to have been displaced 100 to 400 feet along these faults. The Webster syncline, however, is probably much less broken by faults than the Georgetown syncline and therefore is more favorable for further exploration.

PHOSPHATE ROCK

TERMINOLOGY

The terminology used in this report is taken from the most recent bulletin on phosphate rock published by the Geological Survey. In this bulletin L. S. Gardner (1944, pp. 12–13) says:

> 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 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.

Using Gardner's terminology, the phosphate rock in the Deer Creek-Wells Canyon area is divided into three grades in estimating the reserves (table 12): high-grade rock that contains 70 percent or more B. P. L., medium-grade rock that has 50 to 69 percent B. P. L., and low-grade rock that contains 30 to 49 percent B. P. L.

OCCURRENCE AND DISTRIBUTION

The phosphate rock in the Deer Creek-Wells Canyon district is irregularly distributed throughout the phosphatic shale member of the Phosphoria formation as thin beds separated by units of shale, siltstone, and a few impure limestone nodules. The beds of phosphate rock range in thickness from 4 to 86 inches. Although many of the shales and siltstones are more or less phosphatic, most of the higher grades of phosphate rock were deposited in three groups of beds that constitute three zones, referred to in this report as the lower, middle, and upper phosphate zones. Tentative correlations of the phosphate beds in the trenches are given on plates 6 and 7, which were prepared by W. R. Lowell in collaboration with the writer. The criteria for the correlations are stratigraphic position, lithologic composition, and—as indicated by tables 1 to 9—phosphate content.

Lower phosphate zone.—The lower phosphate zone ranges from 50 to 86 inches and averages about 65 inches in thickness (pl. 6). Within the area the samples from the combined beds in the lower phosphate zone average 71.6 percent B. P. L. The samples from trenches J and K (tables 10, 11), 14 miles north of the map area in the northern part of the Slug Creek quadrangle, average 68.3 percent B. P. L. Throughout the area (pl. 1), except in trench I, the lower phosphate zone is overlain by shale or mudstone, which probably would not make a good hanging wall in mining operations. In trench I, however, the lower phosphate zone is overlain by the "Cap lime" (Mansfield, 1927, p. 77), a fossiliferous phosphatic limestone 19 inches thick that should prove satisfactory as a hanging wall. In the Deer Creek-Wells Canyon district, as in the Conda mine 20 miles to the northwest, the lower phosphate zone is probably the most important of the three in the phosphatic shale member.

Middle phosphate zone.—The middle phosphate zone has been recognized in only 2 of the 11 trenches, E and I (pl. 6); it contains the lowest-grade phosphate rock and is the most poorly demarcated of the three zones. Although referred to as the middle phosphate zone, it is in the lower third of the phosphatic shale member only 32 feet above the lower phosphate zone in trench E and 28 feet above the "Cap lime" in trench I. The middle phosphate zone in trench E consists of five units of phosphate rock and phosphatic shale that have a total thickness of almost 8 feet. In trench I the middle phosphate zone is divisible into four units of phosphate rock and shale having a total thickness of 7½ feet. The B. P. L. content averages 50.0 percent. In brief, the middle phosphate zone could be mined as one bed, is fairly uniform in thickness for a distance of at least 1½ miles between trenches E and I, and is not many feet above the basal phosphate zone. It might prove commercially valuable if phosphate rock containing as little as 50 percent B. P. L. can be profitably reduced in electric furnaces.

Upper phosphate zone.—Numerous beds of phosphate rock and phosphatic shale interbedded with fewer and thinner units of siltstone and shale constitute a zone 18 to 20 feet thick referred to in this report as the upper phosphate zone (pl. 7). Unlike the lower and middle phosphate zones the thickness and number of beds of phosphate rock in the upper zone vary widely from place to place. The lower boundary of the upper phosphate zone is not uniform throughout the area, and the upper boundary is drawn arbitrarily at the top of the youngest high-grade phosphate rock in the phosphatic shale member (pl. 7, all trenches). On the east limb of the Georgetown syncline (pl. 1, trenches A, B), the upper zone consists of seven to nine phosphate beds that have a total thickness of 15 to 15½ feet. In these two trenches, however, only 3½ to 4½ feet of beds contains 70 percent or more B. P. L., and the beds are separated by lower-grade phosphate rock and shale. The upper phosphate zone is thickest (21½ feet) in trench H and thinnest (15 feet) in trench B, on the east limbs of the Webster and Georgetown synclines, respectively. The evidence from trenches A, B, G, H, and I (pl. 7) indicates that the high-grade phosphate rock in the upper phosphate zone would have to be mined with the medium- and low-grade phosphate rock and with the interbedded shale and siltstone.

LITHOLOGIC CHARACTER OF THE PHOSPHATE ROCK

The composition, origin, and distribution of the phosphate rock in Idaho, Utah, and Wyoming are discussed and summarized by Mansfield (1927, pp. 208–214) and need not be repeated here. Detailed information pertaining to the thickness, lithologic character, and stratigraphic position of the phosphate rock throughout the entire thickness of the phosphatic shale member is given in the measured section on pages 66–76.

The phosphate rock in the Deer Creek-Wells Canyon district is black, blackish brown, and dark brown gray; when crushed, it is brown or brown gray. Much of the rock is platy-bedded, but some is fissile. The high-grade unaltered rock consists of collophane oolites, 0.05 millimeter to 2 millimeters in diameter, embedded in a matrix of dense collophane. The coarsely oolitic phosphate rock generally contains more phosphorus pentoxide (P_2O_5) than the finely oolitic rock. The larger oolites locally grade into spherical concretionary pisolites 3 to 5 millimeters in diameter. Some beds contain ovoid and irregular-shaped collophane nodules 6 to 55 millimeters in long diameter, many of which average 25 millimeters. Some nodules are homogeneous and appear to consist of cryptocrystalline collophane; others exhibit a tiny cavity at the center surrounded by layers of oolites that are larger in the central than in the peripheral part of the nodules. Analyses indicate that the nodular beds contain less P_2O_5 than the coarsely oolitic beds.

