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PHOSPHATE ROCK NEAR MAXVILLE PHILIPSBURG, AND AVON MONTANA

BY

J. T. PARDEE

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PHOSPHATE ROCK NEAR MAXVILLE, PHILIPSBURG, AND AVON, MONTANA

By J. T. Pardee

ABSTRACT

This paper gives the results of a resurvey of certain areas in Montana to which renewed interest has been directed by the development recently of a market for crude phosphate rock in British Columbia, nearby.

The phosphate rock occurs in these areas as layers distributed through a stratum 12 to 16 feet thick in the lower part of the Permian Phosphoria formation. The neighboring sedimentary rocks are chiefly shale, sandstone, and limestone that range in age from pre-Cambrian to Cretaceous. The formations are involved in a series of tightly squeezed folds and are displaced by an overthrust and by faults of normal type. The folding has caused the phosphate bed to be steeply inclined and to rise to the surface along the sides of several anticlines.

In most places a closely spaced group of the phosphate layers form a workable bed 3 feet or more thick that averages about 70 percent of tricalcium phosphate, or "bone phosphate of lime." In general the phosphate rock contains a small amount of organic matter, and in one place a residue of 2 percent of carbon dust and traces of vanadium, tin, and boron are present.

The topography is favorable to mining through adits, and parts of the 3-foot phosphate bed thus accessible are calculated from profiles and cross sections to contain 18,650,000 tons near Maxville, 8,000,000 tons near Philipsburg, and 600,000 tons near Avon.

INTRODUCTION

This paper is based chiefly upon a resurvey of areas near Maxville and Philipsburg, Mont., described in previous reports.[1] In addition it covers a small area northwest of Avon adjoining the Garrison area. (See fig. 56.)

Since the reports cited were published additional exposures of the phosphate bed have been made by mine workings, and interest in the phosphate deposits of the general region has been greatly increased by the shipment, in 1930–32, of large amounts of the phosphate rock from a point near Garrison to the smelter of the Consolidated Mining & Smelting Co. of Canada at Trail, British Columbia, for use in the manufacture of fertilizer.

[1] Pardee, J. T., The Garrison and Philipsburg phosphate fields, Mont.: U. S. Geol. Survey Bull. 640, pp. 195–228, 1917; Phosphate rock near Maxville, Granite County, Mont.: U. S. Geol. Survey Bull. 715, pp. 141–145, 1921.

The area near Maxville was resurveyed during parts of the summers of 1932 and 1933. In this work the writer received much valuable assistance from the Northwest Development Co. in setting triangulation monuments and from Omer Edgar and Glenn C. Reed as rodmen. The areas near Philipsburg and Avon were examined respectively in 1924 and 1931, chiefly to obtain information needed in the administration of the public lands.

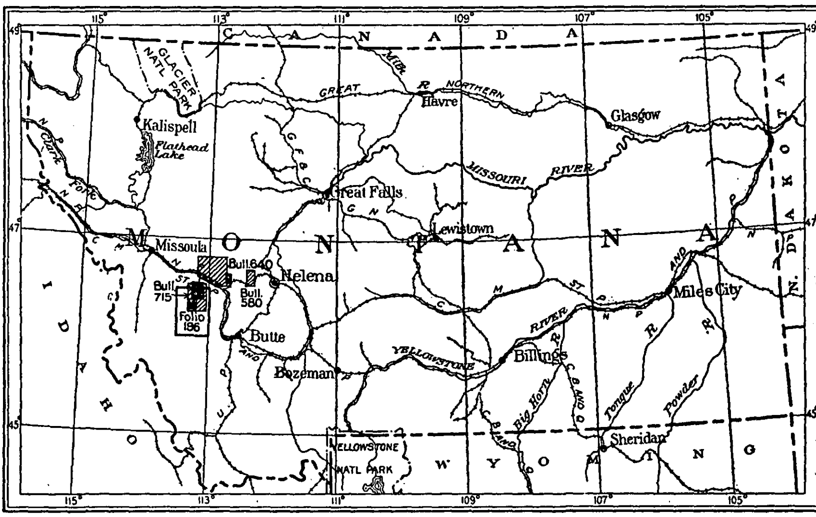

FIGURE 56.—Index map showing location of phosphate areas near Maxville, Philipsburg, and Avon, Mont.

PRODUCTION

The reported production of phosphate rock in Montana in 1929–32 amounted to 94,028 long tons, worth at the mine more than $400,000, as follows:

Production of phosphate rock in Montana, 1929–32 [1]

Year	Long tons	Value at mine	
		Total	Per long ton
1929	40	$400	$10.00
1930	6,005	27,457	4.57
1931	67,893	301,511	4.44
1932	20,090	79,271	3.95

[1] U. S. Bur. Mines, Minerals Yearbook, 1932–33, statistical appendix, p. 26, 1933.

The great bulk of this production came from the mine operated by the Montana Phosphate Products Co. and its successor, William Anderson, on East Brock Creek near Garrison, in an area described in Bulletin 640. Shipments from the particular areas covered by this paper include 2 cars from the mine of C. A. Graveley, near Avon; 10 cars from the Northwestern Improvement Co.'s mine, on Douglas

Creek, near Maxville; and several cars from the mines of Omer Edgar and the Washington Phosphate & Silver Co., near Maxville, and of Dissett Bros., at Philipsburg.

