PRELIMINARY REPORT ON STRATIGRAPHY OF THE PHOSPHATIC SHALE MEMBER OF THE PHOSPHORIA FORMATION IN WESTERN WYOMING, SOUTHEASTERN IDAHO, AND NORTHERN UTAH

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CONTENTS

Lower part of the phosphatic shale member (Phosphoria formation).

CONTENTS (cont'd.)

Page

Areal variations in the phosphatic shale (cont'd.)

Composition (cont'd.)

CONTENTS (cont'd.)

ILLUSTRATIONS

ILLUSTRATIONS (cont'd.)

STRATIGRAPHY OF THE PHOSPHATIC SHALE MEMBER OF THE PHOSPHORIA FORMATION IN WESTERN WYOMING, SOUTHEASTERN IDAHO, AND NORTHERN UTAH

By Vincent Ellis McKelvey

ABSTRACT

Introduction.—The marine Phosphoria formation of the Northwest has long been noted for its large phosphate reserves, but recent discoveries show it to be noteworthy also for its content of vanadium and other minor elements. The economic value of these materials may be enhanced by the great lateral continuity of the beds containing them. The results of stratigraphic studies that demonstrate the continuity and variation of the beds of the phosphatic shale in western Wyoming, southeastern Idaho and northern Utah are presented in the present paper.

The Phosphoria formation in this region is composed of a lower, phosphatic shale member, overlain by the Rex member (cherty limestone). Its aggregate thickness ranges from about 225 to 500 feet. Despite its small thickness it apparently represents much of Permian time.

Lithology and composition.—The phosphatic shale member of the Phosphoria formation consists of soft, black, carbonaceous, fine-grained, phosphatic siltstone and shale interbedded with layers of harder, dark-gray, phosphatic oolite, limestone or dolomite, cherty limestone, and cherty siltstone.

More than 30 elements have been reported from these rocks, among which are less common elements like V, P, F, Cr, Mn, Ni, Mo, Ba, Se, Pb, Cl, Sn, Co, As, Sb, Be, I, Ag, Sr, and rare earths. Of the phosphatic shale member as a whole, 50 to 70 percent is CaO, P_2O_5, CO_2, MgO, and F, mostly as collophane and francolite and calcite or dolomite; 20 to 35 percent is SiO_2,

Fe_2O_3, Al_2O_3, and K_2O, mostly as clay minerals, quartz, and mica; and 5 to 10 percent is organic matter. Most of the minor elements, including vanadium, are in the very fine-grained, acid soluble portion of the rock, but the minerals which contain them have not been seen or identified. The vanadium may be in a hydromica or clay mineral, for it varies roughly in proportion to the amount of "soluble" silica present.

Stratigraphy.--The phosphatic shale member in this region may be divided into two parts, lower and upper, each of which consists of a dominantly phosphatic and calcareous sequence overlain by less phosphatic, largely clastic or siliceous rocks.

The lower part of the member increases in thickness westward from a minimum of 65 feet in the Salt River Range, Wyo., to a maximum of about 165 feet in the Peale Mountains, Idaho, and southward to a maximum of 125 to 150 feet in Dempsey Ridge and the Crawford Mountains. In the Salt River Range the basal beds consist of calcareous siltstone or dolomite, overlain by a phosphatic zone 3 to 5 feet thick. Alternating beds of siltstone and shale form the remainder of the lower part. The most vanadiferous part (termed the vanadiferous zone), which is at the top of the lower part, is 3 to 5 feet thick. It contains six units, each with a distinctive vanadium content. All of the units of the lower part in the Salt River Range are identifiable also in Sublette Ridge, Tump Range, Dempsey Ridge, and the Crawford Mountains, but few beds can be correlated definitely with those in southeastern Idaho. There the lower part is much different, mainly because it contains many phosphatic beds (especially near the base) not present in western Wyoming. Most prominent among these is the lower phosphate bed which, together with the overlying "cap lime," is found over much of southeastern Idaho. The vanadiferous zone in southeastern Idaho is thicker

(8 to 12 feet) and more phosphatic than in western Wyoming.

The upper part of the member increases in thickness southward from a minimum of about 30 feet in the Salt River Range to a maximum of about 100 feet in the Crawford Mountains. Its lower half consists of alternating beds of phosphatic oolite and calcareous or dolomitic siltstone. Several units, including the upper phosphate beds and a thin oolite bed and a "hanging-wall" limestone bed at the top of the vanadiferous zone, extend over much of the region. In the Salt River Range the uppermost part of the phosphatic shale member is hard, gray, thin-bedded cherty siltstone that resembles the Rex member of the Phosphoria. In southeastern Idaho these rocks are soft brown siltstones much like the rest of the phosphatic shale except that they are less phosphatic, although they do contain several thin phosphatic layers.

Areal variations.—Most of the areal variations in thickness of the phosphatic shale member of the Phosphoria are caused by variations in thickness of the phosphate, carbonate, and cherty rocks. The thickness of the other rocks (carbonaceous clastics) is relatively constant over the region.

The phosphate content of the phosphatic shale member increases westward and the carbonate content increases southward. The increase in both constituents is caused by an increase in the number and thickness of high-grade beds and by a general increase in the phosphate and carbonate content of other beds as well. The increase in average phosphate content (from about 5 percent in the Salt River Range to about 12 percent in the Peale Mountains) accounts for nearly half of the increase in thickness of the phosphatic shale member in the Peale Mountains over that in the Salt River Range. The total fluorine content increases westward with increase in the amount of phosphate, but the fluorine-phosphate ratio appears to increase eastward. Cherty rocks are found only in the eastern and southern part of the region.

The vanadium content of the vanadiferous zone, which ranges from 0.1 to more than 1.0 percent V_2O_5 over the region, decreases northward and southward from a belt that trends eastward across the region. In general, the vanadium content of the entire phosphatic shale member parallels that of the vanadiferous zone (a relation which is analagous to that of the phosphate and carbonate).

Origin.—The occurrence of the phosphate, vanadium, and trace elements clearly shows that they are syngenetic—that is, they were deposited at the same time as the enclosing rocks.

The source of most of the constituents was most likely the Phosphoria sea for sea water is the only "source rock" that contains the diverse assemblage of elements found in the rocks of the phosphatic shale member. The volume of phosphate and vanadium in the phosphatic shale is tremendous but comparisons suggest that the Phosphoria sea, given sufficient time, normal contributions from chemical denudation, and normal oceanic circulation, might well have been an adequate source of these elements.

The various elements could not have been concentrated except for the abnormally slow deposition of other sediments that might have diluted them. How slow the deposition of these other sediments may have been is shown by the fact that the phosphatic shale, only 100 to 250 feet thick, may be the time equivalent of the Word and Leonard formations, 3,000 to 5,000 feet thick, of Texas. If these formations contain as much phosphate and vanadium as the phosphatic shale, their average content of vanadium and phosphate is about the same as the average found in all sedimentary rocks.

Slow deposition was not the only factor that led to the concentration of phosphate and vanadium, for the total amounts of these elements vary laterally in individual layers of the phosphatic shale. The factors that controlled precipitation of the phosphate and minor elements are not known but they must have been such that the processes of precipitation and deposition could be repeated many times, and could operate with varying efficiency.

