THE ELLISTON PHOSPHATE FIELD, MONTANA.

By R. W. Stone and C. A. Bonine.

INTRODUCTION.

The first reported discovery of rock phosphate in Montana was made by H. S. Gale, of the United States Geological Survey, at Melrose in October, 1910. This phosphate, at the same geologic horizon as that in the phosphate fields of Idaho, Wyoming, and Utah examined by Survey parties in 1909, suggested the strong possibility of its occurrence in western Montana over an extensive region where Carboniferous rocks outcrop. In 1911, while examining Northern Pacific Railway land-grant lands for the purpose of classification, J. T. Pardee, of this Survey, found rock phosphate at three localities in western Montana—(1) in the Garnet Range, 6 miles north of Garrison; (2) at Philipsburg, on the south slope of Flagstaff Hill; and (3) half a mile east of Elliston; and R. W. Stone discovered rock phosphate 2 miles east of Cardwell, at the summit of the cliffy slope west of Jefferson River. The demands of the work in hand did not permit detailed study of these deposits in 1911. The Melrose area was mapped by R. W. Richards in 1912, but it was not until September, 1913, that an investigation of the deposits discovered by Pardee was undertaken.

A detailed examination of the phosphate field at Elliston was begun September 8, 1913. Snow covered the country above an elevation of 6,000 feet on the 16th of the month but lasted only one day. On the 22d 6 inches of snow fell and interfered with work in the woods for five days. A third storm began October 5, and the camp outfit was stored for the winter October 7, with 2 feet of snow on the land under examination. In spite of the short time thus available the main geologic features were worked out and the outcrop of the phosphate bed was located.

The accompanying map (Pl. IX) shows the location of the phosphate outcrop with relation to land lines and the location of some of the other geologic features. The geologic boundaries actually traced are shown in a solid line. A broken line is used where the location of the boundary is only approximate, as in areas of andesite and granite that were mostly in timber with snow on the ground at the time of the examination. The locations on the map were determined by stadia, plane-table triangulation, or paced traverse tied to corners. The map shows 67 section or quarter-section corners that were found

The writers were assisted in the geologic mapping and prospecting of the phosphate by J. E. Richardson, jr.

GEOLOGY.

GENERAL RELATIONS.