MARKETS

Most of the crude phosphate rock mined in this region to date has been shipped to the smelter at Trail, British Columbia. Some comparatively small lots have gone to the Anaconda Copper Co.'s fertilizer plant at Anaconda, Mont., and to dealers or agents at Seattle or other shipping points who were seeking to establish markets in Australia and Japan.

Sample lots of finely ground "raw rock" produced at the Washington & Montana Phosphate Co.'s mill at Maxville and the fine concentrate from a test run on rock from Dissett Bros.' mine at Philipsburg have been sent to points in the agricultural areas of eastern Washington for trial as fertilizer. What measure of success has attended these attempts to develop new markets was not learned.

During 1933 mining and development work practically ceased. The return of activity on an increasing scale is expected with general industrial recovery.

SURFACE FEATURES

The areas here considered are characterized by rather marked relief, a condition that is favorable to the development and mining of the phosphate bed through adit levels. In the Maxville area Boulder, Gird, and Douglas Creeks and at Philipsburg the stream in Stewart Gulch have cut deep valleys that cross repeated outcrops of the phosphate bed. Intervening ridges carry the phosphate outcrops from 500 to 1,500 feet above the drainage levels of these streams.

The same valleys afford down-grade roadways from the deposits to the Drummond and Philipsburg branch of the Northern Pacific Railway. From the mine-entry sites the distance to the railroad along these valleys ranges from 2 to 8 or 9 miles, but from most of them it is less than 6 miles.

ROCKS

The rocks that underlie the areas described include shale, sandstone, limestone, and related sedimentary beds that range in age from pre-Cambrian to Cretaceous, and sedimentary and igneous rocks of later age that rest upon or intrude them. (See pls. 28, 29, 32.) Summary descriptions of these rocks are given in the reports cited, and most of them are described in detail by Calkins,[2] from whose report the following tabular description is condensed.

[2] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, pp. 35–81, 1913. Calkins, F. C., and Emmons, W. H. U. S. Geol. Survey Geol. Atlas, Philipsburg folio (no. 196), 1914.

Generalized section of pre-Tertiary sedimentary rocks in the Flint Creek Range, Mont.

Geologic age		Formation	Character	Thickness (feet)
Upper Cretaceous	Colorado		Chiefly gray to olive sandstone; some beds of dark-gray to green shale. Top removed by erosion.	1,000+
Upper Cretaceous	Colorado		Fissile black shale.	500
			Unconformity	
Lower Cretaceous		Kootenai formation	Red and green shales and flaggy sandstones. Pebbly bed at bottom. Several thin bands of limestone. Those in lower portion weather buff. The uppermost is crowded with small fresh-water gastropods.	1,500
			Unconformity?	
Jurassic		Ellis formation	Chiefly gray to green shale and sandstone. Buff or yellow on weathered surface. Thin beds of limestone in lower part contain marine Jurassic fossils.	430
			Unconformity	
Carboniferous	Permian?	Phosphoria formation	Gray, somewhat cherty quartzite; weathers rusty brown. A little shale interbedded.	120
Carboniferous	Permian?	Phosphoria formation	Chiefly gray cherty limestone. Marine Pennsylvanian or Permian fossils. A bed of rock phosphate in lower part.	90
Carboniferous	Pennsylvanian?	Quadrant quartzite	Massive fine-grained quartzite, white to pale drab, stained yellowish brown.	220–350
			Unconformity?	
Carboniferous	Pennsylvanian?	Quadrant quartzite	Maroon shale, commonly mottled, and gray to pink magnesian limestone.	100–300
			Unconformity?	
Carboniferous	Mississippian	Madison limestone	Limestone, massive, white to pale gray in upper part; lower part thin-bedded, flaggy, black, weathering light blue; fossiliferous.	1,200–1,500
			Unconformity?	
Devonian	Middle Devonian	Jefferson limestone	Light-gray to black magnesian limestone; fossiliferous.	1,000
Silurian?		Maywood formation	Magnesian reddish, gray, and whitish limestone and gray and green shale.	200–300
			Unconformity?	
Cambrian		Red Lion formation	Laminated siliceous white to drab and purple limestone and black to olive-green calcareous shale.	300
Cambrian		Hasmark formation	Magnesian white to blue-gray limestone and calcareous shale.	1,000
Cambrian		Silver Hill formation	Brown, white, and green banded calcareous shale, siliceous laminated limestone, and dark-green shale.	330±
Cambrian		Flathead quartzite	Vitreous gray to drab quartzite.	150
			Unconformity	
Algonkian	Belt		Shale and sandstone, chiefly red.	5,000
Algonkian	Belt		Thin-bedded siliceous and ferruginous limestone and shale, generally buff on weathered surface. (The underlying formations exposed in other parts of the Philipsburg quadrangle are not present in the Flint Creek Range.)	4,000±

The phosphate rock occurs within the older group, where it is associated with beds of shale, sandstone, and other sediments composing the Phosphoria formation.