INTRODUCTION

The marine Phosphoria formation of the Northwest has long been noted for its large phosphate reserves, but recent discoveries show it to be noteworthy also for its content of vanadium and other minor elements. In southeastern Idaho, western Wyoming, and northern Utah, where the phosphate and vanadium deposits are richest, the Phosphoria consists of a lower, phosphatic shale member overlain by the Rex member (cherty limestone). Their combined thickness ranges from about 225 to 500 feet. Despite their small thickness they apparently represent much of Permian time and are thus the time equivalent of thousands of feet of Permian sediments elsewhere.

A significant corollary of the great disparity in thickness between the Phosphoria and most other Permian formations that are its probable time equivalent is the marked difference in their general composition. The common rock-forming materials, which make up the bulk of the other formations, form only a subordinate part of the phosphatic shale member of the Phosphoria, most of which is nonresistant, black, carbonaceous, phosphatic shale, siltstone, and oolite. This abnormally slow deposition of the common sediments was one of the most important factors in concentrating the phosphate and minor elements, which are present in many other sedimentary rocks but are diluted by other materials.

The commercial value of the phosphate and vanadium depends to a large extent upon the stratigraphic continuity of the beds containing them, and it was to test the stratigraphic continuity of the vanadiferous beds that the present investigation was begun. A detailed description of the vanadium deposits will be presented in another report now in preparation. The present paper describes the lateral continuity and variation of individual layers of the phosphatic shale member in parts of Lincoln County, Wyo., Rich County, Utah, and Bear Lake and Caribou Counties, Idaho.

History of investigation

The phosphate deposits of the Phosphoria formation have been investigated in many areas since the early part of the present century. They were first discovered in 1889 by Richter [1] and in 1897 by Pidcock. [2] Jones [3] later examined the deposits discovered by Pidcock and traced them over parts of northern Utah, western Wyoming, and southeastern Idaho. Weeks and Ferrier began the U. S. Geological Survey land classification work on phosphate in 1906, [4] and since that time the Geological Survey has sampled the phosphate and mapped the Phosphoria formation, on a scale of 1 to 2 miles to the inch, over much of the Rocky Mountain region. [5]

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[1] Richter, Albert, Western phosphate discovery: Mines and Methods, vol. 2, no. 9, p. 207, 1911.

[2] Jones, C. C., Phosphate rock in Utah, Idaho, and Wyoming: Eng. and Min. Jour., vol. 83, pp. 953-955, 1907: The discovery and opening of a new phosphate field in the United States: Am. Inst. Min. Eng. Bull. 82, pp. 2411-2435, 1913.

[3] Idem.

[4] Weeks, F. B., and Ferrier, W. F., Phosphate deposits in Western United States: U. S. Geol. Survey Bull. 315, pp. 449-462, 1907.

Weeks, F. B., Phosphate deposits in Western United States: U. S. Geol. Survey Bull. 340, pp. 441-448, 1908.

[5] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: [illegible]

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Idem: Geography, geology, and mineral resources of the Portneuf quadrangle, Idaho: U. S. Geol. Survey Bull. 803, 1929.

Richardson, G. B., Geology and mineral resources of the Randolph quadrangle, Utah-Wyo.: U. S. Geol. Survey Bull. 923, 1944.

Gardner, L. S., Phosphate deposits of the Teton Basin area, Idaho and [illegible]

Small amounts of vanadium have been known to occur in the phosphate rock of southeastern Idaho since 1911, when chemists of the U. S. Geological Survey found it in a sample from Driggs, Idaho. [6] Other tests made in the years following showed that the phosphate rock contained from 0.02 to as much as 0.52 percent V_2O_5. Production of vanadium as a by-product in the manufacture of superphosphate began in 1941 when, after years of investigation, the Anaconda Copper Mining Co. perfected and placed in operation a process to recover the vanadium from phosphate rock mined at Conda, Idaho.

Vanadium in other beds of the phosphatic shale was first discovered in samples collected by Geological Survey field parties directed by W. W. Rubey from 11 trenches in the Salt River Range and 1 trench in the Wyoming Range. All samples (182) were analyzed for P_2O_5. Of these, the 62 that contained 15 percent or more P_2O_5 and 13 of the 120 containing less than 15 percent were also tested for vanadium and several other constituents. All 75 samples were found to contain at least some vanadium, 18 contained 0.25 percent or more V_2O_5, and 6 contained 0.5 percent or more. When these results became known, vanadium determinations were made on the 107 samples not previously tested for vanadium and later all available [illegible]

Gardner, L. S., Geology and mineral resources of the Irwin quadrangle, Idaho and Wyo.: U. S. Geol. Survey, report in preparation.

Rubey, W. W., Geography, geology, and mineral resources of the Afton and parts of the Cokeville, Labarge, and Jackson quadrangles, Wyo.: U. S. Geol. Survey, report in preparation.

Deiss, Charles, Phosphate deposits in the Deer Creek-Wells Canyon area, Idaho: U. S. Geol. Survey, report in preparation.

[6] Mansfield, G. R., op. cit., p. 212, 1927.

western phosphate field, including many generously furnished by the Bureau of Plant Industry, the U. S. National Museum, and the Tennessee Valley Authority, were tested spectrographically by the Department of Mineralogy and Petrography of Harvard University.

Of all the samples tested, those from southeastern Idaho and western Wyoming contained the most vanadium and the most highly vanadiferous samples were of shale from the upper part of the phosphatic shale member. At that time, it was not known whether the vanadium was present as a syngenetic mineral; whether or not the most vanadiferous samples, which were from sections several miles apart, were from the same bed; or if they were, whether or not this bed was continuous in grade and thickness. However, Rubey recognized the possibility that the vanadium, like the phosphate, was localized in one or more persistent beds and, as a part of the Survey's strategic minerals program, he set out to test this hypothesis in western Wyoming and southeastern Idaho in May 1942. During this phase of the work, in which it was my privilege to assist, 12 relatively complete sections of the phosphatic shale member were sampled in detail. All samples were tested for vanadium by means of a semi-quantitative field test;7/ those found to be highly vanadiferous were then analyzed spectrographically and later by standard chemical methods.

The new data demonstrated that the highest concentrations of vanadium persist at one horizon over a large region,8/ for beds high in vanadium were

