# PHOSPHATES.

## PRELIMINARY REPORT ON THE PHOSPHATE DEPOSITS IN SOUTHEASTERN IDAHO AND ADJACENT PARTS OF WYOMING AND UTAH.

By Hoyt S. Gale and Ralph W. Richards.

### INTRODUCTION.

#### GENERAL OUTLINE OF INVESTIGATION.

On December 9, 1908, the Secretary of the Interior withdrew from all kinds of entry 4,541,300 acres of land in Idaho, Utah, and Wyoming, pending an examination of their phosphate resources. The lands withdrawn were not then supposed to be all phosphate bearing, but they included all areas in which, according to the meager evidence then available, valuable phosphate deposits seemed likely to be present. The field work done in the summer of 1909, on which this report is based, has led to the restoration of some of these lands and to the withdrawal of others, so that the total area now withheld from entry is 2,551,399 acres.

Two parties were detailed by the Geological Survey to examine the lands thus withdrawn. The larger party, which was outfitted at Montpelier, Idaho, about June 1, was in charge of Hoyt S. Gale and included R. W. Richards and C. L. Breger. W. H. Waggaman, of the Bureau of Soils, Department of Agriculture, who was associated with these geologists in the field throughout the season by agreement between the Bureau of Soils and the Geological Survey, assisted in the collection of representative samples of phosphate rock and made field chemical determinations of their content of phosphoric acid. George H. Girty, paleontologist, was with the party during June and July and, with the assistance of C. L. Breger, collected a large amount of material that is important in the study of the stratigraphic relations of the phosphate-bearing beds.

The other party, which was under the direction of Eliot Blackwelder, of the University of Wisconsin, examined phosphate lands in the extreme southern part of the area withdrawn and studied stratigraphic problems in the northern part of the Wasatch Mountains. The results of this work are presented on pages 536–551 of this bulletin.

Besides this geologic work, topographic work was done in two adjacent areas by parties of the Survey under the direction of A. E. Murlin and Albert Pike. One of these areas is in the extreme northeast corner of Utah and the other in the southeast corner of Idaho, and the two together include much of the more accessible parts of the phosphate fields.

During the season the larger geologic party examined about 1,200 square miles, mapped 400 square miles in considerable detail both geologically and topographically, and traced the outcrops of phosphate rocks in this area. Analyses of 330 representative specimens of phosphate rock show accurately the grade or quality of the material found.

The areal surveys made have defined the position and the geologic relations of the larger developed deposits, so that more reliable estimates of available tonnage can be made. The results of the careful study of the stratigraphic relations of the phosphate-bearing formations and the associated strata have simplified the work of identifying and tracing the deposits. Important outcrops of phosphatic beds have been found and mapped in areas lying beyond those now locally recognized as phosphate bearing, including deposits situated in readily accessible parts of the field and not yet covered by mining claims. Evidence has been obtained of the existence in this field of deposits of high-grade phosphate rock in strata of Jurassic age that are much younger geologically than the deposits hitherto recognized, and although the Jurassic deposits have not yet been shown to be of commercial value, they may prove eventually to be of considerable importance.

## LOCATION.

The phosphate deposits described in this progress report[a] are situated in southeastern Idaho and adjacent portions of Wyoming and Utah. The area examined during 1909 comprises parts of Bear Lake County, Idaho, Uinta County, Wyo., and Rich, Weber, and Morgan counties, Utah. The location of the areas covered by the special maps accompanying this report is shown on the index map (fig. 42), page 484.

Other important districts will doubtless be examined and mapped in continuation of the present work; among these may be mentioned the deposits near Paris Canyon, Bloomington, Swan Lake, and Soda Springs, in Idaho, and the supposed extensive fields in Wyoming of which no complete review has yet been made.

[a] It is expected that a more complete report will be issued after further field examinations now contemplated.

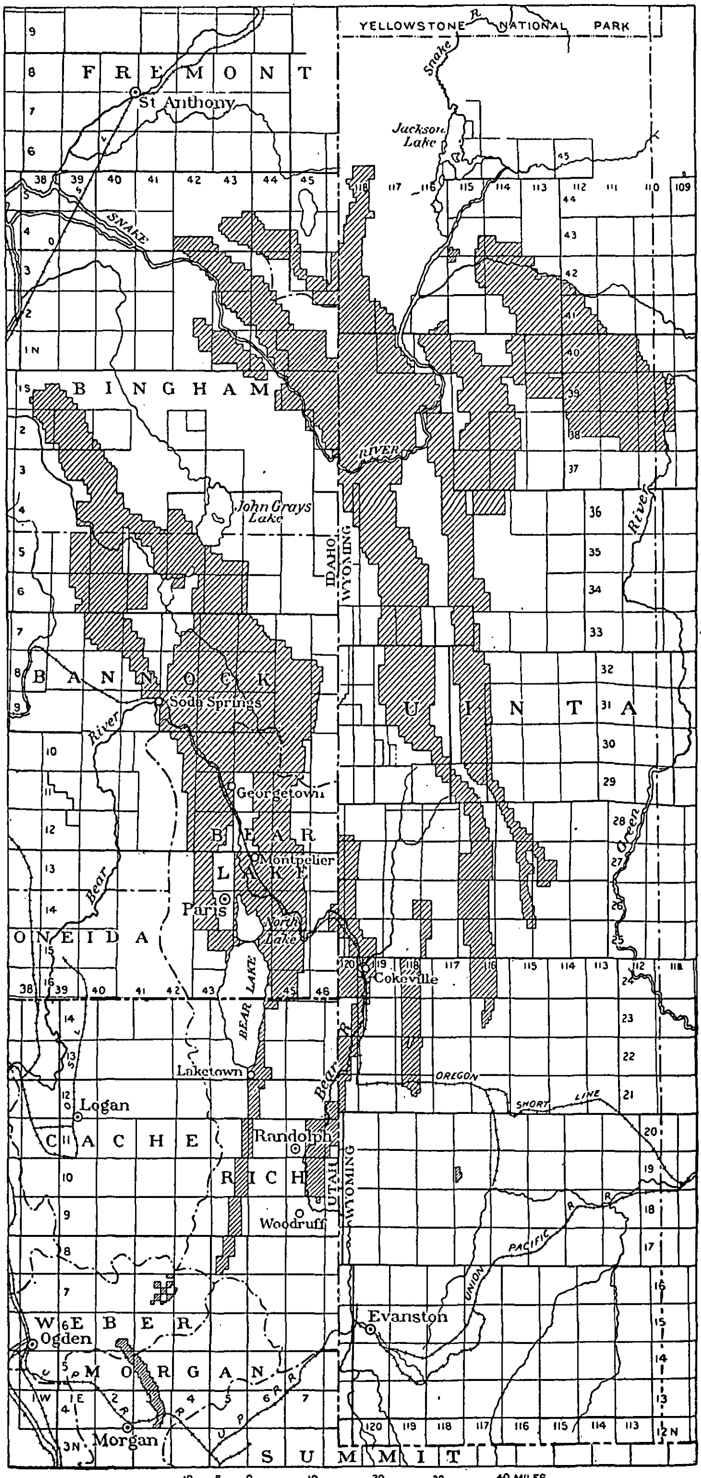


FIGURE 41.—Map showing extent of phosphate reserve of Idaho, Utah, and Wyoming, May, 1910.

The actual limits of these phosphate deposits are not yet known. Phosphate was found by the senior author in the Park City formation in Big Cottonwood Canyon near Salt Lake City. Specimens collected by Boutwell from the Park City formation in the Park City mining district have recently been recognized and identified by chemical test as phosphate rock. This rock is also reported to occur on Mill Creek, southeast of Salt Lake City, where float is said to have been found on a hill to the north of the wagon road above the limekilns, near the main road.

Phosphate rock is reported in Provo Canyon at or near Midway, Utah. Specimens from supposed coal prospects of the same geologic horizon, on Labarge Creek, Wyoming, and from supposedly equivalent rocks east or southeast of the Wind River Range, have been tested, showing phosphate and indicating the wide distribution of these deposits. The extent of similar deposits southward through Utah and possibly into Nevada is suggested. The supposed northern extension of the deposits is outlined by the area of land withdrawals, as shown in figure 41.

## GEOGRAPHY OF AREA EXAMINED IN 1909.

The Preuss Range, in the northern part of the area examined, shows the maximum relief, the difference in elevation between the level of Bear River and the top of Mead or Preuss Peak being 4,000 feet. The extreme relief in the southern portion of the area is 1,700 feet, between the level of Bear River and Rex Peak, in the Crawford Mountains. The mean surface elevation of Bear Lake is 5,925 feet above the sea, as determined by recent level work.

The flood plains of Bear River and Bear Lake occupy one-fifth to one-fourth of the entire area; the remainder is made up of mountains, consisting of the Preuss, Sublette, Crawford, and Bear River ranges. The upland east of Bear Lake, extending to the Idaho-Wyoming line, to the south and west of Bear River, is known as the Bear Lake Plateau.

The Oregon Short Line Railroad, the only transportation line crossing the area, follows the Bear River valley. Montpelier, Idaho, and Randolph, Utah, are the largest towns.

## EARLIER WORK.

The deposits were early prospected because the superficial resemblance of the outcrop to coal blossom attracted the prospector. Their phosphatic nature was first recognized, according to C. C. Jones,[a] in an analysis of a sample taken by R. A. Pidcock on Woodruff Creek, west of the town of Woodruff, Rich County, Utah, in the sum-

[a] Eng. and Min. Jour., vol. 68, 1907, pp. 953-955.

mer of 1897. The true nature of the deposits having been found out, the work of the discouraged coal seekers became of value to the phosphate prospector—a fact which explains the rapidity with which a large portion of the easily accessible deposits were located. Mr. Jones took a prominent part in this early staking out of claims and his paper gives a review of his methods and results.

Weeks and Ferrier[a] in 1907 published a general account of the western phosphate area, with brief descriptions of several of the localities.

In 1908 Weeks[b] published a progress report on his field work in the area, noted the progress of the industry, and discussed the question of markets and the status of phosphate deposits in mining law.

## NATURE AND ORIGIN OF THE ROCK PHOSPHATE.

### ORIGINAL SEDIMENTARY DEPOSITS.

The rock-phosphate deposits of the Idaho, Utah, and Wyoming fields are original sedimentary formations laid down at the time when that part of the earth's surface was largely covered by water. Since the time in which the phosphatic strata were deposited other rock-forming sediments have been accumulated, so that many thousands of feet of subsequent strata have overlain or succeeded them. Deformation of the earth's crust has tilted, folded, and frequently broken these strata, which originally lay flat. Uplift of the land or recession of the sea has subjected the rocks in their disturbed positions to stream erosion and the action of atmospheric agencies, so that great bodies of the more elevated parts have been removed entirely and the truncated edges of the rock strata are now exposed at the surface. The occurrence of the rock phosphate at the surface of the ground now depends on the geologic structure and more or less accidental relationships, such as absence of masking cover of later deposits, depth of erosion, and many minor factors.

The rock-phosphate deposits are thus more properly analogous to coal and limestone and especially to the Clinton iron ores of the Appalachian region than they are to ore deposits such as veins or lodes or to alluvial deposits of the placer type.

### SOURCE OF PHOSPHORIC ACID.

An entirely satisfactory explanation has not yet been given of the source or manner of accumulation of the phosphoric acid. Phosphorus in combined form is one of the mineral constituents in the earth's crust, as it is found in nearly all igneous rocks, generally in

[a] Weeks, F. B., and Ferrier, W. F., Phosphate deposits in Western United States: Bull. U. S. Geol. Survey No. 315, 1907, pp. 449-462.

[b] Weeks, F. B., Phosphate deposits in Western United States: Bull. U. S. Geol. Survey No. 340, 1908, pp. 441-448.

the mineral apatite. It is also found in some meteorites. It is an essential ingredient of living matter, especially of bones. It is present in sea water in the form of phosphates. The phosphatic concretions found on the ocean floor are explained as derived from the decaying bones of dead animals, upon which carbonic acid exerts a powerful solvent action. They form around various nuclei, but preferably upon organic centers, such as shells. These concretions consist mainly of calcium phosphate and carbonate mixed with sand and clay. They have been found on the ocean floor at a depth of 1,900 fathoms (11,400 feet).[a]

As pointed out by Clarke,[b] deposits formed by accumulations from decaying animal remains on the ocean bottom are at best but moderately phosphatic. It seems likely that concentration is usually effected under subaerial or alternating shallow water and land conditions, where atmospheric agencies begin to work on these remains. The soluble carbonates being removed by surface or ground waters, the relatively less soluble phosphates remain, mixed with more or less residual sand and clay.

The conditions favoring the vast accumulation of organic matter during a particular epoch of the Carboniferous period are not explained. Some indications that shallow water conditions prevailed during the deposition of the phosphate beds are found in the ripple-marked layers associated with those beds in a few places. The great lateral extent and uniformity of the deposits indicate uniformly widespread conditions effecting their deposition. The abundance of fossil shells in the phosphatic series is also evidence of marine shallow-water conditions.

## DESCRIPTION OF THE ROCK PHOSPHATE.

The rock phosphate itself is chiefly characterized by an oolitic texture, by which it can usually be recognized in the field. Rounded grains, built up in roughly concentric structure, range in size from the most minute forms visible to the naked eye or by the hand lens to pebble-like bodies half an inch in diameter, rarely larger. In unaltered specimens there is commonly no visible or distinct cementing of the oolitic grains, except where they occur scattered in a groundmass of foreign material. In the weathered condition, however, as the material is commonly found near the surface, the grains have a grayish color and are more or less distinct. The rounded ovules are also characteristically distinct on weather-polished bedding planes of the more oolitic rock.

The rock phosphate varies in color from coaly black, as at Montpelier and at Woodruff Creek, where it was originally mistaken for

[a] Clarke, F. W., The data of geochemistry: Bull. U. S. Geol. Survey No. 330, 1908, pp. 18, 92, 104, 447–451.
[b] Idem, p. 448.

coal at many places along its natural outcrop, to dull gray or iron stained, as in the Beckwith Hills. Its float is characteristically marked with a thin film of bluish-white bonelike coating, resembling chalcedony, in places with reticulated markings; this is thought to be some secondary phosphatic mineral but has not yet been studied. This coating is useful in tracing the concealed outcrop in the field by means of scattered float or fragments to be found in the overlying soil. A dark indigo-blue stain which proved to be fluorite on examination in thin section was observed in some of the beds at the Cokeville mines, but it is not known that this stain has any general significance in relation to the phosphatic composition of the material. The black color which is common in these deposits is thought to be due to bituminous matter, not necessarily bearing any relation whatever to the phosphoric acid content of the rock, as the phosphate salts related to the substance in this rock are probably white or colorless when pure.

Most of the phosphatic rock has, when broken or struck, a fetid odor, which is supposed to be characteristic of these minerals. The limestones associated with the phosphate beds show this same character, and experience does not seem to justify the inference of any direct relation between the amount of the fetid odor given off and the grade of the phosphate rock. Many of the limestones, which have the odor most strongly, contain only a very small percentage of phosphoric acid. It is to be noted that other limestones show this same character, notably those occurring in the Niobrara formation in the Cretaceous section of the Denver region and elsewhere.

## SPECIFIC GRAVITY.

The specific gravity of representative specimens of the high-grade ore from several localities was determined for use in computing estimates of tonnage. The first determinations were made with a Jolly balance and the results obtained are as follows:

*Specific gravity of specimens of rock phosphate.*

| Field No. of specimen. | Source. | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Specific gravity. | Average specific gravity. |
|---|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | | |
| 3 | Montpelier, Waterloo claim, massive ore (two chips). | 38.3 | 83.9 | 2.93<br>2.89 | 2.91 |
| 92-D | Crawford Mountains, Sioux claim (two chips) | 35.7 | 78.2 | 2.86<br>2.94 | 2.90 |
| 94 | Crawford Mountains, Arickaree mine (two chips) | 37.7 | 82.6 | 2.92<br>2.95 | 2.93 |
| 130-C | Ogden River area | 31.8 | 69.6 | 2.89 | 2.89 |
| | General average | | | | 2.91 |

Other determinations on larger blocks of similar material were made by W. T. Schaller, in the laboratory of the United States Geological Survey, as follows: A specimen of compact phosphate rock (high-grade ore) from the mines of the Union Phosphate company, near Cokeville, Wyo., weighing 493.7 grams, gave a density of 2.92; a specimen of compact phosphate rock (high-grade ore) from the Waterloo mine of the San Francisco Chemical Company, near Montpelier, Idaho, weighing 707.5 grams, gave a density of 2.86. For these determinations the specimens were coated with paraffine before being weighed in water, to prevent absorption of water into the mass of the rock.

As a result of the foregoing tests it is probable that the density of the more massive ore of 70 per cent grade or over (tricalcium phosphate equivalent) from this general region is without much doubt between 2.85 and 2.95; an average of 2.90 has been assumed for the tonnage calculations. From this ratio the weight of a cubic foot of the more massive rock phosphate similar to that now being shipped from the mines in this region is about 180 pounds.

## CHEMICAL COMPOSITION.

The chemical composition of the rock phosphate offers a somewhat mooted and a difficult question. Thin sections of the richest ore show under the microscope that the rock consists mainly of ovules or concretions of a cryptocrystalline substance which, in some concretions, is surrounded by banded zones of crystalline fibers with local isotropic bands, all having the same average index of refraction (1.60) and apparently representing the same substance—the phosphatic mineral. In some places the interstices are filled with calcite and in others with an isotropic material which appears to be identical with the substance comprising the cores of the concretions. Specks of purple fluorite are also found in the interstitial material in the slides of the rock from the Cokeville district. The phosphatic mineral includes minute curly, hairlike, and branching plant fragments whose appearance strongly suggests that they represent fungi. The extinction of the double refracting mineral is parallel to the elongation of the fibers and its optical character is apparently negative. Both of these properties are possessed by the mineral apatite, which, however, has a slightly higher index of refraction and a higher specific gravity.

The following more complete analyses of phosphate rock from these fields were made by George Steiger in the laboratory of the United States Geological Survey:

*Analyses of phosphate rock from Wyoming, Utah, and Idaho.*

| | 1. | 2. | 3. | 4. |
|---|---|---|---|---|
| Insoluble | 10.00 | 1.82 | 9.40 | 2.62 |
| $SiO_2$ | None. | .30 | Not det. | .46 |
| $Al_2O_3$ | .89 | .50 | .90 | .97 |
| $Fe_2O_3$ | .73 | .26 | .33 | .40 |
| MgO | .28 | .22 | .26 | .35 |
| CaO | 45.34 | 50.97 | 46.80 | 48.91 |
| $Na_2O$ | 1.10 | 2.00 | 2.08 | .97 |
| $K_2O$ | .48 | .47 | .58 | .34 |
| $H_2O$ | 1.04 | .48 | .61 | 1.02 |
| $H_2O+$ | 1.14 | .57 | .75 | 1.34 |
| $TiO_2$ | None. | None. | None. | None. |
| $CO_2$ | 6.00 | 1.72 | 2.14 | 2.42 |
| $P_2O_5$ | 27.32 | 36.35 | 32.05 | 33.61 |
| $SO_3$ | 1.59 | 2.98 | 2.34 | 2.16 |
| F | .60 | .40 | .66 | .40 |
| Cl | Trace. | Trace. | Trace. | Trace. |
| Organic matter | Not det. | Not det. | Not det. | Not det. |
| | 96.51 | 99.04 | 98.90 | 95.97 |

1. Main phosphate bed, 2½ miles east of Cokeville, Wyo.
2. Dunnellon claim, Crawford Mountains, Utah.
3. Elsinore claim, Tunnel Hollow, between Morgan and Devils Slide, Utah.
4. Preuss Range, 8 miles east of Georgetown, Idaho.

Qualitative examination of the insoluble matter indicates that it consists mainly of silica with minor amounts of kaolin. Quartz was not observed in thin sections of the high-grade ore. The $CO_2$ in some of the rock is apparently nearly all combined with lime in the form of calcite, as is indicated by the presence of the mineral in the sections and the fact that the gas is liberated on treating the powdered rock with dilute acetic acid; but elsewhere it is probably combined in some other way, because calcite is absent in thin sections and the gas is not liberated on treatment of the powder with the acid but comes off when hot dilute HCl is used. The nature of such combination is problematical, but it is possible that the $CO_2$ may be present in a phosphatic mineral of the nature of podolite ($3Ca_3(PO_4)_2.CaCO_3$). The $SO_3$ may be combined with some of the lime, as gypsum or more probably anhydrite, and both minerals have been noted as present in streaks in the lower-grade rock at an exposure in the NW. ¼ SE. ¼ sec. 8, T. 11 N., R. 8 E., in the Crawford Mountains, Utah, but have not been seen in the microscopic examination of the high-grade rock. Another alternative might lie in regarding the $SO_3$ as combined with the alkalies, of which soda is present in an average percentage of 1.5. However, no indications of such compounds are noted under the microscope. A recalculation of the analyses given above, after the alkalies and $SO_3$ and enough of the lime as calcite to satisfy the $CO_2$ have been removed, appears to suggest that the calcium phosphate mineral closely approximates in composition a basic calcium phosphate—probably more basic than apatite because of the absence of the haloids—to which further investigation may warrant the assignment of a new mineral name. By some authorities it is reported, however, that chemical examination of rock phosphates from other fields has "shown indubitably that these phosphatic bodies are members of a series of solid solutions of phosphoric acid in lime." The substance of the rock phosphates of South Carolina, Florida, and Tennessee, "like the coprolites, osteolites, phosphorites, etc., found in more limited quantities in various parts of the world, seems to be an amorphous body containing lime and phosphoric acid in proportions varying more or less from that required by the formula for tricalcium phosphate, and always mixed with some calcium carbonates."[a]

## FIELD DETERMINATION OF PHOSPHORIC ACID.

The desirability of having immediate determinations of the phosphoric acid content of the ores during the field examination led to a cooperative arrangement with the Bureau of Soils by which a chemist of that bureau was detailed with the Idaho party. A special outfit was designed for the chemical work, consisting of compact and durable apparatus; porcelain ware was substituted for glassware where feasible; the chemicals were, so far as possible, carried in solid form for convenience in transportation; distilled water was obtained by means of a simple form of copper still, which was operated in connection with the camp range.

In general, the samples were collected by cutting a channel across the face of the phosphatic beds, or where that was not feasible, by chipping representative pieces from the clean surface, starting at the upper part of the bed and working down toward the base, care being taken to keep the chips of a size approximately proportionate to the part of the bed they represented. The lithologic characters were used in determining the part of a face to be included in a sample; for example, if the upper foot of a bed consisted of coarsely oolitic material it was sampled as a unit and its phosphatic content determined; if the next lithologic interval of the bed was shaly, that portion was sampled as another unit, etc. Occasionally average samples were taken in order to get the average content of the bed and as a check on the determinations made for the several units. It was found in the progress of the work that it was possible in this way to locate the distribution of the high-grade and low-grade materials in the beds. The field determinations of the phosphoric acid are quoted with the several sections of the phosphate beds given in the text and on the plates accompanying these reports, and the following description of the field methods of analysis employed is quoted in full from a report of that work to be issued by the Bureau of Soils:[b]

The weight of the samples ranged from one-half pound to 4 pounds, depending on the thickness of the beds. Each sample was crushed on the small bucking board, quartered down, pulverized in the small porcelain mortar, and finally put through the

[a] Cameron, F. K., and Bell, J. M., The action of water and aqueous solutions upon soil phosphates: Bull. 41, U. S. Dept. Agr., Bur. Soils, p. 9.

[b] Waggaman, W. H., Bull. 69, Bur. Soils, U. S. Dept. Agr. (In press.)

sieve. During damp weather, or when the samples were collected from prospects wet from percolating water, they were dried in an oven, but in these normally dry regions this was seldom necessary.

Two grams of the sample were weighed and brushed into an enameled cup; 25 to 30 c. c. of water (not distilled) were added and 10 c. c. of concentrated nitric acid. The cup was covered with a watch glass, placed on the stove, and the contents allowed to digest for seven or eight minutes. After cooling somewhat, the insoluble material was filtered off, washed thoroughly on the filter, and the filtrate made up to 200 c. c. with water (not distilled). An aliquot (10 c. c. or 20 c. c., depending on the amount of $P_2O_5$ present) was then taken for analysis. This was diluted with 20 to 30 c. c. of water, a few cubic centimeters of saturated solution of ammonium carbonate added, and sufficient nitric acid to render the solution acid to litmus paper. The cup was then returned to the stove, heated to 70° or 80° C., and 25 c. c. of ammonium molybdate solution added, drop by drop, with constant stirring. After standing ten minutes the solution above the precipitate of ammonium phospho-molybdate was decanted and filtered and the precipitate washed as far as possible by decantation until the washings gave no acid reaction. Distilled water was used in this last operation. The filter was then returned to the cup, a little distilled water was added, and a standard solution of potassium hydroxide was added until the yellow precipitate dissolved. Standard nitric acid (matched against the potash solution) was run in from a burette, drop by drop, until the pink color of the indicator—phenolphthalein—disappeared. The quantity of nitric acid used, subtracted from the amount of potassium hydroxide, gave the number of cubic centimeters of the latter solution required to dissolve the yellow precipitate. The potassium hydroxide was of such strength that 1 c. c. equaled 1 milligram of phosphoric acid ($P_2O_5$). This solution was standardized against acid potassium sulphate ($HKSO_4$). The latter being a solid can be readily transported without danger. Definite charges were weighed out in the laboratory before starting for the phosphate area, and these were made up to 200 c. c. as required. When the solution from a 2-gram sample of phosphate is made up to 200 c. c. and 10 c. c. aliquots are used for analysis, all calculations are avoided, for the percentage of phosphoric acid present is the same as the number of cubic centimeters of potassium hydroxide necessary to dissolve the precipitate. If a 20 c. c. aliquot is taken, the amount of potassium hydroxide employed, divided by 2, gives the percentage of phosphoric acid present.

It was found that after the samples were quartered down, it was possible to run through twenty determinations during the day. The results could usually be duplicated within 0.2 of 1 per cent of the actual quantity of phosphoric acid present.

The field chemical determinations quoted throughout the text of this report show the percentage of phosphoric acid contained in the specimens collected, and these have been arbitrarily recalculated to the tricalcium phosphate basis, as that is a factor of comparison in common use in commercial practice.

## IRON AND ALUMINA.

In the manufacture of superphosphates the raw rock phosphate is treated with sulphuric acid and the resulting product is then dried to be used as fertilizer direct or for mixture in combined or compound fertilizers. It is said that in factory practice the product of the acid-treatment process sometimes remains moist and gummy, so that it is difficult to handle, a property which would also interfere seriously with the uses to which the material is put. Iron and alumina are supposed to be the cause of this undesirable property in the manufactured product, as their sulphates show a tendency to take up moisture in a damp atmosphere.

Relatively few iron and alumina tests have been made in connection with the present investigation, as it appears to be generally conceded that the phosphate of these western fields does not contain these elements in objectionable amount. The percentages quoted in the foregoing table (p. 465) are probably indicative of what the general average would be. Each specimen tested shows less than 1 per cent of either radical computed in the usual oxide form.

## ENRICHMENT BY WEATHERING.

A tendency toward enrichment of the content of phosphoric acid is shown in the weathered outcrops of the rock-phosphate beds. As this is what would naturally be expected from the chemical constitution of this material, no extensive investigation of it has been undertaken. An average sample from a partly weathered face in the open-cut quarry on the Waterloo claim at Montpelier was tested, showing 38.0 per cent of phosphoric acid, equivalent to 83.2 per cent of tricalcium phosphate; another average sample of the same bed taken from a fresher face about 50 feet in on the lower entry of the mine gave 34.8 per cent of phosphoric acid, equivalent to 76.2 per cent of tricalcium phosphate; and still another near the north end of the lower entry showed 33.7 per cent of phosphoric acid, equivalent to 73.8 per cent of tricalcium phosphate. This evidence is probably insufficient on which to base general conclusions as to the amount of such enrichment, but the deeper mining operations in various parts of the field seem to have demonstrated that fresh rock from the thicker workable beds usually maintains an average content exceeding 32 per cent of phosphoric acid, which would be equivalent to 70 per cent or over of tricalcium phosphate.

This tendency toward enrichment is readily explained as the result of the leaching by surface or upper ground waters of the more soluble calcium carbonate and possibly other salts, so that the less soluble calcium phosphate is concentrated in the residuum.

No allowance for this factor has been made in the interpretation of the general sections that have been tested, although on account of the weathered condition of many of the samples taken there can be little doubt that a large number are rather above the normal content than truly representative of the beds in depth.

# GEOLOGY.

## STRATIGRAPHY.

### GENERAL STATEMENT.

In a practical discussion of the stratigraphy of the rock-phosphate deposits emphasis is naturally placed on the description of the rocks most directly associated with the phosphate-bearing strata. Recognition of the character and details of the rock formations overlying and underlying the economically valuable beds has a more or less important bearing in the study of these deposits themselves, for it is largely by means of these details that the beds themselves may be identified or traced along their outcrops or estimates may be made of their depth where they pass below the surface. Areas occupied by rocks older than the phosphate would not normally be considered as phosphate land, but some areas where the stratigraphic section is completely overturned furnish exceptions that must be recognized by means of the geologic structure and details of succession in the stratigraphy.

### TABULAR SUMMARY.

A general summary of the stratigraphy of the rocks most directly related to the phosphate beds in the areas that have been studied is given here in brief tabular form. These formations are also described in somewhat greater detail in the following pages, where some of the more complete and detailed sections obtained in the present work are reviewed, as these sections are representative of the more important evidence from which the generalized statements are made.

*Summary of that part of the stratigraphic section most directly related to the phosphate deposits of southeastern Idaho.*

| Geologic age. | Formation. | Thickness. | Description of strata. |
|---|---|---|---|
| Tertiary (Eocene). | Wasatch group. | Not measured (probably several thousand feet). | Includes a considerable thickness of roughly bedded coarse sandstones, clays, and coarse conglomerate or bowlder beds, in places of a deep-red color in the lower part, succeeded by a series of light or pale varicolored clays or marls, with white, locally coarsely oolitic limestones. |
| | Unconformity. | | |
| Cretaceous. | Bear River formation. | Not measured. | Dark shale, sandstone, conglomerate, and some limestone. Contains beds of impure coal near Cokeville. |
| Jurassic-Cretaceous. | Beckwith formation. | No complete measurement. | A thick formation including coarse conglomerate, white to yellowish calcareous sandstone, and sandy shale. Characteristically exposed at the north end of the lower Thomas Fork valley. |

*Summary of that part of the stratigraphic section most directly related to the phosphate deposits of southeastern Idaho*—Continued.

| Geologic age. | Formation. | Thickness. | Description of strata. |
|---|---|---|---|
| Jurassic. | Twin Creek limestone | About 3,500 feet at the type locality. | Consists mainly of limestone, mostly thin bedded or shaly, with some massive strata, which characteristically weather in bluffs or bare wash slopes of white, splintery, shalelike material. Forms the high ridge between upper Montpelier Creek and Thomas Fork valley and is elsewhere prominently exposed. |
| Jurassic or Triassic. | Nugget sandstone. | 1,900 feet in Raymond Canyon. | Massive red and white sandstone and red sandy shale. The greater part is of dark-red or brown color, although in places an upper zone is distinct as a clear white sandstone. Includes intervals of sandy shale, which are, however, generally obscured in outcrops by talus of the harder rock. Forms prominent ridges throughout the Montpelier district. |
| Triassic or Carboniferous (including the Middle and Lower Triassic of Hyatt and Smith.[a]) | Ankareh shale. | 670 feet near Montpelier. | Consists essentially of red shale and mottled red and greenish clay and shale with some sandstone and ilmestone. |
| | Thaynes limestone. | About 2,000 feet or less. | The main body of the formation consists of dark-blue limestone, in many places fossiliferous, weathering to a brown muddy color, also including sandy and calcareous shale. |
| | Woodside shale. | 1,000 feet in the Preuss Range. | Chiefly shales; generally red in the upper part, with the base usually composed of shaly limestone, weathering rusty brown. |
| Carboniferous. Pennsylvanian. | Park City formation. | 600 ± feet. | A formation including three divisible units, as follows: (*a*) One or more massive strata of cherty limestone, prominent as a ledge maker. (*b*) Rock phosphate, phosphatic shale, and minor limestone bands. (*c*) Limestone, massive, usually light bluish, granular weathering, and in some localities containing abundant black chert in rounded nodules. |
| | Weber quartzite. | 1,000 ± feet. | Massive white quartzite, locally rather calcareous, with minor limestone beds and sandy shale forming transition zones near the top and base. |
| Carboniferous. Mississippian ("Wasatch limestone" of King, in part). | (*a*) Limestone, not distinguished from the Madison limestone in the present work. Collections from the extreme northern part of the area studied show an upper Mississippian fauna, younger than that of the Madison. (*b*) Madison limestone. | (?) | Massive blue limestone, a thick formation usually making high mountainous country where brought to the surface in mass; exposed in dark blue or black weathering ledges, locally marked by fossil corals. Forms west slope of Preuss Range from Joes Gap south to Limekiln Hills at Montpelier. Contains phosphatic beds in the Ogden area. (See p. 85.) |

[a] Hyatt, Alpheus, and Smith, J. P., The Triassic cephalopod genera of America: Prof. Paper U. S. Geol. Survey No. 40, 1905, pp. 17 et seq.