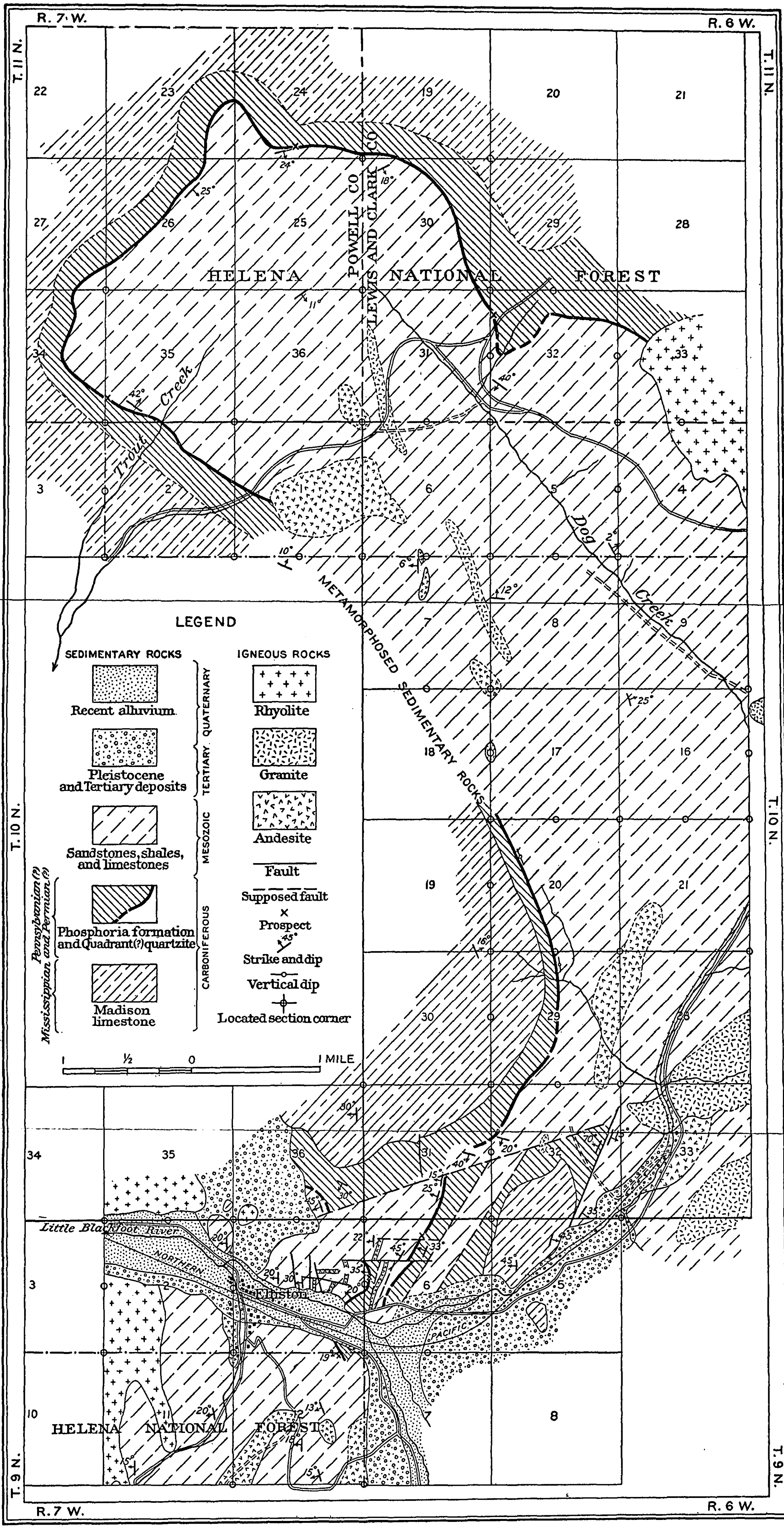
In the Western States rock phosphate occurs in sedimentary beds of Carboniferous age at about the same geologic horizon over a considerable area. Warping or breaking of the earth's crust, igneous intrusion, and erosion have caused the extensive phosphate beds, originally laid down horizontally to be separated into detached areas and tilted at various angles, in some places even vertically. From the regions lying between the phosphate fields hundreds and probably thousands of feet of strata have been removed by erosion.

The sequence and character of the Carboniferous sediments vary rom place to place throughout the region in which phosphate was laid down, but the general relation is fairly constant in western Montana. A knowledge of the sequence of the sedimentary rocks closely related to the phosphate horizon is essential to intelligent prospecting for the phosphate. In many localities the massive blue Madison limestone, which is about 1,000 feet thick and conspicuously exposed, is a guide to the phosphate bed which lies from 400 to 700 feet above it with sandy shale and quartzite between. Massive beds of quartzite, some of which are nearly pure white and strong ledge makers, are separated from the uppermost limestone by 100 to 300 feet of red sandy beds. The phosphate occurs near the top of these quartzite beds. The phosphate commonly lies just above a ledge of massive white quartzite and is overlain by black cherty rock. This statement applies to horizontal beds or to those tilted at a low angle. If the beds are nearly vertical, the phosphate occurs on the side of the quartzite beds farthest from the Madison limestone. The distance between the top of the Madison limestone and the place where phosphate float should be found varies with the attitude of the beds and with the relation of the outcrop to the hill slope.

Above the phosphate horizon are sandstones and shales of Mesozoic age, which are of particular interest in this connection only because they form the cover of the phosphate bed.

SEDIMENTARY ROCKS.

Details of stratigraphy have not been studied, nor are they essential in an economic report. The formations will be mentioned briefly, however, in the order of their age. The rocks range in age from early



MAP OF THE ELLISTON PHOSPHATE FIELD, MONTANA.

Carboniferous (Mississippian) to Recent. They are of both sedimentary and igneous origin.