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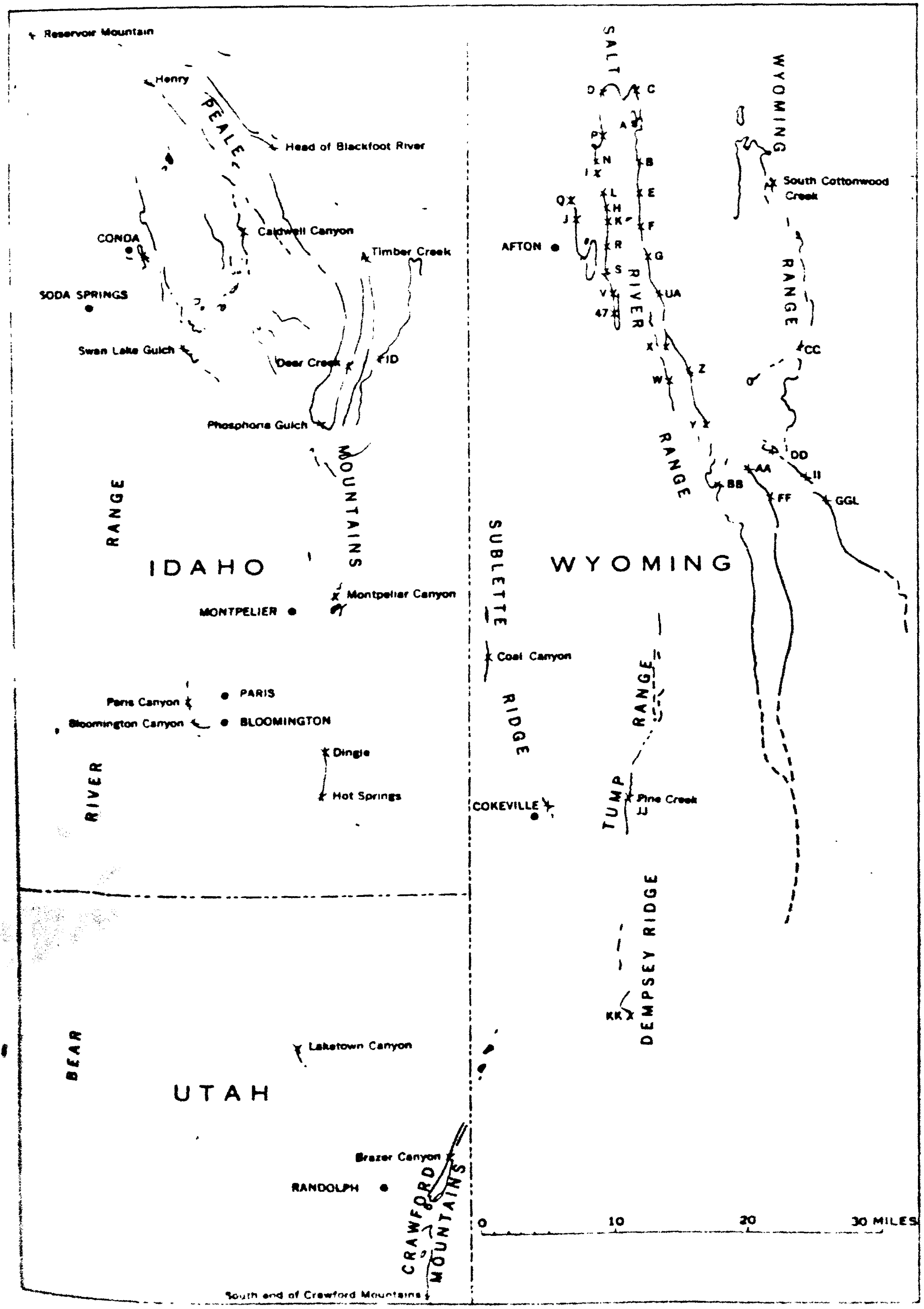
7/ Axelrod, J. M., A field test for vanadium, in Contributions to geochemistry, 1942-45: U. S. Geol. Survey Bull. 950, pp. 19-23, 1946.

8/ Rubey, W. W., Vanadiferous shale in the Phosphoria formation, Wyoming and Idaho (abstract): Econ. Geology, vol. 38, p. 87, 1943.

discovered in relatively the same part of the section in trenches in Sublette Ridge, Cokeville, Montpelier Canyon, and Bloomington Canyon, as well as in the K and M trenches near those (I, H, J, and A) from which the highly vanadiferous "discovery" samples were collected in the Salt River Range near Afton (fig. 1). No criteria other than actual chemical analysis were found then or later for distinguishing vanadiferous from non-vanadiferous beds but we soon learned to identify the vanadiferous beds in the field by their stratigraphic position.

The program was expanded late in August 1942 and the party was joined by another geologist, J. D. Love, and a chemist, Victor North. During this phase of the program the beds of the phosphatic shale were sampled at 44 additional localities spaced 3 to 15 miles apart over the region shown in figure 1. The stratigraphic continuity of the vanadiferous zone was proved beyond a doubt. Although the vanadium content was found to vary over the region, several areas were found in which the vanadiferous beds contain over 0.75 percent V_2O_5. In November 1942 the Bureau of Mines and the Metals Reserve Company selected three of these areas for detailed exploration. J. D. Love, later assisted by L. E. Smith, mapped and described the beds exposed by the Bureau of Mines in the Afton area, Wyo.; J. D. Strobell, Jr., and I mapped and described those exposed by the Bureau of Mines and the Metals Reserve Company in the Sublette Ridge area, Wyo., and those exposed by the Metals Reserve Company in the Paris-Bloomington area, Idaho. During this phase of the work the vanadiferous zone was trenched and sampled at intervals of 100 to 2,000 feet and in addition was sampled underground at intervals of 3 to 20 feet. Whereas much information was obtained on the other beds of the phosphatic shale during the Survey's reconnaissance surveys, the detailed exploratory work necessarily yielded little information on any but the vanadiferous zone and adjacent beds.

FIGURE 1



Map [illegible] western Wyoming, southeastern Idaho [illegible]

[illegible]

The investigation continued until the spring of 1944 when plans for mining the deposits were abandoned because of the alleviation of the vanadium shortage.

Acknowledgements

Many individuals have made significant contributions to this report. Principal among these is W. W. Rubey, who first recognized the possible existence of the vanadiferous zone and who guided the field work through its most critical stages. His sound advice, stimulating suggestions, and encouragement, given through all phases of the work, are reflected in many sections of this report and are gratefully acknowledged.

J. D. Strobell, Jr., provided able assistance in the detailed mapping of the Sublette Ridge and Paris-Bloomington areas. J. D. Love and L. E. Smith described and measured many sections in the Swift Creek, Dry Creek, and Cottonwood Creek areas near Afton, and prepared correlation charts showing the continuity of the beds; most of these sections are not included in this report, but they as well as the correlation charts have been drawn on in describing the rocks in these areas.

Officials of the Wyodak Coal and Manufacturing Co. (agents for the Metals Reserve Company), the Bureau of Mines, and the Anaconda Copper Mining Co., cooperated heartily and extended many courtesies during the field work of 1943. Especially helpful were E. M. Morris, Superintendent, and A. T. Peterson, chemist of Anaconda; H. W. Walker, Vice President, J. D. Johnson, Manager, John Broome, Mine Foreman, W. C. Campbell, L. G. Warren, R. H. Richards, and Harold Sliper, engineers, and A. L. Slaughter and J. A. Harder, geologists of Wyodak; and Forrest Majors, Project Engineer, of the Bureau.

The local residents were extremely cooperative and friendly throughout the work. Mr. A. J. Winters, Superintendent of the Montpelier Schools, kindly provided [illegible]

Professor Lewis M. Cline of the University of Wisconsin, W. W. Rubey and Herbert E. Hawkes of the Geological Survey read the manuscript and made valuable suggestions and criticisms. James Steele Williams of the Geological Survey gave needed advice on the organization of the faunal list.

Sources of unpublished data

It is a pleasure to acknowledge the sources of many of the stratigraphic sections and analyses included in this paper that have been collected by other members of the Geological Survey and by representatives of other organizations as well.

The measurements of the stratigraphic sections were made as follows: South Cottonwood Creek, by John Rodgers; A, B, C, D, and F by Lawrence Gooldy; I, J, and H by Lawrence Gooldy and W. W. Rubey; G, E, and P by Lawrence Gooldy and J. D. Love; K, L, M, N, O, Ua, and Conda by W. W. Rubey; R, S, V, W, X, Y, Z, AA, BB, CC, DD, FF, II, GGL, JJ, KK, and 47 by J. D. Love; and ID by Charles Deiss.