## DETAILED DESCRIPTIONS AND SECTIONS OF FORMATIONS.

### GENERAL SECTIONS.

Several general sections and one detailed section of the rocks overlying the Park City formation have been measured in various parts of the area. In these sections, as with the rocks underlying the phosphate deposits, attention has been directed chiefly to the rocks most directly associated with the special interests of this work, and the following discussion is limited to those rocks which were found important in the recognition of position or depth of the valuable deposits, with a study of stratigraphic thicknesses. The fossils associated with the phosphate beds and found in the overlying strata are in many places valuable guides in determining the position and depth of the phosphate below the surface. If the phosphate beds lay in their original horizontal position, with the succeeding formations in normal sequence above them, then the stratigraphic thickness of the overlying beds would give the measure of depth from the surface to the phosphate. Where the strata are tilted or folded and the various formations are exposed by erosion the factors of dip and identification of the horizon at the surface form the basis for computation of position and depth of the phosphate zone.

The best general section obtained was that in Raymond Canyon, which crosses the Sublette Range and cuts the steeply dipping strata nearly at right angles to the trend of those mountains and the strike of the rocks. This gives the following general intervals:

*Stadia measurement of the Raymond Canyon section, Sublette Mountains, Wyoming.*

| | | Feet. |
|---|---|---|
| Twin Creek limestone: Limestone, white, weathered, splintery, fractured, shaly, and massive (not measured). | | |
| Nugget sandstone: | | |
| Sandstone and quartzite, very massive, dark red and brown, forming heavy talus slopes | 1,700 | |
| Sandstone, massive, and sandy shale, with heavy ledge of conglomeratic white quartzite at top | 200 | |
| | | 1,900 |
| Ankareh shale: Mostly shaly beds, dark-red and maroon shales, and some massive sandstone (not well exposed) | | 700 |
| Thaynes limestone: | | |
| Limestone ledges, very massive, muddy and rusty weathered surface, forming steep, rocky canyon walls | 1,300 | |
| Interval, limited by massive limestone ledges at top and bottom, covered by brown weathered limestone talus and containing some massive limestone strata | 800 | |
| | | 2,100 |
| Woodside shale (upper limit not defined; probably should include some higher beds): Largely concealed by talus of limestone from harder ledges, but including some thin-bedded limestone and shaly beds (not well exposed) | | 600 |

| | | Feet. |
|---|---|---|
| Park City formation: | | |
| Cherty limestone, very massive ledge, single stratum | 80 | |
| Interval entirely concealed by talus except where opened in phosphate prospects | 200+ | |
| Limestone, white, granular, weathered ledges grading into quartzite | 300 | |
| | | 580+ |
| Weber quartzite: Quartzite, white, calcareous and sugary texture in part (measurement omitted because it was not complete). | | |
| Total section as measured | | 5,880 |

Another good section is to be had in the hills east and northeast of Hot Springs, near Bear Lake, Idaho. The measurements obtained at this place are as follows:

*Stadia measurement of section near Hot Springs, Idaho.*

| | | Feet. |
|---|---|---|
| Twin Creek limestone: Limestone, white, shaly, with some massive ledges (incomplete section). | | |
| Nugget sandstone: Sandstone, red and white, quartzitic, massive, thick-bedded | | 2,000 |
| Ankareh shale: Shale, dark red, maroon and iron stained, with massive blue limestone at top | | 700 |
| Thaynes limestone: Limestone, rusty brown or muddy weathered on surface, many massive ledges | | 1,900 |
| Woodside shale: Interval concealed, probably of shaly beds | | 800 |
| Park City formation: | | |
| Chert, black, massive, roughly bedded | 110 | |
| Shale, phosphatic, and phosphate beds | 275 | |
| Limestone, white, sandy, massive ledges | 200+ | |
| | | 585+ |
| | | 5,985+ |

The section of the rocks immediately overlying the phosphate beds in Montpelier Canyon, 1 to 4 miles east of the town, was examined in much detail, with special reference to the paleontologic data to be obtained from it. The fossil collections made have not yet been completely studied.

*Stratigraphic section of beds overlying the Park City formation in Montpelier Canyon, Idaho.*

[By C. L. Breger.]

| | Feet. |
|---|---|
| Mississippian: | |
| 17. Limestone, massive, brecciated, and cherty (overthrust). | |
| Thaynes limestone (2,200+feet): | |
| 16. Shale, gray, thin; like 14; limestone lenses up to 4 feet thick, in many places crowded with terebratuloids | 210 |
| 15. Limestone, brownish, thick bedded; with terebratuloids | 40 |
| 14. Shales, gray to olive, thin; with scattered limestone lenses up to 15 feet thick. Rayed pectinoids abundant locally. Terebratuloids and *Pugnax utah* Marcou? abundant in some of the limestones | 656 |

| | Feet. |
|---|---|
| Thaynes limestone—Continued. | |
| 13. Sandy limestones and calcareous sandstones, the latter thick bedded; upper portion produces brown-weathering talus slopes | 574 |
| 12. Limestones, forming a conspicuous horizon marker recognized as far south as the Woodruff area in Utah; the basal 10 to 15 feet crowded with terebratuloids. Rayed pectinoids and *Pugnax utah* Marcou? also occur at the base as well as higher. | |
| 11. Interval, covered; includes some thin gray shales | 83 |
| 10. Sandstones, locally calcareous and forming brown-weathering talus slopes; contains *Bakewellia* (?); some purer limestone bands or lenses up to 15 feet thick are in places charged with terebratuloids and some *Pugnax utah* Marcou? | 216 |
| 9. Interval, mostly covered; includes some gray shales | 379 |
| 8. Limestone, light colored, resistant; the *Meekoceras* zone of Peale, White, Hyatt and Smith, etc.; a well-defined horizon marker from Hot Springs northward; exposed | 39 |
| Woodside shale (1,000+feet): | |
| 7. Limestone, like 8 but somewhat darker, containing *Myalina* in abundance | 55 |
| 6. Sandstone, gray, shaly below | 87 |
| 5. Shales and thinly laminated sandstones, gray and red, the whole forming a red-bed member which furnishes a persistent horizon marker | 198 |
| 4. Sandstones, light colored, shaly below, quarried for building stone at top, contains large *Myalina* | 200 |
| 3. Limestones, gray, blue, thin bedded, with a couple of massive bands, the whole forming a conspicuous horizon marker. Fossils at base—small lamellibranchs, including a small smooth pectinoid | 48 |
| 2. Shales, gray; with thin-bedded limestone seams and bands, pale cocoa-brown in color | 235 |
| (1 and 2 contain chiefly *Lingula*, with some obscure lamellibranchs.) | |
| 1. Interval, covered, like 2; thickness roughly estimated, possibly more than 150 feet | 150 |
| *Productus* or cherty limestone at top of Park City formation. | |

### MISSISSIPPIAN AND OLDER ROCKS.

The rocks underlying the Weber quartzite in the normal succession include a great thickness of Mississippian and older Paleozoic limestones which were preceded by a series of quartzites and shales. These in turn rest on pre-Paleozoic quartzites, shales, and slates and metamorphic gneisses and schists. This limestone series, which includes in places some Ordovician rocks, is more or less completely exposed in several of the areas studied, notably in the Crawford Mountains, at the head of Woodruff Creek, near Laketown, and along the crest of the Preuss Range east of Georgetown. Smaller areas, presumably of Mississippian limestone, occur at the west foot of the Sublette Range in the anticlinal axis east of Cokeville and in the overthrust mass of these rocks east and northeast of Montpelier. It seems probable that the limestone series described above should be correlated with the "Wasatch limestone" of the Wasatch Mountains in Utah. As defined by the Fortieth Parallel Survey the "Wasatch limestone" contained representatives of the Carboniferous (both Pennsylvanian and Mississippian), Devonian, and Silurian systems. The Pennsylvanian and upper Mississippian portions of the "Wasatch limestone" are not represented in the areas examined so far as evidence has been obtained, except at one point where a small collection supposed to be of upper Mississippian age was made.

The suggestion that the name Madison limestone be applied to the lower Mississippian portion of the "Wasatch limestone" of the earlier surveys as it occurs in the area examined is made by G. H. Girty, thus connoting a correlation of these rocks with formations recognized and mapped in the Yellowstone National Park, the Bighorn Mountains, and elsewhere. Doctor Girty says:

> The fauna of this formation has a wide distribution in the West and always occurs in a limestone matrix. It is my belief that the different outcrops originally formed one continuous sheet. If attention be confined, however, merely to the general area in question [southeastern Idaho, etc.], the fauna is the same as that of the Madison limestone of Yellowstone National Park, and it seems very likely that the rocks themselves will trace directly into the typical Madison formation. In another direction the fauna is that of the basal Carboniferous portion of the "Wasatch limestone" of the Wasatch Range of Utah, and I have no doubt that these beds also were originally continuous. Of course, I am not prepared to say that the Madison in these different areas has exactly the same boundaries, or that through erosion or nondeposition beds are not lacking in one which are present in another section, but I believe that the content is essentially the same. It should be understood that Madison as here suggested includes only the lower Mississippian portion of the "Wasatch limestone." The middle or upper Mississippian part of the "Wasatch limestone" has not been recognized in the area studied by Mr. Gale's party last season except in the Swan Lake region.

Cambrian and pre-Cambrian rocks are extensively developed in the Bear River and Wasatch ranges, where they have been studied by Walcott and described in detail.[a]

### WEBER QUARTZITE.

The Weber quartzite consists chiefly of massive white quartzite, but includes some shale and interbedded calcareous sandstone or limestone at both the top and the base. The thickness of this formation appears to vary considerably in different parts of the region, but about 1,000 feet may be assumed as an average. Uncertainty as to the exact definition of either its top or its bottom may give rise to the variations in the estimates obtained, and it has also been suggested that the formation includes an unconformity, perhaps at the top, but this hypothesis has not been substantiated by evidence in this field. It is difficult to determine the plane of division between it and the underlying limestone in this region, as the two

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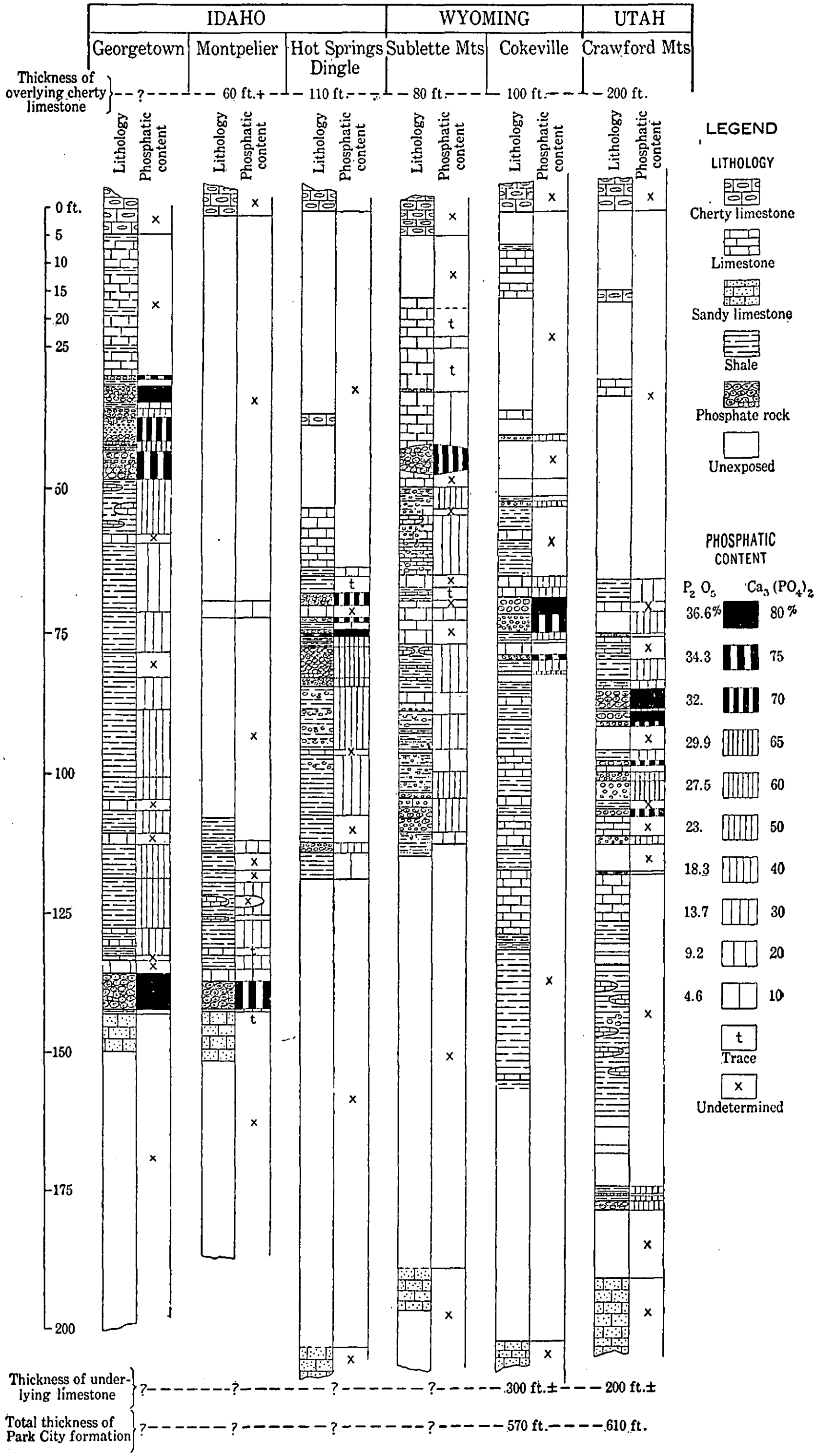
[a] Walcott, C. D., Nomenclature of some Cambrian Cordilleran formations: Smithsonian Inst. Misc. Coll., vol. 53, 1908, pp. 1-12; Cambrian sections of the Cordilleran area; Idem, pp. 167-230.




GENERALIZED COLUMNAR SECTIONS OF PARK CITY FORMATION.

apparently grade into each other by the alternation of sandstone or quartzite and limestone which has been referred to above.

The Weber quartzite forms no important or conspicuous exposures near the phosphate deposits studied in the present work, except at Cokeville and on the west margin of the Crawford Mountains, where the anticlinal fold revealed in the rocks underlying the phosphate is indicative of other outcrops to the west of those now recognized or opened by prospecting. The Weber quartzite is exposed in all the phosphate districts studied except near Montpelier, but its bearing on the occurrence or distribution of the valuable deposits is a relatively negative one, for, like the Mississippian and older rocks, it indicates that the phosphate beds are to be found away from it, in the direction of younger strata.

### PARK CITY FORMATION.

The Park City formation was named in the Park City mining district, Utah,[a] where it is said to have contained the principal bonanzas for which that district is known. The correlation of this formation of the southern Idaho and northeastern Utah section with the rocks of the central and southern Wasatch region is based on faunal and lithologic correspondence between the sections of the two places; this similarity is indeed remarkable considering the distance by which the areas are separated. In the recent study of the phosphate beds, however, much more complete evidence of the continuity, especially of the beds associated with the phosphate, has been found, and the phosphate has recently been identified in the corresponding position in the Park City section. So exact is the lithologic correspondence that the thicknesses and descriptions given for the Park City district are almost directly applicable to the Idaho sections.

The Park City formation is divisible into three parts—an upper cherty limestone; an interval of phosphatic shales phosphate rock and limestone bands; and an underlying limestone, usually massive and commonly containing much chert.

The stratigraphic sections in Plate IV are compiled from numerous measurements of the Park City formation in each of the areas studied. Throughout the course of the work attention was directed chiefly to the study of the details of the phosphatic shale interval, in order to obtain data for possible correlation among the individual beds from place to place.

A massive ledge-forming stratum of chert or cherty limestone immediately overlying the phosphate-bearing shales is distinguished as a separate member, on account of its prominence and its value as a horizon marker from which to trace the outcrops of the phosphate

[a] Boutwell, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, 1907, pp. 434-458.

beds themselves where they are not continuously exposed. This member has locally been referred to as "the cherty lime," "the *Productus* limestone," or "the overlying limestone." It consists of black chert and dark cherty limestones. It is quite distinct from the brown, shaly limestones of the lower part of the Woodside shale, overlying the Park City formation, and to a somewhat less degree distinct from the phosphate and phosphatic shales that underlie it, although in their upper part these shales include some cherty layers which are similar to this massive bed. The thickness of the massive cherty stratum was measured in several places where it was prominently exposed, showing at least 80 feet in Raymond Canyon, Sublette Mountains, Wyoming; 110 feet (probably total thickness) near Hot Springs, at the north end of Bear Lake, Idaho; from 125 to 200 feet at various places in the Crawford Mountains, Utah.

The cherty limestone overlying the phosphate contains some characteristic fossils, in the main species of *Productus*. Of these *P. semireticulatus* is most abundant; *P. humboldti* and *P. subhorridus?* are also present. In some beds *Spiriferina pulchra* and *Stenopora* are found in relatively greater abundance than *Productus*, being commonest in zones near the top of the cherty limestone.

The phosphate-bearing member of the Park City formation, including all the main phosphate beds, consists of 200 feet of massive brown to gray phosphatic shales and beds of rock phosphate, with some limestone and in places cherty bands in the upper part.

The occurrence of rounded or oval limestone nodules, ranging from a few inches to several feet in diameter, is a characteristic feature in the phosphate beds and the phosphatic shales. They consist of very dense, compact, fine-grained limestone, having a fetid odor when struck with a hammer, but showing a low percentage of phosphoric acid wherever tested. As all the dense, fine-grained limestones tested were found to run very low in phosphoric acid, tests of these rocks were abandoned in the latter part of the season's work.

Many detailed sections were measured in the phosphatic shales, especially in those immediately associated with the main phosphate beds. By reason of the weaker constitution of these shaly rocks they commonly give way to weathering and decay at the surface, and the outcrop is usually concealed as a whole or in greater part. Float of the harder rock phosphate remains in the soil and is very readily detected by one who has become familiar with its appearance and with the characteristic bluish-white chalcedony-like coating that forms on its exposed surfaces. Recent prospecting in the Georgetown Canyon district, which had opened a complete and continuous section across the entire formation at the time of this work, afforded rather exceptionally favorable opportunity for examination, measurement, and sampling. Practically the entire shaly section, 140 feet thick, was found on testing to be phosphatic. The beds that were sampled are indicated by numbers in the following section:

*Complete section of the phosphate-bearing strata in Georgetown Canyon, Idaho.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. | |
|---|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft.* | *in.* |
| 144-A | Shale, calcareous, or muddy limestone, brown, weathering into irregular chip fragments; effervesces vigorously | 3.5 | 7.7 | 25 | 6 |
| 144-B | Phosphate rock, oolitic, weathering brown or gray; effervesces slightly; lower 1½ inches somewhat cherty | 35.8 | 78.4 | | 6 |
| 144-C | Shale, hard, brown, calcareous at the top; effervesces vigorously | Trace. | ........ | 1 | |
| 144-D | Phosphate rock, coarsely oolitic, gray; effervesces vigorously | 37.6 | 82.3 | 2 | 11 |
| 144-E | Shale, brownish, earthy, containing 6 inches of phosphate; effervesces considerably | 10.0 | 21.9 | 1 | |
| 144-F | Phosphate rock, including— *Ft. in.*<br>(*a*) Phosphate rock, oolitic, hard, gray, calcareous.... 7<br>(*b*) Phosphate rock, medium, gray, oolitic.... 6<br>(*c*) Shale, phosphatic, light brown.... 4<br>(Sample shows considerable effervescence.) | 21.9 | 48.0 | 1 | 5 |
| 144-G | Phosphate rock, including—<br>(*a*) Phosphate rock, coarsely oolitic, gray, brittle.... 1 2<br>(*b*) Phosphate rock, finely oolitic, brownish gray.... 4<br>(*c*) Phosphate rock, coarsely oolitic, dark gray.... 2<br>(*d*) Phosphate rock, finely oolitic, brownish gray.... 4<br>(*e*) Phosphate rock, coarsely oolitic, gray.... 7<br>(*f*) Phosphate rock, finely oolitic, thin bedded.... 3<br>(*g*) Phosphate rock, coarsely oolitic, gray.... 1 4<br>(Sample effervesces slightly.) | 33.3 | 72.9 | 4 | 2 |
| 144-H | Phosphate rock, including—<br>(*a*) Phosphate rock, medium to finely oolitic, brownish gray.... 7<br>(*b*) Shale, phosphatic, brownish, somewhat oolitic.... 10<br>(*c*) Phosphate rock, coarsely oolitic.... 2<br>(*d*) Phosphate rock, shaly, brown.... 3 | 29.3 | 64.1 | 1 | 10 |
| 144-I | Phosphate rock, including—<br>(*a*) Phosphate rock, coarsely oolitic, brownish-black streaks.... 1 1<br>(*b*) Phosphate rock, shale, brown, thin bedded.... 5<br>(*c*) Phosphate rock, coarsely oolitic, crumbly.... 4<br>(*d*) Phosphate rock, medium to coarsely oolitic.... 3<br>(Sample effervesces considerably.) | 34.7 | 76.0 | 4 | 10 |
| 144-K | Shale, brownish to black, earthy composition, thin bedded, with a few limestone lenses; effervesces slightly | 24.2 | 53.0 | 8 | 9 |
| | Limestone, dark, compact, fetid | ........ | ........ | 1 | 9 |
| 144-L | Shale, brownish to black, earthy; effervesces slightly | 11.7 | 25.6 | 12 | |
| 144-M | Shale, including— *Ft. in.*<br>(*a*) Shale, brownish-black, earthy.... 7<br>(*b*) Concealed, not included in sample (probably same as *a* and *c*).... 4 7<br>(*c*) Shale, brownish black, earthy.... 5 5 | 15.1 | 33.1 | 17 | 1 |
| 144-N | Shale, black, earthy; effervesces slightly | 19.9 | 43.6 | 12 | |
| 144-O | 1. Shale, brownish black, earthy.... 4<br>2. Limestone, single stratum (not sampled).... 2<br>3. Shale, brownish black, earthy.... 4<br>4. Limestone, single stratum (not sampled).... 2 | 21.2 | 46.4 | 12 | |
| 144-P | Shale, black and dark brown, calcareous, earthy; effervesces considerably | 25.8 | 56.5 | 6 | 2 |
| 144-Q | Shale, black, and dark brown, calcareous, earthy; effervesces considerably | 24.6 | 53.9 | 12 | |
| 144-R | Limestone, shaly, brownish gray; effervesces vigorously | 17.8 | 39.0 | 4 | 10 |
| | Limestone, single stratum | ........ | ........ | | 11 |
| | Limestone ("cap lime"), fine, dark gray, fossiliferous | ........ | ........ | 2 | 3 |
| 144-S | Phosphate rock, main bed prospected, coarse to medium, oolitic, gray, contains two or three minor streaks of shaly material; effervesces slightly | 36.8 | 80.6 | 6 | 4 |
| 144-T | Shale, brown, earthy; effervesces slightly | 3.7 | 8.1 | | 9 |
| | Limestone, massive, underlying the phosphatic series. Thickness not determined. | | | | |
| | | | | 139 | 11 |

The thickness of the phosphate-bearing members of the Park City formation varies somewhat, as shown by measurements obtained in other parts of the region. One or more cherty bands are found in the calcareous shale or muddy-weathering limestone at the top of the phosphatic series, making it difficult to define precisely the limits of the overlying cherty limestone. The phosphatic shales as measured include about 170 feet at Cokeville, Wyo., and average about 225 feet in the Crawford Mountains.

Fossils occur at many horizons in the phosphate-bearing members of the Park City formation, some well-preserved specimens having been found in the most massive beds of the rock phosphate itself. Some of the rounded limestone nodules occurring in the phosphate beds are fossiliferous. The main phosphate bed at Montpelier and in the Georgetown area is capped by a 2-foot ledge of dense, fine-grained dark limestone filled with exceedingly well-preserved fossils, from which excellent specimens have been obtained.

The distinction between the phosphate-bearing strata and the underlying limestones is clear in most places, but at its base the Park City formation consists of calcareous sandstone and bands of quartzite alternating with limestone, so that there is a transition into the more typical quartzite of the Weber.

The limestone underlying the phosphate-bearing strata in the Park City formation is usually massive and of sandy composition, occurring in heavy-bedded strata which weather with a light-bluish granular or sandy surface. White calcite in small, irregular crystalline patches is of rather common occurrence throughout this rock.

In the Preuss Range, in Montpelier and Georgetown canyons, this limestone contains much black chert in rounded nodular masses. The average thickness of the limestone is assumed to be about 300 feet, although no accurate determinations have been made. The cherty limestone beds forming the lower part of the Park City formation in Georgetown Canyon contain Pennsylvanian fossils.

### WOODSIDE SHALE.

The Woodside shale immediately overlies the Park City formation and is so called by correlation with the section in the Park City mining district, Utah. It is composed mainly of shaly beds, mostly calcareous, usually showing as "red beds," in the upper part and of shaly or platy brown, rusty-colored limestone, and brown or gray shale in the lower part. It also includes some more or less massive limestones that are described as muddy, as they appear brown and earthy on weathering, being very similar in this respect to the limestones that characterize the overlying Thaynes. The base of the Woodside is quite distinct, for the upper cherty limestone of the Park City formation is usually well defined in contrast with the overlying shales. The upper limit of the Woodside is not so clear. As this formation was originally defined in the Park City district it was intended to include the reddish shaly beds and to be limited by the more massive limestones of the overlying Thaynes.[a] The distinction is perhaps not so clear in this field, but a more or less arbitrary limit may be drawn which corresponds closely with the descriptions and thicknesses given for the typical sections. Where it has been recognized the *Meekoceras* zone has been adopted as a paleontologic definition of the base of the Thaynes. In many sections studied *Meekoceras* is found in massive limestone succeeding a "red bed" shale interval 1,000 to 1,200 feet above the base of this formation.

### THAYNES LIMESTONE.

The Thaynes limestone, overlying the Woodside shale in normal sequence, was named from its occurrence in Thaynes Canyon, near Park City, Utah. It contains marine fossil shells at many horizons, and from the occurrence of certain ammonoids (*Meekoceras*) at its base it has been assigned by Hyatt and Smith to the Lower Triassic.[b] The age of these fossils is, however, not yet proved. The Woodside shale, Thaynes limestone, and Ankareh shale were referred to the "Permo-Carboniferous" by the Fortieth Parallel Survey. The *Meekoceras* beds, where recognized by the Hayden Survey, were referred to the Triassic.

The Thaynes is distinguished chiefly by massive ledge-forming limestones which are in places abundantly fossiliferous. It also includes many shaly intervals and, to a minor extent, some brown-weathering calcareous sandstones that pass by gradations into the limestone. The limestone itself commonly contains a considerable percentage of clay and sand, so that on weathering it assumes a sandy or muddy aspect, making much of it difficult to distinguish from sandstone except on fresh fractures. The thickness of the Thaynes limestone is somewhat less than 2,000 feet as measured in Raymond Canyon, and the measurement obtained in Montpelier Canyon shows at least that thickness, but it is doubtless several hundred feet thinner at other localities from which measurements have been recorded.

### ANKAREH SHALE.

The Ankareh shale of the Park City section was originally described from the exposures in Big Cottonwood Canyon, near Salt Lake City. This formation consists chiefly of clay shale of deep maroon and chocolate colors, massive where fresh, though commonly breaking down with exposure into thinner-bedded shaly material. It includes also some pale-greenish clayey and sandy strata, beds of mottled green and maroon shale, and harder layers of red or greenish sandstone and limy strata, and in the Montpelier district is defined at the top

[a] Understanding received in personal conference with J. M. Boutwell.

[b] Hyatt, Alpheus, and Smith, J. P., The Triassic cephalopod genera of America: Prof. Paper U. S. Geol. Survey No. 40, 1905, pp. 17 et seq.

and bottom by massive limestones. The limestone or calcareous shale at the top distinguishes the Ankareh from the massive sandstones and red sandy shales of the Nugget sandstone. The limestone at the base of this "red bed" formation is the uppermost of the massive beds that constitute the more prominent part of the Thaynes limestone. The total thickness of the Ankareh as measured in the Montpelier district is about 670 feet, including the limestone at the top but excluding the massive underlying limestone strata more properly classed with the main body of the Thaynes.

### NUGGET SANDSTONE.

The Nugget sandstone, overlying the Ankareh shale, is composed chiefly of massive red sandstone, in places much cross-bedded, including also intervals of sandy shale, which are, however, generally obscured at the outcrop by the talus of the more massive strata. In some parts of the area studied beds of pure white and conglomeratic sandstone occur near the base of this formation, and in some areas several hundred feet of white sandstone forms an upper division of the formation. The white sandstone at the top apparently is not found everywhere and where absent may be represented by an unconformity not yet recognized, or the white color may be a local phase of the more common dark-red sandstone. The sandstone is in places vitrified to quartzite. Owing to its massive, resistant character it usually forms high ridges with broad rounding slopes, or in exposure is marked by heavy talus slopes of thick-bedded brown or black weathering sandstone. The thickness of this formation was found to be 1,900 feet in the section measured in Raymond Canyon. Few complete measurements of the formation have been obtained in this general region.

The Nugget is regarded as of either Lower Jurassic or Triassic age, although no fossils have been found in it, its position below the marine Jurassic of the Twin Creek formation and above the beds from which the Triassic ammonoids of Hyatt and Smith are obtained being the basis of this conclusion. It is thought that the formation is in greater part the stratigraphic equivalent of the White Cliff and Vermilion Cliff sandstones of the Uinta and Wasatch mountains, and if so there is some probability that at least the upper part of the Nugget may be Jurassic.

### TWIN CREEK LIMESTONE.

The stratigraphic relation of the Twin Creek limestone to the Carboniferous phosphate-bearing strata is more or less remote, but that formation is extensively represented in territory adjacent to the phosphate fields. It is to be noted, however, that phosphate of commercial quality, supposed to have been derived from this formation, was discovered southwest of Cokeville, as described on page 508. As shown by the measured stratigraphic sections, the base of the Twin Creek is separated from the older phosphate by more than 5,000 feet of strata, so that where that formation occupies the surface in normal and unfaulted positions the Carboniferous phosphate is more than 5,000 feet deep.

The Twin Creek limestone consists almost entirely of limestone of more or less muddy appearance when weathered, much of which is thin bedded and shaly, although more massive strata are also included. The characteristic exposures are bluffs or wash banks of splintery fracturing shaly limestone, with white weathered surfaces. The formation contains a number of fossiliferous strata, which determine its age as marine Jurassic. The total thickness of the Twin Creek limestone is probably over 3,500 feet in this area, although no continuous sections sufficiently well exposed to afford satisfactory measurements were encountered during the present work.

#### BECKWITH AND BEAR RIVER FORMATIONS.

The Beckwith and Bear River formations are extensively developed east of the Sublette Range in Wyoming, and are brought into more or less intimate association with the phosphate-bearing formations by the great fault at Cokeville. Their structural relations in such places render their bearing on the discussion of the occurrence of the phosphate chiefly negative and only the brief descriptions included with the tabular summary on page 469 need be given in this paper.

#### EOCENE AND LATER DEPOSITS.

Of the later deposits those bearing the most direct relation to the outcrop of the phosphate-bearing strata are (1) the Eocene Wasatch group, as defined by the early geologic surveys, and (2) the more recent detrital and alluvial formations. As all these deposits unconformably overlie the older rocks, they cover and as a rule completely conceal not only the outcrops of the underlying strata but also the structural clues from which estimates as to outcrops or structural relations might be obtained.

Detailed consideration of the Wasatch deposits need not be entered into here, as a number of more or less involved geologic problems must be reviewed in such a discussion. The whole body of early Tertiary sediments is referred to under the general designation, Wasatch, or as Eocene.

The basal part of the Wasatch group in the vicinity of the phosphate fields consists of a coarse bowlder conglomerate (Almy conglomerate of Veatch), in most places dark red, unevenly bedded, and including coarse sandstone and shale, generally more or less loosely consolidated. The bowlder-conglomerate beds are succeeded by finer sediments, including clay shale or marly strata with lenticular sandstones and light-colored chalky limestones, the latter containing many bands of coarsely oolitic limestone which appear to be characteristic of this part of the Eocene (Fowkes formation).