Several layers of phosphate rock and phosphatic clay or shale together make up a phosphatic stratum which is generally from 12 to 15 feet thick. This stratum is comparatively soft and nonresistant to weathering, and its outcrop is therefore generally concealed by a surface mantle. As a rule, however, its position can be determined within a few feet by reference to certain neighboring beds that crop out prominently. Of these the nearest and most useful is the quartzite member of the Quadrant formation, a bed 100 feet or more thick of hard fine-grained dense rock that appears light gray on fresh fracture and light reddish brown on weathered surfaces. Its outcrops are cliffy or wall-like and generally prominent enough to be seen from a distance. In most places the phosphatic stratum lies less than 100 feet stratigraphically above the quartzite. Northwest of Avon the two are separated by only about 20 feet of cherty-appearing rock. At an open cut on the south side of Douglas Mountain 40 feet of hard gray limestone containing thin bands of chert separates them. North of Gird Creek in sec. 7, T. 8 N., R. 12 W. (pl. 28), the phosphate is nearly 100 feet above a prominently outcropping bed of the quartzite, and the intervening space is occupied by about 30 feet of cherty limestone and 70 feet of limy sandstone, named in descending order. On Flagstaff Hill, at Philipsburg (pl. 29), the phosphatic stratum is about 30 feet thick and about 100 feet above the main quartzite bed, and part of the intervening space is occupied by cherty limestone. On the upper side of the phosphatic stratum are three beds that generally crop out prominently enough to form useful reference planes. The nearest of these is a bed of extremely fine grained cherty-appearing light- to dark-gray quartzite or sandstone, without the slight reddish tint generally shown by the quartzite of the Quadrant formation. In places its outcrop shows small cavities due apparently to the solution of lime. This bed—probably the equivalent of the Rex chert member of the Phosphoria formation—ranges from 150 to 200 feet in thickness. In the Maxville area (pl. 28) the more prominently exposed part is 40 or 50 feet above the phosphatic stratum, and on Flagstaff Hill from 30 to 40 feet above. In both areas soft shaly beds intervene.

The next higher prominent stratum is a thick bed of sandstone belonging to the Ellis formation, which in the Maxville area crops out from 360 to 400 feet above the phosphate. It is light gray and speckled with grains of black chert.

About 2,000 feet above the phosphate a bed of limestone in the Kootenai formation is crowded with small snail-like fossil shells (gastropods). It forms very persistent light-colored reefs.

The Tertiary "lake beds" and later alluvial deposits bear no relation to the phosphatic stratum and its related rocks except to conceal their outcrops in places. At Philipsburg they form a thick cover over the phosphate outcrop between Red Hill and Flagstaff Hill (p. 29). In the Maxville area and near Avon they do not overlap the outcrops sufficiently to make the position of the phosphatic beds uncertain.

The intrusive granitic bodies came to place later than the phosphatic stratum and its enclosing rocks and evidently have displaced or engulfed large parts of them east of Philipsburg and southeast of the Maxville area. The diorite sills east of the Maxville area are, so far as exposed, not in contact with the phosphate.

STRUCTURE

In the Maxville and Philipsburg areas the phosphatic stratum and its enclosing rocks are involved in a series of rather tightly squeezed folds and are broken and displaced by a great overthrust and by large faults of normal type. The folds and normal faults trend northward, and the axes of the folds persistently descend in the same direction. The beds have been overthrust eastward. A group of small faults superimposed on the structural features mentioned strike northwest. The folding has caused the beds to be steeply inclined and the phosphatic layer to rise to the surface on the sides of several anticlines. The overthrusting has buried the phosphate in places along the west.

FOLDS

Four of the larger folds in the Maxville area are described in a former report [3]—the Dunkleberg Ridge, Royal, Douglas Mountain, and Princeton anticlines, named from east to west. Of these no further information is available for the Dunkleberg Ridge and Royal anticlines or for the other two south of Princeton Gulch.

From Princeton Gulch north the Douglas Mountain anticline is exposed for a distance of 10 miles, beyond which it is concealed by Tertiary and later sediments. Along the axis of this fold Madison limestone is exposed as far as Douglas Mountain. Beyond, as a result of the northward dip of the axis, the Madison is succeeded in order by younger beds. The phosphate bed crops out on both sides of this fold as far as the northern part of sec. 30, T. 9 N., R. 12 W. (pls. 28, 30), the western outcrop being a repetition due to one of the larger normal faults.

The Princeton anticline can be traced from Princeton Gulch northward 6 or 7 miles to Douglas Creek, where it likewise disappears beneath the Tertiary deposits. At the extreme south end this fold brings Jefferson limestone to the surface. The northward dip of its

[3] Pardee, J. T., op. cit. (Bull. 715), pp. 142-143.

axis, somewhat steeper than that of the Douglas Mountain anticline, limits the northward exposure of the phosphate bed at a point in sec. 36, T. 9 N., R. 13 W., on the ridge between Gird Creek and Douglas Creek (pls. 28, 30). The west branch of the Princeton anticline joins that fold at the south. Part of its east side is exposed east of Gird Creek in secs. 2 and 11, T. 8 N., R. 13 W., and a ledge of Quadrant quartzite west of that stream marks its west side. To the north it is buried by overthrust masses and areas of Tertiary and later sediments.

East of the Douglas Mountain anticline a broad syncline carries the phosphate bed to a depth of several thousand feet. Between the Douglas Mountain and Princeton anticlines is a relatively narrow and tightly squeezed syncline, and between the branches of the Princeton anticline a more open one. All the synclines deepen toward the north and become shallower toward the south. The two last mentioned terminate at Princeton Gulch and Gird Creek respectively.

In the Philipsburg area (pls. 29, 31) the principal fold is a rather broad, flat arch called the "Philipsburg anticline" by Calkins.[4] Southeast of Philipsburg it is cut off by intrusive granite. From that point it extends to Wyman Gulch, a distance of 5 or 6 miles, along a course that curves from northwest to northeast. Its axis dips 20° or more northward, and rocks ranging from Belt (pre-Cambrian) to Kootenai (Cretaceous) are exposed in order along its crest. The phosphate crops out on the west side of this fold for 2 miles or more, beginning at a point about a mile north of Philipsburg. Thence, on the north side of Stewart Mountain, it curves around the plunging arch and returns southward a short distance.

