THE GARRISON AND PHILIPSBURG PHOSPHATE FIELDS, MONTANA.

By J. T. Pardee.

FIELD WORK.

The field work upon which the present report is based was done between August 24 and October 25, 1913. The time was expended principally on the area north of Garrison and Drummond, Mont.,

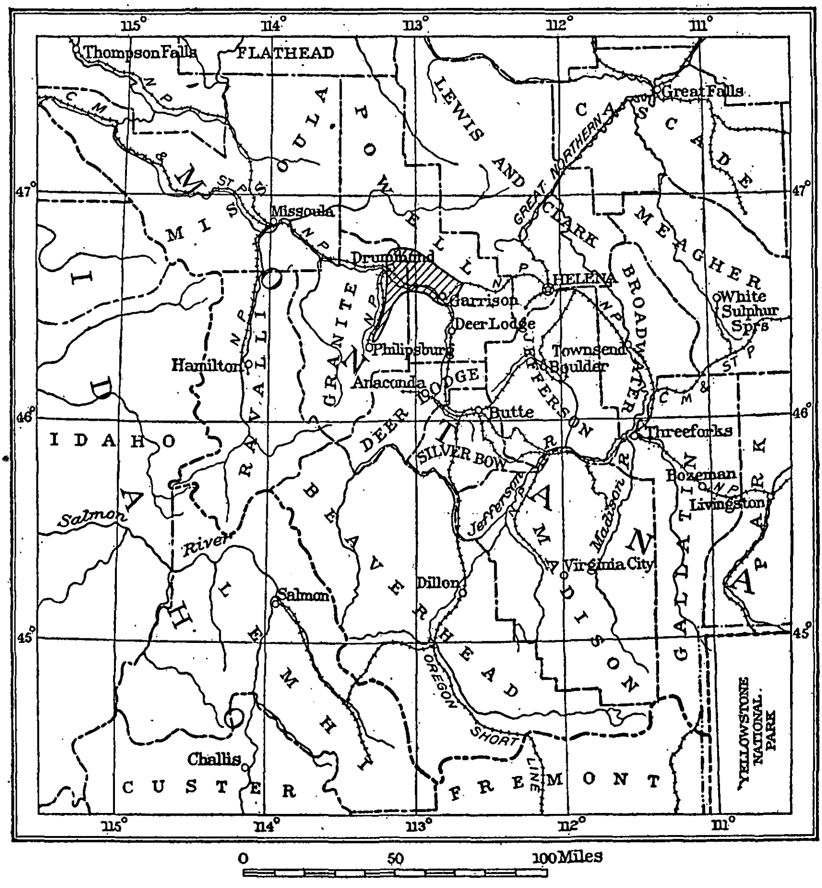


FIGURE 20.—Index map showing location of Garrison and Philipsburg phosphate fields, Mont. Area covered by this report indicated by shading.

referred to as the Garrison field, but a brief examination of the Philipsburg and Maxville localities in the Philipsburg field was made also. (See fig. 20.)

For a base map of the Garrison field the township plats of the General Land Office were utilized, and, in addition, a plane-table survey was projected across the area. As the belt along which the phosphate bed would normally be exposed at the surface is nearly everywhere occupied by deep soil or rock débris, trenches were dug at several points to obtain samples and measurements. Although in the present examination attention was directed chiefly to the outcrop of the phosphate-bearing stratum, sufficient work

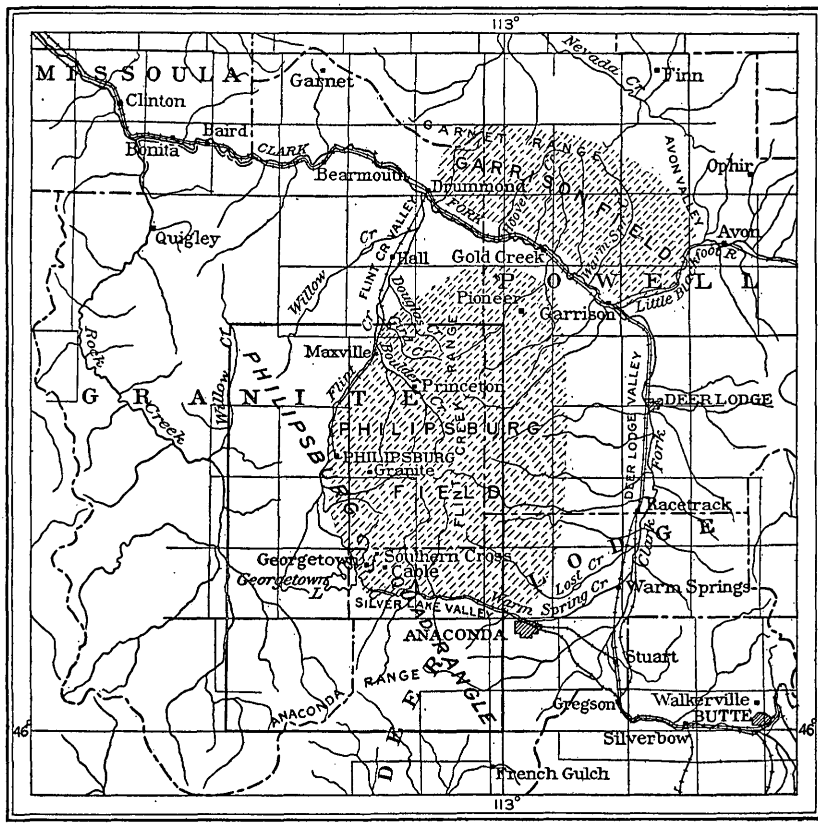


FIGURE 21.—Map showing relation of the Garrison and Philipsburg phosphate fields, Mont., to the Philipsburg quadrangle.

was done in adjoining lands to determine the general succession and structure of the several rock formations, knowledge of which is absolutely essential to a correct estimate of the phosphate deposit. The present survey was tied to others made in the same region in 1910[1] and 1911.[2] The writer was assisted in the field by T. H. Rosenkranz, to whose accurate mapping the knowledge attained

[1] Pardee, J. T., Coal in the Tertiary lake beds of southwestern Montana: U. S. Geol. Survey Bull. 531, pp. 229–244, 1913.

[2] Pardee, J. T., Some further discoveries of rock phosphate in Montana: U. S. Geol. Survey Bull. 530, pp. 285–291, 1913.

of the stratigraphy and structure is in large part due. Mr. Rosenkranz has also aided in the preparation of the present report by the contribution of rock analyses and other researches, contained in an unpublished thesis.

The southwestern three-fourths of the Philipsburg field, including the Philipsburg and Maxville localities, lies within the Philipsburg quadrangle (fig. 21), the exceedingly intricate geology of which was worked out in detail in 1906–1908 by F. C. Calkins.[1] In the Philipsburg quadrangle, therefore, the probable distribution of the phosphate deposit, as shown by outcrops of its inclosing rocks, is already known. Its actual presence or absence, dimensions, and other features, however, remain to be determined. In the course of the present investigation the phosphate bed was uncovered at Philipsburg by trenching and was sampled near Maxville in a tunnel already made by private enterprise.

The geology of that portion of the Philipsburg field north of the Philipsburg quadrangle is not known in detail. As the area is relatively small, however, some of the broader generalizations based on knowledge of the surrounding country may be applied to it.

SUMMARY.

The economic results of the present investigation may be briefly summarized as follows:

Workable deposits of high-grade rock phosphate (containing 60 per cent or more tricalcium phosphate) occur in both the Garrison and Philipsburg fields. That in the Garrison field lies from 6 to 10 miles north of the town of Garrison and is easily accessible, and the portion considered as available to mining contains by estimate 97,000,000 long tons (equivalent to 108,640,000 short tons of 2,000 pounds), an amount about twice as great as the total production of the United States to date. About one-third of the amount lies above the natural drainage levels, and much of this portion can be very readily extracted by means of adits driven along the phosphate bed.

In the Philipsburg field too little work has been done to justify a tonnage estimate, but the deposits are believed to be extensive, and are known to be in two places at least of workable size and readily available to mining.

LITERATURE.

Many papers have been published dealing with the geology of the territory that may be included within the western phosphate region. The principal reports that describe the phosphate deposits, together

[1] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, 1913. Calkins, F. C., and Emmons, W. H., U. S. Geol. Survey Geol. Atlas, Philipsburg folio (No. 196), 1915.

with a few others that describe the geology of the particular area under consideration, are listed below, in order of publication:

Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 457–535, 1910.

Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: U. S. Geol. Survey Bull. 430, pp. 536–551, 1910.

Girty, G. H., The fauna of the phosphate beds of the Park City formation in Idaho, Utah, and Wyoming: U. S. Geol. Survey Bull. 436, 1910.

Gale, H. S., Rock phosphate near Melrose, Mont.: U. S. Geol. Survey Bull. 470, pp. 440–451, 1911.

Richards, R. W., and Mansfield, G. R., Preliminary report on a portion of the Idaho phosphate reserve: U. S. Geol. Survey Bull. 470, pp. 371–439, 1911.

Pardee, J. T., Coal in the Tertiary lake beds of southwestern Montana: U. S. Geol. Survey Bull. 531, pp. 229–244, 1913.

Schultz, A. R., and Richards, R. W., A geologic reconnaissance in southeastern Idaho: U. S. Geol. Survey Bull. 530, pp. 267–284, 1913.

Pardee, J. T., Some further discoveries of rock phosphate in Montana: U. S. Geol. Survey Bull. 530, pp. 285–291, 1913.

Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, 1913.

Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, 1914.

Richards, R. W., and Mansfield, G. R., Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, 1914.

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

Calkins, F. C., and Emmons W. H., U. S. Geol. Survey Geol. Atlas, Philipsburg folio (No. 196), 1915.

Mansfield, G. R., A reconnaissance for phosphate in the Salt River Range, Wyo.: U. S. Geol. Survey Bull. 620, pp. 331–349, 1916.

GEOGRAPHY.

LOCATION AND ACCESSIBILITY.