These formations are extensively developed near the Bear River valley east and south of Bear Lake and west of Randolph and Woodruff, where they effectually conceal most of the underlying geologic formations, including the outcrop of the phosphatic rocks. The deposits on Woodruff Creek are revealed by the erosion valley of that stream where it cuts through this Eocene mantle.

The existence and positions of outcrops of phosphate beds underneath the cover of alluvium in the stream valley bottoms or under talus slopes on mountain sides constitute some of the problems to be met by the study of evidence available in areas adjoining the covered region, where the geology of the underlying beds is revealed. Individual areas are discussed more in detail in the following local descriptions.

## STRUCTURE.

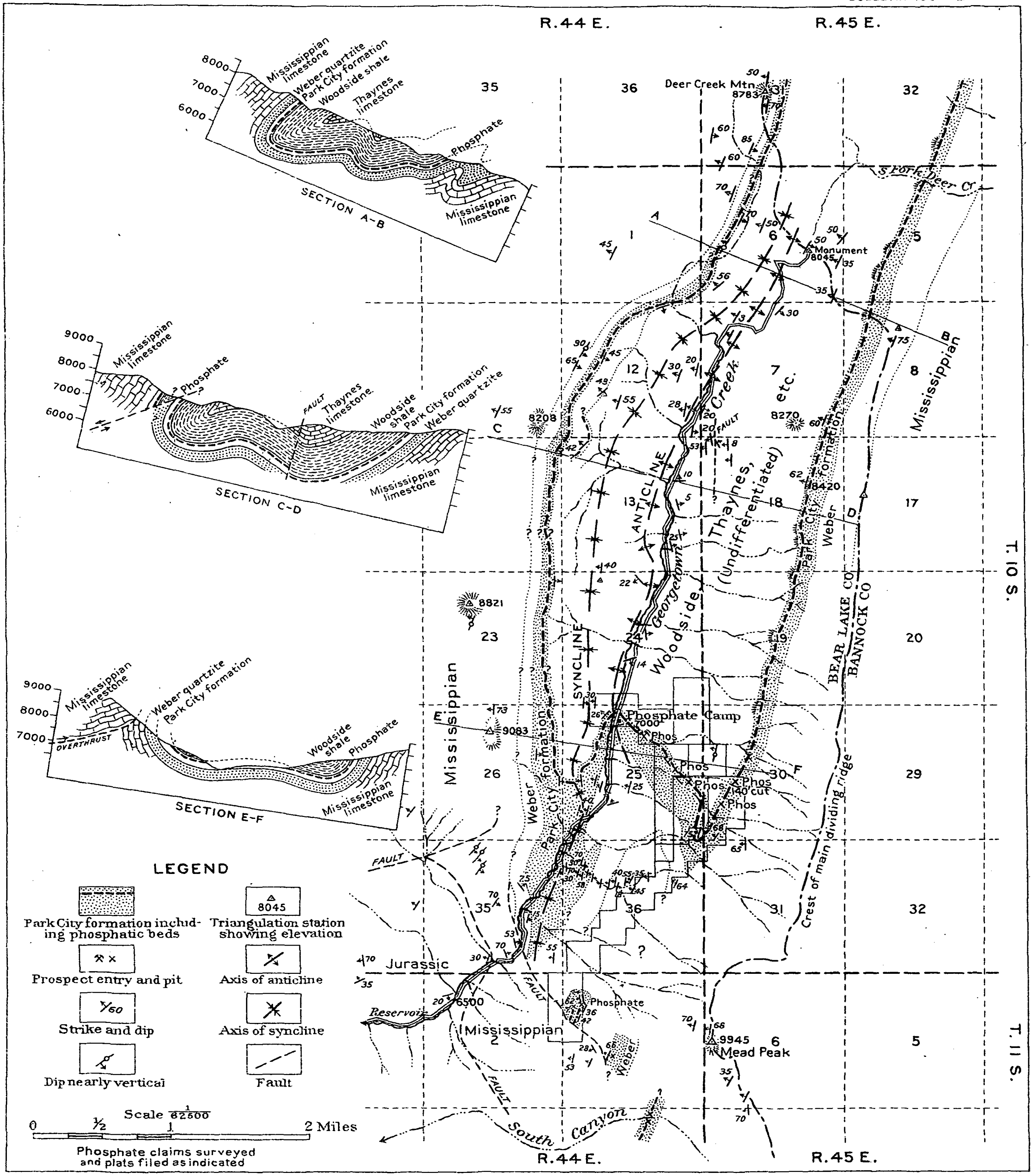
The general geologic structure of this region is that of a closely compressed, overfolded, and overthrust-faulted complex, which is in great part difficult of interpretation. The major structures have a north-south trend, and the direction of the overthrust is universally from the west. The compressive forces have been of such intensity that they have produced many overturned and recumbent folds and overthrust faults, carrying the older hard-rock formations up and over younger strata and contorting and crumpling the beds of the underlying flanks.

Although the complexity is in part rather completely revealed by exposures of Mesozoic and Paleozoic rocks in the more mountainous areas, large expanses of valley lands covered by recent alluvial and detrital deposits and extensive areas masked by Tertiary deposits are probably also characterized by correspondingly complicated rock structure. It is probably altogether unwarranted to assume to predict the attitude or position of beds far beyond the areas from which rather complete evidence is to be had at the surface, and even for such areas the interpretation of some of the evidence is decidedly problematic.

## LOCAL DESCRIPTIONS.

### *AREAS EXAMINED.*

The areas examined in detail during the season's work in 1909 are included in the following list. Maps and local descriptions are given in preliminary form in the following pages, together with tonnage and area estimates, based on more or less arbitrary assumptions, as




PRELIMINARY MAP AND STRUCTURE SECTIONS OF THE GEORGETOWN CANYON PHOSPHATE AREA, IDAHO

The township subdivision shown is projected from corners located in the lower valley of Georgetown Creek, beyond the limits of this map

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explained. The field work of the party was of two types—(*a*) a hasty review, chiefly in the areas in which the evidence is of negative character so far as phosphate is concerned, and (*b*) more detailed surveys and study, including the measurement of outcrops, stratigraphic sections, mapping, sampling, etc. Of the general review little need be said except so far as its results are incorporated in the consideration of the structural and stratigraphic problems of the region and the relation of the areas studied in more detail. The detailed descriptions are arranged for convenience of description, first by the States, and in them roughly according to their location from north to south. The list of areas described is as follows (see fig. 42):

Idaho:
- Georgetown Canyon area.
- Montpelier-Bennington area.
- Hot Springs-Dingle area.

Wyoming:
- Sublette Mountain area.
- Cokeville area.
- Beckwith Hills area.

Utah:
- Crawford Mountain area.
- Laketown area.
- Woodruff Creek area.

This list is by no means complete, not even as to the districts found in the more accessible parts of the region; it comprises only those areas that have been examined.

## *IDAHO.*

### GEORGETOWN CANYON AREA.

#### LOCATION AND DEVELOPMENT.

Phosphate deposits in the upper canyon of Georgetown Creek were among the first to be located soon after the recognition of these deposits as rock phosphate in this western field. This district is directly accessible to Bear River valley and the railroad and the present prospecting is being done in Georgetown Canyon 7 to 10 miles northeast of Georgetown, on the western flank of Mead Peak and the Preuss Range. (See Pl. V.) Phosphate beds extend through Tps. 10 and 11 S., Rs. 44 and 45 E. of the Boise meridian, Idaho, but are also known to be continuous north and northeast of that area, although they have not yet been traced in detail. The canyon of Georgetown Creek forms an elbow, of which the lower half has a general course of S. 70° W. and the upper or northeast half lies in nearly a S. 20° W. direction, evidently derived from or controlled by the geologic structure in that area.

The present study of the Georgetown Canyon district is incomplete; the map presented is tentative in many respects, inasmuch as there are a number of unsolved problems relating to the somewhat complicated structure, and some parts of the mapping on which it is hoped to get further evidence have been omitted. The positions of the

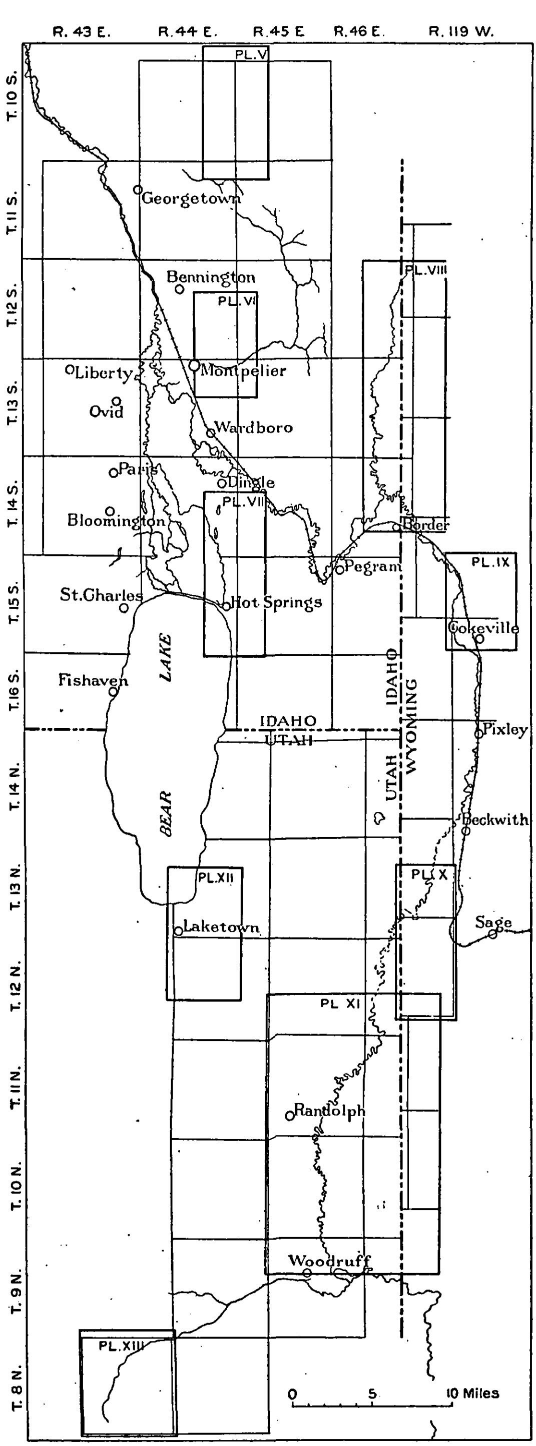



FIGURE 42.—Map showing location of the phosphate areas in Idaho, Wyoming, and Utah.

outcrops of the phosphate beds, shown on the map, are based on locations made from point to point, but the outcrop itself has not been completely traced. It is thought that the representation of the general structure and areal distribution is approximately correct. At the time of the present work in the Georgetown area (September, 1909) development or annual assessment work was being done by the Utah Fertilizer and Chemical Manufacturing Company, which controls all the claims located in this district. Resurveys by the authorized deputy were also in progress and plats have now been filed covering the group of claims shown on this map. The original mineral locations were, however, more extensive, and continued in part as a double strip of placer locations following the outcrop on either side of Georgetown Canyon. These claims appear to have covered most of the actual phosphate outcrop as far as the south fork of Deer Creek on the north and to a point a little beyond South Canyon on the south. As will be pointed out, an extensive area underlain by phosphate at depths presumably nowhere greater than 2,000 feet is included within these outcrops in the upper Georgetown Canyon.

### GENERAL GEOLOGY OF THE GEORGETOWN AREA.

The general structure of the upper Georgetown Valley is synclinal, as shown by the structure sections accompanying the map of this area (Pl. V). A structural trough following the main valley is limited on either side by upturned older rocks that form the high ridges bounding the valley on the east and west. The axis of depression is somewhat complicated by minor or subordinate folds parallel to the general structure. As a whole, the character of the folds and of some related overthrust faults is such as to indicate great lateral compression from thrusts originating somewhere to the west and acting toward the east. The synclinal structures rise somewhat toward the south, so that older rocks are exposed in the lower canyon and the phosphate remains only in some more or less isolated patches on the higher ridges. This part of the area is also involved in some rather extensive faults which are in part indicated on the map, but all are not yet thoroughly understood. The undoubted Jurassic and possibly also Cretaceous beds occupy several square miles north and northeast of the power reservoir (including the W. ½ sec. 35, T. 10 S., R. 44 E.), and these beds are distinctly overthrust by Mississippian limestones on the north and are limited by other Mississippian rocks to the east and southeast. The crest of the Preuss Range east of the upper Georgetown Valley is probably of anticlinal structure, and it is thought that one or more correlative synclines, including the phosphate beds, may exist east and northeast of this divide. The structure in the north end of the Georgetown Valley is fairly regular and more readily determined than that farther south. The apparent duplication of outcrops of the cherty limestone associated with the phosphate, noted in sec. 12, T. 10 S., R. 44 E., is not yet understood, but a hypothetical explanation by the assumption of a fault is indicated in the cross section at that place. The apparent relative thinning or absence of part of the Park City formation or Weber quartzite in the northwestern part of the area mapped also requires further study in the field.

The Park City formation, including the phosphatic strata, is apparently typically developed in the Georgetown Canyon area. No single complete section of the whole formation was obtained, but an excellent exposure of that part which includes all the important phosphate-bearing strata was found in a recently opened prospect in the SW. ¼ sec. 30, T. 10 S., R. 45 E., of the theoretical subdivision as shown on the map (Pl. IV). This section has already been described in considerable detail (p. 477), which need not be repeated here. The cherty limestone overlying the phosphatic strata forms a prominent ledge outcropping at intervals throughout the area and is the principal marker by which the phosphate beds are traced. The limestone underlying the phosphatic beds is composed of massive bedded rocks, containing much black chert in nodular form, in this respect resembling the succession at Montpelier Canyon.

The Weber quartzite, underlying the Park City formation, is well exposed in the main canyon in sec. 25, T. 10 S., R. 44 E., where it shows chiefly as a talus of white, somewhat calcareous, and in places brownish or yellowish weathered quartzite or sandstone.

The Mississippian limestones normally underlying the Weber occupy the dividing ridges both east and west of the upper Georgetown Canyon and are also thrust in by faults at the south end of this phosphate area. A single collection of fossils obtained near the summit of the ridge south of Preuss Peak appears to represent an upper Mississippian fauna. No lithologic distinction between the upper Mississippian and the Madison or lower Mississippian portion of the series was recognized. The Mississippian rocks consist chiefly of massive dark-bluish or black weathering limestone, commonly showing well-preserved corals on the weathered surfaces. The summit of Mead Peak affords an excellent example of the massive dark-bluish fossiliferous limestone of this part of the section.

Of the strata overlying the Park City formation, the Woodside shale, next succeeding, and the Thaynes limestone are most important as furnishing evidence of the depth of the phosphate beds along the axes or within the synclines. The Woodside shale is composed of reddish and brownish weathering shales and some limestones, including one or more characteristic fossil horizons. This formation is also represented in the thin-bedded micaceous shales and fine-grained sandstones of gray, greenish, and brownish casts, outcropping in many of the road cuts north of the phosphate camp. An arbitrary upper limit of the Woodside shale has been assumed to be that marked by the so-called *Meekoceras* zone, which is therefore regarded as the base of the Thaynes. The thickness of the Woodside is about 1,000 to 1,200 feet in this area, and as the outcrop of that formation occupies most of the lands along the channel of upper Georgetown Creek, it thus gives an approximate indication of the depth to the phosphate beds. An excellent example of the "*Meekoceras* limestone" is to be found in the road gap on the divide between this canyon and the south fork of Deer Creek, where it is marked by a rock monument, erected for triangulation. Numerous well-preserved specimens of the "ammonites" or cephalopods from which this zone is named have been obtained here and also at other points lower in Georgetown Canyon. The fauna occurs at several different horizons within the *Meekoceras* zone, which here aggregates 200 to 300 feet in thickness.

As in the Montpelier district, the main phosphate bed in Georgetown Canyon occurs at the base of the phosphate section. It varies in thickness but appears to average somewhat over 6 feet in the places where it has been opened so that its total thickness can be determined. The rock phosphate is of high grade, as shown by the tests, of medium to coarse oolitic texture, and of dark grayish-brown color, almost black when fresh, and contains but little foreign matter in the form of partings. It is capped by a single 2-foot stratum of dark fine-grained fossiliferous limestone, as at the Montpelier properties. As may be seen from the section described on page 23, nearly all these strata appear to be rather highly phosphatic, including several high-grade beds above the principal one occurring at the base. In considering this section as representative, however, it seems best to bear in mind that the exposures from which these samples were taken were near the surface of the ground, the strata standing in nearly vertical position, and all were more or less weathered and of earthy composition, a factor which is generally understood to enrich the phosphatic content. (See p. 468.) Enrichment may have been due in part to a secondary replacement of lime by phosphoric acid, but in most weathered exposures it seems to be largely the result of leaching of the more readily soluble lime, the proportion of the residual phosphates being thereby increased.

The lower phosphate bed has sometimes been locally referred to as the "black phosphate" and an upper prospected bed as the "gray phosphate." There is probably no essential difference in the character of the various high-grade beds of this section, although some are not so dark colored as others and some are more coarsely oolitic. The massive, coarsely oolitic material is generally considered the best. The dark color is believed to be due to carbonaceous matter, extraneous to the phosphatic minerals or substance, and not an indication of the richness of the beds.

The lower main phosphate bed was sampled at the breast of the tunnel on the Highland placer claim (NW. ¼ sec. 1, T. 11 S., R. 44 E.), representing 6 feet of apparently fresh, unaltered rock. The tunnel runs in about 60 feet S. 70° W. and then turns southward, following the bedding or strike for about 30 feet more, and appears to have been one of the principal developments on the claims originally staked in this area. Analysis of this specimen shows 35.7 per cent of phosphoric acid ($P_2O_5$), equivalent to 78.2 per cent of bone phosphate ($Ca_3(PO_4)_2$). Another sample from the lower or main bed in a shallow trench in the NE. ¼ SE. ¼ sec. 25, T. 10 S., R. 44 E., representing a thickness of 6 feet 6 inches, gave 37 per cent of phosphoric acid ($P_2O_5$), equivalent to 81 per cent of bone phosphate ($Ca_3(PO_4)_2$). This was an average sample of massive though somewhat weathered material.

The series of tests recorded in the table on page 477 has already been discussed, and completes the analytical work done for this locality.

### AREA AND TONNAGE.

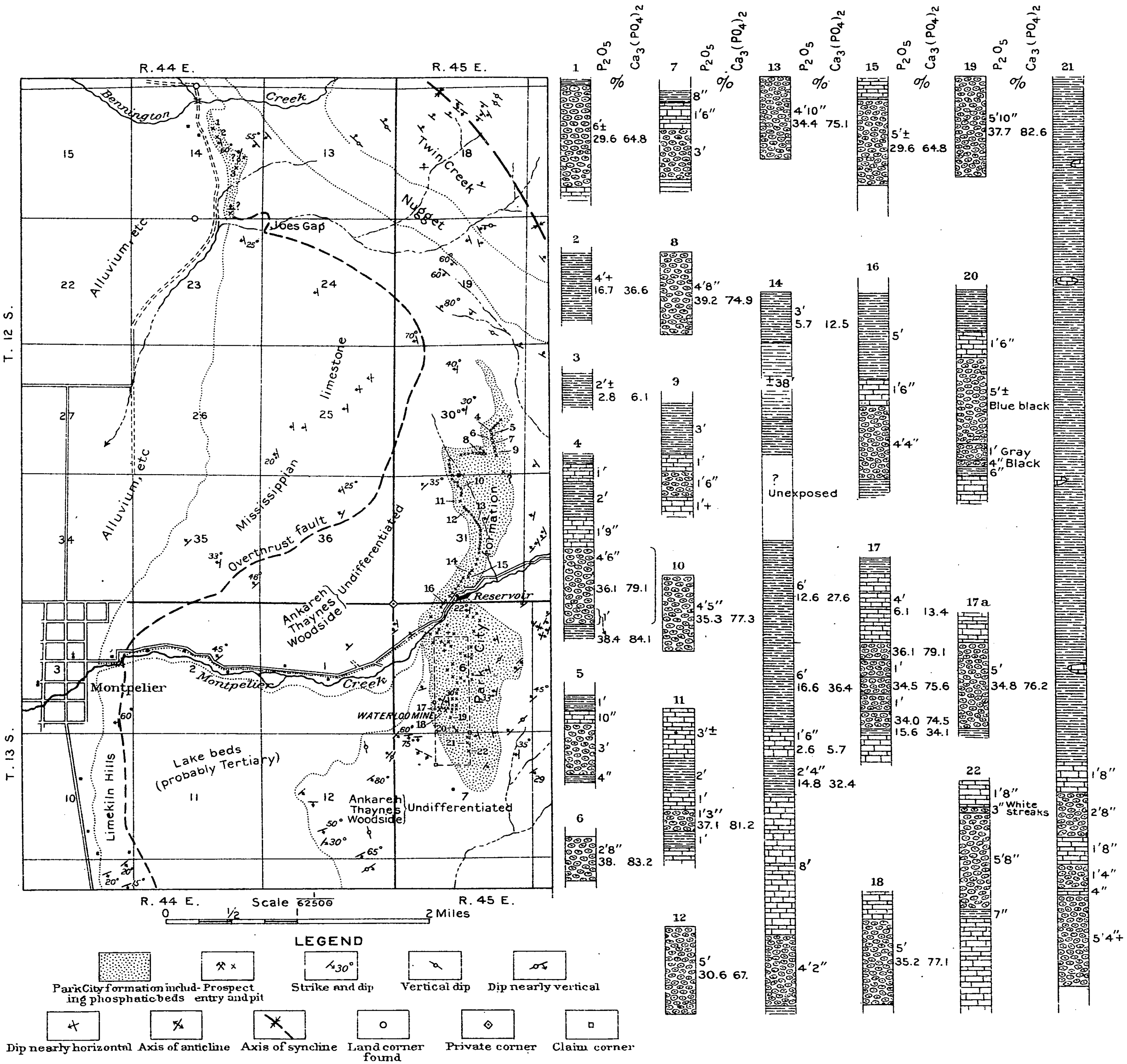
An estimate of the area of the lands underlain by phosphate in this district, including only those lying in the drainage basin of Georgetown Creek, based on the outline shown on the accompanying map (Pl. V), gives 3,840 acres, or 6 square miles. As stated, all of this phosphate may be considered as ultimately available, as the greatest depth from favorable entry points is perhaps not more than 2,000 feet. As shown by the structure sections on the accompanying map (Pl. V), the surface area of the phosphate bed itself is considerably in excess of the areal measurement of the land under which it lies, owing to the fact that the strata are compressed in folds and a vertical element must also be considered in reckoning the volume. The assumption that a single 6-foot bed of phosphate extends under this area, with an extra allowance of 15 per cent for the vertical element in the structural position of the beds, gives somewhat more than 90,000,000 tons of 2,240 pounds from the main bed alone of the best-grade phosphate rock for the area in the drainage basin of Georgetown Creek. The complete section doubtless contains several times this amount of high-grade rock and a much greater mass of low-grade material, but more accurate estimates of the total amount of phosphatic rock available are perhaps not worth while from the present evidence.

## MONTPELIER-BENNINGTON PHOSPHATE AREA.

### LOCATION.

The phosphate deposits in Montpelier Canyon, Idaho, have long been a subject of interest to prospectors and others, and the outcrops of these black rocks had been dug into and tested for coal and mineral values long before their phosphatic content was discovered. The same may also be said of the Bennington outcrops, but when the phosphate itself was recognized, the Montpelier deposits, on account of their proximity to the railroad, appeared to offer exceptional inducements to early commercial development.

The outcrops in Montpelier Canyon lie in a strip extending from north to south through secs. 30 and 31, T. 12 S., R. 45 E., and secs. 6 and 7, T. 13 S., R. 45 E., of the Boise meridian. (See Pl. VI.) The outcrops are visible from points in the town of Montpelier, showing as a black streak traced across the hillsides. The main




MAP OF THE MONTPELIER-BENNINGTON PHOSPHATE AREA, IDAHO, WITH SECTIONS AND ANALYSES OF PHOSPHATE BEDS developments are about due east of Montpelier, and the Waterloo mine is 4½ miles, by wagon road, from the railroad station.

The outcrop of the phosphate rocks is largely covered by mining-claim locations. These claims were originally staked as placers and one of them has been admitted to final proof, the title having been granted to the San Francisco Chemical Company. This firm owns a plant at Martinez, Cal., 37 miles from San Francisco, and is engaged in the manufacture of superphosphates. The company also holds nine other claims in the Montpelier area, three claims on Thomas Fork in the Sublette Mountains, Wyoming, three claims at Swan Lake, north of Georgetown, Idaho, and five claims on Woodruff Creek, Utah. Most of these claims have later been relocated under the lode law, a condition resulting from the inadequacy of the present mining law as applied to the phosphate lands. (See pp. 532–535.)

The Bennington prospects are situated in sec. 14, T. 12 S., R. 44 E., and the deposits on which they are located doubtless form a direct extension of the beds in Montpelier Canyon, although the outcrop of the phosphate itself is concealed for an interval of 2½ miles, a condition to be explained from the geologic structure of the region.

## GENERAL GEOLOGY.

The phosphate deposits of the Montpelier Canyon area outcrop at the crest of a closely compressed, overturned, and somewhat faulted anticline. The general geologic structure of a considerable area in that vicinity is directly incident to this controlling structural feature. The trend of the anticlinal axis is in the main north and south, with a bend toward the west at its north end. The overturning is evidently due to thrusts that have acted from the west toward the east, and the same general tendency is exhibited in even the more minute structural details of the whole area. Minor fractures of overthrust character occur within the phosphate or associated rocks, showing a displacement by minor crumpling and shearing, in which the direction of thrust has evidently been toward the east; thus the strata on the west of the anticline tend to ride up and over, and those on the east show a corresponding compression and internal contortion, as they have borne the weight of the overturned structure. The magnitude of this upheaval is in part shown by the fact that the entire stratigraphic section from the Park City formation up to and including the Twin Creek limestone—a series at least 8,000 feet in thickness—now lies in inverted order on the east side of this axis, with moderate westward dips as if in simple folded structure.

The western overthrust flank of the major anticline is somewhat less disturbed than the underlying flank and the younger formations overlie the older in normal succession; thus the section in the lower Montpelier Canyon, west of the phosphate mine, is relatively simple and affords a fairly good opportunity for detailed study of the overlying Woodside and Thaynes formations. At the extreme lower or west end of the canyon the section is truncated by an overthrust of the Mississippian limestones. Irregularity in structure in this part of the field is shown by the scattering dips and strikes recorded on the map (Pl. V), the entire significance of which has not yet been satisfactorily worked out.

The detailed stratigraphic section of the beds overlying the phosphate in Montpelier Canyon has been reviewed in considerable detail under the heading "Stratigraphy" (pp. 472–473). The Park City formation, which contains the phosphate beds, is apparently typically developed. An upper cherty limestone member containing *Productus* of several species, including *P. semireticulatus* and less commonly other species as distinguishing fossils, overlies about 200 feet of the dark-brown and black phosphatic shales, with which are associated some limestones. The lower part of the Park City formation consists of cherty limestone and shale, probably in large part calcareous. The total thickness can not be determined with certainty in this area on account of the many minor structural irregularities in the exposures of these rocks, but it has been estimated to be about 600 feet or possibly somewhat more.

The formation normally succeeding the Park City is the Woodside shale. A description of these beds is included in the detailed section on page 473; they consist mainly of calcareous shale or shaly limestone, characteristically weathering to a brown or rusty color with sandy or muddy surfaces, including an interval of distinctly red shale in the upper part. A somewhat arbitrary upper limit to the Woodside shale has been adopted, as defined by the *Meekoceras* zone as the base of the more massive limestone sequence which is included with the overlying Thaynes. The thickness of the Woodside shale below the *Meekoceras* zone is about 1,000 feet, or possibly a little more.

The Thaynes limestone consists largely of muddy-brown weathered limestones and calcareous shale, in places very fossiliferous. In many of the more massive strata the rock appears to be made up of a mass of fragmentary shells which show by differential weathering, but the same rock, when freshly broken, appears to be a dense, compact, apparently structureless limestone. The weathered rock commonly looks like rusty sandstone but proves to be a dark-bluish limestone when broken.

The Ankareh, Nugget, and Twin Creek formations are also typically developed, but appear only on the east side of the overturned anticlinal axis in this area. They are, however, in inverted order, and so have only more or less indirect significance as to the depth of the phosphate beds.

Rocks older than the Park City formation are not exposed in the crest of the anticline that brings up the phosphate. The Mississippian limestones are overthrust along the west face of the Preuss Range from Joes Gap to the Limekiln Hills east and southeast of Montpelier. They are shown on the geologic map (Pl. VI) as limited by the fault on the east and disappearing under the alluvium-filled valley on the west.

## PROSPECTS AND DEVELOPMENT.

### WATERLOO CLAIM.

The principal developments in the Montpelier area are on the Waterloo claim in Montpelier Canyon. The phosphate of this claim is situated on a broad, rather smooth, rounded dip slope at the west foot of Waterloo Mountain. The hillsides are traversed by shallow gullies which cut the main phosphate bed in many places. The actual outcrop of the main bed is somewhat difficult to trace with certainty, as the hillsides are grassy and only the harder limestone ledges are naturally exposed. The upper beds of the phosphatic section have been largely removed by erosion from the higher hill slopes, but as these beds dip to the west the whole section may be expected near or below water level. A considerable amount of rock phosphate has been shipped from this place, and the whole property has been rather extensively prospected. The main workings are near the center of the claim, which is of the association placer type (160 acres), an area 1 mile long from north to south and one-fourth mile in width, including the SE. ¼ NW. ¼ and the E. ½ SW. ¼ sec. 6 and the NE. ¼ NW. ¼ sec. 7, T. 13 S., R. 45 E. Near the center of this claim an open cut has been quarried covering an area some 200 feet square, exposing the bare ledges of the limestone underlying the main phosphate bed on the western dip slope of the hill. These rocks dip 30° to 32° W. Two mining tunnels have been run in below the open cut. Both are under shallow cover, the upper one starting directly from the outcrop and the lower one crosscutting but a short distance into the same bed. A shaft has been sunk near the mines just west of the Waterloo claim, but had not been completed at the time the property was visited.

A number of tests and measurements of the main phosphate bed in the Montpelier area were made in the present work, and the results are shown in a graphic way in connection with the map of the district (Pl. V). As indicated in the following section, the principal phosphate bed occurs at the base of the phosphate-bearing sequence and is everywhere overlain by a fossiliferous stratum of dark, fine-grained limestone. The phosphate itself is black, of a shaly or thin-bedded structure, much resembling coal in general appearance, especially in a natural exposure or weathered outcrop, but lacking the pitchy luster of coal. Wherever it lies within 30 or 40 feet of the surface, the main phosphate bed has proved sufficiently soft to be mined with a pick, the entries being advanced with a breast auger drill as in coal mining. The detailed measurements obtained at the mouth of the upper tunnel on the Waterloo claim were as follows:

*Section at Waterloo claim, Montpelier Canyon, Idaho.*

| | Ft. | in. |
|---|---|---|
| Shale | 10+ | |
| Limestone, black, fossiliferous | 1 | 6 |
| Shale, gray to brown, phosphatic (?) | 2 | 6 |
| Limestone (cap rock), very fossiliferous ($P_2O_5$, 6.1 per cent) | 1 | 10 |
| Phosphate, main bed ($P_2O_5$, 38 per cent) | 5 | 6 |
| Shale, brown to black | 1− | |
| Limestone, black, massive strata, underlying the phosphate-bearing section (not measured). | | |
| | 22 | 4 |

The beds on the Waterloo claim dip westward at angles ranging from 17° to 42°, showing also considerable irregularity of strike, even within the limits of the claim. In the large open cut above the upper tunnel there are small displacements or faults of a type that is apparently significant of the character of the larger structures of the whole general region. Slivered fractures in the "cap lime" pass into folds and crumpled zones in the phosphate itself, thickening and thinning the latter bed.

The beds on the Waterloo claim are very conveniently situated for ready accessibility and economical mining, perhaps as much so as in any other part of the area that has been studied. Probably the greater part of this claim is underlain by the main phosphate bed, so that an estimate of tonnage is a comparatively simple matter. Estimating the main bed as 5 feet 6 inches thick under an area of 140 acres gives in round numbers 2,500,000 tons of 2,240 pounds for this single claim. These figures make no allowance for recovery in mining. All of this rock lies above main drainage level and at comparatively shallow depth, so that it is probably readily accessible for mining. Although it is possible that a truly conservative estimate of the tonnage on this claim should be reduced somewhat from the figures just given, to allow for possible irregularity in structure or for crushing and thinning of the workable beds, yet on the other hand these factors are to a certain extent counterbalanced by the probable existence of other workable beds that are usually found in the more complete section and thus may be assumed to be present at the lower or western limits of the Waterloo claim. The more readily available material lying above drainage level will probably be mined before any extensive developments are made reaching below water level.