Most of the vanadium and phosphate analyses quoted in this report were made by Victor North, but many others were made by R. C. Wells, F. S. Grimaldi, J. G. Fairchild, F. L. Schmehl, J. M. Axelrod, Margaret Foster, K. J. Murata, and M. Fleischer. The spectrographic analyses for vanadium were made by John C. Rabbit of the Department of Mineralogy and Petrography of Harvard University. Most of the vanadium analyses on the beds of the vanadiferous zone in the Sublette Ridge area and Paris-Bloomington areas were made by W. L. Ryan of the Wyodak Coal and Manufacturing Co. and some of those on the vanadiferous beds in Sublette Ridge and in the Swift Creek, Dry Creek, and Cottonwood Creek areas in the Salt River Range were made by the Bureau of Mines; although comparatively few of the analyses made by either Wyodak or the Bureau are included in this report, all have been studied in its preparation. The analyses of the rocks at Conda were generously furnished by the Anaconda Copper

Mining Co. The analyses of the samples from trench 1D were made by the Chemical Research Laboratory of the Tennessee Valley Authority. The selenium analyses given in table 4 were made by Prof. O. A. Beath of the University of Wyoming on samples collected by H. D. Thomas, State Geologist of Wyoming.

REGIONAL GEOLOGY

The southeastern Idaho region was the site of deposition of marine sediments during every period from Cambrian to Cretaceous. The Paleozoic rocks consist dominantly of resistant gray limestone, dolomite, quartzite, and sandstone. The Mesozoic rocks form a thick series of alternating limestone, shale, and sandstone. Tertiary rocks, which are nonmarine, are largely clastics, but include subordinate amounts of calcareous marl and volcanic ash. A list of formations exposed in the region, modified slightly from that given by Mansfield,[9] follows:

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[9] Mansfield, G. R., op. cit., p. 48, 1927.

		Thickness (feet)
Pliocene (?):	Salt Lake formation (conglomerate, sandstone, marl)	0 - 1,000±
Eocene:	Wasatch formation (conglomerate, sandstone)	0 - 1,500±
Lower Cretaceous (?):	Wayan formation (sandstone, shale, limestone)	12,000±
	Tygee sandstone	100+
	Draney limestone	175
	Bechler conglomerate	1,700
	Peterson limestone	200
	Ephraim conglomerate	1,000
Upper Jurassic:	Stump sandstone	200 - 600
	Preuss sandstone	1,300
	Twin Creek limestone	3,500±
Jurassic Triassic (?):	Nugget sandstone	1,400±
	Wood shale	150±
	Deadman limestone	200±
	Higham grit	200±
Triassic:	Timothy sandstone	250±
	Thaynes formation (silty limestone, calcareous siltstone, shale)	2,000 - 3,000
	Woodside shale and Dinwoody formation (silty limestone, siltstone, shale)	1,000 - 2,000
Permian:	Phosphoria formation	
	Rex member (chert, cherty limestone)	80 - 300
	Phosphatic shale member	85 - 250
Pennsylvanian:	Wells formation (sandstone, quartzite, limestone)	1,000 - 2,400
Mississippian:	Brazer limestone	1,100+
	Madison limestone	1,000+
Upper Devonian:	Three Forks limestone	200±
Middle Devonian:	Jefferson limestone	[illegible]
[illegible]	[illegible] dolomite	[illegible]

		Thickness (feet)
Upper Ordovician:	Fish Haven dolomite	500
Lower Ordovician:	Swan Peak quartzite	500
	Garden City limestone	1,200
Upper Cambrian:	St. Charles limestone	900 - 1,200
Middle Cambrian:	Nounan limestone	1,000
	Bloomington formation (limestone and shale)	1,200
	Blacksmith limestone	750
	Ute limestone	750
	Langston limestone	350 - 600
Lower and Middle Cambrian:	Brigham quartzite	1,000 - 1,600±
	Total maximum thickness of all formations	46,000+

As a result of strong deformation which began near the close of the Cretaceous, the pre-Tertiary rocks form long, northward-trending folds, many of which are overturned and broken by numerous transverse and bedding faults and by a few great overthrusts of many miles displacement. The Tertiary sediments, which were deposited after a long period of erosion and after the period of most intense deformation are only moderately tilted, but they are broken by normal faults of several hundred feet displacement.

The post-Cretaceous geological history affected the Phosphoria formation in several ways. Because of the regional structure the Phosphoria is at the surface on the limbs of many folds and is characterized by long, northward-trending outcrops (fig. 1). Because the phosphatic shale member is structurally incompetent, in many places it has been thickened or thinned by squeezing and part or all of it cut out or repeated by reverse faults which are so nearly parallel to bedding that even where exposed they cannot be detected except by omission or repetition of beds. Oxidation of the phosphatic shale, in areas where it was at or near the surface during the long period of erosion that preceded deposition of the Tertiary sediments, led to the removal of most of its organic matter and soluble constituents so that in those areas it is much different in appearance and composition.

DEFINITION OF THE PHOSPHATIC SHALE MEMBER OF PHOSPHORIA FORMATION

The phosphatic beds were first mapped as a part of the Park City formation, which had been described by Boutwell[10] in the Park City mining district, Utah. Three members of the Park City formation were differentiated: cherty limestone, overlying the Weber quartzite, at the base: overlain by phosphatic shale; and capped by the "upper *Productus* limestone.'

The upper Productus limestone and the phosphatic shale member were later included in the Phosphoria formation, which was described in 1912 by Richards and Mansfield[11] from Phosphoria Gulch, a small canyon in the Peale Mountains, Bear Lake County, Idaho. They designated the upper unit as the Rex chert member, from Rex Peak in the Crawford Mountains, Rich County, Utah, and called the lower unit simply the phosphatic shale member. They placed the lower cherty limestone member of the Park City formation, together with beds thought to be equivalent to the underlying Weber quartzite and Morgan formation, in the Wells formation, named from Wells Canyon in the Peale Mountains, Caribou County, Idaho.

The Rex chert and phosphatic shale member lose their identity to the north and east, but in the area studied they are fairly distinct. Because the Rex chert member does not contain conspicuous amounts of chert in some parts of this area, it will be referred to merely as the Rex member in this paper.

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

[11] Richards, R. W., and Mansfield, G. R., The Bannock overthrust: Jour. Geology, vol. 20, pp. 684-689, 1912.

FAUNA

Nearly 300 species have been reported from the Phosphoria formation

Fossils collected during the present investigations are being studied by James Steele Williams, but the results are not yet available. Because the fauna in the area studied has been incompletely described, it has appeared advisable to list also the fossils collected from other regions. The faunas of the Park City formation, the Lower Embar formation, and the so-called Sybille, Forelle, and Ervay tongues of the Phosphoria formation, and the Satanka shale are included because they are either now called "Phosphoria" or are believed to be continuations of it; the faunas are separately listed in the table, except for that of the Park City formation.

in Wyoming, Idaho, Utah, and Montana (table 1).