West of the Philipsburg anticline another fold, the Red Hill anticline, begins in Red Hill and extends north 2 miles to a fault. It is tightly squeezed, broken with faults, and overturned eastward. In places at least the phosphate bed appears on both sides of it.

Between these two anticlines is the Wyman Gulch syncline. This fold begins in the southern part of Red Hill and extends northward and northeastward. Beyond Stewart Gulch it deepens rapidly and widens to surround the north end of the Philipsburg anticline. A few miles farther north it is buried by overthrust masses from the west. The west side is overturned eastward and broken by the Bungalow thrust (p. 182). It carries the phosphate outcrop, at least in places.

In the area northwest of Avon the phosphate and its enclosing rocks are deformed by the northeast limb of the Garrison anticline [5] and by an adjoining syncline and the succeeding limb of an anticline (pl. 32). In addition a small fold in the western part of the area rises across the axis of the Garrison anticline. The phosphate bed

[4] Calkins, F. C., op. cit. (Prof. Paper 78), p. 143.
[5] Pardee, J. T., op. cit. (Bull. 640), p. 213.

is carried to a considerable depth by the syncline mentioned and raised to the surface by both of the adjoining anticlines.

FAULTS

The most impressive structural feature of the region that includes the Maxville and Philipsburg areas is a fault on which the overlying mass has moved eastward for a distance of several miles. This fault, which may be referred to as the Philipsburg overthrust, is mapped within the Philipsburg quadrangle and described by Calkins.[6] After the overthrust mass had come to place it was further deformed by folding and faulting, partly engulfed or displaced by intrusive granite, and largely removed by erosion. As a result the thrust plane shows variations in dip, dislocations, and interruptions, and its trace or intersection with the present surface is a correspondingly irregular and broken line (pls. 28, 29).

The overthrust mass is composed chiefly of Belt sandstone and shale but includes younger rocks along its eastern border (pls. 28, 30). It was deformed along an axis extending from Philipsburg north-northeastward to Maxville by arching and by the Bungalow upthrust. To the east, along South Boulder Creek, it was also depressed by a downfold and a normal fault. The elevated portion has been largely removed by erosion, and the underlying rocks are thus exposed as through a window. In the depressed area the overthrust rocks still remain.

Outlying bodies detached from the main overthrust mass by faulting and erosion occur on the slope northeast of Gird Creek in sec. 36, T. 9 N., R. 13 W., and on top of Eyebrow Hill, in sec. 25, south of Douglas Creek. In most places there is rather close agreement in strike and dip between the rocks above and below the thrust plane, but in Eyebrow Hill an anticline formed of Madison and Quadrant beds is superimposed on a syncline in Cretaceous formations.

A fault shown in the tunnel of the Washington Phosphate & Silver Co. just east of Maxville (pls. 28, 30, 33) forms the boundary of the "window" previously mentioned. This fault dips 50°–60° W., and the movement on it was an upthrust of the hanging wall, causing the rocks that had been overridden to lie once more above those overthrust. To the north across Boulder Creek a tunnel of the Fields mine, which was accessible in 1916, penetrates the same fault. A house nearby called "The Bungalow" stands above the fault line and affords a convenient name for it.

North of the Fields tunnel the Bungalow fault is concealed by later sediments, but the dissimilar strikes of two neighboring rock outcrops beyond Gird Creek suggest that it passes between them. Southward the fault has not been definitely traced, but a reverse

[6] Calkins, F. C., U. S. Geol. Survey Prof. Paper 78, pp. 146–148, 1913; Folio 196, 1915.

fault mapped near the head of Wyman Gulch (pl. 29) is suggestively in line with it. That intense compression attended the faulting is shown by a breccia 100 feet thick (pl. 33).

In the Maxville area several strike faults of normal type cut both the overthrust mass and the underlying rocks. Some of them are 10 miles or more long and cause displacements of 3,000 feet or more. One along the west side of the Douglas Mountain anticline repeats the outcrop of the phosphate bed for several miles. At a few places in the Maxville and Philipsburg areas small faults that strike northwest cut across those described.

At the Graveley mine, northwest of Avon, a fault that strikes northwest separates the phosphate bed and its enclosing rocks from an area of extrusive rocks on the northeast that forms the downthrown block (pl. 32). To the southwest across Gimlet Creek the phosphate outcrop is jogged by several normal faults transverse to the axis of the Garrison anticline.

PHOSPHATE ROCK

OCCURRENCE

The phosphate rock is a sedimentary deposit that occurs like coal, as beds enclosed between layers of other sediments. In this region the known phosphate beds are found only in the lower part of the Phosphoria formation, where together with several layers of phosphatic clay or shale they form a phosphatic stratum that ranges in thickness from 9 to 12 feet near Maxville and is 15 or 16 feet thick at Princeton Gulch and Philipsburg (pl. 34, sections A to L).

Individual layers of the phosphate rock range from an inch to a foot or two in thickness and number 5 to 7 or more. Near Maxville their aggregate thickness is about 4 feet, at Philipsburg 5 feet, and at Princeton Gulch 6 feet. They are distributed throughout the phosphatic stratum but occur mostly at the top, where they form a closely spaced group that is generally 3 feet or a little more in thickness. This upper group is therefore the most valuable part of the phosphatic stratum, and its members are referred to collectively as the "main phosphate bed."

