A GEOLOGIC RECONNAISSANCE OF THE UINTA MOUNTAINS, NORTHERN UTAH, WITH SPECIAL REFERENCE TO PHOSPHATE.

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INTRODUCTION.

NATURE AND PURPOSE OF THE EXAMINATION.

The conference of governors in 1908 drew public attention to the question of the future adequacy of our phosphate resources for our own use and led indirectly to the withdrawal from entry of about 7,000 square miles, or 4,541,300 acres, in Idaho, Utah, and Wyoming, pending an examination of their phosphate deposits. The United States Geological Survey has been of the opinion, however, that phosphate deposits are not restricted to the withdrawn areas but have a much wider distribution. The first withdrawal was based partly on information collected by the Hayden Survey from 1872 to 1878 and partly on later detailed and reconnaissance examinations made by the United States Geological Survey. As soon as detailed field work was undertaken on the withdrawn lands the regularity and persistent character of the phosphate deposits were revealed, and it was evident that in many places the old maps were not adequate for outlining phosphate withdrawals and that more data, as well as a more careful and detailed interpretation of the information gathered by the earlier surveys, would be needed before the withdrawals could be extended. It was decided, therefore, not to make additional withdrawals until preliminary examinations of the supposed phosphate areas could be made.

The importance of the phosphate resources and the growing realization of the need for their conservation have given the necessary impetus to their examination. Although the phosphate fields of the eastern United States have long been commercially exploited and some of the rich deposits have become nearly exhausted, it is only in recent years that widespread interest has been attracted to the extensive fields of the Rocky Mountain province, the examination of which was undertaken by the United States Geological Survey in 1908 and has since that time been under the general supervision of Hoyt S. Gale, geologist in charge of nonmetalliferous deposits.

It has been thought by the Geological Survey that phosphate might occur in the Uinta Mountains, in northern Utah, in the same formation as in the neighboring and better-known phosphate fields of Idaho, Montana, Utah, and Wyoming. During the last few years the Survey has received from outside sources numerous reports of the presence of phosphate deposits in the Uinta Mountains and inquiries as to whether or not the Government rewards the discoverer for locating such deposits. The data obtained in this manner were meager and unsatisfactory, as all the material submitted represented rock of very low grade, and no information was given regarding the areal distribution of the deposits. In view of the inadequate and conflicting reports regarding these deposits, the writer made the reconnaissance examination here described. This work was undertaken for the purpose of ascertaining the extent and character of the phosphate deposits in the Uinta field and whether or not it was advisable to include any of the land within a phosphate reserve pending a more detailed study of the deposits and the enactment of a law providing for the disposition of valuable deposits of commercial phosphate. The reconnaissance field work has not been completed, but the results obtained in the examination of the western part of the range are published in this preliminary report, partly in order to place the available information in the hands of those interested in prospecting and locating the deposits that are now being developed and sought for in this and adjoining regions, and partly because of the geologic interest attached to the extension of the known phosphate field and the associated rocks. The examination of the area shows that 224,558 acres, which have been included in the phosphate reserve approved May 11, 1915, may tentatively be regarded as containing valuable deposits of phosphate, and the examination thus serves as a classification of the land as to phosphate. This report supplements the information previously published by the United States Geological Survey on the coal fields in the same general region.

FIELD WORK.

General features.—The field work on which this report is based extended over a period of six weeks, from August 11 to September 22, 1914. It consisted in making a geologic map, locating the geologic features by the usual field methods, and carefully examining in a preliminary manner the phosphate resources of the area. Phosphate beds were examined, sampled, and measured in natural outcrop wherever such exposures could be found without too great an expenditure of time. In the reconnaissance survey the primary object was to obtain accurate data regarding the phosphate resources in order that the public land valuable for its deposits of phosphate might be withdrawn pending further detailed examination and that information concerning the commercial value of the deposits might be as nearly complete and cover as large a field as practicable. It was obviously impossible in the time available to map in detail the outcrops of the phosphate beds throughout so large an area, to measure the thickness of the beds at short intervals wherever exposures occurred, to sample the beds in order to determine the amount of phosphoric acid they contain, to measure at short intervals the thickness of the overlying strata, or to work out the necessary local detailed structure to determine in what places the phosphate beds occur at depths sufficiently near the surface to justify the classification of the land as mineral land.

The geologic work was greatly facilitated by the fact that good topographic maps—the Coalville, Strawberry Valley, Hayden Peak, Gilbert Peak, and Marsh Peak sheets—were available for a large part of the area. In the parts for which no topographic map was available the traverse lines were platted in the field on blank township maps, and intersections were made to the features of geologic interest. In running section or meander lines, courses or directions were taken with a pocket compass, distances were measured by tape or by pacing, and the traverse lines were tied to section corners. Elevations were recorded by means of an aneroid barometer.

Few of the outcrops of the phosphate bed or formation contacts were traversed, but sections of the phosphatic strata were measured at intervals, and their location and the formation boundaries were sketched from known points. The valuable phosphate beds are in large part concealed and can not readily be traced, and therefore the exact location and even the presence of the phosphate bed in much of the region can not be positively determined from the surface indications but must be inferred from a study of the nearest stratigraphic sections that are favorably exposed. Every known prospect that was opened on a phosphate bed was visited, and 37 samples of phosphate rock, representing float or rock in place, were collected for analysis.

Itinerary.—The party, which consisted of the writer and C. P. Jones, driver, outfitted at Evanston, Wyo. The outfit, which included a saddle horse, team, and light mountain wagon, moved south, from Evanston up Yellow Creek and over the divide down Chalk Creek to the mouth of the East Fork, where three days were spent in examining the beds in the vicinity of Porcupine Mountain and along Chalk Creek and its tributaries. The party then moved down Chalk Creek to South Fork, thence over the Elkhorn divide to Weber

River, making only cursory observations on the way. Several days were spent on Weber River in more systematically examining sections, making traverses, and mapping the formations along the river from Peoa, Utah, eastward to Holiday Park and over the divide to the headwaters of the West Fork and Hayden Fork of Bear River. These examinations proved beyond question that the phosphate beds were present, although concealed through much of the area. The party then moved down Weber River to Peoa, thence in a southeasterly direction by way of Marion, Kamas, and Woodland to Provo River, thence up this stream to South Fork and over the divide to Wolf Creek, where several days were spent in a study of the geology and stratigraphy of the southwest side of the range. These studies clearly indicated that the phosphate beds are present on the south side of Provo River, but are not exposed in Rhodes Valley between Provo and Weber rivers. The party then moved down Wolf Creek to Duchesne River and eastward along the south flank of the Unita Mountains to Green River east of Vernal, Utah, making studies of the geology and stratigraphy at several places along the south side of the range. The more systematic geologic work was confined to the phosphate zone, although much information was obtained regarding the overlying and underlying formations. No complete section of the beds that form the central core of the mountains was made. Detailed studies of the phosphate and associated beds along the south side of the range were made along the valleys of the large streams tributary to Duchesne and Green rivers, several days being spent in a study of the geology and stratigraphy of the beds along South Fork of Duchesne River, Duchesne River, Rock Creek, West Fork of Lake Fork, Yellowstone, Uinta, and Whiterock rivers, and Deep, Dry Fork, Ashley, Brush, and Little Brush creeks, and on Green River in the vicinity of Island Park, along the north side of Split Mountain. The party then moved across the Unita Mountains from Vernal, Utah, to Lodgepole Creek, on the north side of the range in the vicinity of Phil Pico Mountain, west of Lucerne Valley, making cursory examinations along the Taylor Mountain and Lucerne Valley road. Several days were spent in the vicinity of Phil Pico Mountain in studying the beds and mapping the phosphate outcrop from Lodgepole Creek west to Burnt Fork Creek. The party then moved eastward through Lucerne Valley to Green River at the mouth of Henrys Fork, making a careful study of the geology and stratigraphy of the beds from Lodgepole Creek east to Green River. Several days were spent in examining the beds east of Green River along Spring Creek and eastward across the divide to Red Creek in the vicinity of Red Creek Gap, which had been visited by the writer in the summer of 1908. The party then moved west to Burnt Fork Creek and continued the examination westward along the north flank of the mountains to Bear River. Studies of the mountains similar to those along the south side of the range were made at many places along the valleys of the larger streams. Several days were spent in a study of the geology and stratigraphy of the beds along each of the following streams: Burnt Fork, East, Middle, and West forks of Beaver Creek, Henrys Fork, Smiths Fork, East, Middle, and West forks of Black Fork, East, Stillwater, and Hayden forks of Bear River; and thence westward to the area between Weber River and Chalk Creek previously examined. The work was then discontinued and the party returned to Evanston by way of Bear River valley.

Land surveys.—The greater part of the area under discussion has been subdivided by the General Land Office, only the more rugged areas along the mountain range in northern Utah between the Utah-Wyoming State line and the boundary of the former Uinta Indian Reservation being unsurveyed. The larger part of the field in Utah was surveyed with reference to the Salt Lake base and meridian; the remainder, or the part formerly included in the Uinta Indian Reservation, all of which has been subdivided, is controlled by the Uinta special base and meridian. Practically all the corners for which search was made were found, although more difficulty was experienced in finding corners in the region surveyed from the Salt Lake base and meridian than in the region controlled by the Uinta special base and meridian. All the area in southern Wyoming and most of the area in northwestern Colorado shown on the map accompanying this report (Pl. V, in pocket) has been subdivided by the General Land Office and was surveyed with reference to the sixth principal base and meridian. All the original surveys in this part of Colorado, as well as those in southern Wyoming, from R. 112 W. eastward to the limits of the area mapped, were very unsatisfactory, and the township plats were of no value; consequently it was found necessary to resurvey all these townships. The resurveys were made and completed by the General Land Office, and resurvey plats are now available. The township, section, and auxiliary corners established in this resurvey are marked by iron posts set by the Government and stamped with the proper description. All the corners so marked can be readily found and are of great value to settlers, because they make it possible to locate land in the township accurately without the aid of a surveyor.

GEOGRAPHY.

LOCATION OF FIELD.

The area covered in this examination lies in northern Utah along the Uinta Mountains between meridian 109° and 111° 30′ and parallels 40° 15′ and 41° 15′, comprising an area of approximately 6,000 square miles extending from the vicinity of Green River westward to the west end of the Uinta uplift in the vicinity of Park City, Utah, on the east flank of the Wasatch Mountains. The phosphate field itself contains a much smaller area, about 350 square miles, in the form of a narrow strip along the flanks of the mountain range between the central area of older rocks composing the central mass of the range and the areas previously mapped by the survey along the outcrop of the Cretaceous coal beds in the Vernal, Deep Creek, Blacktail Mountain, and Coalville fields, Utah, and the Evanston, Henrys Fork, and Rock Springs fields, Wyoming. The phosphate bed and its surface exposures are somewhat irregularly distributed in this narrow strip and occur in four rather widely separated areas of somewhat diversified character.

The greater part of the Uinta Range is situated in northeastern Utah and the remainder in northwestern Colorado, immediately south of Wyoming. The range has an average width of about 35 miles and extends from the Wasatch Mountains eastward to Little Snake River. At its west end it is only about 25 miles wide; at its east end, in the vicinity of Green River, it is nearly twice that width. Through the greater part of the range in Utah the width from the north to the south flank of the mountains is nearly 35 miles. Most of the range west of Green River, which comprises all the more rugged portions, is included in the Ashley and Uinta national forests. The south side of this range, embracing the area within the drainage basin of Duchesne River, from the headwaters of the Duchesne east to the tributaries of Whiterock River, was formerly included in the Uinta Indian Reservation, and a large part of the inhabitants in this region are Indians. The index map of northern Utah and the adjoining States, presented herewith (fig. 7), shows the outline of the phosphate field and its relations to the mountains and the coal fields above mentioned.

PHYSIOGRAPHY AND TOPOGRAPHY.

In general form the range is an elongated, broad, flat-topped arch in which the main east-west divide is nearer the north flank, so that a north-south profile shows an asymmetric slope. In other respects also the fold is irregular, as there are regions of faulting and many localities of abrupt change from low to steep dips and secondary folds. The culminating peaks and ridges lie for the most part along the north side of the broad summit of the arch, although some of them, as Mount Emmons, Leidy Peak, and Marsh Peak, lie near the center or on the south side of the arch. The plateau-like summit has in many places been deeply dissected and eroded into jagged peaks and ridges at whose bases lie immense amphitheaters that widen out and then close into deep canyons, carved through the upturned beds which form the slopes. The central part of the range along the anticlinal crest is formed of nearly horizontal strata, buried at many places beneath glacial material in which numerous lakelets and ponds still remain, held in their rocky basins by accumulations of débris. A great part of this region is occupied by grassy parks, open mead-

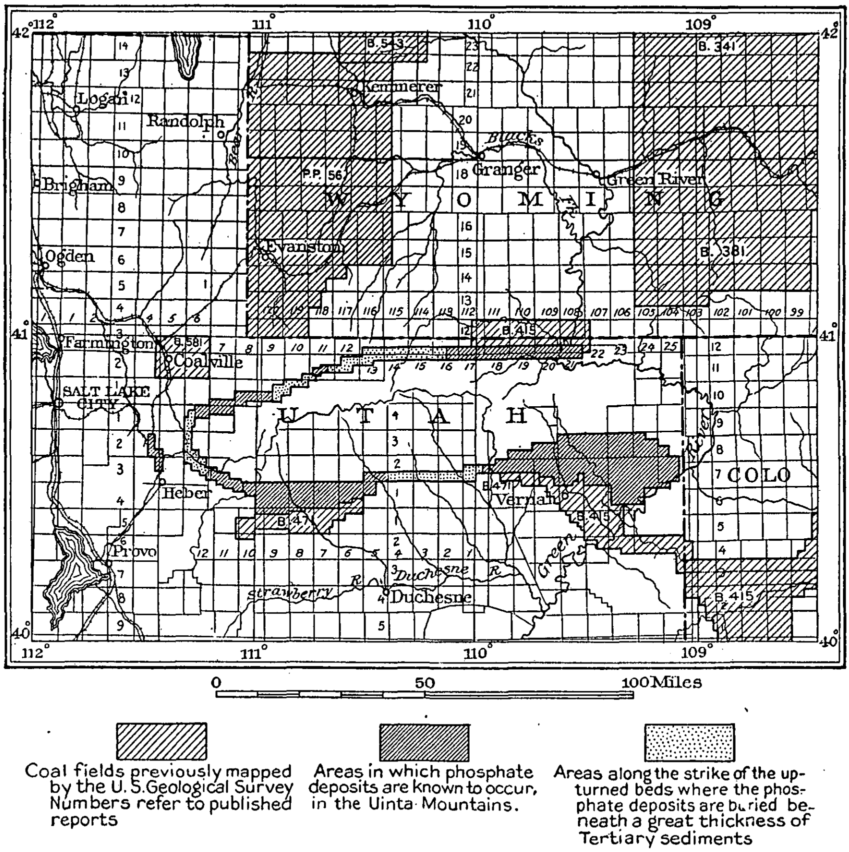

FIGURE 7.—Index map showing the location of the phosphate field in the Uinta Mountain region, Utah, and its relation to the coal fields previously examined by the United States Geological Survey.

ows, and forest-covered areas, above which the barren peaks rise in bold escarpments. The most prominent of these peaks, with their respective elevations, are shown on the accompanying map.

The northern flank of the range slopes off steeply from this central area to a great undulating basin; the southern flank slopes much more gently to an extensive plateau region and thence into an undulating basin similar to the one on the north. These slopes have been deeply incised by the streams that drain the central area. In many places the streams have cut channels with increasing depth until they flow in canyons from 1,000 to 2,000 feet deep. The general surface features on the north and south sides of the range are rough and are made up of many minor irregularities. Many of the slopes of the highlands are dissected into a large number of small valleys; others are gentle plains on one side and have steep escarpments on the other. Generally the surface consists of ridges or hogbacks produced by the unequal erosion of upturned alternating beds of hard sandstone and soft shale. Many of these minor ridges are parallel to the mountain range and represent the strike of different formations; others, more or less parallel to the streams and valleys, are at right angles to the axis of the mountains and represent table-lands or gently sloping plateaus formed in nearly horizontal beds through the agency of erosion.

Some of the higher plateaus, table-lands, or mountains owe their preservation to a thick layer or bed of resistant rock, the Bishop conglomerate, which has withstood erosion better than the soft rocks lying beneath it. This physiographic feature is of interest, as it is of widespread occurrence in eastern Utah. The Bishop conglomerate is strongly developed on both the north and south sides of the range from its eastern to its western end. It was studied by the writer in the Rock Springs region in 1908 and has been described for this area, where it has an elevation from 7,600 to 8,500 feet, by Rich.[1] On the south side of the range, in the longitude of Vernal, the elevation of the plateau ranges from about 8,000 feet at the front to about 9,000 feet where it merges with the old mountain topography of the central portion of the range. Farther west the elevation reaches 10,000 feet or more. This feature has been described for a part of the southwestern portion of the range by Lupton.[2] The top of the plateau sloping gently from the mountain is an old erosion surface that has beveled all the formations regardless of their hardness or position. Near the mountain margin the more resistant strata form low ridges bounding longitudinal valleys that occupy the areas of softer rock. This surface has been covered by a mantle of coarse gravel composed largely of pebbles and boulders of red sandstone from the central portion of the range. Near its outer margin the plateau is cut by deep canyons, few of which reach completely across the plateau, so that east-west travel along the base of the range is comparatively easy, while along the front of the plateau it is practically impossible. At

[1] Rich, J. L., The physiography of the Bishop conglomerate, southwestern Wyoming: Jour. Geology, vol. 18, p. 601, 1910.

[2] Lupton, C. T., The Deep Creek district of the Vernal coal field Uinta County, Utah: U. S. Geol. Survey Bull. 471, pp. 579–594, 1912; The Blacktail Mountain coal field, Wasatch County, Utah: Idem, pp. 595–628.

several lower levels there are gravel-covered benches or mesas that are strongly suggestive of periods of erosion followed by uplifts that allowed further deepening of the stream beds. Besides the broad, nearly level bench land, there are many broad, open valleys and small inclosed basins along all the principal streams, and these tracts are extensively used for agriculture. All that portion of the range west of a north-south line passing through Green River at the mouth of Henrys Fork has been surveyed topographically by the United States Geological Survey, and for topographic details the reader should consult the Marsh Peak, Gilbert Peak, Hayden Peak, Coalville, Strawberry Valley, and Vernal atlas sheets.

DRAINAGE.