Some of the species which distinguish the fauna have a wide distribution but most of them are restricted in occurrence or at least are not equally abundant over the region as a whole. Thus of the species listed in table 1, only about 20 are common to the collections from Idaho and western Wyoming and central and southeastern Wyoming. These include:

Productus semireticulatus
P. multistriatus
P. (Waagenoconcha) montpelierensis
P. (Linoproductus) phosphaticus
P. (Avonia) subhorridus
P. (Pustula) nevadensis
Aulosteges hispidus
Pugnoides osagensis
Rhyncopora taylori
Punctospirifer pulcher
Ambocoelia guadalupensis
Composita subtilita
Nucula montpelierensis
N. pulchella
Leda obesa
L. bellistriata
Plagioglypta canna
Pleuretomaria phosphaticus
Euphemites subpapillosus

Such forms as *Orbiculoidea utahensis*, *Derbya*, *Punctospirifer kentuckyensis*, *Hustedia*, *Schizodus* (except *S. ferrieri*), *Allorisma*, *Deltopecten*, *Myalina*, *Bellerophon*, *Pleurophorus*, and fish teeth are listed from most collections from central Wyoming, but are absent on the lists from Idaho and western Wyoming: on the other hand, *Chonetes ostiolatus*, *Orbiculoidea missouriensis*, *Lingula carbonaria* (?), *Aviculopecten? montpelierensis*, *Pleurotomaria idahoensis*, *Omphalotrochus conoideus*, and ostracods are reported from Idaho but not from central Wyoming. This local distribution may be more apparent than real, for the faunas have been incompletely studied; but such differences in reported occurrence, if not a reliable index of presence or absence, must at least reflect local abundance of fossils. Of interest is the fact that of the species which are widespread, most are brachiopods, including many which have also been reported by King[13] from the Permian of Texas.

Many of the beds contain characteristic faunules over small areas. Examples are the "cap lime" above the lower phosphate bed and the *Omphalotrochus* zone at the top of the phosphatic shale member in the Peale Mountains; the "goniatite" limestone and the *Chonetes*-bearing limestone (the "hanging-wall limestone" above the vanadiferous zone) in Sublette Ridge; the *Orbiculoidea* zone in one of the upper phosphate beds in the Salt River Range; the "*Productus* limestone" of the Rex member in Idaho and Utah; and the lower chert, lower phosphate, *Pustula*, *Hustedia*, and top limestone members described by Branson in the Wind River-Owl Creek mountains of Wyoming. In general, beds which are fossiliferous in one locality seem to be fossiliferous wherever they can

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[13] King, R. E., The geology of the Glass Mountains, Tex., Part II, Faunal summary and correlation of the Permian formations, with description of brachiopods; Texas Univ. Bull. 3042, p. 32, 1930.

be identified; and beds unfossiliferous in one locality are unfossiliferous elsewhere.

Most of the fossils occur in limestone, but some are found in shale and phosphate rock. Regardless of stratigraphic position, the phosphate rock has a more or less typical fauna—*Orbiculoidea*, *Lingula*, gastropods such as *Omphalotrochus* and *Bellerophon*, and fish remains. In central Wyoming[14] and in the Uinta Mountains[15] the phosphate rock carries a depauperate fauna.

A few of the species thus far reported seem to be restricted to one part of the formation over the region. Thus far *Waagenoconcha montpelierensis*, *Pugnoides osagensis*, *Composita subtilita*, *Rhyncopora taylori*, and *Nucula montpelierensis* have been reported only from the lower part of the formation, and bryozoans, *Productus semireticulatus*, *P. multistriatus*, *P. (Avonia) subhorridus*, and *Euphamites subpapillosus* have been reported only from the upper part of the formation. Widespread faunal zones may be established as faunal studies are continued (and especially when more cephalopods are described) but such zones are not now evident.

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[14] Branson, C. C. Paleontology and stratigraphy of the Phosphoria formation: Missouri Univ. Studies, vol. 5, p. 18, 1930.

[15] Williams, J. Stewart, "Park City" beds on southwest flank of Uinta Mountains, Utah: Am. Assoc. Petroleum Geologists Bull. vol. 23, p. 88, 1939.

AGE

Most Permian specialists now agree that the phosphatic shale member of the Phosphoria is equivalent to part of the Guadalupe series and possibly part of the Leonard series as well (table 2)[16]. The age limits of

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[16] References referred to in the table are as follows: Girty, G. H., Fauna of the phosphate beds of the Park City formation in Idaho, Wyoming, and Utah: U. S. Geol. Survey Bull. 436, p. 10, 1910; in Richards, R. W., and Mansfield, G. R., The Bannock overthrust: a major fault in southeastern Idaho and northeastern Utah: Jour. Geology, vol. 20, pp. 683, 687, 1912; in Blackwelder, E., New or little known Paleozoic faunas from Wyoming and Idaho: Am. Jour. Sci., vol. 36, p. 179, 1913; in Mansfield, G. R., Geology, geography, and mineral resources of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, p. 80, 1927. Branson, E. B., The lower Embar of Wyoming and its fauna: Jour. Geology, vol. 24, pp. 660-661, 1916. Branson, C. C., Paleontology and stratigraphy of the Phosphoria formation: Missouri Univ. Studies, vol. 5, pp. 20-21, 1930; Fish fauna of the middle Phosphoria formation: Jour. Geology, vol. 41, p. 174, 1933; Permian sharks of Wyoming and East Greenland: Science, n. s., vol. 79, p. 431, 1934; Pennsylvanian formations of central Wyoming: Geol. Soc. America Bull., vol. 50, p. 1200, 1939. Branson, E. B., and Branson, C. C., Geology of Wind River Mountains, Wyo.: Am. Assoc. Petroleum Geologists Bull., vol. 25, p. 133, 1941. King, R. E., The geology of the Glass Mountains, Tex., Part II, Faunal summary and correlation of the Permian formations, with description of Brachiopods; Texas Univ. Bull. 3042, pp. 30-33, 1930. Williams, James Steele, Sixteenth Internat. Geol. Congress, Guidebook 29, pl. 5, 1933. Miller, A. K., and Cline, L. E., The cephalopods of the Phosphoria formation of northwestern

the Phosphoria have not been established, but Baker and Williams class the underlying beds in the Park City Utah area as Kaibab (Leonard); Frenzel and Mundorff define beds at the base of the Phosphoria or top of underlying Quadrant in the Three Forks, Montana area as Wolfcamp; and Newell and Kummel[17] have shown that the overlying Dinwoody formation in southeastern Idaho is lowermost Triassic (Otoceratan). Baker and Williams and later Frenzel and Mundorff recognized the possibility that the beds at the base of rocks of Phosphoria lithology may not be the same age everywhere; the present studies, which show that the lower part of the phosphatic

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United States: Jour, Paleontology, vol. 8, pp. 281-285, 1934. Miller, A. K., and Furnish, W. M., Permian Ammonoids of the Guadalupe Mountain region and adjacent areas: Geol. Soc. America Spec. Paper 26, pp. 9, 23, 28, 1940. B. K. Licharew, in Williams, James Steele, Pre-Congress Permiam conference in the U. S. S. R.: Am. Assoc. Petroleum Geologists Bull. vol. 22, p. 772, 1938. Baker, A. A., and Williams, James Steele, Permiam in parts of Rocky Mountain and Colorado Plateau regions: Am. Assoc. Petroleum Geologists Bull., vol. 24, pp. 624-625, 1940. Franzel, H., and Mundorff, M., Fusulinidae from the Phosphoria formation of Montana: Jour. Paleontology, vol. 16, pp. 675-684, 1942. Thompson, M. L., Wheeler, H. E., and Hazzard, J. C., Permian fusulinids of California: Geol. Soc. America Memoir 17, p. 8, 1946.

