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PHOSPHATE DEPOSITS NEAR LANDER, WYOMING

BY

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UNIVERSITY OF WYOMING
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PHOSPHATE DEPOSITS NEAR LANDER, WYOMING

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Ralph H. King*

ABSTRACT

Two major zones of phosphate rock, included in the marine sedimentary rocks of the Phosphoria formation of Permian age, crop out low on the northeast flank of the Wind River Mountains southwest of Lander, Wyoming. The beds dip 9° to 20° NE, and the outcrop occupies a belt 2 to 3 miles wide. The formation is 280 to 290 feet thick in this area, and comprises principally light-colored dolomite, limestone, clay, and siltstone. The lower phosphate zone lies 40 feet above the base of the formation; the upper zone lies 100 feet below the top.

Between Baldwin Creek on the northwest and Cherry Creek on the southeast, a distance of about 16 miles, the phosphate rock was trenched and sampled at several places, and the geology was mapped. On the basis of the data thus obtained, the upper phosphate zone is estimated to contain, above drainage level, 100,000,000 short tons of phosphate rock 3 to 6 feet thick, but averaging only 35 percent bone phosphate of lime (B.P.L.)—a low-grade rock. An additional 13,825,000 tons is estimated for each 100 feet (vertically) below drainage level. The lower phosphate zone is estimated to contain, above drainage level, 30,000,000 tons of phosphate rock 3 to 4 feet thick averaging about 52 percent B.P.L.—a medium-grade rock. An additional 3,780,000 tons is estimated for each 100 feet below drainage level.

Mining conditions are generally favorable and transportation is relatively inexpensive.

INTRODUCTION

The phosphate deposits of the Permian Phosphoria formation in the vicinity of Lander, Fremont County, Wyoming, are thin and of only low and medium grade†.

They are of interest chiefly because they lie only 7 miles west to 12 miles south (airline) of the terminus of the Chicago and Northwestern Railroad at Lander. The present study was undertaken to determine reserves and structure of the part of the deposits that lies closest to the railroad, a belt 2 to 3 miles wide and about 16 miles long lying between Baldwin Creek on the northwest and Cherry Creek on the southeast.

To establish the stratigraphic position of the two main beds and all minor beds of phosphate rock, two trenches were cut across the entire thickness of the Phosphoria formation. One trench was situated near Little Popo Agie River (South Fork of Popo Agie River) near the southeast end of the area, the other near Baldwin Creek at the northwest end of the area (plates 1-3, fig. 2). As all the minor beds are less than 12 inches thick, and hence unworkable, they are ignored. Nine trenches across the upper phosphate zone at irregular intervals yielded nothing better than low-grade phosphate rock. Twelve trenches across the lower phosphate zone, cut in 1945, showed phosphate rock of medium grade, thickening southeastward; therefore three additional trenches were cut through this zone in 1946, extending the study as far as Deep Creek. The grade and thickness of the phosphate rock decreased southeast of Cherry Creek, however, so the area between Cherry Creek and Deep Creek was not studied in detail.

The contacts of the Phosphoria formation with the underlying Carboniferous Tensleep sandstone and the overlying Triassic Dinwoody formation and the position of readily recognizable marker beds above each of the main phosphate zones were mapped on aerial photographs (approximate scale 1:31680 and 1:48000), from which the geologic map (figure 3) was prepared. The

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†Low-grade phosphate rock contains 30 to 49 percent bone phosphate of lime, usually abbreviated B.P.L., and medium-grade phosphate rock contains 50 to 69 percent, according to recent usage by the U. S. Geological Survey. Analyses are commonly reported in percent P_2O_5 and 1 ercent P_2O_5 is equivalent to 2.18 percent B.P.L.

most accessible area, that between Little Popo Agie River and Cherry Creek, was mapped by plane table, on a scale of 1:6000. The structural attitude of the beds was also noted.

In the 1945 field season, the week of July 9 to 14 was spent in a preliminary inspection of the area to be studied. Trenching and sampling required two months; a crew of three to five men assisted in this work until early in September. The mapping on aerial photographs was done between September 14 and October 2. W. R. Lowell supervised the trenching and sampling after his arrival on July 23, and assisted with the mapping until his departure on September 23. E. A. Brown served as Junior Geologist from July 13 to September 28.

In the 1946 field season, preliminary work occupied the three days from June 17 to 19 Cutting and sampling of three trenches in the lower phosphate zone was completed July 8. Plane-table mapping of the flatiron area between Cherry Creek and Little Popo Agie River was completed September 5. Will Kyselka served as Geologic Field Assistant throughout the season, assisting with the trenching and sampling and operating the alidade for the mapping. Chao Chia-Hsiang of the Mineral Exploration Bureau of China worked with the party from July 8 to 19. A crew of two men assisted in the trenching and sampling.

Charles F. Deiss conducted the preliminary inspection of the area in July, 1945, and gave valuable advice on techniques and procedures to be followed in studying the deposits. J. D. Love, who studied the oil possibilities in the Lander region, provided stratigraphic sections of the Phosphoria formation in nearby areas, prepared a list of aerial photographs needed, loaned land plats, and gave information on the local geology.

The Geological Survey of Wyoming provided half of the funds required for the investigation. H. D. Thomas, State Geologist of Wyoming, examined

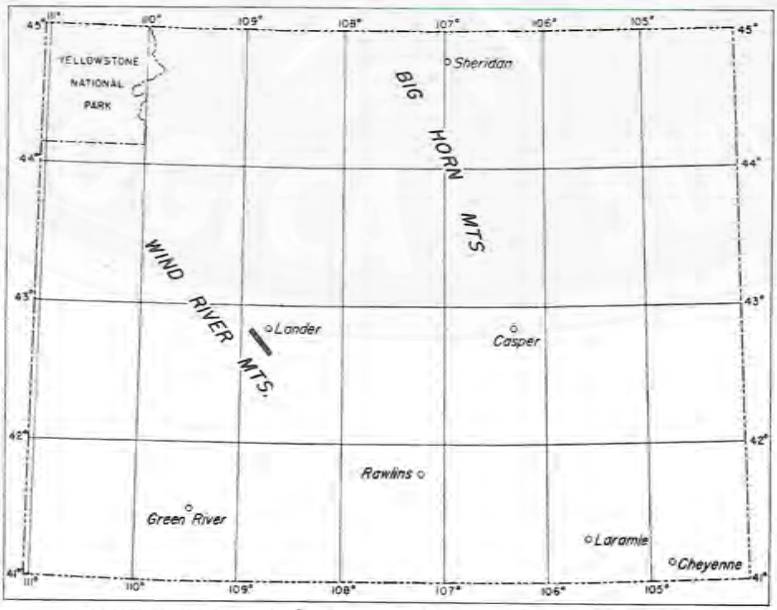

FIGURE 1. INDEX MAP OF WYOMING SHOWING LOCATION OF LANDER PHOSPHATE AREA, FREMONT COUNTY, WYOMING

the area with Deiss and the writer in 1945, and at that time and on subsequent visits made helpful suggestions. H. G. Fisk, Director of the University of Wyoming Natural Resources Research Institute, visited the area twice and also supervised the analytical work, the results of which he supplied promptly.

The Lander office of the Weather Bureau provided barograph readings for correcting altitudes measured by aneroid barometer. L. A. Crofts, an attorney at Lander, assisted in hiring men to help dig and sample the trenches. Because all the townspeople and ranchers were so courteous and hospitable it was a pleasure to live and work among them. William MacFie merits special commendation for his cooperation in facilitating the work on his ranch.

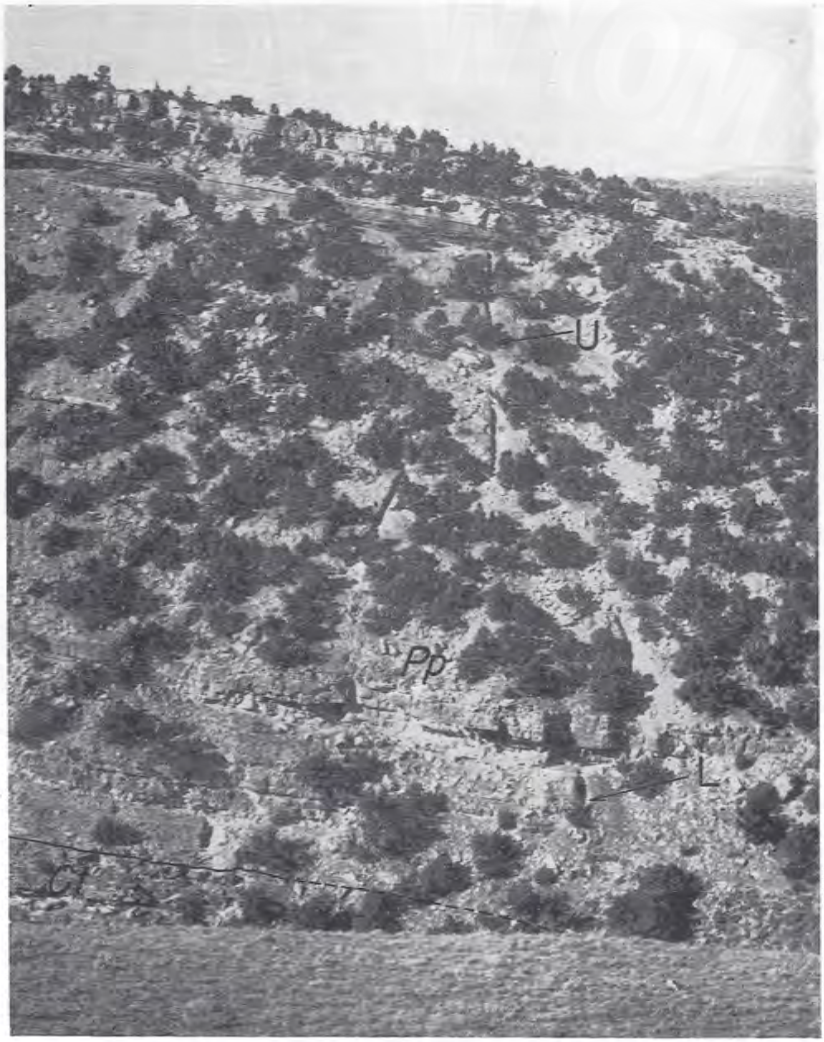

PLATE 1. Trench A, Little Popo Agie River. *Ct*—Tensleep sandstone. *Pp*—Phosphoria formation. U—upper phosphate zone. L—lower phosphate zone. The section of the Phosphoria formation includes virtually the entire 290 feet.

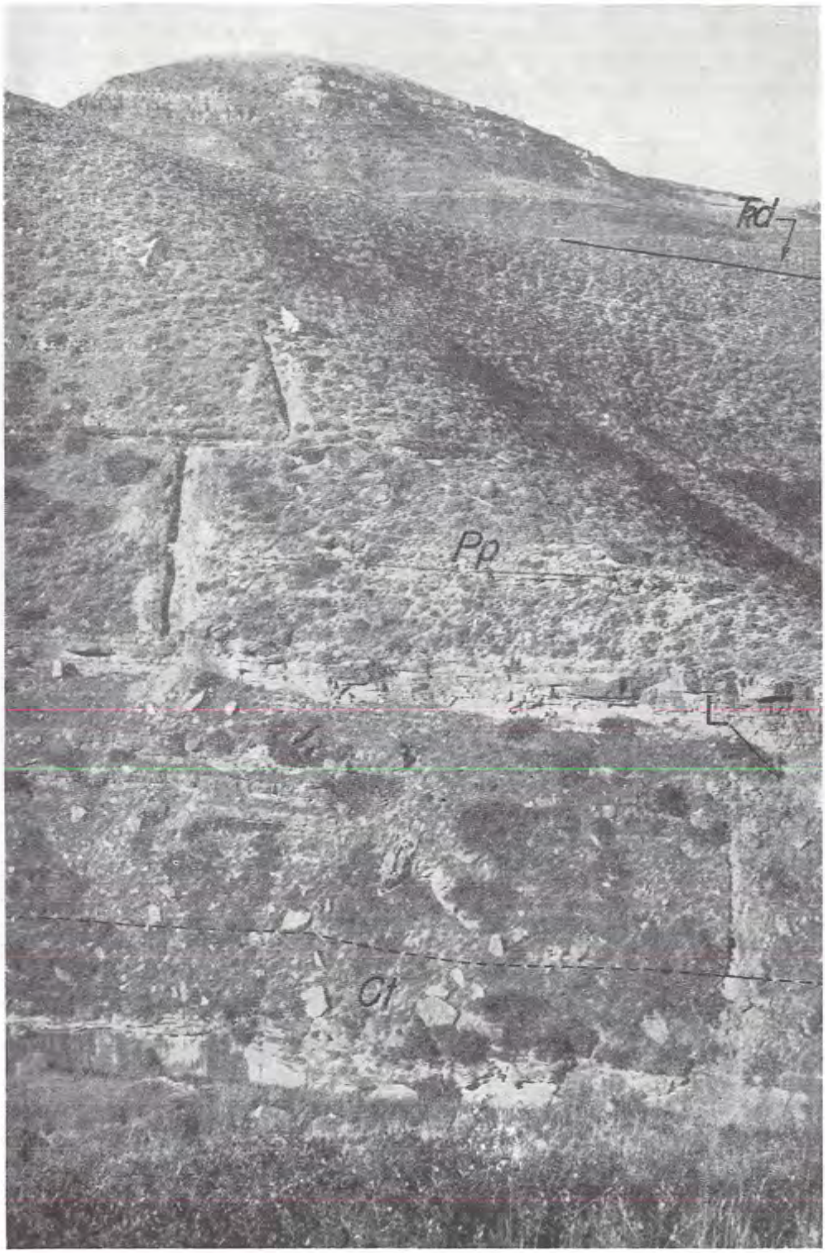

PLATE 2. Lower parts of Trench B, Baldwin Creek. *Trd*—Dinwoody formation. *Pp*—Phosphoria formation. L—lower phosphate zone. *Ct*—Tensleep sandstone. The thickness of Phosphoria rocks between the Tensleep sandstone and the highest part of the trench is about 175 feet. The total thickness here is 278 feet. The distant hill is composed of rocks of the Chugwater formation and Nugget sandstone.

GENERAL GEOLOGY

Physiography

In the vicinity of Lander alternating beds of hard and soft rocks of Mesozoic age, principally clay, sand, and silt, weather to low, irregular multicolored cuestas, which are transected by broad, flat, cultivated valleys. The physiographic detail is infinitely variable, yet the pattern is monotonously repetitious. Table Mountain, a flat-topped remnant of the clastic sediments that filled the entire Wind River Basin in Tertiary time, rises a thousand feet above the general surface, accentuating rather than relieving the uniformity.

In marked contrast, the foothills of the Wind River Range comprise the steep, smooth, grassy dip slopes developed on the hard dolomite and limestone of the uppermost part of the Phosphoria formation. The long, narrow slopes, which may be termed flatirons, rise nearly 2,000 feet in somewhat less than 2 miles. They are separated by narrow valleys cut deep into the softer underlying beds of the formation. Many of the valleys are dry except when the snow is melting, but others contain permanent streams, which originate in the snowfields of the higher mountains or are fed by springs. A few old timber trails and sheep-wagon tracks are the only roads that traverse the country. The one highway into the mountains follows Middle Fork of Popo Agie River through Sinks Canyon, so named because the river flows through an underground channel for a distance of almost half a mile.