Most of the limestone nodules are in siltstone and shale, but some are in the phosphate rock. The limestone nodules are broadly elliptical or irregular in shape and range from 1 inch to 24 inches in thickness and from 2 to 72 inches in long diameter. The limestone appears to be secondary in origin, the calcite having been deposited by ground water long after the clastic sediments were raised above sea level. In several trenches the limestone nodules seemingly grew by addition of calcite in concentric layers. The growing nodules apparently forced the beds of phosphate and other rocks apart, so that the beds curve smoothly around the nodules. Probably none of the limestone nodules consist of more than 55 percent calcite.

Calcite is also irregularly distributed throughout many of the beds of phosphate rock. Petrographic study of the phosphatic shale member by W. R. Lowell indicates that in some beds of phosphate rock the collophane oolites are partly surrounded by calcite and that in others calcite fills most of the pore spaces and has partly replaced the collophane oolites.

The phosphate beds range from 1/20 inch to 6 inches in thickness, but most beds are 1/5 to 1/2 inch thick. The finely oolitic rock generally is thinner-bedded than the coarsely oolitic rock. Beds of pure phosphate grade vertically upward or downward into black phosphatic shale and occasionally into calcareous, brown-tan siltstone. In some places units of high-grade phosphate rock 6 to 24 inches thick are separated by thick units of shale or siltstone, and in others 3- to 5-inch beds of high-grade phosphate rock are interbedded with 1- to 4-inch beds of tan siltstone and shale. The interbedded siltstone will greatly increase the cost of mining and probably will prevent the mining of numerous thin, isolated beds of phosphate rock.

The stratigraphic position of the phosphate beds in the phosphatic shale member in trench I is given in the measured section (pp. 66–76). The relative stratigraphic position and thickness of the phosphate beds throughout the area are shown in the graphic logs on plates 6 and 7.

METHOD OF SAMPLING

The accuracy of the conclusions concerning the grade and thickness of the phosphate rock in the Deer Creek-Wells Canyon area depended to a large extent on the method used to obtain samples in the field. The interpretation of the stratigraphy within the trenches at the time the samples were cut likewise determined the correctness of the thickness of sampled units and of the amount of rock cut from each bed. Accurate samples of phosphate rock were difficult to obtain from the complexly folded and faulted beds. In some places inconspicuous thin beds were repeated; in other places slight flexures produced a long exposure of one bed subparallel to the bedding planes and short exposures of other strata lying at a greater angle to the bedding. Under such conditions a sample cut from a channel accurately but without knowledge of the detailed stratigraphy and structure would be worthless, for it would consist of excessive amounts of some beds and relatively minute amounts of others.

Two types of samples were taken: One was cut from a bench prepared in the wall of the trench, and the other was cut in the wall of the trench from a channel perpendicular to the dip of the beds. The original samples ranged from 25 to 160 pounds in weight and were crushed in the field with hammers to less than a quarter of an inch in size and reduced by quartering on a sample cloth to final splits that weighed from 2 to 9 pounds. The sampled units range in thickness from ⅓ foot to 13⅓ feet, but most of them are less than 3 feet thick. Samples were not cut from uniformly thick rock units because such units would contain both high-grade and worthless rock and therefore would show neither the thickness and grade of the beds of phosphate rock nor the thickness and grade of the worthless rocks that separate the phosphate beds. Consequently, the criterion used to determine the thickness of the sampled units was the change in lithologic character of the rock.

CHEMICAL ANALYSES

Analyses of 202 samples cut from 11 trenches are given in tables 1 to 11. Of the 11 trenches, 9 are in the map area (pl. 5) and 2 are in the northern part of the Slug Creek quadrangle, approximately 14 miles to the northwest (fig. 4). The samples for which complete determinations are given were analyzed in the Chemical Research Laboratory of the Tennessee Valley Authority. The analyses of P_2O_5 in the samples from trenches A, B, C, D, G, and H were made by S. H. Cress, J. G. Fairchild, or M. K. Carron, in the Chemical Laboratory of the Geological Survey. The content of phosphorus pentoxide (P_2O_5) was determined for each of the 202 samples. Complete determinations were made of all samples in trench I (table 9) and of eight other samples that seemed from field tests to be high-grade phosphate rock. The writer computed the B. P. L. content for each sample by multiplying the percent of P_2O_5 by 2.18.

The analyses indicate the following generalizations concerning the phosphate rock in the Deer Creek-Wells Canyon area (pl. 5): The highest-grade phosphate rock is a unit, 9 inches thick, in trench H (pl. 7, unit 11); it contains 35.9 percent P_2O_5 (78.3 percent B. P. L.). The lower phosphate zone, 4 to 7 feet thick (pl. 6), is the thickest phosphate unit containing 70 percent or more B. P. L. The upper phosphate zone (pl. 7) contains more phosphate rock of medium and high grade combined than either the lower or middle phosphate zones; it includes 3½ to 11 feet of rock containing more than 70 percent B. P. L. and 5 to 9 feet of rock containing 50 to 69 percent B. P. L. If the cut-off grade could be held at 50 percent B. P. L., probably an average thickness of 12 feet in the upper phosphate zone would be

TABLE 1.—*Analyses of samples from trench A, Deer Creek-Wells Canyon area, Idaho*

Sample No.	P_2O_5	B. P. L.	Fe_2O_3	Al_2O_3	R_2O_3	CaO	V_2O_5	F	Acid insoluble	Ignition loss	CO_2	Thickness of sampled unit	
												Feet	Inches
1	32.2	70.2										1	6
2	32.6	71.1	0.4	1.3		46.3	0.08	3.53		9.3		1	
3	10.6	22.9											7
4	33.9	73.9	.7	.8		48.8	.08	3.55		7.0		1	4
5	27.1	59.1	1.1	2.6		38.8	.07	3.73		6.4		3	10
6	24.5	53.4										1	4
7	35.6	77.6	.3	.7		50.2	.06	2.88	3.40	4.8		1	10
8	1.6	3.5										2	4
9	23.1	50.4	1.5	3.5		33.3	.06	2.22		7.5		1	3
10	25.5	55.6											8
1E	11.8	25.7										1	2
2E	22.5	49.1											9
3E	23.4	51.0										12	6
4E	.9	2.0			2.64		.006	.25	41.00		5.28	2	1
5E	13.4	29.2										6	7
6E	10.0	21.8			5.90		.013	.82	57.40		None	8	11
7E	6.0	13.1										9	10
8E	13.6	29.6	2.3	4.2		19.9	.06	1.22		19.8		1	5
9E	3.3	7.2										1	8
10E	14.8	32.3										4	11

minable, although the shales interbedded with the phosphate rock would necessitate much selective mining. The middle phosphate zone may not be persistent and uniform in grade throughout the district. It is 7½ feet thick in trench I, but it averages only 51 percent B. P. L. and therefore is the least valuable of the three zones.