[17] Newell, N. D. and Kummel, Bernhard, Lower Eo-Triassic stratigraphy, western Wyoming and southeast Idaho: Geol. Soc. America, Bull. vol. 53, p. 939, 1942.

TABLE 2
PUBLISHED OPINIONS AS TO THE AGE OF THE PHOSPHORIA FORMATION 1/

System	Carboniferous		Carboniferous or Permian	Permian				
Series	Pennsylvanian		Wolfcamp	Leonard		Guadalupe		Ochoa
European equivs.	Moscovian	Geschelian	Sakmarian	Artinskian	Kungurian	Kazanian	Tartarian	
Fusulinid zones	Fusulina	Triticites	Pseudoschwagerina	Parafusulina			Polydiexodina	
Ammonoid zones		Uddenites	Properrinites	Perrinites		Waagenoceras	Timorites	Cyclolobus
Girty, 1910		"Geschelian" ▨						
Girty(?), 1912			"?Permian" ▨	▨				
E. B. Branson, 1916	"Moscovian" ▨							
Girty, 1927				"Artinskian" ▨				
C. C. Branson, 1930		"Late Pennsylvanian-Lowermost Permian" ▨	▨	▨				
H. E. King, 1930						"Word" ▨		
J. Steele Williams, 1932			? ▨	▨	▨	▨ ?		
Miller and Cline, 1934				"Word"; "may be as old as Leonard" ▨	▨	▨		
Licharew, 1937 (in Williams, 1938)				▨ Equivalent to Irghina beds				
C. C. Branson, 1939			"Lower Permian" ▨	▨				
A. A. Baker and J. Steele Williams, 1940						"Younger than Kaibab" ▨		
Miller and Furnish, 1940					▨	▨		
E. B. Branson and C. C. Branson, 1941			"Lower but not lowermost Permian" ▨	▨				
Frenzel and Mundorff, 1942			As old as Wolfcamp ▨					
Thompson, Wheeler and Hazzard, 1946			▨ "Upper Wolfcampian" but "younger than the type section of the Wolfcamp formation"					

1/ Because the classification of the Permian has changed from time to time, the various age determinations, especially those expressed in terms of "Lower, Middle, or Upper Permian," are difficult to compare with one another. An effort has been made to show the age limits as the author intended them in terms of the Permian classification in existence at the time, but, to avoid misrepresentation of the author's opinion, his own designation is quoted wherever possible. The Geological Survey has not made any official correlation of the provincial Permian series of West Texas with those of Russia; that given here is taken from C. O. Dunbar, The type Permian: its classification and correlation: Amer. Assoc. Petroleum Geologists Bull. vol. 24, p. 266, 1940.

shale to the south becomes more calcareous and more like the upper part of the Wells, indicate that this possibility should be considered in further work.

LITHOLOGY

Composition

Lime, phosphate, silica, carbon dioxide, organic matter, magnesia, alumina, iron oxide, and fluorine, listed in approximate order of abundance, are the principal constituents of the phosphatic shale member, but in addition more than 20 other elements have been reported. Enough data are not available to determine the average composition of the phosphatic shale, but a rough idea of the relative proportions of some of the principal constituents may be had from the average of analyses representing 137.8 feet of the phosphatic shale member at trench ID in the Peale Mountains, presented in table 3. A list of elements reported from the phosphatic shale is shown in table 4. Because the mineral particles of the rocks are very fine-grained and tend to be obscured by organic matter, their identities are difficult to determine, but will be listed insofar as known.

Table 3

Composition of 57 samples representing 137.8 feet of the phosphatic shale member of the Phosphoria formation at trench ID 1/

	Average (percent)	Maximum (percent)	Minimum (percent)
P_2O_5	14.1	35.5	0.3
CaO	24.6	50.2	3.9
Fe_2O_3	2.0	5.0	0.4
Al_2O_3	3.2	6.6	0.4
F	1.47	3.84	0.04
V_2O_5	0.10	1.16	0.01
Acid insoluble	[illegible]	71.7	3.9
Ignition loss	15.8	39.3	[illegible]

1/ Samples collected by Charles Deiss of the Geological Survey; analyses made by the Chemical Research Laboratory of the Tennessee Valley Authority. The total thickness of the phosphatic shale member at this locality is about 179 feet. Approximately half of the beds not sampled are described as shale and siltstone and the other half as calcareous siltstone or limestone: all are probably low in phosphate. Therefore the average F and P_2O_5 content of the member is lower than shown by the analyses (the average P_2O_5 content is probably about 12 percent) and the content of other constituents is somewhat higher.

Lime, phosphate, carbon dioxide, magnesia and fluorine, mostly as phosphate and carbonate minerals, make up 50 to 70 percent of the phosphatic shale member. Two mineral forms of phosphate are differentiable. The most abundant is an isotropic-appearing mineral (known from X-ray studies to have the crystal structure of apatite[18]) described as collophane;[19] the other, a birefringent mineral whose optical properties, according to W. W. Rubey and W. T. Schaller, are those of francolite ($10\ CaO.3P_2O_5.CaF_2.CO_2$),[20] forms only a small part of most of the phosphate rock and is apparently secondary. Analyses show that the bulk of the phosphate rock has a chemical composition similar, at least qualitatively, to francolite. W. W. Rubey found by petrographic examination that most of the carbonate rocks in the Salt River Range are dolomite.

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[18] Hendricks, S. B., Hill, W. L., Jacob, K. D., and Jefferson, M. E., Structural characteristics of apatite-like substances and composition of phosphate rock and bone as determined from microscopical and X-ray diffraction examinations: Indus. and Engin. Chem. vol. 23, pp. 1413-1418, 1931.

[19] Mansfield, G. R., op. cit., p. 367, 1927.

[20] Sandell, E. B., Hey, M. H., and McConnell, Duncan, The composition of francolite: Mineralogical Mag. pp. 395-401, 1939.