The mountains are rugged and heavily wooded. Some of the mountain valleys are little more than slits in the resistant Paleozoic and pre-Cambrian rocks.

Stratigraphy

Carboniferous (Pennsylvanian)

The only Carboniferous formation included in the present study is the Pennsylvanian Tensleep sandstone.

Tensleep sandstone.—The Tensleep sandstone was named by Darton (1904, pp. 394-401) from exposures in the lower canyon of Tensleep Creek on the west flank of the Big Horn Mountains, about 100 miles northeast of Lander. The Tensleep is a transgressive sandstone, that is, it was deposited in an encroaching sea, hence it is of somewhat different age in different places. In the Lander area it is late Des Moinesian in age (Branson and Branson, 1941, p. 132).

The Tensleep sandstone underlies the Phosphoria formation unconformably (Branson, 1930, p. 8; Branson and Branson, 1941, p. 132), part of the Tensleep sandstone having been removed by erosion prior to deposition of the lowest beds of the Phosphoria. On Baldwin Creek (plate 2) soft sandstone about 15 feet thick overlies a prominent ledge-forming indurated sandstone. This indurated bed constitutes the top of the Tensleep sandstone on Little Popo Agie River (plate 1), the soft sandstone having been removed before Phosphoria time.

The predominant rock type is light-buff calcareous fine-grained sandstone, which darkens on weathering. The streams that cross the outcrop have cut narrow gorges, the walls of which stand almost vertical, and in places overhang. Joints striking 45° from the trend of the mountains are prominent, especially on Baldwin Creek, where the "incised meanders" of the stream follow and accentuate the joint pattern. Buttresses bounded by parallel joints constrict the valley of Squaw Creek in places. On the slopes between valleys the sandy soil derived from the Tensleep rocks supports a heavy growth of timber, which

PLATE 3. Upper part of Trench B, Baldwin Creek. *Trd*—Dinwoody formation. *Pp*—Phosphoria formation. U—upper phosphate zone, here very fossiliferous. The thickness of Phosphoria rocks shown is about 125 feet.

contrasts sharply with the grassy or scrubby vegetation growing on the Phosphoria formation, and greatly facilitates areal mapping of the contact between the two formations.

Permian

All the Permian rocks of the Wind River Range are included in the Phosphoria formation. How much of Permian time is represented by the Phosphoria sediments is not known. Some Carboniferous (Pennsylvanian) rocks may be included in the lowest part.

Phosphoria formation.—The name Phosphoria formation was assigned by Richards and Mansfield (1912, pp. 683-689). The type locality is Phosphoria Gulch in southeastern Idaho, 125 miles west of Lander.

The contact with the overlying Triassic Dinwoody formation seems to be conformable (Branson, 1930, p. 8), although the change in lithology is abrupt. In the Lander area differences in dip and strike of the Dinwoody beds from those of the underlying Phosphoria beds are no greater than the local variation in dip and strike within the Phosphoria formation. The stratigraphic relationship with the Pennsylvanian Tensleep sandstone has been discussed in connection with the description of that unit.

The rocks of the Phosphoria formation are mostly light in color and are principally argillaceous and calcareous, but few beds are composed of a single constituent. The carbonate rocks are neither limestone nor dolomite, but intermediate, although some beds approach one or the other in composition. Even these beds, however, contain some clay, silt, limonite, or chert. The clastic sedimentary rocks are all fine-grained, but are only moderately well sorted, and most of them contain carbonates. The total thickness of the Phosphoria formation in the Lander area is 280 to 290 feet (fig. 2).

The description of such beds involves the use of multiple modifiers, so the measured sections include a plethora of such terms as "argillaceous calcareous siltstone", "argillaceous silty dolomite", and "silty dolomitic clay". A slight error of judgment may result in classifying such rocks under the wrong heading. Slight lateral variation in composition may necessitate different classifications for the same bed in sections only a short distance apart. Correlation of individual units is therefore difficult and not entirely reliable. Nevertheless certain groups of beds can be correlated readily.

In the lower 40 feet of the formation the beds are principally silty to sandy carbonate rocks, but there is some siltstone and fine sandstone, possibly derived from the underlying Pennsylvanian Tensleep sandstone. Chert is abundant, and some calcite geodes were observed in the upper part of this sequence. No individual bed seen in the Baldwin Creek section was recognized in the Little Popo Agie River section, and vice versa. The two sections are similar in general, but different in all details. On high points these basal beds are locally silicified and their soil supports timber similar to that on the Tensleep sandstone. Orange-yellow to dark reddish-brown jasper fragments are abundant, especially above the level of the old surface represented by the top of Table Mountain. A silicified cross-bedded shell breccia or coquina was noted near Trench L, southwest of Table Mountain. A few silicified fossils in carbonate matrix were found in an almost inaccessible spot south of Willow Creek.

Above these basal beds lies the lower phosphate zone, which is described in detail in the chapter on phosphate rock. It is 1 to 4 feet thick and locally is packed with orbiculoid brachiopods. It is overlain by thin interbedded

clay and dolomite totaling about 4 feet thick. Over these is a bed of light greenish-gray impure chert 15 to 16 inches thick.

The next higher unit is a prominent dolomite, which is uniformly about 21 feet thick and commonly forms an almost vertical cliff. The top of this dolomite is taken as the top of the lower member of the Phosphoria formation as shown on figures 3 and 6. It is thin-bedded in the upper 3½ to 4½ feet, massive in the next 8½ to 9 feet, and somewhat less massive in the lower 8 to 9 feet. This lower part includes abundant calcite geodes as much as 3 inches in diameter, some of which contain small quartz crystals or dry bituminous material in addition to the calcite. In the field this dolomite was termed the geodal ledge, and that term is used in this report to identify the unit. This dolomite and the top limestone are the only beds that form extensive dip slopes. The outcrop of the geodal ledge is marked by a scattered growth of small brush or bushes of various types. In a few places, notably the vicinity of Trench H, silicified scaphopods and bellerophontid gastropods are common in the upper part.

The next higher unit is light-gray slightly calcareous clay. Chert and silty seams are abundant in the upper 10 feet. The thickness ranges from 18 feet on Baldwin Creek to 27 feet on Little Popo Agie River, but the measurement at the latter point may not represent the true thickness. A short distance west of the trench in which the section was measured the higher beds are broken and tilted by what seems to be an extensive landslide, as suggested by Condit (1924, p. 25), although lower beds seem undisturbed. The situation implies that this clay bed has "flowed" under loading, and may be locally thickened. Distinctive geodes are found in this clay bed. The size ranges from 1 inch to 8½ inches, but most specimens are 2½ to 3 inches in diameter. The thin shell is chalcedony, the lining is calcite, and dry bituminous material occupies part of the cavity of many specimens. The surface of some specimens is stained with limonite. Near Middle Fork of Popo Agie River some blue to bluish-green geodes were collected.

This clay bed and the next higher one, well exposed in the two long trenches, were seen in only one natural outcrop, a small gully near the northeast corner of the downfaulted block in the fork of Willow Creek. There the clay was coated with carbonate having a thickness of only a fraction of an inch, but sufficient to suggest to the casual or hurried investigator that the entire sequence of beds is limestone. The presence of this coating on the clay, together with the scarcity of exposures, may account for the fact that these beds have not previously been recorded as clay in measured sections, as far as known to the writer.

Dolomite, silty dolomite, and dolomitic and limy siltstone 6 to 9 feet thick comprise the next higher beds. On Baldwin Creek gray-white pseudobrecciated chert forms a bed 1 foot thick at the base of this sequence; the overlying siltstone also contains some chert.

Calcareous silty clay about 25 feet thick overlies the preceding sequence. It is chiefly light-gray, locally stained yellowish by limonite. It contains some thin seams of siltstone and dolomite.

Above the clay is a carbonate sequence about 12 feet thick containing abundant chert and locally yielding large rusty-weathering slabs. On Baldwin Creek, this sequence includes just below the middle a 4-foot bed of impure chert. In this area this whole carbonate sequence contains a considerable amount of silt, though only a small amount of silt was noted in it near Little Popo Agie River.

Calcareous gray clay 15 to 20 feet thick overlies the preceding beds. This clay is locally silty.

Above the clay is a sequence of moderately resistant beds 25 to 30 feet thick, which locally forms a slight ledge, especially at the tips of flatirons. These beds are composed of silty limestone and dolomite and include a 5-foot bed of siltstone at the base. Chert, clay, and calcite geodes are less abundant than in other resistant beds of the Phosphoria formation.

Above this sequence is the upper phosphate zone, which is described in detail in the chapter on phosphate rock. It is about 3 to 6 feet thick, and contains a few species of brachiopods in great abundance in the area north of Willow Creek.

Sepia claystone 40 to 45 feet thick overlies the upper phosphate zone. It is somewhat calcareous, and the upper part is silty. Minor seams of phosphate rock a few inches thick within this claystone were not studied in detail.

Above the sepia claystone is a bed of nodular to wavy-bedded black and green impure chert about 15 feet thick. In places it contains minor seams of phosphate rock a few inches thick. Locally the upper part is calcareous and the contact with the overlying bed is gradational. This bed, and possibly the overlying rocks, may correlate with the Rex chert member of the Phosphoria formation in southeastern Idaho and western Wyoming. The top of the chert is taken as the top of the middle member of the Phosphoria formation (figs. 3 and 6).

The uppermost part of the Phosphoria formation (upper member of figs. 3 and 6) consists of 35 to 40 feet of resistant carbonate rocks and some limy siltstone, which contain a few calcite geodes and some chert. Analyses of two chip samples show that about one-fifth of the material is insoluble in dilute hydrochloric acid. Most of this residue is silt and fine sand distributed through the limestone and dolomite. Because these top beds are very resistant they form long narrow dip slopes, which are the most prominent topographic feature of the outcrop of the Phosphoria formation.

Triassic

The Triassic rocks of the Lander area consist of the Dinwoody formation and several units usually lumped together under the name Chugwater formation. No outcrops of Chugwater beds were mapped except one small area in the NE¼ sec. 6, T. 31 N., R. 99 W., which was included with the Dinwoody formation.

Dinwoody formation.—The name Dinwoody formation was suggested by Blackwelder but seemingly first published by Condit (1916, p. 263). The type locality is Dinwoody Canyon, on the northeast flank of the Wind River Range about 50 miles northwest of Lander. An early Triassic age is assigned to these rocks.

The Dinwoody formation is conformably overlain by and grades laterally into the Chugwater formation, of which it is a color facies (Thomas, 1934). The stratigraphic relationship with the Permian Phosphoria formation has been discussed in connection with the description of that unit.

The rocks of the Dinwoody formation are predominantly clay shale, moderately well laminated, sandy, and tan to greenish-tan in color. Minor constituents comprise silty layers and irregular thin lenses of sandy to clayey iron-stained limestone, creamy-white to greenish-tan. The general color of weathered outcrops is dull greenish-gray. Locally limonite pseudomorphs after pyrite weather out of the rock. In the Lander area the total thickness of the Dinwoody formation probably is less than 50 feet.

Outcrops of this formation are restricted to the valley walls and the bases of the flatirons and are not extensive, as these soft rocks are readily eroded. The formation was not completely exposed at any locality visited. In many places the Dinwoody beds are truncated and overlain by terrace deposits. Some of the limestone lenses form miniature flatirons lapping up onto the bases of the long dip slopes of the Phosphoria formation.

Fossils are locally abundant but poorly preserved. They are molds of a few simple clams of narrowly restricted facies. The only specimens of these fossils that were collected were obtained from a thin calcareous bed about 5 feet above the base of the formation exposed at the top of the bluff on the south side of Little Popo Agie River about 150 feet northwest of the east quarter corner of sec. 8, T. 31 N., R. 99 W.

Quaternary

Within the area studied the Quaternary rocks comprise stream deposits and slumped material. No glacial deposits were found, although part of the stream deposits was derived from glacial debris.

Terrace deposits.—Small areas covered by unconsolidated terrace deposits were mapped along the northeast edge of the outcrop of the Phosphoria formation. These deposits are composed of numerous boulders and cobbles derived from glacial deposits, and much reddish silt and clay derived principally from Mesozoic redbeds. They are recognized as terrace deposits because of the lithology and also because of the uniform gentle slope of the surface. The disposition seems to indicate deposition by large streams that formerly flowed along the strike of the bedded rocks, but which were captured by the present drainage. The contact with underlying bedrock commonly is hidden by slump.

Alluvium in the stream valleys was not mapped separately. Except in Middle Fork of Popo Agie River the alluvium is virtually confined to the stream beds as far downstream as the Phosphoria-Dinwoody contact.

Landslides.—Slump deposits were not mapped separately except in areas where they were so thick and extensive as to be classified as a landslide. The composition is, of course, the same as that of the adjacent bedded rocks from which the slump was derived. A hummocky surface, well shown on aerial photographs, and an erratic dip of individual blocks characterize these deposits. In the area south of Willow Creek part of the debris may have slumped from the fault scarp. The dip of 70° W. noted in sec. 2, T. 31 N., R. 100 W., by Condit (1924, pl. 3) was measured on a large slump block.

Structure

General statement.—The Lander Phosphate deposits lie on the northeast flank of the great Wind River anticline. In the area studied the dip of the beds ranges from 9° to 20° NE, the dip increasing up slope. Local variations of a few degrees are not uncommon. The only variations from a simple monocline are the faulted area near Willow Creek and the anticline between Barrett Creek and Red Canyon Creek.

Faults.—The only faults observed in the area mapped (fig. 3) affect the Willow Creek area. The dip slope northwest of Willow Creek lies somewhat lower than its extension southeast of Willow Creek, and a large block between the forks is still more depressed. The north border of the block is marked by a long scissors fault trending slightly north of east entirely across the outcrop of the Phosphoria formation. Along the north branch of Willow Creek and

up the slopes westward for most of its length, the fault is upthrown on the north. The pivot lies 200 yards north of the main fork of Willow Creek. Downstream to the eastward the fault is upthrown on the south. The western third of the fault is paralleled on the south by another pivot fault. The east end of this fault is upthrown on the north as is the adjacent part of the main fault, but the west end is upthrown on the south, forming with the main fault a narrow graben. These faults were not traced beyond the contact of the Phosphoria formation and the Tensleep sandstone.

A north-trending fault upthrown on the east forms the east border of the block. The southeast branch of Willow Creek follows the line of the fault. Throughout most of its length the trace of the fault is effectively concealed by slump and landslide debris, possibly derived in part from the fault scarp. This fault seems to split and die out abruptly near the east-trending fault, although a northward continuation may be offset beyond the mapped area by lateral movement along the east-trending fault.

One minor fault was noted a quarter of a mile north of the west end of the east-trending fault and another 200 yards south of the pivot. A few minor tear faults were observed along the east-trending fault at the north end of the north-trending fault.

The plane of the north-trending fault may be gently inclined, as the trace seems to be somewhat sinuous, but the others seem to be vertical. The maximum vertical displacement of the east-trending fault is of the order of 200 feet. The displacement along the north-trending fault may exceed 1000 feet (fig. 3, sec. C-C').