Madison limestone (*Mississippian*).—The Madison limestone is extensively exposed north of Elliston, and the position of its upper part is shown on the map. As the formation is about 1,000 feet thick, its outcrop is wide where the beds lie at a low angle. In general it is a thick-bedded blue limestone, weathering white or light gray, somewhat fossiliferous and carrying irregular cherty nodules. The beds where highly tilted commonly make prominent outcrops. A detached small area of Madison limestone is partly exposed by a quarry at the limekilns 2 miles east of Elliston. The main outcrop of limestone in this field lies west and north of the phosphate outcrop, as shown on the map.

Quadrant (?) quartzite (Pennsylvanian?) and Phosphoria formation (Permian?).—The Madison limestone is overlain by about 700 feet of later Carboniferous rocks, of which the lower 640 feet is tentatively correlated with the Quadrant quartzite of the Three Forks quadrangle and other areas to the southeast, and the upper 80 feet, which contains the phosphate beds, is correlated with the Phosphoria formation of Idaho and southern Montana. Where the rocks are tilted at a high angle the outcrop of these formations is narrow; but in the northern part of the field, where the dip is less than 45°, the outcrop is a quarter of a mile or more wide. It extends in an S-shaped belt from the rhyolite in sec. 33, T. 11 N., R. 6 W., to sec. 36, T. 10 N., R. 7 W., where it is hidden by Tertiary lake deposits just north of Elliston.

The following section was measured where the beds stand vertical but are not particularly well exposed:

Section at northwest corner of sec. 20, T. 10 N., R. 6 W.

	Feet.
Phosphoria formation:	
Sandstone and shale, soft, greenish brown	75
Phosphate rock, shown by bluish-white float	5
Quadrant (?) quartzite:	
Quartzite, white, massive, ledge maker	50
Quartzite, gray, pink, and white, interstratified with shale	210
Sandstone and shale, concealed	200
Quartzite, gray and pink, variegated	30
Shale, sandy, soft, reddish in places	150
Madison limestone:	
Limestone, blue, weathers white	1,000+

The black chert in some places overlying the phosphate bed seems to be absent at this point, though it is well exposed in sec. 6, T. 9 N., R. 6 W.

Mesozoic formations.—The beds overlying the phosphate are mainly thin-bedded buff-weathering sandstone and shale and arenaceous limestone. Black chert is common immediately above the phosphate.

Not far above it is a conspicuous thick-bedded quartzose sandstone which is hard enough to make ledges and commonly develops coarse talus. This sandstone carries numerous minute particles of black chert, which give it a speckled appearance. It is well exposed in the hill half a mile northeast of Elliston depot.

No place was found at Elliston where the beds younger than the phosphate could be measured successfully. The stratigraphic section is complicated by faults and by sills of andesite porphyry.

Cenozoic deposits.—Deposits of sand, gravel, clay, and tuff, commonly known as Tertiary lake beds, occur just north of Elliston. An unconsolidated deposit of gravel in the SW. ¼ sec. 31, T. 10 N., R. 6 W., probably may be correlated with the post-Tertiary and preglacial terrace gravels found in this part of the State.

At the forks of Blackfoot River, east of Elliston, there is a stretch of hummocky topography resembling glacial moraine. Alluvial gravel, sand, and silt, extensive enough to be shown on a map of the scale here used are found only near Elliston.

IGNEOUS ROCKS.

Andesite.—The oldest igneous rock in the Elliston field is andesite, a porphyritic rock, occurring in several varieties, which was originally poured out on the surface in a great sheet and also interbedded with Mesozoic sediments. Remnants of this flow now cap some of the ridges. One of these remnants is along the crest of the divide between Elliston Creek and Little Blackfoot River in sec. 12, T. 9 N., R. 7 W., another, in which pyroxene phenocrysts are prominent, crowns the ridge at the northeast corner of sec. 18, T. 10 N., R. 6 W. From this point for 2 miles or more northward small patches of andesite occur intermittently along the crest. Other areas of andesite are shown on the map, but their boundaries are less certain, as they occur in timber and away from the phosphate horizon.