Table 4

Elements reported from the phosphatic shale*
(listed in order of maximum amount reported)

	Maximum (percent)	Rock type or bed from which reported	Minimum (percent)	Rock type or bed from which reported
SiO_2	95	Chert (estimated)	none	Upper phosphate bed
CaO	52.2	Phosphate rock	1.4	Vanadiferous zone
P_2O_5	38.6	Upper phosphate bed	0.1	Dolomite
CO_2	38.6	Dolomite	0.04	Vanadiferous zone
Organic matter	25.8	Shale	0.6	Phosphate rock
MgO	17.7	Dolomite	0.03	Cherty phosphate rock
Al_2O_3	12.6	Vanadiferous zone	0.4	Limestone or dolomite
F	7.0	Phosphate rock	0.04	Limestone or dolomite
Fe_2O_3	5.0	Phosphatic shale	0.3	Phosphate rock
S	4.1	Vanadiferous zone	none	Dolomite
H_2O-	3.5	Vanadiferous zone	0.3	Phosphate rock
K_2O	3.2	Vanadiferous zone	0.06	Phosphatic oolite
V_2O_5	2.5	Vanadiferous zone	none	Calcareous siltstone
Na_2O	2.1	Phosphate rock	0.1	Dolomite
H_2O+	1.4	Phosphatic oolite	0.6	Phosphate rock
ZnO	1.3	Vanadiferous zone	none	Vanadiferous zone
TiO_2	1.0	Vanadiferous zone	none	Phosphate rock
Cr_2O_3	0.8	Clay	none	Mudstone
Mn	0.6	Vanadiferous zone	< 0.001	Vanadiferous zone
NiO	0.3	Clay; vanadiferous zone	none	Vanadiferous zone
MoO_3	0.1	Vanadiferous zone	none	Phosphate rock
BaO	0.07	Phosphate rock	none	Vanadiferous zone
Se	0.068	Vanadiferous zone	0.019	Mudstone
PbO	0.05	Vanadiferous zone	$<$0.001**	Phosphate rock
CuO	0.03	Vanadiferous zone	0.002	Phosphate rock
Cl	0.03	Phosphate rock	0.01	Phosphate rock
SnO	0.03**	Clay	$<$0.001**	Shale
Co_2O_3	0.02**	Vanadiferous zone	$<$0.001**	Shale, phosphate
As_2O_3	0.006	Vanadiferous zone	0.001	Phosphate rock
Sb_2O_3	0.003**	Vanadiferous zone	$<$0.001**	Phosphate rock
BeO	0.001**	Phosphate rock	$<$0.001**	Vanadiferous zone
I	0.00026	Phosphate rock	0.00008	Phosphate rock
Ag	0.26 (oz)	Vanadiferous zone		
Sr	trace**	Vanadiferous zone	none	Vanadiferous zone
Rare earths	trace	Phosphatic oolite	none	Cherty phosphate

WO_3 not found in spectographic tests made on about 75 samples from various beds of the phosphatic shale member in southeastern Idaho and western Wyoming; Bi_2O_3,OdO, and HgO were not found in spectrographic tests on two samples from the vanadiferous beds.

* The maximum and minimum values are probably of correct order of magnitude for the first 12 or 15 compounds listed, although additional analyses will probably extend them slightly. The maximum and minimum values listed for the other substances are based on too few determinations to be considered reliable.

** Spectrographic analysis; all other determinations by chemical analysis.

Fluorine in excess of that required in the phosphate minerals (0.0892 P_2O_5) is generally found in western phosphates 21/ and in many places at least part of this fluorine is present as purple fluorite in grains of both megascopic and microscopic size. The megascopic crystals of fluorite, which are found almost exclusively in coarse-grained oolite or pisolite, or in thin veinlets along joint planes, are secondary.

Silica, iron, alumina, and potash probably make up 20 to 35 percent of the phosphatic shale as a whole. Silica is present as quartz, chert, and in silicates, in combination with alumina and possibly iron. Detrital clay, quartz, feldspar, and mica have been identified microscopically by W. W. Rubey, but the quartz, feldspar, and mica make up a relatively minor part of the phosphatic shale as a whole. An iron sulphide, pyrite, or marcasite, is found in nodules underground in the unaltered part of the phosphatic shale in the Paris-Bloomington area, but it has not been found at the surface there, nor in any other part of the region. Brown, red, yellow, and green iron stains and coatings are abundant on the beds at the surface, however, and are especially characteristic of the beds of the vanadiferous zone.

Organic matter makes up 5 to 10 percent of the entire phosphatic shale member of the Phosphoria but little is known as to its composition. Some beds of the phosphatic shale in Montana contain 25 to 30 gallons of distillable hydrocarbons to the ton 22/ but the only rocks in the southeastern

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21/ Mansfield, G. R., The role of fluorine in phosphate deposition: Am. Jour. Sci., vol. 238, p. 865, 1940. Jacob, K. D., Hill, W. L., Marshall, H. L., and Reynolds, D. S., The composition and distribution of phosphate rock with special reference to the United States: U.S. Dept. Agr. Tech. Bull. 364, p. 866, 1940.

22/ Bowen, C. F., Phosphatic oil shales near Dell and Dillon, Beaverhead County, Mont.: U.S. Geol. Survey Bull. 661, pp. 315-320, 1918. Condit, D. D., Oil shale in western Montana, southeastern Idaho and adjacent parts of Wyoming and Utah: U.S. Geol. Survey Bull. 711, pp. 15-40, 1919.

Idaho-western Wyoming-northern Utah area found to contain them were the rocks of the vanadiferous zone in the Paris-Bloomington area, which contain 6 to 10 gallons a ton and which contain enough total organic matter to ignite spontaneously under optimum conditions.

Efforts to identify the minerals containing the minor elements, including vanadium, have not been successful, principally because these minerals are so exceedingly fine-grained and so obscured by organic matter that they cannot be studied microscopically. Positive identification probably will not come until special methods are devised for removing the organic matter and even then probably electron-microscope study will be required.

Chemical analyses, interpreted by W. W. Rubey, indicate that the vanadium is most probably in a clay mineral (hydromica), though it may also be in a complex organic compound. Practically all of the vanadium is in the acid-soluble fraction of the rock; its amount increases roughly with the amount of silica soluble in alkali after acid treatment, suggesting that it is associated with some decomposable silicate; and with increase in potash and H_2O+, both essential constituents of hydromicas. On the other hand, it also increases roughly with increase in amount of organic matter, though notable exceptions suggest that if it is an organic compound it is one of variable composition. That the vanadium is not in the phosphate mineral is certain, for in a gravimetric separation of the rock it is found with the lightest constituents (organic matter and clay) rather than with the heaviest particles (collophane and francolite): and in a size separation it is found with the finest constituents (clay and organic matter) rather than with the coarsest (collophane and francolite).

Little is known about the chrome mineral, but the fact that most of it is in the [illegible]-soluble portion of [illegible] shows that it [illegible] chromite and suggests that chrome and vanadium might be in the same mineral. Some of the other trace elements—arsenic, manganese, zinc, and copper—are also in the acid-soluble portion of the rock.[23]

Secondary vanadium minerals, including hewettite ($CaO.3V_2O_5.9H_2O$), pascoite ($2CaO.3V_2O_5.11H_2O$) and sincosite ($CaO.V_2O_4.P_2O_5.5H_2O$) are found in the zone of enrichment in the Paris-Bloomington area.

Rock types

The phosphatic shale member of the Phosphoria formation consists largely of nonresistant, dark-colored, carbonaceous phosphatic rocks that are difficult to name. The principal rock-forming constituents may be considered as organic matter, fine-grained clastics, and chemical precipitates—dolomite or calcite, chert, and phosphate. Although some of the rocks are predominantly one or another of these materials, most of them are mixtures. As shown in the classification used in the explanation to plates 1-7, four basic rock types are present: siltstone or mudstone, oolite, limestone or dolomite, and chert. Because some of the siltstones develop fissility on weathering, shale is a common type in surface exposures. The common mixtures are calcareous siltstone, calcareous shale, oolitic siltstone, oolitic shale, oolitic chert, oolitic (phosphatic) limestone, cherty limestone, and siliceous siltstone. The relative abundance of the various rocks at several localities is shown in table 5 and may be seen also by a study of the stratigraphic sections on plates 1-7. Sandstone does not occur in the phosphatic shale in the area studied, and sand as a minor constituent of other rocks is very rare.