The deformation described above has caused the phosphate bed in most places to be steeply inclined (pls. 30, 32). It is carried to the surface by several of the anticlines and lowered to considerable depths in some of the synclines. The overthrust masses doubtless bury parts of it west of the Maxville and Philipsburg areas. The phosphate outcrop is repeated by faulting along the west side of the Douglas Mountain anticline, but most of the other strike faults displace the deposit underground (pl. 30). In addition, slight displacements by the northwest faults may be observed at several places. At the Fields tunnel and the mine of the Washington Phosphate & Silver Co. the

Bungalow fault has crushed the phosphatic stratum and its adjoining bed to a formless breccia (pl. 33).

Since the deformation described was accomplished, much of the elevated part of the phosphate bed has been cut away by erosion. The bulk of the remainder is therefore present in the synclines and sides of the anticlines.

COMPOSITION

The amount of phosphatic material in the phosphate rock as determined by analysis is usually reported as tricalcium phosphate ($Ca_3(PO_4)_2$), commonly known as "bone phosphate of lime" or "b. p. l." In the Maxville area, as shown in sections A to G, plate 34, samples of the phosphate rock range in b. p. l. content from 67.05 to 73.27 percent and average slightly more than 70 percent. In collecting these samples certain narrow clay or shale seams were rejected, as indicated in plate 34. Inclusion of them may give a result 10 percent lower, as shown by samples from the Edgar tunnel (pl. 34, F). Samples of the beds designated "phosphatic clay" (pl. 34, A, B, I, L) contain somewhat less than half as much b. p. l. as the phosphate rock. Layers of the material called "phosphatic chert" are visibly high in silica and low in phosphate. No analyses of them are available. In the Philipsburg area the samples indicate a somewhat lower average. In addition to those given in plate 34 a sample from a 3-foot layer 100 feet west of the New Hope shaft showed 69.68 percent of b. p. l. and one from a 3-foot layer at the face of the 100-foot tunnel on Flagstaff Hill 63.35 percent.

The chief impurities in the phosphate rock are clay and silica. The silica occurs mostly in the form of fine-grained cherty-appearing quartz. Determinations of iron and alumina have not been made in the Maxville area, but samples from Philipsburg (pl. 34) show from 3 to 5 percent of those substances together, the clay-free samples containing the smallest amount.

In general when struck with a hammer the phosphate rock emits a fetid odor due to the presence of a little organic matter.

In the mine of the Washington Phosphate & Silver Co., east of Maxville, sheared and crushed phosphate rock occurring in the Bungalow fault breccia is coal-black. A sample of pulp made from it in the company's mill contained 34.03 percent of b. p. l. Examination of specimens in the laboratory of the United States Geological Survey shows that the black color is due to the presence of 2 percent or more of carbon dust. Some of the specimens are cut by veinlets of calcite and very thin seams of a white mineral that is probably gypsum. Some contain seams of a soft black vitreous mineral that, when heated in a test tube, yields no evidence of volatile organic matter except a faint odor but burns slowly in the presence of oxygen, leaving a small amount of ash. Apparently no hydrocarbons are now present as such, but the fixed carbon and the black vitreous mineral were probably derived from such compounds or from other organic matter by the heat generated during the folding and faulting. In places the cleavage planes in the sheared rock are coated with thin greenish films that contain vanadium. Several tests of the same material failed to show any uranium. A spectroscopic test by George Steiger, however, detected traces (0.02 percent or more) of tin and boron but no gold, tungsten, tantalum, cadmium, germanium, or beryllium.

In the Philipsburg area the b. p. l. content of samples ranges from 45 to 64 percent and averages about 55 percent (pl. 34, I, K, L). A sample of material in the ore bin at the Dissett mine from which most of the clay had separated during handling contained 64.05 percent of b. p. l. and 3.01 percent of iron and alumina.

The highest grade of the phosphate rock so far reported from the areas here considered occurs in the mine of C. A. Graveley, northwest of Avon. A recent shipment of 100 tons from this mine averaged 76.4 percent of b. p. l., and a sample of a 3½-foot layer in the face of the tunnel contained 79.06 percent.

In neighboring areas phosphate rock containing 80 percent or more of b. p. l. is reported at the mine of the Northwestern Improvement Co. near Elliston, and more than 67,000 tons shipped from the Anderson mine, northwest of Garrison, in 1931 averaged 69.8 percent.

BENEFICIATION

The analyses of mine and ore bin samples from the Dissett mine (pl. 34, I) show that the mere handling of the phosphate rock tends to enrich it by shaking out some of the clay not separated in mining. At the Edgar mine a sample from which the clay seams were excluded was 10 percent richer than one which included them. These facts suggest that the "run of mine" product might be materially improved either by coarse-crushing and dry screening or by washing.

A wet gravity-concentration test was made by the operators of the Dissett mine in 1931 on the material classified as phosphatic clay (pl. 34, I). After fine grinding the material was washed in a crude launder that had been originally designed to concentrate sulphides and gold from quartzose ores. The result reported was a concentration of 2 into 1, the crude material containing about 40 percent of b. p. l. and the concentrate 65 percent. The results obtained by investigators of the United States Bureau of Mines [7] by wet-concentration methods on Florida phosphatic sands were somewhat better. Recently a still higher concentration was obtained by flotation.[8] These

[7] Lawrence, H. M., and O'Meara, R. G., Gravity concentration on certain Florida phosphatic sands: U. S. Bur. Mines Rept. Inv. 3018, 1930.