TABLE 2.—*Analyses of samples from trench B, Deer Creek-Wells Canyon area, Idaho*

Sample No.	P_2O_5	B. P. L.	Fe_2O_3	Al_2O_3	R_2O_3	CaO	V_2O_5	F	Acid insoluble	Ignition loss	CO_2	Thickness of sampled unit	
												Feet	Inches
1	12.3	26.8	------	------	------	------	------	------	------	------	------	5	------
2	4.3	9.4	------	------	------	------	------	------	------	------	------	------	10
3	13.6	29.6	------	------	3.64	------	0.09	1.65	15.10	------	None	1	4
4	6.5	14.2	------	------	------	------	------	------	------	------	------	12	4
5	13.6	29.6	------	------	------	------	------	------	------	------	------	7	5
6	14.2	31.0	------	------	------	------	------	------	------	------	------	6	8
7	1.1	2.4	------	------	------	------	------	------	------	------	------	1	7
8	20.5	44.7	------	------	5.48	------	.15	1.50	20.70	------	0.10	13	4
9	29.2	63.7	------	------	------	------	------	------	------	------	------	4	1
10	13.3	29.0	------	------	------	------	------	------	------	------	------	1	1
11	33.1	72.2	0.4	0.9	------	47.1	.07	3.55	------	8.6	------	2	------
12	26.3	57.3	------	------	------	------	------	------	------	------	------	2	10
13	18.4	40.1	------	------	------	------	------	------	------	------	------	1	1
14	4.9	10.7	------	------	------	------	------	------	------	------	------	1	6
15	34.0	74.1	.5	.6	------	50.1	.05	3.71	------	4.5	------	1	6
16	1.5	3.3	------	------	------	------	------	------	------	------	------	2	9
17	16.0	34.9	1.4	3.5	------	32.9	.07	1.75	------	13.2	------	1	------
18	26.3	57.3	------	------	------	------	------	------	------	------	------	------	6

TABLE 3.—*Analyses of samples from trench C, Deer Creek-Wells Canyon area, Idaho*

Sample No.	P_2O_5	B. P. L.	Fe_2O_3	Al_2O_3	CaO	V_2O_5	F	Ignition loss	Thickness of sampled unit	
									Feet	Inches
1	33.1	72.3	0.4	0.9	47.6	0.33	3.59	6.8	1	9
2	33.1	72.3	------	------	------	------	------	------	5	5

TABLE 4.—*Analyses of samples from trench D, Deer Creek-Wells Canyon area, Idaho*

Sample No.	P_2O_5	B. P. L.	Fe_2O_3	Al_2O_3	CaO	V_2O_5	F	Ignition loss	Thickness of sampled unit	
									Feet	Inches
1	33.0	72.0	0.8	1.3	45.4	0.09	3.30	8.5	5	------
2	21.5	46.9	------	------	------	------	------	------	2	2
3	20.5	44.8	------	------	------	------	------	------	4	5

TABLE 5.—*Analyses of samples from trench E, Deer Creek-Wells Canyon area, Idaho*

Sample No.	P_2O_5	B. P. L.	Fe_2O_3	Al_2O_3	CaO	V_2O_5	F	Acid insoluble	Moisture (105°C.)	Ignition loss	Thickness of sampled unit	
											Feet	Inches
1A	27.2	59.3	1.1	2.7	39.1	0.23	2.71	19.4	1.0	6.3	------	4
2A	34.4	75.0	.4	.9	49.5	.18	3.53	3.4	.7	6.6	2	4
3A	32.2	70.2	.7	1.3	46.2	.32	3.35	6.2	1.0	7.7	------	6
4A	33.9	73.9	------	------	------	------	3.61	3.7	.9	------	1	11
5A	30.1	65.6	------	------	------	------	2.94	11.5	1.0	------	------	6
6	23.3	50.8	------	------	------	------	2.41	28.1	1.5	------	------	11
7	24.9	54.3	------	------	------	------	2.41	24.2	1.3	------	1	11
8	10.4	22.7	------	------	------	------	1.08	44.3	3.2	------	------	10
9	24.3	53.0	------	------	------	------	2.31	23.4	1.6	------	1	------
10	25.2	54.9	------	------	------	------	2.65	22.0	1.6	------	2	11
11	24.8	54.1	------	------	------	------	2.31	22.0	1.9	------	6	9
12	24.7	53.8	------	------	------	------	2.31	20.0	2.3	------	5	------
13	2.3	5.0	------	------	------	------	.27	13.8	.8	------	2	5
14	12.1	26.4	------	------	------	------	1.18	48.1	2.1	------	4	------
15	3.4	7.4	------	------	------	------	.37	14.6	.9	------	2	6
16	18.3	39.9	------	------	------	------	2.00	32.3	2.4	------	1	4
17	22.3	48.6	------	------	------	------	2.28	19.9	3.3	------	1	3
18	23.3	50.8	------	------	------	------	2.18	19.4	2.9	------	------	5
19	26.6	58.0	------	------	------	------	2.67	13.5	2.5	------	4	5
20	18.9	41.2	------	------	------	------	1.88	30.0	2.9	------	1	4
21	10.5	22.9	------	------	------	------	1.02	45.8	3.1	------	3	1
22	13.2	28.8	------	------	------	------	1.29	39.4	3.5	------	3	11
23	8.8	19.1	------	------	------	------	.88	56.2	2.1	------	------	8
24	.9	2.0	------	------	------	------	.31	3.1	5.0	------	1	3
25	11.6	25.3	------	------	------	------	1.18	46.4	2.7	------	8	5
26	4.2	9.2	------	------	------	------	.47	70.5	1.3	------	2	------
27	3.6	7.8	------	------	------	------	.29	73.2	1.6	------	7	------
28	2.2	4.8	------	------	------	------	.22	80.1	1.3	------	1	1
29	.6	1.3	------	------	------	------	.04	49.6	.8	------	1	------

TABLE 6.—*Analyses of samples from trench F, Deer Creek-Wells Canyon area, Idaho*