The drainage of the area discussed in this report belongs to two great systems—that of Green River, whose waters flow to the Pacific by way of Colorado River and the Gulf of California, and that of the Great Basin, whose waters enter Great Salt Lake. The Uinta Mountains constitute one of the prominent ranges in the Rocky Mountain province, but for the most part they do not form the divide between two drainage systems. Most of the streams heading in the mountains, except those in the west end of the range, flow down the dip at approximately right angles to the range until they pass beyond the hard Paleozoic rocks along the mountain flanks, where they take an eastward trend and eventually reach Green River. The chief tributaries of Green River on the north side of the mountains are Blacks Fork and Henrys Fork from the west and Bitter Creek from the east. On the south side of the mountains the main tributaries on the west side of Green River are Duchesne River and Ashley and Brush creeks. The east end of the range is drained chiefly by Yampa River and its tributaries. The northern, northwestern, and southwestern parts of the west end of the range lie, respectively, in the drainage areas of Bear, Weber, and Provo rivers and their tributaries. These streams flow in diverse directions, finally reaching by circuitous routes the east end of Great Salt Lake within 20 miles of one another. In many parts of the range some of the headward portions of the streams, on emerging from the interior area, continue north or south along radial courses through outlying ridges and down their gentle or steep outward-facing slopes; others on reaching these ridges turn abruptly and escape by longitudinal valleys whose alluvial bottoms are terraced and trenched. Many of the streams exhibit several types of drainage in different parts of their course; for example, Provo and Weber rivers, the master streams at the west end of the range, have longitudinal courses for a large part of their extent and then abruptly take diverse courses, one flowing south and the other north. Both streams are fed by headwaters of transverse radial streams as well as by streams flowing against the dip toward the central area of the range.

ACCESSIBILITY.

Railroad facilities.—For the most part the field discussed in this report is without direct railroad facilities, although it lies between two transcontinental lines, the Union Pacific on the north and the Denver & Rio Grande on the south. Only in its west end is the Uinta Range traversed by a railroad. The remainder of the area is entirely without railroad transportation, and, although surveys for several lines have been projected through this area, none have been completed. Some of the grades were partly constructed and later abandoned. The Nebraska-Wyoming Western surveyed a route in 1901 across the southwestern part of Wyoming by way of Cumberland and Evanston, Wyo., thence south by Yellow Creek, across the divide into Chalk Creek, and down that stream to Coalville. A portion of the grade for the roadbed along Chalk Creek and Yellow Creek, although partly completed, was later abandoned, as may now be seen at several places along the wagon road.

The Denver & Salt Lake Railroad ("Moffat road") is partly constructed in the eastern part of Routt County, Colo., and bids fair in the near future to be pushed westward near the southern part of the field to Salt Lake City. An extension of the Uintah Railway has been surveyed from Watson to Vernal, Utah, crossing the projected route of the "Moffat road" near Green River. The Union Pacific Railroad has made a preliminary survey south from Rawlins and Wamsutter, Wyo., to Craig, Colo., for the purpose of entering the Yampa Valley. At present active work on all these projects has been temporarily abandoned.

The phosphate field can readily be reached from cities on the railroads by means of wagon roads. The north side of the field can best be reached from Rock Springs, Green River, or Evanston, Wyo., on the Union Pacific Railroad, by traveling along any of the main highways leading south toward the mountains, a distance of 40 to 80 miles. From the west end of the range the route to the fields is by way of Provo, on the main line of the Denver & Rio Grande Railroad, or over a branch of that line to Heber, Utah. A fairly good wagon road extends from Heber up the valley of the Provo to the outcrop of the Park City beds on the South Fork of Provo River, a distance of 35 miles.

Another route starts from Park City, the terminus of a branch of the Union Pacific Railroad that joins the main line at Echo City, Utah. The journey can be made on horseback or wagon up the

South Fork of Provo River, through Woodland, over the divide, and down Wolf Creek and the West Fork of Duchesne River, through Stockmore to points farther east on the south side of the range. The north side of the range is reached by following the road from Park City eastward to Kamas, thence northward through Marion and Oakley to Weber River, and thence up this stream, or by following the road up Weber River from Coalville, Utah, another station on the Park City branch.

The phosphate field can be approached from the south by two routes. A daily mail stage carrying passengers and express from Price to Vernal may be used as far as Myton, on Duchesne River, where a private conveyance can be obtained for the remainder of the journey up that river, a distance of about 65 miles, or the traveler may remain on the stage as far as Vernal and hire a private conveyance from that place. The other southern approach is from Colton, on the Denver & Rio Grande, by mail stage to Duchesne (Theodore), and private conveyance up Duchesne River to the phosphate field, a distance of 40 miles.

To enter the phosphate field from the east one should leave the Denver & Rio Grande Railroad at Mack, Colo., take the Uintah Railway to Watson, Utah, the Uintah Railway automobile stage to Vernal, and a private conveyance for the rest of the journey. Another route from Watson may be followed by taking an automobile stage that runs to Fort Duchesne and a private conveyance for the remainder of the journey up Duchesne River, a distance of about 75 miles.

Roads and trails.—Good wagon roads in the area back from the mountains are numerous and traverse the country in various directions from one drainage basin to another. The best roads are generally in the valleys of the main streams or along the table-like ridges parallel to the streams. In the mountainous areas the roads lie for the most part in the larger valleys or upon the gentle dip slopes on the south and north sides of the range. Good roads lead up all the major streams to the rugged portions of the mountains, and trails continue up the streams and across the mountain divide to the headwaters of contiguous drainage areas on the opposite side of the range. The trails continue down these valleys and finally connect with roads leading to settlements farther down. Numerous short wood roads lead from the main wagon roads to the timber. Sheep trails and wagon routes used by the sheepmen, as well as logging and timber roads, may be seen in many out of the way places. Good trails connecting the principal roads are maintained by the Forest Service.

Only two good wagon roads lead across the range. The western of these roads leaves the north flank of the range from Lucerne Valley and Birch Creek by way of Carter dugway, passing through the

Government parks on the way to Taylor Mountain, and thence down the south slope of the range between Ashley and Brush creeks to Vernal, Utah. The other road crosses the range near the east end, extending southward from Green River and Rock Springs by way of Bitter Creek and Aspen Mountain to Red and Willow creeks, Bridgeport, and Browns Park, thence southwest across Green River to Diamond Mountain and down the south slope of the range, crossing Little Brush, Brush, and Ashley creeks on the way to Vernal.

One of the main routes of travel between the west end of the range in the vicinity of the upper Provo and Weber valleys and the settlements along the south side of the range at Duchesne (Theodore), Myton, Fort Duchesne, Vernal, Island Park, and Jensen is along the north side of Duchesne River. A road on the south side of the river swings abruptly to the southwest a short distance south of Blacktail Mountain and leads through Strawberry Valley and Daniels Canyon to Heber, Utah. The wagon route to Heber most frequently used by the settlers in Duchesne Valley extends up the river as far as the old site of Stockmore, thence up the South Fork of the Duchesne to the mouth of Wolf Creek, up that creek, over the mountains, and down South Fork of Provo River. A traveler on horseback or with a buggy or light wagon can follow up the South Fork of the Duchesne and down Lake Creek to Heber, thus greatly shortening the distance. The old Indian trail extending from Whiterock Indian Agency to Heber passes through this part of the area and is still used as a trail or secondary road leading up Farm Creek, through Farm Creek Pass, crossing Rock Creek, and continuing to the east.

The main route of travel around the west end of the range from Provo and Weber rivers to the towns and settlements along the north side of the range is down Weber River to Coalville, up Chalk Creek, crossing the divide to Yellow Creek or Bear River, eastward along the old Fort Floyd (Salt Lake)-Fort Bridger emigrant road by way of Hilliard and Piedmont to Fort Bridger, and thence eastward to Granger and Green River. The main route around the east end of the range is from Rock Springs southward by way of Aspen Mountain and Salt Wells and Vermilion creeks to Ladore, at the lower end of Browns Park, and thence southeastward to Little Snake and Yampa rivers.

SETTLEMENTS AND VILLAGES.

The area under discussion is for the most part sparsely settled. A large part of the central belt along the mountain range is without agricultural settlers. The only inhabitants are a few prospectors, miners, hunters, and the lumber and logging crews that are engaged in cutting out timber both within and outside the national forests.

On both the north and south sides of the mountains there are ranches in all the larger valleys up as far as the mouths of the tributary canyons. Some of the bench land between the larger valleys is also used for agriculture, and wherever water is available this bench land can be made productive. Some of the soil is adapted to dry farming and the land is being taken up for this purpose. The settlements, however, are for the most part confined to the valleys or the bench lands in their immediate vicinity.

On the north side of the mountains the land has been taken up extensively for agriculture in three localities—along Bear River, along Blacks Fork in the vicinity of Fort Bridger and Mountain View, and along Henrys Fork from Lonetree east to Flaming Gorge.

Most of the land along the Bear River bottoms from Evanston southeast to the Wyoming State line, including Hilliard Flat and the lower part of Mill Creek, is devoted to agriculture. Evanston, the county seat of Uinta County, Wyo., on Bear River, is the main supply point for the area north of the Uinta Mountains. Hilliard was a thriving town immediately after the construction of the Union Pacific Railroad, when large sawmills and charcoal kilns were constructed there. Since the completion of the Aspen tunnel this town has been without a railroad and its present population consists of but a few families.

Another agricultural community of considerable importance includes the settlements in the vicinity of Fort Bridger, Mountain View, and Robertson, where there is an abundant supply of water for irrigation and good broad bottoms admirably adapted to farming. This early became one of the principal centers of settlement in the region and remains to-day one of the most productive agricultural localities in Uinta County. Besides the settlements there are scattered ranches on the bench lands and on many of the smaller streams between Fort Bridger and the mountains. The largest villages and trading posts in this area are located at Fort Bridger and Mountain View.

The third agricultural community on the north side of the range lies much nearer the base of the mountains and includes the bottom lands along Henrys Fork and its southern tributaries from Lonetree east to the mouth of Henrys Fork. The upper ranches on these smaller streams are near the base of the mountains, where the streams escape from their canyons. Lucerne Valley, on Spring Draw Creek near the mouth of Henrys Fork, contains the largest farming community in this locality. Part of the water used in this valley for irrigation is furnished by the Lucerne Valley canal, which is supplied by the headwaters of Sheep Creek.

Probably the most thickly settled agricultural community in the region at the present time lies at the west end of the Uinta Range.

The area includes the ranches along Weber River and Chalk Creek from Coalville south to Oakley, thence south through Rhodes Valley to Woodland, and thence along Provo River to Heber, Utah. Throughout this area all the valuable bottom and bench lands along the Weber and the Provo and their tributaries and all the level land in Rhodes Valley lying between the two rivers is utilized for agriculture. The soil is good and the farms here compare favorably with those in the vicinity of Salt Lake and Provo. The largest towns in this part of the field are Heber, on Provo River, the county seat of Wasatch County; Coalville, a mining town on Weber River and the county seat of Summit County; and Kamas, an important agricultural town near the center of Rhodes Valley.

On the south side of the range the country is even more sparsely settled than on the north side. However, as on the north side of the range, there are scattered ranches along all the larger streams below their narrow canyons. The only two localities on the south side within the area under discussion where agricultural settlement is as extensive as on the north side are along Dry Fork and Ashley Creek in the vicinity of Vernal and along Whiterock and Uinta rivers in the vicinity of Whiterock, Hayden, and Fort Duchesne, within the former Uinta Indian Reservation.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

The rocks in the Uinta Mountain region range in age from pre-Cambrian to Quaternary, inclusive. All the formations will not be described in this preliminary report, as it is the intention of the writer to prepare a more complete report on the geology of the Uinta uplift as soon as the preliminary examination of the east end of the range has been completed. The Park City formation, in which the phosphate deposits occur, and the formations immediately underlying and overlying the Park City, will be described so that the phosphate-bearing beds and the rocks associated with them may be compared with the phosphate-bearing beds of other localities in the Rocky Mountain region. The succession of the rocks underlying the Park City formation in the area under consideration is set forth in some detail by Boutwell[1] and Veatch.[2] The upper part of the strati-

[1] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, 1912.

[2] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: U. S. Geol. Survey Prof. Paper 56, 1907.

graphic section in this region has been also described by Veatch [1] and by the writer.[2] The upper part of the stratigraphic section on the south side of the range has been described by Gale [3] and Lupton.[4]

WEBER QUARTZITE (PENNSYLVANIAN).

Overlying the massive Pennsylvanian limestones, which may be considered as at least in part equivalent to the Morgan formation of the Wasatch Range, is a thick, massive gray to white quartzite or sandstone that has been correlated with the Weber quartzite of the Wasatch Range. With this quartzite are associated small quantities of chert and limestone. The absence of impurities and cementing material is conspicuous. On fresh fracture the quartzite is pure white to light brownish gray and it usually weathers to a light shade, although in some localities it has a decided brownish color. The quartzite or sandstone is fine, even grained, and dense. The exceedingly brittle nature of the rock causes it to break into sharp, irregular fragments that form conspicuous talus slopes. In some localities the sandstone has been so completely metamorphosed into quartzite that the form of the original constituent grains is not readily discernible by the naked eye. In many other places along both sides of the range, however, the Weber quartzite is nothing more than a rather soft sandstone in which the original grains are poorly cemented and readily detected and which on weathering produces a fine-grained sand remarkably free from impurities. Good exposures of this formation may be seen along both sides of the Uinta Range west of Green River wherever the beds have not been obscured by the overlying Tertiary deposits or by the Bishop conglomerate, of late Tertiary or early Quaternary age. The distribution of these beds is shown on the accompanying map (Pl. V, in pocket). East of the area examined and east of Green River the Weber quartzite beds are exposed by erosion at many places along the south flank of the mountains and along the crest of the Midland anticline at the south side of Blue Mountain, in Colorado, where it forms the center of the oval basin south of Midland Ridge.

The total thickness of this formation is approximately 2,200 feet in the western part of the Uinta Range and about 1,600 feet in the

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[1] Veatch, A. C., op. cit.

[2] Schultz, A. R., The northern part of the Rock Springs coal field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull 341, pp. 256–282, 1909; The southern part of the Rock Springs coal field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 381, pp. 214–281, 1910.

[3] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 55–94, 1910.

[4] Lupton, C. T., The Deep Creek district of the Vernal coal field, Uinta County, Utah: U. S. Geol. Survey Bull, 471, pp. 579–594, 1912; The Blacktail (Tabby) Mountain coal field, Wasatch County, Utah: Idem, pp. 595–628.

vicinity of Green River. Powell gives the thickness in the east end of the range as 1,000 feet or more.

These quartzite beds appear to be conformable with the underlying formation and to grade through less siliceous beds to the massive limestones below, which are at least in part equivalent to the Morgan formation. At no locality where these beds were examined was it apparent that an unconformity exists between these two formations. Berkey,[1] however, states that an erosive unconformity occurs in the upper Carboniferous beds in the western Uinta region just above the massive and cherty limestone member and below the last heavy quartzite of the Paleozoic section. S. F. Emmons,[2] who studied the relations of these beds on Duchesne River in the same locality where Berkey made his observations, did not recognize the unconformity and states that in spite of a most careful search he failed to find the basal conglomerate on which Berkey's scheme of correlation is mainly based. Weeks,[3] who was associated with Emmons in his studies in 1906 and who continued the studies throughout the range, makes the following statement regarding this supposed unconformity:

> The evidences of unconformity at the base of the Carboniferous Weber quartzite are inconclusive, as, contrary to Berkey's observations, no basal conglomerate in this series was noted in the Uinta area. Occasionally there is a small development of shales, but the transition from the underlying limestone to quartzite is usually through light-gray, fine-grained sandstones.

Except in Berkey's paper, no reference to an unconformity at this horizon has been made in any of the published reports on the Uinta and Wasatch ranges, so far as the writer is informed, and until more detailed work proves the presence of such an unconformity the beds in the Uinta Range must be considered conformable. The geologists of the Fortieth Parallel Survey did not recognize this quartzite formation as a separate unit but included it with their "Upper Coal Measures," and Powell[4] calls it the "Yampa sandstone" and describes it as the lower member of his "Upper Aubrey group."

PARK CITY FORMATION (PENNSYLVANIAN AND PERMIAN).

The Weber quartzite is overlain by a series of limestones of Pennsylvanian and Permian age, with which are associated some calcareous sandstones, shales, and chert. This formation contains the

[1] Berkey, C. P., Stratigraphy of the Uinta Mountains: Geol. Soc. America Bull., vol. 16, p. 524, 1905.

[2] Emmons, S. F., Uinta Mountains: Geol. Soc. America Bull., vol. 18, p. 298, 1907.

[3] Weeks, F. B., Stratigraphy and structure of the Uinta Range: Geol. Soc. America Bull., vol. 18, p. 442, 1907.

[4] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains, p. 149, U. S. Geol. and Geog. Survey Terr., 2d div., 1876.

phosphate deposits and has yielded the bonanzas that during the last decade have made the Park City mining district, in the Wasatch Range, Utah, a famous lead and silver camp. The formation consists for the most part of thin-bedded arenaceous limestones and shales with some massive limestone ledges near the base. Although consisting chiefly of limestones, it may be subdivided into four more or less distinct members which are usually recognizable in different parts of the field—(1) the upper thin-bedded shaly gray limestone series, which weathers readily, forming depressions, and at a distance has the appearance of a clay or shale bank; (2) the upper or cherty limestone beds, which contain a large percentage of concretionary chert nodules and lenses; (3) a phosphatic shale series, in which bands of chert and limestone occur; and (4) the lower limestone member, consisting primarily of massive light and gray limestones, some beds of which are from 5 to 25 feet thick. The upper member of shaly limestones has thus far not furnished any identifiable fossils but nevertheless has lithologic characteristics so distinctive that it is easily recognized wherever it is exposed. On Brush and Little Brush creeks and in the vicinity of Green River on both sides of the range this member is considerably thicker than at the west end of the field and consists of grayish-drab limestone and shaly limestone with a few streaks of pink or red clay near the top, all weathering to a dull slate gray so that the entire series, seen from a distance, looks like a gray clay bank. In some respects these beds resemble the Dinwoody formation along the east side of the Wind River Mountains, in western Wyoming. Future detailed work may result in differentiating them into a formation, but for the present they are retained as a part of the Park City formation.

The upper cherty limestone member is variable in detail but is prominent and easily recognized throughout the range. It consists of massive gray to cream-colored limestone 20 to 25 feet thick, underlain by gray and greenish dark chert in a matrix of shale. It is a controlling factor in the topography and produces long faceted dip slopes along the south side and a part of the north side of the mountain front. Certain parts of this member are highly fossiliferous and contain abundant specimens of *Leioclema*, *Derbya*, *Spiriferina pulchra*, and *Lingulidiscina utahensis*; other parts resemble somewhat the Rex chert member of the Phosphoria formation of eastern Idaho.