[8] Lawrence, H. M., and Roca, E., Flotation of low-grade phosphate ores—II: U. S. Bur. Mines Rept. Inv. 3105, 1931.

results are mentioned to show that much of the material in the phosphatic stratum outside the main phosphate bed may, when the market demands, prove to be workable.

RESERVES

The most easily workable and consequently the most valuable parts of the phosphate bed are those that lie above existing drainage levels. The topography in many places permits the deposit to be opened by adit levels or crosscuts projected from easily accessible locations. In general, the bed is inclined sufficiently to be mined by overhead or gravity stoping.

Within the areas here considered the phosphate bed, where not badly disturbed by faulting, shows no great variations in thickness. It is believed that an average of at least 3 feet can be safely counted on. With that figure and the aid of the accompanying cross sections and profiles (pls. 30–32), which are drawn to scale, the amounts available in any particular block can be calculated approximately. For an example may be taken the block that lies above an adit level supposed to be driven 5,000 feet north from Douglas Creek, the site of the Northwest Improvement Co.'s tunnel 3, on the bed that crops out on the east side of the Douglas Mountain anticline. From sections B–B′ and C–C′ and profile V–V′, plate 30, it appears that the slope height of the bed above the adit ranges from 0 to 850 feet and averages 450 feet. Therefore the area of this block is 2,250,000 square feet, and its content of phosphate, if the bed is 3 feet thick, is 6,750,000 cubic feet. As 13 cubic feet of phosphate in place is equivalent to 1 ton of 2,240 pounds, the amount is, in round figures, 500,000 tons. In a similar manner the following amounts may be calculated:

Estimates of phosphate rock above possible entries driven at natural drainage levels

Maxville area	*Long tons*
East limb of Douglas Mountain anticline from sec. 30, T. 9 N., R. 12 W., south to Princeton Gulch, in sec. 20, T. 8 N., R. 12 W. Outcrop 3 (pl. 30, profile V–V′, cross sections A–A′ to F–F′)	4, 350, 000
West limb of Douglas Mountain anticline from sec. 30, T. 9 N., R. 12 W., south to Princeton Gulch, in sec. 19, T. 8 N., R. 12 W. Outcrop 2 (pl. 30, profile W–W′, cross sections A–A′ to F–F′)	4, 000, 000
West limb of Douglas Mountain anticline from sec. 31, T. 9 N., R. 12 W., south to Princeton Gulch, in sec. 19, T. 8 N., R. 12 W. Outcrop 1 (pl. 30, profile X–X′, cross sections B–B′ to F–F′)	3, 850, 000
East limb of Princeton anticline from sec. 36, T. 9 N., R. 13 W., south to slope north of Princeton Gulch (pl. 30, profile Y–Y′, cross sections B–B′ to F–F′)	3, 350, 000

Estimates of phosphate rock above possible entries driven at natural drainage levels—Continued

	Long tons
Maxville area—Continued	
West limb of Princeton anticline from sec. 36, T. 9 N., R. 13 W., south to slope above Gird Creek in sec. 11, T. 8 N., R. 13 W. (pl. 30, profile Z–Z′, cross sections B–B′, C–C′, D–D′)	1, 600, 000
East limb of west branch of Princeton anticline in secs. 2 and 11, T. 8 N., R. 13 W., east of Gird Creek	1, 500, 000
	18, 650, 000
Philipsburg area	
Around Philipsburg anticline from Red Hill, in sec. 24, T. 7 N., R. 14 W., north and east to South Boulder Creek, in sec. 3, T. 7 N., R. 13 W. (pl. 31)	8, 000, 000
Northwest of Avon	
From Graveley mine northwest 2 miles in secs. 2 and 3, T. 10 N., R. 9 W. (pl. 32)	600, 000

Large additional amounts of phosphate are probably to be found above natural drainage levels on the sides of the Red Hill anticline, near Philipsburg, and on the west side of the Wyman Gulch syncline, between Stewart Gulch and Maxville, but information on which to base a trustworthy estimate is not available. There is also a small quantity in Flagstaff Hill.

Below natural drainage levels there is a large amount of phosphate that may be regarded as a reserve for the distant future. For the purposes of classification, lands that are underlain by phosphate of the quality and thickness here described down to a depth of about 2,200 feet are considered phosphate-bearing. The total amount of phosphate within such a depth is indicated to be 30,000,000 tons in the Philipsburg area and 90,000,000 tons in the Maxville area.

DEVELOPMENT WORKINGS

In the last few years development workings have been made on the phosphate bed along Douglas Creek and at other places near Maxville, on Red Hill near Philipsburg, and on the property of C. A. Graveley, near Avon.

Along Douglas Creek in sec. 31, T. 9 N., R. 12 W., the Northwestern Improvement Co. has driven adit levels on three segments of the phosphate beds that extend to the surface on the flanks of the Douglas Mountain anticline (pl. 28). From west to east these segments are known respectively as beds 1, 2, and 3, and their adit levels by the same names. Adit 1 is 50 feet long; adit 2, 160 feet; and adit 3, 500 feet. Depths below the surface to which they expose the phosphate range from about 30 feet at adit 1 to about 250 feet at adit 3. Ore bins are built at adits 2 and 3, and adit 3 is equipped with chutes for overhead stoping. In other places nearby, mostly on Douglas Mountain in secs. 30 and 31, the phosphate bed is exposed by open cuts and pits.