The two major faults intersect almost at right angles and cross the trend of the anticlinal Wind River Mountains at angles of almost 45°. This pattern is suggestive of failure by shearing under compressional stress, which would tend to produce extensive lateral movement along the faults.

Folds.—The only major fold examined is the asymmetric anticline between Barrett Creek and Red Canyon Creek. It has been described by Condit (1924, p. 25) and by Branson and Branson (1941, p. 148, fig. 8), who disagree on the magnitude of the dip of the western limb. No new information was obtained, but the thrust fault at the south end, mentioned by Condit, was noted.

A few minor flexures or swells were observed, but they are too small to be shown on figure 3. One such flexure is indicated on the large-scale map (fig. 6) by the change in dip and the consequent change in spacing of contours on the dip slopes. This monocline trends somewhat west of north through Tub Spring and on across Little Popo Agie River. It may account in part for the extensive landslide that was mentioned on page 8 in the discussion of the clay above the geodal ledge.

A drag fold east of the north-trending fault on Willow Creek is indicated by a dip of 43° W.

PHOSPHATE ROCK

Terminology

Following Gardner (1944, pp. 12-13), the term phosphate rock is restricted to rock containing at least 30 percent bone phosphate of lime (B.P.L.), which is equivalent to 13.8 percent phosphorus pentoxide (P_2O_5) by weight. Phosphate rock containing 30 to 49.9 percent B.P.L. (13.8 to 22.9 percent P_2O_5) is classified as low grade. That containing 50 to 69.9 percent B.P.L. (22.9 to 32.1 percent P_2O_5) is classified as medium grade, and phosphate rock

containing more than 70 percent B.P.L. (32.1 percent P_2O_5) is classified as high grade. All the phosphate rock found in the Lander area is included in the low-grade and medium-grade categories.

Occurrence and distribution

General statement.—The phosphate rock in the Lander area was deposited from marine water as extensive but relatively thin layers interstratified with rocks of other composition. Subsequently, these strata were tilted into the great anticline of the Wind River Mountains. Although much phosphate rock has been eroded from the main part of the range and much is buried beneath younger sediments in the Wind River Basin, still a great amount is preserved along the lower slopes above stream level, where resistant overlying rocks have until now protected it from erosion.

Exposures of the phosphate rock are few, and it was not feasible to attempt to show them on the small-scale map (fig. 3). In fact, the outcrop of either phosphate bed is difficult to locate exactly except by trenching. Inasmuch as the upper part of the Phosphoria formation weathers to steep slopes, the upper phosphate zone extends only 100 to 200 feet farther up dip or along the strike than the top limestone and dolomite member, the base of which was mapped. Similarly the lower phosphate zone generally extends only a few feet beyond the geodal ledge, the top of which was also mapped. The geodal ledge locally forms dip slopes, however, and in those areas the lower phosphate zone may extend as much as 750 feet beyond the mapped contact. On the other hand, the amount of phosphate rock lying above drainage level is somewhat less than indicated by the contacts. These diserepancies are believed to compensate one another.

Lower phosphate zone.—The phosphate rock in the lower zone is medium grade except in the vicinity of Squaw Creek and in the southernmost trenches (Y and Z), where it is somewhat below medium grade. Trench P, 2 miles west of Trench A, yielded samples that averaged only 22.5 percent P_2O_5 (49.1 percent B.P.L.) according to analyses made by the laboratory of the Tennessee Valley Authority, and 22.8 percent P_2O_5 (49.7 percent B.P.L.) according to analyses made by the University of Wyoming Natural Resources Research Institute. The average grade of the phosphate rock included in the ore blocks, 23.6 percent P_2O_5, is still within the medium-grade category. The range is 22.5 to 26.3 percent P_2O_5. For the whole area mapped, however, the range is 21.5 to 29.7 percent P_2O_5.

North of Willow Creek the lower phosphate zone is less than 3 feet thick, which is herein regarded as the present minimum workable thickness of medium-grade rock. The area where the zone is thickest is that extending from Cherry Creek to Willow Creek, and even here it is less than 4 feet thick. The details of thickness, grade, and lithology of the lower zone are shown in figure 4.

Upper phosphate zone.—The rock in the upper phosphate zone is all low grade. Samples from only two trenches averaged as much as 20 percent P_2O_5 (44 percent B.P.L.) and no individual sample yielded more than 22 percent P_2O_5. The grade ranges from 15.2 to 20.2 percent P_2O_5, and within the ore blocks averages 17.1 percent P_2O_5 (35 percent B.P.L.)

The zone is thickest in the area between Willow Creek and Little Popo Agie River, where it averages less than 6 feet thick. At the north end of the area the thickness is less than 3 feet. The details of thickness, grade, and lithology of the upper zone are shown in figure 5.

Minor beds of phosphate rock.—The sepia clay and siltstone beds above the upper phosphate zone contain two thin seams of phosphate rock (fig. 2).

In Trench A on Little Popo Agie River the lower one is 4 inches thick and the upper one is 2 inches thick. In Trench B on Baldwin Creek the lower one is 6 inches thick and the upper one is 3 inches thick. In Trench A there are two thin seams of phosphate rock in the chert overlying the sepia clay; the lower one is 5 inches thick and the upper one is 4 inches thick. These beds in the chert were not seen in Trench B. Such thin seams did not merit further prospecting, and so were not trenched elsewhere.

Lithology

The phosphate rock in the Lander area is bedded only indistinctly, except at contacts with rocks of different composition. Beds within the phosphate rock are distinguished more by lithologic variation than by physical breaks. The material may therefore be regarded as massive, if that term is accepted in this slightly modified sense. There is a suggestion of irregular to wavy bedding within units of uniform lithology.

The texture ranges from granular to finely nodular. Much of the rock is composed chiefly of grains the size and shape of oölites and pisolites. Field examination of the particles with the aid of a hand lens failed to reveal any concentric structure, however, so terms (i.e.: "oölitic" and "pisolitic") that would imply its presence are enclosed in quotation marks.

The Lander phosphate rock presumably includes an intimate mixture of several closely related calcium-phosphate and calcium-fluo-phosphate minerals. The abundance of amorphous to cryptocrystalline material and the minute size of the crystals in the crystalline material make specific identification difficult, separation of pure minerals being almost impossible under these conditions. Detailed mineralogic investigation seems to be unwarranted at this time.

In addition to phosphatic material, the rock contains calcium carbonate and insoluble material. The latter is chiefly clay, silt, and very fine sand. It constitutes 6 to 36 percent of each sample, but most samples contain 10 to 20 percent. Minor constituents comprise 1 to 3 percent of MgO, probably present as carbonate; 2.8 to 3.7 percent fluorine as a constituent of the phosphate; generally less than 2 percent R_2O_3, that is, iron and aluminum oxides; and not more than 3.7 percent sulfate (SO_4), probably present as gypsum. Only ten samples were analyzed for sulfate. All samples were tested for vanadium, but none showed as much as 0.1 percent V_2O_5. Glauconite was noted in many specimens, and it may be the source of the R_2O_3.

The color of the phosphate rock is predominantly gray-black to brown-black, but it ranges from dark-gray and dark-brown to black. In some specimens of low-grade rock, light-gray to gray silt and carbonate matrix can be distinguished from darker phosphate.

The rock is tough rather than hard, and strongly cohesive. In digging the trenches it was observed that the rock tended to flake when the pick was driven into the bedding planes, but chipped or crumbled slightly when struck normal thereto. A few pieces could be lifted out as slabs or flags.

Method of Sampling

All trenches were cut approximately 30 inches wide and normal to the apparent dip. Pick and shovel were used to remove soil, slump, and weathered bedrock. Pick and hand pick were then used to trim the floor to a bedding plane and the face to a plane normal thereto. All loose material was swept from the face, sides, and floor with a whisk broom.

Non-phosphatic rocks in Trenches A and B were chip-sampled, but all phosphate rock and adjacent beds both above and below the phosphate zones were sampled by cutting a 2-inch by 6-inch channel down the face.

Each sample was crushed to pass a ¼-inch screen, then rolled, coned, and quartered, and duplicate splits weighing 2 to 5 pounds each were prepared in the field. One set of samples was sent to the laboratory of the Tennessee Valley Authority and the other to the University of Wyoming Natural Resources Research Institute. Analytical results obtained by these organizations agreed as follows: Of 68 samples analyzed by both laboratories, 34 (50 percent) checked within 0.5 percent, 53 (78 percent) checked within 1.0 percent, and only 7 (10 percent) differed more than 1.5 percent. Slight discrepancies may have resulted because all fine material that remained on the cloth after the samples were sacked was swept into one of the sacks, possibly altering the relative composition of the splits.

A composite sample weighing more than a ton and representing the full thickness of the lower phosphate zone was cut from Trench A, Little Popo Agie River, and shipped to the University of Wyoming Natural Resources Research Institute.

Chemical analyses

The following tables include all analytical data. Inasmuch as only a few samples were tested for such constituents as SO_3 the results of such tests are included in supplementary tables below the main tables. Phosphate content as determined by the Tennessee Valley Authority laboratory is indicated by figures in italics. Results obtained by the Natural Resources Research Institute at the University of Wyoming are shown by figures in roman type. All samples were tested for vanadium, but only those that contained traces are listed.

DETAILED STRATIGRAPHIC SECTIONS AND CHEMICAL ANALYSES

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH A
Little Popo Agie River, 13 miles south of Lander, Wyoming,
¼ mile west of east ¼ corner, sec. 8, T. 31 N., R. 99 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		TRIASSIC DINWOODY FORMATION Siltstone and shale, thinly interbedded, calcareous, limonitic, variegated gray, tan, and dull green; 3′ exposed.				
		PERMIAN PHOSPHORIA FORMATION				
	107	Limestone, argillaceous, earthy to crystalline, gray-white to creamy, thin bedded, unevenly bedded; contains much crystalline calcite (secondary?) in blebs and stringers, and trace of limonite. Top uneven.	2	0±		
	106	Dolomite, finely crystalline, pale dull-brown, not well bedded, but strongly jointed, angular; upper 11″ gray.	6	5		
	105	Dolomite, calcareous, dense, light gray, very massive, well bedded; contains some 1″ tan chert nodules near top.	9	2		
	104	Siltstone, dolomitic, light gray, thin bedded, poorly bedded.	0	10		
A 33	103	Limestone, earthy, cream color, massive; full of gray chert in nodules and irregular bands. Two (?) beds, very irregular.	9	0±		19.9
	102	Limestone, dolomitic, dense, light gray, massive; contains numerous green and tan to gray clay "oölites" and some molds of shell fragments.	3	0		
	101	Dolomite, argillaceous, somewhat cherty, dense, light tan, nodular, poorly bedded; contains some calcite geodes and nodules. Thin, soft shaly parting at base.	1	7		
	100	Dolomite, silty, dense, light gray, thin bedded, wavy bedded; full of nodules of chert like underlying 99; both the dolomite and chert contain quartz-lined calcite geodes and nodules.	2	6		

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
	99	Chert, dolomitic, dull blue-greenish gray; under lens seems minutely granular; nodular, wavy bedded, silty laminae on bedding planes; contains a few calcite nodules; becomes more calcareous upward.	9	0		
	98	Phosphate rock, very calcareous, granular to "pisolitic", poorly sorted; contains some greenish chert. Gradational from underlying chert; top uneven.	0	4±		
A 32	97	Chert, subtranslucent, greenish-gray, under lens seems minutely granular; massive, five or six beds, wavy bedded; slightly calcareous argillaceous silt laminae on bedding planes; contains some 1″ limonite nodules and calcite nodules and geodes.	3	6		68.8
	96	Siliceous shale, light grayish-green, nodular; paper-thin clay laminae abundant at base and top, scattered throughout, curving around nodules; contains some ½″ limonitic concretions.	1	7		
	95	Phosphate rock, gray, comprising granules and irregular pellets of dark gray phosphate and some greenish-gray clay. Gradational with underlying 94.	0	5		
A 31	94	Siliceous shale, gray-black grading upward into grayish-green, massive below, fissile above; contains stringers of white calcite.	1	4		50.6
	93	Siltstone, very fine grained, argillaceous in lower part grading into dolomitic in upper part, poorly bedded in lower part, wavy or nodular in upper part; contains some phosphate grains or pellets and some 2″ calcite geodes.	3	7½		
A 30	92	Phosphate rock, argillaceous, granular to "pisolitic", poorly sorted, gray-black, contains some amber-colored fish (?) remains.	0	2	2.1	64.7
	91	Siliceous shale, dark gray, nodular; contains some 2″ calcite geodes in top; gradational with underlying 90.	1	3		

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH A
Little Popo Agie River, 13 miles south of Lander, Wyoming,
¼ mile west of east ¼ corner, sec. 8, T. 31 N., R. 99 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
	90	Siltstone, very fine grained, like lower part of bed 88, but becoming thin bedded and nodular in upper 1 to 1½ feet.	15	7	2.2	
A 29	89	Phosphate rock, argillaceous, granular, gray-black, shaly or platy bedded; contains few amber-colored chalcedony (?) granules.	0	4	*3.4*	60.3
A 28	88	Siltstone, very fine grained, or silty mudstone, somewhat calcareous, dull sepia to brownish-gray, upper 5′ grayish-tan; massive, nodular, jointed.	17	2	*0.7*	65.1
	87	Clay, calcareous, yellow-brown, containing black and gray phosphate grains and pellets.	0	0½		
A 27	86	Mudstone, somewhat calcareous, dull sepia, only moderately well bedded, somewhat nodular, jointed; contains 1″ seams of phosphate 5″ and 14″ above base.	2	1	3.0 *3.1*	58.9
A 26	85	Phosphate rock, calcareous, argillaceous, granular to "pisolitic", poorly sorted, gray-black; contains some amber-colored fish (?) fragments.	0	9	15.3 *15.2*	36.2
A 25	84	Clay shale or mudstone, somewhat silty and calcareous in lower part, dark gray-brown, not well bedded.	0	10½	*1.8*	47.7
A 24	83	Phosphate rock, calcareous, granular to "pisolitic", irregular grains, gray-black to brown-black; contains few amber-colored fish (?) fragments and other scraps. Strong oily odor.	1	8	20.6 *21.2*	23.5

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
A 23	82	Limestone, dense, brown-black; full of small irregular phosphate grains or pellets, many of which are internal molds of mollusk shells, principally snails. Somewhat argillaceous 1″ zone at center of bed.	0	11	16.7 *16.1*	14.5
A 22	81	Phosphate rock, slightly calcareous and argillaceous, finely "oölitic", few "pisolites", brown-black; contains few paper-thin light tan clay partings in lower 3″, and a few fossil fragments.	0	10½±	22.0 *21.6*	15.5
A 21	80	Siltstone, dolomitic, argillaceous, light gray-tan, one massive bed; contains some phosphate "oölites", dark gray to brown, most numerous in lower part. Top wavy.	0	11±	*3.1*	16.5
	79	Phosphate rock, calcareous, granular, some "oölites" and "pisolites", not well sorted, gray-black; contains some molluscan (?) fragments and amber-colored fish (?) fragments.	0	11		
	78	Siltstone, very fine grained, slightly calcareous, gray; contains numerous black phosphate "oölites", some "pisolites", and some amber-colored fish (?) fragments.	0	4		
A 20	77	Phosphate rock, slightly calcareous, "oölitic", gray-black, contains some amber-colored fragmental fish (?) remains.	0	5	22.4 *22.0*	15.4
	76	Phosphate rock, calcareous, argillaceous, "oölitic", much limonitic stain, giving a mottled yellow-gray tinge; contains few fragmentary fish (?) remains.	0	2		
A 19	75	Dolomite, argillaceous, dense, not well bedded, somewhat wavy, consists of about eight beds; contains some glauconite and limonite. Top slightly nodular.	3	3±	*1.7*	29.8

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH A

Little Popo Agie River, 13 miles south of Lander, Wyoming,

¼ mile west of east ¼ corner, sec. 8, T. 31 N., R. 99 W.