### NORTHWARD EXTENSION OF PHOSPHATE.

Other claims situated both east and west of the principal phosphate outcrop, but chiefly on its extension to the north, have been located in the Montpelier Canyon area. On these the more complete section of the phosphate beds, 150 to 200 feet thick, is represented here and there. Numerous sections, chiefly of the main bed, were examined in the prospects, many of which had caved so badly since the opening was made that they did not afford much evidence of the actual condition of the beds. Phosphatic strata range through an interval of 150 to 200 feet, but as they are composed essentially of soft and readily eroded material they are almost universally covered by soil or talus from harder rock ledges and fresh exposures are to be had only where recent prospecting has opened them.

A partial section of the phosphatic shales was measured and sampled in a horizontal trench cut across the steeply dipping beds on a spur northwest of the Montpelier waterworks dam, and is given in the following table:

*Section of phosphatic beds in Montpelier Canyon, Idaho.*

| | Ft. | in. |
|---|---|---|
| Shale, soft, phosphatic (sampled 2 to 3 feet in the upper part); top not reached | 40 | |
| Limestone stratum, brecciated; weathers to an earthy or muddy color | 2 | 6 |
| Shale, soft, black, mixed with earth ($P_2O_5$, 12 per cent) | 2 | |
| Shale, including soft, thick limestone nodules | 3 | |
| Shale, black; appears somewhat phosphatic | 2 | |
| Shale, black, containing one large limestone nodule (not included in sample) ($P_2O_5$, 12.6 per cent) | 6 | |
| Limestone, cross section of nodule interbedded in black shale; measured at its thickest part | | 8 |
| Shale, black, claylike; shows little or no sign of oolitic structure ($P_2O_5$, 16.6 per cent) | 5 | |
| Limestone, hard, dark colored, similar to nodules that occur in the overlying shale; appears phosphatic at top ($P_2O_5$, 2.6 per cent) | 1 | 5 |
| Shale, black, probably phosphatic ($P_2O_5$, 14.8 per cent) | 2 | 4 |
| Limestone, somewhat fossiliferous; forms the roof of the main phosphate bed | 2 | |
| Phosphate, main bed not measured at this place, approximate thickness | 5 | |
| | 72 | 5 |

Extensive, almost continuous prospecting along the outcrop northward from the waterworks dam has traced the main bed in Phosphate Gulch and across a dividing spur to the west side of Home Canyon, in the eastern part of sec. 30. At this locality the outcrop disappears and it was not found again nearer than the exposures to the south of the lower end of Bennington Canyon, at the western foot of the Preuss

Mountains. Prospects revealing the phosphate are, however, reported in line with the anticlinal axis near the divide between Home Canyon and Joes Gap. It is thought that this disappearance of the outcrop of phosphate beds is to be explained by the pitching of the axis of the anticline along which the phosphate has been brought up, so that although the deposits themselves are probably continuous, the outcrop is lost for intervals across the intervening high land. Much irregularity is to be observed in following the outcrop in and beyond Phosphate Gulch, where local slips and faults offset the beds in many places. The sections measured, together with the results of chemical tests, are shown in graphic form on the diagram accompanying the map (Pl. VI).

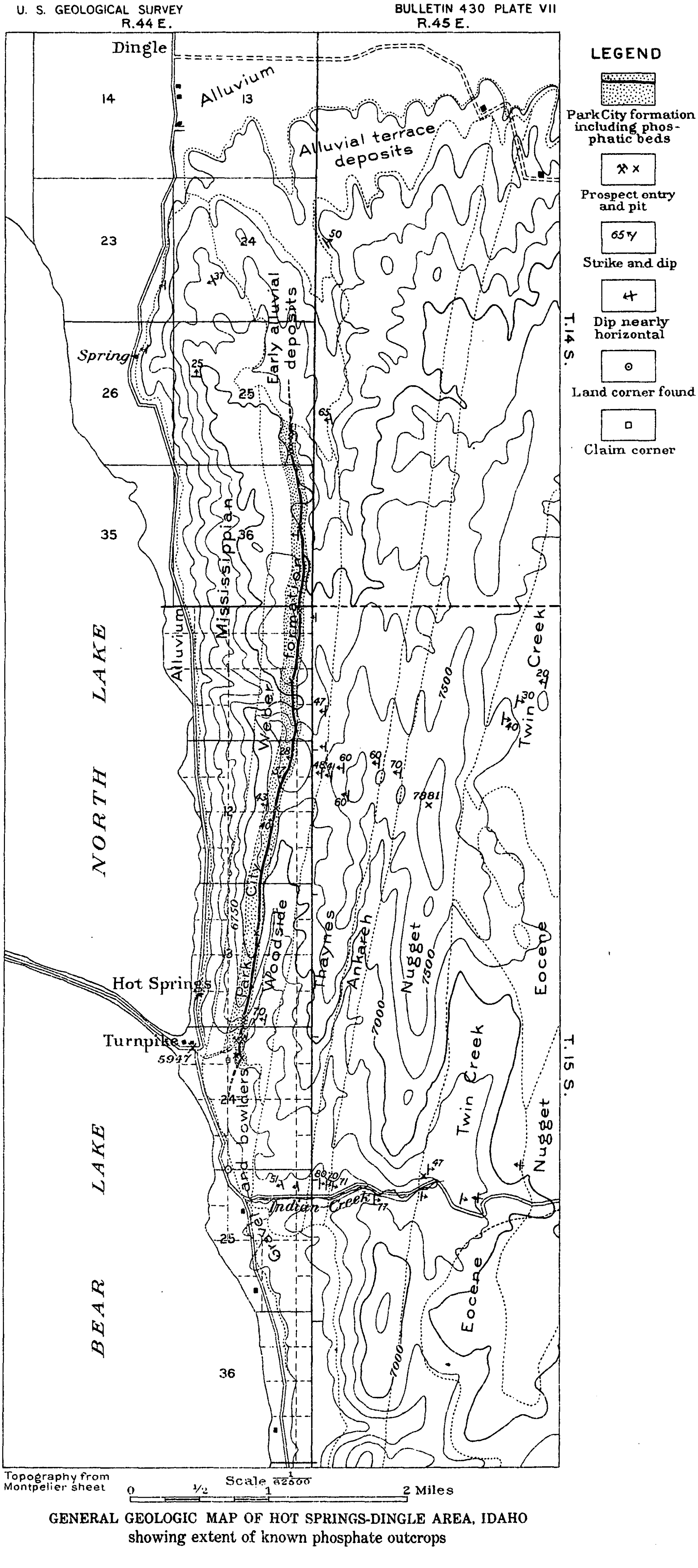
### SOUTHWARD EXTENSION OF PHOSPHATE.

In the immediate vicinity of the Montpelier area the phosphate has not been traced by outcrops south of the Waterloo claim. Although the structure is far from simple, the evidence apparently indicates that the anticline by which these outcrops are brought up pitches toward the south. The southern extension of the workable deposits is lost in the low grass-covered slopes southeast of Waterloo Mountain. By inference from structures observed in the harder rock strata associated with the phosphate beds, the concealed outcrop is assumed to nose around the end of this pitching anticline, as represented on the map. Outcrops of limestones both overlying and underlying the phosphate beds have been observed in the E. ½ sec. 6, presumably forming a part of the east flank of the anticline already described. All the strata on the eastern flank of the major anticline are, however, considerably contorted, and it seems likely that the outcrop of the phosphate beds on the east flank is to a large extent cut out by more or less extensive overthrusting near the axis of the overturned anticline. This explanation has been assumed to account for a failure to discover a second outcrop in Montpelier Canyon east of the waterworks dam or in Phosphate Gulch.

The phosphate beds occurring on the underlying side of the overturned anticline doubtless pass to great depths, perhaps 10,000 feet or more, as the inverted section may be assumed to double over the axis of the recumbent syncline. For this reason it is extremely doubtful if much of the territory east of the major anticlinal axis can ever be considered valuable for the phosphate that probably underlies it.

### BENNINGTON OUTCROPS.

Outcrops of the phosphate and the overlying cherty limestone near Bennington Canyon have already been mentioned (p. 493). As explained, they are thought to be brought up by the same structural fold by which the Montpelier phosphate beds are revealed. An inter-




GENERAL GEOLOGIC MAP OF HOT SPRINGS-DINGLE AREA, IDAHO
showing extent of known phosphate outcrops

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

val of about 2½ miles between the outcrop in Phosphate Gulch and Home Canyon and those near Bennington is covered by younger beds, evidently arched over the axis of the anticline referred to, which may be traced through the divide separating the drainage of Joes Gap from Home Canyon. This structure is in part obscured to the west, near the summit of the ridge, by the overthrust body of Mississippian limestone of which the Joes Gap cliffs are a part.

### AREA AND TONNAGE.

An estimate of the available phosphate on the Waterloo claim has already been given, in which the total of 2,500,000 long tons is based on a single 5½-foot bed of the best-grade material. Complete and reliable estimates covering the whole area in the vicinity of Montpelier Canyon are practically impossible, owing in part to the uncertainty arising from the irregularity of the geologic structure. Only the most general estimates can be made, as, for instance, those based on an assumption of the existence of a 5-foot bed of phosphate rock available to a depth of about 2,000 feet, or for a distance of half a mile from the outcrop on the more gently dipping beds. The total length of the outcrop as known at present is about 15,000 feet, in which is considered only those beds on the west flank of the major anticline. On the assumptions stated, this would give a total of approximately 16,000,000 long tons in the Montpelier area. The standards given are, of course, exceedingly arbitrary, but are in a general way comparable to those used in the other estimates made in this report. Any attempt to take into account other beds of either the best or the low-grade phosphatic material introduces into the computation so many additional factors of uncertainty, which would have to be reckoned through merest assumption, and runs up the figures to such an almost incomprehensible quantity that the simplest form of statement will perhaps serve best for purposes of comparison.

## HOT SPRINGS-DINGLE PHOSPHATE AREA.

### GENERAL LOCATION.

Phosphate beds extend in a belt of continuous outcrop about 4½ miles long from the vicinity of Hot Springs, at the northeast corner of Bear Lake, to the valley flats south of Dingle, Idaho. (See Pl. VII.) The nearest shipping point is Dingle, on the Oregon Short Line Railroad, which is about 10 miles from the south end of this belt, near Hot Springs. The outcrop of the phosphate itself is characteristically somewhat obscured, as the soft, shaly beds readily break down on exposure and are concealed by soil and slide, but its position is distinctly indicated by the prominent ledges of the associated cherty bed that forms a most conspicuous and easily recognizable marker and occurs throughout this area to the east of the phosphate.

### GEOLOGY.

Like the deposits in the Sublette Mountains, Wyoming, those at Woodruff Creek, Utah, and those near Paris and Bloomington, Idaho, the Hot Springs phosphate beds are exposed in an extensively overturned stratigraphic section. These beds presumably represent the underlying eastern flank of an anticline which has been overturned toward the east and from which the upper or western flank has been completely removed by erosion or perhaps displaced by faulting. In spite of the magnitude of the major overturn, the structure is comparatively regular in minor detail and little evidence of distortion or crushing was observed in the softer beds. Some transverse offsets are shown in the massive cherty ledges associated with the phosphate beds, an instance being noted in the channel of the dry wash on which the Hot Springs prospects are located.

Although the strata dip toward the west at the outcrops, it is evident from the structure that these beds must turn back to an easterly dip in depth, so that they pass in normal position through the series of folds observed between Hot Springs and the Wyoming state line. The stratigraphic section at Hot Springs is apparently very much like those of the Sublette Mountains and other places in this general region.

### PHOSPHATE BEDS.

The outcrop of the phosphate strata is readily identified and traced by means of the excellent exposures of the black chert ledge which forms so conspicuous a marker in this area. The phosphate itself has been prospected to a small extent, but at none of the openings that have been made was there revealed a satisfactory section of all the phosphatic beds. It appears, however, that the series is much like that at Montpelier and doubtless contains similar workable beds, as well as a considerable amount of lower-grade rock, not at present considered commercially valuable.

The principal developments consist of a double set of entry tunnels opening the phosphate at the same place and located in a small gulch about half a mile east of Turnpike post-office, at Hot Springs. These entries are situated in the NW. ¼ NE. ¼ sec. 24, T. 15 S., R. 44 E. The duplication of work at the discovery tunnels is the result of conflict among claimants to the property. The following is a complete section, together with the analytical tests made, of the beds exposed underground in the crosscut joining the entry tunnels; it was made at the time of examination of this property (September, 1909):

*Section of phosphate and associated beds at Hot Springs, Idaho.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. Ft. | in. |
|---|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft.* | *in.* |
| | Limestone, compact, hard | ........ | ........ | 10+ | |
| 141-A | Shale, brown, earthy, calcareous | 9.0 | 19.7 | 1 | 6 |
| 141-B | Shale, earthy, massive | 2.0 | 4.4 | 2 | 8 |
| 141-C | Phosphate, oolitic, massive, dark gray | 32.8 | 71.8 | 2 | 2 |
| | Limestone, massive stratum | ........ | ........ | 2 | 2 |
| 111-D | Phosphate, medium to coarsely oolitic, dark gray | 32.3 | 70.7 | | 11 |
| 141-E | Shale, brownish, earthy, calcareous | 3.5 | 7.7 | 1 | |
| 141-F | Phosphate, medium grained, oolitic; dark gray | 36.3 | 79.5 | 1 | 3 |
| 141-G | Phosphate: (a) Shale, calcareous ... *In.* 5; (b) Phosphate, oolitic, brownish ... 4; (c) Shale, brownish, phosphatic ... 2; (d) Shale, brownish, phosphatic ... 11 | 27.5 | 60.2 | 1 | 10 |
| 141-H | Phosphate, medium to coarse grained, oolitic (main entry tunnel) | 29.1 | 63.7 | 5 | 10 |
| 141-I | Phosphate, medium to coarse grained, including pebbly texture | 28.0 | 61.3 | 1 | 5 |
| 141-K | Shale, phosphatic, dark brown, earthy | 24.3 | 53.2 | 11 | |
| | Limestone | ........ | ........ | 1 | |
| 141-L | Shale, phosphate, dark brown, earthy | 12.9 | 28.3+ | 10 | 6 |
| | Shale, phosphate, dark brown, earthy | ........ | ........ | 4 | 11 |
| 141-M | Shale, phosphatic, somewhat oolitic | 20.3 | 44.5 | 1 | 8 |
| 141-N | Shale, phosphatic, dark brown, earthy | 5.2 | 11.4 | 4 | 6 |
| | | | | 64 | 4 |

A section of a workable bed recently opened in a prospect tunnel 600 feet S. 15° W. of the main entries described above exposes material of apparently higher grade than any included in the preceding section. The correlation of this bed with any particular part of that section can not now be positively made, but it seems likely that the 63 feet of strata exposed in the crosscut of the main entry described above do not include all of the best material that may be present in that section.

*Section from prospect near Hot Springs, Idaho.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. Ft. | in. |
|---|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft.* | *in.* |
| 137-A | Phosphate, coarsely oolitic, dark gray | 36.2 | 79.3 | 1 | 3 |
| 137-B | .....do | 24.7 | 54.1 | | 5 |
| 137-C | .....do | 34.8 | 76.2 | 1 | 8 |
| 137-D | .....do | 37.0 | 81.0 | 1 | 8 |
| | Average | 35.0 | 76.5 | *a* 5 | |

*a* Total.

## AREA AND TONNAGE.

Calculations based on assumptions similar to those used in the other areas for estimates of the tonnage of valuable rock phosphate are given as follows:

The known outcrop of the phosphate beds is 23,500 feet in linear extent, beyond which, both to the north and south, these rocks are doubtless continuous and readily accessible for a distance of 10,000 feet or more ($1\frac{1}{2}$ miles on the north and half a mile toward the lake on the south), where bed rock is assumed to be under relatively shallow cover. Thus the estimates are based on a total length of 33,500 feet. The strata dip to the west at angles averaging from 40° to 60° and an ultimate depth along the bed of 2,000 feet has been assumed as the limit of the rock that need be considered immediately available in mining. Taking into consideration but a single 5-foot bed of higher-grade ore (equivalent to 70 per cent or more of tricalcium phosphate) and assuming that such a bed may be found in some part of the section throughout the field, we obtain in round numbers 27,000,000 long tons of phosphate for the Hot Springs area.

A strip of 40-acre tracts adjoining the phosphate outcrop, arranged so as to include the surface overlying the bed wherever it is not more than 2,000 feet in depth, covers an area of approximately 1,300 acres, or about 2 square miles.

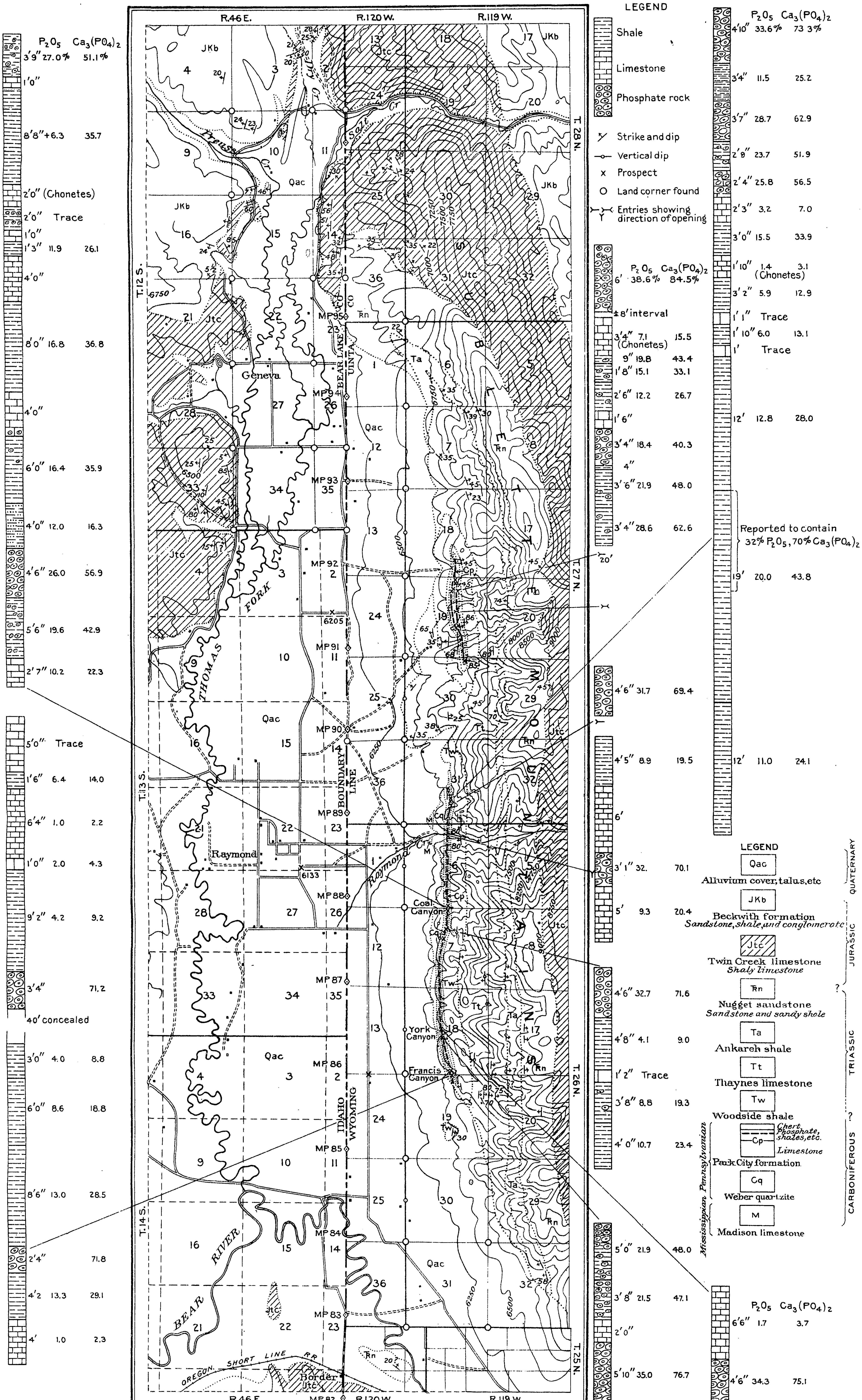
## *WYOMING.*

### SUBLETTE MOUNTAIN PHOSPHATE AREA.

#### LOCATION, ACCESSIBILITY, ETC.

The Sublette Range as approached from the west is a somewhat isolated mountain mass, rising abruptly from the flat valleys of Thomas Fork and Bear River just east of the Idaho-Wyoming state line. The maximum relief between Bear River and the highest summit is 3,250 feet. The range is terminated at the north by the Salt Creek branch of Thomas Fork. Southward it extends as a high rugged ridge for about 15 miles, beyond which it is continued 8 miles in lower, more or less disconnected peaks and ridges, ending in the two rocky hills just east of Cokeville. The main range is cut transversely by the deep, narrow canyon of Raymond Creek, and the lower ridge at the southern end of the range is also cut through to water level by the valley of Birch Creek, a short distance northeast of Cokeville.

The principal phosphate area of the Sublette Mountains lies along its western foothills, just above the slide-rock and valley fill at the margin of the Thomas Fork valley. (See Pl. VIII.) Outcrops of the phosphate beds have been located about 3 miles north of the canyon mouth of Raymond Creek and in almost continuous outcrop an equal distance south. All these beds are readily accessible from Thomas Fork and are within easy access of the Oregon Short Line in Bear River valley. This railroad at Border station is about 6 miles due south of Raymond post-office.




GEOLOGIC MAP OF SUBLETTE MOUNTAINS, WYOMING, AND ADJACENT PORTIONS OF IDAHO
showing extent of known phosphate outcrops, with sections and analyses of phosphate beds

## GEOLOGY OF THE SUBLETTE MOUNTAINS.

### STRUCTURE.

The Sublette Mountains evidently represent a closely compressed anticline, of which the western flank is in greater part either cut away by the erosion, or has been thrown down by faulting on the Thomas Fork side. The anticlinal axis lies along the west foot of the range, and the phosphate is brought up in the crest of the anticline. The main range consists of the steeply dipping strata on the eastern flank of the anticline, lying apparently in normal succession; the eastern slopes of the mountains are composed of the later Jurassic and possibly Cretaceous rocks, involved in subordinate folds of closely compressed structure that are evidently related to the major axial fold.

The major anticline plunges toward the north and the structure is well brought out in the distribution and attitude of the rocks exposed in that part of the area. On the west and to the south, however, the alluvium-filled valleys conceal nearly all evidence of the structural relations and the geology of the underlying rocks is to be understood only in a general way by inference from scattered exposures.

The exposures of phosphate beds near Cokeville are brought up along a subordinate anticlinal axis east of the main anticline of the Sublette Range. The beds in the Cokeville area are commercially and structurally distinct from the deposits on the west side of the Sublette Mountains in the Thomas Fork valley. (See Pl. IX.)

### STRATIGRAPHY.

The general stratigraphic section in the Raymond Creek canyon has been described on page 471. The Park City, Woodside, Thaynes, Ankareh, Nugget, and Twin Creek formations are apparently here typically developed. The Weber quartzite underlying the Park City includes some massive, sugary white calcareous strata which were not distinctly differentiated from the lower limestones of the Park City formation or from the uppermost Mississippian limestone at the time this work was done, but it is thought that both in the Sublette Range proper and in the hills east of Cokeville the Weber is either thinner or less characteristically quartzitic than at most other parts of the field.

The summit of the Sublette Range south of Raymond Canyon is covered with a deposit of gravel and water-rounded bowlders, concealing the outcrops of underlying rock. For the most part these materials appear to be but slightly agglomerated at the surface, exceptions, however, being noted in the wash bluffs on the east side of the summit. This deposit is probably a remnant of the Eocene conglomerate (lower Wasatch), which is found in much more extensive development at lower elevations, but which is here elevated to approximately 9,000 feet above sea level. Later movements in this range have, therefore, taken place in Eocene or post-Eocene time, if the assumption of Wasatch age of the conglomerate is correct.

## PHOSPHATE DEPOSITS.

### T. 27 N., R. 119 W., WYOMING.

The northernmost exposure of the phosphate-bearing portion of the Park City formation consists of a closed outcrop in secs. 18, 19, and 30, T. 27 N., R. 19 W., circling around the northward-plunging anticlinal axis. This particular outcrop is significant in that it gives a definite clue to the major structure of the Sublette Range, which is obscured toward the south by the cover of alluvium and talus. In section 30 the Woodside shale and a portion of the Thaynes limestone form an uneroded arch, which covers the Park City beds for a distance of about a mile. In the same section erosion has been effective in uncovering the eastern outcrop of the Park City formation and its inclosed phosphatic portion. The deposits of alluvium, however, have concealed the position of the nose of the southern outcrop of the anticline and the outcrop of the phosphate beds on the western flank of the fold. The best (though incomplete) section of the phosphate beds, measured on the northern outcrop, is as follows:

*Section of phosphatic beds in sec. 19, T. 27 N., R. 119 W., Wyoming.*

| Field No. of specimen. | | $P_2O_5$ | Equivalent to $Ca_3(PO_4)_2$. | Thickness. | |
|---|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft.* | *in.* |
| 44 | Phosphate rock, grayish black, oolitic | 38.6 | 84.5 | 6 | |
| | Interval, concealed | | | 8+ | |
| 43-A | Limestone, grayish black, hard; fossils | 7.1 | 15.5 | 3 | 4 |
| 43-B | Shale, black, in part oolitic, soft | 19.8 | 43.4 | | 9 |
| 43-C | Shale, black, in part oolitic | 15.1 | 33.1 | 1 | 8 |
| 43-D | Shale, black, in part oolitic, massive | 12.2 | 26.7 | 2 | 6 |
| | Limestone | | | 1 | 6 |
| 43-E | Phosphatic rock, black, coarsely oolitic, soft | 18.4 | 40.3 | 3 | 4 |
| | Limestone | | | | 4 |
| 43-F | Shale, black, soft, oolitic | 21.9 | 48.0 | 3 | 6 |
| 43-G | Shale, brownish black, oolitic | 28.6 | 62.6 | 3 | 4 |

The cross section of the anticlinal axis is well exposed in the gulch in which the above section was measured. Immediately underlying the portion of the section given in detail is a series of dark-colored shales containing limestone lenses which indicate the total thickness of the phosphatic portion of the Park City formation as somewhat less than 100 feet at this place. The sandy limestones of the basal part of the Park City formation and the overlying cherty beds make prominent cliffs directly above and east of the prospects.

In the southeast corner of sec. 31 there are several prospects, but the best section is exposed in the tunnel opened by the San Francisco

Chemical Company. The direction of the tunnel is nearly northeast and southwest and it cuts the approximately vertical beds at right angles. The section measured at this point comprises 74 feet of beds. The lithologic details and the results of the chemical determinations obtained from the samples are given on Plate IV.

#### T. 26 N., R. 119 W., WYOMING.

Raymond Canyon cuts the Sublette Range in a steep, narrow, and rocky gorge transverse to the trend of the range and to the major axes of folding in the strata. The phosphate beds are exposed by prospecting in the NW. ¼ NE. ¼ sec. 6, T. 26 N., R. 119 W., by entry tunnels through the slide rock on the south side of the canyon. The cherty limestone forms a most prominent exposure in the canyon, standing nearly vertical like a massive rock wall about 80 feet thick, through which the creek passes in a gap hardly wider than the creek channel and the wagon road. The phosphate bed exposed in the principal prospects occurs high in the shaly division of the Park City formation, being relatively much nearer the cherty ledge than is the principal bed of the Montpelier section.

The following section was measured and samples were collected at the Raymond Canyon prospects:

*Partial section of phosphatic beds in Raymond Canyon, Wyoming.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. | |
|---|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft.* | *in.* |
| 42-A | Shale, grayish brown | 8.9 | 19.5 | 4 | 5 |
| | Limestone | | | 6 | |
| 42-B | Phosphate, massive, compact, black, oolitic | 32.0 | 70.1 | 3 | 1 |
| 42-C | Limestone, dark, fine grained | 9.3 | 20.4 | 5 | |
| | | | | 18 | 6 |

From this point southward the cherty ledge and phosphatic shales may be traced in almost continuous outcrop for 3 miles. These exposures cross the spurs running off from the main range, so that the outcrop itself follows an irregular profile, being intersected by the many lateral gulches draining this mountain slope. The principal prospects are found at the bottoms of the larger canyons and show the beds dipping east or west at steep angles.

All of the better-grade phosphate in this area is exceedingly compact and hard, so that it requires blasting in running in the entry tunnels. It has a dark color and displays oolitic texture, as elsewhere.

Coal Canyon, approximately on the section line at the south side of sec. 6, affords one of the most complete sections. The dark shaly beds were originally prospected for coal in several entries that extend to a considerable depth. An open-cut trench, partly caved, revealed a clear section for part of the series, from which the following measurements were made. The hillsides above the trench are covered with a heavy growth of vines and scrubby brush, and the outcrops there are concealed in slide rock.

*Section in Coal Canyon, Sublette Mountains.*

| Field No. of specimen. | Description of beds. | $P_2O_5$ | Equivalent to $Ca_3(PO_4)_2$. | Thickness. | |
|---|---|---|---|---|---|
| | Cherty limestone, massive; *Productus* abundant. | *Per cent.* | *Per cent.* | *Ft.* | *in.* |
| | Limestone, shaly and shattered | | | 1 | 9 |
| | Limestone, blocky | | | 3 | 2 |
| | Limestone, shaly, oolitic, crushed | | | 1 | 10 |
| | Limestone, black, shattered, fossils (*Chonetes*) | | | 9 | 8 |
| | Phosphate rock, shaly, oolitic, impure | | | | 5 |
| | Limestone, black, coarse, and shale in part sandy | | | 7 | 8 |
| | Limestone, black, hard, with 3 inches of crushed shale, fossils | | | 1 | 8 |
| | Phosphate rock, oolitic (in Francis Canyon, 3′ 4″; 7.2 per cent) | | | 5 | 10 |
| | Limestone, dark gray, blocky, fossils | | | 2 | 1 |
| 41-A | Shale, brownish-black, somewhat oolitic | 27.0 | 51.1 | 3 | 9 |
| | Limestone, gray, fossils | | | 1 | |
| 41-B | Shale, brownish black, calcareous | 16.3 | 35.7 | 8 | 8 |
| | Limestone, dark gray, hard, fossils | | | 2 | |
| 41-C | Shale, brown, with oolitic layers | Trace. | Trace. | 2 | |
| | Limestone | | | 1 | |
| 41-D | Shale, soft brown, calcareous | 11.9 | 26.1 | 1 | 3 |
| | Limestone, gray, massive, fossils | | | 4 | |
| 41-E | Shale, black and brown, thin bedded | 16.8 | 36.8 | 8 | |
| | Limestone, gray, shattered, oolitic at base | | | 4 | |
| 41-F | Shale, grayish brown, calcareous, oolitic, medium to fine, in part sandy | 16.4 | 35.9 | 6 | |
| 41-G | Shale, grayish brown, calcareous, sandy | 12.0 | 16.3 | 4 | |
| 41-H | Phosphate rock, coarse, oolitic | 26.0 | 56.9 | 4 | 6 |
| 41-I | Phosphate rock, oolitic in part | 19.6 | 42.9 | 5 | 6 |
| 41-K | Limestone, grayish black, sandy | 10.3 | 22.3 | 5 | |
| | Interval covered to underlying limestone (about) | | | 90 | |
| | Total phosphate series (about) | | | 184 | |

A "main bed" of rock phosphate, 4 feet 6 inches thick, in Jackson Canyon, about one-fourth of a mile south of Coal Canyon, was sampled, showing 32.7 per cent of phosphoric acid, equivalent to 71.6 per cent of tricalcium phosphate.

Prospects on the north side of York Canyon, in the NE. ¼ SW. ¼ sec. 18, revealed a bed of phosphate 4 feet thick, which showed on test 34.3 per cent of phosphoric acid, equivalent to 75.1 per cent of tricalcium phosphate. A prospect on the south side of the same canyon opens a bed of phosphate 5 feet 10 inches thick, giving 35.0 per cent of phosphoric acid, equivalent to 76.7 per cent of tricalcium phosphate.

A considerable series of beds was sampled and tested from prospects and exposures in Francis Canyon, in the NW. ¼ NE. ¼ sec. 19. Here two beds 3 feet 4 inches and 2 feet 4 inches thick ran 32.5 and 32.8 per cent of phosphoric acid (equivalent to 71.2 and 71.8 per cent of tricalcium phosphate). They are separated by an interval of 57 feet 6 inches. Numerous other beds contain more or less phosphatic material similar to that in the Coal Canyon section.