The phosphatic shale is probably the most distinctive member of the Park City formation. It is made up largely of black and green, decidedly fissile shale 40 to 50 feet thick and beds of limestone, sandstone, chert, and phosphate ranging in thickness from a few inches to several feet. Some of the beds of limestone and phosphate contain an abundance of fossils, a few of which have been collected for identification. In addition to the Bryozoa there are numerous comminuted fossil fragments, glauconite, and scattered foraminiferal shells. This member is probably equivalent to the lower part of the Phosphoria formation in eastern Idaho, as described by Richards and Mansfield.[1]

The lowest member consists chiefly of massive limestone with some beds of shale and sandstone. It is more variable than the overlying members and in some localities appears to be entirely missing, as the phosphatic shale or phosphate bed rests directly upon the Weber quartzite. It is probably owing to variations in this member and the upper member of the formation that the Park City shows so great differences in thickness throughout the field. The total thickness ranges from 250 feet or less to 850 feet or more in parts of the field where the beds have been measured. In certain portions of eastern Idaho where the phosphate deposits have been studied in great detail the lowest member of the Park City formation as here described was considered a separate member of the Park City formation, and later was included with the Weber quartzite and underlying beds as a part of the Wells formation. It appears, however, from the facts thus far gathered in the Uinta Range, that it must be considered a part of the Park City formation as defined by Boutwell in his Park City reports.

The contact between the Weber quartzite and the overlying Park City formation has been a subject of considerable study without definite results. The beds in many localities appear to be conformable, but the relations from place to place and the position of the phosphate series with regard to the Weber quartzite make it appear that the Park City formation unconformably overlies the Weber quartzite. However, until the beds are studied in greater detail and careful areal mapping is completed it will not be possible to state definitely the extent or magnitude of the unconformity. It seems improbable, however, that the relation between the Weber quartzite and the phosphate beds of the Park City formation can be satisfactorily accounted for in any other manner. Boutwell, who studied the formation in the Park City region of Utah, comes to the conclusion that the strata lie conformably upon the underlying Weber quartzite and that sedimentation proceeded unbroken from Mississippian time to the end of Park City time. He calls attention, however, to the fact that one geologist reported a marked unconformity at this horizon and that his own studies were not as conclusive or definite as might be wished. Blackwelder,[2] in his studies of the

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

[2] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, pp. 531–533, 542, 1910.

Wasatch Range, recognized the unconformable relation between the Weber quartzite and the overlying Park City beds and concluded that in the Wasatch Range there is an unconformity between the Weber quartzite and the overlying Park City phosphatic beds of Permian age. In another report[1] Blackwelder states that the base of the Park City formation is generally marked by beds of white and pink soft sandstone separated from the Weber quartzite by an obscure unconformity, which appears nevertheless to be one of considerable magnitude. Similarly, in the Wind River and Gros Ventre Mountains the Park City is known to rest upon the Tensleep sandstone (horizon of Weber quartzite) in apparent conformity at many localities, but close examination reveals evidence of an uneven erosion surface with some conglomerate at the base of the Park City beds. A similar unconformity has also been reported by Richards and Mansfield[2] in eastern Idaho. The conditions that prevailed during the period of deposition of the Park City formation mark the transition from those under which the great thickness of Weber sandstones was laid down to those under which the sediments formed red shale. The strata indicate deposition in comparatively shallow water and show an unstable or fluctuating shore line, as it appears that both elevation and depression of the shore occurred.

The irregularities and differences in thickness of the Park City formation may best be illustrated by giving some of the measured sections in different parts of the field. Boutwell's type section of the Park City formation in Big Cottonwood Canyon, Utah, given below, does not state the thickness of the phosphate bed or the phosphatic shale, nor does he show the horizon at which it occurs. However, the work done by Gale in the Park City district in 1909 proves that the phosphate occurs near the middle of the formation and is included with the 104 feet of beds overlying the 18 feet of siliceous arkose. In discussing the phosphate deposits Boutwell states that the phosphate bed noted at several points is about 3 feet thick and contains 32.6 per cent P_2O_5, or 71 per cent bone phosphate.

Type section of Park City formation in Big Cottonwood Canyon, Park City, Utah.

	Feet.
Grayish-white limestone, with fine gray and white cherts increasing toward bottom	19
Shale and fine buff sandstone	19
Dark-gray limestone; thin chert, red shale, and porous loose member at base	7
Sandy shale	11
Yellowish-gray quartzitic sandstone, changing into cherty white lime below	21

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

[2] Richards, R. W., and Mansfield, G. R., op. cit., pp. 16, 22.

	Feet.
Gray and white banded chert, with a few white sandstone intercalations	52
Fine calcareous sandstone, with lentils of chert and brecciated fragments of sandstone	8
Float of buff sandstone and shale, becoming more shaly and calcareous at base (containing phosphatic shale and 3-foot phosphate bed near base, 32.6 per cent P_2O_5; 71.39 per cent $Ca_3(PO_4)_2$)	104
Siliceous arkose, comprising mainly rounded quartz grains and feldspars cemented with ferruginous material	18
Compact grayish quartzite	20
White compact sugary sandstone, fossiliferous at base	8
Fine gray and pink massive quartzite, with brown sandstone and gray-white chert bands near base	30
Light-gray limestone, weathering whitish gray with an imbricated pattern; fine gray lime near base; carries good faunas at two horizons in particular, 20 and 55 feet above the base	27
Gray calcareous sandstone	24
Fine gray limestone	9
Float showing bits of grayish and brown calcareous sandstone	36
Sandy limestone, more calcareous at base, with cavernous weather surface	22
Float; upper sandy beds at top of Weber quartzite	31
	466

Section of phosphate beds of Park City formation on South Fork of Duchesne River, in the NW. ¼ sec. 25, T. 1 N., R. 9 W. Uinta meridian, Utah.

	Ft.	in.
Gray limestone; numerous fossils; on weathering has a greenish-yellow appearance	110	0
Greenish-drab limestone, with considerable chert nodules; cherty lenses, calcite geodes and veins, and some quartzite; contains numerous lenses and bands of phosphate one-half inch to 6 inches in thickness	17	0
Greenish-drab shales; chip readily into ½-inch to 1-inch pieces	3	0
Phosphate		8
Greenish-drab shale	2	0
Bluish-black phosphate shale; contains some phosphate throughout (phosphate sample No. 11, p. 92); 5.63 per cent P_2O_5; 12.33 per cent $Ca_3(PO_4)_2$	5	6
Phosphate bed containing fossils (phosphate sample No. 12, p. 92); 17.55 per cent P_2O_5; 38.43 per cent $Ca_3(PO_4)_2$	1	8
Black chert	6	6
Bluish-black fissile shale; chips into small pieces	16	6
Whitish-drab limestone, somewhat siliceous, more or less broken and in irregular beds	32	0
Gray limestone, with bands of chert	44	0
Gray-white sandstone; upper part of Weber quartzite	20	0
	258	10

Section of phosphate beds of Park City formation on east side of Whiterock River, in sec. 30, T. 2 N., R. 1 E. Uinta meridian, Utah.

	Feet.
Reddish-brown shales and sandstones	20
Gray siliceous limestone	2
Light yellowish-gray limestone, somewhat sandy	15
Gray limestone, with much chert; weathers brown similar to that overlying phosphate bed and immediately below the red beds	20
Cherty limestone, with layers of chert and concretionary chert nodules	20
Brownish-purple shales and sandstones, with green specks	15
Gray cherty limestones, forming massive ledge	8
Reddish-brown shales and thin shaly sandstones, with some green bands of shale and thin beds of limestone	100
Brownish-gray limestone that weathers dark and has pitted surfaces	20
Compact yellowish-gray limestone, somewhat cherty	27
Cherty grayish-green limestone, with nodules and bands of chert and thin beds of phosphate 1 to 4 inches thick	15
Brownish-drab and greenish-blue shales	10
Phosphate bed with chert nodules (phosphate sample No. 18, p. 92); 26.39 per cent P_2O_5; 57.79 per cent $Ca_3(PO_4)_2$	3
Drab phosphatic shale, with chert nodules and bands	5
Gray phosphatic limestone (phosphate sample No. 17, p. 92); 23.48 per cent P_2O_5; 51.42 per cent $Ca_3(PO_4)_2$	3
Bluish-gray phosphatic shale, with bands of phosphate and chert	6
Chert band containing a little phosphate on outer margins	¼
Bluish-gray shale	1½
Gray-brown asphaltic sandstone, with some phosphate	1
Whitish-gray limestone	1
Compact gray limestone	4
Weber quartzite; white sandstone, poorly cemented.	
	296¾

Section of Park City formation east of road from Vernal to Taylor Mountain, in the NW. ¼ sec. 4, T. 3 S., R. 21 E. Salt Lake meridian, Utah.

	Ft.	in.
Gray shaly limestone to base of red beds; top not seen	220±	
Light-gray limestones, some in massive beds, others thin bedded and compact, similar to those forming the top slope of the mountain. Some shales interlaminated with limestones	220	0
Green shales, with chert nodules and lenses of chert; concretionary and at a distance look like conglomerate	10	0
Greenish shales, containing some phosphate beds	2	0
Phosphate bed; dark to greenish shales and limestone (phosphate sample No. 27, p. 92); 22.73 per cent P_2O_5; 49.78 per cent $Ca_3(PO_4)_2$	3	2
Green shale, 4 inches, underlain by chert layer 2 inches thick		6

	Ft.	in.
Greenish sandy shales	1	0
Phosphate bed		3
Green shale, in thin beds		8
Dark phosphate material containing bands of black and green shale, layers of chert, and broad bands of sandstone; phosphate bands a few inches to a foot or more thick that appear as rich as those above and below (Nos. 27 and 28)	8	0
Phosphate material in layers; some thin beds, others thick (sample No. 28, from horizon sampled on Ashley Creek); 23.69 per cent P_2O_5; 52.88 per cent $Ca_3(PO_4)_2$	3	4
Greenish-gray limestone	1	0
Thin-bedded green shale		8
Dark-gray phosphatic sandstone	2	0
White sandstone (Weber quartzite), not well cemented.		
	472	7

Section of Park City formation west of road at east end of Phil Pico Mountain, in sec. 4, T. 2 N., R. 18 E. Salt Lake meridian, Utah.

	Feet.
Grayish shale to base of red beds	230
Gray limestone with bands of red	83
Light-gray limestone; one 10-foot ledge	42
Phosphatic shale series	92
Grayish massive limestone	125
Sandstone (Weber) along road.	
	572

Section of phosphate beds of Park City formation along small ravine south of the Boars Tusk, in (unsurveyed) T. 2 N., R. 21 E. Salt Lake meridian, Utah.

	Feet.
Upper member of Park City formation, consisting of shales and shaly limestone	200
Massive ledge of limestone, overlying the phosphate member	25
Phosphate member of Park City formation, including the chert beds	125
Limestone, basal part of Park City formation, overlying Weber quartzite	100
	450

Section of Park City formation along Green River above Horseshoe Canyon, in T. 3 N., R. 21 E. (unsurveyed) Salt Lake meridian, Utah.

	Ft.	in.
Limestone and shales of the upper part of the Park City formation; resemble the beds on Brush Creek, on the south side of the range. Thickness not measured.		
Massive ledge of limestone	15	0
Concretionary ledge of limestone	1	8
Phosphatic shales with thin beds of phosphate and bands of chert	1	8
Thin black paper-like shales	1	6

	Ft.	in.
Phosphatic material (sample No. 33, p. 92); 24.88 per cent P_2O_5; 54.49 per cent $Ca_3(PO_4)_2$	3	0
Thin black paper-like shales	1	10
Phosphatic material (sample No. 32, p. 92); 27.36 per cent P_2O_5; 59.92 per cent $Ca_3(PO_4)_2$	4	2
Group of limestone beds at base of phosphate beds	400±	

The Park City beds are well exposed on the north side of the range along South Fork of Weber River, at the west end of the range, and from Burnt Fork Creek eastward to the Boars Tusk, east of Green River, where the beds are cut out by the Uinta fault. Between Bear River and Burnt Fork Creek the beds are largely concealed by Tertiary and later sediments, being exposed only at the head of Mill Creek and on the divide between Mill Creek and Blacks Fork. On the south side of the range the beds are well exposed from Duchesne River eastward to Green River except in the vicinity of Yellowstone and Uinta rivers, where they are concealed by Tertiary or later deposits. The Park City formation throughout much of this region forms the dip slopes that rise gently into the mountain range. The geologists of the Fortieth Parallel Survey did not recognize this formation but included these beds with their "Upper Coal Measures group," and Powell included them with his "Upper Aubrey group" and called them the "Bellerophon limestone." Although the beds are highly fossiliferous and a good collection can be obtained at almost any locality, the conditions under which the present work was conducted did not warrant making extensive collections. Three small fossil lots were brought to the Survey and identified by G. H. Girty, who states that they contain the Phosphoria fauna. Lot 1 was collected from the limestone ledge overlying the phosphatic shale series; lots 2 and 3 were collected from the phosphate bed itself.

Lot 1. Limestone overlying phosphate shale, in the NW. ¼ sec. 30, T. 2 S., R. 22 E. Salt Lake meridian:

Nucula sp.
Plagioglypta canna.
Euphemus subpapillosus.

Lot 2. Upper phosphate bed in the NE. ¼ sec. 8, T. 3 S., R. 19 E. Salt Lake meridian:

Yoldia mcchesneyana.
Small undetermined gastropod.

Lot 3. Lower phosphate bed in the NE. ¼ sec. 8, T. 3 S., R. 19 E. Salt Lake meridian:

Lingulidiscina utahensis.

A fuller discussion of the fauna is given in a report by Girty.[1]

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

TRIASSIC AND JURASSIC (?) FORMATIONS.

The passage from the Park City formation to the overlying red-bed series is apparently a normal transition, and the beds are entirely conformable. Near the end of the Park City epoch red beds similar in lithologic character to those in the overlying red-shale series were deposited, and these are succeeded by more or less massive limestone beds, so that it is in places difficult to ascertain just where the boundary between them should be drawn. For example, it can not be stated at present whether the top of the Park City formation should be drawn at the base or at the top of the upper thin-bedded shaly gray limestone series, or whether the latter beds are not equivalent to at least a part of the Dinwoody formation along the east flank of the Wind River Mountains, in west-central Wyoming. In the Uinta region, however, these shaly limestone beds are treated as the upper member of the Park City formation, the upper boundary of which has been placed at the top of the highest massive limestone, or the light-gray shaly limestones where the massive beds are absent, and beneath the pronounced continuous red-shale series composing the Woodside shale.

The rocks overlying the Park City formation consist of a great thickness of red, brown, and purple shale, sandstone, and limestone that can readily be divided into separate formations, near the middle of which is an unconformity. The entire red series is commonly referred to as the "Red Beds" and is doubtless equivalent to the Chugwater and Dinwoody formations of central Wyoming. Good exposures of these beds may be seen on Duchesne River in the vicinity of Stockmore and on Weber River in the region of the Mahogany Hill, in the Coalville quadrangle. This series of red beds was described and mapped by the Fortieth Parallel Survey in part as "Permo-Carboniferous" and in part as Triassic. Powell classified the beds as Shinarump, Vermillion Cliff, and White Cliff groups. This series of beds was later divided by Boutwell[1] in the Park City region into the Woodside, Thaynes, Ankareh, and Nugget formations. These formations have been traced and identified by the writer throughout the Uinta Range. For a description of them the reader is referred to Boutwell's report.

STRUCTURE.

FOLDS.

UINTA ANTICLINE.

General features.—The structure of the Uinta uplift, considered as a whole, is comparatively simple. On closer study, however, the

[1] Boutwell, J M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, pp. 52–59, 1912.

long, narrow, flat-topped east-west fold which is here called the Uinta anticline is found to be much more complex and to consist of numerous secondary anticlines and synclines, some parallel to the main axis and others at right angles to it. There are also numerous low cross folds along the flanks of the major fold, expressed in undulations, local sags, and irregularities along both sides of the range. The anticlinal fold is further complicated by many normal faults and some thrust faults, both parallel and transverse to the strike of the beds. The major structural feature of the Uinta Mountains, however, consists of a huge east-west anticlinal arch approximately 100 miles long, and from 35 to 50 miles in width. This huge arch, which consists of rocks ranging in age from pre-Cambrian to Tertiary, separates the Green River Basin on the north from the Uinta Basin on the south. The Green River Basin near its southern part is in turn divided by the Rock Springs anticline, one of the more prominent north-south folds along the north side of the Uinta Range, into two smaller basins, the Bridger Basin on the west and the Red Desert or Washakie Basin on the east.

The present mountain mass is somewhat dissected by erosion, but in general the larger features are those determined by the underlying rock structure. The principal anticlinal fold extends from the Wasatch Range on the west to the Rocky Mountains on the east. Not everywhere throughout this distance is it of equal magnitude. There is, for example, a marked synclinal depression between the west end of the Uinta Mountains and the east flank of the Wasatch Range. Eastward from this synclinal depression the anticlinal arch becomes more pronounced, being much wider, and in the vicinity of Green River it is composed of two or more parallel ridges separated from each other by narrow synclinal basins. The major anticline extends eastward through Axial Basin, bends southeastward, and merges into the corresponding uplifts and folds of the White River Plateau, which are clearly a part of the Rocky Mountain system. This connecting axial uplift in the eastern extremity is of comparatively slight magnitude as a structural feature and is crossed by several transverse synclinal depressions similar to the one at the west end of the range, but it is nevertheless of geologic importance as separating the two extensive basins of the younger Cretaceous and Tertiary rocks that lie to the north and south of it. In parts of Axial Basin the major fold shows no greater intensity of uplift than other folds that are considered of secondary magnitude along the north and south sides of the Uinta Range.

Central area.—Along the broad central flat-arched anticlinal axis there are numerous slight sags and local undulations, but the average attitude of the strata in this part of the arch ranges from the horizontal to a dip of 5° or 6°. Farther back from the axis both to the north and to the south the dips become steeper and steeper toward the outer margins of the fold. The dips of the strata along the north side of the arch are as a rule more than twice as great as those along the south side and give rise to a distinct flexure, in which the beds not only assume an abrupt increase in dip but are in places overturned and faulted.