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
A 18	74	Dolomite, siliceous, dense, gray, thin bedded, nodular. Gradational into overlying bed.	2	1±		
	73	Siltstone, dolomitic, banded tan and gray, platy, almost shaly.	0	8½±		59.3
A 17	72	Dolomite, silty, light gray, tinged greenish-tan, nodular bedded.	0	2½±		
	71	Siltstone, dolomitic, gray-tan tinged with green, thin bedded, top 3″ shaly.	2	4		
	70	Limestone grading into dolomite, argillaceous, dense, light gray, thin bedded, moderately well bedded; contains some limonite, glauconite, and chalcedony.	2	2		39.9
	69	Siltstone, slightly calcareous, argillaceous, light greenish-tan, thin bedded, not well bedded.	1	2		
	68	Limestone, argillaceous, dense, light gray, thin bedded, not well bedded; contains some glauconite and limonite.	0	9		
A 16	67	Dolomite, grading upward into dolomitic limestone, somewhat argillaceous, dense, gray, fairly massive (about eight beds), only moderately well bedded, jointed at all angles; contains layer of scattered calcite geodes 1′ below top.	6	2		
	66	Clay, silty, somewhat calcareous, yellowish-tan, somewhat nodular bedded.	1	1		23.1
	65	Dolomite, dense, light gray, faintly mottled with rose and yellow tints, massive except bottom 2″, notably sharp regular joints.	3	11		

Sample No.	Bed No.		THICKNESS Ft.	THICKNESS In.	P_2O_5 (percent)	Acid insol. (percent)
	64	Silt, argillaceous, calcareous, light gray and light tan, bedded.	2	11		
	63	Silt, argillaceous, slightly calcareous, bluish-gray, columnar to nodular.	3	2		
	62	Clay, somewhat calcareous, olive-tan, some gray, nodular.	2	9		
A 15	61	Clay, somewhat calcareous, light gray to olive-gray, nodular to poorly bedded. Thickness difficult to measure, as is bed 50.	17	1±		63.3
	60	Clay, dolomitic, silty, yellow-brown; contains numerous stringers of dark translucent chert or chalcedony, and limonitic streak at top.	0	7		
A 14	59	Dolomite, siliceous (silica evenly distributed in small particles or banded, not as sand grains), more calcareous upward, light lavender-gray, moderately massive, well bedded to irregular; contains shaly parting 8″ above base, and some light gray chert nodules.	4	1		73.7
	58	Limestone, cherty, dense, gray, wavy bedded.	0	10±		
	57	Dolomitic clay, hard, gray-white, not well bedded, upper third more shaly bedded, but still irregular, and gray; contains some chalcedony-shelled calcite-lined geodes, and nodules of gray-black chert, some arranged roughly in bands.	2	5		
	56	Chert, gray-black.	0	1		
	55	Clay, dolomitic, hard, light gray, bedded.	1	11		
A 13	54	Shale, calcareous, light gray, but darker than underlying beds, somewhat nodular in upper part; contains some stringers of chalky $CaCO_3$ and a few blebs of limonite.	0	9		51.7
	53	Clay, dolomitic, light gray; contains some opaline silica.	0	8		
	52	Dolomite, dense, light gray.	0	10		
	51	Siltstone, dolomitic, light gray, one bed.	0	5		

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH A
Little Popo Agie River, 13 miles south of Lander, Wyoming,
¼ mile west of east ¼ corner, sec. 8, T. 31 N., R. 99 W.

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
	50	Clay, silty, somewhat calcareous, light gray, some yellow-brown iron stain; very nodular, too poorly bedded to measure precisely, and too thick to trench in single cut.	15	0±		
	49	Clay, somewhat silty and calcareous, yellow-brown, nodular, interbedded at top with overlying 50.	2	0±		
	48	Clay, calcareous, tough, gray, no lamination or parting, cuts smooth.	0	11		
	47	Clay, calcareous, light gray, slightly greenish, coarsely nodular; contains some bands, stringers, and nodules of limonite.	2	10		
A 13 Cont.	46	Clay, waxy, mottled and banded olive-gray, some yellow iron-stain; nodular, passing upward imperceptibly into silty dark gray clay; contains numerous calcareous stringers.	2	9±		
	45	Dolomite, dense, light bluish-gray, very uneven.	0	4±		
	44	Clay, silty, somewhat calcareous, gray-white, yellowish from pin-point limonite grains, nodular.	2	0±		
	43	Clay shale, slightly calcareous, olive-green to olive-brown, laminated, grading upward into gray, somewhat nodular.	0	11		
	42	Dolomite, dense, tan, one bed irregularly parted.	0	5		
A 12	41	Dolomite, very fine grained, light gray, peppered with small dark specks, massive; all except bottom 12″ is sandy and shows some minor cross-bedding; contains thin shaly parting 2′ above base, above which is massive bed 2′ 7″ thick, overlain by three irregular beds totaling 9″.	5	4		52.0

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
	40	Silty clay, calcareous, light tan, some streaks of orange-tan and light gray, fairly well bedded; contains very irregular bands of porous chalcedony containing bituminous material, about 11″, 17″, and 36″ above base; more limy bands in top 20″ become transitional in top 4″ into overlying 41.	6	5		
A 11	39	Clay, somewhat calcareous, light gray, but darker than underlying 38, and a few streaks of orange-tan, irregularly to well bedded, bed becomes lighter and better stratified toward top, where it includes some irregular silty layers less than 1″ thick; contains some geodes comprising chalcedony shell and drusy to crystalline calcite lining, some filled with bitumen and some coated with limonite; largest geode noted, 8½″ in diameter.	12	8		67.2
	38	Clay, somewhat calcareous, mottled and banded light gray and orange-tan, nodular to irregularly bedded.	8	9		
	37	Limestone, somewhat dolomitic and siliceous, dense, gray to dark gray; porous to cavernous, the openings lined with about 1 mm. of minutely fibrous calcite and partly filled with tan to greenish-gray calcareous clay.	0	9½±		
A 10	36	Dolomite, dense, somewhat porous, light gray, moderately well bedded, about six beds.	3	10		11.9
	35	Dolomite, somewhat argillaceous, very fine grained, somewhat porous, light tannish-gray, single massive bed; in upper 2′ contains some poorly preserved fossils and a few small irregular chert nodules, and locally there is a fairly definite 2″ band of nodules 2½′ below top.	8	8		
	34	Dolomite, somewhat argillaceous, very fine grained, light gray, massive, but only moderately well bedded, three to five beds; contains some thin local shaly partings, very few fragments of fossils, and numerous calcite geodes 3″ or smaller.	8	3		

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH A
Little Popo Agie River, 13 miles south of Lander, Wyoming,
¼ mile west of east ¼ corner, sec. 8, T. 31 N., R. 99 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
A 9	33	Chert, white mottled with light to dark gray, under lens seems minutely granular; nodular; contains trace of calcite, few ½" to 1" limonite concretions, and scattered nodules of green chert. Contact with overlying bed locally gradational.	1	3		75.5
	32	Dolomite, argillaceous, dense, light gray, slightly greenish in lower part two massive beds; contains few shell fragments and some opaline silica.	1	8		
	31	Clay, somewhat calcareous, light gray, shaly at base to nodular at top; contains few fossil fragments and some ¼" to 2" limonite concretions.	0	8½		
A 8	30	Dolomite, argillaceous, dense, light gray, gray in middle part, grades irregularly into dolomitic clay at base, lower third not well bedded, separated by shaly parting from upper two thirds, which is a single bed containing ½" to 2½" calcite geodes filled with bituminous material.	1	6	4.1	20.6
	29	Phosphate rock, granular, some "oölites", "pisolites", and snail-shell fillings, black, contains about 30% orbiculoid fragments and a trace of glauconite and calcite.	0	4		
A 7	28	Dolomite, dense, tannish-gray, two thin beds; some limonite-coated calcite geodes containing bituminous material spread the parting. Bottom surface uneven.	0	4±		40.7
	27	Clay, gray silty, olive-brown waxy, and some greenish and lavender, mixed and variegated.	0	2½	11.2	

Sample No.	Bed No.		THICKNESS Ft.	THICKNESS In.	P_2O_5 (percent)	Acid insol. (percent)
	26	Clay shale, gray and olive-brown; contains pin-point opaline silica (?) concretions and a few 2″ bluish chalcedony concretions containing some calcite and limonite.	0	3	*11.1*	
A 7 Cont.	25	Phosphate rock, calcareous, "oölitic" to "pisolitic" and irregular, black; contains a few shell fragments, principally orbiculoids.	0	1¼		
	24	Shale, somewhat phosphatic, especially in lower part, gray in lower part to olive-brown in upper part; contains some orbiculoid fragments. Probably gradational with underlying bed.	0	2		
	23	Phosphate rock, non-calcareous, "pisolitic", some shell fillings, gray-black; contains some orbiculoids.	0	4½	28.8	11.0
A 6	22	Phosphate rock, calcareous, "oölitic" and "pisolitic", black, grading into phosphatic limestone in upper part; contains orbiculoid fragments and trace of glauconite.	0	10±	*28.1*	
	21	Limestone, dense, gray, but full of black oval phosphate "pisolites" 3 mm. or smaller; contains some brown orbiculoid shells and some white calcite. Top and bottom somewhat irregular.	0	2±		
A 5	20	Phosphate rock, "oölitic", some 3 mm. "pisolites", gray-black to black; contains some glauconite in lower part, a 3″ to 4″ band of orbiculoids near center, and stylolitic line of glassy gypsum (?) at top that looks white. Top surface uneven.	2	4±	25.6 *25.4*	13.5

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH A
Little Popo Agie River, 13 miles south of Lander, Wyoming,
¼ mile west of east ¼ corner, sec. 8, T. 31 N., R. 99 W.

Sample No.	Bed No.		THICKNESS Ft.	THICKNESS In.	P_2O_5 (percent)	Acid insol. (percent)
	19	Limestone, dolomitic, dense to fine grained, light gray, irregularly bedded; contains some glauconite and phosphate, some calcite geodes, and some silicified fossils, chiefly Bryozoa, especially in top. Top surface very uneven.	4	0±		
	18	Siliceous shale, white to gray-black, not well bedded; contains some chalcedony cavities lined with minute quartz crystals. Top surface very uneven.	0	10±		
A 4	17	Greensand, fine grained sandstone, quartz and glauconite, the latter partly altered to limonite; contains a few phosphate grains. Fills irregularities in top of bed 16.	0	3±	*1.5*	33.4
	16	Limestone, dolomitic, fine grained, somewhat porous, gray; contains few phosphate pellets and few fossils. Transitional zone at base weathers back in cliff face, although it contains ½" nodules of white chert or chalcedony. Top surface nodular.	6	0		
	15	Dolomite, silty, fine grained, light gray weathering yellowish, massive; contains three nodular bands and some scattered nodules of gray-black chert that weathers yellow.	9	5		
	14	Shale, non-calcareous, limonitic, tough; thin red line at top.	0	3±		
	13	Impure chert or jasperoid, variegated in yellow, red, gray, some green, nodular.	0	8		
	12	Limestone, very fine grained, light gray, containing about 25% nodular chert,	1	10		
A 3		tannish gray at base and yellow to reddish near top. Upper surface uneven.			*Trace*	38.1
	11	Dolomite, very fine grained, light gray, horizontally lined.	0	4½		
	10	Clay shale, calcareous, olive-brown to chocolate-colored.	0	4		
	9	Sandstone, calcareous, fine to medium grained, poorly sorted, tannish-gray, massive, shaly parting in middle.	1	7		

Sample No.	Bed No.		THICKNESS Ft.	THICKNESS In.	P_2O_5 (percent)	Acid insol. (percent)
A 2	8	Clay shale, tan, gray, and lavender; contains small lenses of dolomitic sandstone like underlying bed.	2	0	*Trace*	43.0
A 1	7	Sandstone, dolomitic, fine grained, but not well sorted, light gray except for brown petroliferous stains, irregularly bedded; contains some greenish shale inclusions and trace of glauconite.	1	8	*Trace*	51.4
	6	Dolomite, silty, very fine grained, light gray faintly tinged with lavender; two thin beds and an upper thicker bed.	0	6½		
	5	Clay, non-calcareous, yellow and chocolate-colored, not well bedded.	0	2½		
	4	Chert, translucent, fused-oölitic, light bluish-gray, one bed.	0	2¾		
	3	Dolomite, silty, very fine grained, tannish-gray, horizontally lined, one bed.	0	3¼ ±		
	2	Clay shale, somewhat calcareous, tan, orange on bedding planes, not well bedded.	0	5½		
	1	Limestone, dolomitic, fine grained, light gray, irregularly divided into about 10 beds, but not well bedded except upper 2′, which is sandy. Lower 3′ 10″ contains numerous small to large (3″) spherical to angular chert concretions or pebbles and grades into upper sandy part. The chert is white, some gray. (3 feet included in sample A 1)	5	10		
			289	11¼		
		PENNSYLVANIAN TENSLEEP SANDSTONE				
	0	Sandstone, calcareous, fine grained, massive, forms ledge. Not measured.				

Supplementary analyses

Sample No.	R_2O_3	*CaO*	*MgO*	F_2	SO_3
A 29					0.4
A 27					0.4
A 26					1.6
A 24					2.3
A 23					1.5
A 22					2.4
A 20					2.4
A 6	1.5	43.4	1.1	3.6	3.3
A 5	1.7	40.8	1.5	3.2	3.5

Samples A 7, A 11, A 15, A 17, A 18, A 25, A 26, A 27, and A 29 yielded less than 0.1 percent V_2O_5.

The one-ton composite sample, equivalent to A 5 and A 6, was analyzed separately, with the following results:

Moisture loss 110° C	0.8
Ignition loss	7.3
SiO_2	14.4
P_2O_5	27.1
CaO	40.6
F_2	3.4
SO_3	3.6
MgO	1.8
R_2O_3	1.2
CO_2 by evolution	5.5
Acid insoluble	14.3
Fe_2O_3	0.8
Cl_2	trace
Cr_2O_3	trace
V_2O_5	none
TiO_2	0.10

The above figures total more than 100 percent because of duplications, e.g., acid insoluble and SiO_2.