The rock-phosphate deposits of the Western States are distributed over a large, indefinitely bounded area composed of adjoining parts of southwestern Montana, eastern Idaho, western Wyoming, and northern Utah and generally known as the western phosphate region. Of the several phosphate localities, those near Garrison and Philipsburg, Mont., which are the northwesternmost in the general region mentioned, are referred to herein as the Garrison and Philipsburg fields. Their limits can not, so far as present knowledge goes, be very definitely placed. For the purposes of the present report, however, the Garrison field may be defined as extending from Avon Valley west to the town of Drummond and from Clark Fork north to the summit of the Garnet Range or a little beyond. The Philipsburg field, which adjoins the Garrison field on the south, may be considered approximately equivalent to the area of the Flint

Creek Range, or that lying between the Deer Lodge and Flint Creek-Philipsburg valleys. The two fields combined cover the northeastern part of Granite County and a small adjoining part of Powell County, Mont.

The Garrison and Philipsburg fields lie a short distance west of the Continental Divide, within the drainage basin of Clark Fork of the Columbia (locally known as Deer Lodge River), and adjoin the principal mining and smelting section of the State. The river that divides them is closely followed by the main lines of the Northern Pacific and Chicago, Milwaukee & St. Paul railways, and the Philipsburg field is touched, in addition, by the Butte, Anaconda & Pacific Railway and the Philipsburg branch of the Northern Pacific.

The great agricultural region of the Mississippi Valley lies about 1,000 miles to the east, and the principal grain-growing localities of the Columbia basin are from 300 to 500 miles to the west. The seaports on the Pacific Ocean are about 700 miles west. In considering possible markets for the rock phosphate or its products, however, the facts that agricultural valleys of considerable extent are near by and that large areas in the Northwest heretofore considered suitable for grazing only are being brought under cultivation should not be overlooked.

TOPOGRAPHY.

Although western Montana contains many flat lowlands of notable size, much the larger part of it is occupied by mountains. As a rule the main lowlands, of which the Clark Fork valley is a typical example, separate the mountains into more or less detached groups. Of these the Garnet and Flint Creek ranges dominate, respectively, the areas referred to herein as the Garrison and Philipsburg fields.

From its blunt north end, which borders the Clark Fork valley for about 10 miles below Garrison, the Flint Creek Range extends south-southwestward a distance of about 30 miles. It is a broad, massive elevation that has an average summit level between 8,000 and 9,000 feet, or about 4,000 feet above the valleys on the east, west, and north. On the south it appears from most viewpoints as a large north spur of the imposing Anaconda Range, although as a matter of fact the two are distinctly but not widely separated by Silver Lake valley. In detail the surface of the Flint Creek Range is rugged, the northern part in particular being characterized by deep canyons and alpine peaks.

The Garnet Range is much less prominent than its neighbor to the south. The portion covered by the present report is about 25 miles long, trends west-northwest, and has a general elevation of about 6,500 feet. In distant views its broad summit appears nearly level and its contour rather smooth. In detail, however, it is seen to be moderately dissected by streams and to have some fairly prominent ridges and peaks, of which the highest is Mount Baldy (elevation, 7,690 feet).

It is convenient, in describing this region, to conform to local usage of the terms "canyon" and "valley." As a rule, all the steep-walled, comparatively narrow mountain valleys are called canyons, and the term "valleys" is used only for the broader depressions that separate the principal mountain groups. Thus the canyons are the valleys within the mountain ranges, and the valleys are the lowlands between them. Furthermore, whether by accident or otherwise, this classification agrees with a geologic grouping based on age and origin. Thus the valleys date from early Tertiary time and are chiefly of structural origin, and the canyons are of late Tertiary or Quaternary age and due to erosion alone. That the local residents should have made such a classification is not surprising, in view of the differences not only in size but in the cross sections between the structural and erosional valleys. Cross sections of the structural valleys are similar in general to those of a shallow dish or bowl, the sloping sides of which gradually curve into the bottom, while cross sections of the erosional valleys are either V-shaped or show distinct angles at the junctions of the slopes and the level bottom. The canyons in the Garnet Range that dissect the phosphate deposits most extensively are those of Warm Spring Creek,[1] East Brock Creek, and Brock Creek. The Warm Spring Creek canyon, which begins about 5 miles above the junction of the stream with Clark Fork, is a rugged V-shaped trench 1,600 feet or more deep. The canyons of the other two streams are not so deep and precipitous but likewise extend well back into the range.

A part of the valley of Clark Fork and the lower part of the Flint Creek valley together form a large irregular basin, elongated in a southeast-northwest direction, which separates the Garnet and Flint Creek ranges. Its width is about 6 miles at Garrison and 12 or 15 miles at the widest point to the northwest. Clark Fork crosses the basin from southeast to northwest and lies somewhat north of the middle, rather close to the foot of the Garnet Range. Viewed generally, the inward slopes of the basin decrease gradually as they approach the river. Elevations along the river range from about 3,900 feet at Drummond to about 4,300 feet at Garrison, but between the river and the foot of the adjacent mountain slopes there is in places a difference of as much as 1,000 feet.

In detail the basin floor is dissected by rather narrow, shallow, geologically recent stream trenches separated by broad, flat-topped remnants of the basin floor known as bench lands.

[1] This creek should not be confused with the one of the same name that flows past Anaconda.

The Garrison and Philipsburg fields are well supplied with surface water. Several vigorous and persistent streams that are valuable for power and irrigation drain the Flint Creek Range. The streams of the Garnet Range, however, are much smaller and, except Warm Spring Creek, become low or dry in the summer. Warm Spring Creek is evidently so named because after sinking and flowing underground about 2 miles the water rises with a lukewarm temperature. It is interesting to observe, also, that where the stream reappears, near the mouth of the canyon, it is about doubled in volume, is extremely "hard" with calcium carbonate, and has built a dam of travertine or a similar limy deposit 60 feet high.

CLIMATE, VEGETATION, AND SETTLEMENTS.

In this region the precipitation is light or moderate and the temperature rather low. From observations covering a considerable period of time the mean annual temperature at Helena and Missoula, Mont.,[1] is determined to be 43° and 44° Fahrenheit, respectively, and the annual rainfall 13.3 and 15.5 inches. The stations mentioned are about 50 miles east and west of the Garrison field and occupy situations comparable to points in the Clark Fork and Flint Creek valley.

The climate, however, varies considerably from place to place, according to the altitude. The main valleys and the lower slopes, which probably have a temperature and a rainfall equivalent to the mean of those given, or 43½° Fahrenheit and 14.4 inches, respectively, are rather dry and have a climate mild enough to permit the cultivation of grains and hardy fruits. The amount of rain or snow fall and the cold increase with increase in altitude, and in the higher portions of the Flint Creek Range three-quarters of the year is wintry.

Some of the higher peaks of the Flint Creek Range project above timber line, but most of the area is covered above the 6,000-foot contour with a forest of lodgepole pine except where it has been stripped for fuel. The belt between the valley levels and 6,000 feet is partly timbered with varieties of fir, the trees being mostly segregated in groves on the northerly slopes, which retain moisture better than other exposures. The uncultivated parts of the valleys as a rule lack timber, but are thickly covered with bunch grass and other forage plants.

Outside of the principal mining districts in the Flint Creek Range the mountainous portions of the area contain few inhabitants. The valleys, however, have a considerable population and several towns.

[1] Henry, A. J., Climatology of the United States: U. S. Dept. Agr. Bull. Q, pp. 802, 804, 805, 1906.

Philipsburg (population 1,109, census of 1910), situated in a celebrated silver mining district at the west foot of the Flint Creek Range, is the most important. Maxville, formerly Flint, 12 miles to the north, and Georgetown, about the same distance to the south, are smaller mining camps.

At the southern foot of the Garnet Range are several agricultural settlements, of which the largest is Drummond and the one nearest to the main phosphate deposit is Garrison.

In addition to the mining and reduction of metalliferous ores, the principal industries of the region are stock raising and the cultivation of grains.

GEOLOGY.

STRATIGRAPHY.

PRE-TERTIARY SEDIMENTARY ROCKS.

GENERAL FEATURES.

The general succession of the pre-Tertiary sedimentary rocks occurring in the Garnet and Flint Creek ranges is shown by the following table. The column representing the Garnet Range is made up chiefly of sections measured along Warm Spring, Brock, and Hoover creeks; that for the Flint Creek Range is condensed from the report on Philipsburg quadrangle by Emmons and Calkins.[1]

Generalized sections of pre-Tertiary sedimentary rocks in the Garnet and Flint Creek ranges, Mont.

Geologic age.		Formation.	Garnet Range.		Flint Creek Range.	
			Character.	Thickness (feet).	Character.	Thickness (feet).
Upper Cretaceous or Tertiary?			Conglomerate. Contains abundant pebbles and cobbles as much as 6 inches in diameter of Madison limestone, quadrant quartzite, and rocks probably of Ellis and Kootenai formations. Many beds of pale-yellow sandstone in upper portion. Top removed by erosion.	700+		
Cretaceous (Upper Cretaceous).	Colorado? or Montana?		Chiefly medium to fine buff-weathering, gray sandstone, also many variegated beds in which dull shades of green predominate, with some thin pink or purple beds near the top. Considerable dull-colored argillite in lower portion.	4,800		

[1] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper, 78, 1913.

Generalized sections of pre-Tertiary sedimentary rocks in the Garnet and Flint Creek ranges, Mont.—Continued.

Geologic age.		Formation.	Garnet Range. Character.	Thickness (feet).	Flint Creek Range. Character.	Thickness (feet).
Cretaceous (Upper Cretaceous)—Continued.	Colorado.		Alternate layers of buff to brown weathering, gray sandstone and dull-green to black shale. Some thin bands of limestone near top contain marine fossils of Colorado age.	2,300	Chiefly gray to olive sandstone; some beds of dark-gray to green shale. Top removed by erosion.	1,000+
			Fissile black shale.	500-650	Fissile black shale.	500
			-Unconformity		-Unconformity	
Cretaceous (Lower Cretaceous).		Kootenai formation.	Chiefly purple and maroon shale. Several interbedded layers of gray to green and maroon sandstone and thin beds of limestone. The lower limestones weather buff. The uppermost is crowded with small fresh-water gastropods.	1,350	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?		-Unconformity?	
Jurassic.		Ellis formation.	Chiefly buff-weathering limy shale. Near the middle a layer of cross-bedded gray sandstone 100 feet or more thick. Thin beds of limestone in lower part contain marine Jurassic fossils.	400-650	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		-Unconformity	
Carboniferous.	Permian?	Phosphoria formation.	Chert, cherty quartzite, gray sandstone, and limy shale. Varies in thickness and composition from place to place. A bed of rock phosphate at bottom.	50-300	Gray, somewhat cherty quartzite; weathers rusty brown. A little shale interbedded.	120
					Chiefly gray cherty limestone. Marine Pennsylvanian or Permian fossils. A bed of rock phosphate in lower part.	90
	Pennsylvanian?	Quadrant quartzite.	Light to brownish gray quartzite, pure. Rusty brown on weathered surface.	200-300	Massive fine-grained quartzite, white to pale drab, stained yellowish-brown.	220-350
			-Unconformity?		-Unconformity?	
			Deep-red shale and impure limestone. Shale commonly mottled with light-colored spots.	250	Maroon shale, commonly mottled, and gray to pink magnesian limestone.	100-300
			-Unconformity?		-Unconformity?	
	Mississippian.	Madison limestone.	Limestone, massive and light gray to blue in upper part, thin bedded and dark gray in lower; fossiliferous.	1,500	Limestone, massive, white to pale gray in upper part; lower part thin bedded, flaggy, black, weathering light blue; fossiliferous.	1,200-1,500
			-Unconformity?		-Unconformity?	
Devonian.	Middle Devonian.	Jefferson limestone.	Chiefly light-gray to black limestone; fossiliferous.	700	Light-gray to black magnesian limestone; fossiliferous.	1,000

Generalized sections of pre-Tertiary sedimentary rocks in the Garnet and Flint Creek ranges, Mont.—Continued.