Granite.—Granite, or more technically quartz monzonite, outcrops in small areas in the east half of the field. These croppings are outliers of the Boulder batholith, a great mass of intrusive granitic rock extending uninterruptedly from Blossburg and the vicinity of Helena to the Highland Mountains, 16 miles south of Butte. An intrusion of granite near the northeast corner of sec. 16, T. 10 N., R. 6 W., has altered the invaded sandstone to beds of almost solid garnet rock, with calcite, tourmaline, actinolite, epidote, and diopside. The map shows two long, narrow bands of granite on the west side of Dog Creek. These are the approximate locations of float found along the mountain side in timber. Bedrock was not discovered, and the shape and character of the intrusions are not known. The rock appears to be hornblende granite porphyry, probably an offshoot from the main mass of quartz monzonite.

Rhyolite.—Rhyolite occurs west of Elliston and also on the Continental Divide east of Dog Creek. These areas are merely remnants of lava flows poured out over this region, probably in Miocene time and when the topographic relief was similar to that of the present. Much larger areas of rhyolite are to be seen farther west on Blackfoot River, particularly near Avon.

STRUCTURE.

In the north end of the Elliston phosphate field the rocks form a structural trough or syncline having a northwest-southeast axis in the valley of Dog Creek. In the south half of the field the rocks form a structural arch or anticline, the axis of which is along the west side of sec. 31, T. 10 N., R. 6 W., parallel with and west of the synclinal axis. This arch ends abruptly, however, in fault blocks, the intricate structural details of which have not been fully determined.

The fault blocks are tilted at angles of 10° to 90°, and the phosphate bed is traced with little difficulty, but the exact position of the faults is hard to determine. Abrupt changes from nearly horizontal to vertical bedding and the offsetting of andesite sills afford abundant evidence that faulting has taken place, but a mantle of gravel and talus masks the bedrock at vital points for the determination of the faults.

PHOSPHATE.

PHYSICAL CHARACTERISTICS.

The phosphate rock in western Montana is readily distinguished by its finely oolitic texture, thin bluish-white coating on weathered surfaces, heavy specific gravity, and peculiar odor.

Texture.—In the Elliston field the oolitic texture is readily recognizable. The oolites or ovules, which form a very large percentage of the rock, range for the most part from 0.01 to 0.1 inch in diameter. In the rich rock near Elliston a large percentage of the oolites are about 0.04 inch in diameter, or smaller than the head of a common pin. The oolites in much of the rock are so tightly cemented that they are broken through by joints or fractures. In the weathered outcrop of the richest rock the oolites are freer and fragments show miniature mammillary surfaces from which the rounded nodules can be easily separated. Even to the unaided eye it is apparent that some of the oolites have a distinct concentric structure. By the aid of a magnifying glass it is seen that some have a white center surrounded by a dark band with a white edge; others a dark center, a succession of white and dark bands, and a white edge. Other oolites appear to be a solid homogeneous chalk-white substance and some have a central cavity. Although at first glance these ovules appear to be round, closer examination shows that most of them are spheroidal and some discoidal. This shape seems to be inherent rather than induced by pressure, for parallelism of elongated ovules is not produced.

Weathering.--The fresh rock phosphate of this field is dark gray to black in color, but the weathered surface is characterized by a bluish-white tinge known as phosphate bloom. Each individual oolite of a thoroughly weathered surface is white or bluish white, and where the oolites are abundant they commonly give this color to the surface. Phosphate rock is found in which not only the oolites but the matrix weathers to a nearly pure white, and the float may then be as white as if it had been given a thin coat of kalsomine. There are outcrops—for example, near the north quarter corner of sec. 6, T. 9 N., R. 6 W.—in which a red matrix gives a red or pink tinge to the weathered surface. The phosphatic character of the rock is readily recognized, however, by the white oolites.

Specific gravity.—A rich phosphate rock is noticeably heavy compared with quartz, chert, or other rocks of the same volume. The average specific gravity for rock containing 70 per cent of tricalcium phosphate is about 2.9.