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH B
Baldwin Creek, 8 miles west of Lander, Wyoming,
in SW ¼ sec. 18, T. 33 N. R. 100 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		TRIASSIC DINWOODY FORMATION Clay shale, calcareous, sandy, tan and greenish-tan, moderately well laminated; contains some irregular lenses of iron-stained limestone, sandy to argillaceous, creamy-white to greenish-tan, and some silty bands. 2′ 6″ measured.				
		PERMIAN PHOSPHORIA FORMATION				
B 27	90	Limestone, argillaceous, dense to recrystallized, creamy-tan, some limonite stain; substylolitic in part. Top uneven.	0	2½±		21.5
	89	Limestone, dense, light gray tinged with lavender, single bed, hard, forms top of scarp; contains some calcite grains.	1	4		
	88	Dolomite, silty, dense, creamy-white to gray-white, thin bedded, well bedded; contains a few small calcite geodes.	1	4		
	87	Sandstone, calcareous, fine grained, light gray, thin bedded, moderately well bedded; about 2″ below top there is a band of small (1½″) chert nodules, light bluish-gray, sub-oölitic, containing fossil fragments.	1	6		
	86	Limestone, sandy, dense, light gray, thin bedded; contains some limonite streaks and crystalline calcite.	3	6		
	85	Sandstone, dolomitic, fine grained, gray-white, thin bedded, but not well bedded; full of light bluish-gray chalcedony.	1	10		

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
B 27 Cont.	84	Limestone, sandy, dense, light gray, massive; contains abundant small chert nodules and small calcite geodes, especially in bottom.	5	1		
	83	Dolomite, silty, finely crystalline, light gray, massive; contains some small (¾″) calcite geodes near middle.	6	9		
	82	Siltstone, calcareous, light bluish-gray to light gray, massive; upper 1′ or so irregularly platy jointed; contains numerous small (2″) calcite geodes.	5	6		
	81	Dolomite, limy, silty, dense to finely crystalline, light medium-gray, massive; contains numerous grains of dark mica and a few flecks of bright green clay. Two 3″ nodular bands of chert about 3′ 4″ and 4′ 2″ above base, very light gray but weathering black.	5	2		
	80	Dolomite, slightly silty, dense, creamy white, massive, two beds, shaly parting between; contains numerous flecks of bright green clay and some calcite geodes.	3	9		
	79	Dolomite, limy, silty, dense, light gray to gray, one massive ledge; contains flecks of bright green clay and about 15% chert in irregular nodules and rough bands. The chert is light gray, some dark gray, somewhat geodal, and contains numerous fossil fragments and some bright green clay.	4	10		
B 26	78	Siliceous shale, silty, gray-black, but weathers tan to greenish; thin bedded, nodular to wavy bedded, contains a few limonite nodules and calcite geodes, especially in lower part. Thin lenses in top 6′ are virtually solid chert.	13	7		70.6
B 25	77	Siltstone, argillaceous, somewhat dolomitic, gray-black to brown-black, laminated to thin bedded; some soft sepia shales interbedded in bottom 1½′.	12	10		
	76	Phosphate rock, granular to "oölitic", brown-black, calcareous light brown matrix; contains few orbiculoid shells.	0	3		61.2
	75	Clay, silty, dolomitic, dark bluish-gray, massive.	13	10		

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH B
Baldwin Creek, 8 miles west of Lander, Wyoming,
in SW ¼ sec. 18, T. 33 N., R. 100 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
B 24	74	Phosphate rock, finely and evenly "oölitic", black, in scanty gray-white calcareous matrix; thin uneven bedding.	0	6		33.1
B 23	73	Clay shale, calcareous, light gray, thinly laminated, containing large nodules of gray to blue-green dolomitic siltstone, which make up about 70% of the rock.	6	0		65.8
	72	Clay shale or mudstone, silty, non-calcareous, sepia, moderately well laminated to thin bedded.	12	11		
B 22	71	Phosphate rock, granular to "oölitic", slightly calcareous, brown-black.	0	3	7.4	44.9
	70	Clay shale, slightly calcareous, sepia.	0	11		
B 21	69	Phosphate rock, similar to underlying 68, but thin bedded to platy.	1	8	18.0	16.7
	68	Phosphate rock, granular to nodular gray-black phosphate in scanty light gray limestone matrix; massive, but weathers platy.	1	2	18.4	
B 20	67	Coquina, calcareous, phosphatic, gray-black, thin to platy bedded, some spiriferoids but more productids, and a few *Composita*. Gradational into 68 above.	0	10	9.7	19.3
	66	Coquina, calcareous, glauconitic, light gray, nodular to wavy bedded, principally *Neospirifer pseudocameratus* (Girty), a few *Punctospirifer pulcher* (Meek). Gradational into 67 above.	1	3±	9.8	

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
B 19	65	Limestone, sandy, glauconitic, dense, light gray, massive, becoming thin bedded at top; contains a few silicified fossil fragments.	3	3	4.0	18.9
B 18	64	Limestone, argillaceous, dense, light tan, massive, contains numerous shell fragments, grains of glauconite and limonite.	1	10		
	63	Dolomite, dense, gray, massive, irregularly jointed; contains traces of fossils and of glauconite and some small red-brown clay "oölites".	3	6		
	62	Limestone, argillaceous, dense, light tan, one bed; contains some silicified shell fragments and a few grains of glauconite.	0	8		
	61	Limestone, dolomitic, dense, dull grayish-brown, massive; contains some silicified shell fragments, a few specks of glauconite and limonite, and irregular nodules of black chert bordered with buff and packed with sponge spicules and other fragmentary remains.	3	7		36.4
	60	Limestone, dolomitic, dense, white, specked with tan clay "oölites", massive; contains a few calcite shell fragments.	2	4		
	59	Dolomite, argillaceous, dense, light gray; specks of limonite in the lower of the two beds.	1	2±		
	58	Dolomite argillaceous, dense, light gray to gray, nodular bedded; contains some specks of bituminous material and sparse fragments of fossils; top surface uneven.	1	2±		
	57	Siltstone, argillaceous, somewhat dolomitic, light gray, fairly massive, fairly well bedded, irregularly jointed.	5	4		
B 17	56	Clay, silty, dolomitic, light gray, blocky to nodular, not well bedded; contains limonite bands (about 1" thick) about 6" and 30" above base and irregular zone 9½' above base. Grades upward into 57.	15	2		62.3

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH B
Baldwin Creek, 8 miles west of Lander, Wyoming,
in SW ¼ sec. 18, T. 33 N., R. 100 W.

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
	55	Limestone, silty, recrystallized, porous, white to brownish-gray, thin bedded; contains much limonite and silica; top uneven.	0	5±		
	54	Siltstone, dolomitic, light gray, somewhat banded, locally mottled, thin bedded, well bedded; contains some disseminated chert and silicified shell fragments, decreasing upward.	3	2		
B 16	53	Limestone, finely crystalline, gray, somewhat wavy bedded, full of chert, possibly more than half, disseminated and in nodules, light gray and light bluish-gray, weathering orange-brown. Forms flat slabs of cherty float.	1	11		64.5
B 15	52	Siliceous shale, silty, dolomitic, light grayish-tan, laminated to nodular; few thin seams of dark bluish-gray chert in lower 20″; upper 28″ almost all chert, subtranslucent, light tan and light to dark gray, nodular bedded.	4	0		58.1
B 14	51	Dolomite, dense, light gray and gray, massive, becoming shaly at top and grading into overlying 52; contains irregular nodules of chert, subtranslucent, dark bluish-gray.	2	5		25.7

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
	50	Siltstone, dolomitic, argillaceous, light gray, lower part well bedded in three beds, 1½", 5½", and 1½" thick, the upper 1½" bed shaly laminated.	0	10		
	49	Clay, silty, dolomitic, light gray, nodular below, laminated above; contains lenses or nodules of dense light gray argillaceous dolomite as much as 8" thick between the nodular and thin bedded portions.	1	10±		
	48	Siltstone, argillaceous, dolomitic, light gray, massive, irregularly jointed; contains limonite blebs and small lenses. Top surface very uneven.	1	7±		
B 13	47	Clay, silty, non-calcareous, olive-gray, thin bedded, moderately well bedded; contains flattened nodules or small lenses of limonite.	0	6½		55.5
	46	Clay, sandy, calcareous, light gray, some light tan, thin bedded, moderately well bedded; contains some limonite blebs. Top is nodular.	3	3		
	45	Clay, silty, dolomitic, light gray to light tan, locally porous or vuggy, massive, blocky, fairly well bedded; shows limonite wash on joints.	14	7		
	44	Clay shale, calcareous, light gray and light tan, poorly laminated; contains some calcareous lenses and limonite sheets.	1	0		
	43	Dolomite, argillaceous, dense, light gray, very regularly bedded and jointed.	2	6		
	42	Clay, calcareous, gray tinged with yellow.	0	6		
	41	Dolomite, finely crystalline, gray, massive; flecked with limonite.	2	1½		
B 12	40	Siltstone, dolomitic, light gray to light tan, thin bedded; contains some chert.	1	1½		50.4
	39	Siltstone, calcareous to siliceous, tan and gray-brown, poorly laminated; contains some chert in small blebs and flat nodules.	1	7		
	38	Chert, pseudo-brecciated, gray-white; contains some calcite. One bed.	1	0		

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH B
Baldwin Creek, 8 miles west of Lander, Wyoming,
in SW ¼ sec. 18, T. 33 N., R. 100 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
	37	Clay shale, silty, dolomitic, light gray, some greenish-tan; irregular band of nodular chert, white to bluish-gray, near center, some coarse calcite in chert.	3	6		
	36	Dolomite, silty, argillaceous, dense, light gray, full of large irregular nodules of chert, mottled gray and blue-gray; contains a few small fragments of fossils.	1	4		
B 11	35	Clay shale, silty, calcareous, light tan and light gray; contains bands or thin lenses of mottled pseudo-brecciated chert, light to dark whitish-to bluish-gray, which contain a few calcite geodes. There a few thin (less than 1") silty bands.	5	2		66.9
	34	Mudstone, silty, dolomitic, light gray, moderately well bedded.	0	10½		
	33	Clay shale, somewhat silty and calcareous, light gray, some light tan; shows some limonite stain; contains a band of 3" to 8" chert or chalcedony nodules about a foot above the base.	7	1		
	32	Siltstone, argillaceous, dolomitic, light yellow-gray, nodular; contains some limonite and nodules of chert, variegated, tan to blue-gray.	0	7		

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
	31	Dolomite, dense to finely crystalline, gray, thin bedded.	2	10		
	30	Dolomite, argillaceous, dense, but porous owing to molds of mollusks, most of which contain bituminous material, fresh rock light gray to gray, weathering yellowish, massive, angular.	8	10		
	29	Dolomite, silty, dense to porous, light gray to light tan, massive, about four beds; contains numerous calcite geodes. Upper surface may be minor unconformity. Weathers rounded, in contrast to overlying 30.	3	10		
B 10						21.3
	28	Geodes; mammilary calcite geodes containing doubly terminated quartz crystals and bituminous material constitute almost the entire rock, coalescing irregularly. Interstices are filled with silty clay shot with stringers and grains of calcite. Top and bottom irregular, thickness 6″-8″.	0	7±		
	27	Dolomite, argillaceous to silty, dense, light gray weathering yellowish; silicified shell fragments fairly common; calcite geodes abundant in upper part.	4	6		
	26	Siliceous shale, bluish-gray to greenish-gray, limonitic brown on joints, laminated below to nodular above, grading upward into wavy bluish-gray chert. Top irregular.	1	4±		
B 9	25	Dolomite, dense, gray. One bed.	0	4		67.4
	24	Dolomitic shale, bluish-gray, thin bedded, moderately well bedded except nodular in lower 4″ and some spheroidal nodules throughout; contains limonite disseminated and in a band at top.	1	3		

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH B
Baldwin Creek, 8 miles west of Lander, Wyoming,
in SW ¼ sec. 18, T. 33 N., R. 100 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
	23	Dolomite, dense, light gray; contains some pearly to dark gray orbiculoids. Two beds, top uneven.	1	6		
	22	Clay shale, light gray, laminated; contains a few pearly gray orbiculoids.	0	2½		
	21	Dolomite, silty, dense, light gray, one bed; contains trace of phosphate, some pearly gray orbiculoid shells.	0	6		
B 8					3.4	24.8
	20	Clay shale, olive-tan to olive-green; contains some phosphate and numerous orbiculoid shells.	0	1½		
	19	Dolomite, silty, dense, light tan, two beds; contains trace of phosphate.	0	2		
	18	Clay shale, olive-drab, laminated.	0	2		
	17	Phosphate rock, calcareous, granular to "pisolitic", greenish-black; contains abundant amber-colored shell fragments, some phosphatic molds of snail shells, and considerable glauconitic clay.	0	4	26.6	15.2
B 7					26.5	
	16	Phosphate rock, brown-black, upper part calcareous, finely "oölitic", lower part contains some bluish opaline silica and fragments of orbiculoids; contains traces of glauconite and limonite.	0	7		

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
	15	Siltstone, calcareous, light gray, one bed; full of orbiculoids; contains some glauconite and dark gray phosphate "oölites".	0	8		
	14	Limestone, locally siliceous and argillaceous, glauconitic, crystalline, porous, gray, massive; contains some calcite geodes.	5	2		
	13	Dolomite, silty, hard, dense, light gray, locally gray from biotite; lower thick bed and upper thinner bed, both irregular.	1	2±		
B 6	12	Chert, sand, and carbonates, not thoroughly indurated, nodular, not well bedded; contains fragments of fossils.	0	9	3.1	9.1
	11	Limestone, slightly dolomitic and sandy, dense, gray, full of molds of shell fragments, some of which contain bituminous material; two massive beds, separated by shaly partings; contains some 3″ calcite geodes.	3	0		
B 5	10	Sandstone, dolomitic, fine grained, well sorted, gray-white, locally gray from biotite, massive, moderately well bedded; contains abundant chert in nodules, bands, and "curling stones", mostly white to bluish-gray, weathering yellowish. Top and bottom irregular, top being wavy line in middle of what otherwise would seem to be a single bed.	15	0±		44.1
B 4	9	Dolomite, somewhat sandy, dense, light gray, massive (about five beds); contains some fragmentary shells and molds.	5	4		10.7
B 3	8	Dolomite, argillaceous to fine sandy, dense, light gray, flecked with limonite at base; contains beds and nodules of chert, light bluish to lavender-gray, as much as 8″ thick.	3	8		46.4
	7	Sandstone, calcareous, fine to medium grained, not well sorted, light gray.	0	8±		

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH B
Baldwin Creek, 8 miles west of Lander, Wyoming,
in SW ¼ sec. 18, T. 33 N., R. 100 W.