Southern slope.—The strata along the south side of the Uinta fold are moderately steep, showing throughout much of the area dips of 10° to 20°. In many places the angles of dip along the outcrop of the Mesozoic strata are from 20° to 45°, and in local areas 70° or 80°. The south limb of the fold is, however, much more uniform and regular than the north limb, although there are regions of faulting and abrupt changes to steep dips along both flanks of the range. Numerous secondary folds or undulations transverse to the major fold may be observed on the south side of the range. The structure is somewhat more complicated by a small amount of faulting, some of which is transverse to the strike of the beds.

On the south side of the mountains there are also a number of secondary folds whose axes are approximately parallel to that of the main Uinta fold. Two of these occur near the east end and one near the west end of the range. The one at the west end lies south of Currant Peak and is more or less complex. At present very little is known regarding the distribution of the formation along the axis of this fold, which brings to the surface beds of Triassic and Carboniferous age. The structure in this part of the field causes the Cretaceous rocks that strike east and dip 30° to 60° S. in the vicinity of the "narrows" of Red Creek to swing abruptly in the vicinity of Red Creek Peak and assume an almost due north direction, with eastward dips of 32° in the upper part and 60° in the lower part of the Cretaceous. The structure to the south and southwest of this anticlinal fold is largely unknown, as the older strata are covered deeply by rocks of Tertiary and later age. There may be at least two synclines and one anticline, in which Cretaceous and Jurassic beds are exposed, approximately parallel to the Wasatch Range, between this anticlinal fold and the east flank of the main Wasatch uplift. A short distance to the east, along the north side of Blacktail Mountain, the crest of a small east-west anticline is exposed in rocks of Mesaverde (late Cretaceous) age. The structure of the anticlinal fold south of Currant Peak is further complicated by considerable faulting, and it is quite probable that similar disturbances have affected the deeply buried rocks to the south.

At the east end of the range, in the vicinity of Green River, south of the mountains, there are two pronounced anticlinal folds whose axes are parallel to the Uinta Mountains—the Section Ridge anticline and the Split Mountain anticline. These two folds form, respectively, the western extension of Blue Mountain uplift and the Yampa Plateau.

Northern slope.—The structural relations along the north side of the Uinta anticlinal fold differ materially from those along the south side. For a considerable distance along the central part of the range on both the north and south sides the older beds are buried beneath the overlapping Tertiary sediments or by glacial material supporting a heavy growth of timber that completely conceals the structure, particularly along the north side of the range between Bear River and Henrys Fork. In contrast with the strata on the south side, which form long dip slopes and maintain nearly uniform dips over large areas, the strata on the north side whereever exposed are upturned at rather steep angles within a very short distance of the axis of the fold. The general easterly strike of the beds varies locally, as on the southern slope, and the dips of the strata change greatly along the strike, ranging near the west end of the range from 45° to 80° and as a rule increasing from the axis of the fold northward to the abrupt, faulted flexure along the northern margin of the fold briefly mentioned on page 56. Some of the largest faults observed in the Uinta Range occur along this flexure. Along Weber River and in the divide between Weber and Bear rivers the beds overlying the Weber quartzite are overturned, and the Weber quartzite dips from 80° N. to 90°.

The structure along the north side of the range from Weber River eastward to Green River is much the same as that outlined above. Throughout this part of the range, or eastward to Burnt Fork Creek, the structure along the outer margin of the fold is completely masked by Tertiary formations and glacial material, and the only evidence bearing upon it is obtained from the attitude of the beds along the central part of the arch and from the prominent Mississippian limestone that forms a bold east-west ridge extending for many miles, in which the beds are nearly vertical. Small outcrops of this limestone may be seen on all the larger streams along the north flank of the range from Weber River to Green River, except on Smiths Fork, where it is completely buried beneath later sediments, as it is in the areas between the larger streams. From Burnt Fork Creek eastward to Green River the exposures are good and the structural relations remain approximately the same as at the west end of the range. Near the headwaters of Sheep Creek, several miles west of Green River, there is a pronounced fault whose throw increases toward the east. A short distance east of Horseshoe Canyon on Green River the entire Carboniferous section is cut out and the red quartzite that forms the central part of the range is brought into contact with successively higher and higher beds toward the east until it lies next to the Upper Cretaceous. The attitudes of the strata on the north and south sides of this fault line are very different; the steeply upturned beds, in places vertical or overturned, lie along the north side of the fault contact, and the red quartzites immediately to the south of the fault dip to the north at comparatively low angles. The structure north of the Uinta Mountains is similar to that on the south side of the range in that the secondary folds seem to be restricted largely to the east and west ends of the range, but this may be due in part to the fact that the intervening area is almost entirely concealed by Tertiary and later sediments. Unlike the structure on the south side, however, the anticlinal folds appear to be approximately at right angles to the main Uinta fold and more nearly parallel to the Wasatch Mountain uplift. The more complex structure occurs at the west end of the range; that near the east end is comparatively simple. The larger secondary folds are the Coalville-Park City, Porcupine Mountain, and Meridian anticlines, at the west end of the range, and the Rock Springs anticline, near the east end.

SECTION RIDGE ANTICLINE.

The westward-pitching anticline on the south side of the range that forms the western extension of Blue Mountain is called the Section Ridge anticline. This fold, as recognized in the outcrops of the harder strata involved, passes beneath water level at Jensen, on Green River, and is of no structural importance in Ashley Valley. Sandstones that carry Benton fossils show in the river bank just above water at Jensen. The anticlinal fold is clearly revealed in Section Ridge, east of Green River, where a great rock wall over 3,000 feet in height stands on the north side of Cliff Creek and parallel to its upper course. The point of greatest flexure is near the south side of the fold, and therefore the south side of the ridge shows the steeply tilted beds of the hard Jurassic sandstones, with the lightly dipping strata of the same formation capping the summit. Toward the west, as the whole fold pitches in that direction, the harder strata form concentric curved ridges at the foot of the higher rocky escarpment.

SPLIT MOUNTAIN ANTICLINE.

North of Section Ridge and more or less parallel with it is a second ridge that extends westward from the Yampa Plateau and pitches in the same direction as Section Ridge. This craggy sandstone ridge is formed by the Split Mountain anticline, through which Green River passes in a deep canyon. The rocks exposed along the axis of the fold range in age from Carboniferous to Cretaceous.

The fold corresponds in form to that of Section Ridge, to the south, but is higher and reaches farther west, its axis pitching in that direction. As represented by the harder ledges at the base of the Cretaceous section, the fold disappears near the lower course of Brush Creek. At the western foot of Split Mountain the harder formations stand out as concentric curved ridges, passing around the end and continuing back to the east on its north side in the direction of Island Park. Along Brush Creek some minor irregularities of the larger anticlinal structure were noted, as is shown on the geologic map accompanying this report.

JENSEN SYNCLINE.

Between the Split Mountain and Section Ridge anticlines is a broad, open valley that extends in an easterly direction and opens into Ashley Valley west of Green River. This valley is a synclinal depression known as the Jensen syncline. East of Green River the synclinal basin becomes narrower and lies on older rocks. The western part of the basin is occupied by the hills and ridges carved out of the grayish-drab Cretaceous shale. The eastward extent of this syncline has not been determined, but it probably extends eastward for a considerable distance between Blue Mountain and Yampa Plateau.

ISLAND PARK SYNCLINE.

North of Split Mountain and between it and the uplift of the main Uinta Range is a much larger and broader open valley parallel to the one south of Split Mountain and, like it, opening into Ashley Valley and extending from Ashley Valley near Vernal eastward to Green River. At the east end, where the broad valley terminates on the north, east, and south against high cliffs and canyons, it is known as Island Park, and this name is given to the synclinal depression that forms the valley. Throughout the greater part of the distance this depression is occupied by the hills and ridges that have been carved out of the grayish-drab Cretaceous shale. Much of the topography closely resembles badland forms.

COALVILLE-PARK CITY ANTICLINE.

The structure of the rocks in the Coalville area is that of a slightly overturned anticline extending in a northerly direction. The beds rise toward the southeast on the northwest limb of this anticline with dips of 15° to 30° and a strike of N. 47° E., flatten rather abruptly on the broad, flat top of the fold, and descend precipitously on the southeast side with a strike of about N. 20° E. The whole thickness of Cretaceous rocks exposed at the surface, or about 9,000 feet, is involved in the fold, the beds descending in the syncline on the southeast from a surface altitude of 6,500 feet to approximately 500 feet below sea level and rising again to the surface about 4 miles east of the anticline, on the northwest flank of the Porcupine Mountain fold, which probably connects on the north with the folds southwest of Evanston, Wyo. The south end of the Coalville anticline is obscured by the overlying Wasatch (Eocene) formation, but it is believed that the anticlinal structure continues much farther south and probably connects with the anticline on Weber River south of Wanship, Utah, and with the Park City anticline still farther to the south.

The general geologic structure of the formations in the Park City area, at the west end of the Uinta Mountain uplift, is that of an anticline whose axis trends somewhat east of north at nearly right angles to the major anticlinal axis of the Uinta fold and more nearly parallel to the Wasatch Range. The anticline pitches toward the northeast, and the broad arch is considerably modified by strong faulting and minor local folding, some of which was very probably caused by intrusions. The Park City anticline, like the Coalville anticline, consists of a broad, low arch, but the sedimentary formations exposed at the surface in it are much older. The beds composing its flanks dip gently toward the northwest and to the east and southeast. The western limb includes beds from the Weber quartzite to the Nugget sandstone inclusive, and dips approximately 35° to the west and north. Just north of Park City the strike of the beds gradually swings around toward the east and the beds disappear beneath extensive flows of andesite. They reappear within a short distance, however, striking south and passing down the east side of the area to form the eastern flank of the Park City anticline.

To the east, in the synclinal depression between the Park City anticline and the west end of the Uinta Mountains, lies Rhodes Valley. A large part of the synclinal area is covered by great flows of andesite lava which floor the valley between the two mountain ranges.

Several miles northwest of the Coalville-Park City anticline another and more abrupt fold brings the Cretaceous rocks to the surface in the valley of Weber River 2 or 3 miles below Echo City. The fold is probably a part of the eastern limb of the anticline whose beds are exposed along the Union Pacific Railroad from Devils Slide west to Morgan, Utah, and which forms the eastern part of the Wasatch Range. The eastern limb of this anticlinal fold apparently parallels the fold at Coalville, Utah. Between the western anticline, which is a part of the Wasatch uplift, and the Coalville anticline lies the syncline of Echo Canyon, which involves to some extent the strata of the Wasatch formation.

Wegemann,[1] who studied the coal deposits in this field, states that the beds in the Coalville anticline north of the town of Coalville strike about N. 35° E. Near the town, however, the strike changes, so that in the vicinity of the Sargent mine, on the west side of the Weber, it is N. 19° E. The upper beds hold the same strike for about a mile farther south, to the point where they are covered by the overlying Wasatch deposits. They give no indication of a minor fold which involves the lower beds just southeast of the town of Coalville. The outcrop of the principal bed of coal (of Upper Cretaceous age and locally known as the "Wasatch" bed), formerly mined at Coalville, takes a direction approximately due south at the old Buell & Bateman mine and, swinging to the southeast, is opened at the mine of the Superior Fuel & Briquette Co. From this place it swings to the northeast and east, thus outlining the small fold above mentioned, and is opened on the north end of the adjoining syncline at the old Howard mine, in the NW. ¼ sec. 15, T. 2 N., R. 5 E. From this opening it can be traced a short distance to the southeast but is soon lost beneath the Wasatch cover. It probably turns again in a south or southwest direction to conform with the strike of the coal beds exposed in Spring Canyon, but how far south it may extend before connecting with the outcrop marking the southeast side of the fold is impossible to determine. The coal beds in Spring Canyon appear, from their position and the character of the associated strata, to represent those north of The Narrows at Chalk Creek, which lie 850 feet below the "Wasatch" coal bed exposed at the Hoffman mine. If the coal in Spring Canyon really belongs to this lowest coal group, the anticline probably continues for a considerable distance farther south and may be directly connected with the anticline that crosses Weber River 1½ miles south of Wanship and represents the northward extension of the northward-plunging Park City anticline.

PORCUPINE MOUNTAIN ANTICLINE.

East of the Coalville-Park City anticline lies the Porcupine Mountain anticline, whose axis is nearly parallel to the one on the west and extends in a northerly direction. The anticline plunges toward the south and passes beneath Tertiary sediments a short distance south of Chalk Creek. A large part of the Jurassic rocks that form the crest of the fold is buried beneath Tertiary sediments a short distance north of Porcupine Mountain, but a part of this anticlinal

[1] Wegemann, C. H., The Coalville coal field, Utah: U. S. Geol. Survey Bull. 581, p. 168, 1915.

fold may be traced northward to the Needles and Medicine Butte, respectively south and northeast of Evanston, Wyo. The Porcupine Mountain anticline, along the southeast side of which are exposed strata belonging to the Frontier and Aspen formations, of Upper Cretaceous age, and the Beckwith formation, chiefly of Jurassic age, similar to those in the Evanston field, represents the southward extension of the Rock Creek-Needles anticline as described by Veatch.[1] The anticlinal fold near its south end is somewhat broken by faults. At least one fault cuts diagonally across the anticline, and it is very probable not only that the structure there is further complicated by faults but that some of the faults observed by Veatch and the writer in 1905 in the Evanston region, associated with the anticlinal structure, extend southward to Porcupine Mountain. As the beds are largely covered by Tertiary deposits, individual faults can not be traced readily from place to place, and their identification is therefore difficult.

MERIDIAN ANTICLINE AND ASSOCIATED FOLDS AND FAULTS.

From 10 to 15 miles east of the Porcupine Mountain, Rock Creek, and Needles anticline is another zone of disturbance which extends in a northerly direction and parallels the strike of the older beds to the west, but only the southern part of this zone lies within the area here considered. Exposures of the older beds do not extend as far south along this belt of complex structure as they do in the Porcupine Mountain anticline, whose older beds are, similarly, not exposed as far south as those in the Coalville-Park City anticline. The underlying folded structure in each zone east of the Coalville-Park City anticline no doubt extends south to the north flank of the Uinta Range, but toward the east the older beds along the north-south anticlines are concealed by Tertiary sediments farther and farther back from the range.

The southern exposures of the complexly folded rocks in this eastern area lie north of an east-west line that passes through the north end of Porcupine Mountain and consist of three more or less distinct units which are described in detail for the region to the north by Veatch.[2] From east to west they are (1) the west limb of the Meridian anticline, a fairly regular fold along the east side of which, farther north, are one or more secondary folds; (2) a somewhat irregular and in places overturned syncline, the Hilliard-Lazeart syncline; and (3) a much broken and faulted anticline lying west of the Hilliard-Lazeart syncline and separated from it by a

[1] Veatch, A. C., Geography and geology of southwestern Wyoming, with special reference to coal and oil: U. S. Geol. Survey Prof. Paper 56, p. 110, 1907.

[2] Idem, p. 108.

very large and continuous thrust fault—the Absaroka faulted anticline. To the west of the exposures of these older rocks, or between the Absaroka anticline on the east and the Porcupine Mountain, Rock Creek, and Needles anticline on the west, there is probably a broad syncline which represents the southward continuation of the Fossil syncline, though it is deeply buried in this area beneath Tertiary deposits.

Meridian anticline.—The Meridian anticline is almost wholly buried by Tertiary strata, which cross the anticline, dip east toward the Green River Basin, and obscure practically all clues to the position of the fold. From the exposures along the west limb of the anticline and along its crest in the region to the north, in the valley of Little Muddy Creek, 3 or 4 miles east of Cumberland, Wyo., and also from the well boring of the Union Pacific Railroad at Bridger station,[1] the approximate location of the anticlinal axis beneath the Tertiary beds may be inferred, if it is assumed that the structure is a simple anticline. In the region to the north, however, there is considerable evidence that it is not a simple anticline at its northern extremity, and this complexity may extend southward to the Uinta Mountains. It is indeed highly probable that other similar folds, both anticlinal and synclinal, may occur beneath the Tertiary sediments of the Green River Basin east of the Meridian fold, in the area between it and the Rock Springs anticline. The crest of the Meridian anticline, as shown by the exposures to the north and inferred from its probable approximate position beneath the Tertiary beds, is composed almost wholly of strata of the Beckwith formation, but the exposures along the west limb are composed of Cretaceous sediments. The anticline, so far as known, is very regular, although the beds are displaced locally by minor faults.

Hilliard-Lazeart syncline.—West of the Meridian anticline, in the vicinity of Hilliard, Wyo., the parallel syncline is entirely overturned, the lower or eastern limb dipping westward at angles from 25° to 30° and the upper or western limb from 90° to 130°. Between Hilliard and the Aspen tunnel it becomes a normal syncline with dips of 20° to 30° on the east and 40° to 75° on the west. The Adaville formation, of probable Mesaverde age, which is present along the deepest parts of this syncline at Hilliard and in the area to the north, is separated into four isolated areas along the synclinal axis by its rise and pitch. Only one of these areas, that in the vicinity of Hilliard, lies within the area covered by this report. The beds along the west limb of the syncline are greatly disturbed, the amount of disturbance increasing with their proximity to the Ab-

[1] Veatch, A. C., op. cit., pp. 155–156.

saroka fault line. A short distance south of Hilliard the beds are concealed by later sediments.

Absaroka faulted anticline.—West of the Hilliard-Lazeart syncline is an enormous thrust fault, the Absaroka fault, along which the strata have been overthrust from the west. A short distance south of Hilliard the fault is concealed by Tertiary sediments, but it can be traced northward for many miles along the east side of the Absaroka, Salt River, and Snake River mountains into eastern Idaho. Along this fault the displacement in some localities approximates 15,000 to 20,000 feet. In the vicinity of Hilliard the Beckwith strata are in contact with Frontier beds of Upper Cretaceous age, of about the horizon of the Oyster Ridge sandstone member, and the total stratigraphic displacement, including the distributive faulting to the east of the main fault, is from 10,000 to 15,000 feet. In the region from Hilliard northward for many miles there is a zone of pronounced faulting and folding just east of the main Absaroka fault and apparently associated with it. In this zone of faulting is the Oil Spring fault, which extends from Hilliard Flat northward for a distance of 12 miles and passes beneath the Tertiary cover. Between Hilliard and Altamont it has produced a duplication of the Oyster Ridge sandstone which is somewhat confusing to one not familiar with the stratigraphy. West of the Absaroka fault there is some folding which indicates faulted anticlinal structure. To the west of this anticlinal area the beds dip westward, indicating that the area between the faulted Absaroka anticline on the east and the Porcupine Mountain, Rock Creek, and Needles anticline on the west is a broad syncline. On Sulphur Creek and around Knight the Jurassic beds just west of the fault suggest a closely compact anticline which marks the eastern limit of this parallel and overturned syncline on the west. The eastward-dipping beds of the Bear River formation and the coals near old Mills siding on the Union Pacific Railroad cut-off, on Sulphur Creek due south of Knight, are clearly on the upper or eastward flank of an overturned syncline.