Geologic age.		Formation.	Garnet Range.		Flint Creek Range.	
			Character.	Thickness (feet.)	Character.	Thickness (feet).
Silurian?		Maywood formation.	Thin-bedded gray limestone. In places streaked and mottled with pink and yellow.	600±	Magnesian reddish, gray, and whitish limestone and gray and green shale. —Unconformity?	200-300
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.	—Unconformity		Vitreous gray to drab quartzite. —Unconformity	150
Algonkian.	Belt.		Shale and sandstone, chiefly red. Bottom not exposed.	1,000+	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 absence of the Flathead quartzite, the Silver Hill formation, and the Hasmark formation from the Garnet Range, as shown by the section, is thought to be due to a delayed submergence of that area beneath the Cambrian sea. This interpretation, however, is based on a single observation on the divide between Hoover and Chimney creeks, where a limestone thought to be the equivalent of the Red Lion directly overlies Algonkian shale. It should therefore be considered as possibly to be modified in the light of future investigations.

Exclusive of the Algonkian rocks, whose association with the bed of rock phosphate under consideration is very remote, both sections, viewed broadly, show a gradual progressive change in composition from bottom to top. In a general way they may be divided into a lower, an intermediate, and an upper group, in which limestone, shale, and sandstone, respectively, are the predominant kinds of rock. The lower group may be taken as comprising all the strata below the Quadrant (?) quartzite, the intermediate group those from the Quadrant (?) quartzite to the black Colorado shale, inclusive, and the upper group those above that shale. Except the relatively thin Flathead quartzite, which is present only in the Flint Creek Range section, the lower group consists almost exclusively of limestone. The intermediate group is composed of alternate layers of limestone, shale, and sandstone, of which, however, the shale forms more than half. The phosphate bed occurs in the lower part of this group. The upper or sandstone group contains several beds of shale but is practically free from limestone.

In the Garnet Range the rocks have a generally regular distribution. The limestone group largely occupies the summit area and the shale group the south slopes. The adjacent valley is underlain by the sandstone group, which, however, is concealed in many places by Tertiary and later deposits.

The distribution of the rocks in the Flint Creek Range is difficult to characterize in general terms. The rocks of the sandstone and shale groups are most abundant toward the north, but all the formations are irregularly and more or less widely distributed.

In general, the three main groups described give rise to distinctive surface features. The limestone group forms cliffs and crags which, because of their prevailing light color, may be seen and recognized for long distances. Because of the different degrees of hardness of its beds the shale group is characterized by ridges and hollows. Except locally, where hardened by contact with igneous rocks, as in the foothille east of Hoover Creek, the sandstone group is marked by rather low and smooth surfaces.

As the phosphate bed nowhere crops out prominently, its location must usually be determined by reference to outcrops of the adjacent rocks. In the following paragraphs the formations most useful for this purpose are described and the stratigraphic distances of the phosphate bed above or below them are given. Where the regular sequence of the rocks has not been disturbed, the stratigraphic distance is a factor of general application for locating the probable position of a concealed bed with reference to an exposed one. It is the vertical distance between the given beds considered as occupying the regular order and horizontal position in which they were laid down, or, in other words, the distance measured along a line perpendicular to the planes of stratification, which are generally upturned in this region.

MADISON LIMESTONE.

The Madison limestone is a remarkably persistent formation throughout the western phosphate field. In the Garrison field the phosphate bed or its equivalent lies from 450 to 550 feet, and in the

Philipsburg field from 350 to 650 feet stratigraphically above it. Because of its habit of forming conspicuous light-colored cliffs and crags, the Madison is easily recognized and generally well known. Although some of the other limestones are prominent in places, none is comparable in extent and massiveness with the Madison or is likely on close inspection to be mistaken for it. The upper and more massive portion of the Madison limestone commonly contains irregular bodies of gray chert, some of which are very large. In places its outcrops are superficially stained red with ocher derived from the overlying red beds of the Quadrant (?) quartzite. The Madison generally contains abundant fossils of Mississippian age, of which a cone-shaped coral is especially useful for identifying the formation in the field. In a specimen broken so as to show a cross section this fossil appears as a little wheel about an inch in diameter with the hub a little off the center.

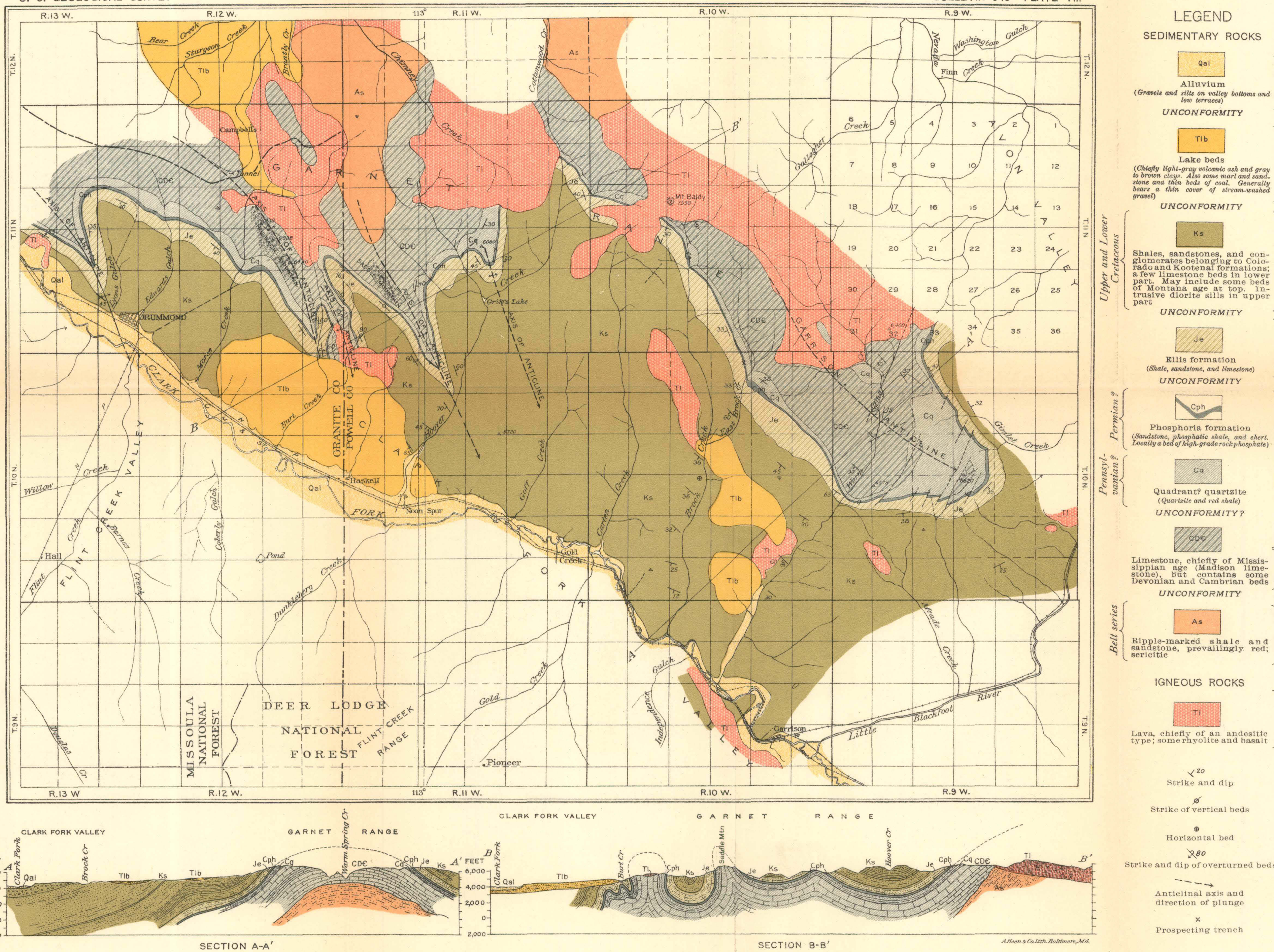
In the Garrison field the Madison limestone is practically confined to the summits of the Garnet Range, along which it forms a broad, irregular but almost continuous belt. Its most prominent outcrops are in Saddle and Hogback mountains and the cliffs and crags along some of the canyons, notably that of Warm Spring Creek.

The occurrence of the several formations in the greater part of the Philipsburg field is shown in detail by the geologic map of the Philipsburg quadrangle.[1] In this area the Madison limestone is widely distributed, and some of its most prominent outcrops are along the canyons of Boulder and Flint creeks above Maxville.

QUADRANT (?) QUARTZITE.

The Quadrant formation as described in the Philipsburg folio lies next above the Madison and consists of a shale member above which are two beds of quartzite separated by several feet of impure limestone. The beds above the lower quartzite are believed to be equivalent to the Phosphoria formation of southeastern Idaho and are described on pages 207–211 under the name Phosphoria, only the lower quartzite and the underlying shale being included here under the term Quadrant (?) quartzite. In the eastern part of the Garrison field the phosphate bed lies directly upon the quartzite. At Philipsburg the two are separated by about 30 feet of impure limestone. The shale member does not crop out prominently. It is generally red in color and commonly marked with large oval spots of pale green or yellow. In places considerable red ocher that has resulted

[1] Calkins, F. C., and Emmons, W. H., U. S. Geol. Survey Geol. Atlas, Philipsburg folio (No. 196), 1915.