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
B 2	6	Silt, sandy, dolomitic, light gray, some light buff, nodular, thin bedded, poorly bedded. Top irregular.	1	8±		49.7
B 1	5	Sandstone, fine grained, well sorted, light gray, grading upward into sandy dolomite, gray white; wavy bedded.	1	2		62.4
	4	Silt, calcerous, grading upward into sandy dolomite; soft, gray-white, thin bedded; contains lenses of crystalline dolomite and nodules of bluish chert, as much as 9″ thick.	2	3		
	3	Sandstone, fine grained, well sorted, light gray mottled with yellowish, thin bedded.	0	5		
	2	Sand, calcareous, fine grained, well sorted, soft, white to light gray, wavy bedded, poorly bedded; contains numerous minute limonite specks.	1	5		
Not sampled	1	Sand, fine grained, well sorted, gray-white, poorly bedded, becoming more calcareous and firm upward, top 1″ being sandy dolomite.	1	1±		
			278	2½		

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		PENNSYLVANIAN TENSLEEP SANDSTONE				
	0	Sandstone, fine grained, well sorted, gray-white, weathering dirty gray; calcareous material present is presumably secondary, as prominent cleavage is noticeable on fresh fracture; massive, cross-bedded, top uneven. About 10′ of such beds overlie buff-weathering cliff-forming member. Not measured.				

Supplementary analyses

Sample No.	R_2O_3	CaO	MgO	F_2
B 7	2.2	40.1	1.4	3.5

Samples B 2, B 11, B 17, B 22, and B 23 yielded less than 0.1 percent V_2O_5.

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH C
Sinks Canyon (Middle Fork Popo Agie River),
in S½ NW¼ NW¼, sec. 9, T. 32 N., R. 100 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION UPPER PHOSPHATE ZONE				
C 15	6	Shale, silty, slightly calcareous, sepia, thin bedded, poorly bedded. 1′ 7″ exposed.			2.7	67.5
C 14	5	Phosphate rock, granular to "pisolitic", gray-black; contains some tan calcareous matrix.	0	3½	18.1 *16.5*	22.2
	4	Clay shale, calcareous, sepia, laminated; contains a few blackish phosphate grains.	0	6		
	3	Phosphate rock, calcareous, granular to "pisolitic", dark gray in light tan matrix, poorly laminated; contains some shell fragments.	1	2		
C 13	2	Phosphate rock, calcareous, especially middle portion, light tan tinged light gray by abundant granular to "pisolitic" gray phosphate; contains numerous fossil brachiopods (spirifers and productids).	2	7±	15.7 *14.2*	11.6
C 12	1	Limestone, argillaceous, dense, light gray; contains numerous dark gray phosphate "oölites" and rounded glauconite grains. Top uneven.	1	4±	2.7	20.0
Not sampled	0	Limestone, dense, tan, massive; contains some gray phosphate "oölites" and some glauconite, partly altered to limonite. Not measured.				

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		LOWER PHOSPHATE ZONE				
Not sampled	14	Siltstone, dolomitic, argillaceous, light greenish-gray, some blue-greenish, thin bedded, irregularly bedded. Not measured.				
	13	Siliceous shale, lower 8″ brown-green, upper part dark to light gray, faintly bluish, lower 6″ laminated, upper part wavy to nodular bedded. Chert seems minutely granular under lens.	2	0		
C 11	12	Dolomite, silty, dense, light gray to light greenish-gray, massive, but gradational into underlying shale; contains some glauconite, some molds and fragments of shells, some 3″ fossiliferous chert nodules in top 8″, and some calcite geodes in lower part.	1	10		25.6
C 10	11	Shale, dolomitic below, waxy above, gray-tan to olive-tan, limonitic on joints near top.	0	7		39.1
C 9	10	Dolomite, dense, greenish, phosphatic in spots, similar to 7.	0	10½±		
	9	Clay, calcareous, buff to light gray; contains shell fragments and phosphate "oölites" and nodules. Top and bottom irregular.	0	4±	*5.1*	19.4
C 8	8	Phosphate rock, calcareous, "oölitic" to "pisolitic", gray-black; contains some glauconite and numerous amber-colored orbiculoid fragments. Top irregular.	0	3±	28.9 *28.7*	8.1
C 7	7	Dolomite, dense, light greenish-tan, some light gray, two beds, base somewhat shaly; contains some thin-shelled orbiculoids and a few gray-black phosphate "oölites".	0	6½	*3.1*	16.8

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH C
Sinks Canyon (Middle Fork Popo Agie River),
in S½ NW¼ NW¼, sec. 9, T. 32 N., R. 100 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
C 6	6	Clay shale, somewhat calcareous, in part waxy, olive to tan; contains a few ¼" gray-black phosphate pellets.	0	4½	*6.4*	43.3
C 5	5	Phosphate rock, calcareous, glauconitic in lower part, finely "oölitic", few "pisolites", gray-black below to brown-black above, moderately well bedded; contains some orbiculoid fragments.	0	7½	26.8 *25.2*	13.7
C 4	4	Limestone, argillaceous, streaked greenish-gray and dark gray, single bed; contains some darker phosphate "oölites" and black glassy silica(?).	0	3	12.1 *12.2*	14.6
C 3	3	Phosphate rock, calcareous, somewhat siliceous, granular to "oölitic", dark gray, thin bedded, moderately well bedded; contains some greenish clay.	0	10	25.3 *26.2*	11.9
C 2	2	Phosphate rock, slightly calcareous, granular, some "oölites", brown-black, platy to wavy bedded; packed with amber-colored to gray-buff orbiculoid shells; contains some glauconite.	1	2	26.7 *26.4*	11.5
C 1	1	Limestone, sandy, glauconitic, gray, platy to wavy bedded; contains numerous amber-colored orbiculoids; tubules or worm borings at base extend into underlying o.	0	9	*10.0*	53.0
	0	Dolomite, argillaceous, slightly glauconitic, dense, light gray. Not measured.				

Supplementary analyses

Sample No.	R_2O_3	CaO	MgO	F_2
C 8	2.8	43.4	1.7	3.4
C 5	0.9	40.2	3.0	2.9
C 3	0.9	41.3	2.9	2.9
C 2	0.6	42.3	2.8	3.3

Samples C 6, C 7, C 10, and C 11 yielded less than 0.1 percent V_2O_5.

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCHES D AND E
on Willow Creek, in
SW¼ sec. 25, T. 32 N., R. 100 W.

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
		PERMIAN PHOSPHORIA FORMATION UPPER PHOSPHATE ZONE (Trench D)				
D 5	4	Clay, silty, dolomitic, gray, lavender-gray, and sepia interbedded. 3′ 4″ exposed, 2′ 3″ sampled.			5.8 *6.5*	43.6
D 4	3	Phosphate rock, calcareous, granular to "pisolitic", blue-black, thin bedded; contains a 2½″ band of sepia clay 18½″ above base.	2	5	15.7 *17.4*	24.1
D 3	2	Phosphate rock, calcareous, granular to "oölitic", brown-black, thin bedded below to massive above; contains fossils, principally spirifers and productids.	1	3	21.0 *22.0*	11.3
D 2	1	Limestone, phosphatic, gray-black phosphate in light tan matrix, massive.	2	9	14.5 *14.0*	12.4
D 1	0	Limestone, silty to sandy, dense, light gray, massive. 1′ 5″ exposed.			*4.2*	16.5
		LOWER PHOSPHATE ZONE (Trench E)				
E 5	6	Clay, somewhat calcareous, waxy, olive-tan. Not measured, 6″ sampled.			*4.8*	42.4

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
	5	Phosphate rock, calcareous, glauconitic, granular to "pisolitic", gray-black, not distinctly bedded, basal 1″ shaly; contains many internal molds of pelecypods.	0	7½		
E 4	4	Limestone, argillaceous, dense, light gray, lenticular; contains some dark gray phosphate grains. Thickness 1″—4½″.	0	3±	28.3 *28.0*	12.6
	3	Phosphate rock, calcareous, granular, few "oölites", gray-black, not distinctly bedded; contains trace of glauconite and some orbiculoid shells.	0	8½		
E 3	2	Limestone, dense, gray, massive; contains numerous grains and pellets of drab-gray phosphate and some orbiculoid shells.	1	1½	13.2 *13.6*	6.4
E 2	1	Phosphate rock, calcareous, glauconitic, granular to "pisolitic", gray-black, thin bedded; full of orbiculoid shells.	0	11½	26.8 *26.4*	14.0
E 1	0	Limestone, sandy, glauconitic, somewhat phosphatic, dense light gray, massive.	1	1	*11.5*	50.4

Supplementary analyses

Sample No.	R_2O_3	CaO	MgO	F_2	V_2O_5
E 4	1.2	42.4	1.4	3.4	....
E 2	0.9	41.6	0.7	3.3	trace

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH F
on Squaw Creek, in
center of sec. 29, T. 33 N., R. 100 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION UPPER PHOSPHATE ZONE				
Not sampled	6	Mudstone, silty, non-calcareous, sepia, but darker than 4. 2′ 6″ exposed.				
F 9	5	Phosphate rock, non-calcareous, granular to "pisolitic", gray-black, lower part shaly bedded, upper part platy.	0	4½	9.5	40.8
	4	Mudstone, slightly calcareous, sepia, fairly well bedded.	0	9		
F 8	3	Phosphate rock, slightly calcareous, granular to "pisolitic", brown-black, thin bedded, platy bedded; gradational with overlying 4.	1	2	22.3 *21.9*	18.7
F 7	2	Phosphate rock, granular to "pisolitic", gray-black in light gray calcareous matrix, especially through middle third, which might be called "limestone", but gradational; massive, but not well bedded.	2	0	19.5 *18.9*	12.9

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
F 6 2′ sampled	1	Limestone, argillaceous, glauconitic, dense, gray-tan; contains some grains of phosphate, dark gray; fills top of underlying 0.	0	3	7.5	21.7
	0	Limestone, dense, gray-tan, massive; contains some glauconite and limonite. Top irregular. Not measured.				
		LOWER PHOSPHATE ZONE				
Not sampled	6	Dolomite, argillaceous, dense, light greenish-gray, well bedded; contains some shell fragments.	0	6		
	5	Clay shale, calcareous, light olive-brown, poorly laminated; contains some pearly orbiculoid shells and some grains of phosphate.	0	3		
F 5	4	Phosphate rock, calcareous, granular to "pisolitic", soft, gray-black; contains numerous pearly orbiculoid shells and some flattened nodules that seem to be fossil "nests" rich in glauconite.	0	3½	19.3	25.6
	3	Clay shale, calcareous, dull brown to olive-gray, poorly laminated; contains trace of phosphate.	0	3½		

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH F
on Squaw Creek, in
center of sec. 29, T. 33 N., R. 100 W.

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
F4 11″	2	Phosphate rock, silty, calcareous, especially in middle part, granular, some "pisolites", gray-black in light gray matrix, platy bedded, upper third shaly except top 1½″, which is single hard smooth bed; contains numerous orbiculoid shells.	2	11	26.9 *26.0*	17.3
F3 10″					15.0 *15.0*	7.5
F2 1′2″					22.9 *24.0*	21.3
F 1	1	Limestone, sandy, glauconitic, dense, light gray to gray, thin bedded, moderately well bedded; contains some gray-black phosphate grains and a few orbiculoid fragments.	2	3	*10.3*	37.4
Not sampled	0	Limestone, argillaceous, dense to crystalline, light gray, massive; contains some glauconite grains and a few gray phosphate grains. Not measured.				

Supplementary analyses

Sample No.	R_2O_3	CaO	MgO	F_2
F 4	1.7	41.0	1.1	3.0
F 2	1.4	39.2	1.3	3.0

Samples F 1, F 2, and F 9 yielded less than 0.1 percent V_2O_5.

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH G
Gully between Squaw and Baldwin Creeks, in
SW¼ sec. 19, T. 33 N., R. 100 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION UPPER PHOSPHATE ZONE				
Not sampled	7	Clay shale, calcareous, sepia, thin bedded. 1′ 3″ exposed.				
G 9	6	Phosphate rock, granular to "pisolitic", brown-black, in sparse light gray calcareous matrix, platy bedded, not well bedded.	0	3½	7.3	39.2
	5	Clay shale, calcareous, tan, moderately well laminated except top 1″.	0	7		
G 8	4	Phosphate rock, calcareous, argillaceous, granular to "pisolitic", brown-black, laminated to platy, moderately well bedded.	1	4	20.2 *19.4*	21.3
G 7	3	Phosphate rock, calcareous, argillaceous, granular, some small nodules, gray-black, some light gray streaks, platy bedded, not well bedded.	1	0	16.8 *17.8*	12.0

Sample No.	Bed No.		THICKNESS Ft.	THICKNESS In.	P_2O_5 (percent)	Acid insol. (percent)
G 6	2	Limestone, silty, argillaceous, dense, drab gray, massive; contains some phosphate as gray granules and small (2 mm.) "pisolites". Grades into overlying 3.	1	4±	8.9	16.8
	1	Limestone, argillaceous, silty, very glauconitic, dense, light gray to light tan, massive, irregularly bedded and jointed; contains abundant fossils, principally spirifers and productids. Grades into overlying 2.	1	6±		
Not sampled	0	Limestone, argillaceous, glauconitic, dense, light gray to light tan, massive. Top wavy. Not measured.				
		LOWER PHOSPHATE ZONE				
Not sampled	7	Dolomite, silty, dense, gray, massive; contains 1" limonite nodules.	1	1		
G 5	6	Clay, dolomitic, light gray to waxy olive-gray; some limonite stain.	0	11	8.9	34.5
	5	Phosphate rock, calcareous, granular to "pisolitic", gray-black, very irregular; contains numerous amber-colored orbiculoid fragments.	0	1½±		
	4	Clay shale, calcareous, waxy, olive-tan.	0	3½		

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
G 4	3	Phosphate rock, somewhat calcareous, some silt streaks, granular, some small pellets or large "pisolites", gray-black, thin bedded to shaly; contains some ¼" limonite nodules.	0	9	28.3 *27.2*	12.1
G 3	2	Limestone, argillaceous, dense, light gray, massive; contains much phosphate in granules and some small (2 mm.) "pisolites".	0	9½	11.7 *12.6*	12.7
G 2	1	Phosphate rock, calcareous, granular, few "pisolites" (2 mm.), gray-black; contains abundant amber-colored orbiculoid fragments. Grades into overlying 2.	0	6±	27.6 *27.2*	14.8
G 1	0	Limestone, argillaceous, glauconitic, dense, light gray, massive; contains a few molds of shell fragments. Top very uneven. Not measured. 3′ 4″ sampled.			*1.3*	4.9

Supplementary analyses

Sample No.	R_2O_3	CaO	MgO	F_2
G 4	2.3	42.7	1.4	3.6
G 2	1.3	40.9	0.8	3.4

Samples G 4, G 5, G 6, and G 9 yielded less than 0.1 percent V_2O_5.