Just south of the prospects in Francis Canyon the outcrop of the cherty ledge associated with the phosphate beds appears to bend sharply eastward, so that this stratum flattens against the slope of the hill. This feature is probably of local significance, perhaps of entirely superficial character, but the phosphate has not been discovered south of this point, and it is assumed that the anticline or possible partial overthrust by which this outcrop has been brought up plunges here or is covered by the gravel bowlders and alluvial deposits. The structure of the main range south of Francis Canyon is apparently regular, forming a direct continuation of the structures in the northern part, but as the valley areas enter progressively farther into the range as it is followed toward the south, the outcrops are truncated at the valley margins, and further tracing of the phosphate becomes impossible.

### AREA AND TONNAGE.

The total distance between the northernmost and the southernmost point of exposure of the phosphate beds is approximately 34,000 feet. The outcrop is not, however, directly traceable at the surface through the entire distance. The area under which the phosphate is assumed to be minable is narrow, owing to the steep inclination of the beds. In order to compare the tonnage of this district with that of the other areas in this region, estimates are presented on the basis of a minimum recovery of 5 feet of high-grade ore. The content of the bed on the east side of the anticline, computed to a depth of 2,000 feet along the bed, is 27,000,000 long tons. One-fifth of this amount, or 5,400,000 tons, is available from the area of double outcrops at the north end, and it is probable that prospecting by drilling might demonstrate the presence throughout the length of the range of the entire western flank of the fold. The total minimum quantity of phosphate in sight in the Sublette Mountain area, exclusive of the doubtful concealed western flank, is somewhat over 32,000,000 tons of 2,240 pounds.

## PHOSPHATE AREA NEAR COKEVILLE.

### LOCATION, ACCESSIBILITY, ETC.

The phosphate deposits near Cokeville, Wyo., are situated less than 2½ miles northeast of the town. The ready accessibility and the favorable situation of the beds have led to their early development, and this district is reported to have produced about 6,000 tons of high-grade phosphate rock to date. (See Pl. IX.)

## GENERAL GEOLOGY.

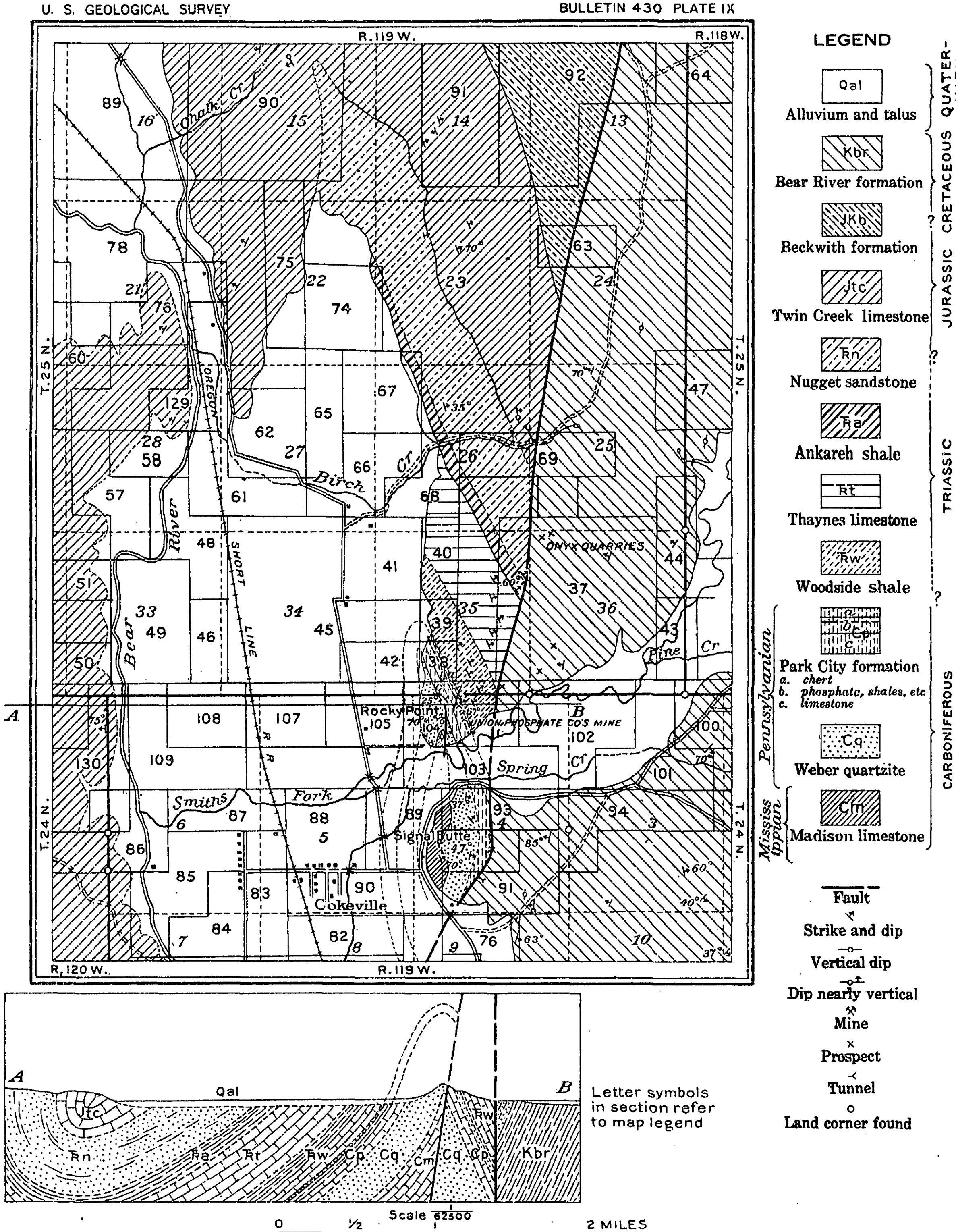
The rocks of the Cokeville area correspond in the main with the stratigraphic section described under the general heading "Stratigraphy," beginning on page 469. The geologic structure involves an anticline broken at its axis and truncated on the east by a second and greater fault, which has introduced into the eastern part of the area beds of Cretaceous age. These beds, the Bear River formation, were called Laramie by the Hayden Survey[a] and were later described by T. W. Stanton[b] and assigned to a horizon in the late Cretaceous older than Laramie. The fold which brings up to outcrop the phosphate beds belongs to the same system of disturbances as the larger folds of the Sublette district, with which, geographically, the Cokeville area would naturally be considered as a unit. Commercially, however, the two areas are distinct and they are discussed separately in this report.

The oldest rocks in the Cokeville district are compact gray limestones (Madison limestone), whose Mississippian age is indicated by traces of zaphrentoid corals. Small areas of these rocks are found in the axis of the anticline, both north and south of Smiths Fork. Conspicuous outcrops occur on the west side of Signal Butte, 1½ miles east of Cokeville. The dips at this point are easterly and the outcrop is regarded as forming the east-central portion of the unsymmetrical anticline.

Ledges of the vitreous white to brownish Weber quartzite form the conspicuous jagged ribs of Rocky Point, and it is possible to trace individual beds of this formation up the western flank and over the crest of the anticline, but it is doubtful if the same beds can be identified on the eastern flank, owing to the readjustment and shifting produced by a nearly vertical break near the axis of the fold. A large portion of Signal Butte, including the summit, consists of a calcareous quartzite which should probably be referred to the Weber.

The Park City formation is best exposed on the east side of Rocky Point and the following section, measured by G. H. Girty, gives the amount and distribution of the rocks uncovered at this place, together with the phosphate content of the principal beds as determined by tests made in the present work:

[a] Eighth Ann. Rept. U. S. Geog. and Geol. Survey Terr., 1876, pp. 144, 145.
[b] Am. Jour. Sci., 3d ser., vol. 43, 1892, pp. 98-115.




PRELIMINARY GEOLOGIC MAP AND STRUCTURE SECTION OF THE COKEVILLE AREA, WYOMING

ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY

*Section of Park City formation near phosphate mines, Cokeville, Wyo.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. | |
|---|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft.* | *in.* |
| | Shales, reddish, base of Woodside shale. Chert, black, with occasional beds of clear, bluish-gray limestone; thickness estimated (fossils—*Productus*, *Chonetes*, and *Rhynchopora*) | | | 100 | |
| | Interval, concealed | | | 6 | |
| 55-A | Shale, calcareous, hard | 17.4 | 38.1 | 1 | |
| | Limestone, black, siliceous (fossils) | | | 4 | |
| | Interval, concealed | | | 2 | |
| | Limestone, black, earthy | | | 3 | |
| | Interval, concealed, probably some limestone | | | 20 | |
| | Limestone, black, hard | | | 1 | 6 |
| | Interval, concealed | | | 3 | |
| 55-B | Phosphate rock (?), oolitic, with *Lingula* | 19.4 | 42.5 | 1 | 2 |
| | Interval, concealed; in part shale, black, fissile | | | 6 | 8 |
| 55-C | Shale, brown, fissile | .4 | .9 | 3 | |
| | Shale, brownish, sandy, somewhat massive, calcareous | | | | 10 |
| 55-D | Phosphate rock, black, oolitic, hard, and massive | 28.5 | 62.4 | 1 | 1 |
| 55-E | Clay shale, brown, lower portion softer than upper | 1.0 | 2.2 | 3 | 9 |
| | Limestone, black, shaly | | | 1 | 4 |
| 55-F | Shale, soft brown | .8 | 1.8 | 1 | 6 |
| | Shale, calcareous, sandy, massive in part | | | 5 | 3 |
| 55-G | Limestone, oolitic, in part shaly | 22.2 | 48.6 | 1 | 11 |
| 55-H | Limestone, black, oolitic, hard, weathers brown | 18.6 | 39.7 | 1 | 6 |
| 55-I | Phosphate rock, black, oolitic, hard | 37.0 | 81.0 | 3 | . |
| 55-K | Phosphate rock, grayish-black, hard | 33.2 | 72.7 | 2 | 4 |
| 55-L | Shale, grayish-brown, soft | 29.5 | 53.7 | 1 | 4 |
| | Shale, brown, sandy, thin-bedded | | | | 6 |
| | Limestone, brown, earthy, massive | | | 2 | 1 |
| 55-M | Phosphate rock, gray, medium, oolitic | 33.4 | 73.1 | 1 | |
| 55-N | {Shale, brown, somewhat oolitic<br>{Shale, brown | 19.5 | 42.7 | 1 | 11<br>3 |
| 55-O | Shale, grayish-black, oolitic | 25.6 | 56.1 | | 7 |
| | Shale, somewhat oolitic | | | 1 | 6 |
| | Shale, sandy, black, oolitic, rather massive | | | 1 | 8 |
| | Shale, brown, massive | | | 1 | |
| | Limestone, light brown, earthy, massive | | | 1 | 7 |
| | Shale, phosphatic, contains nodules of limestone | | | 2 | 3 |
| | Limestone, dark gray, earthy | | | 1 | |
| | Shale, black, oolitic | | | 4 | 2 |
| | Limestone, black, hard, earthy (fossils) | | | 4 | 10 |
| | Shale, brown | | | 3 | 6 |
| | Limestone, brownish gray, earthy | | | 1 | 6 |
| | Shale, brownish black | | | 1 | 10 |
| | Limestone, brownish, soft, earthy, fairly massive | | | 3 | 6 |
| | Limestone, black, massive, weathers brown | | | 2 | |
| | Shale, black, fissile, weathers brown | | | 4 | 2 |
| | Limestone, grayish brown | | | 1 | 3 |
| | Shale, black, soft | | | 1 | 6 |
| | Shale, black, soft, contains some phosphatic concretions (fossils) | | | 1 | 6 |
| | Shale, soft, black | | | 2 | 10 |
| | Limestone, black | | | 1 | |
| | Shale, black, weathers brown | | | 2 | 3 |
| | Interval, concealed | | | 45 | |
| | Limestone, gray, siliceous, grading below to glassy white Weber quartzite | | | 300 | |
| | Approximate total thickness | | | 571 | 4 |

For purposes of graphic comparison, this section is included on Plate IV. The remarkably persistent characteristics of the Park City formation are again illustrated by this section. The lower portion consists of sandy limestone beds overlain by a series of phosphatic shales containing lenticular, fetid limestones and beds of high-grade phosphate rock, and these are in turn overlain by the chert, which here makes a prominent hogback. The position of the outcrop of the main phosphate bed can often be readily determined for prospecting by measuring from this chert marker.

On the east limb of the more or less broken anticline in the northern part of the area shown on the map the section overlying the Park City formation in normal sequence is continuous to the Beckwith formation. Directly east of the phosphate mines, however, the fault has cut so far to the west that the base of the Thaynes limestone is barely included in the section there. The formations overlying the Park City and west of the fault are typical Woodside shale, Thaynes limestone, and Ankareh shale.

The Bear River formation is composed mainly of dark shales, carbonaceous beds, gray and buff sandstones, and brownish conglomerate. The carbonaceous beds have been prospected in various places for coal, but no beds of economic importance appear to have been found. Beds of probable Eocene age cap several of the higher hills and ridges in places, but are of no recognized economic importance, and their mapping would have served only to obscure the representation of the harder rock formations. The alluvium of Bear River valley and the aprons of wash bordering the hills form an effective blanket over a large part of the area west of the anticlinal axis and necessarily render hypothetical all conclusions concerning the distribution of underlying bed-rock formations.

For purposes of discussion of the geologic structure the area is naturally divided into two structural units by a major fault crossing the area from north to south. This fault is of the normal or gravity type and its maximum displacement is along the axis of the anticline where presumable Cretaceous rocks lie against the Mississippian limestone. This contact is concealed by the alluvial deposits, however, and the maximum exposed displacement is found in the vicinity of the prospects on the southeast side of Signal Butte. Here the Park City formation lies against the Cretaceous. The stratigraphic displacement decreases in amount toward the north, and it is possible that the fault passes into a fold in that direction.

The eastern structural unit is composed of contorted and for the most part steeply dipping rocks of the Bear River formation, and in that area the phosphate deposits, if present, lie at a depth of more than 9,000 feet. The western unit comprises the sharp anticlinal fold mentioned above, which brings up the phosphate-bearing formation. The eastern portion of the anticline is clearly shown by the areal distribution and the prevailing easterly dips of the formations involved. West of the anticlinal axis in Rocky Point the phosphate is concealed by the alluvium and wash and may be so disturbed that any attempt at approximation of its position would prove of slight value. An endeavor has been made, however, to indicate on the map a hypothetical position and trend for the western or suballuvium area of the Park City formation. The beds are shown where they would occur, provided the dips of the intervening strata in the western limb correspond to the dip readings obtained on the west bank of Bear River and on the west side of Rocky Point. It therefore seems probable that the underlying structure is somewhat as represented and that the actual position of the concealed phosphate could be determined by a series of test borings. No data concerning the thickness of the alluvium cover in this locality are available, but it may be at least 200 feet thick and so permeated with water that the expense of mining the phosphate under such conditions would be great and not warranted under present circumstances.

## DEVELOPMENT.

The mine at Cokeville, which has been developed by the Union Phosphate Company, consists of a series of tunnels run in on the strike of the main phosphate bed. The mining practice followed involves the breaking of the rock by overhead stoping; stopes are opened above the several tunnels through upraises; the rock is hard, and air drills are used in putting in the holes; the breaking is done with giant powder; the stopes are set with timbers and the rock or ore is allowed to settle between the timbers and drawn off by chutes into cars that in turn dump into the lower stopes, which are used for storage purposes, the ore being finally drawn off into the car on the lower level, which dumps into the outside bins for loading the wagons. Little work has been done in the upper tunnel, but the other three are each approximately 1,000 feet in length.

Offsets were noted in the second and lowest tunnels. One has about 6 feet throw at a distance of approximately 50 feet from the entrance. Another, about 1,050 feet in and about 35 feet back from the face of the tunnel, shows a displacement of unknown throw. An examination of the surface above the mine revealed the existence of a fault—probably the same one that shows in the deeper parts of the tunnels, with a direction of N. 15° E. and a horizontal offset of about 55 feet to the northeast on the north side.

The section of the "main beds" is fairly constant, and its details and the distribution of the phosphate content are given in the section of the Park City formation on page 505. The portion mined and shipped at present is 5 feet 4 inches thick with an average content of over 35 per cent of phosphoric acid, equivalent to 75 per cent of tricalcium phosphate.

A number of prospects have been opened in the search for phosphate deposits on the southeast side of Signal Butte, south of Smiths Fork. The northernmost is located in the NW. ¼ SE. ¼ sec. 4, and consists of a pit in a yellow, claylike material and an east-west trench showing a brecciated portion of the phosphatic rocks of the Park City formation. In tract 91 there are three or four small openings and a tunnel about 80 feet in length, running westward in a brecciated zone of phosphatic rocks, among which, however, no clearly defined bed of high-grade material was observed. The pronounced brecciation noted in all openings in this part of the area is interpreted as indicating the proximity of the fault plane.

### TONNAGE.

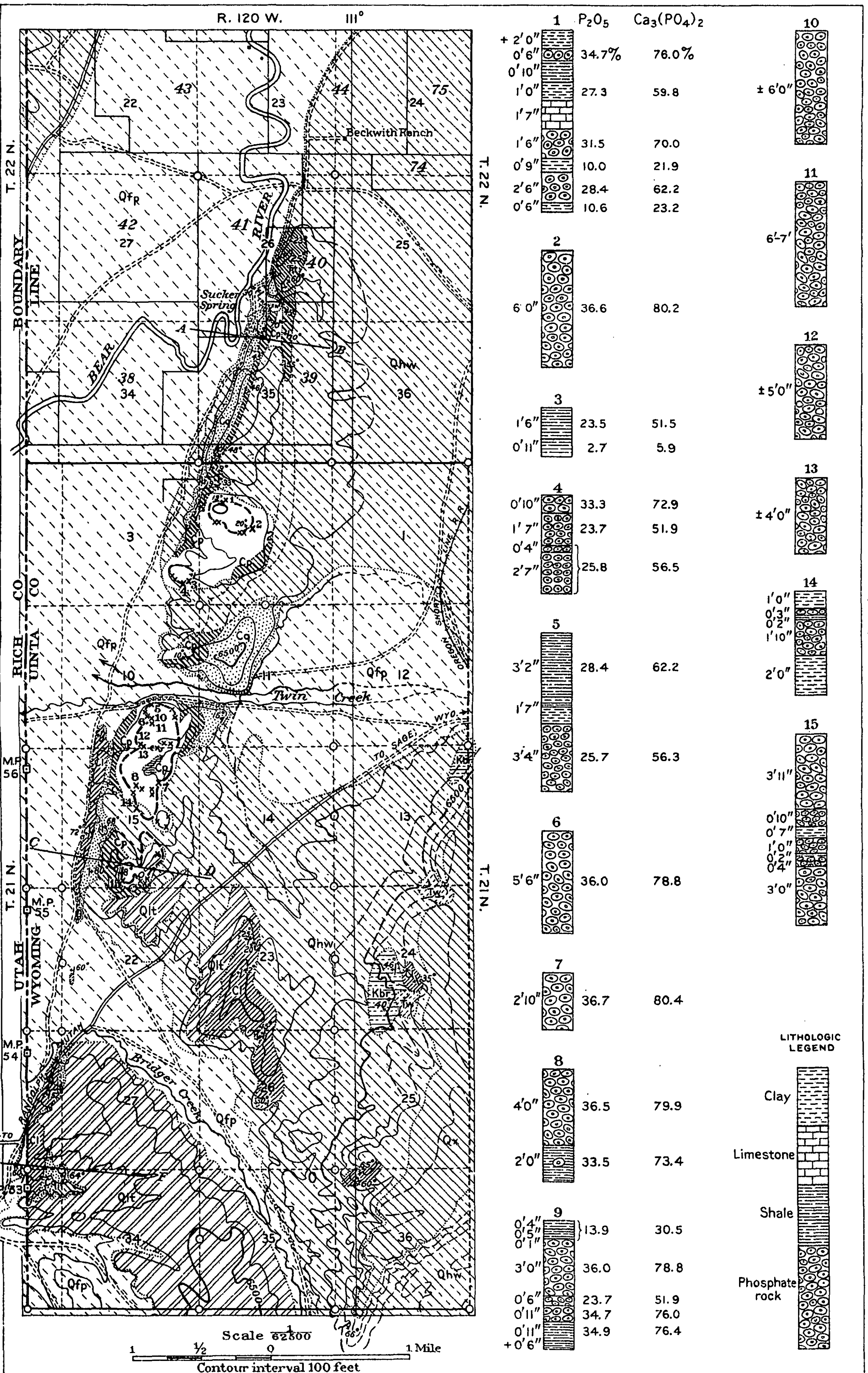
The length of the traced outcrop of the main phosphate bed on the east side of the anticline north of Smiths Fork is approximately 3,000 feet. A consideration of the tonnage of the bed, based on recovery of 5 feet of the total thickness to a depth of 2,000 feet along the bed, yields a total of 2,400,000 tons, of 2,240 pounds, as the available quantity of phosphate in the Cokeville area. This represents a minimum estimate of the tonnage of high-grade phosphate rock in the area and excludes that portion of the ore lying above the water level in and about the mine.

The character of the deposits south of Smiths Fork is too problematical and the extent of development has been too insufficient to permit an estimate of the phosphate contained in them. The amount of rock within 2,000 feet of the surface in the concealed western portion of the anticline, provided that it occurs in a normal anticlinal structure, probably exceeds by about four times the figures of the above estimate.

### PHOSPHATE NEAR COKEVILLE PRESUMABLY DERIVED FROM THE TWIN CREEK LIMESTONE.

In a hasty review of the area southwest of Cokeville a piece of rock picked up at the witness monument of the quarter-section corner on the west side of sec. 36, T. 24 N., R. 120 W., Wyoming, was found on test to be rock phosphate equivalent to about 70 per cent bone phosphate grade. This rock was collected with a considerable number of other specimens from oolitic limestone of the Twin Creek formation, such as is observed in many places throughout the Idaho, Wyoming, and Utah field. Most of the dark-bluish oolitic limestone specimens, many of which represented rock in place, proved to contain but a negligible trace of phosphoric acid. The specimen of commercial phosphate was derived from float, and being of angular form, had probably not been transported far. This phosphate much resembles the oolitic Jurassic beds found in natural outcrop near by, and is thought to have been derived from this portion of the formation. No outcrops of the older or Carboniferous phosphates are now known nearer than those at the Cokeville mines, a distance of more than 6 miles. The Twin Creek phosphate beds have not, however, been found in place.

A second visit to the locality has not served to identify the original bed. More float of practically the same material was collected on




MAP OF BECKWITH HILLS PHOSPHATE AREA, WYOMING, WITH SECTIONS AND ANALYSES OF PHOSPHATE BEDS

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

the township line, about 150 feet west of the southwest corner of sec. 36, which is about on the strike of the same beds and seems to indicate the continuity of such a phosphatic horizon through at least that distance. The following analyses were obtained from the specimens collected:

Float found at the quarter section corner on the west side of sec. 36, T. 24 N., R. 120 W., Wyoming (phosphate rock, dull brownish, obscurely oolitic, fragments of 4-inch stratum showing bluish-white coating, as on float of phosphate in other areas): 30.8 per cent of $P_2O_5$, equivalent to 67.4 per cent of $Ca_3(PO_4)_2$.

Float found near the southwest corner of sec. 36, T. 24 N., R. 120 W., Wyoming (phosphate rock, dull brownish, obscurely oolitic, indistinguishable from specimen described above): 32.6 per cent of $P_2O_5$, equivalent to 71.4 per cent of $Ca_3(PO_4)_2$.

Further search in other parts of the field for phosphatic beds in the Twin Creek limestone has not yet been rewarded, but it must be acknowledged that this search has not been very thoroughly prosecuted.

## BECKWITH HILLS AREA.

### LOCATION AND DEVELOPMENT.

The Beckwith Hills phosphate area is situated in Tps. 21 and 22 N., R. 120 W., on the western border of Wyoming. (See Pl. X.) The area represents a northern outlier of the Crawford Mountain district, but has been reduced by erosion to a much greater extent than that district, so that the phosphate-bearing formation covers at present only a small portion of the area originally occupied by it in this region.

The Beckwith Hills consist of a series of low hills lying north, somewhat east, of the Crawford Mountains and having a trend which coincides with the general strike of the rock formations. The hills are separated from one another by the gaps of Twin Creek and Bridger Creek.

The mining developments in the district are limited to prospecting work done in connection with the annual assessment requirements of the mining law. Many of the claims are located under both the placer and the lode laws, and in most cases the two locations have been made by conflicting parties. So far as known, none of the claims have been patented.

The nearest shipping point is Sage station, on the Oregon Short Line Railroad, and the average haul is about 4 miles, over a practically level road.

### GENERAL GEOLOGY.

The data available for deciphering the structural conditions existing in this area are more or less fragmentary, because of the extensive cover of Quaternary deposits, and all conclusions concerning the structure are necessarily hypothetical. An attempt has been made to solve the problems by working out the simplest solution that is consistent with the observations obtained in the field.

A portion of the Park City formation left by erosion appears to lie along either the axis or the lower flanks of a syncline which ranges from a nearly upright to an overturned, nearly horizontal or recumbent position in different parts of the area. This change is shown by

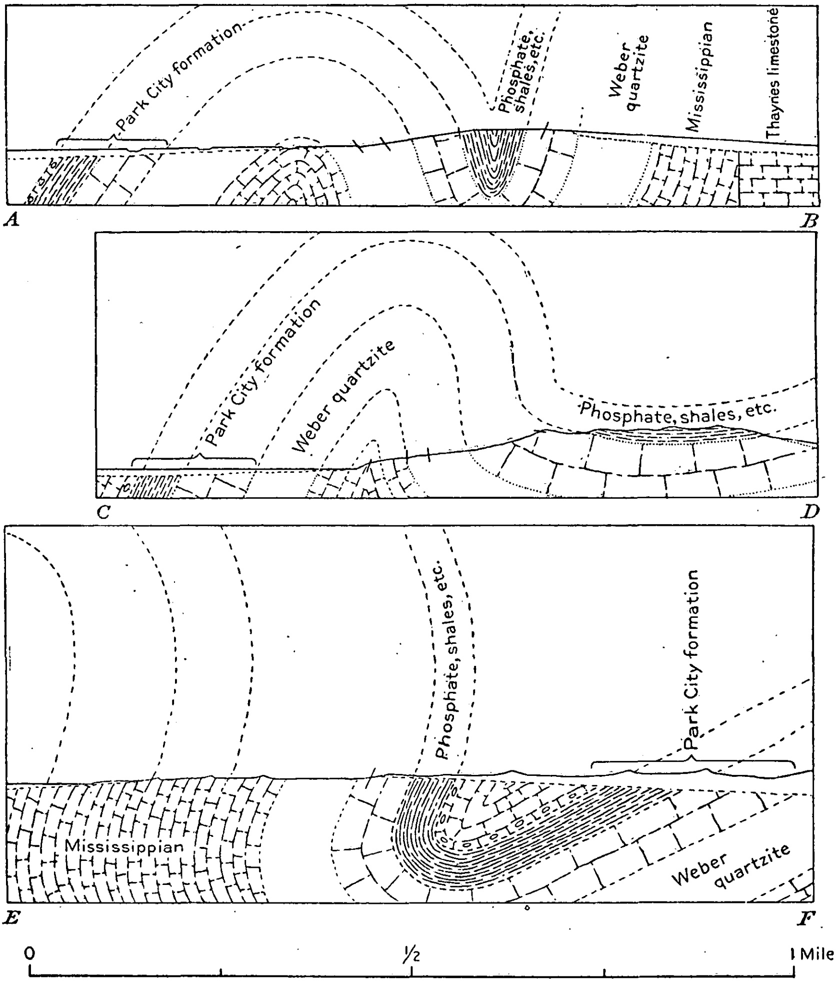



FIGURE 43.—Diagrammatic structure sections of the Beckwith Hills area, Wyoming. (See Pl. X.)

the graphic structure sections in figure 43, which illustrate conditions across the northern, middle, and southern parts of the area. The synclinal structure is assumed to be continuous between the sections. A detailed examination of the phosphate prospects showed minor plications and rolls, too small for representation on the map and of such a character that they will not cause any great amount of trouble in the development of the principal bed. A fault was found which cuts across the northern apex of the syncline and brings the Thaynes limestone into juxtaposition with the arenaceous limestone of the Park City formation underlying the phosphate-bearing shales. The extension of this fault in both directions is concealed by the Quaternary deposits.

The outcrop of the Park City formation is especially conspicuous along the western margin of the Beckwith Hills. The phosphatic rocks consist of a succession of about 200 feet of black and gray shales and gray, compact, fetid limestones, usually lenticular, with at least one 5 foot to 5 foot 6 inch bed of high-grade, coarsely oolitic phosphate rock nearly at the center of the phosphate-bearing zone and probably corresponding to the main bed in the Crawford Mountain district. So far as known, the high-grade bed is not included in that portion of the syncline present in T. 22 N., R. 120 W. The outcrop of the main bed in the township to the south is indicated on the map (Pl. X), and the results obtained in the examination of the exposures in the various prospects are summarized in the following statements.

### PHOSPHATE BEDS

A number of prospects on the south side of the hill in sec. 2 indicate that the thickness of the bed here averages about 6 feet and that it consists of a gray, coarsely oolitic phosphate rock containing 36.6 per cent of $P_2O_5$, or 80.2 per cent of bone phosphate. The prospect on the north side of the same hill shows a totally different section, apparently of a lower bed, which is as follows:

*Partial section of phosphate beds in sec. 2, T. 21 N., R. 120 W.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. |
|---|---|---|---|---|
| | | Per cent. | Per cent. | Ft. in. |
| | Clay, with fragments of phosphate rock | | | 1 2 |
| 81-A | Phosphate rock, gray, coarsely oolitic | 34.7 | 76.0 | 6 |
| | Shale, red and yellow | | | 3 |
| | Shale, gray, soft | | | 3½ |
| | Shale, reddish gray | | | 4 |
| 81-B | Phosphate rock, brownish gray, soft | 27.3 | 59.8 | 1 |
| | Limestone | | | 1 7 |
| 81-C | Phosphate rock, coarsely oolitic, soft | 31.5 | 70.0 | 1 6 |
| 81-D | Phosphate rock, shaly, gray, brown, soft | 10.0 | 21.9 | 9 |
| 81-E | Phosphate rock, dark gray, oolitic | 28.4 | 62.2 | 2 6 |
| 81-F | Phosphate rock, shaly, brown | 10.6 | 23.2 | 6 |

The small hill in the SE. ¼ sec. 3 has been prospected by several entries, and the following section is a combination of the measurements obtained in the two eastern prospects:

*Partial section of phosphate beds in sec. 3, T. 21 N., R. 120 W.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. |
|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft. in.* |
| 84-A | Shale, gray, soft | 23.5 | 51.5 | 1 6 |
| 84-B | Shale, gray, shaly, soft | 2.7 | 5.9 | 11 |
| 84-C | Phosphate rock, gray, oolitic, soft | 33.3 | 72.9 | 10 |
| 84-D | Phosphate rock, light gray, oolitic, soft | 23.7 | 51.9 | 1 7 |
| 84-E | Phosphate rock, coarsely oolitic (*Ft. in.* 4); Phosphate rock, gray, hard, grading to black; pebbly at base (2 3) | 25.8 | 56.5 | 2 7 |

A large number of prospects have been opened on the hill immediately south of the Twin Creek gap. One of the best sections exposed is the following, measured in a tunnel in the NW. ¼ SW. ¼ sec. 10:

*Partial section of phosphate beds in sec. 10, T. 21 N., R. 120 W.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. |
|---|---|---|---|---|
| 83A | Phosphate rock, mostly soil-like, but contains some oolitic material | *Per cent.* 28.4 | *Per cent.* 62.2 | *Ft. in.* 3 2 |
| | Shale, red and gray, fine grained | ........ | ........ | 7 |
| 83B | Phosphate rock, gray, oolitic | 25.7 | 56.3 | 8 |
| | Phosphate rock, reddish gray, fine grained | | | 10 |
| | Phosphate rock, gray, oolitic | | | 1 10 |

The southernmost of the prospects, in the SE. ¼ sec. 15, shows a better and perhaps a more typical section:

*Partial section of phosphate beds in sec. 15, T. 21 N., R. 120 W.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. |
|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft. in.* |
| 87A | Phosphate rock, dark gray to black, oolitic, hard | 13.9 | 30.5 | 4 |
| | Shale, brown, earthy, thin, black | | | 5 |
| 87B | Pebble bed | 36.0 | 78.8 | 1 |
| | Phosphate rock, dark gray to black, massive, hard | | | 2 11 |
| 87C | Phosphate rock, fine grained, oolitic, hard | 23.7 | 51.9 | 6 |
| 87D | Phosphate rock, black, coarsely oolitic | 34.7 | 76.0 | 11 |
| 87E | Phosphate rock, light gray, sandy and shaly | 34.9 | 76.4 | 10 |
| | Shale, soft, iron-stained | | | 1 |

The above, together with the other analytical results obtained in this area, are shown graphically on Plate IV. It will be noted that the prospecting in the Beckwith Hills has been limited to the main bed, and additional trenching would be necessary to determine the character and amount of other beds and lower-grade phosphate rock present. It is, however, probably comparable to the material found in other districts where detailed sections of the entire succession have been made. (See, for example, the series of tests recorded in the table on p. 477.)