GEOLOGIC MAP AND SECTIONS OF THE GARRISON PHOSPHATE FIELD, MONTANA

Scale $\frac{1}{125,000}$

1 0 1 2 3 4 5 6 7 8 9 10 Miles

1916

from the weathering of this stratum has imparted a conspicuous color to the soil or stained the underlying Madison.

Because of its prominent outcrops and close association with the phosphate bed, the quartzite member is particularly valuable as a guide to the location of the phosphate. It commonly forms bold reefs and knobs of a grayish-yellow or light reddish-brown color and is inclined to be massive and blocky. It is mostly fine grained and vitreous, is light gray on fresh fracture, and in places has a cherty appearance is the upper part. It is not unlike the Flathead quartzite, and the two may be confused unless some of the adjoining strata are present in regular sequence to aid in the differentiation.

From the southeast end of the Garnet Range westward to Drummond and beyond the Quadrant quartzite forms a sinuous belt parallel to that of the adjoining Phosphoria formation (see Pl. VIII) and commonly situated near the top of the main slope. Its outcrops are especially prominent in the canyons of Warm Spring, East Brock, and Brock creeks, where blocky talus has accumulated below them. It also forms a conspicuous wall that curves around the southeast shoulder of Saddle Mountain and a knob near the center of T. 10 N., R. 9 W., northeast of Garrison, in which the rock is brecciated by faults.

In the Philipsburg field the Quadrant (?) quartzite forms the summits of the knobs near Philipsburg known as Flagstaff Hill and Red Hill and the long north-south reefs that cross the basins of Boulder, Gird, and Douglas creeks, as well as many prominent features elsewhere.

The Quadrant (?) quartzite has not been recognized in the southern part of the western phosphate region. Formations probably equivalent to it in part are the Weber quartzite and Morgan formation in Utah and the Wells formation in Idaho.

PHOSPHORIA FORMATION.

In southeastern Idaho and adjacent regions the phosphatic shales and cherty beds at the top of the Paleozoic section are known as the Phosphoria formation. In that region the Phosphoria is composed of an upper cherty member and a lower shale member that is highly phosphatic, and some of the beds contain abundant fossils of Pennsylvanian or Permian species. As a rule there is a bed of high-grade rock phosphate at or very near the bottom. The Phosphoria overlies a thick accumulation of sediments, chiefly sandstone or quartzite, of Pennsylvanian age, known as the Wells formation, which in turn rests upon a limestone of upper Mississippian age that overlies the Madison limestone. No angular discordance between the

Phosphoria and the Wells has been observed, but the Wells appears to have been eroded in places before the Phosphoria was deposited. In Montana, at Melrose[1] and Elliston,[2] as well as in the area under consideration, the phosphate-bearing formation, although generally thinner, has a similar composition and apparently the same stratigraphic position, and the application of the name Phosphoria in Montana is therefore believed to be warranted.

The character of the Phosphoria formation is shown by the following sections from the Garrison, Philipsburg, and Melrose fields, Mont., together with one from southeastern Idaho, where the formation attains its greatest development.

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[1] Gale, H. S., Rock phosphate near Melrose, Mont.: U. S. Geol. Survey Bull. 470, pp. 440–451, 1911.

[2] Stone, R. W., and Bonine, C. A., The Elliston phosphate field, Mont.: U. S. Geol. Survey Bull. 580, pp. 373–383, 1913.

Sections of Phosphoria formation in Montana and Idaho.

Garrison field, Mont.				Philipsburg field, Mont.: Flagstaff Hill.		Melrose, Mont.[a]		Southeastern Idaho: Georgetown Canyon and vicinity.[b]	
West of Drummond.		Warm Spring Creek north of Garrison.							
Limestones, shale, and sandstone of Ellis formation (Jurassic).		Limestone, shale, and sandstone of Ellis formation (Jurassic).		Limestone and shale of Ellis formation (Jurassic).		Shale and limestone (Triassic? or Jurassic?).		Yellow to green shale (Woodside shale, Lower Triassic).	
Unconformity?		Unconformity?							
	Feet.		*Feet.*		*Feet.*		*Feet.*		*Feet.*
Grayish chert	0–100	Yellow to gray chert	35	Yellowish-brown sandstone and quartzite	130	Chert (and quartzite?)	105	Purple to brown chert, cherty limestone, and shale	240–550
Drab shale, slightly phosphatic	20±	Gray to brown chert, phosphatic, with a 4-foot bed of rock phosphate at bottom	18	Red to brown shale	20	Stratum of phosphatic shale and bed of rock phosphate at bottom.		Phosphatic shales, with some thin beds of fetid limestone and several beds of rock phosphate	83–193
Brown sandstone containing scattered nodules of rock phosphate	11			Yellowish-brown sandstone and shale; phosphatic; several thin beds of rock phosphate at bottom	30				
	131±		53		180		105		500±
Unconformity?		Unconformity?						Unconformity?	
Sandstone, limestone, and quartzite (Quadrant? quartzite).		Reddish-weathering quartzite; cherty at top (Quadrant?).		Cherty limestone and pure quartzite (Quadrant?).		Cherty limestone, sandstone, quartzite, and shale (Quadrant?).		Sandy limestones and quartzites (Wells formation).	

[a] U. S. Geol. Survey Bull. 470, pp. 444–446, 1911.

[b] U. S. Geol. Survey Bull. 577, pp. 22–29, 1914.

The character and composition of the Phosphoria formation vary somewhat within the Garrison and Philipsburg fields. Between Garrison and Drummond the lower member loses much of its phosphate and becomes predominantly sandy, and both members increase in average thickness but show notable irregularities in that respect. Between the Garnet Range and Philipsburg the upper member changes from a cherty-appearing rock to one that is apparently nothing but sandstone. A specimen of what appeared to be chert, from the Warm Spring Creek section, proved on microscopic examination to be an extremely fine grained quartz sandstone with an abundant siliceous cement.

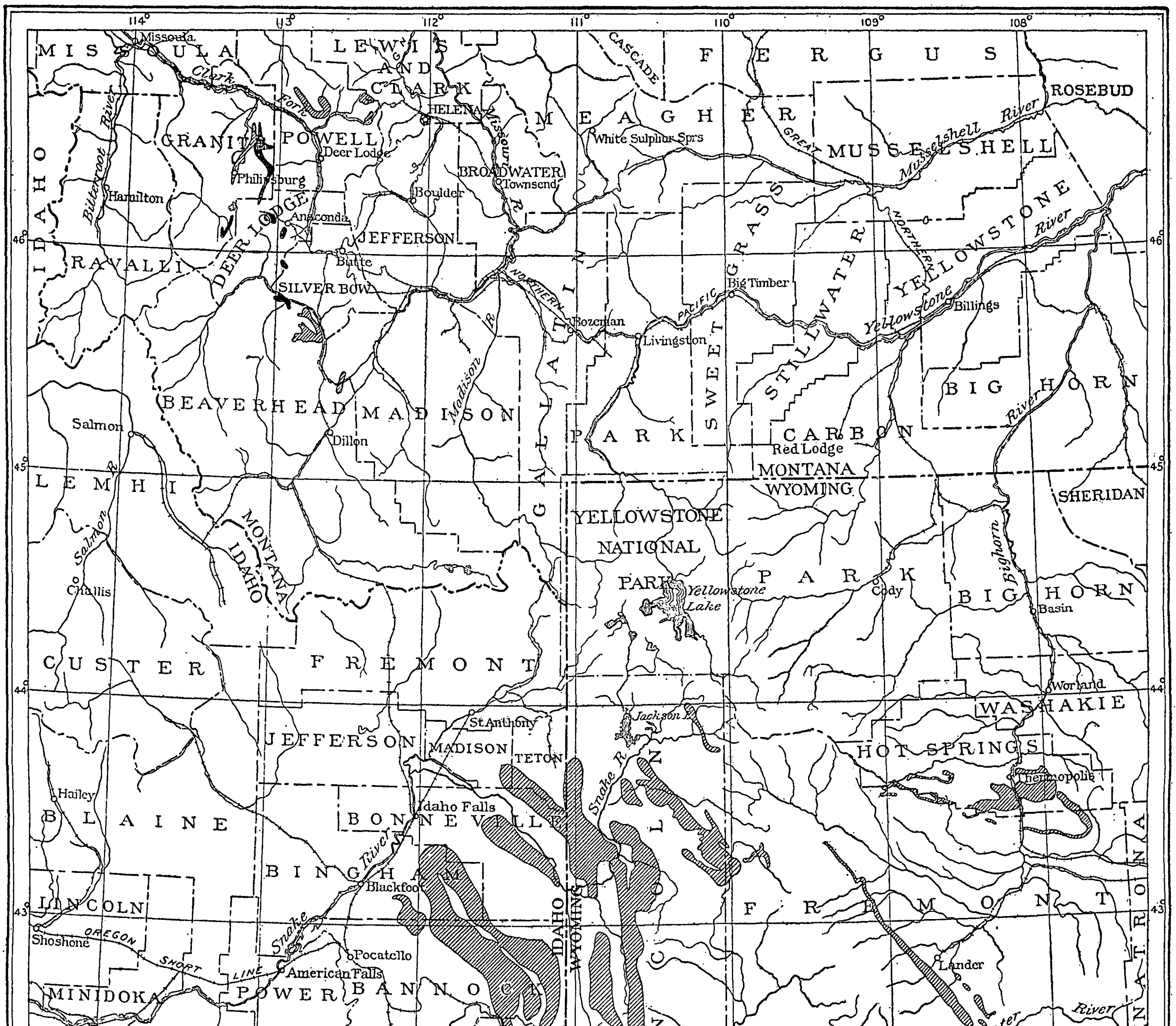
In the portion of the Garrison field lying west of Hoover Creek the Phosphoria formation, although fairly persistent, contains no phosphate deposits of present economic importance. The equivalent of the phosphate bed is a stratum of fine, soft yellowish-gray sandstone of varying thickness, weathered portions of which are characterized by pale-pink and brown bands.