Between Douglas and Gird Creeks, in sec. 36, T. 9 N., R. 13 W., two adits of Omer Edgar, each about 50 feet long and equipped with ore-loading platforms, are made on the phosphate outcrop that rounds the north end of the Princeton anticline.

In sec. 12, T. 8, N., R. 13 W., about 2 miles south of the Edgar mine, a tunnel at the Blue Bell mine of Eplin & Horton penetrates the phosphate bed on the east flank of the Princeton anticline at a depth of about 80 feet. On Gird Creek about three-quarters of a mile southeast of the Blue Bell mine the continuation of phosphate bed 1 on the west flank of the Douglas Mountain anticline is partly exposed near the portal of a tunnel of the Barnes mine.

A short distance southeast of Maxville the tunnel of the Washington Phosphate & Silver Co. (pl. 33) penetrates, at a depth of about 300 feet, broken masses of the phosphate bed that lie within the breccia zone accompanying the Bungalow fault. At this working ore bins and a mill for fine grinding of the phosphate rock have been erected.

On Red Hill, near Philipsburg, the workings of the Dissett mine consist of a crosscut adit 300 feet long from which a north drift connects with an inclined shaft. They expose the phosphate bed to a depth of 100 feet at the south end of the Wyman Gulch syncline. Incomplete exposures are made on the same fold by a trench at the New Hope mine, a mile to the north, and on Stewart Mountain, about 3 miles to the northeast. In 1924 the phosphate bed on Flagstaff Hill had been developed by a tunnel 100 feet long and by several trenches on ground that is now occupied by the manganese milling plant of the Trout Mining Co.

In the tunnel of C. A. Graveley, near Avon, the phosphate bed is exposed at a depth of 80 feet.

Outside the areas covered by the present report, much development work was done several years ago by the Anaconda Copper Mining Co. at Warm Spring Creek, north of Garrison, on segments of the phosphate bed, elevated along the west limb of the Garrison anticline.[9] More recently extensive mining was done at East Brock Creek farther northwest on the same fold by William Anderson, who produced and shipped a large amount of phosphate rock (p. 185).

Near Elliston considerable development work has been done recently by the Northwestern Improvement Co. along outcrops described in a former report.[10]

[9] Pardee, J. T., U. S. Geol. Survey Bull. 640, p. 219, 1917.

[10] Stone, R. W., and Bonine, C. A., The Elliston phosphate field, Mont.: U. S. Geol. Survey Bull. 580, pp. 373-383, 1915.

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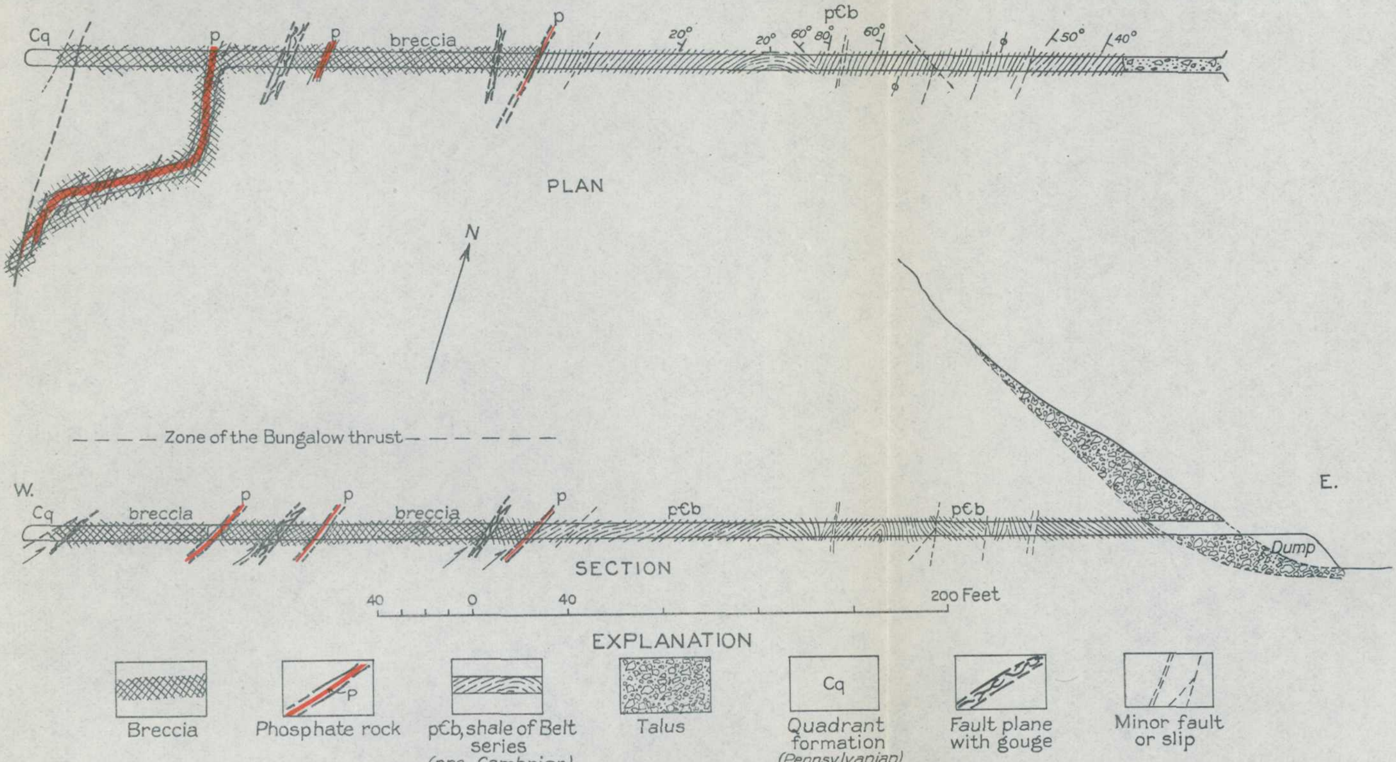