Sample No.	P_2O_5	B. P. L.	Fe_2O_3	Al_2O_3	CaO	V_2O_5	F	Acid insoluble	Moisture (105°C.)	Ignition loss	Thickness of sampled unit	
											Feet	Inches
1	35.5	77.4	0.6	0.9	48.0	0.17	3.37	3.5	0.9	8.2	4	2
2	25.0	54.5	------	------	------	------	2.49	23.5	1.3	------	3	4
3	27.4	59.7	------	------	------	------	2.61	17.2	1.4	------	3	9
4	13.4	29.2	------	------	------	------	1.22	50.6	1.7	------	1	5
5	25.1	54.7	------	------	------	------	2.59	19.5	1.7	------	3	3
6	11.5	25.0	------	------	------	------	1.02	53.0	1.8	------	3	7
7	19.1	41.6	------	------	------	------	1.96	26.7	3.6	------	3	------
8	23.6	51.5	------	------	------	------	2.41	20.2	2.5	------	------	9
9	25.3	55.1	.8	2.5	36.4	.04	2.92	12.3	2.6	14.4	------	11
10	22.3	48.6	1.4	3.6	30.6	.03	2.10	23.3	3.1	15.8	4	3

TABLE 7.—*Analyses of samples from trench G, Deer Creek-Wells Canyon area, Idaho*

Sample No.	P_2O_5	B. P. L.	Fe_2O_3	Al_2O_3	CaO	V_2O_5	F	Ignition loss	Thickness of sampled unit	
									Feet	Inches
1	20.0	43.6							2	5
2	1.6	3.5							3	6
3	5.3	11.6							1	7
4	14.6	31.8							2	6
5	6.1	13.3							2	4
6	9.6	20.9							2	4
7	5.6	12.2								11
8	20.3	44.2								7
9	12.9	28.1							3	4
10	22.7	49.5							3	2
11	29.4	64.1	0.7	1.7	44.5	0.43	3.30	11.6	3	1
12	33.2	72.4							1	6
13	19.2	41.9							1	7
14	33.6	73.2							2	5
15	30.8	67.1							1	6
16	23.5	51.2							1	2
17	34.9	76.1	.3	.9	49.5	.09	3.71	5.4	1	4
18	1.9	4.1							1	11
19	25.4	55.4	1.2	3.3	35.5	.04	2.53	7.7		7
20	21.3	46.4								6
21	27.7	60.4								4

TABLE 8.—*Analyses of samples from trench H, Deer Creek-Wells Canyon area, Idaho*

Sample No.	P_2O_5	B. P. L.	Fe_2O_3	Al_2O_3	CaO	V_2O_5	F	Acid insoluble	Moisture (105°C.)	Ignition loss	Thickness of sampled unit	
											Feet	Inches
1	7.2	15.7									1	5
2	2.4	5.2					0.43	18.8	1.2			6
3	12.5	27.2									1	11
4	18.2	39.7									2	4
5	14.6	31.8									2	10
6	15.4	33.6									3	5
7	.8	1.7					.08	20.5	.6		1	5
8	17.0	37.1									3	7
9	27.7	60.4					2.92	12.2	2.2		2	
10	34.3	74.8									1	10
11	35.9	78.3										9
12	28.3	61.7	0.7	1.1	47.6	0.12	2.86	7.6	.9	10.6	1	4
13	21.3	46.4										9
14	12.4	27.0										11
15	34.3	74.8	.5	1.3	47.8	.12	3.59			6.7	1	8
16	26.9	58.6									1	11
17	33.8	73.7									1	6
18	32.2	70.2									3	1
19	7.9	17.2										6
20	25.6	55.8									1	
21	9.0	19.6									1	10
22	32.2	70.2	.4	.9	49.2	.07	3.79			4.5	2	1
23	1.5	3.3					.27	71.3	1.5		2	1
24	24.6	53.6									1	1
25	20.0	43.6										6
26	4.0	8.7					.37	73.3	2.4		1	11
27	26.1	56.9										4

TABLE 9.—*Analyses of samples from trench I, Deer Creek-Wells Canyon area, Idaho*