ROCK SPRINGS DOME.

The Rock Springs dome or anticline, near the east end of the Uinta Range, east of Green River, extends in a north-south direction approximately at right angles to the Uinta uplift. It consists of Cretaceous and Tertiary strata which rise in the midst of the nearly horizontal rocks of the Green River Basin and partly divide the southern portion of the basin into two smaller units, the Bridger Basin on the west and the Red Desert or Washakie Basin on the east. The major axis of the fold is approximately 90 miles long and lies near the west limb, along which the beds dip 5°–30° W.; those along the east limb dip 5°–10° E. The minor axis is approximately 50 miles long and extends across the dome in a direction north of east, passing north of Aspen Mountain and through a point 4 miles north of Black Buttes, a station on the Union Pacific Railroad. Several small anticlines and synclines occur upon the main dome. Two of the largest of these cross folds are near the south end of the dome and are parallel to the minor axis of the fold and to the trend of the Uinta uplift. The oldest beds involved in this dome are of Montana age. They are exposed in the vicinity of Baxter, a station on the Union Pacific Railroad, and crop out for a distance of about 30 miles along the crest of the dome. The Rock Springs dome is separated from the Uinta uplift by a narrow and comparatively shallow synclinal depression parallel to the Uinta uplift.

FAULTS.

GENERAL FEATURES.

Although the primary structure of the Uinta Mountains is comparatively simple, the low-arched anticline is somewhat complicated by both normal and thrust faulting. By far the most intense faulting occurs along the north flank of the range, where the outcrops of the Mesozoic beds exhibit one of the major flexures of the anticlinal arch. Extensive faulting has also occurred west, northwest, and southwest of the west end of the range and in the area between the Uinta and Wasatch mountains. Along the south side of the range minor faulting has occurred in a number of localities. A short distance back from the major structural axis of the mountains the faults exert but slight influence on the distribution of coal and phosphate beds. Many small faults have no doubt passed unnoticed in the reconnaissance examination, and there may be many larger faults along the central part of the range entirely within areas that were not visited. Faults occur at many places along the strike of the soft shales, which seem to constitute a line of weakness, and such faults may be passed unnoticed in a preliminary examination during which only a small part of the area can be studied.

SOUTHWEST OF DUCHESNE RIVER.

Considerable faulting has taken place in the older rocks along the anticlinal fold south of Currant Peak, about midway between the Uinta and Wasatch ranges. The structure in this part of the field is complex, and the amount of faulting has not been ascertained. It is very probable, however, that these disturbances have materially affected the distribution of the phosphate beds both along the anticlinal arch and in the more deeply buried synclinal basins between it and the Uinta fold on the northeast and the Wasatch Range on the southwest.

SOUTH SIDE OF UINTA RANGE.

Berkey,[1] in describing the faulting of the beds in the Uinta Range in the vicinity of Duchesne River, states that the most persistent fault of the south flank of the range crosses the East Fork of Duchesne River at the mouth of Iron Creek, a small tributary from the west. The fault strikes east and is in all this immediate district the dividing line between the great basal quartzite of the Uinta Mountains and the shales, sandstones, and limestones of the later Paleozoic. A throw of at least 3,000 feet is measurable at this point and in the adjacent gorges, where the fault shows plainly, but on the plateau to the east between Duchesne River and Rock Creek the break may be easily overlooked, as the formations seem to be in normal succession. Toward the east the major fault line cuts strata higher in the series, at least through the Carboniferous rocks. There are in this vicinity other small faults and shattered zones along which there has been vertical displacement. The magnificent section of Paleozoic beds exposed along the walls of the gorge is rendered rather difficult to read through the abundant slips or faults parallel to the stream, by which narrow slices of the walls are let down a few hundred feet here and there, probably by sapping, so that portions of the cliff sections are duplicated. S. F. Emmons,[2] who examined the locality in the Duchesne Valley in 1906, concludes that the Iron Creek fault has not the structural significance that Berkey would assign to it and states that it can be traced only 7 or 8 miles on each side of the Duchesne Valley, though similar strike faults occur at several points along the southern flanks of the range, more commonly where the strata have taken an abrupt downward bend, so that the existence of the faults there is less evident than on Duchesne River. In spite of its striking prominence in the valley bottom, the Iron Creek fault could not be detected on the plateau-like summits of the spurs on either side of Duchesne River, except by a special search. This fault is usually interpreted as a normal fault, although Weeks,[3] who examined it in 1906 in company with Emmons, states that it is normal where it crosses Duchesne River at the mouth of Iron Creek, but that at the head of the West Fork of Rock Creek it has developed into a thrust fault. The fault extends nearly parallel to the strike of the beds and can be traced for only a short distance. Similar faulting at this horizon has been observed farther east and is to a large extent associated

[1] Berkey, C. P., Stratigraphy of the Uinta Mountains: Geol. Soc. America Bull., vol. 16, p. 523, 1905.

[2] Emmons, S. F., Uinta Mountains: Geol. Soc. America Bull., vol. 18, p. 297, 1907.

[3] Weeks, F. B., Stratigraphy and structure of the Uinta Range: Geol. Soc. America Bull., vol. 18, p. 443, 1907.

with minor warpings of the beds, which have in places been sharply plicated and compressed.

A sharp anticlinal fold was observed along the west side of Whiterock River, directly opposite the prominent point of Weber quartzite on the east side of the river known as Whiterock Point. To the northeast this fold develops into a fault with the downthrow on the east. The fault strikes east of north and can be observed along the west side of Mosby Mountain until it passes beneath the Bishop conglomerate that forms the flat table-land of the mountain. The displacement of the fault is not great but is sufficient to cut out most of the shale series overlying the red quartzite, the quartzite being in places in direct contact with the Mississippian limestones. A good section of all the strata in normal position, from the Mississipian limestone down through the underlying brown-maroon shales, sandstones, and limestones to the red quartzite beds, can be seen west and south of Whiterock River.

A fault somewhat similar to the one on Whiterock River was observed along the west side of Dry Fork in the area between that stream and Little and Lake mountains. The fault here strikes northwest and the downthrow is on the southwest. The displacement is not great but has slightly affected the distribution of the phosphate beds. The block between Dry Fork and Whiterock River has been dropped by normal faulting. The fault plane is readily observed northwest of Little Mountain but was not traced farther northwest. In the vicinity of Little Mountain several small faults were noted, the throw of which, although slight, is sufficient to be troublesome in mining coal or phosphate. Similar faults no doubt occur at many places along the major fault lines and elsewhere along the south side of the range.

Another fault of about the same magnitude as the one west of Dry Fork was observed on Brush Creek, southeast of Taylor Mountain. This fault is approximately parallel to the one along Dry Fork and, like it, has the downthrow on the southwest. Along parts of Brush Creek there is a marked difference in the position of the phosphate-bearing Park City formation on the two sides of the stream, the beds lying much higher on the east side than on the west. This difference may be due in part to a sharp fold that has been faulted. There are other disturbances along this fault line farther northwest, in the area between Dyer's mine and Taylor Mountain, but the structural relations have not been worked out in a satisfactory manner. The limestones in the vicinity of Dyer's mine lie much farther north than those at the south end of Taylor Mountain. Whether this displacement is due to faulting, to folding, or to both has not been determined. There is evidence of minor folding, fissuring, and faulting, and probably all these processes have taken place.

WEST END OF UINTA RANGE.

Park City area.—At the west end of the Uinta Range faulting has modified the structure much more than along the south side of the range. In this region the continuity of the Park City anticline has been greatly broken by faulting and intrusion. A number of zones of faulting have considerably modified the structure. In the northeastern part of the district Boutwell obtained evidence of a great and remarkable dislocation which he called the Frog Valley fault. The facts observed by him indicate a great compound overthrust fault in which the west side has ridden up over the east side for many hundred, probably more than 2,000, feet. The principal faults in the Park City area have been described by Boutwell.[1] Considerable faulting has also taken place along the Park City-Coalville anticline, farther northeast. The older rocks throughout much of this area are covered by lava flows and Tertiary sediments which completely conceal the underlying structure.

Coalville area.—A little north and east of Coalville, at about the middle of the Coalville anticline, a block of strata 2 miles in width from northeast to southwest has been dropped by faulting with reference to the adjacent beds. The faults bounding this block on the northeast and southwest are by no means simple ones. On the southwest four distinct faults may be observed within a distance of 1¼ miles, the downard movement of the central block being thus distributed along four different lines of fracture. The fault bounding the displaced block on the northeast is apparently a simple fracture where it crosses Grass Creek, but a short distance to the south it branches into a number of faults, as is shown by an isolated mass of coal in the middle of sec. 27, T. 3 N., R. 5 E. Numerous small faults have been noted in the northeastern workings of the Wasatch mine, in the NE. ¼ sec. 3, T. 2 N., R. 5 E., and it is probable that these faults will be found to increase in displacement toward the larger fault. The flattening of the rocks on the crest of the fold, which is approximately 3 miles in width, accounts for the fact that whereas the upper coal on Grass Creek is displaced less than half a mile by the greater fault which crosses secs. 23, 26, and 35, T. 3 N., R. 5 E., the lower bed cropping out farther southeast and thus nearer to the top of the fold is by the same fault displaced a horizontal distance of over 2 miles. The movement was probably vertical, the block southwest of the fault being dropped, and the horizontal displacement may thus be accounted for by a movement

[1] Boutwell, J. M., op. cit., pp. 94–96.

of only a few hundred feet in the gently dipping beds near the crest of the fold. The trace of the fault to the south is somewhat uncertain. It is possible that the abrupt change in dip at The Narrows, in the SW. ¼ sec. 12, T. 2 N., R. 5 E., is in line with the fault, but whether or not it passes between the coal exposures in the SW. ¼ sec. 1 and the NE. ¼ sec. 11, of the same township, is undetermined.

REGION NORTHWEST OF UINTA RANGE.

Porcupine Mountain area.—A few miles east of the faulted Coalville anticline a fault cuts diagonally across the south end of the Porcupine Mountain anticline. The fault strikes south of west, nearly at right angles to the strike of the beds. The downthrow is on the south side of the fault, where the Upper Cretaceous Aspen shale is carried approximately 1 mile west of the exposures on the north side. Detailed work in this part of the field will no doubt prove the presence of other faults. It is very probable that some of the faults observed along the Rock Creek-Needles anticline in the vicinity of Evanston, Wyo., extend southward to Porcupine Mountain.

Bear River area.—Several miles east of the Rock Creek, Needles, and Porcupine Mountain anticline and accompanying faults lie the highly distorted and faulted beds that mark the location of the great Absaroka thrust fault. This fault zone extends into the area covered by this report only a few miles before it passes beneath the Tertiary and later sediments and is lost to view. As the faults along both of these disturbed zones can be studied much better in the area to the north and have been described by Veatch,[1] no discussion of them will be given here.

NORTH SIDE OF UINTA RANGE.

Marked faulting has also taken place along the north base of the Uinta Mountains and parallel with it. A prominent east-west fault zone was observed in the vicinity of Rockport, Utah, on Weber River. This faulted zone or band of shattered rocks can be traced eastward along the south side of Elkhorn Divide and Big Piney Mountain and north of the Mahogany Hills to Weber River, in T. 1 N., R. 6 E., where it passes beneath the river alluvium and glacial deposits. It no doubt extends eastward along the bottom lands of Weber River to T. 1 N., R. 8 E., where it again can be traced for a distance of 5 miles across the divide between Weber River and West Fork of Bear River, to be once more lost from view beneath the Tertiary sediments that occupy the area to the east. The true nature of the

[1] Veatch, A. C., op. cit., p. 110.

fault zone at places along the range where it can be observed has not been determined. Enough has been seen, however, to warrant the statement that it is not a simple fault but is somewhat complex, consisting of a compound fault or a series of associated faults more or less parallel to the strike of the range. Near Rockport the faulted zone lies well down on the north limb of the Uinta anticline and is for the most part in beds of Beckwith age, which dip 40°–50° N., the downthrow being to the north. Whether the fault at the west end of the range is a normal or a thrust fault was not determined, but from the facts gathered along the north side of the range farther east it appears that throughout much of the area it is a thrust fault in which the force came from the south or southeast. The throw increases materially toward the east. North of the Mahogany Hills the Twin Creek limestone on the south is brought into contact with the Beckwith on the north. The same relations are observed as far east as Weber River in T. 1 N., R. 7 E., where the Cretaceous beds on the north are brought into contact with the Jurassic and Triassic beds on the south. These conditions apparently prevail for a considerable distance along Weber River, and on the divide in T. 1 N., R. 9 E., the Frontier formation was found in contact with the Twin Creek limestone, of Jurassic age, and the Triassic red beds of the Thaynes and Woodside formations. The beds south of the fault in the vicinity of the Mahogany Hills and the lower part of Weber River dip 35°–40° N., whereas along the upper part of the river and in the divide between Weber and Bear rivers they are much steeper, dipping 60°–80° N., and in a few places vertical or even slightly overturned. The beds north of the fault throughout this distance are completely overturned, dipping 90°–130° N. The overturned relations may best be observed in the Frontier beds east of Big Piney Mountain and in the Frontier and Twin Creek beds on the divide between Weber and Bear rivers. East of this divide all evidence of the fault is concealed by Tertiary sediments.

From the evidence obtained along the outcrops of the older beds along the north base of the range it appears that the abrupt change in dip for the most part occurs along the extreme north flank of the mountains, as in the western part of the range, and the overturned and faulted zone may therefore lie approximately along the strike of the Jurassic and Cretaceous rocks, which are almost everywhere buried beneath the nearly horizontal Tertiary sediments. This view is further strengthened by the facts observed by Gale while examining the upper part of the Cretaceous rocks in the Henrys Fork coal field, in the vicinity of Manila and Linwood, Utah. Gale[1] states

[1] Gale, H. S., Coal fields in northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 236, 237, 1910.

that the Mesaverde formation crops out at Green River near the center of the broad valley area north of Flaming Gorge, just north of the mouth of Henrys Fork. Toward the west the formation is evidently cut off by a fault near Linwood post office, on Henrys Fork. Opposite Linwood post office, about a quarter of a mile north of Henrys Fork, two thick beds of coal are exposed in nearly vertical position. The strike of the beds is N. 67° W. and the dip 80°–85° S., clearly indicating that they are overturned. Toward the east the outcrop follows the direction of the recorded strike for a few hundred feet, then bends abruptly south and disappears under an upper terrace capped by consolidated river deposits. The Mesaverde beds appear to lie close to a line of evident structural displacement, probably a fault of considerable magnitude.

The north flank of the range is apparently much broken by faults along the abrupt flexure in the Jurassic and Cretaceous beds, which are largely obscured by the Tertiary strata that unconformably overlie the older rocks. Neither the stratigraphic relations nor the structure is therefore clearly revealed.

The displacements which the formations in the Uinta Range have suffered are numerous, and some of them are of great vertical extent. The principal displacement, however, has occurred along the Uinta fault, the major fault of the Uinta region. This fault was observed only on the north side of the range from the headwaters of Sheep Creek eastward to the northwest corner of the State of Colorado. Neither the eastern nor the western limit of the fault was seen. In the vicinity of Lucerne Valley, near the mouth of Henrys Fork, the fault lies about 6 miles south of Linwood post office and extends approximately parallel to the faulted zone above described. Near the source of Sheep Creek the fault lies entirely in the red quartzite series that makes up the main part of the anticlinal crest of the range, and the amount of displacement can not readily be determined. The downthrow is on the north, and considerable evidence indicates that this is a thrust fault in which the pressure came from the south or southeast. West of Sheep Creek the fault strikes south of west, cutting across the headwaters of Burnt Fork, the tributaries of Beaver Creek, Henrys Fork, and Smiths Fork some distance north of Burro, Gilbert, and Wilson peaks. The westward extension of this fault apparently is represented by the fault or sharp fold in the strata north of Gilbert Peak. South of the area of disturbance the beds are nearly horizontal, but on the north they dip 30° N. Toward the east the fault strikes approximately N. 75° E., with many changes and irregularities from place to place that indicate more clearly the character of the thrust fault. The displacement also rapidly increases and cuts out successively higher and higher beds in Paleozoic stratigraphic section. The lower Paleozoic beds are largely cut out west of Sheep Creek, which the fault crosses, in T. 2 N., R. 19 E., and all the Paleozoic section up to the Weber quartzite is cut out west of Green River so that the red quartzite series rests against the steeply upturned and in places overturned beds of the Weber formation. A few miles east of Green River, 3 miles east of Flaming Gorge, in the vicinity of the Boars Tusk, all the beds up to the Cretaceous have been cut out, and the red quartzites rest against the steeply upturned and overturned Cretaceous formations. Still farther east, in T. 1 N., R. 23 E., in the divide between Spring and Red creeks, 3 miles south of Richards Mountain, the fault has cut out all of the Cretaceous section up to the Mesaverde formation, and the red quartzite beds rest against the overturned beds of the Rock Springs coal group and overlying beds. In T. 1 N., R. 25 E., the fault cuts out all of the Mesaverde formation, and toward the east it apparently cuts out more and more of the normally overlying beds. In the divide between Red and Willow creeks the fault passes beneath the Tertiary cover and is lost from view. The Tertiary beds south of Richards Mountain also in places rest against the red quartzites, but the erosion along the tributaries of Spring and Red creeks has revealed the underlying structure.

Everywhere along the line of the Uinta fault there is profound disturbance. The beds north of the fault are greatly disturbed, steeply upturned, and in places overturned, and the beds of the red quartzite series south of the fault are nearly horizontal or dip 10°–40° N. East of Green River there appear to be secondary folds or plications on the gently northward-dipping limb of the major anticline, involving the beds of the red quartzite series. However, as the eastern part of the range has not been examined, no further statement regarding its structure can be made at this time. The Uinta fault is probably not a simple fault plane, but the major fault is accompanied by numerous secondary faults more or less parallel to the zone of faulting. Small faults are numerous along this zone, and many of them occur along the strike of the shale or softer beds, which seem to form a line of weakness. Many of the faults along this zone, as well as in other parts of the field, have probably been passed over without recognition, and future detailed work will no doubt prove the presence of many local disturbances not here described. The Uinta fault is by far the largest in this region, and its displacement in the vicinity of Red Creek, according to present information, involves a stratigraphic interval of not less than 20,000 feet. Most of this displacement seems to be vertical, although there may also be a horizontal displacement of considerable magnitude.