The base of the Phosphoria is well defined in the Garrison field, where the phosphatic portion rests directly upon the Quadrant (?) quartzite. At Philipsburg, however, some limestone, whose relationship is in doubt, separates the phosphatic stratum from the quartzite (the lower quartzite of the Quadrant of the Philipsburg folio). This limestone is tentatively included with the Quadrant.

The known distribution of the Phosphoria formation, which is practically the same as that of the lands underlain by workable deposits of rock phosphate (see Pl. IX), ranges over an area of about 100,000 square miles that extends from western Montana into northern Utah and central Wyoming. The formation is most abundantly developed in the south-central part of this region, between which and the much smaller areas of the formation in Montana there is a considerable gap. There is reason to believe, however, that future explorations will show the Phosphoria to be present in parts of the intervening area also.

In the Garrison field the Phosphoria (see Pl. VIII) forms a narrow band that winds in and out along the southerly slopes of the Garnet Range. The portion of this band that is of greatest value with regard to the occurrence of rock phosphate forms a large loop that curves around the southeast end of the range north of Garrison, and lies for the most part near the summit of the main slope at an altitude of about 6,500 feet. To the west of this loop are several smaller but generally parallel curves that in places carry the formation down to the valley level (4,500 feet).

In the Philipsburg field the Phosphoria, if it is everywhere present in the upper part of the Quadrant formation as mapped in the Philipsburg folio, has a wide distribution but is most abundantly



Base mainly from U.S. Land Office maps

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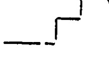

Area underlain by important deposits

Area probably underlain by important deposits

MAP SHOWING DISTRIBUTION OF PHOSPHATE LANDS IN THE WESTERN UNITED STATES.

Rock phosphate will probably be found not only in the areas indicated by shading but in many other places between Yellowstone National Park and the known Montana occurrences.

developed to the north of Philipsburg. It forms several long north-south bands and loops which cross the basins of Boulder, Gird, and Douglas creeks, and some of which extend northward beyond the limits of the Philipsburg quadrangle.

The shale and phosphate member of the Phosphoria does not crop out prominently. Its position is commonly marked by a slight depression in which much soil and rock débris have accumulated.

The cherty member in places forms knobs and reefs, of which the outcrop on the west slope of Flagstaff Hill at Philipsburg is an example, but it is generally much less conspicuous than the Quadrant quartzite.

ELLIS FORMATION.

Although Triassic strata occupy large areas in southeastern Idaho, they are absent in the localities under consideration, where the Phosphoria is overlain without angular discordance by the Jurassic Ellis formation. In the Garrison field a prominently outcropping bed of gray sandstone lies near the middle of the Ellis, about 300 feet above the phosphate bed. It is easily recognized by a cross-bedded structure that is generally emphasized on the weathered surface by rusty streaks. The rock is further distinguished by conspicuous grains of black scattered through the gray. It contains a thin pebbly bed near the bottom and is disrupted by weathering into blocky flagstones and coarse fragments that clutter the surface near its outcrop. In places, as near the summit of the main slopes of the Garnet Range east of Brock Creek, it forms prominent reefs. In the Philipsburg field an equivalent stratum is moderately conspicuous in the basin of Gird Creek, where it lies between 300 and 400 feet above the phosphate bed.

KOOTENAI FORMATION.

Although the outcrops of the Kootenai formation are generally subdued, it can ordinarily be recognized in the Garrison and Philipsburg fields by its predominant red, purple, and maroon colors. It contains two rather prominent beds of limestone, each from 30 to 100 feet or more in thickness. The lower limestone is about 1,150 feet above the phosphate bed, is pale yellow on the weathered surface, and shows rather conspicuously small bodies that branch like twigs. In places this stratum is split into two layers by 100 feet or so of shaly beds. The upper limestone is about 1,800 feet above the phosphate bed, is light gray to blue on the weathered surface, and is crowded with fossils of small fresh-water snails. Two or three layers in this stratum generally crop out as narrow but prominent reefs and walls, as shown, for example, on the hill immediately back of Drummond.

Next above this limestone and forming the topmost stratum of the Kootenai is a 100-foot bed of sandstone and shale. It is generally inconspicuous, but in the Garnet Range from Brock Creek east it has been partly transformed to a quartzite that forms prominent reefs and knobs. In appearance these are not unlike outcrops of the Quadrant (?) quartzite except that they are narrower and in places their bedding planes are ripple marked.

TERTIARY AND LATER ROCKS.

Several formations which are confined practically to the main valleys and whose relations to the phosphatic stratum are accidental are not included in the tabular sections but were described more particularly in a former report.[1] They consist of sands, clays, and marls of late Tertiary age that underlie the bench lands, gravels that cover them, and the more recent alluvium of the stream flood plains or bottom lands.

Igneous rocks which in many places are found in close proximity to the phosphatic stratum but whose relations to it are purely accidental occur in both the Garnet and Flint Creek ranges. Those of the Garnet Range are chiefly lavas that were spread over the surface from time to time. Those of the Flint Creek Range are chiefly granites (in the more common significance of that term)—rocks that, in a fluid condition, came up from unknown depths and either forced aside the strata or engulfed them. For the most part the granites are confined to the central and higher portions of the range. In the Garnet Range east of Drummond the only rocks similar in origin and texture to the granites are some dense, heavy dark grayish-green crystalline rocks (gabbros) that occur in sheetlike masses or sills wedged in between beds of the sandstone group (Colorado). Microscopic examination of a coarsely granular specimen from the outcrop of a sill 400 feet thick that occurs in the Colorado formation about 1,550 feet above its base east of Hoover Creek shows it to contain augite, hypersthene, olivine, biotite, and feldspar, of which the ferromagnesian minerals predominate. About 30 per cent of the feldspar is orthoclase, the remainder being calcic labradorite. The principal outcrops of these rocks are in the foothills east of Hoover Creek, half a mile west of the mouth of Brock Creek, and along Little Blackfoot River 8 or 10 miles east of Garrison. No outcrop, however, lies within several thousand feet stratigraphically of the phosphate bed.

Several patches of andesitic lava, remnants of fairly extensive flows, occur in the Garnet Range, mainly on the summit and northern slopes. The predominant variety of this rock forms the summit of

[1] Pardee, J. T., Coal in the Tertiary lake beds of southwestern Montana: U. S. Geol. Survey Bull. 531, pp. 232–236, 1913.

Mount Baldy, and in a part of the area between that point and the head of Hoover Creek overlies and conceals the outcrop of the phosphatic stratum. A specimen from the summit of Mount Baldy is a dense gray cryptocrystalline rock with a platy structure. Under the microscope it shows augite and altered hypersthene in a fine-grained groundmass practically devoid of phenocrysts, also some plagioclase and glass and accessory iron ore. The exposures of the andesitic rock appear grayish or purplish brown and are commonly broken by very numerous joints into thin plates or, less commonly, into small fragments shaped like distorted rhombs. Here and there are small patches of other lavas, some of which have the composition of basalt and some of rhyolite.

STRUCTURE.

FOLDS.

Except the Tertiary and later strata, which are but slightly folded, the bedded rocks of the areas under consideration are in general steeply tilted. The Garrison field is dominated by a series of parallel folds, the axes of which have a general southeasterly direction and incline downward to the southeast. Erosion has worn away the upper portions of the ridges (anticlines) and exposed the upturned edges of certain beds, including the Phosphoria formation, which wind back and forth along the south slope of the Garnet Range. (See Pl. VIII.) The largest individual fold is a broad arch, the Garrison anticline (Pl. VIII, section *A-A*), that occupies the area east of Brock Creek and causes the trace of the Phosphoria formation to form a loop open to the northwest. On the flanks of this anticline the beds are inclined 40° to 65° from the horizontal, and around its southeast end 20° to 40°. The smaller folds that occupy the area from the Garrison anticline westward to Drummond and beyond are tightly compressed (Pl. VIII, section *B-B*), and the rocks involved in these folds therefore show very steep dips, vertical attitudes being not uncommon, and the outcrops form a series of narrow pointed loops.

The rocks of the Philipsburg field have been folded even more severely than those of the Garnet Range, and the beds therefore dip steeply nearly everywhere. Not uncommonly they are overturned, lying one above another in reverse order. Within the Philipsburg quadrangle the general direction of the folds is a little east of north, and the pitch is northward. Within a distance of 5 or 6 miles north of the quadrangle the structural axes bend to a general northwesterly direction parallel to those of the Garnet Range. A detailed description of the structure in the Philipsburg quadrangle is given in the report by Emmons and Calkins.[1]

[1] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, 1913.

Considered in general terms as to their structure, the Garnet Range and, less plainly, the Flint Creek Range, are anticlinal, and the intervening valley of Clark Fork is a broad compound syncline.

FAULTS.

In the Garnet Range faults are of no great structural importance. So far as observed, they are most conspicuous in the southeast end of the Garrison anticline, which is crossed transversely by several parallel fractures. These dip steeply northwest, and on each the block to the northwest has dropped slightly. The displacements are shown by jogs that slightly narrow the loop formed by outcrops of the Phosphoria formation (Pl. VIII). A zone of faults that have caused slight dislocations extends from Drummond northeastward to Hogback Mountain. Elsewhere, although small faults are doubtless present, none were observed. The position of most of the faults observed is marked by masses of crushed recemented rock or breccia, especially where the faults cross the Quadrant (?) quartzite.

In the Philipsburg field, on the other hand, faults are numerous, and the dislocations many of them have caused are so extensive that beds far removed from each other in the normal sequence are made to adjoin. Both normal and thrust faults occur, and the general direction of the larger ones is north or northeast, parallel to that of the folds. In many places faults, as shown by the Philipsburg folio, follow closely the trend of the areal exposures of the Quadrant (?) quartzite, a fact which allows the possibility that in places the Phosphoria may have been cut away.

GEOLOGIC HISTORY.

With respect to the main geologic events in the Garrison-Philipsburg area, the vast amount of time that has elapsed since the deposition of the Algonkian rocks may be divided into two periods of strongly contrasting conditions. In comparative terms the earlier period was a time of monotonous quiet dominated by sedimentation; the later period one of vigorous mountain building and erosion.