Sample No.	P_2O_5	B.P.L.	Fe_2O_3	Al_2O_3	CaO	V_2O_5	F	Acid insoluble	Moisture (105°C.)	Ignition loss	Thickness of sampled unit	
											Feet	Inches
1	2.9	6.3	3.4	6.6	4.6	0.51	0.24	71.8	2.7	11.3	------	7
2	33.0	71.9	.6	.7	47.4	.22	3.28	3.9	1.1	8.9	1	6
3	32.1	70.0	.5	1.1	46.4	.23	3.18	4.1	1.3	11.3	3	3
4	28.0	61.0	.5	1.9	44.2	.14	3.24	8.1	1.3	10.9	------	10
5	21.9	47.7	1.0	3.3	33.9	.07	2.39	24.6	1.9	11.7	3	------
6	25.4	55.4	1.0	2.4	37.5	.24	2.51	17.6	2.0	12.4	7	7
7	18.7	40.8	1.6	3.3	26.8	.49	1.69	34.9	2.0	12.0	3	6
8	25.2	54.9	.9	2.2	36.3	.41	2.43	18.4	2.2	14.5	2	8
9	9.2	20.1	2.0	4.5	18.0	.03	.98	45.8	2.1	16.9	2	9
10	5.1	11.1	1.0	1.4	27.8	.01	.61	20.9	1.0	32.2	3	1
11	23.9	52.1	1.5	3.1	34.6	.13	2.57	17.6	2.9	16.0	1	11
12	23.9	52.1	1.4	3.1	35.8	.03	2.84	17.0	2.9	16.7	2	10
13	23.3	50.8	1.2	3.8	34.8	.03	2.33	14.5	3.3	19.4	1	6
14	20.4	44.5	1.4	3.4	34.6	.02	2.08	22.2	2.0	15.6	1	3
15	10.2	22.2	2.9	6.1	17.8	.02	1.18	47.0	3.0	16.8	2	5
16	12.0	26.2	2.3	4.3	23.2	.03	1.31	37.9	2.8	19.2	4	4
17	13.6	29.6	1.9	4.5	27.6	.02	1.49	29.2	3.2	21.3	3	5
18	7.3	15.9	2.9	5.2	15.3	.03	.67	53.7	2.3	15.7	4	6
19	2.4	5.2	3.2	3.5	5.5	.02	.20	74.0	1.6	11.9	5	3
20	2.5	5.4	3.1	4.4	5.3	.05	.37	74.0	1.9	12.3	4	3
21	.3	.7	.5	.4	28.8	.01	.04	17.2	.4	39.3	4	4
22	2.0	4.4	3.8	6.2	3.9	.02	.24	76.5	1.3	10.2	1	3
23	9.2	20.1	2.9	6.2	14.6	.02	1.04	53.3	2.6	31.5	2	1
24	2.0	4.4	3.1	5.1	9.6	.02	.20	65.1	1.9	15.6	1	10
25	9.4	20.5	2.4	4.2	25.1	.02	.96	35.6	2.6	21.6	3	8
26	7.9	17.2	2.4	4.1	26.5	.04	.84	30.4	3.1	28.5	2	1
27	9.6	20.9	2.4	3.8	21.5	.03	1.10	39.7	3.3	22.2	3	4
28	12.6	27.5	2.5	4.8	21.0	.08	1.47	27.4	5.4	30.2	1	5
29	9.6	20.9	3.8	4.7	13.8	.02	1.00	58.2	1.9	10.9	------	8
30	17.5	38.2	5.0	2.6	25.6	.01	1.90	42.9	1.2	8.6	1	3
31	2.4	5.2	3.0	2.1	9.0	.01	.20	66.5	1.0	13.6	7	4
32	22.6	49.3	2.0	2.8	32.4	.04	2.41	25.8	1.9	11.3	1	3
33	13.4	29.2	2.8	4.6	19.4	.07	1.29	43.8	2.5	15.2	1	6
34	2.6	5.7	2.9	4.0	4.7	.04	.24	76.3	2.0	11.9	2	9
35	4.7	10.2	2.7	4.2	7.7	.09	.53	64.5	2.7	16.8	1	6
36	2.2	4.8	2.5	3.1	4.3	.02	.29	78.7	1.7	9.7	2	3
37	14.6	31.8	1.9	3.4	23.8	.04	1.59	39.9	1.9	13.8	1	10
38	3.2	7.0	2.1	2.9	12.6	.02	.37	59.3	1.5	17.5	1	4
39	10.7	23.3	2.2	3.0	14.8	.02	1.12	59.5	1.5	9.0	2	5
40	24.2	52.8	1.2	2.5	34.2	.03	2.61	22.8	1.8	11.4	------	6
41	6.0	13.1	2.8	2.5	10.2	.01	.80	69.8	1.1	7.7	1	5
42	28.0	61.0	1.7	1.9	39.6	.01	3.10	18.7	.7	5.9	------	11
43	13.0	28.3	2.5	3.6	19.8	.03	1.43	47.1	2.0	12.6	4	3
44	16.7	36.4	2.0	3.9	25.3	.06	1.63	32.2	3.1	17.1	1	9
45	2.3	5.0	1.6	2.1	22.6	.04	.22	35.1	1.0	28.1	2	6
46	18.1	39.5	1.7	3.5	27.6	.16	1.86	29.6	3.3	17.8	3	9
47	25.4	55.4	1.0	2.4	37.0	.36	2.53	12.5	3.1	16.8	3	6
48	20.1	43.8	.9	2.5	38.3	.44	1.90	11.1	3.1	21.1	2	6
49	34.3	74.8	.5	1.2	47.2	.25	3.51	4.6	1.3	8.6	2	------
50	34.4	75.0	.6	1.0	48.7	1.16	3.63	4.7	1.0	5.9	1	1
51	17.0	37.1	1.9	4.2	24.8	.11	1.80	40.7	1.5	8.4	1	9
52	32.0	69.8	.6	1.2	47.5	.13	3.53	6.4	1.1	7.3	1	8
53	21.8	47.5	1.8	3.6	31.7	.05	2.22	30.5	.9	5.3	2	4
54	9.0	19.6	2.9	5.2	11.6	.07	.84	61.8	1.1	6.4	------	10
55	33.8	73.7	.6	1.3	47.6	.13	3.57	6.8	1.0	6.5	1	4
56	35.5	77.4	.4	.5	50.8	.05	3.84	4.4	.6	4.6	------	10
57	24.1	52.5	.7	1.8	41.4	.01	2.51	14.9	1.0	12.3	------	4

TABLE 10.—*Analyses of samples from trench J, Deer Creek-Wells Canyon area, Idaho*

Sample No.	P_2O_5	B. P. L.	Fe_2O_3	Al_2O_3	CaO	V_2O_5	F	Acid insoluble	Moisture (105° C.)	Ignition loss	Thickness of sampled unit	
											Feet	Inches
1	17.5	38.1	1.9	3.7	31.2	0.45	1.86	26.3	1.3	11.9	------	4
2	31.8	69 3	.6	1.2	47.4	.27	3.22	6.0	.8	7.1	2	2
3	32.6	71.0	------	------	------	------	3.28	4.1	.9	------	1	9
4	31.4	68.4	------	------	------	------	3.22	4.9	1.3	------	1	7

TABLE 11.—*Analyses of samples from trench K, Deer Creek-Wells Canyon area, Idaho*

Sample No.	P_2O_5	B. P. L.	Fe_2O_3	Al_2O_3	CaO	V_2O_5	F	Acid insoluble	Moisture (105° C.)	Ignition loss	Thickness of sampled unit	
											Feet	Inches
1	14.9	32.5					1.51	39.5	2.0			8
2	30.0	65.4	0.8	1.5	46.2	0.16	3.33	6.9	.8	7.5	1	6
3	31.0	67.6					3.35	3.9	1.0		1	8
4	30.9	67.3	.6	1.1	48.1	.15	3.37	5.0	.7	8.5	1	5
5	23.5	51.2					2.33	21.8	1.1		2	3
6	27.4	59.7					2.75	14.7	1.2		1	1
7	33.2	72.4					3.18	7.5	.7		1	5
8	29.7	64.7					2.92	9.4	1.3		2	6
9	23.3	50.8					2.20	25.8	1.2		2	4
10	30.7	66.9					3.20	8.4	1.1		1	7
11	19.1	41.6					1.80	27.1	.7		1	

RESERVES

Basis of estimates.—The estimates of inferred reserves given in table 12 (p. 94) are based on three sources of information: geologic mapping, 10 transverse structure sections (pl. 5) drawn from the geologic map (pl. 5), and chemical analyses of 202 samples (tables 1–11) taken from 11 trenches. The estimates are not accurate enough to be considered indicated reserves because the overburden of unconsolidated sediments (p. 78) prevented uniform spacing of the trenches. In addition, as has been pointed out, the overburden covers nearly all the phosphatic shale member, hides the contacts between formations to a large extent, and doubtless conceals many faults that affect the phosphate deposits. Consequently, the geologic map (pl. 5) does not represent precise delimitation of the formations and may omit numerous faults. Furthermore, the number of trenches and samples is too small to indicate accurately the grade of the rock throughout the district. Until many uniformly spaced adits are dug, an accurate detailed geologic map cannot be made. In this report, therefore, all tonnage estimates must be classed as inferred.