### AREA AND TONNAGE.

The area of known phosphate land in the Beckwith Hills district is estimated to comprise approximately the following acreage:

*Phosphate land in Beckwith Hills district.*

| | Acres. |
|---|---|
| Section 2 | 27 |
| Section 3 | 8 |
| Sections 10 and 15 combined | 101½ |
| Section 15 | 25 |
| | 161½ |

Additional areas of land underlain by phosphate are suspected in secs. 22 and 34, but no data are available for estimating their extent. Such data can not be obtained except by shafting or drilling through the terrace cover. All of the phosphate in the main bed in the proved area must be regarded as the minimum amount available, and computation on the basis of an average thickness of 5 feet yields a total minimum in round numbers of 2,800,000 tons of 2,240 pounds in the Beckwith Hills area.

The portion of the phosphate-bearing section below this bed undoubtedly contains an even greater amount of material which may be regarded as ultimately available, and the tonnage of the concealed portion of the phosphate beds mentioned above can not be considered because of lack of data.

## *UTAH.*

## CRAWFORD MOUNTAIN AREA.

### LOCATION, ACCESSIBILITY, ETC.

The Crawford Mountains include what is at present the most extensively prospected and perhaps one of the best known and most readily accessible of the larger phosphate areas that has yet been brought to public attention. These mountains lie in the eastern side of Rich County, Utah, extending into southwestern Uinta County, Wyo. If the Beckwith Hills are considered as a separate area all the known phosphate deposits in the Crawford Mountains lie on the Utah side of the state line. The prospected outcrops are situated in parts of T. 9 N., R. 7 E.; T. 10 N., Rs. 7 and 8 E.; and T. 11 N., Rs. 7 and

8 E., all referred to the Salt Lake guide and meridian, Utah. (See Pl. XI.)

The beds of the Beckwith Hills were without doubt originally continuous with the deposits of the Crawford Mountains, but are now separated from them by gaps or intervals from which erosion has removed all the phosphate-bearing rocks. On account of the isolation of the Beckwith Hills tracts, they are described as an independent area.

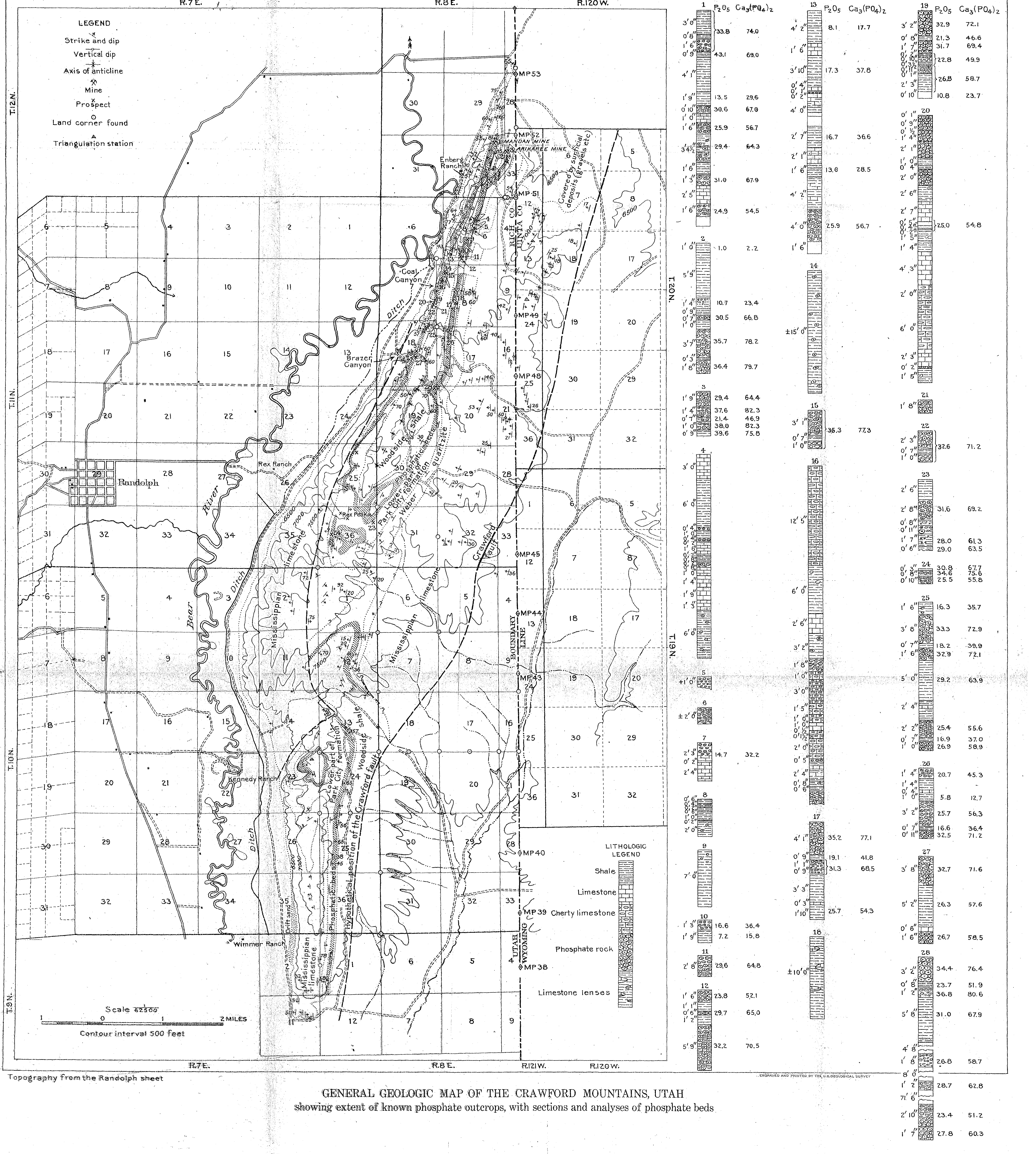
The shipping point nearest the Crawford Mountain phosphate deposits at the present time is Sage, Wyo. The whole area is, however, easily accessible by railroad routes, for it is practically surrounded by low valleys, especially by the flat bottom lands of Bear River, which reach within a very short distance of the prospected area.

## GEOLOGY.

The phosphate beds are typically developed in the Crawford Mountains. The relations of the phosphate-bearing strata to both overlying and underlying rock formations, though involved in more or less structural complexity, are nevertheless clearly revealed throughout the area, and it is, therefore, an excellent place to study the geology of these deposits.

The stratigraphic sequence, as has been described in a general way on pages 469–470, includes the section from the Mississippian or older limestones at the base to the Woodside or possibly lower Thaynes, the latter being the remnants included along the axes of the deeper parts of the major synclines. Small patches of presumably Wasatch and late surficial deposits, such as gravel, bowlders, and sands and alluvium, are not necessarily differentiated so far as their practical bearing on the occurrence and accessibility of the phosphate is concerned. The principal and more complete sections of the Park City formation, including the phosphate, are illustrated in a graphic way in Plates IV and XI.

The geologic structure of the Crawford Mountains is evidently related to the general structure of the whole region studied, being produced by great compression caused by thrust movements originating from the west and resulting in closed folds of north-south extension and overthrust faults, in which the older rocks ride up and over the younger, all dipping in the same westerly direction. The northern half of these mountains consists on the west flank of an anticline, apparently developing into an overthrust fault or being overridden and concealed by an overthrust near the middle of the west face of the range. The continuous syncline extending from the northern extremity of the range to the highest summit at Rex Peak parallels the western marginal anticline and includes most of the prospected




GENERAL GEOLOGIC MAP OF THE CRAWFORD MOUNTAINS, UTAH

showing extent of known phosphate outcrops, with sections and analyses of phosphate beds phosphate deposits. East of the syncline that contains the phosphate similar folds in the older rocks, including the Mississippian rocks, are brought to the surface, so that these evidently form the principal axis of the range. On the east these Paleozoic limestones abut directly against the later Tertiary or Cretaceous and Tertiary rocks, which are assumed to have been brought into this relation by a fault, the exact character of which has not been determined. This fault is also supposed to mark the entire western margin of the Crawford Mountain area, and from this fact it has been referred to by Veatch[a] as the Crawford fault. Its position is in greater part obscured by the covering of Quaternary gravels and silts, but in at least one place, in the SE. ¼ sec. 32, T. 11 N., R. 8 E., the Cretaceous sandstone is exposed in contact with the Palezoic limestone. In a less distinct way its position is traced by the alignment and abrupt termination of the higher ridges exposing the older rocks, to the east of which the low rolling valleys are presumably eroded in the softer Tertiary strata.

In the southern half of the Crawford Mountains the structure is not so regular as that to the north. South of Rex Peak the folds as a whole rise so that the phosphate beds are found only in patches on the high tops and are eroded entirely for an interval of a mile or more. On the west flank of the mountains the overthrust of Mississippian limestone broadens, forming a precipitous rocky wall near the middle of the range. The phosphatic beds reappear in a somewhat irregular synclinal fold about 2 miles south of Rex Peak, and from this point they have been traced to the extreme south end of the mountains, following the west side. The southern extremity of the Crawford Mountains so far as exposed is evidently a comparatively simple anticline, of which the west flank is steep and in part overturned. All these relations are brought out to a certain extent by the areal distribution of formations and the dip and strike symbols shown on Plate XI.

## PROSPECTS AND DEVELOPMENT.

### GENERAL STATEMENT.

The patented claims in the phosphate lands, as shown on the map, are located in the northern part of the area. These claims are of the lode type and therefore follow the outcrops of the phosphate beds on either flank of the syncline in which the deposits are folded. Other claims have been staked covering a large part of the outcrops south of the patented ground to a point about 3 miles south of Rex Peak, beyond which, so far as known to the authors, no claims exist, nor have the deposits been locally recognized.

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[a] Veatch, A. C., Geology and geography of a portion of southwestern Wyoming: Prof. Paper U. S. Geol. Survey No. 56, 1907, Pl. III.

Besides the recognized outcrops others may be inferred from the structure. In the northern part of the area several small prospects at the Enberg ranch have revealed the presence of the phosphate on the west flank of the marginal anticline. The outcrops are situated low on the hill slope, near the level of the valley bottom, and are probably covered by slide or valley fill throughout the greater part of their extent. There is every reason to believe that beds of high-grade phosphate are present on this side of the mountains and will at some time prove valuable for mining, although no claims have yet been staked on this outcrop. At the south end of the range the apparently simple anticlinal structure revealed in the Mississippian and possibly older limestones exposed suggest an outcrop of the phosphate on the west side of the range, somewhere in the river bottom lands, perhaps near the Wimmer ranch, corresponding to the outcrop as discovered along the east foot of this ridge. An attempt to judge with any degree of accuracy the position of these concealed outcrops is probably not warranted from the data available, but it is entirely possible that such beds may at some time be discovered either by search or by accident.

#### T. 12 N., R. 8 E.

The known occurrence of phosphate in T. 12 N., R. 8 E., is limited to secs. 32 and 33, although by extension of the outcrops northward in the same general trend as the structures to the south the beds may be and doubtless are continuous into secs. 29 and 28 and to the northeast, crossing the state line into Wyoming.

The main phosphate bed that is worked is well exposed in numerous prospects and in the mine at the extreme north end of the exposed beds. Similar entry tunnels have been run in on both the east and west flanks of the syncline; that on the east, the more extensively worked, is known as the Arikaree mine, and that on the west as the Mandan.

The Arikaree mine is located in lot 2, sec. 33, about 1,700 feet S. 30° W. from the 52-mile post on the Utah-Wyoming state line. Rock phosphate has been mined here for a number of years. The material is shipped to the American Agricultural Chemical Company's fertilizer plant near Los Angeles, Cal., with whom the Bradley Brothers, owning the Crawford Mountain properties, are allied. The mine consists of a main tunnel 450 feet in length and a drift following the main phosphate bed for about 300 feet; a moderate amount of ore has been worked out in stopes above the drift.

The bed worked measures from 53 to 60 inches in total thickness, but is divided into two parts by the so-called "gray streak." This is a leaner parting, 2½ to 7 inches thick, and separates about a foot of the high-grade ore at the bottom of the bed from the upper part.

The most massive or less shaly material and that most coarsely oolitic is considered the best ore. The rock of the workable bed is dark gray when freshly taken out, drying to a light gray in the air. It is of fine to medium and in part coarsely oolitic texture and shows both massive and shaly structure.

The dip of the beds in the Arikaree mine is 50° W. and the strike N. 32° E. In mining the bed the upper bench is first taken out and the entry and chutes are drawn clear. Then the lean-ore streak is dug out and discarded, the entries being similarly cleared, after which the lower bench is mined and the entry again advanced on the upper part of the bed. Thus the discarding of a few inches of lean material adds materially to the expense of mining in an effort to hold the product at the highest possible grade.

A section of the main bed is as follows:

*Representative section of main bed at Arikaree mine, Crawford Mountains.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. |
|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft. in.* |
| 93-A | Phosphate, gray, coarsely oolitic | 29.4 | 64.4 | 1 9 |
| 93-B | Phosphate, gray, oolitic | 37.6 | 82.3 | 1 4 |
| 93-C | Phosphate, brown, shaly, somewhat oolitic (lean streak) | 21.4 | 46.9 | 7 |
| 93-D | Phosphate, gray, medium to coarse, oolitic | 38.0 | 82.3 | 1 |
| 93-E | Phosphate, fine-grained, shaly, somewhat oolitic (not mined) | 34.6 | 75.8 | 9 |
| | Average | 32.2 | 70.3 | [a] 5 5 |

[a] Total.

The Mandan mine, now abandoned, enters the main phosphate bed on the west side of the syncline. It consists of a single entry tunnel run in about 250 feet, of which the first half is through slide rock. Like the Arikaree, it is at the extreme north end of the visible outcrops of phosphate. It is situated in lot 1, sec. 32, about 1,950 feet S. 70° W. of the 52-mile post on the Utah-Wyoming state line, and is about 1,300 feet northwest of the Arikaree. The outcrops of the main bed are about 1,200 feet apart across the syncline at this place. The west flank of the syncline is steep, either vertical or locally overturned; in the mine the strike is N. 24° E. and the dip 81° to 82° W. The east flank dips about 50° W., as stated. It seems likely, therefore, that the bed is not more than 600 or 800 feet below the surface at its deepest point in this part of the field, and the total breadth of the minable deposit between the outcrops is perhaps approximately 2,000 feet.

Samples and measurements of the phosphate and associated beds exposed in the Mandan mine gave the following results:

*Partial section of phosphate beds at the Mandan mine, Crawford Mountains.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. | |
|---|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft.* | *in.* |
| 95 | Main bed: | | | | |
| | Phosphate, gray, coarsely oolitic | 33.8 | 74.0 | 3 | 6 |
| | Phosphate, lean streak | | | | 8 |
| | Phosphate, gray, fine, oolitic | | | 1 | 6 |
| 96-G | Shale, phosphatic, gray | 31.5 | 69.0 | | 9 |
| | Shale, brown, calcareous | | | 4 | 1 |
| 96-F | Shale, brownish gray, calcareous | 13.5 | 29.6 | 1 | 9 |
| 96-E | Phosphate, coarsely oolitic, gray | 30.6 | 67.0 | | 10 |
| | Limestone | | | 1 | 1 |
| 96-D | Phosphate, oolitic, gray | 25.9 | 56.7 | 1 | 6 |
| 96-C | Phosphate and shale, alternating bands | 29.4 | 64.3 | 3 | 3 |
| | Shale, brown | | | 1 | 6 |
| 96-B | Phosphate, oolitic, calcareous | 31.0 | 67.9 | 1 | 3 |
| | Limestone | | | 2 | 5 |
| 96-A | Phosphate, dark gray, oolitic | 24.9 | 54.5 | 1 | 6 |
| | | | | 25 | 7 |

Numerous other prospects extending southward from the Arikaree and Mandan mines trace the outcrop of the main phosphate bed visibly. An open cut in lot 5, sec. 32, exposed an excellent section of the bed on the east flank of the syncline and a series of representative samples was collected at this place, which is on the Sioux lode claim.

*Representative section including the main bed on Sioux claim, Crawford Mountains.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. | |
|---|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft.* | *in.* |
| 92-A | Shale, massive, brown, calcareous, earthy | 1.0 | 2.2 | 1 | |
| | Shale, calcareous | | | 5 | 9 |
| 92-B | Phosphate, dark gray, coarsely oolitic | 10.7 | 23.4 | 1 | 4 |
| | Shale, calcareous | | | | 9 |
| 92-C | Phosphate, dark gray, coarsely oolitic | 30.5 | 66.8 | | 7 |
| | Shale | | | 1 | |
| | Main bed: | | | | |
| 92-D | Phosphate, massive, dark gray, oolitic | 35.7 | 78.2 | 3 | 7 |
| | Shale, brown | | | | 3 |
| 92-E | Phosphate, massive, gray, oolitic | 36.4 | 79.7 | 1 | 8 |
| | | | | 15 | 11 |

The outcrops on the west flank of the syncline have been prospected in the gulch just east of the Enberg ranch, about half a mile from the house. It is reported that ore was taken from this place when the first shipments were made in this district. Two beds are opened in old drifts, but the section as a whole is not well exposed.

The small pits revealing the third outcrop of the phosphate beds near the Enberg house have already been mentioned (p. 516) in connection with the discussion of the structure at this place. The showing was not sufficient to warrant measurement or sampling.

#### T. 11 N., R. 8 E.

The syncline bearing the phosphate beds in the northern Crawford area broadens as traced to the south through T. 11 N., R. 8 E., and the reserve of phosphate correspondingly increases. The axis of the syncline is for the most part marked by a valley or depression of the surface, this feature becoming most marked toward the south as it approaches Rex Peak and the summit of the range. Thus the beds that outcrop on either flank dip toward and underlie the intervening valley area. The phosphate beds are protected from erosion by the upper cherty limestone of the Park City formation. The valleys along the axis of the syncline are excavated in the softer shales of the Woodside. Probably the greater part of the outcrop of the phosphate rocks in this township is covered by claim locations, mostly of the lode type, although there are also duplicate locations, as elsewhere, made in both placer and lode form.

The distribution of the beds is represented by the map (Pl. XI). The following sections measured and samples taken for analysis are probably representative and serve for partial comparison with the Arikaree and Mandan sections already described.

*Section of phosphate and associated beds on Tuscarora claim, in NW. ¼ NW. ¼ sec. 17, T. 11 N., R. 8 E.*

| | Ft. | In. |
|---|---|---|
| Phosphate beds in upper part of section not well exposed. | | |
| Shale or hard clay rock, brown and grayish | | 6 |
| Phosphate (main bed), hard, massive, uniformly oolitic (1-inch coarse pebbly layer at top) | 5 | 9 |
| Shale, brown to black, very thin bedded, oolitic in thicker bands, evidently phosphatic | 5 | 3 |
| Shale, like above, but thicker bedded | | 10 |
| Limestone, massive, single stratum | 2 | 3 |
| Phosphate, alternating thick and very thin bedded | 2 | 8 |
| Phosphate, hard, coarsely oolitic, black, single stratum | 1 | |
| | 18 | 3 |
| More phosphate underlying, not exposed. | | |

*Section of phosphate and associated beds in Brazer Canyon, in NW. ¼ SE. ¼ sec. 18, T. 11 N., R. 8 E.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. |
|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft. in.* |
| 100-A | Phosphate, dark gray, coarsely oolitic | 32.7 | 71.6 | 3 8 |
| 100-B | Phosphate, brown, shaly | 26.3 | 57.6 | 5 2 |
| | Limestone | | | 6 |
| 100-C | Phosphate, brownish gray, oolitic | 26.7 | 58.5 | 1 6 |
| | | | | 10 10 |

*Section of phosphate and associated beds in Brazer Canyon, "Otto claim," approximately in NE. ¼ NE. ¼ sec. 19, T. 11 N., R. 8 E.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. |
|---|---|---|---|---|
| | Main bed: | *Per cent.* | *Per cent.* | *Ft. in.* |
| 97-A | Phosphate, dark gray or black, massive, coarsely oolitic | 34.9 | 76.4 | 3 2 |
| 97-B | Phosphate, shaly, brown, weathered, oolitic | 23.7 | 51.9 | 8 |
| 97-C | Phosphate, dark, almost black, oolitic | 36.8 | 80.6 | 1 2 |
| 97-D | Phosphate, brown, shaly, finely oolitic | 31.0 | 67.9 | 5 8 |
| | Interval concealed, probably shaly | | | 4 8 |
| 97-E | Phosphate, or limestone, dark gray or black, massive | 26.8 | 58.7 | 1 8 |
| | Limestone, cherty | | | 8 |
| 97-F | Phosphate, dark gray, massive, calcareous | 28.7 | 62.8 | 1 2 |
| | Interval concealed | | | 71 6 |
| 98-A | Shale, brown (*Ft. in.* 1 5); Phosphate, gray, oolitic (4); Shale, brown (1) | 23.4 | 51.2 | 2 10 |
| 98-B | Phosphate, brown, earthy material | 27.8 | 60.3 | 1 7 |
| | | | | 102 1 |

The foregoing sections are given as typical of the small part of the phosphatic section available for measurement, representing the beds most directly associated with the main bed. Undoubtedly there are other beds, ranging from those of higher-grade rock rich in phosphoric acid to those containing only a trace, which are not included in the partial sections detailed here. Complete measurements or samples can not be obtained from the customarily poor exposures at the outcrop. It may perhaps be assumed that the main bed prospected is the thickest bed and contains the most readily workable mass of high-grade material in the section. Many other sections were measured and samples tested, and a record of the results is shown in a graphic way on the general map (Pl. XI).

The syncline containing the phosphate broadens somewhat at Brazer Canyon, and opens out even to a greater extent south of that place, so that a considerable body of the Woodside shale is included along its axis. These strata consist of shaly limestones, weathering dark sepia-brown at the base of the section adjacent to the Park City rocks, and conspicuous bright-crimson and vermilion-red shale in the upper beds of this same section at the very axis of this fold. A stratigraphic interval of about 600 feet of beds overlying the Park City formation is represented on the axis of this syncline in the lower part of Brazer Canyon.

### T. 11 N., R. 7 E.

The structures carrying the phosphate beds extend into secs. 24, 25, and 36, T. 11 N., R. 7 E., as shown on Plate XI. As this part of the field is more or less remote from present shipping facilities, only shallow prospects have been dug to hold the claims, but the main bed prospected shows notable resemblance to that at the Arikaree and Mandan mines and to other sections measured between them and this end of the field.

#### T. 10 N., R. 7 E.

A considerable area of undeveloped phosphate land is situated in T. 10 N., R. 7 E. Some claims appear to have been staked in secs. 1 and 12, but so far as known the other outcrops shown on the accompanying map have not been located and it is believed that their existence has not heretofore been recognized.

The structure of the southern extension of the Crawford Mountains is essentially that of a simple anticline. On the west of this fold a remnant patch including the phosphate beds is still preserved in the NE. ¼ sec. 23. The beds are capped by the overlying cherty-limestone ledge and evidently owe their preservation to it. The outcrop of the phosphate beds that has been traced to the south end of the mountains at the eastern foot is evidently that of the east flank of the anticline, which is generally steep and in part overturned. The outcrop on the west flank is concealed in the valley bottoms if present.

No attempt was made to prospect this outcrop. Samples of float picked up at several places show the presence of high-grade material, and workable beds similar to those prospected farther north are probably present.

#### T. 9 N., R. 7 E.

The southernmost extremity of the Crawford Mountains reaches into secs. 1, 2, 11, and 12, T. 9 N., R. 7 E., and the phosphate beds have been identified as far south as the NW. ¼ NW. ¼ sec. 12. There seems little doubt that the outcrop would be continuous for a considerable distance beyond that point were it not for the erosion and alluvial fill in the Bear River valley. No examination has been made south of Bear River, and the older rocks there are believed to be masked by the cover of Eocene strata.

### AREA AND TONNAGE.

Only the most general estimates have been attempted of the area or tonnage of available phosphate in the Crawford Mountains. The area included within the outcrops of the phosphate beds north of Rex Peak is approximately 1,860 acres. Rather rough estimates of area being made for the lands in the southern half of the range, a total of about 2,800 acres, or 4.4 square miles, is given as comprising the known phosphate land of the Crawford Mountains.

The tonnage estimates given here are based on the known linear extent of the phosphate outcrop. There are, so far as known, 113,000 feet of outcrop of the phosphatic strata in the Crawford Mountains. In all parts of the area these beds probably do not pass to a depth of 2,000 feet and in places perhaps not even to 1,000 feet—as, for example, in the narrower or shallower parts of the northern syncline; but there are also places where the bed is probably available to a greater depth than 2,000 feet from the outcrop, and for the purpose of general estimates the depth of the available beds below the outcrop is assumed to be 2,000 feet. If the beds are vertical, this assumes that it is possible to mine to the depth of 2,000 feet, which is not unreasonable. Based on the foregoing premises, and considering only a single 5-foot bed of phosphate from the much larger series of beds known to exist, this estimate gives a total of 90,000,000 tons of 2,240 pounds of available rock phosphate of 70 per cent grade or over in bone phosphate for the Crawford Mountain area.

## LAKETOWN DISTRICT.

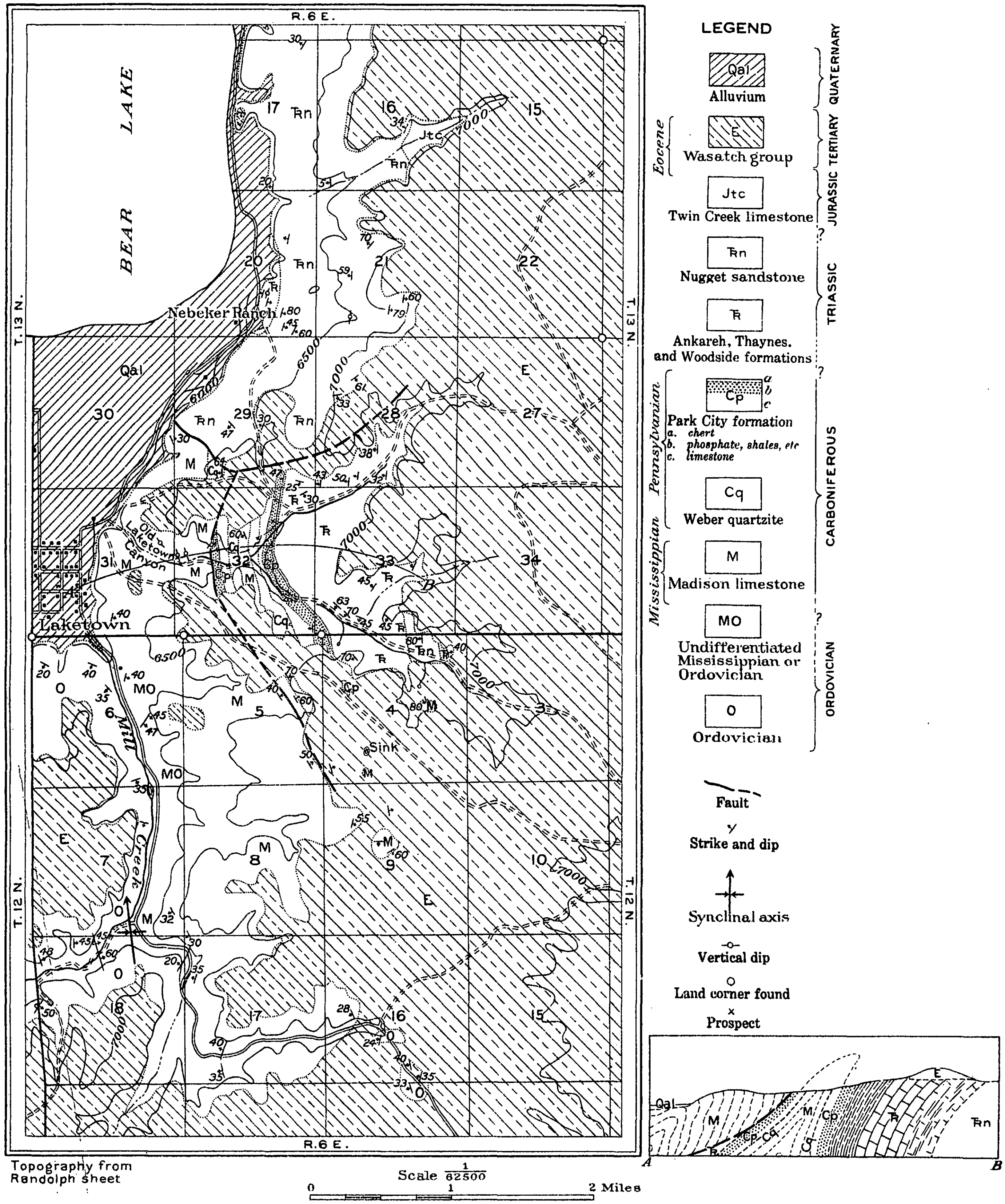
### GENERAL STATEMENT.

The Laketown area, Utah, is located at the south end of Bear Lake and the phosphate deposits occur about a mile east of the town. (See Pl. XII.) At the present time the district is without adequate transportation facilities. Sage, Wyo., the nearest shipping point, in about 20 miles distant over the Bear Lake Plateau, and the cost of hauling the phosphate rock to that station would doubtless prove prohibitive on account of heavy grades, if not on account of the distance. It is possible, however, that shipment in shallow-draft barges could be made to Montpelier or to Dingle, Idaho, by way of the lake and Bear River. Transportation by water would, of course, be possible only during the summer months. Another and possibly a better solution of the problem would be accomplished by the construction of a railway along the west shore of the lake between Laketown and Montpelier. The phosphate deposits of this area are of relatively minor extent, but contain rock of excellent grade.

### GEOLOGY.

The eastern portion of the area is thickly covered by the conglomerates, sandstones, and limestones of the Wasatch group (Eocene) These have, however, been removed in places, chiefly along drainage channels, and a complex of older rocks which range in age from Ordovician to Jurassic has been exposed.

The Laketown area is the only district in which any attempt was made to study the rocks older than the Mississippian limestones, as it afforded the most favorable opportunity to observe that part of the stratigraphic section. Cambrian quartzites, limestones, and shales occur to the west of Laketown and are extensively developed in the mountain range on the west side of Bear Lake, continuing northward




MAP AND STRUCTURE SECTION OF THE LAKETOWN PHOSPHATE AREA, UTAH

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

to Paris Peak and beyond, and southward into the Monte Cristo divide. No Cambrian rocks are known at the surface east of the Bear River Range as far as eastern Uinta County, Wyo., near Labarge Mountain. Fossiliferous Ordovician rocks composed of limestones with some quartzitic bands and including some flat-pebble limestone conglomerates supposed to be characteristic of these beds are well represented west of the main canyon south of Laketown and also in sec. 16, T. 12 N., R. 6 E., where small patches of limestone are exposed along the road. Between the localities mentioned a deep syncline probably exists, the axis of which approximately follows the lower canyon south of Laketown and is occupied by rocks of the Mississippian series. The interval between the Ordovician rocks and the definitely recognizable fossiliferous Madison limestone (Mississippian) comprises several hundred feet of alternating light-colored sandy limestones and quartzite which may prove to be Silurian and includes a heavy-bedded limestone, weathering dark or black, which may represent the black Devonian limestone of the Wasatch Mountains. In the hasty examination of these supposedly Silurian and Devonian rocks no fossils were observed.

The Weber quartzite does not outcrop conspicuously in the district, but is estimated to be represented by not more than 300 feet of strata. The Park City formation is present and shows a normal succession of siliceous limestones overlain by a series of phosphate-bearing beds, succeeded in turn by the cherty limestones, as in the typical section elsewhere described.

The phosphate-bearing rocks are exposed on both flanks of a closely compressed anticline, having a north-south axis, which crosses Old Laketown Canyon a little over a mile east of the town. The lower part of this canyon is cut in Madison and possibly also older limestones which are faulted against the Park City formation, including the phosphate beds. The fault is well shown at the Austin-Wilcox phosphate claims, where Mississippian fossils occur in the ledges that are in direct contact with the phosphate beds exposed. In passing eastward up Laketown Canyon from these claims one crosses the anticlinal axis, in which Madison limestone and some calcareous Weber quartzite are exposed, and finds on the east flank of that structure the principal or more valuable outcrop of the phosphate beds. In this flank the beds are all overturned to the east, so that the strata are in inverted order, with westerly dips. East of the Park City strata are the younger formations—Woodside, Thaynes, and Ankareh—and the Nugget is extensively developed on the higher ridges. Owing to the overturned structure, the phosphate probably reaches inaccessible depths east of the outcrop. Eastward or normal dips are resumed in the surface strata in the NE. ¼ sec. 4, T. 12 N., R. 6 E.