Odor.—Phosphate rock when freshly broken gives off for a moment a fetid odor. The fume is not exactly bituminous nor sulphurous but is very characteristic; it is not particularly disagreeable. Some rock gives off so strong an odor when rapidly broken that it can be smelled readily at a distance of 3 or 4 feet. It is not believed that the intensity of the odor given off is in proportion to the phosphatic content.

ORIGIN.

The origin of the western phosphate has been little studied owing to the short time that has elapsed since the discovery and to the lack of development of the deposits. The scope of the present paper will not permit a discussion of the hypotheses advanced to explain its origin. The facts observed in the field, however, indicate that it is a bedded sedimentary deposit laid down in Pennsylvanian or Permian time in waters rich in phosphate of lime. The abstraction of this phosphate of lime and its deposition in oolitic bodies may have been accomplished entirely by chemical means or by phosphate-secreting marine organisms.

THICKNESS AND COMPOSITION.

The phosphate bed was completely exposed by prospect trenches at four points. One natural exposure of the entire bed was found. At four other places an unsuccessful attempt was made to cut a trench down to the bed. One of these places was an old cut opened by some prospector who evidently recognized the material but failed to reach bedrock. The five localities where the bed was wholly uncovered are indicated on the map (Pl. IX) and described in detail below. In the tables are given the thickness and character of beds and analyses of samples from prospect trenches opened by the writers in the Elliston field. The descriptions begin with the northeast end of the outcrop.

Float phosphate was found in the E. ½ sec. 32, T. 11 N., R. 6 W., and in sec. 33 up to the boundary of an area underlain by rhyolite. This float was found by searching in small patches around the base of trees where snow had melted off. No attempt was made to dig a trench because snow prevented making a careful choice of location. The line shown on the map is the location of abundant float. A sample for analysis was taken by gathering small fragments of float at many points along half a mile of outcrop. An analysis of the sample collected in this manner gave 29.62 per cent P_2O_5, equivalent to 64.6 per cent tricalcium phosphate.

Close beside the road in the NW. ¼ sec. 32, T. 11 N., R. 6 W., a prospect pit was found in which considerable white phosphate rock had been unearthed. The abundance of float warranted digging, but an attempt on the part of the writers to uncover bedrock was as unsuccessful as that of the earlier prospector. A sample was taken by breaking chips from many pieces on the piles around the trench. These were mixed and quartered, and the quarter retained showed on analysis 35.85 per cent P_2O_5, equivalent to 78.3 per cent tricalcium phosphate. This is the highest percentage of phosphate obtained in the Elliston field and may be accounted for by the fact that the rock was more weathered than the other samples. The weathering of phosphate rock tends toward enrichment from 3 to 5 per cent, owing to leaching of the more soluble lime carbonate.

Float was found across sec. 30, T. 11 N., R. 6 W., on clear slopes and in the woods 250 feet north of the southeast corner of sec. 24, T. 11 N., R. 7 W. Although several inches of snow covered the ground, phosphate was discovered around the base of trees where the snow had melted away for a few inches. A trench was dug on the crest of a ridge in section 24, where the beds strike N. 80° E. and dip S. 24°. The following section shows the character of the rock at this point:

Section of phosphate bed in trench in SE. ¼ SW. ¼ sec. 24, T. 11 N., R. 7 W.

No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
	Quartzite, hard, black, cherty.	*Per cent.*	*Per cent.*	*Ft. in.*
43	Quartzite, phosphatic	12.98	28.3	1 5
44	Phosphate	30.55	66.6	3 4
	Quartzite, hard, dark.			

Float is plentiful through the woods to the west of this trench. A second trench was dug on a ridge top in section 35. The beds at this point strike N. 50° W. and dip 42° NE. at the top of the section and 35° NE. at the bottom. The section is as follows:

Section of phosphate bed 1,000 feet north of southwest corner of sec. 35, T. 11 N., R. 7 W.

No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
	Quartzite, sandy.	*Per cent.*	*Per cent.*	*Ft. in.*
55	Phosphate, cherty	33.24	72.5	1 3
	Phosphate, good			1 8
	Shale, yellow			3
	Phosphate, good			2 0
	Chert, phosphatic			3
	Quartzite.			