PLAN AND SECTION ALONG TUNNEL OF WASHINGTON PHOSPHATE & SILVER CO.

EXPLANATION OF PLATE 34, BULLETIN 847-D

A. Trench across outcrop 3 on north slope of Douglas Mountain in sec. 30, T. 9 N., R. 12 W.

B. Face of Northwest Development Co.'s tunnel 3 at Douglas Creek in sec. 31, T. 9 N., R. 12 W.

C. Trench across outcrop 2 on south slope of Douglas Mountain near top, in sec. 31, T. 9 N., R. 12 W.

D. Face of Northwest Development Co.'s tunnel 2 at Douglas Creek in sec. 31, T. 9 N., R. 12 W.

E. Face of Northwest Development Co.'s tunnel 1 at Douglas Creek in sec. 31, T. 9 N., R. 12 W.

F. Face of Edgar tunnel 1 in N½ sec. 36, T. 9 N., R. 13 W.

G. Face of tunnel at Blue Bell mine near center of sec. 2, T. 8 N., R. 13 W.

H. Slope north of Princeton Gulch in sec. 18, T. 8 N., R. 12 W. (U. S. Geol. Survey Bull. 715, p. 144, 1921.)

I. Shaft of Dissett mine in sec. 24, T. 7 N., R. 14 W.

K. Trench on Stewart Mountain in sec. 8, T. 7 N., R. 13 W.

L. Trench on south slope of Flagstaff Hill, Philipsburg. (U. S. Geol. Survey Bull. 640, p. 224, 1917.)

M. Face of tunnel at Graveley mine in sec. 2, T. 10 N., R. 9 W., near Avon.

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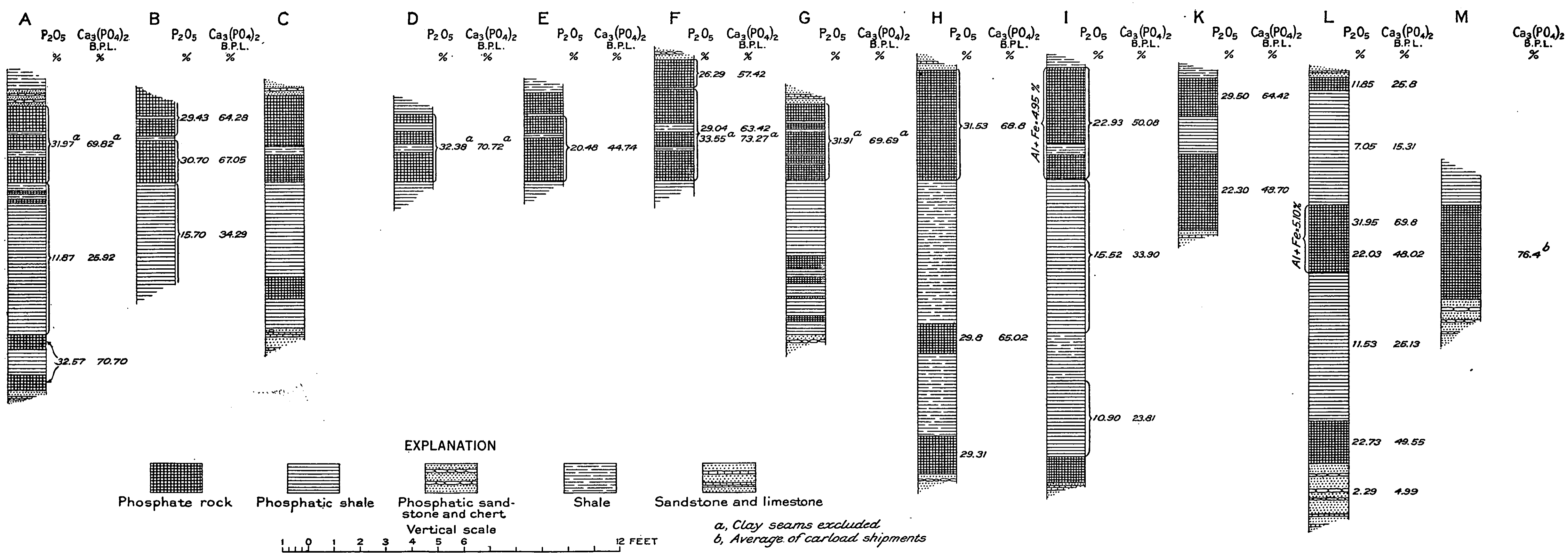

COLUMNAR SECTIONS OF PHOSPHATE AND ASSOCIATED BEDS NEAR MAXVILLE, PHILIPSBURG, AND AVON, MONT.