The Woodside shale, Thaynes limestone, and Ankareh shale occur in the area and are mapped for the purposes of the present report as undifferentiated Triassic.

The Nugget sandstone outcrops in the series of rugged hills along the east side of Bear Lake and is conspicuous because of its reddish coloring. However, although this formation is composed mainly of reddish sandstones, it contains some uncolored sandstones in its upper portion.

The only outcrop of the Twin Creek limestone seen in the area is in sec. 16, but undoubtedly considerable areas of these Jurassic beds are concealed by the Tertiary cover in secs. 22, 27, and 34, T. 13 N., and probably in sec. 3, T. 12 N.

The Tertiary deposits are made up of the typical red iron-stained conglomerates, sandstones, and buff and white limestones of concretionary texture, which range from finely oolitic to coarse nodular. In places these concretionary limestones were seen to grade into and include limestone conglomerates in a manner which strongly suggests that they are of littoral origin.

The alluvial deposits consist of soils and gravels which have been derived from the areas drained by the canyons that open toward the lake and reworked along the lake shores.

The geologic structures revealing the phosphate beds in Old Laketown Canyon are terminated to the north by an east-west fault zone. This is presumably identified as a distinct fault in the ridges south of the Aquila Nebeker ranch, where the red Nugget sandstone is offset into contact with older Paleozoic limestones near the middle of the west side of sec. 29, T. 13 N., R. 6 E. North of this transverse fault zone the rocks exposed are the Twin Creek and Nugget formations, which are folded in a complex traceable northward into the Hot Springs area, near the north end of the lake. The upper limestones of the Thaynes and the mottled maroon and greenish shaly strata of the Ankareh outcrop in the crest of an anticlinal fold just east of the dwelling on the Nebeker ranch. The phosphate beds are probably about 3,000 feet deep at that place, but they dip to greater depths on both the east and the west of the anticlinal axis.

## PHOSPHATE BEDS AND ASSOCIATED STRATA.

East of the overthrust Mississippian limestone in Old Laketown Canyon the Park City formation outcrops on both flanks of the compressed and overturned anticline described above. The western exposure is but partial, however, on account of the shearing produced by the overthrust, and the eastern outcrop shows a section which would be easily recognized as typical after study of the several sections illustrated on Plate IV. The cherty limestone, here comprising the upper 80 to 100 feet of the formation, weathers into bright-yellow splintery fragments.

Little prospecting has been done in the phosphate beds of this district. The only area recognized prior to 1909 was the small patch of much crushed phosphate on the western outcrop in direct contact with overthrust Mississippian limestone. Two shallow pits had been opened in the SE. ¼ NW. ¼ sec. 32. It was locally reported that these openings when made (1907) showed a 2-foot bed of high-grade phosphate rock averaging 36.6 per cent of $P_2O_5$, or 80 per cent of $Ca_3(PO_4)_2$, and 40 feet of material averaging 13.7 per cent of $P_2O_5$, or 30 per cent of $Ca_3(PO_4)_2$. A sample taken represented a 9-inch face of the richest-appearing material lying next to the fault. This sample doubtless does not represent the full thickness of the original bed, but when analyzed was found to contain 31.8 per cent of $P_2O_5$, or 69.6 per cent of $Ca_3(PO_4)_2$. The other prospect is in the underlying dark-colored thin-bedded shales, whose phosphatic content can be assumed with a fair degree of certainty to fall between 30 and 50 per cent of $Ca_3(PO_4)_2$.

The existence of the phosphatic shales farther up the canyon and on the eastern flank of the anticline was discovered by the Geological Survey party, and float phosphate rock collected from the surface was found to contain 34.3 per cent of $P_2O_5$, or 75.4 per cent of $Ca_3(PO_4)_2$. The location of a bed of high-grade rock which was regarded as the principal bed was determined and the outcrop trenched and sampled as follows:

*Section of phosphate rock in sec. 32, T. 13 N., R. 6 E.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. |
|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft. in.* |
| 134-A | Cherty limestone, phosphate rock, gray, coarse to medium, oolitic. | 36.3 | 79.5 | 1 5 |
| | Shale, brown | | | 4 |
| 134-B | Phosphate rock, gray, coarse, oolitic, friable | 37.3 | 81.7 | 5 |
| 134-C | Phosphate rock, gray, fine, oolitic | 26.4 | 57.0 | 5 |
| 134-D | Phosphate rock, gray, coarse, oolitic, weathers into flat concretions up to 1 inch in diameter | 36.7 | 80.4 | 6 |
| 134-E | Phosphate rock, fine grained, oolitic, weathered | 26.0 | 56.5 | 8 |
| 134-F | Phosphate rock, gray, fine to medium, oolitic | 34.1 | 74.7 | 2 10 |
| | | | | 6 7 |

The total thickness of phosphate rock represented in this section, exclusive of the unsampled 4-inch parting at the top, is 6 feet 3 inches, and the average phosphate content is about 33 per cent of $P_2O_5$, or 73 per cent of $Ca_3(PO_4)_2$. The presence of soil introduced into the many minute joints in the phosphate rock has probably caused the results to fall below the normal amounts that would be obtained in samples taken farther in on the bed. The quality of this phosphate rock compares well with that of the rock seen in the main beds of the other districts and is up to the standard of ore considered minable by the phosphate companies operating in the western fields at the present time. The presence of other beds of high-grade phosphate rock and the amount or character of the low-grade material have not been determined. It is suspected that a complete section of the beds would correspond closely with that part of the section measured and sampled at Hot Springs, Idaho (p. 497) and in general would be comparable with the section of the entire series of phosphate beds represented on Plate IV.

### AREA AND TONNAGE.

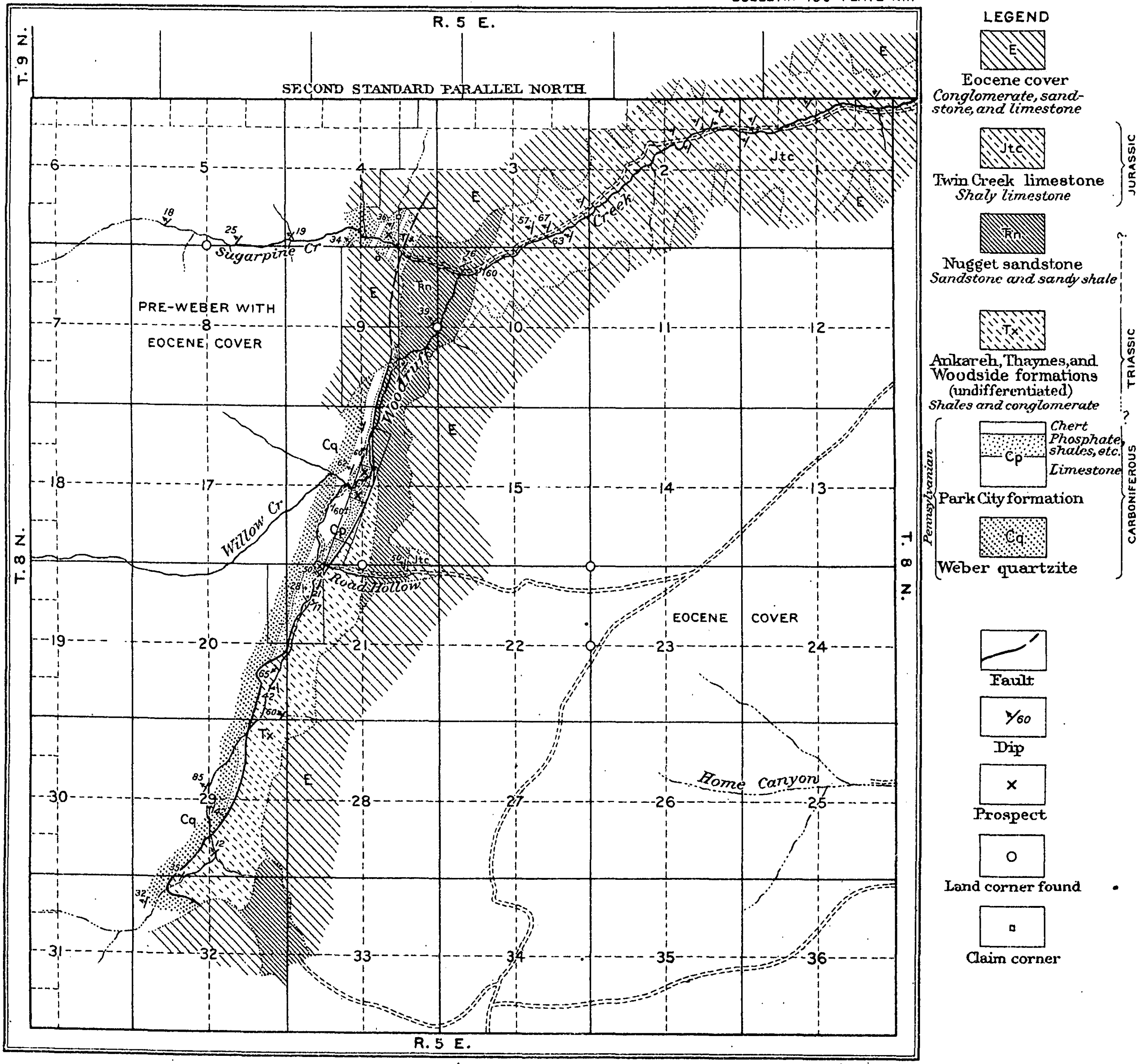
In computing the area and tonnage of all rock present in the high-grade bed the outcrop on the eastern flank of the anticline is alone considered, the western outcrop being rejected because of doubt as to its presence or value beyond the meager exposures in Old Laketown Canyon. The length of the eastern outcrop exposed between the boundaries of the Tertiary cover on the north and south flanks of the canyon is about 1.3 miles, or approximately 7,000 feet. A depth along the bed of 2,000 feet is assumed to be minable. On the basis of a 6-foot bed the estimate obtained is, in round numbers, 6,750,000 tons of 2,240 pounds for the Laketown area. This figure must be regarded as conservative, but no data exist from which a satisfactory conclusion can be obtained as to the amount of the phosphatic values contained in the remainder of the section. It is fairly certain, however, that the main body of phosphatic shales will, as in the other areas, in time prove of at least equivalent value to that of the content of the bed discussed above, especially if the agricultural use of 40 to 60 per cent raw phosphate shall become general.

However, under present conditions of transportation the Laketown deposits must be considered as a reserve rather than as deposits in which developments are to be expected in the near future.

## WOODRUFF CREEK AREA, UTAH.

### LOCATION AND DEVELOPMENT.

The phosphate deposits usually referred to as the Woodruff Creek area are situated on Woodruff, or Twelvemile Creek and on a fork of the latter known as Sugar Pine Creek, in Rich County, Utah. (See Pl. XIII.) The developments are about 14 miles, in a direction somewhat south of west from the town of Woodruff. The openings on the phosphate beds are limited to a few pits and drifts, all of which were badly caved at the time of the present examination. The Woodruff Creek area compares rather unfavorably with most of the other districts described in this report, especially in two respects—transportation facilities and the geologic conditions affecting that part of the Park City formation which carries the phosphate. A




Scale $\frac{1}{62500}$

0 ½ 1 2 Miles

GEOLOGIC MAP OF PHOSPHATE DEPOSITS NEAR WOODRUFF, UTAH wagon road has been constructed by the San Francisco Chemical Company as part of the assessment work incident to holding the phosphate claims. The development work on the claims themselves appears to have been perfunctory, with the idea of meeting the requirements of the mining law rather than of proving the extent and character of the deposits. Water grades down Woodruff Creek and thence following the Bear River valley offer feasible railroad routes, should it become desirable to reach this property in that way.

### GENERAL GEOLOGY.

The outcrops of the rocks immediately related to the phosphate deposits are limited to the bottoms of the deep canyons which have been cut by Woodruff or Twelvemile and Sugar Pine creeks through the Eocene cover, comprising at least 1,000 feet of the overlapping limestones and conglomerates of the Wasatch group. The general structure of the whole area is that of a completely overturned sequence, from the older Paleozoic rocks to the Jurassic. The area is presumably at the eastern margin of the major anticline of the Monte Cristo divide. The whole attitude of the rocks is expressive of a strong compressive force originating west of this area and acting toward the east; it is in conformity with and is probably a direct continuation of the similar structure on the west shore of Bear Lake and north of that region. The Woodruff Creek area is also regarded as the west flank of a recumbent syncline having a nearly northeast axis which may be recognized in the section on Woodruff Creek below the phosphate outcrops.

These rocks are faulted by overthrusts from the west. A fault zone may be traced from north to south, evidently developed throughout chiefly along the weaker shaly members of the Park City and Woodside formations. On Sugar Pine Creek the combined Woodside, Thaynes, and Ankareh formations appear abnormally thin, owing to the telescoping action of the fault zone included at this place within their boundaries. Definite evidence of the existence of the fault is seen immediately above that part of Twelvemile Canyon lying in the Nugget sandstone, where the phosphate-bearing shales of the Park City formation are found close to the Nugget. In secs. 21 and 28, T. 8 N., R. 5 E., the phosphatic shales lie in contact with the Woodside shale, the normally interstratified *Productus*-bearing cherty limestone characteristic of the upper portion of the Park City formation being absent. The Weber quartzite in secs. 20 and 29 was observed in contact with beds supposed to belong to the Lower Triassic. The existence of the fault zone is further indicated by observed minor faults, mashing, brecciation, and slickensides in various places along Twelvemile Creek in secs 16, 20, 21, and 29, and south of the mouth of Road Hollow slumping and readjustment are indicated by the disturbed condition of the phosphate shales.

The existence of a fault zone of this kind and magnitude has a marked economic bearing on the value of the phosphate deposits of this area, as it serves both to reduce the amount of available phosphate and to render difficult the mining of that portion of the deposits which may possibly be regarded as available.

## PHOSPHATE AND ASSOCIATED ROCK STRATA.

The Park City formation is best exposed in this district in sec. 4, T. 8 N., R. 5 E., and so far as noted shows nearly the normal succession of beds as found elsewhere. It is limited at its base by a series of sandy limestones and at its top by the cherty limestones bearing *Productus* and *Spiriferina*. West of the outcrop of the Weber quartzite the rocks noted are composed of quartzites and metamorphosed conglomerates of probably pre-Weber age. Their age or relation to the Weber quartzite were not determined. Rocks of Carboniferous age are not known to outcrop in the township other than as shown on the accompanying map (Pl. XIII). The overlying formations, except where faulted, are thought to be present in nearly normal sequence.

The prospect in the SW. ¼ SE. ¼ sec. 4, on the Colbert placer claim, was caved and no measurements were obtained at the time of this examination. It is reported that the bed exposed in this opening measured 5 feet and was composed of high-grade phosphate rock. A 5-foot bed of similar quality is also said to have been exposed in an open cut found by the present survey to be in the northwest corner of the Seymour placer claim, or the SE. ¼ SE. ¼ sec. 4.

The prospects in secs. 16 and 21 were also so badly caved that it was impossible to obtain satisfactory measurements of the phosphate rock or to collect representative samples for analysis. A sample was taken from an old entry in the SW. ¼ SE. ¼ sec. 16, representing 2 feet of brownish-black shale which contained 12.2 per cent of $P_2O_5$, equivalent to 26.5 per cent of $Ca_3(PO_4)_2$. Brown oolitic phosphate rock collected at random from the dump of a caved prospect in the NE. ¼ SW. ¼ sec. 16 yielded better results—23.7 per cent of phosphoric acid, equivalent to 51.9 per cent of bone phosphate. A trench in the SE. ¼ SW. ¼ sec. 16 showed about a 5-foot face of rather coarsely oolitic material which has been reported to contain from 30 to 32 per cent of $P_2O_5$, which is equivalent to 65.5 to 69.9 per cent of $Ca_3(PO_4)_2$.

A caved tunnel and a stripping in the NW. ¼ NW. ¼ sec. 21 exposed somewhat less than 60 feet of the phosphate series. An analysis of a selected sample taken from the outcrop at this point contained only 15.2 per cent of $P_2O_5$, or 33.3 per cent of $Ca_3(PO_4)_2$.

### AREA AND TONNAGE.

The area underlain by phosphate in this district can be determined only by extensive and presumably costly prospecting. At present no basis exists for a satisfactory estimate of the tonnage. It is doubtful, however, if thorough prospecting will be considered warranted under the present conditions of accessibility and uncertain value of the deposits. It seems that the Woodruff area, although, as reported, one of the first discovered, will probably be among the last to undergo extensive economic development.

## SUMMARY.

### TONNAGE OF THE AREAS EXAMINED.

As has been stated, the districts now recognized as containing phosphate deposits of commercial availability have been by no means completely reviewed in the foregoing detailed consideration, for this report is of preliminary character and covers only the results of the last season's field work. The estimates of area and tonnage given are, of course, approximate at best, but they are derived from the most complete data available at the present time. Emphasis should be placed on the fact that all these estimates are based to a considerable extent on arbitrary assumptions, all of which, however, are carefully explained in the text accompanying the statements. All the estimates made are intended to be amply conservative.

Of the assumptions on which the tonnage estimates are based, the most arbitrary and probably the most deficient in expressing a just estimate of the field is that which takes into account only a single 5 to 6 foot bed of phosphate rock as workable and available throughout the known extent of these areas. The review of the detailed sections shows how vastly greater than the result so obtained the actual total phosphoric acid content of these rocks must be. At the present time, however, only rock equivalent on the average to 70 per cent or more of tricalcium phosphate is considered shipping ore, and of this material there is usually to be found in a single section only one bed that attains a thickness of 5 feet or more. For this reason any particular locality usually has what is referred to as its "main bed." A glance at the generalized columnar sections given in Plate IV shows that in fact high-grade rock phosphate occurs in at least two major horizons in the phosphatic section, of which the "main bed" appears to be an upper or a lower member, according to minor local variations. An attempt to compute accurately the vast tonnage of intermediate and low-grade phosphatic material involves numerous additional arbitrary assumptions, several of which would at present be based on evidence so insufficient or incomplete as to make them of little value.

The figures presented are thus chiefly of value as expressing a minimum and, with little doubt, an exceedingly conservative estimate and for comparison among the various areas they are repeated in summary form below. It should be distinctly understood that they represent but part of the entire field:

*Tonnage estimates of phosphate rock available in the various areas reviewed in this report.*

| | Long tons. |
|---|---|
| Georgetown area | 90,000,000 |
| Montpelier-Bennington area | 16,000,000 |
| Hot Springs-Dingle area | 27,000,000 |
| Sublette Mountain area | 32,000,000 |
| Cokeville area | 2,400,000 |
| Beckwith Hills area | 2,800,000 |
| Crawford Mountain area | 90,000,000 |
| Laketown area | 6,750,000 |
| Woodruff Creek area (not estimated). | |
| | 266,950,000 |

## RELATIONS OF THE OGDEN AND WEBER RIVER AREAS.

The report on the examination of the phosphate deposits east of Ogden, Utah, by Eliot Blackwelder forms the succeeding paper in this volume. Comparison with the results of that work seems to indicate that the rock-phosphate deposits decrease in thickness and relative value or richness in phosphoric acid toward the south. Analyses of rock from the localities near Salt Lake City, south of the Ogden and Weber River areas, though they may not be representative of the best material and do not give any indication of the amount of ore available, seem to show a relatively lower content of phosphoric acid in that general direction. Reports from these localities persistently state that even the better beds are relatively thin where found, 12 to 24 inches being the usual thickness given. From the sections detailed in the report on the Ogden and Weber areas, there appears to be at one locality a 13-foot bed showing an average content of phosphoric acid equivalent to 46.1 per cent of tricalcium phosphate, and the report also refers to beds exposed at other localities which average from 39 to 62 per cent of tricalcium phosphate. Of the analyses obtained only those of residual fragments or "float" have shown a composition comparable with that of the better material of the larger fields to the north.

## SIGNIFICANCE OF WORK DONE AS TO TOTAL EXTENT OF DEPOSITS.

The continuity of the deposits within the area already examined is a good indication that these beds originated under conditions of great uniformity and wide extent, both in manner of deposition and in the character of the material brought in to make up the strata. Continuity of the rock formations with which the phosphate is identified throughout the area of lands withdrawn in the phosphate reserve (see fig. 41) is well established in a general way. The actual commercial availability of phosphate deposits beyond the areas now known can be determined only by examination and study. Such scattering evidence bearing on this subject as has been brought together seems to indicate the great probability that the deposits are at least as extensive as the first predictions implied, and it is well within the limits of possibilty that these western fields may prove to be as extensive as any of the other known fields of the world.

## AVAILABILITY OF LOW-GRADE PHOSPHATES.

In the tonnage summaries of the several districts brief references have been made to the possibilities of future use of the low-grade phosphate-bearing rocks, and a statement in review of the entire field may serve to emphasize the importance of this phase of the subject. Throughout the areas covered by the present tonnage estimates of high-grade rock, the phosphatic portion of the Park City formation contains in addition at least 40 feet of phosphatic shales, averaging perhaps 18 per cent of $P_2O_5$, equivalent to about 40 per cent of $Ca_3(PO_4)_2$, or, in round numbers, 2,000,000,000 tons of low-grade rock. The problem of utilizing such material, in either a raw or a mixed state, is one of importance, with regard not only to the deposits here discussed, but also to those in certain of the eastern fields—notably Florida, where large quantities of low-grade and even some high-grade rock are discarded at present. The phosphatic shales of the western fields can be cheaply mined and cheaply ground and apparently in their natural condition contain organic substances which, when subjected to soil-weathering conditions, tend to gradually render their phosphoric acid content available either as a plant food, as a neutralizer of soil toxins, or otherwise. Experimental and practical applications of ground phosphate (phosphate meal or floats) are reported to be successful to a certain extent in this country and also in France and Russia. Furthermore, the exponents of this system of soil treatment maintain that it is free of the evils attendant on the use of superphosphates—namely, a tendency toward excessive acidity and the accumulation of harmful or injurious sulphates. The question is raised whether the future treatment of the soils of this country as a whole, or at least in part, may not lie in the direction of utilizing the natural phosphates rather than in the sole use of the high-grade material in the form of superphosphates.

## NEED OF REVISION IN THE MINING LAW AS APPLIED TO PHOSPHATE LANDS.

*Provisions in mining law for method of locating phosphate claims.*—When the existence of valuable deposits of rock phosphate in the public lands in Idaho, Utah, and Wyoming was discovered about five years ago, an interesting question in the application of the American mining law was brought forward. In the establishment of the mining law and its subsequent enactments and provisos and the development of regulations thereunder the subject of rock-phosphate deposits had never been specifically taken into consideration. Prior to the granting of the first patent as placer land in the Idaho phosphate fields all entries for lands embracing phosphate deposits had related to placer locations. Phosphate deposits of a true placer type exist and form a most valuable part of the Florida and South Carolina fields, but the rock-phosphate deposits of Idaho, Utah, and Wyoming are undoubtedly more properly analogous to coal than to either of the types of mineral deposits specified in the other mining laws. When the western phosphate deposits were discovered and the lands came to be staked and claimed in mineral locations, no recognized precedent had been established as to the proper form of entry upon such lands.

*Character of western phosphate deposits.*—A study of the phosphate beds of the Idaho, Utah, and Wyoming fields, and of the relation of the ores to the series of stratified rocks within which they are interbedded, shows them to be original sedimentary deposits. The phosphate rocks are part of the great series of sedimentary strata, deposited under water at a time when this region was largely submerged. Since the deposition of these beds other deposits have accumulated in a similar manner to a thickness of many thousands of feet, and deformation of the earth's crust has folded and broken the originally flat-lying strata. Thus the rock-phosphate ores are far more similar in the manner of their occurrence and origin to such deposits as coal, sandstone, and limestone, and especially to the Clinton iron ores of the Appalachian region, than they are to the ore deposits formed in veins, lodes, shoots, or to alluvial deposits of the placer type.

*Mineral claims as defined by law.*—Except for coal lands, mining claims as defined by the laws may be of two classes—placer and lode claims. A lode claim as prescribed is a parallelogram 1,500 feet in length along the course of the mineral vein or lode and of a width not to exceed 300 feet on either side of the vein or lode at the surface. No strict definition of the terms "vein" or "lode" is given, but one is implied (sections 2320 and 2329, Rev. Stat.) where deposits of this class are referred to as "bearing gold, silver, cinnabar, lead, tin, copper, or other valuable deposits," and placers as "including all forms of deposit, excepting veins of quartz or other rock in place." The placer law provides for the sale of not more than 20 acres of land to any individual, but fixes the price at $2.50 an acre, which is half that of the lode claim. The privileges acquired in a lode claim include, however, what are known as extralateral rights. Other requirements for acquirement of title to the land are essentially equivalent in the two forms of entry.

Since the establishment of the lode and placer laws, and aside from that relating to coal lands, separate enactments of Congress have authorized the application of the provisions of the placer-mining law, first to lands chiefly valuable for building stone and later to lands containing petroleum or other mineral oils and chiefly valuable therefor. Still a third enactment has extended the placer form of entry to deposits of salt in any form. Thus exception to the definition of a lode deposit as necessarily "rock in place" is officially recognized.

*Western phosphate deposits not strictly of lode or placer type.*—Owing to the precedent that had been established from the first placer locations that had been granted in Florida, it was at first assumed that phosphate lands in Idaho should also be located under the placer proviso of the mining laws. In both the legal and the geologic meaning of the term, the Idaho rock-phosphate deposits are certainly "rock in place." They are analogous to most sedimentary building-stone deposits in the manner of their formation, but like coal they are also bodies of valuable mineral inclosed between walls. According to the scientific or geologic definitions, these deposits are not properly lodes or veins. In any sense, however, the western phosphate deposits do not conform to the placer type, and unless by specific act of Congress it appears that there is so far no sufficient warrant for their location under the placer law.

Court decisions have not always upheld the strict or scientific definition of the term "vein" (or lode used in the same sense as vein), and there is, therefore, reasonable doubt as to the applicability or nonapplicability of that term in its legal sense to these phosphate deposits. Undoubtedly they are not veins or fissure fillings according to the accepted mineralogical or geologic definitions. The so-called popular mining use of the terms vein and lode very probably originated in large part through necessities arising from the inapplicability of the mining law. Loose interpretation has been forced in the effort to stretch the provisos of the law to cover conditions not provided for. Certain legal authorities—perhaps a majority—may be quoted as entirely in favor of a loose popular interpretation of the term "lode," so that bedded sedimentary rocks would also fall within that class.[a] However justified this may be for the present status under the law, or however well substantiated in court decisions, the fact remains that it is incongruous and illogical and points to the need for special consideration by Congress.

[a] Lindley, C. H., A treatise on the American law relating to mines and mineral lands, 2d ed., vol. 1, 1903 (footnote under 290a), p. 510, and other references.

*Titles granted in western phosphate fields.*—Title has passed in two cases in the western phosphate lands—the Waterloo claim at Montpelier, Idaho, and the Bradley group of claims in the Crawford Mountains, Utah. The Waterloo patent was granted as a placer and the Bradley claims were later allowed to patent as lodes. As previously stated, prior to the granting of the Waterloo patent all entries for phosphate lands were made in the Florida field and presumably covered deposits of the true placer type, and it appears that the distinction between those deposits and the phosphate beds of western fields was perhaps not clearly brought out at that time. Under a strict interpretation of the present law, with a recognition of the true character of the western deposits, it may be held in the courts that they must be considered as covered by the lode law. It is to be hoped, however, that further patents in these western fields may be withheld until an equitable adjustment of the existing difficulties can be provided.

*Extralateral rights.*—The most serious objection to the application of the lode law to the western rock phosphate fields is the interpretation thereby placed on the so-called extralateral rights. A recognition of the inapplicability of this proviso in the case of coal lands was early brought out by the necessity for providing for their disposition. On account of the bedded character of the phosphate deposits and the great uniformity of the beds throughout wide areas, in the strata with which they occur, there is not the uncertainty as to their continuity in depth that prevails with respect to typical mineral lodes or veins in the stricter definition of the terms. Under the application of this proviso of the law title would be granted not only to the outcrop of the phosphate but also to the beds in depth as far as they continue to dip, even if the dip is but very slight. This would enable the locator of a single lode to extend his extralateral rights for long distances, even for a number of miles in regions where the rocks continue to dip for that distance. It is perfectly obvious that such methods of disposition can not be contemplated as a proper administration of the public lands.

*Injustice of present law to individuals and communities.*—The possibility for contest and legal controversy over the form in which original locations had been made in the phosphate fields was early recognized. Most of the first entries were made as placer claims; many of the original placer claims were later relocated as lodes, as a rule by other persons than the first holders. This relocation is said to have been done surreptitiously, so that it constituted in effect claim "jumping." Original locators had proceeded in apparent good faith to survey, develop, and improve the property to which they were seemingly entitled. The opportunity for contest and litigation has been seized, and almost invariably double locations are now made along the outcrops in the most accessible parts of the fields, double assessment work is done, and other unwarranted expenses are being incurred. Aside from the injustice to the individuals concerned, this procedure is an economic waste, to be ultimately paid for by the consumer and the general public. The burden thus imposed on the development of the phosphate lands is in direct contradiction of the policy of encouragement of mining industries, is an obvious hindrance to the honorable exploitation of these valuable deposits, and by reaction on the community constitutes a general repression of the possible industrial advancement.

*Assessment work unnecessary and wasteful.*—Whatever the advantage of the proviso in the law requiring annual improvement or assessment work on both placer and lode claims, existing conditions observed in the phosphate fields indicate that such work is certainly unnecessary and wasteful as applied to phosphate lands. A moderate amount of development is usually necessary to fully reveal the character, value, or extent of the deposit on any claim, but the requirement of an annual expenditure of $100 on each claim, or its equivalent for a group of claims, is, in almost every case where actual commercial operation of the property is not commenced, exorbitant and wasteful, both in itself and in its practical application.

*Present status of phosphate lands.*—At the present time all public lands known or supposed on good evidence to contain valuable phosphate deposits are withdrawn, by an order of the Secretary of the Interior, from all forms of entry under the public-land laws. These withdrawals are only temporary, as they are intended to prevent further entanglements and to preserve the present status of the lands until appropriate action shall be taken by Congress.

# PHOSPHATE DEPOSITS EAST OF OGDEN, UTAH.

By Eliot Blackwelder.

## INTRODUCTION.

The most important known deposits of lime phosphate still belonging to the Government are scattered through northern Utah, southeastern Idaho, and southwestern Wyoming. This field was reconnoitered several years ago by F. B. Weeks,[a] who visited the previously known localities. In 1909 the larger part of the field was surveyed by a party in charge of Hoyt S. Gale, whose report appears elsewhere in this volume, and the deposits in a relatively small area in the Wasatch Mountains east of Ogden, Utah, were investigated by the present writer, assisted by J. M. Jessup and M. A. Becher.

## GEOGRAPHY.

The phosphate deposits here considered are situated in Weber and Morgan counties, Utah, in the drainage basins of Weber and Ogden rivers. (See fig. 44.) Topographically the district includes two ranges of mountains imperfectly separated by a chain of intermontane basins. The western range is the one usually called the Wasatch Mountains. That on the east is the southward extension of the Bear River Range or Plateau. The western range is considerably higher, narrower, and more rugged than the eastern range, which is plateau-like, but deeply dissected by canyons. The Morgan and Huntsville basins, between the ranges, are broad and flat-bottomed and are thoroughly cultivated.

The hilly and mountainous parts of the district were once forested but are now largely denuded of timber. They are, however, well covered with tough oak brush on the higher slopes and sage on the lower slopes. The two rivers and their principal branches are permanent streams, but many of the smaller canyons are dry most of the year. Wherever there is soil and water for irrigation the land is under cultivation. The mountains are used as range for bands of sheep, which keep the grass and flowers closely cropped.

[a] Bull. U. S. Geol. Survey No. 315, 1907, pp. 449–462; No. 340, 1908, pp. 441–447.

The Union Pacific Railroad crosses the district from east to west, and several railroads run north and south along the west base of the Wasatch Range. Good wagon roads lead into the Huntsville and Morgan basins, but in the mountains roads worthy the name are scarce, and many of the canyons are quite impassable for vehicles.