REGION NORTHEAST OF UINTA RANGE.

The great Uinta fault no doubt separates the greater part of the Uinta anticline from the Rock Springs anticline, whose axis is nearly at right angles to that of the Uinta fold. The structural relations of the older rocks at the junction of these two anticlines is entirely concealed, however, and can only be inferred from the structure ascertained at more distant points on the two folds. The two anticlines are closely related structurally, and the faulting observed elsewhere in the Uinta Range is equally well represented, although on a somewhat smaller scale, in the Rock Springs anticline.

The general dome or anticlinal structure of the Rock Springs arch is somewhat complicated by many normal faults of considerable throw. Here and there the horizontal displacement along the fault line amounts to 3 miles; the vertical movement is usually less than 100 feet but in a few localities reaches several hundred feet. Near the south end of the Rock Springs anticline, in T. 14 N., R. 103 W., along the crest and south limb of a low anticline parallel to the Uinta uplift, there is an overthrust fault which has a vertical displacement of 200 feet. The fault plane dips 20° S., indicating that the thrust came from that direction.

Some of the faults extend across the dome, others cut only one limb or part of one limb, and still others extend for only a few hundred feet or a mile or two and then die out. Some of the larger faults have been traced for a distance of more than 20 miles. The general trend of the faults is nearly at right angles to the strike of the rocks or across the axis of the major anticline. In some places, however, the angle of departure is large and the fault more nearly parallels the strike than the dip of the beds. This is well illustrated near the north end of the dome, where the faults cut some of the rocks at right angles to their strike and before dying out continue approximately along the strike of the underlying beds. The position of the larger faults is shown on the map accompanying the writer's report on the southern part of the Rock Springs coal field.[1]

In addition to the larger faults that are readily detected on the surface, numerous small faults are encountered in mine workings. In the Rock Springs coal group, from the Van Dyke or lowest coal bed upward, there is at many places a system of characteristic joints or slips that cut the coal at short intervals from floor to roof. These slips incline toward the south, and along many of them there are displacements of half an inch to a foot or more. As a rule these small faults do not interfere with mining but rather assist in breaking or parting the coal, thereby making it easier to mine. In regions of

[1] Schultz, A. R., U. S. Geol. Survey Bull. 381, pl. 15, 1910.

much faulting the offsetting of the coal beds may so increase the cost that mining will be abandoned or development work stopped.

The exact period of the faulting is not known. It may have occurred at different times during the gradual uplift of the dome after the end of Cretaceous deposition. It is believed, however, that most if not all of the faulting in the Rock Springs area occurred when the leucite lava flows at its north end were poured out on the surface and was associated with the movements that gave rise to the renewed uplift in the Uinta Mountains immediately before the period of deposition of the Bishop conglomerate, which is entirely independent of the faults and folds in the underlying rocks and is probably of post-Eocene age.

PHOSPHATE DEPOSITS.

EARLY INVESTIGATIONS.

Phosphate deposits of commercial possibilities were first discovered in the Rocky Mountain area by Albert Richter,[1] of Salt Lake City, who recognized the true character of the deposits, located a number of claims, and in 1889 opened discovery pits on them in Weber and Cache counties, Utah, in the area between La Plata and Bear Lake. Phosphate deposits in this part of Utah were independently recognized in 1897 by R. A. Pidcock, who found some old prospects, presumably opened for gold, in a soft black formation on Twelvemile Creek, a branch of Woodruff Creek, Rich County, Utah, from which he gathered some material that on analysis proved to be phosphate. In 1903 C. C. Jones[2] examined and studied these deposits on Woodruff Creek and traced their outcrop in many places in southeastern Idaho, southwestern Wyoming, and northeastern Utah. The United States Geological Survey's investigations in the Rocky Mountain phosphate field began in 1906, and the more detailed work was undertaken in 1909. Since then reconnaissance and detailed study and classification of phosphate and nonphosphate lands have been made a part of each summer's field work. The results have been published in the form of progress reports. These reports, together with other data available in the Survey, indicate that the phosphate beds occur and have been traced in part south, east, and west from the locality where they were first found in northeastern Utah, in the vicinity of the Idaho, Utah, and Wyoming State line, halfway across the State of Wyoming in an easterly direction and across the western part of the State in a northerly direction, across the eastern part of Idaho along the Wyo-

[1] Richter, Albert, Western phosphate discovery: Mines and Methods, vol. 2, p. 207, 1911.

[2] Jones, C. C., Phosphate rock in Utah, Idaho, and Wyoming: Eng. and Min. Jour., vol. 83, pp. 953–955, 1907; The discovery and opening of a new phosphate field in the United States: Am. Inst. Min. Eng. Trans., vol. 47, pp. 192–216, 1913.

ming line, across the north end of Utah east of Salt Lake, and southward along the east side of the Wasatch Mountains nearly to the center of the State. The phosphate deposits also extend northward to the vicinity of Helena and Philipsburg, in west-central Montana, covering an area that measures about 220 miles from east to west and 420 miles from north to south.

Rock-phosphate deposits of the same type as those in the vicinity of Woodruff, Rich County, Utah, those in the vicinity of Montpelier, Idaho, and those along the east flank of the Wind River Mountains, in Wyoming, were found by the writer in August and September, 1914, while he was engaged in a geologic reconnaissance examination of an area in northeastern Utah in the vicinity of the Uinta Mountains. The phosphate deposits occur on both sides of the range in Summit, Wasatch, and Uinta counties. It is believed that commercial deposits of phosphate have not heretofore been generally known in this part of Utah, and no sign was observed that these beds had ever been thoroughly prospected for phosphate, although in two places, one on West Fork of Lake Fork and the other along Little Brush Creek, the beds have been examined for coal and oil and small, shallow trenches cut across the bed. On the west side of Little Brush Creek Mr. Goodman, a local rancher, prospected these beds and opened a short tunnel in the phosphate series, finding some high-grade rock.

In the Uinta region the phosphate rock, which was recognized by its physical characteristics, was found as float along the outcrop of the phosphate bed, and rock in place was also found along the south and north flanks of the Uinta Mountains. The more massive part of the bed, which is usually found as float, somewhat resembles a dark, coarse, granular limestone which may be mistaken on casual examination for a dark fine-grained basalt or a very fine sandy conglomerate. It has an oolitic structure, is dark gray to brown or black in color, is noticeably heavier than the other sedimentary rocks with which it occurs, and on many of the weathered surfaces has a bluish-white coating. The specific gravity of the richer phosphate rocks in this field is about 2.8. The oolitic texture, though constituting one of the most definite features of the phosphate rock, is in places somewhat obscure, and in others it is entirely missing and the bed may be composed of shale, sandstone, or nonoolitic limestone, rich in phosphoric acid. Because of the weaker constitution of the shaly rocks they commonly give way to weathering and decomposition at the surface, and the phosphate outcrop thereby becomes concealed wholly or in greater part, while the harder fragments of phosphate rock remain in the soil and are readily detected by one who is familiar with its appearance. In parts of the field rock-phosphate float is but moderately abundant in the vicinity of the

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outcrops of the phosphate bed, but in other parts the surface is covered with numerous small fragments of phosphate rock.

DISTRIBUTION OF DEPOSITS.

The distribution of the phosphate beds and the Park City formation, which contains them and which is equivalent to the Phosphoria formation and the upper part of the Wells formation of eastern Idaho in the Bear Lake region, can be partly inferred by reference to the accompanying map (Pl. V, in pocket). The outcrops of the phosphate beds seen in the field are shown by lines with small crosses; the inferred outcrops whose locations are reasonably certain are shown by the same symbol. For parts of the field where the structure is complex or the phosphate beds are entirely covered by Tertiary or later sediments and were therefore not examined, the inferred positions are not indicated, although it is reasonably certain that the phosphate beds occur within certain well-defined limits at considerable depths below the later sediments.

The phosphate beds in this area are very similar to those described by Gale, Richards, and Mansfield in their reports on the area in eastern Idaho, and in many respects they resemble even more closely the phosphate deposits along the east flank of the Wind River Mountains. Only a few small prospects have been opened on the phosphate beds in the area examined, and most of these were opened for purposes other than to mine the phosphate rock. No attempt was made in the reconnaissance examination to prospect the phosphate outcrops, and therefore a detailed description of the beds can not be given. Samples of float and fragments of rock in place picked up at several localities along the outcrop to show the character and richness of the phosphate deposits indicate the presence of high-grade material and show that workable beds similar to those prospected in the Bear Lake region are undoubtedly present. A preliminary study of the phosphate rock was made, and samples were collected in some of the localities along both the north and south sides of the range, the results of which will be briefly discussed in this report.

The phosphate beds are not continuously exposed along either flank of the mountain range, as large areas near the center on both the north and south sides of the anticline are concealed by Tertiary and later sediments, which divide the phosphate exposures into four areas, two on the north side of the range and two on the south side. The two on the north are the Henrys Fork area, near the east end, and the Weber-Bear River area, on the west, the two on the south are the Whiterock-Brush Creek area at the east and the Provo-Duchesne River area near the west end. It is highly probable, however, that the phosphate deposits are continuous throughout the areas in which they are concealed but lie at considerable depths below the Tertiary cover. At the west end of the range, where the phosphate-bearing beds are not everywhere concealed by overlying Tertiary deposits, the outcrop is nevertheless largely covered by soil, glacial material, and vegetation, so that it is exceedingly difficult to find exposures of the phosphate bed or of the Park City formation sufficiently satisfactory to permit measurement of the entire series. The best exposures of these beds at the west end of the range occur along Weber River near the mouth of the South Fork.

Throughout the Uinta Mountain uplift the entire phosphatic series, which constitutes only a part of the Park City formation, is approximately 35 feet thick and varies from place to place. In this formation there is a single phosphatic zone in which the beds of phosphate, thick and thin, rich and lean, occur. Some of the beds several inches in thickness consist almost entirely of phosphatic material; others are composed chiefly of chert nodules and lenses with a little phosphate material. The thicker beds consist of cherty limestone, shale, sandstone, and phosphate beds from 1 to 6 feet in thickness. Individual layers or beds in this series contain more or less phosphatic salts ranging from 1 to 70 per cent tricalcium phosphate, the maximum being equivalent to 32 per cent phosphoric acid. When compared over large areas these layers are found to be variable as to both character of bed and quantity of phosphoric acid present, not only vertically but horizontally, and yet in many respects they are rather uniform and constant in character and have throughout the field certain common characteristics. Even where the basal member of the Park City formation is present in this field no trace was found of the lower phosphate bed that is present in that basal member along the southeast flank of the Wind River Mountains. In many places, however, this member appears to be missing and the main phosphate series rests upon the Weber quartzite.

The richest portion of the phosphatic zone is generally a dark-gray oolitic sandy limestone thickly speckled with black phosphatic granules and containing in places small particles of tarlike gilsonite and other hydrocarbon compounds. When the phosphate rock is dissolved in nitric acid it leaves a copious residue of fine sand with a tarlike oily substance which probably represents the material that gives the fetid or petroliferous odor readily noted when the rock is broken with the hammer. Certain layers of this rock are filled with disk-shaped fossils (*Lingulidiscina*) and numerous specimens of *Nucula* and other diminutive pelecypods, which are badly broken and poorly preserved. From this phase of the rock there are all gradations both in composition and in color to phosphatic gray, brown, and black shales, phosphatic fossiliferous limestone and dolomite, and phosphatic sandstone and chert. Samples of rock that have been collected for analysis from the phosphate zone represent as a rule only a small part of the entire series, having usually been taken from one or more of the richer-looking beds that range in thickness from 1 to 6 feet. The results thus far obtained indicate that the phosphate deposits are fairly uniform throughout the range, although some of the analyses show a much lower phosphate content than others. Some of the rock samples were known not to represent the best part of the bed but were collected in order to show the variations in the phosphoric acid content of the strata. Until the beds have been carefully sampled at the same horizons at many more localities it will not be possible to make a definite and reliable statement regarding the variation in the phosphate beds from point to point along the outcrop or from bed to bed at different stratigraphic positions. In fact, the appearance of the phosphate rock itself can not be relied upon in selecting the richest material, as the color, texture, and general appearance of the rock are very deceptive and the leanest-appearing portion may on analysis be found to be surprisingly high in tricalcium phosphate.

PHOSPHATE DEPOSITS ON NORTH SIDE OF UINTA RANGE.

WEBER-BEAR RIVER AREA.

The Park City formation, in which the phosphate deposits occur, is known to be present on the north side of the range from its west end in the vicinity of the Mahogany Hills, where Weber River cuts a canyon through the beds overlying the Park City formation before emerging into the broad, open valley 2 miles northeast of Oakley, Utah, eastward to the divide between Weber River and the West Fork of Bear River, where the outcrops of the phosphate-bearing beds are concealed beneath Tertiary sediments. Approximately 12 miles farther northeast along the strike of the beds, at the head of Mill Creek, a tributary to Bear River, and in the divide between Mill Creek and Blacks Fork, the phosphate-bearing beds are exposed in a small area where the Tertiary beds have been removed by erosion. Eastward from this divide to the vicinity of Burnt Fork, which forms the western limit of the eastern phosphate area, the beds are buried beneath the Tertiary sediments.

The phosphate-bearing beds at the head of Mill Creek overlie the Weber quartzite, which in this part of the field, as well as farther west, along the south side of Weber River, forms a prominent and conspicuous ridge. One of the tributaries of Mill Creek cuts directly across this ridge at nearly right angles and exposes a part of the Park City formation, and another tributary flows for a short distance along the north side of the ridge parallel to the strike of the beds and thus exposes part of the Park City and the overlying red beds. The exposures at the head of Mill Creek and in the divide between this stream and Blacks Fork are poor, and it is only with difficulty that even an approximate section can be measured, as the Tertiary sediments and glacial material in most places mask the underlying formations. The Park City beds are overlain in apparent conformable relation by 100 feet of red beds that are probably equivalent to the Woodside shale. No doubt the Woodside shale here is much more than 100 feet thick, but its upper portion is concealed. The Park City beds lying between the Woodside shale and the Weber quartzite are approximately 600 feet thick and consist of the following series:

Approximate section of phosphate-bearing beds of the Park City formation at the head of Mill Creek, in T. 2 N., R. 11 E. Salt Lake meridian, Utah.

	Feet.
Limestone and shale	36
Limestone	4
Limestone and shale	40
Cherty sandstone	20
Calcareous sandy beds	6
Shaly limestone, gray	94
Gray limestone and shale	360
White sandstone, gray limestone, and shale	40
	600

The phosphate bed itself was not exposed at any point along the strike of the Park City formation, but abundant float was observed along the apparent outcrop to indicate clearly that the bed, though concealed, must be present beneath the soil and débris. No sample of the phosphate float fragments was collected at this point for analysis. Farther west, in the divide between Bear and Weber rivers in T. 1 N., R. 9 E., the Park City beds are still more completely concealed and it was not possible to measure any part of the formation. Search was made for phosphate float a short distance back from the Weber and Park City contact along the north slope of the Weber quartzite ridge, and in most places it was readily found. The outcrop or strike of the Park City formation was not traced throughout the Weber River area, but wherever examination was made the phosphate float fragments were found. No detailed section of the phosphate series, however, could be made without first opening a trench to the underlying beds. Fragments of phosphate float were picked up along the strike of the Park City beds in the SW. ¼ sec. 17, T. 1 N., R. 9 E., on the divide between Weber River and the West

Fork of Bear River about half a mile south of the bench mark shown on the Hayden Peak topographic sheet as 9983 but marked on the iron post 9963 feet. The result of the analysis of these fragments (No. 3, p. 92) shows 67.47 per cent of tricalcium phosphate and proves the presence of some high-grade phosphate rock.

The Park City formation from the Weber-Bear River divide westward to Oakley, Utah, strikes southwest, and dips 35° to 85° to the north or northwest. At three places the beds are crossed by large rivers, along which ideal exposures of the phosphate beds should be expected. However, at none of these places was the phosphate bed itself seen. West of the divide the first stream that cuts across the formation is the Weber, in T. 1 N., R. 8 W.; the second is Smith and Morehouse Creek, in T. 1 N., R. 7 E.; and the third is the South Fork of Weber River, in T. 1 S., Rs. 6 and 7 E. Along the South Fork the Park City beds are well exposed and a good measurement of the entire formation can no doubt be made. No measurement was made, however, in this preliminary examination, and the phosphate bed itself was not seen in place, although float fragments were observed at many points along the strike of the beds. On Weber River south of the Mahogany Hills, at the mouth of Whites Creek, the Park City beds swing abruptly toward the south, and within a short distance the beds strike nearly due south and pass beneath the bottom lands of Rhodes Valley. On the west side of the synclinal depression in which Rhodes Valley lies, along the east side of the Park City anticline, the phosphate beds are again exposed in the vicinity of Park City, Utah. This locality was not visited in the course of the writer's preliminary examination, but the deposits have been described by Boutwell in the report already cited.

Two samples of float phosphate rock were picked up on the east side of Smith and Morehouse Canyon in the NE. ¼ sec. 36, T. 1 N., R. 7 E. Sample 1 (see p. 92) consists of chert fragments which appear to be colored slightly by their content of phosphoric acid but are composed largely of quartz, and sample 2 apparently represents the phosphate bed. Both of these samples were collected only a few feet above the contact of the Weber quartzite and Park City formation. Float sample 4 was collected a short distance to the east, in the SE. ¼ sec. 28, T. 1 N., R. 8 E., about halfway between Weber River and Smith and Morehouse Canyon, and float sample 5 was collected in the SE. ¼ sec. 33, T. 1 N., R. 7 E.; both of these probably represent the phosphate bed. More detailed examinations along the strike of the phosphate bed will no doubt reveal localities where the bed can be sampled and measured without opening prospect pits, but none were observed in the preliminary examination. The float samples, the analyses of which are given in the table on page 92, indicate, however, that some high-grade phosphate rock occurs in this part of the range.

HENRYS FORK AREA.

The eastern phosphate area on the north side of the Uinta Mountains lies along the north flank of the mountains from 6 to 8 miles south of Henrys Fork and more or less parallel to that stream. At its east end, near the mouth of Henrys Fork, the phosphate beds lies less than 2 miles south of the river, and within a short distance they are cut out entirely by the Uinta fault south of the Boars Tusk, a prominent topographic point in T 2 N., R. 21 E., 3 miles east of Horseshoe Canyon of Green River. The Henrys Fork area extends from the Boars Tusk westward to the divide between Burnt Fork and the East Fork of Beaver Creek, a distance of approximately 30 miles. The general strike of the beds is east, although, owing to the minor irregularities in the main Uinta fold, numerous deviations from this trend were observed along the outcrop. The strata at the east end are in places nearly vertical and near the fault are largely overturned. The dip is generally to the north and varies from point to point, being as low as 15° in some places and nearly vertical in others. Near the west end of the outcrop the beds usually dip 35°–60° N.