The estimates were obtained by multiplying the length and breadth of each block by the thickness of beds, taken from measurements in trenches A to I (pls. 6 and 7) and assumed to be uniform, and dividing the product (volume in cubic feet) by 12 to obtain the tonnage. The average specific gravity of high-grade phosphate rock is 2.90, so that each cubic foot weighs approximately 180 pounds (Mansfield, 1927, p. 210) and 11.11 cubic feet weighs about a ton. Because the rock is not uniform in density, however, a factor of 12 cubic feet per ton was used in computing the estimated tonnage.

Inferred reserves above drainage level.—The estimates, which apply only to reserves above drainage level, are given in table 12 for the three grades of phosphate rock in each of the blocks on each limb of the synclines under the headings "Georgetown syncline," with subheadings

"West limb" and "East limb," and "Webster syncline," with subheadings "West limb," "East limb (north area)," and "East limb (south area)."

Field work in 1944 indicated that the only part of the west limb of the Georgetown syncline that contains unmashed or only partly broken phosphate deposits is the area from half a mile to 1½ miles north of Deer Creek Mountain (pl. 5); for this block the drainage level, above which the reserves of phosphate rock are estimated, is at an elevation of 7,300 feet. The most promising part of the east limb of the Georgetown syncline for exploitation is the area that extends north from the South Fork Deer Creek to about five-eighths of a mile beyond Black Dugway (pl. 5), with the drainage level for this second block also at an elevation of 7,300 feet.

The area on the west limb of the Webster syncline for which tonnage is estimated—drainage level, 7,250 feet in elevation—lies between the fault south of the South Fork Deer Creek and the south end of the map area (pl. 5). The area included in the estimate for the block labeled "East limb (north area)"—drainage level, 7,000 feet in elevation—extends from Wells Canyon northeast to Deer Creek (pl. 5), and the tonnage estimate for the block labeled "East limb (south area)"—drainage level, 7,250 feet in elevation—is for the 2-mile strip from Wells Canyon southward. This is probably the most promising block for further exploration.

Total inferred reserves.—The Deer Creek-Wells Canyon area, as mapped in 1944 (pl. 5), may contain more than 27,000,000 tons of high-grade phosphate rock (70 percent or more B. P. L.), nearly 53,000,000 tons of medium-grade rock (50 to 69 percent B. P. L.), and nearly 40,000,000 tons of low-grade rock (30 to 49 percent B. P. L.)—a grand total of almost 120,000,000 tons of inferred phosphate rock that contains 30 percent or more B. P. L. The total figure probably does not mean very much, however, because not all the reserves in any one section could be mined profitably and those in the widely separated blocks would have to be mined in three separate operations.

TABLE 12.—*Inferred reserves of phosphate rock above drainage level, Deer Creek-Wells Canyon area, Idaho*

[Grand total of reserves in Deer Creek-Wells Canyon district is approximately 120,000,000 short tons of high-, medium-, and low-grade phosphate rock combined]

Location of deposits	Short tons of high-grade phosphate rock (B. P. L., 70 percent or more)	Short tons of medium-grade phosphate rock (B. P. L., 50 to 69 percent)	Short tons of low-grade phosphate rock (B. P. L., 30 to 49 percent)
Georgetown syncline:			
West limb: [1]			
Upper phosphate zone	1, 250, 000	1, 750, 000	800, 000
Middle phosphate zone		1, 500, 000	450, 000
Lower phosphate zone	1, 350, 000		
Phosphate rock outside the three zones			2, 950, 000
Total in west limb	2, 600, 000	3, 250, 000	4, 200, 000
East limb:			
Upper phosphate zone	1, 600, 000	2, 250, 000	1, 000, 000
Middle phosphate zone		1, 950, 000	600, 000
Lower phosphate zone	1, 750, 000		
Phosphate rock outside the three zones			3, 850, 000
Total in east limb	3, 350, 000	4, 200, 000	5, 450, 000
Total in Georgetown syncline	5, 950, 000	7, 450, 000	9, 650, 000
Webster syncline:			
West limb:			
Upper phosphate zone	3, 700, 000	2, 800, 000	2, 100, 000
Middle phosphate zone		2, 850, 000	900, 000
Lower phosphate zone	2, 450, 000		
Phosphate rock outside the three zones		7, 300, 000	5, 700, 000
Total in west limb	6, 150, 000	12, 950, 000	8, 700, 000
East limb (north area):			
Upper phosphate zone	4, 700, 000	3, 550, 000	2, 650, 000
Middle phosphate zone		3, 600, 000	1, 100, 000
Lower phosphate zone	3, 100, 000	350, 000	
Phosphate rock outside the three zones		9, 250, 000	7, 250, 000
Total in north area	7, 800, 000	16, 750, 000	11, 000, 000
East limb (south area):			
Upper phosphate zone	4, 400, 000	3, 350, 000	2, 450, 000
Middle phosphate zone		3, 400, 000	1, 050, 000
Lower phosphate zone	2, 900, 000	300, 000	
Phosphate rock outside the three zones		8, 650, 000	6, 800, 000
Total in south area	7, 300, 000	15, 700, 000	10, 300, 000
Total in Webster syncline	21, 250, 000	45, 400, 000	30, 000, 000
Total in both synclines	2, 7200, 000	52, 850, 000	39, 650, 000

[1] Estimates based on samples and sections from trenches A, B, C, and D on east limb of Georgetown syncline; west limb not sampled.