During the earlier and longer period, which includes Paleozoic and all but the latest part of Mesozoic time, the surface was generally low; sometimes it was slightly above sea level, but more commonly it was submerged and receiving the sediments derived from the surrounding more or less distant lands. The period began with the advance of the sea from south to north over a surface of moderate relief eroded in the top of the Algonkian shale. Its earliest record is that afforded by the Flathead quartzite, a formation which is composed chiefly of beach sands, and whose absence from the

Garnet Range is interpreted to mean that the sea had not yet overspread that area. Soon, however, the region was entirely submerged by a practically clear sea, in which the great group of limestone beds ending with the Madison (lower Mississippian) was laid down. For a time deposition ceased, probably because the surface was elevated to or above sea level, but the process recommenced at the beginning of the Pennsylvanian epoch. The fact that sands and muds were brought in at this time shows that the land was either nearer than before or was being more vigorously eroded. The red color of the mud that formed the lower member of the Quadrant (?) quartzite is generally believed to indicate absence of vegetation and therefore an arid climate in the lands that were being eroded.

After the sands composing the Quadrant (?) quartzite, whose purity indicates that they were derived from a sea beach, were laid down, a change in the conditions, not yet well understood, permitted the precipitation of highly phosphatic material. During this epoch the water was at times more or less muddy over most of the general phosphate field, as shown by the shales that are interbedded with the rock phosphate. In the Garrison field the shale and rock phosphate give place to fine sandstone toward the northwest, showing that a beach existed not far away in that direction. Whether the beach was the mainland or merely an island is not known positively, but the absence of phosphatic rocks west of this locality supports the view that it was a point on the western mainland shore of the Phosphoria sea. For a considerable time afterward, represented in southeastern Idaho and adjacent regions by thick strata of Triassic age, no sediments were deposited in the Garrison and Philipsburg fields, or if any did accumulate, they were subsequently washed away. Presumably the surface was above sea during this interval, but not far enough above to be deeply channeled by streams.

The sea or a shallow arm of it again occupied this area during most of Jurassic time and part of Cretaceous time. The late Mesozoic deposits show, however, that marine conditions were in general gradually replaced by those characteristic of fresh-water and land areas, which became permanent in later Cretaceous time. Altogether during the period of quiet sedimentation about 13,000 feet of material accumulated in practically horizontal beds, the upper two-thirds of which overlay the phosphate deposit. That in places the phosphate bed is uncovered at present is due to the general deformation and erosion that occurred in the succeeding period.

The later period began with a mountain-building epoch that probably included parts of both late Cretaceous and early Tertiary time. In this epoch, evidently through the agency of great pressure, the hitherto flat-lying strata were severely folded, elevated, and in places broken and piled upon one another. In the area of the Garnet Range the axes of the folds assumed the average northwesterly direction of the Rocky Mountain structure, but in the Flint Creek Range they were turned to a rather exceptional course of north-northeast. In the latter area, in addition to being tightly folded, the beds were extensively dislocated by faults and invaded from below by large masses of granite. The Garnet and Flint Creek Range areas were dominated by anticlines and the intervening area of Clark Fork valley by a syncline. In general, therefore, the mountains and lowlands of this early epoch appear to have coincided in position with those of to-day.

As the anticlinal ridges were gradually worn down by erosion the upturned and hitherto concealed strata were exposed at the surface. Although erosion must have been active from the time the land first became elevated, it evidently was at first unable to reduce the mountains as rapidly as they grew. Later, however, the mountain-building forces apparently died out, and before the Tertiary period was well advanced erosion had become the dominant process.

During the epoch of erosion, which continued until about the middle of Tertiary time, the general region was worn down to a low surface, in general of but little relief. Doubtless the sites of the former mountains, at least of the ancient Flint Creek Range, were marked by moderate elevations, and there is reason to believe that to the west of Drummond the ancient Clark Fork followed essentially its present course.

During the succeeding and final epoch the surface was generally reelevated several thousand feet and the canyons and valleys of to-day were formed. This epoch was also characterized by lava flows and by the accumulation in the principal valleys, which at times held lakes, of thick sediments, composed largely of volcanic sand.

Clearly the canyons of this area were cut by the streams that occupy them, but no hypothesis based on erosion alone is sufficient to explain the origin of the broad, more or less inclosed basins of which the Clark Fork and Flint Creek valley is an example. Although their histories have not been fully interpreted, there is strong evidence, particularly the deformation of the lake beds, in support of the view that these basins are due chiefly to warping of the surface, aided by dislocation along faults.

This latest epoch was relatively short compared to any of the other periods into which, for convenience, the geologic history of this region has been divided. Its length was so great, however, as to be difficult of conception by the human mind. From the work done by the streams in excavating their canyons—for example, those sunk in the hard rocks of the Flint Creek Range—geologists estimate the length of this epoch (from Oligocene time to the present) as more than 1,000,000 years.

PHOSPHATE DEPOSITS.

GENERAL DISTRIBUTION AND CHARACTER IN THE WESTERN REGION.

In the western region rock phosphate occurs at two horizons in the Paleozoic section—at the top of the Madison limestone and in the Phosphoria formation. The bed at the top of the Madison is, locally, at least, of workable dimensions,[1] but its extent and value outside of certain localities in northern Utah are not yet known. All other known phosphate deposits in the western region, including those described in the present report, occur in the Phosphoria formation or its equivalents.

Deposits of rock phosphate occurring in the Phosphoria formation or its equivalents are irregularly distributed over an area of about 100,000 square miles, commonly known as the western phosphate region, that includes adjoining portions of Montana, Idaho, Wyoming, and Utah. Plate IX shows the location of the known deposits that are regarded as of economic importance, the shaded areas being those so far classified by the Geological Survey as phosphate lands. According to the definition adopted, phosphate lands must be underlain (except under certain conditions of uncommon occurrence in the western region) by a bed of rock phosphate 1 foot or more in thickness, which contains 30 per cent or more of tricalcium phosphate and which lies within depth limits that range, as the other factors increase, from 0 to 5,000 feet vertically below the surface. The northwesternmost of these deposits are those of the Garrison and Philipsburg fields. The relatively small area of these fields, however, does not mean that their deposits are of unimportant volume; on the contrary, it draws attention to the enormous magnitude of the deposits as a whole.

That the phosphate region extends northward far beyond the latitude of Garrison is suggested by a recent discovery of rock phosphate on an east-west section passing through Banff, Alberta.[2]

Throughout the western region the rock phosphate of the Phosphoria formation occurs as a sedimentary or bedded deposit associated with cherty rocks and shales. As a rule it is somewhat softer than limestone but is noticeably heavier than ordinary sedimentary rocks, its average specific gravity being about 2.9. It is further characterized by an oolitic texture (composed of small round grains that suggest fish roe) and a thin bluish-white coating developed on

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[1] Finch, E. H., Rock phosphate of Mississippian age in northern Utah: U. S. Geol. Survey Bull. — (in preparation).

[2] Adams, F. D., and Dick, W. J., On the extension of the Montana phosphate deposits northward into Canada (paper presented at the twenty-eighth annual meeting of the Geological Society of America, Washington, D. C., December, 1915).

weathered surfaces. When freshly broken it has a fetid odor, and the fractures produced, if the specimens are undecomposed, generally cut through the grains instead of passing around them.

The phosphate beds exhibit a considerable range in purity and thickness, but most of those mapped are from 3 to 8 feet or more in thickness and contain 60 per cent or more of tricalcium phosphate. Ordinarily the chief impurity present in the deposits is fine quartz sand, together with small amounts of other substances, including bituminous matter.

The mineral composition of the rock is not definitely known. The phosphorus is undoubtedly combined with lime, and as analyses of the purest material obtainable show the proportions represented by the formula of tricalcium phosphate, $Ca_3(PO_4)_2$, that substance is assumed to be present, although it has not been identified in crystal form.

Although the phosphate beds vary in thickness and composition from place to place, their irregularities are not to be compared with those of metalliferous lodes. They are rather to be estimated like beds of coal or limestone, of which measurements and samples at intervals of a mile or more suffice for a general average. In the western region as a whole the phosphate beds are inclined, and commonly the dip is sufficiently steep to indicate that overhead stoping would be the most suitable method of mining. Because some of the more soluble impurities have been leached out, samples of float (loose fragments that have become detached and transported by natural agencies to greater or less distances from the bed) or of superficial portions of the bed may contain 4 or 5 per cent more phosphorus pentoxide than those from underlying portions. As the deposits have not been explored beyond depths of a few feet the actual composition of their deeper portions is unknown, but on well-substantiated theoretical grounds the phosphorus pentoxide is believed to show no further essential diminution with depth.

EASTERN PART OF THE GARRISON FIELD.

DISTRIBUTION AND OCCURRENCE.

In the Garrison field the economically important portion of the phosphate deposit is confined to the area east of Hoover Creek. West of that stream the phosphatic stratum, although fairly persistent, is of low grade. The distribution and attitude of the phosphate bed east of Hoover Creek are controlled by the Garrison anticline, a large fold that has a northwesterly course and pitches southeast. The trace of the bed, which is practically equivalent to that of the Phosphoria formation, as shown by the map (Pl. VIII), is a narrow band, 18 miles or more in length, in the form of a huge fishhook so placed that the southeast end of the Garnet Range lies within the curve. Except where it is lowered by erosion 1,500 feet or more in the canyons of Warm Spring, Brock, and East Brock creeks, the band lies near the summit of the main slope, at a general altitude of 6,500 feet.

Along this course the dip of the phosphate bed ranges from 30° to 65° and with respect to the mountain mass is outward, or in the same direction as the general slope of the surface. Thus from Hoover Creek to Warm Spring Creek, a distance of 10 miles, the strike is southeast and the dip southwest. Beyond Warm Spring Creek, as the bed rounds the end of the range, the strike gradually changes, at first to the east, then to the north, and finally to the northwest, and the direction of the dip changes correspondingly.

Adjoining the Garrison anticline on the southwest is a corresponding downfold that at the deepest portion has carried the phosphate bed to a depth of about 10,000 feet below the present surface. Farther southwest, in the foothills of the Flint Creek Range, north of Boulder Creek, the deposit is reelevated to the surface by other folds. To the east of the Garrison arch the phosphate bed is again depressed and covered by a thick overburden of Tertiary rocks, but it reappears at the surface in the vicinity of Elliston.

As a rule the position of the phosphate bed is marked by a shallow soil-covered trench in which loose fragments of rock phosphate (float) are more or less abundant and, because of their light-colored superficial coating, generally conspicuous.

For the most part the rock phosphate of the area under consideration does not differ in appearance from the general type as described in a former paragraph. The grains vary slightly in size but average about 1 millimeter in diameter, which is about equivalent to that of a small pin head. The rock is predominantly black but in a few places has a pink shade, owing to a little iron oxide in the matrix, or is brown and rather soft, apparently because of decomposition.