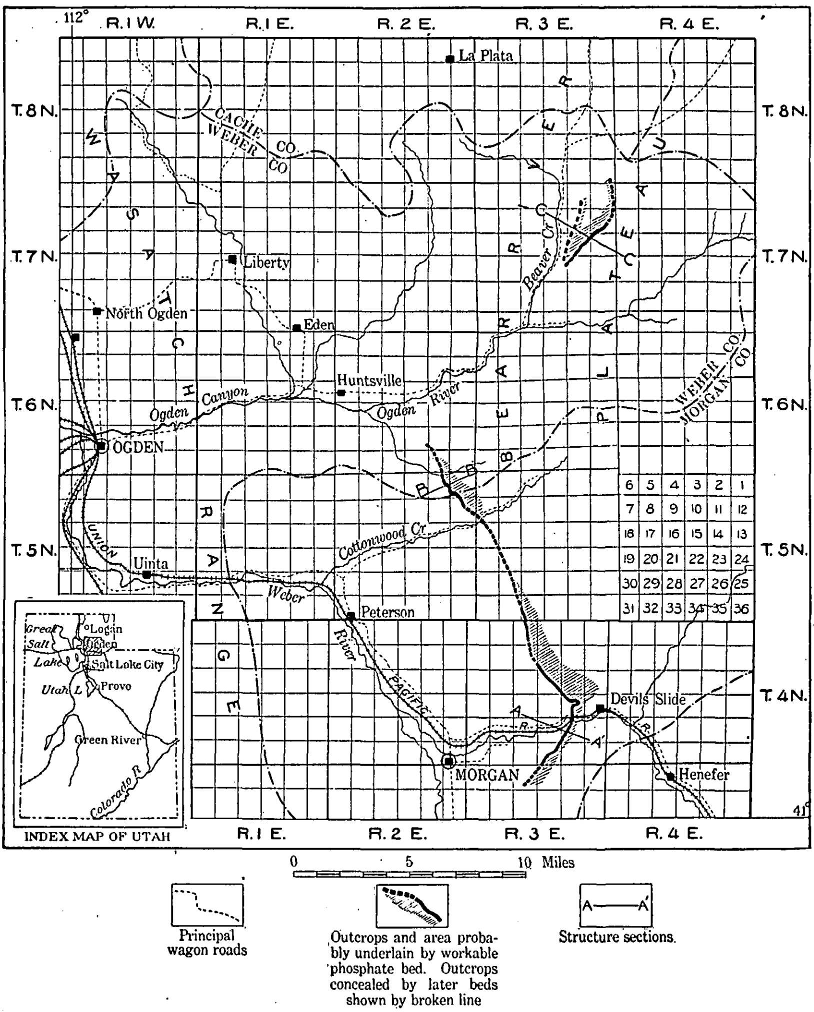



FIGURE 44.—Map showing distribution of phosphate deposits near Ogden, Utah. By Eliot Blackwelder.

## GENERAL GEOLOGY.

### PREVIOUS REPORTS.

The geology of this district is described in the reports of the Hayden Survey and the Fortieth Parallel Survey of the sixties and seventies. Since that time only papers on special subjects, most of them brief, have been published. A list of the more important of these papers follows:

ATWOOD, W. W., Glaciation in the Uinta and Wasatch mountains: Prof. Paper U. S. Geol. Survey No. 61, 1909.

BOUTWELL, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, 1907, pp. 434–458.

DAVIS, W. M., Mountain ranges of the Great Basin: Bull. Mus. Comp. Zool. Harvard Coll., vol. 42, 1903, pp. 128–177.

GILBERT, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890.

KINDLE, E. M., Occurrence of the Silurian fauna in North America: Am. Jour. Sci., 4th ser., vol. 25, 1908, pp. 125–129.

——— Fauna and stratigraphy of the Jefferson limestone: Bull. Am. Paleontology, Ithaca, N. Y., No. 20, 1908.

WALCOTT, C. D., Cambrian faunas of North America: Bull. U. S. Geol. Survey No. 30, 1886.

——— Cambrian sections of the Cordilleran area: Smithsonian Inst., Misc. Coll., vol. 53, 1908, pp. 167–230.

WEEKS, F. B., Phosphate deposits in the western United States: Bull. U. S. Geol. Survey No. 340, 1907, pp. 441–447.

WEEKS, F. B., and FERRIER, W. F., Phosphate deposits in western United States: Bull. U. S. Geol. Survey No. 315, 1906, pp. 449–462.

## FORMATIONS.

The rocks in the Ogden district range in age from Archean to Quaternary. The principal formations are given in the section which follows. This is based partly on the earlier surveys, but chiefly on the later studies above mentioned and the writer's work of the past season.

*Generalized section of rocks in the Ogden region, Utah.*

| | Feet. |
|---|---|
| Quaternary: Lake Bonneville beds and alluvium | ? |
| Unconformity. | |
| Tertiary and Quaternary: High-level gravels | ? |
| Unconformity. | |
| Tertiary (lower Eocene): Wasatch formation (tuffaceous conglomerate, sandstone, shale, and fresh-water limestone) | 0–3,000 |
| Unconformity (Cretaceous rocks occur just east of this district). | |
| Jurassic and Triassic strata (not studied in connection with the work on the phosphate deposits) | 8,000–11,000 |
| Triassic or Carboniferous (Permian): | |
| Ankareh shale | 1,500 |
| Thaynes limestone | 1,200 |
| Woodside shale | 1,200 |
| Carboniferous: | |
| Pennsylvanian— | |
| Park City formation (limestone, shale, and phosphate rock) | 500–1,600 |

| | Feet. |
|---|---|
| Carboniferous—Continued. | |
| Pennsylvanian—Continued. | |
| Unconformity. | |
| Weber quartzite | 0–4,000 |
| Red beds | 0–1,000 |
| Unconformity. | |
| Mississippian: "Wasatch limestone" of King, in part (consists of upper fossiliferous black limestone, middle reddish and buff shale, and lower gray dolomites devoid of fossils) | 4,000–5,000 |
| Devonian: Jefferson limestone | 500–1,000 |
| Silurian limestone | 100–400 |
| Ordovician limestone, with local shale and quartzite | 500–2,000 |
| Cambrian, chiefly limestone, with beds of shale and a basal quartzite; divided by Walcott into eight formations | 1,847–6,600 |
| Unconformity. | |
| Algonkian (?): "Cambrian quartzite" of King (alternating quartzite, graywacke, and slate) | 10,000–12,000 |
| Unconformity (?), not observed. | |
| Archean, complex of schist, gneiss, etc. | |

The formations of chief importance in connection with the phosphate investigations are those of Triassic (?) and Carboniferous age, including the Mississippian, Pennsylvanian, and Permian (?).

## CARBONIFEROUS SYSTEM.

### MISSISSIPPIAN SERIES.

In this district the Mississippian series is readily divisible into three formations. At the base, intergrading with limestone probably of Devonian age, are brittle gray dolomites with thin beds of drab shale. They have furnished no fossils, and their age is estimated from their stratigraphic position. Separated from the dolomites by an obscure and probably unimportant unconformity is a shaly formation about 250 feet thick. This comprises shales, shaly limestone, thin-bedded dolomite, and soft sandstone, in which the prevailing colors are red, pink, buff, and ash-gray. Many of the strata have sun cracks, but fossils are rare or altogether lacking. The shaly formation grades upward into dark-gray and black limestones which are alternately thick and thin bedded. In these limestones middle Mississippian fossils are generally abundant. In the northern part of the district the fossiliferous limestones are succeeded by 1,000 to 2,000 feet of shales, thin-bedded limestone, chert, and sandstone containing fossils provisionally referred by Girty to the late Mississippian (Kaskaskia) horizon of the Central States. At the base of this shaly succession there is a lean phosphatic zone which appears to be of little value within this district, but may prove to be worth prospecting elsewhere.

## PENNSYLVANIAN SERIES.

### WEBER QUARTZITE AND UNDERLYING RED BEDS.

In the southern part of the district the Mississippian limestone and the Park City phosphatic beds are separated by the thick Weber quartzite, and the underlying red beds. At the type locality in Weber canyon the quartzite is said to be 5,000 to 6,000 feet thick, but it thins toward the north and entirely disappears within 8 miles, so that farther north the Park City formation is everywhere directly in contact with the Mississippian strata. At the base of the Weber quartzite and intergrading with it, there are red beds consisting of brick-red sandstone with some sandy shale and thin beds of cherty gray limestone. The limestones have yielded a few fossils that are closely related to those in the lower part of the Weber quartzite, and are considered by Girty to be of Pennsylvanian age. The red beds are separated from the underlying limestone by a distinct unconformity, but the testimony of the fossils seems to indicate that the interruption of deposition was brief. The Weber quartzite proper consists of creamy-white quartzite or hard sandstone interbedded, particularly in the lower part, with cherty dolomites of dark gray to black color. A characteristic of the upper beds of the quartzite is a coarse pitting of the surface which is probably due to the leaching out of calcite unevenly distributed through the formation.

### PARK CITY FORMATION.

The Park City formation contains the only workable deposits of phosphate rock at present known in this district. It consists largely of black cherty limestone with beds of shale and phosphate rock. The base is generally marked by white and pink beds of soft sandstone, separated from the Weber quartzite by an obscure unconformity which appears nevertheless to be one of considerable importance. A conspicuous and persistent member of black or gray cherty limestone follows the sandstone, and upon this lie the alternating beds of shale, limestone, and phosphate rock which contain the workable deposits. The upper part of the formation consists of lighter-colored shales, drab, gray, and olive green, with thin beds of limestone. Fossils are not abundant, but those found above and within the phosphatic zone are indicative of late Pennsylvanian age.

## TRIASSIC OR CARBONIFEROUS.

The Park City formation is followed by rocks which are believed to be of either Triassic or Permian age or both. In the Park City district Boutwell has divided these rocks into three formations, all of which can be recognized in the valley of Weber River. The first, the Woodside shale, consists of brick-red ripple-marked shale and thin beds of shaly limestone, passing downward gradually into the gray and greenish shale at the top of the Park City formation. The red shale is followed by the Thaynes limestone, consisting of argillaceous gray limestone and interbedded calcareous gray shale. The limestone layers contain abundant pelecypod shells. The Thaynes limestone grades upward into the Ankareh shale, which consists of red shales and thin-bedded greenish limestones, the shales being characterized here also by many ripple marks. This formation is well exposed in the railway cut just west of Devils Slide station.

## STRUCTURE.

In considering the structure of the district four units need to be discriminated—(1) the Archean rocks, (2) the great series of beds ranging from Algonkian (?) to Cretaceous, (3) the Tertiary, and (4) the late Quaternary. Each of these four units has its own independent structural features.

The structure of the Archean rocks is so complex that it is as yet almost unknown. The rocks are not widely exposed in the district, and they have so little to do with the subject of this report that no further mention of them seems necessary.

The Algonkian-Paleozoic-Mesozoic sequence, which for brevity's sake may be called the folded sequence, is structurally a unit. From top to bottom the beds are almost parallel in stratification, and such differences in degree of alteration as exist are dependent more on local factors than on age. Within this sequence there are several unconformities, all of which are relatively obscure. Two of them, however, are of considerable importance—that at the base of the Cambrian and that within the Pennsylvanian. The whole sequence has been moderately folded and at the same time locally broken into slabs where there has been overthrusting. Normal faults of later date, and probably of two generations, further complicate the structure of these beds. The main Wasatch Range is essentially a monocline with moderate eastward dip, sharply cut off on the west. The western limit is generally believed to be a normal fault scarp of rather recent date. Although the simple monoclinal structure prevails from Brigham northward to the end of the range and is evident here and there farther south, the structure is far more complex in the Ogden district, chiefly because there the rocks are affected by many overthrusts. There is one master thrust which brings the Algonkian strata out over Carboniferous and all older beds. This runs from the front of the range near Willard diagonally across the mountains to the east end of lower Ogden Canyon and thence along the east base of the range to the point where it disappears beneath the alluvium near Weber River. West of and beneath this master thrust there are several other large and many smaller overthrusts.[a] Several small transverse normal faults with roughly east-west trend shift the outcrops of the monoclinal succession in the vicinity of Ogden. A very large normal fault runs from the city of Ogden east by north across the Huntsville basin and far into the Bear River Range. It shifts all the pre-Tertiary outcrops horizontally one-fourth of a mile to 3 miles.

The portion of the Bear River Range which enters this district may be separated into two divisions, the part north of the great Huntsville fault and the part south of that line. In the southern division the structure appears to be largely monoclinal with dips varying from nearly horizontal to vertical and even overturned. Except where overturned the dips are eastward, as in the main range. This monocline is by no means simple, being interrupted by at least one prominent knee-shaped fold and perhaps by two. Considered in ground plan it shows also small drag folds, the axes of which are parallel to the dip of the monocline. Most of these little folds are overturned toward the southeast. They are largely confined to the weak shaly beds and seem to be a result of slipping of the more competent strata along the bedding. On the west side of Mount Morgan there is a series of faults, apparently of the normal type. These have been traced northward almost to the Huntsville fault, but they are largely obscured by superficial gravel.

In the northern division of the Bear River Range the structure is that of a broad syncline or synclinorium, which pitches gently northward and eventually embraces Cache Valley as well as the Bear River Mountains. No faults of noteworthy dimensions have been found in this structure within the limits of the Ogden district. The sequence appears to be unbroken. On the west the great mass of Algonkian quartzites and slates is followed in turn by the entire Paleozoic succession up to and including the Park City formation with its phosphate beds. On the east limb the beds are involved in gentle minor folds, so that the Paleozoic sequence, particularly the Mississippian limestone, outcrops for many miles where it has been uncovered in the canyons. The eastern limit of the syncline is beyond the area under consideration.

The Tertiary beds were laid down upon a hilly or mountainous surface left by erosion some time after the folding and faulting of the older rocks. They are now thickest where there were Tertiary valleys, as along Beaver Creek and thence south to Devils Slide. Elsewhere they cap plateaus and ridges, where they have been left isolated by the trenching of valleys. The beds are nearly horizontal, but dips of 5° to 10° are not uncommon and some as high as 20° have been recorded. This implies that they have been slightly folded since they

[a] This structure is described in greater detail in the writer's paper "New light on the geology of the Wasatch Mountains, Utah" (Bull. Geol. Soc. America, vol. 21, 1910).

were deposited. To this nearly horizontal blanket of Tertiary beds is due the concealment of the phosphate beds in most of northern Utah.

There is a younger formation, consisting of coarse quartzite gravel and bowlders, which was probably first deposited in the Tertiary period. The gravel is strewn over the ridges and flat divides, particularly in the Bear River Plateau. It is generally found upon outcrops of the Eocene sandstone, but is not by any means confined to such situations. It was probably laid down on a higher surface in an earlier cycle of erosion; but as the valleys were cut deeper and the hills wasted away the gravel sheet has worked its way down over the slopes until it now forms a veneer of variable, but generally slight thickness.

The Quaternary sediments occupy the terraces and floors of the valleys and broad basins. They are still in their original attitude and are essentially unconsolidated.

## THE PHOSPHATE DEPOSITS.

### SURFACE DISTRIBUTION.

With the exception of a small patch of lean phosphate rock in lower Ogden Canyon, the known exposures of phosphate beds in the district considered in this paper are confined to the Bear River Range. They are best exposed in upper Weber Canyon, whence the outcrop has been traced several miles to the north and southwest. In the valley of Cottonwood Creek, an important tributary of Weber River, the phosphate deposits are concealed, but are doubtless present. They reappear here and there with very poor exposures in the valley of Sheepherd Creek, southeast of Huntsville. From that point the outcrop has been shifted several miles eastward by the great Huntsville fault. The continuation is therefore found in the divide, just east of Beaver Creek, north of the south fork of Ogden River. In that region, also, the distribution of the phosphate deposits is not readily determined, because the cover of Tertiary rocks conceals the outcrop, except in one of the principal canyons.

### GENERAL CHARACTERISTICS AND RELATIONS.

Deposits of rock phosphate have been found at two horizons in the Paleozoic rocks of the district. The lower bed is of late Mississippian age and is probably too lean to be workable under present conditions. The upper bed is a part of the Park City formation (Pennsylvanian) and is generally of workable richness and thickness. H. S. Gale, while working in northern Utah and southern Idaho, found phosphate deposits also in the Jurassic rocks. In the Ogden district the Jurassic system is exposed only at Devils Slide, and there no detailed examination of the rocks was made.

The phosphate zone in the Mississippian limestone comprises black and brown shale, with black chert and limestone, alternating in thin beds through a thickness of 100 to 200 feet. Being easily eroded, the beds are rarely well exposed and the details of the succession are therefore not known. Some of the black shales thought to be phosphatic have been analyzed, but they show less than 20 per cent of calcium phosphate. Pieces of much richer oolitic phosphate rock, however, have been found on the outcrop of this zone, and on this account it is thought probable that there are some rich, though perhaps thin, beds of true phosphate rock in the Mississippian system.

The richer phosphate beds of the Park City formation are the only ones that have hitherto received attention. The phosphatic portion of the formation consists of an alternation of dark limestone, shale, and phosphate rock in beds ranging from a few inches to 15 feet in thickness. There appear to be all possible gradations between limestone and phosphate rock. The richest in phosphate is a hard black rock with distinct oolitic and generally nodular structure. When freshly broken the rock gives off a strong and disagreeable odor, resembling that of hydrogen sulphide. The outer surfaces of the oolitic beds turn gray on exposure, and in this condition they are more or less mottled with short white streaks and round dots. Microscopic examination shows that the rock consists of little round nodules closely packed together and cemented by some extraneous material, generally calcite. The oolitic bodies appear rich brown in thin section, but jet black in the mass. They show concentric structure only imperfectly. Some of the little white streaks above mentioned prove to be chips of shells made of aragonite or calcite. Among these shells marine brachiopods and gastropods are identifiable. The less pure varieties of the phosphate rock merely have fewer of the little oolitic bodies and a correspondingly larger proportion of the cement. In some beds the cement contains abundant sand grains, and rarely it is distinctly siliceous. The phosphatic shales carry 10 to 20 per cent of tricalcium phosphate, but seem to lack the oolitic structure. In them the phosphatic material is in a disseminated or macerated state. Some of the black limestones are richer in tricalcium phosphate than the shales, and a microscopic examination shows that they contain many scattered oolitic bodies.

In this upper phosphatic series two thick and eventually workable seams of phosphate rock have been found. These average 7 to 8 feet in thickness, but at one point, on Weber River, are 10 and 13 feet thick. In addition, there are several beds ranging from 1 to 3 feet in thickness which are separated by thin strata of phosphatic limestone and, taken together, may prove to be valuable. It is evident from the character of the beds and their association with marine fossils and limestone that they are of marine origin. This may be taken to mean that they are relatively uniform in value and thickness over considerable areas and that they do not change materially in depth. In other words, this material is purely an original concentration.

## UTILIZATION.

The lean phosphate deposits in the Mississippian series are as yet wholly undeveloped. In only one place do they seem to have been even examined. The upper phosphatic series has, however, received more attention.

So far as known, little prospecting for phosphates was done in this region before the last decade, and as yet the phosphate deposits have been prospected in only a part of the district. Where most thoroughly explored, as in Weber Canyon, many shallow pits and trenches have been dug to find the position of the beds, and there are a few short drifts which penetrate into the formation. According to available information, however, there has been no shipment or sale of rock phosphate, or, if any, only such as may be regarded as experimental. No mining is now being carried on. The long haul to California, the nearest market at present, is expensive. The current price at the market is low. These two factors combine to render the mining of phosphate rock in Utah unprofitable to-day.

## DESCRIPTION OF DEPOSITS BY LOCALITIES.

### WEBER CANYON.

The phosphate deposits of this district are best exposed in the upper canyon of Weber River between Morgan and Devils Slide station on the Union Pacific Railroad. The lower phosphatic zone has not been recognized in this valley, but the upper zone is better known here than at any other point.

Weeks and Ferrier, in their reconnaissance report,[a] have described the general features of the deposits. The best-exposed section is that just west of Robison's ranch and is given below in detail. It comprises the lower part of the Woodside shale and all of the Park City formation. The line of division between the two is indefinite.

*Section of beds near Robison's ranch, Weber Canyon.*

| | Feet. |
|---|---|
| Shale and sandstone; interbedded layers of gray, olive, and brown color | 62 |
| Shale, chocolate-colored, sandy texture | 12 |
| Shale, platy, greenish | 4 |
| Limestone, dense, hard, gray, in thin slabs, interbedded with olive shale (*Lingula*) | 27 |
| Shale, black to gray, with many thin beds of gray and pale-green limestone (*Lingula*) | 80 |

[a] Weeks, F. B., and Ferrier, W. F. Phosphate deposits in western United States: Bull. U. S. Geol. Survey No. 315, 1907, pp. 454-455.

| | Feet. |
|---|---|
| Limestone, grayish or olive, shaly, and shale | 22 |
| Limestone, hard, salient, with yellow pitted surface | 2 |
| Shale, gray to purplish, calcareous, with one thin bed of white limestone | 11 |
| Limestone, mottled gray and red, with brown chert seams and thin beds of shale | 48 |
| Shale, blocky, calcareous, gray | 28 |
| Limestone, gray, crystalline, mottled with red (many Pennsylvanian fossils near the top) | 45 |
| Concealed | 40 |
| Limestone, light gray, hard and somewhat argillaceous | 70 |
| Concealed by wash | 45 |
| Limestone, reddish and mottled | 2 |
| Limestone, light gray, earthy | 37 |
| Limestone, dark gray, brittle, and on the outside ashy | 17 |
| Sandstone, friable, calcareous, white | 50 |
| Concealed by slope wash | 40 |
| Limestone, black, with large nodules of black chert | 9 |
| Concealed by débris of shales, more or less phosphatic | 143 |
| Limestone, dense, black, and cherty | 2 |
| Shale, black and phosphatic | 6 |
| Limestone, dense, black, and cherty | 5 |
| Phosphate rock, black, partly oolitic (tricalcium phosphate average 46.1 per cent) | 13 |
| Limestone, phosphatic, black, cherty (tricalcium phosphate, 21.9 per cent) | 5 |
| Chert, hard and blocky, black | 1 |
| Limestone, black, with black chert nodules | 4 |
| Phosphate rock, rather uniform, dense black rock with many nodular and oolitic layers (tricalcium phosphate average 39.2 per cent) | 10 |
| Limestone, black and cherty | 10 |
| Limestone, gray, hard and blocky (tricalcium phosphate 8.8 per cent) | 8 |
| Limestone, black, with much chert, interbedded with layers of shaly phosphate rock 1 to 4 inches thick (tricalcium phosphate average 15 per cent) | 40 |
| Limestone, black and phosphatic (tricalcium phosphate 9.6 per cent) | 3 |
| Limestone, black, rather siliceous and hard (tricalcium phosphate 8.8 per cent) | 1 |
| Limestone, black, cherty (tricalcium phosphate 15.3 per cent) | 2 |
| Limestone, black, hard, and siliceous (tricalcium phosphate 11.8 per cent) | 1 |
| Limestone, dark gray, with great masses of black chert | 157 |
| Concealed by débris, chiefly of limestone | 45 |
| Limestone, sandy, gray, without chert | 25 |
| Breccia, sandy, light gray | 20 |
| Concealed by soil and débris | 230 |
| Sandstone, friable, white | 40 |
| Sandstone, white, with limonite concretions | 10 |
| (Breccia at base in other sections.) | |
| | 1,232 |

It will be observed that in this section there are two thick beds of phosphate rock together with several thinner strata. It also appears that some of the limestone beds contain important quantities of tricalcium phosphate which may some day give them commercial value.

From Weber Canyon the phosphate beds have been traced both north and southwest across the mountains. (See fig. 45.) On the south they bend to the southwest, but after crossing Tunnel Hollow and the next dry canyon beyond the formation passes beneath the thick Eocene deposits near the township boundary and does not reappear within this district. In that part of its course it is exposed

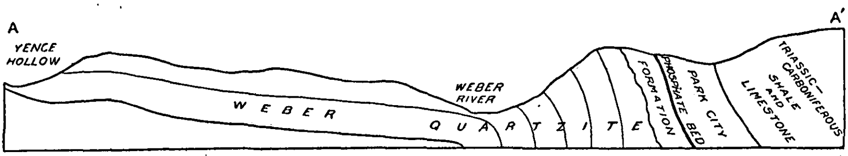



FIGURE 45.—Structure section through upper Weber Canyon, Utah, between Morgan and Devils Slide.

in many shallow test pits and trenches along the slopes of the ridges. There are also natural exposures of some value. Analyses of full sections of single phosphate beds here give 39 to 62 per cent of tricalcium phosphate.

North of Weber Canyon the outcrop makes a sharp bend, caused by a little overturned drag fold, and then continues north by west for a distance of 4 or 5 miles. Within this distance it is locally interrupted by thin caps of Eocene conglomerate and at the end it is completely buried by the same formation. Little prospecting has been done along this part of the outcrop, but there are fair exposures in ravines sufficient to show that the formation does not change materially in character within this distance.

## SHEEPHERD VALLEY.

Sheepherd Valley is a small shallow valley tributary to Ogden River, 6 to 7 miles southeast of the village of Huntsville. It comprises the southeastern part of T. 6 N., R. 2 E., and the northeast corner of T. 5 N., R. 2 E. The hills there are low and heavily covered with gravel and soil and the valleys are neither deep nor rugged. For this reason exposures are poor. The phosphate beds themselves are not actually visible at any point. (See fig. 46.)


FIGURE 46.—Structure section of Paleozoic beds in Sheepherd Valley, southeast of Huntsville, Utah.

In this district both phosphatic zones have been found. The lower or Mississippian zone consists of gray and black phosphatic shales and limestone with characteristic fossils. It is much too lean to be of present importance. The details of the upper zone can not be ascertained without trenching, but it is probable that the succession is much like that in Weber Canyon, which is only 10 to 11 miles away. The beds reach the surface as they cross several low ridges. They are, however, thickly covered with soil, and at both ends they are completely buried beneath Eocene deposits. The residual soil lying upon the outcrops contains abundant pieces of the characteristic oölitic phosphate rock, like that in the better-known deposits in Weber Canyon. Analyses made by W. H. Waggaman, of the United States Department of Agriculture, of average collections of these pieces of float materials after sorting show the following percentages of tricalcium phosphate: Coarse gray oolitic rock, 72.9; fine gray oolitic rock, 70.3; hard gray vermicular rock, 69.6.

The Paleozoic rocks in this locality are known to be broken by several important faults. It is therefore hazardous to predict the position of the phosphate beds beneath the Eocene cover. There is no doubt that the whole succession is cut off at the great Huntsville fault, so that it does not extend farther northwest. Sheepherd Valley bears no evidence of having been explored for phosphate deposits. At the time of the writer's visit the very presence of such beds seemed to be unknown to the people of the vicinity.

### BEAVER CREEK.

Beaver Creek is one of the principal branches of South Fork of Ogden River. The phosphate deposits in its vicinity lie chiefly east of the creek, and are exposed only in the second and third canyons east of it. On the divides they are buried by level Eocene strata 100 to 2,000 feet thick. (See fig. 47.)

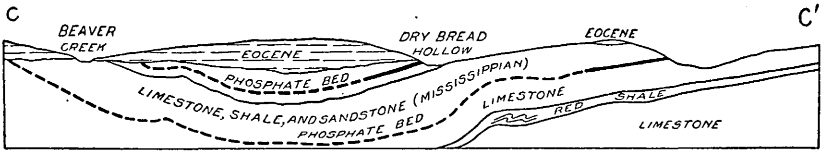



FIGURE 47.—Structure section through Beaver Creek syncline, Utah.

The following is a partial section of the Carboniferous rocks in Dry Bread Hollow, one of the canyons tributary to South Fork of Ogden River:

*Partial section of Carboniferous beds in Dry Bread Hollow.*

| | Feet. |
|---|---|
| Park City formation (top concealed): | |
| Limestone, buff and white, with poor Pennsylvanian fossils.. | 10 |
| Concealed, shaly beds, probably in part phosphatic......... | 130 |
| Phosphatic beds, shale, limestone, and rock phosphate (detailed succession not observable)......................... | 118 |
| Shale, gray, calcareous, with thin beds of limestone.......... | 180 |

| | Feet. |
|---|---|
| Park City formation—Continued. | |
| Limestone, gray-white to dark gray, with shale partings | 152 |
| Concealed | 54 |
| Limestone, gray and crystalline | 10 |
| Concealed | 85 |
| Sandstone, soft, creamy white | 125 |
| Limestone, light gray, with chert nodules | 20 |
| Sandstone, white and calcareous, with one thin bed of limestone | 75 |
| Unconformity (?). | |
| Mississippian series: | |
| Limestone, gray, crystalline and fossiliferous | 40 |
| Shale, purple and gray, with layers and nodules of gray and bright-green limestone, mottled with red blotches richly fossiliferous | 100 |
| Limestone, gray, with large masses of chert | 15 |
| Limestone, dense, blue-gray | 6 |
| Limestone, thin bedded, pink, more or less sandy | 10 |
| Limestone, hard, blue-gray | 4 |
| Limestone, dark gray, and blackish dolomite, some nodules of gray chert | 200 |
| Limestone, thin bedded and shaly, gray to buff-white, with shale partings | 80 |
| Sandstone, light brown, calcareous | 5 |
| Limestone, dark gray to black, siliceous or dolomitic; fossils abundant, but poorly preserved | 215 |
| Limestone, gray to buff, thin bedded | 60 |
| Limestone, gray, crystalline and massive | 12 |
| Sandstone, buff and gray, calcareous | 5 |
| Limestone, siliceous, black | 6 |
| Limestone, earthy and dolomitic, brown to gray | 62 |
| Limestone, massive, brown | 15 |
| Phosphatic beds, black limestone with chert, brown shale, and shaly phosphate | 100 |
| Limestone, gray, cherty | 20 |
| Shale, phosphatic | 6 |
| Limestone; the body of the Mississippian limestone, the upper beds of which are dark and cherty. | |

Both phosphatic zones are fairly well exposed in this locality. As usual, the lower is too lean to be of value at present; but the upper contains richer beds of phosphate rock essentially like those in Weber Canyon. The outcrop of the lower zone takes an irregular northeasterly course and its ultimate limit in that direction has not been found. The upper or workable zone is exposed for only a few miles along the west slope of Dry Bread Hollow. From a study of the structure of the region it is evident, however, that both zones occupy a shallow syncline underlying the divide between Dry Bread Hollow and Beaver Creek. The course of the outcrop of the workable beds could be determined by a moderate amount of drilling through the Eocene cover, but even without that it is possible to indicate the general position of the bed. Where not buried by Tertiary strata the upper zone is generally covered with soil, and there are no diggings affording better exposures. Débris upon the outcrop shows, however, that the zone contains beds of oolitic phosphate rock comparable to those at Robison's ranch in Weber Canyon.

One claim appears to have been staked on the Beaver Creek deposits, but very little work has been done on it and there seems to be little interest in the locality at present. This is due chiefly to the facts that the field is 20 to 30 miles from the nearest railroad and that the actual exposures are in a canyon which can not at present be reached by wagons. The cost of constructing roads and hauling the product to the railroads is so great in proportion to the current market price of the phosphate rock that these remote deposits can not be profitably mined for many years to come. They will, however, help to form a reserve which may be needed in the distant future.

### OGDEN CANYON.

In the limestone cliff at "The Oaks" resort, about 2 miles below the upper end of Ogden Canyon, there is a zone of black shale and limestone, which proves on analysis to be decidedly phosphatic. The richest material is contained in two beds of black shaly rock, each about 2 feet thick. Analysis of a random sample from this bed, by W. H. Waggaman, of the United States Department of Agriculture, gives 42.5 per cent of tricalcium phosphate. In this exposure the usual oolitic texture was not seen.

At this point the beds are highly folded. The age of the zone is not known, but the rocks with which it is associated resemble the Mississippian limestone succession. The outcrop runs up the canyon slopes to the north and south, but can not continue much more than a mile in either direction because large faults there cut off the entire Paleozoic sequence. This deposit, although much richer than the others found in the Mississippian rocks of Utah, is so much disturbed that it can not be easily worked.

## PROBABLE EXTENSION OF THE PHOSPHATE DEPOSITS.

The geologic structure of the district indicates that the Park City formation, which contains the workable phosphate deposits, continues northward and northwestward, beneath the Tertiary deposits, for many miles from the Beaver Creek locality. The Cache Valley syncline probably contains the formation buried under a considerable thickness of later deposits. From the known relations to older formations which are exposed it is believed that the outcrop of the phosphatic series runs northwestward along the west edge of Paradise Valley to the vicinity of Wellsville, and thence northward along the east base of the Wasatch Range for an undetermined distance. The outcrop lies under a cover whose depth is difficult to estimate, but which appears to conceal it completely. If, as the writer suspects, the east side of Cache Valley is bounded by a fault, then the phosphate deposits will not be found there, except at great depths. The southern part of the Morgan Basin may well, however, conceal good phosphate beds continued southwest from Weber Canyon.

# SURVEY PUBLICATIONS ON PHOSPHATES AND OTHER MINERAL FERTILIZERS.

The following papers relating to phosphates, gypsum (land plaster), and other mineral materials used as fertilizers have been published by the United States Geological Survey or by members of its staff. Further references will be found under the head of "Gypsum."

The government publications, except those to which a price is affixed, may be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Those marked "Exhausted" are not available for distribution, but may be seen at the larger libraries of the country.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