SUMMARY AND CONCLUSIONS

All the phosphate rock in the map area (pl. 5) is within the phosphatic shale member of the Phosphoria formation. The phosphatic shale member is 179 to 200 feet thick, rests on the upper cherty limestone of the Wells formation, and is overlain by the Rex chert member of the Phosphoria formation. Because the phosphatic shale member is covered nearly everywhere, its position must be determined in the field in relation to outcrops of the Wells or the Rex formation.

In some places, faults have displaced or cut out the phosphate rock and mixed worthless shale, siltstone, or limestone with it. In other places, folding has caused the beds to be mashed thin and to lie at all positions from horizontal to vertical. Hill wash, talus, landslides, and alluvium blanket much of the bedrock and thereby prevent accurate geologic mapping and greatly increase the cost of sampling and other exploratory work. In order to sample the phosphate rock accurately at uniform intervals throughout the district, the overburden and underlying phosphatic shale member should be explored by adits. Core drilling might not be satisfactory, inasmuch as the phosphate rock probably would be difficult to core.

The phosphate rock in the Webster syncline could no doubt be mined more easily than the rock in the Georgetown syncline. However, the latter may be more accessible to rail transportation.

The lower phosphate zone contains the most persistent high-grade phosphate rock of the three zones; it ranges in thickness from 4 to 7 feet (pl. 6) and is the most valuable in the area. The upper phosphate zone contains several beds of high-grade phosphate rock whose combined thickness ranges from 3½ to 11 feet and medium-grade phosphate rock whose combined thickness ranges from 5 to 8½ feet. The upper phosphate zone is the thickest of the three zones, but the beds seemingly are lenticular, tend to be less persistent in grade, and are separated by irregular beds of shale and siltstone. Many nodules and irregular lenticular beds of impure limestone also are intercalated in the upper zone. The middle phosphate zone, the least valuable of the three zones, is known in the area only from two trenches (pl. 6, trenches E, I) and probably has little economic importance.

The block most favorable for exploitation seems to be in the Webster syncline extending southward from Wells Canyon for 2 miles. In this block the rocks probably are less broken by faults and less intensely folded and mashed than elsewhere in the Deer Creek-Wells Canyon district. The lower phosphate zone in the block is estimated to contain 2,900,000 tons of high-grade and 300,000 tons of medium-grade phosphate rock. Estimates for the upper phosphate zone are 4,400,000 tons of high-grade phosphate rock and 3,350,000 tons of medium-grade rock. The combined upper and lower phosphate zones in the Webster syncline south of Wells Canyon, therefore, are estimated to contain 7,300,000 tons of high-grade inferred phosphate rock and 3,650,000 tons of medium-grade inferred rock, a total reserve of 10,950,000 tons above the cut-off grade of 50 percent B. P. L.

The Webster syncline north of Wells Canyon is less favorable for exploitation than the area south of the canyon but is more favorable than the Georgetown syncline. The lower phosphate zone in this block of the Webster syncline may contain 3,100,000 tons of high-grade and 350,000 tons of medium-grade phosphate rock, a total inferred reserve of 3,450,000 tons above the cut-off grade of 50 percent B. P. L.

The part of the Georgetown syncline that extends northward from the South Fork Deer Creek for nearly 2 miles and from Deer Creek Mountain for more than 1 mile contains the least promising block of phosphate rock in the area. The lower phosphate zone in this part of the Georgetown syncline may contain 3,100,000 tons of high-grade phosphate rock.

The total inferred reserves in the Deer Creek-Wells Canyon area of phosphate rock containing 30 percent or more B. P. L. may amount to 120,000,000 tons. Of this figure, 27,200,000 tons are thought to be high-grade, 52,850,000 tons medium-grade, and 39,650,000 tons low-grade rock. Since much of the rock cannot be mined profitably, however, these estimates of total tonnage imply too great a value. The lower phosphate zone will be the easiest to mine. Because the high- and medium-grade phosphate beds are interbedded in the upper phosphate zone, they probably will have to be mined together. Selective mining, also, will be necessary in the upper phosphate zone to eliminate worthless shale and siltstone interbedded with the phosphate rock.

ANNOTATED LIST OF REFERENCES

In the following list of references, the publications cited in this report are preceded by an asterisk. The other papers are listed because they may be useful in connection with future exploration of the area. They contain information concerning the origin, stratigraphy, and structure of the phosphate deposits in southeastern Idaho and adjacent parts of Utah and Wyoming.

Blackwelder, Eliot, 1916, The geologic role of phosphorus: Am. Jour. Sci., 4th ser., vol. 42, no. 250, pp. 285–298, figs. 1, 2. Postulates a cycle of changes, through which phosphorus may pass, in the rocks of the earth's crust and in plants and animals. A comprehensive original paper discussing the origin of phosphate rock.

*Boutwell, J. M., 1907, Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, no. 5, pp. 434–458, figs. 1–8, map. Gives the original descriptions of the Woodside shale (pp. 446–448) and Thaynes formation (pp. 448–452).

Branson, C. C., 1930, Paleontology and stratigraphy of the Phosphoria formation: Missouri Univ. Studies, vol. 5, no. 2, 99 pp., 16 pls., 1 fig. An excellent discussion of the fossils contained in the Phosphoria formation. The stratigraphic position of the fossils (pp. 14–20), the age and correlation of the Phosphoria (pp. 20–23), and its paleogeography (pp. 23–24) are discussed.

*Condit, D. D., 1917, Relations of the Embar and Chugwater formations in central Wyoming: U. S. Geol. Survey Prof. Paper 98–O, pp. 263–270, pls. 61–63, figs. 25, 26. The original description of the Dinwoody formation is given (p. 263). The lower part of the Woodside shale in the Deer Creek-Wells Canyon area is probably equivalent to the Dinwoody.

*Gardner, L. S., 1944, Phosphate deposits of the Teton Basin area, Idaho and Wyoming: U. S. Geol. Survey Bull. 944–A, pp. 1–36, pls. 1–4, fig. 1. An excellent summary of the lithologic character and geologic structure of the Phosphoria formation northeast of the Deer Creek-Wells Canyon area. Gives a brief discussion of the terminology and sampling procedure used in field examination by the Geological Survey of phosphate deposits in Idaho, Utah, and Wyoming.