The analysis includes the four phosphatic layers but not the 3-inch parting. Several pounds of material from these four beds was crushed, mixed, and quartered at the trench to give an average sample.

In ascending the east fork of Trout Creek phosphate float is first seen in the road beside a cabin near the line between secs. 1 and 2, T. 10 N., R. 7 W. This float has come down a steep hillside, and the outcrop is considerably east of the cabin. From Trout Creek southeastward across the head of Gold Canyon Creek for a distance of 3 miles the rocks are so metamorphosed and distorted that no trace of the phosphate could be found. At the east side of an old sheep corral at the northwest corner of sec. 20, T. 10 N., R. 6 W., float was found and traced continuously down a ridge to the south quarter corner of sec. 20. Between this quarter corner and the creek, 1,000 feet to the south, phosphate float is abundant; but several attempts to reach bedrock by shallow trenching were unsuccessful. Float phosphate was traced across the NW. ¼ NW. ¼ sec. 32, but could not be found near the west quarter corner of this section.

Near the center of sec. 31 the offsetting of the uppermost bed of Madison limestone and overlying red sandy shales is apparent, but the writers were unable to trace the phosphate up to the fault line. It is readily traced, however, from a point near the center of sec. 31 southward three-quarters of a mile along the crest of a quartzite ridge. Float was found at the highway on a direct continuation of this course, but the bed was not discovered in some places in the last quarter of a mile. This bed was exposed with a little trenching near the north line of sec. 6, where the following section was revealed:

Section of phosphate bed 800 feet south of north quarter corner of sec. 6, T. 9 N., R. 6 W.

No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
	Chert, black.			
	Shale, cherty.	*Per cent.*	*Per cent.*	*Ft. in.*
36	Phosphate	11.89	26.0	2 11
	Chert, slightly phosphatic			2 7
38	Phosphate	15.31	33.4	6
	Quartzite.			

Outcrops and two other small trenches in the immediate vicinity showed beds similar in thickness and quality to those of the above section.

In 1911 J. T. Pardee discovered float phosphate close to Elliston in the NE. ¼ SE. ¼ sec. 1, T. 9 N., R. 7 W. The locality is on the east side of a small gulch and just west of the upper bridge over Little Blackfoot River. The float was found a few feet above flood-plain level on the dip slope of a great cliffy quartzite ledge. An analysis of this float[1] gives 30.0 per cent P_2O_5, equivalent to 65.5 per cent $Ca_3(PO_4)_2$. This float is from an outcrop about half a mile long in a fault block. It is easily traced up the dip slope a few rods east of the east quarter corner of sec. 1, over the crest of the knob and around the east side to the place where the writers uncovered the entire bed by a trench, as follows:

Section of phosphate bed in trench in SW. ¼ NW. ¼ sec. 6, T. 9 N., R. 6 W.

No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
		Per cent.	*Per cent.*	*Ft. in.*
	Chert, phosphatic			1 0
	Shale, yellow			3-6
29	Phosphate	28.25	61.6	5 9
	Quartzite, yellowish			2
	Concealed			8 0
	Quartzite, white, massive.			

The phosphate bed can be traced by float about 200 yards northward from this trench to the locality where an unsuccessful attempt was made to uncover the bed. It was not found north of the gulch. Here the quartzite ledge on the south side of an old road opposes younger sandstone on the north side, indicating the presence of an east-west fault.

About three-quarters of a mile southeast of the Elliston depot, in the NE. ¼ NE. ¼ sec. 12, T. 9 N., R. 7 W., a trench was dug 8 feet long and 2½ feet deep, which uncovered an 8-inch bed of phosphate between quartzite below and black chert above. This phosphate was believed

[1] U. S. Geol. Survey Bull. 530, p. 290, 1913.

to be the same as the lower bench of the exposure in section 6, 1 mile to the northeast, but heavy cover prevented excavating for the upper bench. The 8-inch bed contains 16.15 per cent of P_2O_5, which is equivalent to 35.1 per cent $Ca_3(PO_4)_2$. This analysis is very close to that of the 6-inch bed in the first table on page 381.