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH H
West of tip of 3d flatiron south of Baldwin Creek,
in NW¼ sec. 25, T. 33 N., R. 101 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION LOWER PHOSPHATE ZONE				
H 5	9	Clay, buff, 4″ exposed.				
	8	Dolomite, silty, dense, light gray; contains numerous silicified shell fragments.	0	6		
	7	Clay, somewhat calcareous, dirty yellow-green, laminated.	0	1½	13.1	15.9
	6	Phosphate rock, calcareous, soft, friable, gray-black but strongly iron-stained, laminated; contains numerous shell fragments.	0	2½		
H 4	5	Dolomite, silty, argillaceous, dense, light grayish-tan (some limonite stain), massive; contains a few ½″ limonite nodules. Top uneven.	0	6½	1.5 1.8	16.8
	4	Clay, non-calcareous, buff, poorly laminated; contains a few phosphate grains.	0	1		
H 3 3½″	3	Phosphate rock, siliceous, calcareous, granular to "pisolitic", gray-black, thin bedded, moderately well bedded; contains trace of glauconite and numerous orbiculoid shells.	1	0½	28.3 28.8	13.5
H 2 9″					30.7 30.1	9.8

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
	2	Limestone, dolomitic, sandy, dense, gray-white, thin bedded, irregularly bedded; contains a few 3″ chert nodules, some dark gray phosphate granules and "pisolites", and locally a profusion of pearly gray to amber-colored orbiculoid shells.	1	1		
H 1 3′ 1″ sampled	1	Limestone, dolomitic, glauconitic, dense, light gray; contains a trace of phosphate.	0	2½	8.9	4.9
	0	Limestone, dolomitic, argillaceous, dense, light gray-tan; contains some glauconite grains. Top uneven. Not measured.				

Supplementary analyses

Sample No.	R_2O_3	CaO	MgO	F_2	V_2O_5
H 3	1.3	42.1	0.4	3.5	....
H 2	0.9	42.9	2.2	3.7	trace

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH I
Tip of flatiron south of gully between Squaw and Baldwin Creeks,
N½ SE¼ sec. 25, T. 33 N., R. 101 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION UPPER PHOSPHATE ZONE				
Not sampled	5	Clay shale, somewhat silty, calcareous, sepia, moderately well laminated. 1′ 6″ exposed.				
I 4	4 3	Phosphate rock, calcareous, granular to "oölitic", brown-black, thin bedded. Clay, calcareous, buff, shaly; contains a few phosphate grains.	0 0	4 4	*11.3*	32.6
I 3	2	Phosphate rock, very calcareous, granular to "oölitic", gray-black phosphate in drab-gray matrix, very thin bedded; contains a few shell fragments.	2	4	20.6 *21.3*	16.5
I 2	1	Phosphate rock, calcareous, becoming more so upward, granular to "pisolitic", dark gray phosphate in drab-gray matrix, thin bedded below to massive above; contains abundant fossils, mostly productids.	2	2	17.1 *19.1*	13.3
I 1	0	Limestone, dolomitic, argillaceous, glauconitic, somewhat phosphatic, dense, tan, massive; contains abundant spirifers and productids. 1′ 2″ exposed, 8″ sampled.			*7.8*	17.7

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCHES J AND K

Tip of flatiron behind Hornecker Ranch, in
SE¼ sec. 6, T. 32 N., R. 100 W.

Sample No.	Bed No.		THICKNESS Ft.	THICKNESS In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION UPPER PHOSPHATE ZONE—Trench K				
Not sampled	6	Clay, calcareous, silty, sepia, shaly bedded. 1′ 6″ exposed.				
K 4	5 4	Phosphate rock, very calcareous, granular to "pisolitic", brown-black. Clay, very calcareous, slightly silty, pale brown; contains a few brown-black phosphate grains.	0 0	2 9	*6.8*	35.7
K 3	3	Phosphate rock, calcareous, granular to "pisolitic", brown-black, platy bedded; contains some internal molds of gastropods and pelecypods.	3	2	20.5 *20.8*	17.0
K 2	2 1	Limestone, dense, ocher, massive, one bed; contains numerous gray phosphate pellets and a few glauconite grains. Phosphatic limestone, dense to granular, some "oölites" and "pisolites", light brown and brown-black; contains some glauconite and numerous productids.	0 0	10 10½	15.4 *15.5*	13.3
K 1	0	Limestone, dense, yellow-brown, massive; contains a few shell fragments and some glauconite. 6″ exposed.			*4.7*	16.8

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCHES J AND K

Tip of flatiron behind Hornecker Ranch, in
SE¼ sec. 6, T. 32 N., R. 100 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		LOWER PHOSPHATE ZONE—Trench J				
	8	Dolomite, somewhat silty, dense, light gray, thin bedded, contains some gray-black orbiculoids.	0	7		
	7	Phosphate rock, calcareous, granular to "pisolitic", brown-black strongly iron-stained, shaly, friable; full of amber-colored orbiculoid scraps.	0	2		
J 5	6	Dolomite, silty, dense, light gray, thin bedded; contains a few orbiculoid fragments and phosphate pellets, gray.	0	6	*7.8*	23.7
	5	Clay, calcareous, gray and dull grayish-green, some iron stain; contains some large calcite nodules stained with bituminous matter.	0	4½		
	4	Phosphate rock, very calcareous, granular, few "oölites", gray-black, platy bedded; contains a few orbiculoid fragments and some pale-green clay.	1	3	26.0	13.5
J 4	3	Phosphate rock, somewhat calcareous, dense to granular, some "oölites", mostly light gray, some gray-black; contains some orbiculoids and a trace of glauconite.	0	2	*24.9*	
	2	Phosphatic limestone, fine grained, salt-and-pepper, single bed; packed with orbiculoids; contains some glauconite and apple-green clay.	0	6		

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
J 1	1	Limestone, sandy, dolomitic, sugary, gray, thin bedded; contains some glauconite and phosphate.	1	5	*11.1*	51.0
Not sampled	0	Dolomite, silty, glauconitic, dense, light gray, massive. Not measured.				

Supplementary analyses

Sample J 4 yielded 1.4% R_2O_3, 41.8% CaO, 1.4% MgO, 3.4% F_2.
Samples K 3 and K 4 yielded less than 0.1% V_2O_5.

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH L
West tip of flatiron back of Table Mt., in
N½ SE¼ sec. 28, T. 32 N., R. 100 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION LOWER PHOSPHATE ZONE				
	6	Dolomite, very argillaceous, dense, yellowish, thin bedded, deeply etched. 7″ exposed.				
L 4	5	Phosphate rock, granular, very deeply weathered,* so that it resembles green and brown sand.	0	2	*4.2*	20.0
	4	Dolomite, argillaceous, especially in bottom 1″, dense, yellowish on account of limonite stain, thin bedded, irregularly bedded.	0	5		
	3	Clay, slightly calcareous, waxy, olive-tan.	0	6		
L 3	2	Phosphate rock, somewhat calcareous, granular to finely "pisolitic", light gray, very thin bedded, deeply weathered* and somewhat iron-stained; contains a few orbiculoid fragments.	0	9	25.6 *29.1*	9.8
L 2	1	Phosphate rock, deeply weathered,* resembles yellowish sand, but some nodules are firm. These nodules are calcareous, granular, light greenish-gray, and contain a few grains of glauconite and numerous amber-colored orbiculoid fragments. Bedding no longer apparent.	2	0	25.0 *24.3*	13.4
L 1	0	Sandstone, dolomitic, very fine grained, well sorted, mottled iron-stained greens and yellows, platy bedded. Not measured. 4′ 6″ sampled.			*4.2*	52.8

Supplementary analyses

Sample No.	R_2O_3	CaO	MgO	F_2
L 3	1.3	44.3	1.6	3.4
L 2	1.2	41.5	3.1	3.1

Samples L 3 and L 4 yielded less than 0.1 percent V_2O_5.

* This region stands well above the level of Table Mountain, so has presumably been long exposed to weathering.

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCHES M AND N
Mat Weed Canyon, in
NW¼ sec. 6, T. 31 N., R. 99 W.

Sample No.	Bed No.		THICKNESS Ft.	THICKNESS In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION UPPER PHOSPHATE ZONE—Trench M				
Not sampled	9	Silt, sepia, thin bedded, moderately well bedded. 1′ exposed.				
	8	Phosphate rock, calcareous, "oölitic", few granules and "pisolites", brown-black, one bed; contains few amber-colored orbiculoid fragments.	0	3		
	7	Silt, partly dolomitic, sepia to dark brown, thin bedded, not well bedded.	1	5		
M 6	6	Phosphate rock, calcareous, granular-"oölitic", bluish-black, soft, thin bedded, friable; contains some drab clay.	0	2	*6.2*	43.7
	5	Silt, dolomitic, yellowish-black, thin bedded to nodular, not well bedded.	0	8		
M 5	4	Phosphate rock, similar to underlying 3, but gray-black to bluish-black, coarser, platy bedded.	1	6	21.2 *21.5*	20.2
M 4	3	Phosphate rock, calcareous, more so at top, granular to "pisolitic", brown-black below to gray-black above in light gray matrix; many of the phosphate grains are internal molds of snails and clams.	1	5	20.8 *20.3*	13.8

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
M 3	2	Dolomite, silty, argillaceous, dense, gray, weathers yellowish, massive, irregularly jointed.	0	8	2.4 *1.8*	6.6
M 2	1	Phosphate rock, granular and "oölitic", dull black in light gray calcareous matrix, sparse at base, but increasing notably upward, massive, weathers thin bedded; lowest part contains trace of glauconite and some amber-colored orbiculoid fragments.	1	10	21.0 *20.3*	13.7
M 1	0	Dolomite, very silty, dense, light gray, massive; contains trace of glauconite and some minute tan clay balls. Not measured, 9″ sampled.			*1.3*	16.3
		LOWER PHOSPHATE ZONE—Trench N				
Not sampled	6	Dolomite, silty, very finely crystalline, light gray, thin bedded, moderately well bedded; contains some dark gray orbiculoid fragments.	0	9½		
	5	Clay, calcareous, waxy, olive-green (much rusty iron-stain), poorly laminated.	0	3½		
N 2	4	Phosphate rock, slightly calcareous, dense, some granular, few "oölites", black, thin bedded, not well bedded; contains some green clay and pearly gray and amber-colored orbiculoid fragments.	0	7		
	3	Clay, very calcareous, waxy, olive-gray; contains a few gray-black phosphate granules and "oölites".	0	1	27.0 *25.8*	14.9
	2	Phosphate rock, slightly calcareous, finely and evenly granular except for some scattered large "oölites", gray-black, platy bedded; contains trace of glauconite and small shell fragments. Discontinuous clay parting at base.	0	7½		

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCHES M AND N
Mat Weed Canyon, in
NW¼ sec. 6, T. 31 N., R. 99 W.

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
N 1	1	Phosphate rock, calcareous, granular, some "oölites", some of which are internal molds of snails, gray-black, thin bedded, moderately well bedded; contains numerous pearly gray to amber-colored orbiculoid shells, some glauconite and crystalline calcite. Top 6″ more calcareous, gray, pocked with orbiculoid fragments.	2	2	22.4 *21.3*	15.4
Not sampled	0	Dolomite, silty, argillaceous, dense, yellowish-gray; contains some grains of glauconite and gray phosphate in "nests". Not measured.				

Supplementary analyses

Sample N 2 yielded 2.3% R_2O_3, 40.3% CaO, 1.4% MgO, and 3.1% F_2.
Sample M 6 yielded less than 0.1 percent V_2O_5.

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH O

Slope above flatiron north of Mat Weed Canyon, in
NW¼ SE¼ sec. 1, T. 31 N., R. 100 W.

Sample No.	Bed No.		THICKNESS Ft.	THICKNESS In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION LOWER PHOSPHATE ZONE				
Not sampled	8	Dolomite, very silty, dense, light yellowish-tan, thin bedded; contains some limonite and crystalline calcite nodules. 6″ exposed.				
	7	Clay, calcareous, waxy, olive, limonitic.	0	10		
O 3	6	Phosphate rock, slightly calcareous, evenly granular, dark gray, thin bedded; contains some calcite, limonite, green clay, and shell fragments.	0	4		
	5	Phosphate rock, dark gray granules to pellets in gray-white calcareous matrix, thin bedded, indistinctly bedded; contains some shell fragments.	0	7	26.4	12.8
	4	Phosphate rock, calcareous, granular, few "oölites", dark gray, weathers greenish, thin bedded; contains some orbiculoid fragments.	0	9½	*26.3*	
O 2	3	Dolomite, argillaceous, dense, light gray, thin bedded; contains some gray-black phosphate granules to "pisolites", a few glauconite grains, and some orbiculoids as in 2. Becomes more limy upward.	1	0	17.2 *15.0*	7.2

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH O

Slope above flatiron north of Mat Weed Canyon, in NW¼ SE¼ sec. 1, T. 31 N., R. 100 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
O 1	2	Phosphate rock, calcareous, sandy, granular, lower bed gray, upper dark gray; contains some glauconite and limonite; packed with pearly gray orbiculoid shells.	0	6½	26.9	17.2
	1	Phosphate rock, very sandy, somewhat dolomitic, granular, some "oölites", greenish-brown; contains some glauconite grains, much iron-stain, and numerous pearly gray orbiculoid shells.	0	5½±	27.0	
Not sampled	0	Sandstone, slightly calcareous, fine grained, well sorted; contains some glauconite and clay. Not measured.				

Supplementary analyses

Sample No.	R_2O_3	CaO	MgO	F_2	
O 3	1.4	39.9	1.1	3.0	
O 1	0.8	40.9	1.2	3.0	

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH P

Slope above canyon north of Little Popo Agie, in
S½ SE¼ of sec. 12, T. 31 N., R. 100 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION LOWER PHOSPHATE ZONE				
P 3	3	Phosphate rock, slightly calcareous, granular to "pisolitic", some being internal molds of mollusks, gray-black to brown-black, thin bedded.	1	1	28.1 *26.2*	10.5
P 2	2	Dolomite, argillaceous, dense, light gray, thin bedded, moderately well bedded; contains abundant phosphate granules and "oölites", and some amber-colored and gray orbiculoid fragments.	1	3	16.0 *15.5*	4.7
P 1	1	Phosphate rock, sandy, calcareous, granular, few "oölites", gray-black phosphate in light gray matrix, thin bedded to platy bedded; contains some green clay and abundant amber-colored orbiculoid shells, top 7″ being full of them.	1	5	24.8 *26.0*	18.0
Not sampled	0	Sandstone, calcareous, fine grained, well sorted, greenish-tan; contains some glauconite, phosphate, and amber-colored orbiculoid fragments. Some filled tubules in top. 3″ exposed.				

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH P

Slope above canyon north of Little Popo Agie, in
S½ SE¼ of sec. 12, T. 31 N., R. 100 W.

Supplementary analyses

Sample No.	R_2O_3	CaO	MgO	F_2
P 3	1.7	42.6	1.0	3.3
P 1	1.5	39.5	1.5	3.4

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH X

North bank of Cherry Creek on east line of sec. 17, T. 31 N., R. 99 W., 1500 feet south of NE corner

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION LOWER PHOSPHATE ZONE				
X 4	7	Shale, silty, non-calcareous, black.	0	3		
	6	Phosphate rock, slightly calcareous, granular, few "pisolites", gray-black; contains few orbiculoid fragments.	0	1	9.8 9.7	54.7
	5	Clay, silty, non-calcareous, sepia.	0	2		
X 3	4	Phosphate rock, very calcareous, coarsely "pisolitic" to granular, thin bedded, poorly bedded, gray-black; contains some orbiculoid fragments.	0	5½	24.1	14.6
	3	Dolomite, silty, dense, shaly bedded, gray.	0	3	23.5	
	2	Phosphate rock, calcareous, "pisolitic" to granular, thin bedded, black; contains a few glauconite grains.	0	8½	23.4	
X 2	1	Phosphate rock, increasingly calcareous upward, granular, some "pisolites", thin bedded, poorly bedded, brown-black below to gray-black above; contains some glauconite grains and abundant orbiculoids. Ranges from 1′ 10″ to 2′ 3″.	1	10	24.0 23.0 22.8	11.9

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH X

North bank of Cherry Creek on east line of sec. 17, T. 31 N., R. 99 W., 1500 feet south of NE corner

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
X 1	0	Dolomite, silty, dense, gray; contains some tubules filled with overlying phosphate rock, some calcite geodes. 3′ 6″ exposed. Top is very uneven, showing 5″ relief within trench.			0.7 0.7	5.4

Supplementary analyses

Sample No.	R_2O_3	CaO	MgO	F_2	
X 3	1.2	39.2	1.2	3.0	
X 2	1.5	41.5	2.6	2.8	

Sample X 4 yielded less than 0.1 percent V_2O_5.