The first low range of hills along the base of the main ridge in this area is due in part to its capping by the more resistant limestone ledges of the Park City formation. The quartzite beds in the upper part of the Weber formation, immediately below the Park City, are comparatively soft and weather readily, causing a depression between the base of the Park City beds and the lower part of the Weber formation. The dip slopes of the low front ridge are composed almost everywhere of Park City beds, and, as a result of the erosion which has occurred, the phosphate bed winds up and down the slopes between the higher points of the hills and the lower depressions along the valleys that cut almost at right angles across the strike of the beds. The phosphate bed crops out through much of the area south of Sheep and Lodgepole creeks and in the western part cuts directly across Lodgepole and Birch creeks and Burnt Fork. The phosphate beds are not well exposed at the west end of the area, but farther east the entire series is well shown. On the northwest bank of Burnt Fork in sec. 36, T. 3 N., R. 16 E., a prospect tunnel has been cut in the upper part of the cherty phosphatic limestone, presumably for copper. Two thin beds of phosphatic material were encountered, but the main phosphatic bed and associated shales were not opened by the tunnel, and it is probable that the prospectors failed to recognize the phosphatic character of the material penetrated. No measurement of the main phosphate bed or the Park City formation could be made from any of the natural exposures. The approximate position of the phosphate bed, however, can be located from the position of the underlying and overlying rocks and from the abundance of float along the strike of the beds.

On the west side of Birch Creek in the SW. ¼ sec. 34, T. 3 N., R. 17 E., fragments of phosphate float were picked up for analysis. An attempt was made to get a large variety of fragments in order to represent the entire bed from which the material was derived. After being ground together, all the material gathered proved on analysis (No. 29, p. 92) to contain 44.76 per cent of tricalcium phosphate. On the west bank of Lodgepole Creek in the SW. ¼ sec. 3, T. 2 N., R. 18 E., where the irrigation ditch has exposed the phosphatic shale series, a sample was collected from a 4-foot bed near the base of the series. This sample on analysis (No. 30, p. 92) yielded 67.28 per cent of tricalcium phosphate, clearly indicating the presence of high-grade phosphate in this part of the range. Farther east Lodgepole Creek cuts through the overlying beds and exposes the phosphate bed in the stream in the northwest corner of T. 2 N., R. 19 E., south of Jessen Butte. On the west bank of Sheep Creek south of the mouth of Lodgepole Creek a sample of phosphate rock was collected from a 2-foot bed. This sample represents a peculiar phase of the phosphate series not generally present or at any rate not readily observed, as it was seen for the first time in the section on Lodgepole Creek, where the irrigation ditch exposed the beds. Here, as well as on Sheep Creek, the 2-foot bed lies about 10 feet above the bed sampled on Lodgepole Creek and is not as rich in phosphoric acid as the lower bed. The sample on Sheep Creek (No. 13, p. 92) contained 58.21 per cent of tricalcium phosphate, as compared with 67.28 per cent from the lower bed on Lodgepole Creek. Two other samples were collected from the phosphate series on the east side of Green River at the upper end of Horseshoe Canyon, in the SW. ¼ sec. 31, T. 3 N., R. 21 E. The stratigraphic position of the phosphate beds sampled at this point is given in the section on page 53, and the analyses of the two samples (Nos. 32 and 33) are given in the table on page 92.

PHOSPHATE DEPOSITS ON SOUTH SIDE OF UINTA RANGE.

PROVO-DUCHESNE RIVER AREA.

The western phosphate area on the south side of the range lies along the south flank of the mountains from Provo River in the vicinity of Woodland, Utah, eastward across the divide between

Provo and Duchesne rivers, crosses the Duchesne south of its junction with the South Fork, continues eastward, crosses numerous small tributaries of Duchesne River, Rock Creek, and the West Fork of Lake Fork at nearly right angles, and disappears beneath later deposits in T. 2 N., R. 5 W., Uinta meridian, a short distance farther east. The phosphate bed and other strata of the Park City formation are not exposed continuously throughout this distance but are in many places concealed beneath Tertiary deposits, the Bishop conglomerate, glacial material, soil, and river gravels. East of the exposures along West Fork of Lake Fork the beds are masked by later deposits for a distance of about 25 miles, but they reappear in the vicinity of Whiterock River in T. 2 N., R. 1 E. Uinta meridian. The beds are no doubt continuous at considerable depth between these two localities. Here, as on the north side of the range, the Tertiary and later deposits appear to extend farther back into the mountains and conceal all traces of the Park City and other pre-Tertiary formations.

The phosphate beds throughout this area strike in a general easterly direction and dip 10°–45° S. At both the east and west ends of the area the strike swings somewhat to the north, giving the outcrop a somewhat curved or convex form. The phosphate bed in the western part of the area lies entirely south of Provo River and is almost entirely concealed by later sediments, as it is also in the divide between Duchesne and Provo rivers. The best exposure of the Park City beds in the Provo River valley was observed on the South Fork of Provo River in T. 4 S., R. 8 E. Salt Lake meridian. The beds here strike northwest and dip 25° SW. Farther northwest the beds are more completely buried by later deposits, and only along the deeper streams can traces of the underlying beds be observed. Even on South Fork the exposures are very meager and only a fragmentary knowledge of the Park City formation can be obtained. Along Provo River southeast of Woodland, Utah, the Park City phosphate-bearing beds are not exposed but are probably present at a considerable distance below the surface. The beds may indeed be continuous throughout Rhodes Valley, passing beneath Woodland, Kamas, and Marion, and may join the outcrop of the beds observed on Weber River northeast of Oakley, Utah. At no point along the strike of the phosphate beds south of Provo River were the beds seen in place. Their approximate location was inferred from the underlying formations and from the fragmentary pieces of phosphate float picked up on South Fork, Willow Hollow Creek, Little South Fork, and Bench Creek. The analyses of these float fragments (Nos. 6, 7, 8, and 9) are given in the table on page 92. Phosphate deposits no doubt occur also in the highly folded and faulted area lying between Heber

Mountain and Currant Peak on the northeast and the Wasatch Mountains on the southwest. This area probably represents the southeastward extension of conditions similar to those in the Park City district along the Park City anticline.

East of the divide, between Provo and Duchesne rivers, the Park City beds are fairly well exposed, and numerous localities may be selected where the phosphate bed and the entire formation can readily be measured. At one of these localities, on the South Fork of Duchesne River, 1½ miles below the mouth of Wolf Creek, a measurement was made and two samples of phosphate rock (Nos. 11 and 12) were collected. This measured section and the position of the phosphatic series are shown on page 50. The analyses of the rock are given in the table of analyses. The phosphate series is also exposed at several places along Wolf Creek but is for the most part covered by soil and timber. Two samples of the phosphatic-shale series were obtained along the north side of Wolf Creek. One (No. 13) represents 6 feet of phosphatic shale and was collected at a point where a small stream has exposed a part of the beds; the other (No. 14) represents 4 feet of the shale series, presumably at the same horizon, collected at a place where a small cut in a bank along the wagon road indicated the presence of the phosphatic-shale beds. Neither of these samples shows a very high content of phosphoric acid. They may or may not represent the best phosphate bed in the section exposed at this point. It is more likely, however, that they represent some of the phosphatic shales rather than the main phosphate bed. It is very probable that better grades of phosphate are present in some of the other beds in the phosphatic member of the Park City formation. Sample 10, representing a 4-foot bed of phosphate, was collected from the west side of Duchesne River below the site of the old town of Stockmore, Utah. This rock contains approximately 40 per cent of tricalcium phosphate.

East of Duchesne River the phosphate outcrop was not traced continuously all the way to Rock Creek, but it is reasonably certain that the phosphate rocks are present throughout this distance. On Rock Creek and the small tributary valley to the east the Park City beds were observed, but the phosphate bed was nowhere seen. Fragments of phosphate float, however, were observed along the strike of the formation in both places, indicating the presence of phosphate deposits in this locality. No samples of this float material were collected, as the phosphate fragments appeared to be like those previously gathered for analysis farther west. In the divide between Rock Creek and West Fork of Lake Fork the phosphate-bearing beds are concealed beneath Tertiary sediments and the Bishop conglomerate.

On the east and west sides of West Fork of Lake Fork the beds are exposed in a very small area. Samples 15 and 16, neither of which is high in phosphoric-acid content, were collected from the phosphatic-shale series northeast of the stream. The main phosphate bed lies some distance above the two beds sampled and was not sampled at this point. Sample 15 represents 6 feet of asphaltic sandstone containing only about 9 per cent of tricalcium phosphate. It is reported that this bed has been prospected for oil at several localities along the south side of the Uinta Range, from West Fork of Lake Fork to Duchesne River and from Whiterock River eastward to Green River. The sandstone apparently contains some asphaltic material at many localities. Sample 16 was taken from 3 feet of thin-bedded bluish-black phosphatic shale that overlies the asphaltic sandstone and looks particularly lean but contains 26.89 per cent of tricalcium phosphate. East of this locality, for a distance of about 25 miles, no exposures of the phosphate beds or the Park City formation in which they occur were observed. It is entirely possible, however, that when detailed work is undertaken in this area and a careful search made along all the smaller streams and valleys other exposures of the Park City beds may be found in the larger drainage valleys along Yellowstone and Uinta rivers.

WHITEROCK RIVER-BRUSH CREEK AREA.

The eastern phosphate area on the south side of the Uinta Range extends from the vicinity of Whiterock River eastward to Island Park on Green River, a distance of about 45 miles. The outcrop of the phosphate beds is parallel to the mountain range and is cut directly across by Whiterock River, Dry Fork, and Ashley, Brush, and Little Brush creeks. At the east end of the area, between Diamond Mountain and Green River, the outcrop swings abruptly southward. South of Island Park the strike again turns abruptly and the outcrop strikes west, parallel to the outcrop on the north side of the Island Park syncline. A short distance east of Brush Creek the outcrop of the phosphate beds swings southward around the west end of the Split Mountain anticline and continues eastward on the south side of this anticline until it crosses Green River. The beds no doubt continue much farther to the east between the Split Mountain and Section Ridge anticlines and along the south side of Section Ridge and Blue Mountain, but they have not been traced east of Green River and the location of the formation is not known. The dips near the east end of the Island Park syncline along the north side of Split Mountain are 40°–80° N.; at the west end they are 45° N. Along the north side of Split Mountain the Park City beds extend well up on the north slope of the anticline, and good exposures of the phosphate bed are rare.

Along the south side of the main Uinta fold the dips range in general from 5° to 40° S., but throughout most of this area they are between 10° and 25°. However, at the west end along Whiterock River the beds dip 75° S. and are in places nearly vertical. In the area between Mosby and Diamond mountains the Park City beds form the dip slope on the south flank of the Uinta fold and in many places the phosphate beds are cut into by the smaller tributaries of Ashley and Brush creeks, so that the actual outcrop of the phosphate bed is much more irregular and complex than is shown on the accompanying map. These irregularities can not be shown on the scale of the map, and few of them were located in the field. Along many of the deeper tributaries the streams have cut down to the Weber quartzite, in which the beds of the dry gulches lie. The outcrop of the phosphate bed at the upper margin of the dip slope is also concealed in many places by the Bishop conglomerate. The outcrop was not traced in the area between Diamond Mountain and Island Park, the approximate location being determined from Island Park and the south part of Diamond Mountain.

On Whiterock River the exposures of the Park City beds are restricted to a small area on the east and west banks. The phosphate bed here is nearly vertical, dipping from 75° S. to 90°, and crops out in a narrow band near the south base of the prominent point on the east side of the river locally known as Whiterocks Point, composed of the Weber quartzite. A section of the Park City formation was measured south of this point, and two samples of phosphate—Nos. 17 and 18—were collected for analysis. The details of the section and the position of the phosphate beds sampled are given on page 51. Both of the beds sampled show phosphate rock of good grade, containing 51.42 and 57.79 per cent of tricalcium phosphate. A short distance east of Whiterock River the phosphate beds are concealed by the Bishop conglomerate and Tertiary sediments, which cover most of the area on Mosby and Lake mountains.

The phosphate deposits are again exposed on Mosby Creek, where the beds strike in a general easterly direction and dip approximately 20° S. Near the head of a small tributary to Deep Creek, in the NE. ¼ sec. 8, T. 3 S., R. 21 E. Salt Lake meridian, the phosphate bed was sampled. The section is very similar to that on Whiterock River, and the phosphate is equally good. Sample 19 represents 1 foot of phosphate rock, containing many small black shells, which lies in the upper part of the phosphatic shale series, and sample 20 represents a 3-foot bed of phosphate near the bottom of the series. Both samples contain phosphoric acid equivalent to more than 57 per cent of tricalcium phosphate. In the northeast corner of T. 3 S., R. 19 E., and the western part of T. 3 S., R. 20 E., there is a prominent fault, which displaces the phosphate beds. The fault strikes northwest along the west side of Dry Fork, and the downthrow is to the southwest. The amount of displacement was not determined. East of the fault, on the west bank of Dry Fork, a sample of the phosphatic shale series was collected from a bed about 100 feet below the crest of the steep escarpment along the southwest side of Dry Fork. The beds here lie between two massive ledges, of which the lower one belongs to the Weber quartzite and the upper to the Park City formation. The phosphate sample (No. 21) represents only the part of a fossiliferous bed 2 feet thick, in which fossils are abundant. This part of the bed contains 56.39 per cent of tricalcium phosphate and appears to be about the same as that farther to the west.

In the divide between Dry Fork and Ashley Creek the outcrop of the phosphate bed is in part concealed by the Bishop conglomerate, and the exact distribution is therefore not known. The same conditions prevail in the divide between Ashley and Brush creeks. Good exposures may, however, be seen in this vicinity along certain parts of the canyon walls, where the phosphate beds cross the streams. Throughout most of this area the rocks strike in a general easterly direction and dip 8° to 25°, forming long dip slopes composed almost entirely of Park City beds. In many places the smaller streams and canyons have cut through the phosphate and their bottoms now lie in the Weber quartzite, thus making the outcrop of the phosphate beds very irregular, as is in part shown on the accompanying map. Only a very few of these irregularities are indicated on the map, as no attempt was made to map the outcrops along the small canyons and valleys. The phosphate in this part of the field seems to be fairly uniform, and the sections on Ashley Creek and along one of the small canyons on the dip slope in sec. 4, T. 3 S., R. 21 E., are almost identical. The position of two of the phosphate beds sampled in this section and the thickness of the beds are given on pages 51–52. Sample 27 was collected from the upper bed in the SW. ¼ sec. 7, T. 3 S., R. 21 E., and sample 28 from the lower bed in the NW. ¼ sec. 4. The upper bed represents 3 feet 2 inches of dark to greenish shales and limestones that contain 49.78 per cent of tricalcium phosphate. The lower bed consists of thin and some thick layers of phosphate rock having a total thickness of 3 feet 4 inches and contains an average of 52.88 per cent of tricalcium phosphate.

Very much the same conditions as between Ashley and Brush creeks prevail throughout the area east of Brush Creek and west of Diamond Mountain. Just how far the phosphate bed follows up the dip slope and whether its outcrop in the upper part of the dip slope is concealed in this area beneath the Bishop conglomerate were not determined, but it appears that the lower margin of the Bishop conglomerate in this part of the range rests upon the Weber quartzite. Along Brush Creek in T. 2 N., R. 21 E., there appears to be a sharp fold or fault which causes a marked difference in the attitude of the phosphate beds on the east and west sides of the creek. The relations and the real significance of the fold or fault were not ascertained. The general appearance indicates that a fault extends in a southeasterly direction, roughly parallel to the one west of Dry Fork, with the downthrow on the west. The phosphate series strikes east and the dips are 8° to 15° to the south. The beds can be traced all along the south flank of the range to Diamond Mountain, where they and the overlying strata are concealed by the Bishop conglomerate.

Sample 22, representing a 2-foot phosphate layer in the shale series 20 feet above the Weber quartzite in sec. 31, T. 2 S., R. 22 E., was found to contain 58.30 per cent of tricalcium phosphate. This phosphate bed is overlain by about 10 feet of shaly limestone and greenish shales that contain considerable phosphatic material but do not appear as rich in phosphate as the bed sampled. Another sample (No. 23) was collected from a 2-foot bed on the west side of a small valley east of Brush Creek in sec. 28, T. 2 S., R. 22 E., and found to contain 55.93 per cent of tricalcium phosphate. Below this bed there is a concretionary layer several feet thick that contains a little phosphate and much chert. Sample 24, collected in the SW. ¼ sec. 24, T. 2 S., R. 22 E., on the west side of Little Brush Creek, comes from approximately the same horizon as Nos. 22 and 23, and the section here appears to be about the same. At this point, however, 4 feet of the overlying shale was sampled and included with the lower 2 feet corresponding to the bed sampled at the other two localities. Although the entire 6 feet appears to contain more clay and sand than the beds farther west, the analysis shows nearly as high a phosphate content as the lower 2 feet at the other two localities, namely 53.55 per cent of tricalcium phosphate. Farther up the dip slope on the same side of Little Brush Creek, in sec. 14, T. 2 S., R. 22 E., Frank V. Goodman has prospected these beds and opened a small tunnel at this horizon. He states that in some places the phosphate rock rests directly upon the Weber quartzite but that elsewhere layers of talc and other materials intervene between the phosphate beds and the Weber formation. The phosphate beds range from 3 to 4 feet in thickness and are interbedded with considerable other material so that the entire series is 25 to 30 feet thick. Mr. Goodman reports that some of the rock collected on Little Brush Creek and analyzed by a Salt Lake City firm yielded 80 per cent of tricalcium phosphate. Three samples of phosphate rock (Nos. 35, 36, and 37), collected by him from the outcrop of the bed in a small gulch on the west side of Little Brush Creek in the SE. ¼ sec. 14, T. 2 S., R. 22 E., and sent to the writer for analysis, yielded from 43.5 to 49.7 per cent of tricalcium phosphate. The beds are similar in many respects to those represented by sample 24 and to those examined at other localities along the south side of the range.