The general absence of large pieces of float is due to the fact that the rock has a pronounced fissility parallel to the bedding and numerous joints at right angles to the fissility, along which it splits into blocks and slabs, few of them larger than an ordinary brick.

The only natural exposure of the rock phosphate seen covers a small area on the steep slope west of East Brock Creek, but in a few other places the soil cover is very thin. Additional exposures were made by digging trenches on Warm Spring Creek near the center of T. 10 N., R. 9 W., and at other points as indicated on the map (Pl. VIII).

Above and below the phosphate bed are layers of gray to yellow, red, or brown fine-grained brittle rocks that have the appearance of chert. A foot or two of the lower layer and exceptionally as much as 15 feet of the upper layer are noticeably phosphatic. For the most part, as indicated by variations in the bluish-white coating, the phosphatic substance is very finely divided and irregularly distributed through the rock. In places it is segregated in small round black grains that are scattered sparsely through the rock and form tiny but conspicuous white spots on weathered surfaces. Microscopic examination of the phosphatic chert from the exposure on East Brock Creek shows it to be composed of extremely fine quartz sand, with an abundant siliceous cement. Some of the inclosed phosphate granules have an angular fragment of quartz as a nucleus around which the phosphatic material is gathered in concentric layers.

Along a course of 12 miles east of Brock Creek prospect trenches were made at three points (see Pl. VIII), at each of which the phosphate deposit has a thickness of 4 feet or more. As the distribution of float between these exposures is fully as abundant as near them, it is believed safe to assume 4 feet as the average thickness of the bed throughout. At Hoover Creek, however, 6 miles northwest of the East Brock Creek exposure, the phosphate bed is but 1 foot thick. Whether the decrease of 3 feet is distributed over a large or a small part of this distance, in which there are no exposures, is problematic, but the abundance of the float indicates that the width is not noticeably diminished within a mile to the northwest of East Brock Creek.

COMPOSITION.

Analyses of the phosphate bed at three exposures east of Brock Creek are given below:

Analyses of phosphate bed in southeastern part of the Garnet Range, Mont.

[R. K. Bailey, analyst.]

Locality.	Thickness.	P_2O_5 (phosphoric anhydride).	Equivalent to $Ca_3(PO_4)_2$ (tricalcium phosphate).
	Ft. in.	*Per cent.*	*Per cent.*
East Brock Creek	4 0	35.10	76.6
Warm Spring Creek	4 3	30.16	65.8
8 miles northeast of Garrison, near center of T. 10 N., R. 9 W.	4 0	30.98	67.6

The relatively high phosphatic content of the sample from East Brock Creek is apparently due to the fact that it represents a portion of the deposit directly exposed to the weather and therefore enriched by leaching. Before the other samples were collected a soil cover and some loose weathered material at the top of the bed were removed. The compact and unaltered appearance of the sample from Warm Spring Creek, together with the fact that it represents the bed near the bottom of a geologically recent natural excavation 1,500 feet deep, lead to the conclusion that it is but little if any richer than the deeply buried portions of the deposit in general. It is believed, therefore, that an average of at least 60 per cent tricalcium phosphate may be safely assumed for the deposit throughout. In addition analyses of the overlying phosphatic chert show 14.7 per cent and 7.8 per cent of tricalcium, respectively, for layers 9 feet and 4 feet thick at Warm Spring Creek and northeast of Garrison.

The chief impurities in the rock phosphate of the area under consideration are sandy and clayey sediments, the composition of which is shown by the following analysis:

Analysis of rock phosphate from Warm Spring Creek, near Garrison, Mont.

[T. H. Rosenkranz, analyst.]

Silica (SiO_2) and insoluble matter	6.00
Alumina (Al_2O_3)	1.10
Magnesia (MgO)	.30
Water (H_2O)	1.45
Iron oxide (Fe_2O_3)	.45
Carbon dioxide (CO_2)	2.20
Lime (CaO)	46.90
Phosphorus pentoxide (P_2O_5)	32.10
(Corresponding to 70.1 per cent $Ca_3(PO_4)_2$).	
Sulphur trioxide (SO_3)	2.10
Undetermined	7.40
	100.00

On the assumption that practically all the phosphorus pentoxide is combined with lime as tricalcium phosphate, a small proportion of lime remains which is probably present as carbonate or sulphate (gypsum) in part. Qualitative tests show the undetermined portion to consist of organic matter, soda (Na_2O), and small amounts of other substances, including chlorine and fluorine. The latter two suggest the presence of the mineral apatite. The soda suggests that some partly decomposed feldspar sand is mingled with the quartz. The organic matter is probably the cause of the fetid odor that the rock yields when hammered.

AVAILABILITY AND TONNAGE.

The phosphate outcrop is everywhere considerably higher than the railways, and its distance from them ranges from 3 miles at the east end of the Garnet Range to 8 miles at Hoover Creek. The two localities most favorable for extensive mining operations are located where the phosphate bed is crossed by Warm Spring and East Brock creeks, 5 and 6 miles, respectively, upstream from the transcontinental railways mentioned. The route to each of these deposits leads through an easily traversed valley that has an average grade of about 100 feet to the mile.

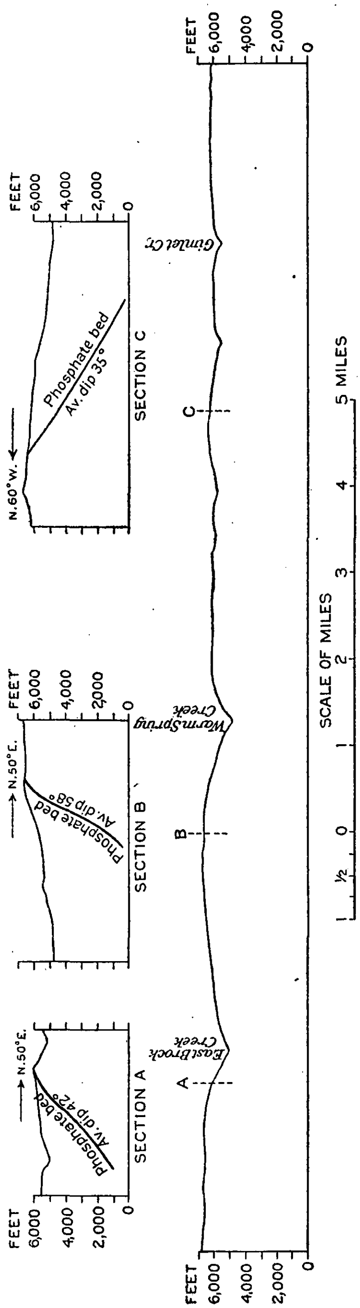

FIGURE 22.—Profile and sections along phosphate bed east of East Brock Creek, Garrison field, Mont. Lower figure is a profile of the outcrop as it would appear were its curves straightened out. The phosphate bed is really bent between the points B and C through an angle of 180°, causing the dip to change from southwest through south to northeast.

The superficial portion of the phosphate deposit is the most valuable, because it is perhaps somewhat enriched through leaching of the soluble constituents and most readily available to mining. Beneath the outcrop east of East Brock Creek, which has a linear extent of 12 miles, there is evidently a considerable quantity of 70 per cent rock phosphate that could be mined by surface workings. Much of it can be very readily mined by adits driven on the bed where it is crossed by Warm Spring and East Brock creeks. A generalized profile (fig. 22) shows the outcrop to be notched by the streams mentioned to vertical depths of 1,500 feet or more (equivalent to about 2,000 feet on the dip slope of the bed). The quantity of rock phosphate containing 60 per cent or more of tricalcium phosphate that could be stoped above adits 5,000 feet in length, driven to the right and left on the bed at the levels of the streams mentioned, is estimated at more than 6,000,000 long tons, or twice the present annual production of the United States. The estimate is based on the profile (fig. 22), the dips as given, an average thickness of 4 feet, and a weight of 180 pounds to the cubic foot of rock phosphate. For example, the block west of Warm Spring Creek above a 5,000-foot adit has an area approximately equivalent to that of a triangle of 5,000 feet base and 1,950 feet altitude.

$$5,000\times\frac{1,950}{2}\times4=19,500,000 \text{ cubic feet}=1,566,964 \text{ long tons.}$$

Elsewhere the deposit is in general less favorably situated for mining by adit levels, but in places it can be reached at considerable depths by crosscut tunnels of practicable lengths. The total volume of the deposit above the level of Warm Spring Creek (4,800 feet) and east of a point 1 mile northwest of East Brock Creek is estimated at more than 35,000,000 long tons. Below this block is a much greater quantity of rock phosphate, which, however, will naturally be more and more expensive to mine as depth increases. Each block representing 1,000 feet in depth (on the dip) is estimated to contain more than 20,500,000 long tons, and if 3,000 feet is assumed as the limit of profitable mining, the Garrison field contains at least 97,000,000 tons of available rock phosphate.

WESTERN PART OF THE GARRISON FIELD.

The sandstone of the Phosphoria formation in the western part of the Garrison field (see p. 210) contains sparingly and irregularly scattered bodies of rock phosphate that range in size from mere specks to nodules 1 inch in diameter, but average about a quarter of an inch. In addition, irregular cherty layers above or below the sandstone are slightly phosphatic. As a rule the phosphate nodules are relatively concentrated in a layer of the sandstone about 1 foot thick, as shown by the following sections:

Sections of phosphatic stratum in western part of Garrison field, Mont.

[W. C. Wheeler, analyst.]

Locality.	Character.	Thickness.	P_2O_5 (phosphorus pentoxide).	$Ca_3(PO_4)_2$ (tricalcium phosphate).
Hoover Creek, sec. 13, T. 11 N., R. 11 W.	Cherty quartzite.			
	Coarsely oolitic rock phosphate. Grains ⅛ to ¼ inch in diameter embedded in abundant sandy matrix	*Ft. in.* 11½	*Per cent.* 18.60	*Per cent.* 40.55
	Red chert, slightly phosphatic	5+		
	Quartzite.			
Burt Creek, sec. 36, T. 11 N., R. 12 W.	Sandstone, red, quartzitic	4+		
	Sandstone with abundant coarse grains or nodules of rock phosphate as much as 1 inch in diameter	7	16.29	34.51
	Similar sandstone, except that phosphate nodules are less abundant	1 0	2.66	5.80
	Chert	2 0		
	Sandstone, slightly phosphatic	25+		
Northwest of Drummond, sec. 23, T. 11 N., R. 13 W.	Sandstone and shale, slightly phosphatic	15+		
	Sandstone with nodules of phosphate as much as ¾ inch in diameter	1 6	7.54	16.43
	Chert and sandstone, slightly phosphatic; contain fragmentary pelecypods and plants	4+		
	Impure limestone.			