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH Y

South bank of Deep Creek 100 yards downstream from thrust fault, in NE¼ NE¼ sec. 34, T. 31 N., R. 99 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION LOWER PHOSPHATE ZONE				
	8	Shale, silty, slightly dolomitic, black; contains few phosphate "oölites"; grades upward into light gray clay.	0	2		
	7	Phosphate rock, slightly calcareous, granular to "pisolitic", gray-black, contains some orbiculoid shells.	0	1		
Y 3	6	Dolomite, silty, somewhat phosphatic, one thin jointed bed below, upper part shaly bedded, gray-black to dark gray.	0	3½	11.5 11.4	32.8
	5	Phosphate rock, similar to Bed 3.	0	1		
	4	Dolomite, phosphatic, dense, gray; one bed; the phosphate granules and "pisolites" are dark gray.	0	2½		
	3	Phosphate rock, slightly calcareous, gray-black, one bed, full of pelecypod molds and small nodules, which give a conglomeratic appearance; contains some orbiculoid shells. Ranges from 3″ to 4″.	0	3½	22.7	11.1
Y 2	2	Siltstone, dolomitic, jointed, faintly laminated, brown-black.	0	2½	22.6 22.3	
	1	Phosphate rock, somewhat calcareous, granular to "pisolitic", thin bedded, not well bedded, gray-black, slightly glauconitic; contains abundant orbiculoid fragments.	2	6½		

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH Y
South bank of Deep Creek 100 yards downstream from thrust fault,
in NE¼ NE¼ sec. 34, T. 31 N., R. 99 W.

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
Y 1	O	Phosphate rock, sandy, somewhat dolomitic to calcareous, regularly jointed, dark gray; contains some glauconite. Top slightly irregular.	1	2	19.1 18.9 18.6	29.9

Supplementary analyses

Sample Y 3 yielded less than 0.1 percent V_2O_5.

In the field, Bed O was thought to be the limestone that underlies the lower phosphate zone, therefore no lower beds were sampled.

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH Z

South side of tributary of Barrett Creek, above spring, but 100 yards below fork, in NE¼ NW¼ sec. 28, T. 31 N., R. 99 W.

Sample No.	Bed No.		Thickness Ft.	Thickness In.	P_2O_5 (percent)	Acid insol. (percent)
		PERMIAN PHOSPHORIA FORMATION LOWER PHOSPHATE ZONE				
Z 5	8	Shale, silty, non-calcareous, brown-black.	0	3		
	7	Phosphate rock, slightly calcareous, granular, some "pisolites", gray-black; contains some amber-colored orbiculoid fragments.	0	1	*13.4* *13.5*	42.9
	6	Clay, silty, slightly dolomitic, sepia.	0	2½		
Z 4	5	Phosphate rock, somewhat calcareous, granular to "pisolitic", gray-black, thin bedded, not well bedded; contains some orbiculoid shells and pelecypod molds.	0	5	22.3	14.8
	4	Dolomite, silty, dense, shaly bedded, gray.	0	3½	*23.0*	
	3	Phosphate rock, calcareous, "pisolitic" below to mostly granular above, thin bedded, poorly bedded, gray-black; contains amber-colored orbiculoid fragments.	0	8½	*22.8*	
Z 3	2	Phosphate rock, calcareous, light gray containing black "pisolites" and some "oölites" and granules; contains numerous shell fragments. One bed.	0	7	14.4 *14.4* *14.2*	6.4

CHEMICAL ANALYSES AND DETAILED STRATIGRAPHIC SECTION—TRENCH Z
South side of tributary of Barrett Creek, above spring, but 100 yards below fork, in NE¼ NW¼ sec. 28, T. 31 N., R. 99 W.

Sample No.	Bed No.		THICKNESS		P_2O_5 (percent)	Acid insol. (percent)
			Ft.	In.		
Z 2	1	Phosphate rock, slightly calcareous, granular to "pisolitic", not well bedded, gray-black; contains some pelecypod molds and light gray to amber-colored orbiculoid shells.	1	5	25.3 25.2 24.8	11.0
Z 1	0	Dolomite, dense, light gray below, to sandy, dark gray above; contains some glauconite and phosphate granules. Top uneven.	1	5	6.2 6.1	29.2
Not sampled	00	Limestone, coarse grained, white to gray-white. 5″ exposed.				

Supplementary analyses

Sample Z 2 yielded 2.0% R_2O_3, 41.2% CaO, 0.9% MgO, 2.9% F_2.
Samples Z 1, Z 2, and Z 5 yielded less than 0.1 percent V_2O_5.

Reserves

Basis of estimate.—The estimate of reserves is based on four factors: area covered by the gently dipping sedimentary deposit, thickness of the phosphate rock, grade of phosphate rock in each zone, and tonnage factor.

Most of the area was mapped on a scale of 1:31680, that is, 2 inches to 1 mile (fig. 3). As mentioned in the paragraphs on Occurrence and Distribution, the outcrop of the phosphate zones was not mapped, but easily recognizable horizons somewhat above each zone were mapped and used as the basis for subdividing the Phosphoria formation into lower, middle, and upper members. The area underlain by phosphate rock was estimated by measuring by planimeter the areas above drainage level outlined by the mapped contacts. Although the areas containing phosphate rock extend somewhat farther up the slopes (updip) than the mapped contacts, they do not extend as far downstream (downdip), so the differences are believed to compensate, and the error in estimating area is no greater than other errors involved. The areas thus measured are, of course, horizontal projections of the true areas, but inasmuch as the dip is generally about 10° or 11°, the error involved in using the horizontal projection is less than 2 percent, which is comparable to an error of ¼ to ½ inch in measurement of thickness. On the plane-table map (fig. 6) the outcrops of the phosphate zones were mapped as accurately as possible, and for one block (Block XVIII) the area measured is the actual area indicated by the outcrop above drainage level.

The error in total thickness of a zone as measured in any trench is believed to be less than ½ inch. In trenches such as A and X, where the top of the limestone underlying the lower phosphate zone is uneven or nodular, the variation in thickness is indicated in the measured sections, but the minimum thickness of phosphate rock was used in estimating reserves. Thin beds of clay, dolomite, etc., overlain and underlain by thick beds of phosphate rock were sampled with the phosphate rock and included in the measured thickness of the zone. Conversely, thin beds of phosphate rock separated from the main zone by thick clay, dolomite, etc., were excluded.

The average grade of a phosphate zone in a trench was determined by combining the analyses of individual beds weighted according to the thickness represented by each sample (figs. 4, 5). The analytical data provided by the Tennessee Valley Authority were used in preference to those from the Natural Resources Research Institute. This choice does not imply any difference in the quality of the work; analyses made by the Tennessee Valley Authority have been used in other work and they are used herein to facilitate comparison with other areas.

The average grade of the phosphate rock in each block was estimated by interpolation between the trenches on each side of the block.

A factor of 12 cubic feet per ton was used in converting volume of phosphate rock to short tons (2,000 pounds). Mansfield (1927, pp. 209-210) indicates that high-grade rock weighs about 180 pounds per cubic foot (11.1 cu. ft. per short ton), but the impurities in the lower-grade rock are lighter than phosphate, hence the density is less, and a larger volume is necessary to weigh a ton. C. F. Deiss (personal communication) used the figure of 12 cubic feet per ton in his work in Idaho in 1944. Here again there is a possible source of error, but an error of ¼ cubic foot per ton in the tonnage factor is only about 2 percent.

Table of estimated reserves.—Blocks are numbered consecutively from northwest to southeast. The northeastern limit of each block is a straight line across the base of the flatirons, connecting the points where the mapped horizon crosses the valleys, except Blocks I to III, the northeastern limit of which is the estimated position of the 3-foot isopach line. In Blocks I to XIV, inclusive, the lower zone is less than 3 feet thick hence tonnage estimates cover only the upper zone. In Blocks XV to XVIII, inclusive, each zone is more than 3 feet thick, so tonnages of phosphate rock have been estimated for each zone. In each of these four blocks the boundaries of the two zones differ, but, because the areas underlain by the two zones overlap extensively, they have been treated as a single block. In the area southeast of Cherry Creek the data are not adequate to permit an estimate of reserves. The rock is all low grade, and there is a sharp anticlinal fold and some faulting, which would increase the difficulty of mining in that area. The area along Willow Creek that is bounded on the north and east by faults has also been excluded, although it contains some phosphate rock.

TABLE OF ESTIMATED RESERVES OF PHOSPHATE ROCK

(see fig. 3)

Block No.	Description	Above drainage level					Reserves (short tons)	Additional reserves for each 100 feet vertically below drainage level, (short tons)
		Trenches in Block	Area (acres)	Average thickness		Estimated average B.P.L. (percent)		
				feet	inches			
I	Tip of third flatiron south of Baldwin Creek, extending down tip from Trench I	I	93	3′	9″	44	1,250,000	†
II	Flatiron south of preceding	....	198	3′	9″	44	2,700,000	†
III	Do., north of Squaw Creek	F	202	3′	9″	44	2,750,000	300,000
IV	Flatiron south of Squaw Creek	....	483	3′	7″	44	6,250,000	900,000
V	Flatiron south of preceding	....	154	4′	2″	43	2,325,000	400,000
VI	Do.	....	264	4′	8″	42	4,475,000	875,000
VII	Do., below Trench K	K	106	4′	10″	41	1,850,000	225,000
VIII	Flatiron south of preceding	....	272	4′	8″	40	4,600,000	525,000
IX	Do.	....	98	4′	7″	37	1,625,000	325,000
X	Flatiron north of Middle Popo Agie	C	48	4′	6″	33	775,000	†
XI	Indefinite "flatiron" southwest of Table Mountain	....	920	5′	0″	34	16,700,000	2,700,000
XII	Two flatirons below Trench L	....	411	5′	7″	35	8,325,000	900,000

TABLE OF ESTIMATED RESERVES OF PHOSPHATE ROCK

(see fig. 3)

Block No.	Description	Above drainage level				Reserves (short tons)	Additional reserves for each 100 feet vertically below drainage level, (short tons)
		Trenches in Block	Area (acres)	Average thickness	Estimated average B.P.L. (percent)		
XIII	Flatiron north of North Fork of Willow Creek	....	397	5′ 10″	36	8,400,000	1,075,000
XIV	Flatiron north of Willow Creek, faulted on south side	D	80	6′ 4″	37	1,825,000	425,000
XV	Willow Creek to Mat Weed Canyon, upper zone	M	802	5′ 10″	38	16,950,000	1,800,000
XV	Do., lower zone	N, O	662	3′ 7″	51	8,610,000*	1,440,000
XVI	Mat Weed Canyon to canyon north of Little Popo Agie, upper zone	....	416	5′ 7″	40	8,425,000	1,050,000
XVI	Do., lower zone	....	397	3′ 8″	52	5,280,000*	830,000
XVII	Flatiron north of Little Popo Agie, upper zone	A	195	5′ 10″	40	4,125,000	1,050,000
XVII	Do., lower zone	A, P	576	3′ 8″	53	7,660,000*	730,000
XVIII	Little Popo Agie to Cherry Creek, upper zone	....	312	6′ 0″	40	7,825,000	1,275,000
XVIII	Do., lower zone	X	661	3′ 5½″	53	8,340,000*	780,000

* Medium-grade phosphate rock. All others are low-grade.

† Blocks lie entirely above drainage level.

Total estimated reserves.—Indicated reserves of phosphate rock above drainage level in beds not less than 3 feet thick total 130,000,000 short tons. Of this total, 100,000,000 tons is low-grade rock in the upper phosphate zone distributed through almost the whole area. About one fourth, or 30,000,000 tons, is medium-grade rock in the lower phosphate zone between Willow Creek and Cherry Creek. For each 100 feet vertically below drainage level, the additional reserves of low-grade phosphate rock amount to 13,825,000 tons, and of medium-grade rock to 3,780,000 tons.

Most accessible area for exploitation

The flatiron between Little Popo Agie River and Cherry Creek was selected for detailed mapping (fig. 6) for the following reasons: The lower phosphate zone here is about 3½ feet thick and contains about 25 percent P_2O_5 (55 percent B.P.L.) which is as good as can be found near Lander. From Lander this area is easily reached by the following surfaced state highway (Farson road) about 11 miles to Little Popo Agie River, then a graded county road (Red Canyon road) about 3 miles upriver, then the ranch road to MacFie's ranch house in the NW¼ sec. 9, T. 31 N., R. 99 W. From the ranch a trail runs the length of the flatiron and beyond. This trail is steep and rough, but can be traveled by jeep or pickup truck, and could be used for bringing a core-drill rig into the area. Below the point where the outcrop of the lower phosphate zone crosses Little Popo Agie River the canyon broadens and contains a narrow flood plain that extends within 100 yards of the outcrop of the lower phosphate zone at stream level.

Mining conditions

The principal deterrents to exploitation of this area are the thinness and relatively poor grade of the phosphate rock, as compared with the deposits in Idaho, Montana, and western Wyoming. Minor factors are the roughness of the bottom, or floor, and the softness of the first 1 to 1½ feet of material above the lower phosphate zone, which might cause some contamination.

The advantages of the area are many and of unequal significance. The 15-mile haul to the railroad at Lander is mostly over surfaced road. The station at Lander is about 300 feet lower than the lowest part of the deposit above stream level. The freight rate to prospective markets in the Middle West is less than that from the deposits farther west. Good water is abundant. Timber, electric power, and coal, oil, and gas for fuel are available at no great distance. In the area mapped in detail (fig. 6) no faults or strong folds were found. All material mined could be moved downgrade in the workings by shaker conveyor, the grade ranging from 10 to 18 degrees in the area mapped in figure 6. The bottom, or floor, would be solid, though uneven, and the top could be cut easily to provide additional headroom where needed. The geodal ledge would provide adequate protection for the workings. Good drainage and ventilation would be almost automatic.

CONCLUSIONS

Reserves of phosphate rock are adequate to maintain extensive mining operations for many years. Mining conditions in general are favorable, although the richer bed is thin. The principal adverse factor is the relatively poor quality of the rock, the best of which is in the lower range of medium grade. Experiments now being conducted by the Natural Resources Research Institute indicate that the rock can be beneficiated, but the cost of processing might more than offset any savings in mining and transportation costs. The possibilities, however, seem to warrant the detailed economic study that must precede any attempt to exploit the deposits.

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