A short distance east of Little Brush Creek the outcrop of the phosphate bed passes beneath the flat-topped table-land of Diamond Mountain, which is capped by the Bishop conglomerate. East of the mountain the beds are again exposed and may be traced around the east end of the Island Park syncline. The phosphate bed was not traced in this area but was observed south of Island Park, along the north side of Split Mountain, where a sample of phosphate rock (No. 26) was collected west of Green River near the east end of the mountain. The sample represented 2 feet of the phosphate bed and yielded on analysis 65.94 per cent of tricalcium phosphate. The entire bed was not exposed at this locality, and it is therefore impossible to state the thickness of the phosphate bed along the north side of Split Mountain. A sample of phosphate float (No. 25) was picked up near the west end of the mountain, a little farther west along the strike of the bed, and yielded on analysis 61.01 per cent of tricalcium phosphate, clearly indicating the presence of high-grade rock in this part of the Split Mountain anticline. It is very probable that similar beds occur along the south side of Split Mountain and can likewise be traced around the west end of Section Ridge and eastward into western Colorado. How much farther the deposits extend southward and eastward into northwestern Colorado is not known. It is very probable, however, that the Park City beds containing the phosphate deposits may extend throughout the eastern part of the Uinta uplift and may indeed extend eastward into the Rocky Mountain uplift.

UTILIZATION OF ROCK PHOSPHATE.

The principal use of phosphate rock is to fertilize garden and farm lands that are deficient in phosphorus or that are being used for intensive cultivation so that more phosphorus is needed to maintain production. Phosphorus is one of the three essential mineral plant foods, the other two being potash and nitrates. The need for fertilizer containing these three ingredients will become more apparent with the deterioration of agricultural lands or when these same lands are required to furnish a larger crop yield for the ever-increasing population of the world. Some of the virgin lands not yet under cultivation may be deficient in phosphate, and their yield would be improved by the application of fertilizer, but by far the greater and principal use of phosphate material will be on lands that are intensively cultivated in order to produce better crops through stimulation and control of the growing period. The largest use for phosphate as well as other fertilizers in the future will be on the richest and most productive soils, in order to maintain or increase the yield per acre. The natural rock phosphate in its slightly water-soluble form is but slowly rendered available in the ground, although recent experiments indicate that if the very finely crushed rock is applied to agricultural soils the phosphorus is taken up by the plants, and the annual yield is greatly increased. For immediate crop results in application to the soil the natural rock is usually first decomposed with sulphuric acid, forming what is known in the fertilizer trade as superphosphate.

The chief obstacles to the development of the western phosphate industry at the present time are the high cost of transportation of the bulky crude product and the lack of markets for fertilizers sufficiently near to warrant its development. A high-grade fertilizer that will be able to stand the transportation charges is the product that is desired. As soon as such a fertilizer is placed on the market at a price which justifies its use in the densely settled agricultural communities the development of the western phosphate fields will be assured.

On both sides of the Uinta Mountains there are numerous large water powers that can be utilized in the manufacture of nitrates from the atmosphere or in the manufacture of commercial fertilizer from phosphate rock, atmospheric nitrogen, and rock high in potassium, such as leucite rock of Sweetwater County, Wyo.[1] In the processes now used for the fixation of atmospheric nitrogen cheap power and cheap supplies of lime and coke or of limestone are essential. All of these except coke are present at many places in the range, but probably no locality is as favorably situated as the one on Green River at Horseshoe Canyon, where the Reclamation Service has made preliminary surveys for the erection of a large dam. At this point a large and cheap power can be developed, large quantities of limestone are present, and the phosphate beds as well as the overlying and underlying limestones cross Green River a short distance above the proposed dam site. When the dam is completed the stored water will flood Green River back to the Union Pacific Railroad at the town of Green River and furnish cheap water transportation from the dam to the railroad. There are probably only a few places where power can be obtained cheaply enough and in large enough quantities to warrant an undertaking of this kind.

[1] Schultz, A. R., and Cross, Whitman, Potash-bearing rocks of the Leucite Hills, Wyo.: U. S. Geol. Survey Bull. 512, 1912.

Much of the agricultural land of the Western States is relatively virgin soil, and as its original phosphate content has not been exhausted by crops, it is less in need of fertilizers than the older farm lands in thickly settled communities of the East and South. Except where the virgin lands are deficient in phosphorus the need for this kind of fertilizer in the Rocky Mountain States is not urgent. The use of fertilizers in agriculture is said to be fast increasing on the Pacific coast and also in other parts of the West where intensive farming is practiced. There will henceforth probably be a more rapidly growing market for fertilizer products in both the middle and far West, and it is to this territory that the western phosphate producer must look primarily for markets.

ANALYSES OF PHOSPHATE ROCK.

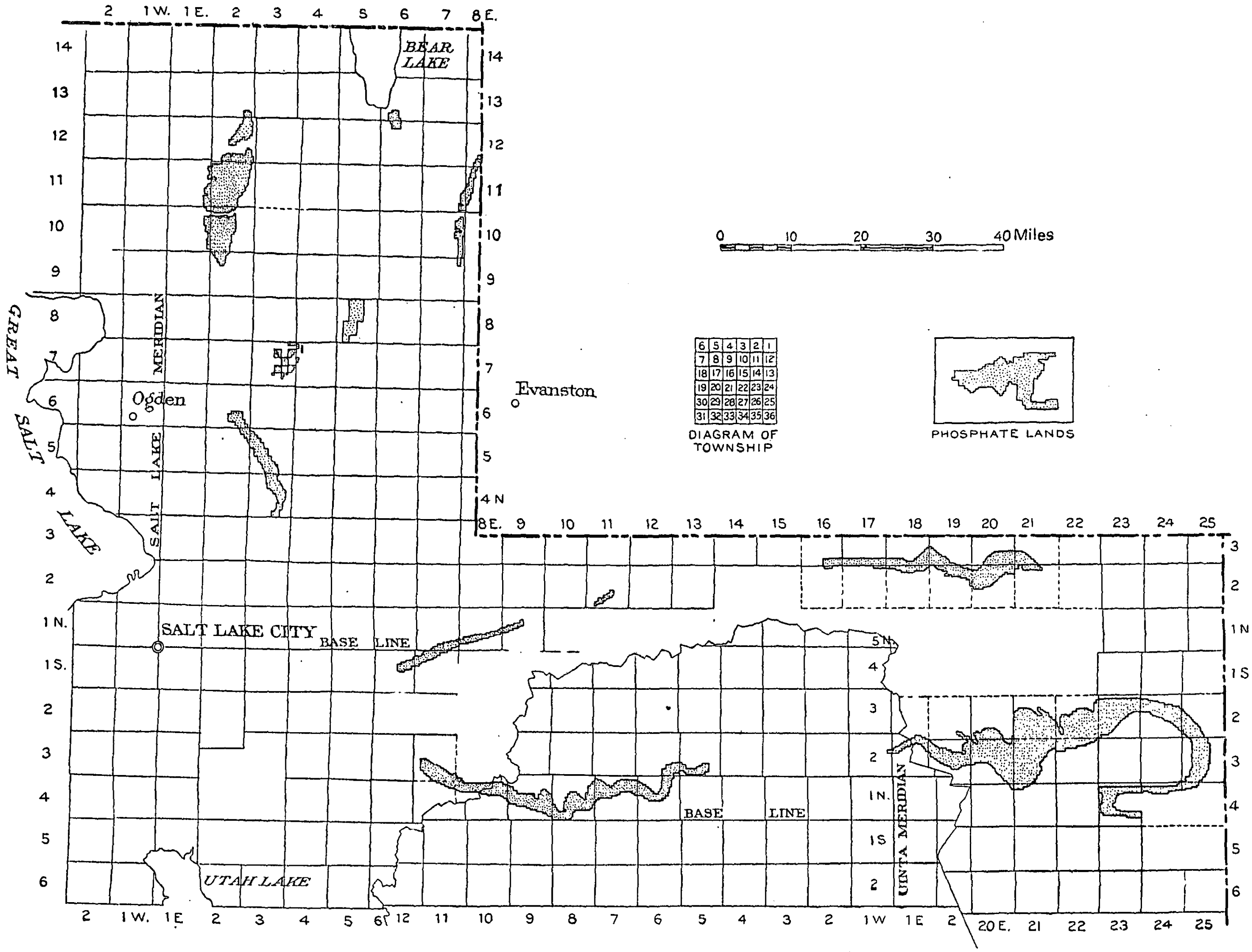
The 37 samples collected, with one exception, represent phosphate rock in place and phosphate float along the outcrop on the north and south flanks of the Uinta Range. They have been analyzed in the laboratory of the United States Geological Survey by W. C. Wheeler, with the results stated below. Eleven of these samples represent float fragments consisting of small pieces of rock from a part of the phosphate bed not now exposed but probably lying a short distance below the surface cover. One sample (No. 34) represents the coal horizon in the Carboniferous beds of Pennsylvanian age and shows no trace of phosphate. Some of the other samples represent different beds at the same localities and indicate the vertical variation in the phosphate series. Although the material is the best at hand, the samples and analyses as a whole can hardly be considered truly indicative of the character of the best material in the undisturbed bed, which may give much better results. The localities from which rock phosphate samples were obtained are indicated by consecutive numbers, 1 to 37, on the accompanying map (Pl. V). The numbers also show the order in which they were collected, beginning in the northwestern part of the field in the Weber River area.

Analyses of phosphate float or rock samples collected in the Uinta Mountains, northeastern Utah.

No. on Pl. V.	Location.			Thickness of phosphate bed sampled.	Phosphate content (per cent).		Remarks.
	T.	R.	Section.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	
1	1 N.	7 E.	36, NE. ¼	Float.....	Trace.	Trace.	Primarily chert fragments.
2	1 N.	7 E.	36, NE. ¼	...do......	25.80	56.50	Fragments of phosphate rock.
3	1 N.	9 E.	17, SW. ¼	...do......	30.81	67.47	Do.
4	1 N.	8 E.	28, NW. ¼ SE. ¼	...do......	11.74	25.71	Do.
5	1 N.	7 E.	33, SE. ¼	...do......	30.20	66.14	Do.
6	3 S.	7 E.	20, NW. ¼	...do......	25.82	56.55	Do.
7	3 S.	7 E.	28, NE. ¼	...do......	25.64	56.15	Do.
8	3 S.	7 E.	26, SW. ¼	...do......	28.05	61.43	Do.
9	4 S.	8 E.	6, NE. ¼	...do......	20.54	44.98	Do.
10	1 N.	8 W.	31, NE. ¼	4'.........	18.27	40.01	Part of phosphate bed.
11	1 N.	9 W.	25, NW. ¼	5' 6"......	5.63	12.33	Phosphatic shale bed.
12	1 N.	9 W.	25, NW. ¼	1' 8"......	17.55	38.43	Fossiliferous bed at base of shale series.
13	1 N.	9 W.	18, NW. ¼	6'.........	10.42	22.82	Part of phosphatic shale.
14	1 N.	9 W.	18, NE. ¼	4'.........	16.76	36.70	Do.
15	2 N.	5 W.	27, SW. ¼	6'.........	4.15	9.09	Thin-bedded phosphatic shale.
16	2 N.	5 W.	27, SW. ¼	3'.........	12.28	26.89	Asphaltic sandstone containing phosphate.
17	2 N.	1 E.	18, NE. ¼	3'.........	23.48	51.42	Phosphatic limestones.
18	2 N.	1 E.	18, NE. ¼	3'.........	26.39	57.79	Phosphate bed.
19	3 S.	21 E.	8, NE. ¼	1'.........	26.47	57.97	Fossiliferous phosphate bed.
20	3 S.	21 E.	8, NE. ¼	3'.........	26.40	57.82	Phosphate bed.
21	3 S.	20 E.	8, NW. ¼	2'.........	25.75	56.39	Fossiliferous phosphate bed.
22	2 S.	22 E.	31, NW. ¼	2'.........	26.62	58.30	Phosphatic shale near base of series.
23	2 S.	22 E.	28, SW. ¼	2'.........	25.54	55.93	Part of phosphate bed.
24	2 S.	22 E.	24, SW. ¼	6'.........	24.45	53.55	Phosphate bed.
25	4 S.	23 E.	11, NE. ¼	Float.....	27.86	61.01	Fragments of phosphate rock.
26	4 S.	24 E.	10, NE. ¼	2'.........	30.11	65.94	Part of phosphate bed.
27	3 S.	21 E.	7, SW. ¼	3' 2"......	22.73	49.78	Phosphate shale and limestone.
28	3 S.	21 E.	4, NW. ¼	3' 4"......	23.69	52.88	Phosphate bed.
29	3 N.	17 E.	34, SW. ¼	Float.....	20.44	44.76	Fragments of phosphate rock.
30	2 N.	18 E.	3, SW. ¼	4'.........	30.72	67.28	Phosphate bed.
31	2 N.	19 E.	3, SW. ¼	2'.........	26.58	58.21	Concretionary oolitic phosphate bed.
32	3 N.	21 E.	31, SW. ¼	4' 2"......	27.36	59.92	Phosphate bed.
33	3 N.	21 E.	31, SW. ¼	3'.........	24.88	54.49	Do.
34	1 S.	45 E.	32, NE. ¼	3'.........	None.	None.	Coal sample from bed in rocks of Pennsylvanian age.
35	2 S.	22 E.	14, SE. ¼ SE. ¼	3'.........	21.32	46.70	Part of phosphate bed.
36	2 S.	22 E.	14, SE. ¼ SE. ¼	4'.........	19.85	43.47	Do.
37	2 S.	22 E.	14, SE. ¼ SE. ¼	4'.........	22.70	49.71	Do.

The analyses show considerable variation, but they indicate the presence of some high-grade rock that carries approximately the equivalent of 70 per cent of tricalcium phosphate. Many of the samples were not collected from the richer parts of the bed, and it did not seem advisable in the preliminary work to sample all the phosphate beds in the phosphatic series in order to determine the richest part of the beds in any one section.

The average of the phosphate rock now being shipped from southeastern Idaho and southwestern Wyoming runs about 70 per cent of tricalcium or bone phosphate. Experience has shown, however, that weathered phosphate rocks are commonly enriched 3 to 5 per cent or more, owing to the leaching of the more soluble lime carbonate, and may therefore show a higher phosphate content at or near the surface than at greater depths. On the other hand, in a region like that examined the harder and more siliceous float fragments are com-



MAP SHOWING PHOSPHATE RESERVES IN UTAH JULY 1, 1917.

Dotted areas indicate phosphate lands.

monly the only ones found along the outcrop or exposed at the surface and may show a lower content than the richer layers of the main phosphate bed.

PRODUCTION AND DEVELOPMENT.

The phosphate industry in the Rocky Mountain region has made slow progress. In 1912 the Western States produced 11,612 long tons, valued at $49,241. In 1913 approximately 5,919 long tons was mined, of which 5,053 tons was sold at an average price of $3.60 a ton, or a total value of $18,167, showing a decrease of 56 per cent from the 1912 production. This production constituted only one-fifth of 1 per cent of the entire phosphate output of the United States in 1913. The showing remained about the same in 1914, when the Western States produced 5,030 long tons, valued at $15,488, an average price of $3.08 a ton. All the phosphate rock was mined near Montpelier, in Bear Lake County, Idaho, and near Border and Cokeville, in Lincoln County, Wyo. The phosphate production in 1914 was considerably decreased throughout the United States, and the Western States were apparently less affected than the Southern States.

The total quantity of phosphate rock mined in the United States in 1914 was 2,734,043 long tons, valued at $9,608,041, compared with 3,111,221 long tons, valued at $11,796,231, in 1913, a decrease of 12 per cent in quantity and 19 per cent in value. No rock was reported as mined in 1914 in Arkansas, Kentucky, or Utah, and each of the producing States showed a decline. In Florida the decrease amounted to nearly 19 per cent, in Tennessee 3 per cent, and in South Carolina 1.4 per cent, but in Idaho and Wyoming the production remained approximately the same. The decrease from 1912 to 1914 in the entire country amounted to approximately 8 per cent in quantity and 18 per cent in value. Until about 1885 South Carolina furnished more than 95 per cent of the phosphate rock marketed in the United States; its production in that year was 673,192 long tons, valued at $4,145,097. Since then the South Carolina production has fallen off, and in 1894 it was surpassed by Florida and in 1899 by that of Tennessee; in 1914 its production amounted to only 3.9 per cent of the total. Tennessee furnished 18 per cent, Florida 68 per cent, and the Western States only a fraction of 1 per cent.

The delay in development of the western phosphate deposits may be attributed in part to the fact that some of the properties first located had been involved in litigation, in part to the high cost of transportation from the deposits to localities where phosphate is needed for depleted soils, and in part to the fact that the agricultural public does not yet fully appreciate the increased production made possible by the use of phosphate fertilizer. Thus far only a few localities in the West have shipped phosphate rock for commercial use. All the localities at which small mines have been opened and from which rock has been shipped are in the Bear Lake region in southeastern Idaho, northeastern Utah, and western Wyoming, where the deposits were first discovered. In 1912 shipments were made from all these States, but since that time the reported production includes only Idaho and Wyoming. Slight as the development in the Western States has been in the older localities, there is still a marked contrast between the Bear Lake locality and the region described in this report, for in the Uinta area the phosphate deposits have received practically no attention from the prospector and their very existence seems to be unknown to him or to the inhabitants. What little prospecting has been done along the phosphate outcrop was undertaken with the idea of locating a coal bed from which a supply of coal could be obtained, with the expectation of locating an oil sand, or in search of copper or other metalliferous minerals.

No detailed work upon which to base a reliable estimate of tonnage has been done in this field. It is apparent, however, from the reconnaissance examination that a large amount of phosphate is present. Every acre underlain by a horizontal bed of phosphate 4 feet thick would yield approximately 14,000 tons, and where the phosphate bed is steeply tilted the amount beneath an acre is much greater. The approximate location and distribution of the known phosphate deposits in Utah are shown on the map (Pl. IV), which gives the areas in Utah included in outstanding phosphate reserves on July 1, 1915.

The phosphate beds along the north side of the Uinta Mountains lie at a considerable distance south of the main line of the Union Pacific Railroad, in southern Wyoming, and those at the west end of the range lie a considerable distance from the Park City branch of the Union Pacific Railroad. The deposits on the south side of the mountains lie a long distance north of the Denver & Rio Grande Railroad or its branch lines, but along both flanks of the mountains the deposits are readily accessible by wagon roads up the larger valleys. As soon as the Moffat road (Denver & Salt Lake) is built through from Craig, Colo., to Salt Lake City, Utah, it will bring railroad shipping facilities on the south side of the range within a few miles of the phosphate outcrop. This route is one that offers no unusual difficulties for the construction of a railroad, and with spur lines built up the larger valleys to the phosphate outcrops a short haul would place the phosphate rock on the main line.