Girty, G. H., 1910, The fauna of the phosphate beds of the Park City formation of Idaho, Utah, and Wyoming: U. S. Geol. Survey Bull. 436, 82 pp., 7 pls. Contains a description of the genera and species of fossils from the Phosphoria formation in Idaho, Utah, and Wyoming. Most of the fossils described in the paper were collected from the "Cap lime" near Montpelier, Idaho. The remainder came from other faunal zones in the phosphatic shale member of the Phosphoria formation.

Jacob, K. D., Hill, W. L., Marshall, H. L., and Reynolds, D. S., 1933, The composition and distribution of phosphate rock with special reference to the United States: U. S. Dept. Agr. Tech. Bull. 364, 90 pp., 33 tables. This is a very important paper on the chemistry of phosphates. It contains a comprehensive discussion of the chemistry of the phosphate rock and gives many complete chemical analyses of phosphate rock from widely separated localities. The phosphate deposits of the United States are summarized by States, those of Idaho being discussed on page 6.

Mansfield, G. R., 1918, Origin of the Western phosphates of the United States: Am. Jour. Sci., 4th ser., vol. 46, no. 274, art. 27, pp. 591–598. The author concludes that the "phosphatic oölites and their matrix were probably deposited originally as carbonate of lime in the form of aragonite." A brief but comprehensive discussion of the origin of the Western phosphate deposits.

———, 1920, Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, 152 pp., 13 pls. (including maps), 4 figs. Phosphate deposits are discussed on pages 105–114. The author estimates that there are 738,526,700 long tons on Fort Hall Reservation, summarizes the results of field study of the phosphate deposits in Idaho northeast of the Deer Creek-Wells Canyon area, and discusses phosphate reserves for each township in the Fort Hall Indian Reservation in which they occur.

*———, 1927, Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, 453 pp., 70 pls., 46 figs. The largest, most comprehensive, and most important paper yet published concerning the phosphate deposits of southeastern Idaho. The geologic map of the Crow Creek quadrangle (pl. 7) covers the Deer Creek-Wells Canyon area.

———, 1931, Some problems of the Rocky Mountain phosphate field: Econ. Geology, vol. 26, no. 4, pp. 353–374, figs. 1, 2. An excellent summary of the stratigraphy, lithologic character, and paleogeography of the Phosphoria formation. Figure 2 is a paleogeographic map of the Phosphoria sea.

———, 1940, Recent studies of reserves of domestic phosphates: Am. Inst. Min. Met. Eng. Tech. Paper 1208, 10 pp., 1 fig., 6 tables. Contains new estimates of reserves of phosphate rock in Idaho, Montana, Utah, and Wyoming. Figure 1 is a graphic section across the entire phosphatic shale member of the Phosphoria formation in the main tunnel of the Anaconda Copper Mining Co.'s phosphate mine at Conda, Idaho.

———, 1940, The role of fluorine in phosphate deposition: Am. Jour. Sci., vol. 238, pp. 863–879, fig. 1. Discusses the origin of phosphate rock and emphasizes two essentials of phosphate deposition: "First, a combination of circumstances favorable to the accumulation of phosphoric acid, and, the presence of some agent to fix that phosphoric acid in relatively insoluble form. It is suggested here that this agent may be fluorine."

Norris, E. M., 1944, Underground mining of phosphate rock in Conda, Idaho: Mining and Metallurgy, vol. 25, no. 454, pp. 481–485, illus. An excellent brief discussion of the lithologic character of the phosphatic shale member ("160 ft. thick") and of the lithologic character and chemical composition of the phosphate rock, which "lies in two beds, each about 7 ft. thick, * * * lying respectively at the base and top of the phosphatic shale series." The plan of the mine and its equipment and method of development are discussed more fully.

Pardee, J. T., 1917, The Garrison and Philipsburg phosphate fields, Montana: U. S. Geol. Survey Bull. 640–K, pp. 195–228, pls. 8, 9, figs. 20–22. Discusses the origin of the phosphate rock in the Western States and suggests that a cold climate may have been a necessary condition.

*Richards, R. W., and Mansfield, G. R., 1912, The Bannock overthrust, a major fault in southeastern Idaho and northeastern Utah: Jour. Geology, vol. 20, no. 8, pp. 681–709, figs. 1–5. Contains the original descriptions of the Phosphoria formation (pp. 684–689), Rex chert member (p. 684), and Wells formation (pp. 689–693). Describes the Bannock overthrust in the Preuss Range.

*———, 1914, Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, 76 pp., 14 pls., 3 figs. Contains the first published descriptions of the stratigraphy, structure, and phosphate deposits in Tps. 9 and 10 S., R. 45 E., and the first published geologic and topographic maps of these townships (pls. 12, 13). Gives estimates of tonnage in the townships (pp. 58–64), stratigraphic sections, and several analyses of the phosphatic shale member (pp. 26–27). The structure sections on plates 12 and 13 are the first published illustrations of the folds later named the Georgetown syncline, Webster syncline, and Snowdrift anticline.

*Richardson, G. B., 1913, The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, no. 214, art. 39, pp. 406–416. Contains the original description of the Brazer limestone (pp. 413–414).

———, 1941, Geology and mineral resources of the Randolph quadrangle, Utah–Wyoming: U. S. Geol. Survey Bull. 923, 54 pages, 8 pls., 2 figs. The phosphatic shale member of the Phosphoria formation is mapped as a separate cartographic unit (pl. 1). The occurrence and character of the phosphate rock are discussed, and eight sections of phosphatic beds and the content of phosphorus pentoxide, P_2O_5, and of bone phosphate of lime, $Ca_3(PO_4)_2$, in the measured units (pp. 44–48) are given.

Smith, G. O., et al., 1913, The classification of the public lands: U. S. Geol. Survey Bull. 537, 197 pp., 8 figs. Phosphate lands are discussed on pages 39–40 and 123–134.

Waggaman, W. H., 1910, A review of the phosphate fields of Idaho, Utah, and Wyoming, with special reference to the thickness and quality of the deposits: U. S. Dept. Agr. Bur. Soils Bull. 69, 48 pp., map, tables. The Georgetown area is discussed on pages 13–16. Table 2 gives the content of P_2O_5 in 19 samples from sec. 30, T. 10 S., R. 44 E.

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