Although the phosphate nodules are smooth and more or less spherical in form, they do not appear to be waterworn pebbles but rather are aggregates or concretions. Microscopic examination of specimens from Hoover Creek shows them to be aggregates of small round grains composed of a fibrous mineral and embedded in a sandy matrix. A thin section of a nodule from the exposure northwest of Drummond shows it to be chiefly an amorphous homogeneous mass of a reddish-black color. Distributed through the mass are a few slender crystals, 0.05 millimeter or less in length, that show interference colors of a low order and probably represent a chlorocalcium phosphate, which, however, does not have the characteristics of apatite. In addition, a few fine rounded quartz grains are scattered through the phosphatic substance and here and there appear to be partly replaced by it. Hematite, to which the reddish color is due, occurs in small irregular bodies, but no calcite was observed.

PHILIPSBURG FIELD.

In the Philipsburg field a deposit of rock phosphate of similar character to that of the eastern part of the Garrison field occurs at the same stratigraphic position. Its probable distribution in the Philipsburg quadrangle is equivalent to the distribution of the Quadrant formation, which includes the Phosphoria, as mapped in the Philipsburg folio. Accordingly, the phosphate may be expected in greater abundance north of Philipsburg, especially in the basins of Boulder, Gird, and Douglas creeks, than elsewhere. The bed is almost everywhere tilted steeply, and the relief of the surface is so varied that a large part of the deposit can be mined through adits.

As in the Garrison field, the phosphatic stratum is generally concealed by a surface mantle, and except along Gird and Douglas creeks, float phosphate is very scanty, so far as known. The character of the phosphate deposit at the two localities in which it has been exposed is shown by the following sections:

Sections of phosphate bed in northern part of Philipsburg field, Mont.

[W. C. Wheeler, analyst.]

Locality.	Character.	Thickness.	P_2O_5 (phosphorus pentoxide).	$Ca_3(PO_4)_2$ (tricalcium phosphate).
Philipsburg, south slope of Flagstaff Hill.	Yellowish-brown sandstone.	*Ft. in.*	*Per cent.*	*Per cent.*
	Brown phosphate	6	11.85	25.8
	Brownish-yellow shale	4 6	7.05	15.37
	Hard black phosphate	1 4	31.95	69.8
	Soft clayey phosphate	1 4	22.03	48.02
	Brown to blue-gray shale	5 6	11.53	25.13
	Brown to black phosphate	1 8	22.73	49.55
	Phosphatic chert	2 0	2.29	4.99
	Dull-gray limestone.			
Maxville, tunnel on property of J. D. Fields.	Fault gouge and breccia	3+		
	Soft crushed black phosphate	3 11	15.20	33.13
	Brown sandstone with black shaly partings, slightly phosphatic	15+		

The layers that compose the phosphate deposit on Flagstaff Hill are concealed by 3 feet or more of soil and are considerably decomposed to an additional depth of 2 or 3 feet. The dip averages 55° W., and all but a moderate-sized block of the deposit at this locality lies below the natural drainage levels. At the Maxville exposure the bed stands vertically, is severely crushed, and is in part cut away by a fault, and the phosphate is somewhat mixed with foreign matter. The sample analyzed is therefore not fairly representative.

Northeast of Maxville, on the slopes adjacent to Gird and Douglas creeks, loose fragments of high-grade rock phosphate, some of which are more than 1 foot thick, are conspicuous in the surface mantle. Their composition, size, and abundance indicate that where it is not deteriorated because of faults or similar accidents the deposit is comparable in size and quality to that of the eastern part of the Garrison field.

USES.

Rock phosphate, after being subjected to certain chemical treatment, is used as a constituent of mixed fertilizers and is also, in a finely ground form, applied directly to the soil.[1] The conditions that govern the use of phosphatic fertilizers are beyond the scope of this report, but the fact that their use is highly beneficial under proper conditions is well established, and a steadily increasing demand for these fertilizers is to be expected.

The Garrison and Philipsburg fields are favorably situated for the manufacture of the chemically prepared fertilizer because of their nearness to the great smelters of western Montana, the potential sources of vast quantities of sulphuric acid, which is the principal chemical reagent used.

ORIGIN.

The western phosphate deposits are highly phosphatic shales and sandstones that accumulated on the bed of a Pennsylvanian or Permian sea. Their features and manner of occurrence both generally and in the Garrison and Philipsburg fields make it certain that practically no addition or concentration of phosphatic material has taken place since the beds were laid down. In this respect they differ from most of the known valuable deposits of rock phosphate elsewhere, which are generally regarded as due to concentration. For example, those of South Carolina and Florida have been determined to be chiefly the concentrated residues from the leaching of phosphatic limestones, as, in fact, are most of the other known

[1] Methods of manufacture of phosphatic fertilizers are described by Waggaman and Fry in U. S. Dept. Agr. Bull. 312, 1915.

phosphate deposits not related to igneous rocks. Perhaps the nearest analogue of the western phosphate beds is the Tennessee blue phosphate rock, from which, however, they differ in some important particulars. Compared with other sedimentary strata, the distinctive feature of the beds that compose the western phosphate deposits is their remarkably large content of phosphatic matter, a difference that has not been adequately explained.

Practically all sedimentary rocks contain small amounts of phosphates as original constituents. Large numbers of analyses show maximum averages of 0.08 per cent phosphoric acid in ordinary sandstones, 0.20 per cent in shales, and 0.42 per cent in limestones.[1] The mineral apatite, a minor original constituent of practically all igneous rocks and also a principal constituent of many veins, is regarded as the principal ultimate source of the phosphates. The transference of the phosphatic material from the original apatite to the sedimentary rocks is accomplished chiefly by solution and organic action, but the steps in the process are not fully understood. However, phosphates finally become dissolved in the ocean, from which, together with calcium carbonate, they are absorbed by marine organisms. When these organisms die their skeletons or shells become incorporated in the sediments accumulating at the bottom, but in general not before there has been opportunity for a partial re-solution of the calcium carbonate. The deposits thus formed are as a rule only feebly phosphatic, but they may be enriched as long as they are exposed to action of the sea water.

A process observed in the Baltic and North seas,[2] and doubtless effective elsewhere, consists in a re-solution, short migration, and reprecipitation of the phosphate as nodules or concretions gathered about shell fragments or other objects that serve as nuclei. As the deposits thus formed, however, do not, so far as known, contain more than 3 per cent of lime phosphate, the richness of the western phosphate beds seems to demand special conditions of which no present-day counterparts are known. It may be supposed that either from a most unusual and abundant source phosphates were rapidly supplied to the sea, or that conditions especially favorable to the solution and retention of calcium carbonate by the sea water but not hindering the ordinary precipitation of phosphate existed for a considerable time. In the opinion of the writer, the first supposition is exceedingly improbable, but the second is worth consideration as a working hypothesis. As is well known, the solution of calcium carbonate is favored by the presence of carbon dioxide (CO_2), which is retained most abundantly by water of low temperature.

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[1] U. S. Geol. Survey Bull. 591, p. 23, 1915.

[2] Murray, John, and Hjort, Johan, Depths of the ocean, pp. 185 et seq., 1912.

In addition to an atmospheric source, the ocean receives carbon dioxide from organic substances that decompose at the bottom. Sea life is known to swarm in shallow basins situated in regions of variable climate. There is reason to believe that the late Carboniferous sea of the western phosphate region was of moderate depth and teemed with organisms of some sort, of which the bituminous matter in the rock phosphate is a residue. The known existence of glaciers elsewhere during this general period is believed to warrant the assumption of a variable climate, cool enough to maintain cold water in all but perhaps the superficial layers in the basin. Thus conditions unfavorable to the growth of coralline limestone or the chemical precipitation of lime are supposed to have characterized the period of phosphate deposition. Furthermore, water charged with carbon dioxide would tend to dissolve whatever limy objects came into it and thus hinder the growth of limestone composed of shells and skeletons of marine organisms. Therefore, it being assumed that the precipitation of phosphate at the ordinary rate was unhindered, that material would accumulate in a comparatively pure form. Perhaps the most important part of the whole problem relates to the manner in which the phosphatic substance was transferred from solution in the sea to the deposits at the bottom. The rather meager knowledge available on this subject suggests that the process was complex but is not sufficient to explain it in detail.

It is not to be denied that conditions essentially similar to those sketched in the foregoing paragraphs exist in many places to-day, without, so far as known, a noteworthy accumulation of phosphate. This fact, however, is not necessarily fatal to the hypothesis advanced, for the western phosphate deposits constitute an exceptional feature thought to be the result of conditions resembling those of to-day but intensified.

The bulk of the western phosphate beds is enormous. The known deposits as partly estimated contain 5,290,296,900 tons[1] of recoverable high-grade rock phosphate, which is evidently but a fraction of that originally contained in the region as a whole. In view of the knowledge available for this general region it seems not unreasonable to think that the area within a boundary roughly circumscribing the known phosphate lands (see Pl. IX), or between 50,000 and 100,000 square miles, was formerly underlain by deposits the equivalent of a continuous bed at least 5 feet thick and containing 30 per cent of phosphorus pentoxide. The fact of a great volume, however, needs no further explanation than a continued or extensive application of the process, whatever it was, that initiated the formation of

[1] Mansfield, G. R., Phosphate resources of the United States (paper read before Second Pan American Scientific Congress, Jan. 4, 1916).

this unique deposit. For example, to release sufficient phosphoric acid from its original matrix to form a bed of rock phosphate 5 feet thick, containing 30 per cent of phosphorus pentoxide, the decomposition of a layer of igneous rock of average composition (0.29 per cent P_2O_3),[1] about 500 feet thick, would be required. A similar layer of phosphate considered as a residue would require the leaching of about 350 feet of limestone of the average composition (0.42 per cent P_2O_5),[2] whether the limestone was dissolved as it accumulated, which is supposed to have been true for these deposits, or during a later period.

[1] U. S. Geol. Survey Bull. 591, p. 22, 1915.

[2] Idem, p. 23.