It is apparent from its position and attitude that the quartzite ledge which is exposed along the road at the section corner three-quarters of a mile southeast of Elliston, and on which this phosphate bed lies, is the same as that which makes a cliff at the bridge, one-third of a mile farther north. This bed would underlie Elliston if not interrupted by faults.

The last exposure of phosphate to be described is that nearest to Elliston; but in some ways it is the least important, although the phosphate is of high grade and the bed has the greatest thickness measured in this field. The locality is half a mile north of east of Elliston depot, on the north side of the river, 20 feet or more above the flood plain. It is a quarter of a mile west of the west end of the quartzite cliff near the upper bridge. At this point the beds in a natural exposure strike north and are vertical. Beds on three sides dip at low angles and the outcrop of the phosphate is only a few rods long. There is every indication, therefore, that the bed is in a small fault block. The section is as follows:

Section of phosphate bed in SW. ¼ NE. ¼ sec. 1, T. 9 N., R. 7 W.

No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
		Per cent.	*Per cent.*	*Ft. in.*
25	Chert, black, phosphatic	15.52	33.84	1 10
26	Chert, black, nonphosphatic	Less than 5		3 10
27	Phosphate	29.82	61.1	6 0
28	Phosphate, spotted, cherty	19.96	43.7	1 6
	Limestone, soft, yellow, shaly.			

From the above data and the accompanying map it is seen that a bed of phosphate rock ranging in thickness from 3 to 5 feet and averaging approximately 65 per cent in tricalcium phosphate outcrops for 9 miles in the north half of the Elliston field. An estimate of the tonnage of phosphate rock in the northern part of the field is presented below, the land underlain by the phosphate bed in secs. 1 and 2, T. 10 N., R. 7 W.; secs. 19, 30, 31, 32, and 33, T. 11 N., R. 6 W.; and secs. 23, 24, 25, 26, 27, 34, 35, and 36, T. 11 N., R. 7 W., being considered as equal to 7 square miles, and any phosphate land in the northwest corner of T. 10 N., R. 6 W., being omitted.

At a specific gravity of 2.9 phosphate rock weighs 181.8 pounds to the cubic foot, or 3,959.6 short tons to the acre for every foot in thickness of the phosphate bed. This makes 2,534,144 tons to the square mile for every foot of flat-lying bed, or 70,956,032 tons of phosphate rock in the 7 square miles, the bed being estimated to average 4 feet in thickness. As the bed does not lie flat and there are differences of 1,200 feet in elevation of the outcrop, the actual tonnage would be greater.

In the south half of the Elliston field the phosphate bed stands nearly vertical along about 2 miles of its outcrop, but near Elliston it is so faulted that an estimate of the area underlain by it is difficult. On the assumption, however, that this part of the field contains the equivalent of 3 miles of outcropping bed that could be mined to a depth of half a mile, there is in the south half of the field 1½ square miles underlain by phosphate; and as the few measurements in this part of the field suggest an average thickness of 4 feet, an estimate is possible of 15,204,864 tons of phosphate rock in the south half, making a total of more than 86,000,000 tons in the whole Elliston field.

ACCESSIBILITY AND USE.

The phosphate in the south half of the Elliston field is within 2 miles of the Northern Pacific Railway and readily accessible to it. The farthest point in the northern part of the field is between 6 and 7 miles from the railway by way of Dog Creek valley, down which there is an easy grade.

Rock phosphate is used in the manufacture of fertilizer. In the process the rock is finely ground and mixed with a nearly equal part by weight of sulphuric acid. The result of this mix is an acid calcium phosphate which, when dried and pulverized, is the substance sold as superphosphate. In this form the phosphoric acid is more readily available as a plant food than it is in the original or raw state.

There has been no development of these deposits owing to their recent discovery and to the lack of markets sufficiently near to justify mining and reduction. The demand for fertilizer products in the Western States is not large, owing to the lack of intensive cultivation and the newness of the agricultural lands; but there is a growing tendency to use fertilizer where the land is farmed extensively, especially in the Middle West. The western phosphate deposits are favorably situated to meet a demand from this section of the country and will probably be utilized in the future.