Nearly all of the oolitic rocks are phosphatic, but not all of them are dominantly phosphatic, nor are all phosphatic rocks oolitic.[24] The oolite

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[23] Mansfield, G. R., op. cit. Prof. Paper 152, p. 299, 1927.

[24] Gardner, L. S., Phosphate deposits of the Teton Basin area, Idaho and Wyo.: U. S. Geol. Survey Bull. 944a, p. 16, 1944.

Table 5, Part I

Total thickness of various rock types of the phosphatic shale member of the Phosphoria at several localities in western Wyoming, southeastern Idaho and northern Utah

	South Cotton-Wood C.		D*		Ua		K		Coal Canyon		Coke-ville*	
	Ft.	%	Ft.	%	Ft.	%	Ft.	%	Ft.	%	Ft.	%
Non-calcareous, non-phosphatic and non-cherty rocks	37.6	31.9	22.7	24.0	28.6	23.2	36.3	35.8	19.4	13.7	30.8	21.0
Siltstone	26.5	22.5	22.7	24.0	15.9	12.9	28.5	28.2	9.5	6.7	7.1	4.8
Shale	11.1	9.4	—	—	12.7	10.3	16.8	16.6	9.9	7.0	23.7	16.2
Clay	—	—	—	—	—	—	1.0	1.0	—	—	—	—
Phosphatic, oolitic, and pisolitic rocks	43.6	37.0	31.7	33.6	19.2	15.4	17.2	17.0	65.6	46.6	41.6	28.5
Oolite and phosphate rock	17.5	14.8	23.6	25.0	13.3	10.7	14.1	13.9	29.3	20.8	20.3	13.9
Siltstone	14.4	12.3	6.7	7.1	3.0	2.4	1.7	1.6	12.6	8.9	3.1	2.1
Shale	11.7	9.9	1.4	1.5	2.9	2.3	1.4	1.3	20.5	14.6	13.7	9.4
Clay	—	—	—	—	—	—	—	—	—	—	—	—
Limestone or dolomite	—	—	—	—	—	—	—	—	3.2	2.3	4.5	3.1
Calcareous rocks	19.0	16.1	35.7	37.8	70.5	57.0	42.4	42.0	38.2	27.0	68.6	46.8
Limestone or dolomite	—	—	4.9	5.2	9.0	7.3			33.9	24.0	40.3	27.5
Siltstone	18.0	15.3	30.8	32.6	59.0	47.7	40.6	40.2	4.0	2.8	7.6	5.2
Shale	1.0	0.8	—	—	2.5	2.0	1.8	1.8	0.3	0.2	20.7	14.2
Cherty rocks	17.7	14.9	2.3	2.4	—	—	—	—	—	—	2.6	1.7
Chert	—	—	—	—	—	—	—	—	—	—	—	—
Oolite and phosphate	—	—	2.3	2.4	—	—	—	—	—	—	0.5	0.3
Siltstone	3.5	2.9	—	—	—	—	—	—	—	—	—	—
Limestone	14.2	12.0	—	—	—	—	—	—	—	—	2.1	1.4
Calcareous and phosphatic rocks	—	—	2.2	2.1	5.4	4.4	5.3	5.2	17.8	12.7	2.9	2.0
Siltstone	—	—	2.2	2.1	—	—	5.3	5.2	14.6	10.4	—	—
Shale	—	—	—	—	5.4	4.4	—	—	3.2	2.3	2.9	2.0

Table 5, Part II

Total thickness of various rock types of the phosphatic shale member of the Phosphoria at several localities in western Wyoming, southeastern Idaho and northern Utah

	Brazer C.*		Conda*		Caldwell C.*		ID		Montpelier C.	
	Ft.	%	Ft.	%	Ft.	%	Ft.	%	Ft.	%
Non-calcareous, nonphosphatic and noncherty rocks	18.0	8.7	19.9	12.4	46.1	32.4	29.9	16.7	22.2	13.8
Siltstone	6.0	2.9	16.0	10.0	37.3	26.2	16.5	9.2	13.5	8.4
Shale	12.0	5.8	0.2	0.1	8.8	6.2	13.4	7.5	8.7	5.4
Clay	--	--	3.7	2.3	--	--	--	--	--	--
Phosphatic, oolitic, and pisolitic rocks	52.7	25.7	140.7	87.6	69.6	48.9	107.4	60.0	47.2	29.5
Oolite and phosphate rock	14.8	7.2	15.6	9.7	14.9	10.5	43.3	24.2	21.3	13.3
Siltstone	3.2	1.6	106.6	66.4	3.2	2.2	16.4	9.2	17.3	10.8
Shale	21.9	10.7	11.2	7.0	37.8	26.6	39.5	22.0	5.7	3.6
Clay	--	--	7.3	4.5	--	--	--	--	--	--
Limestone or dolomite	12.8	6.2	--	--	13.7	9.6	8.2	4.6	2.9	1.8
Calcareous rocks	110.0	53.7	--	--	21.6	15.2	30.3	16.9	62.6	39.1
Limestone or dolomite	88.4	43.2	--	--	6.4	4.5	16.6	9.2	29.8	18.6
Siltstone	19.9	9.7	--	--	11.2	7.9	8.3	4.6	13.9	8.7
Shale	1.7	0.8	--	--	4.0	2.8	5.4	3.0	18.9	11.8
Cherty rocks	12.9	6.3	--	--	--	--	--	--	--	--
Chert	10.0	4.9	--	--	--	--	--	--	--	--
Oolite and phosphate	--	--	--	--	--	--	--	--	--	--
Siltstone	--	--	--	--	--	--	--	--	--	--
Limestone	2.9	1.4	--	--	--	--	--	--	--	--
Calcareous and phosphatic rocks	11.6	5.7	--	--	5.0	3.5	12.0	6.7	28.0	17.5
Siltstone	7.9	3.9	--	--	5.0	3.5	8.5	4.8	8.6	5.4
Shale	3.7	1.8	--	--	--	--	3.5	1.9	19.4	12.1

* Phosphatic shale member not completely exposed.

or pisolite grains range in size from a fraction of a millimeter to more than 2 centimeters in diameter, although those about ½ to 1 millimeter in size are most abundant. They are generally moderately spherical, although in places, such as at Laketown Canyon, Utah, they are conspicuously flattened or irregular in shape. Individual oolite grains are generally cemented by other rock particles (as in shale and siltstone) or by phosphate (as is generally the case in phosphate rock), but in some places they are loose and uncemented. Where well cemented the phosphate rock is hard and breaks across the oolite grains. Oolites are difficult to identify where the rocks are unweathered. Thus, only 14 feet of the section measured in the 509 crosscut in the mine at Conda (pl. 5) was described as oolitic, compared to about 67 feet in the ID trench, although the thickness of phosphatic beds and the total phosphate content is about the same at the two localities.

The phosphate rock develops a characteristic white or bluish-white bloom on weathering. W. W. Rubey [25] has devised a method for estimating the grade of the rock by developing the bloom artificially. A drop of concentrated HCl is placed on the rock and allowed to dry; if a white coating forms, the rock contains appreciable amounts of phosphate and the more dense the coating the higher the phosphate content. Rubey first found that the coating developed on rocks containing more than about 25 percent B.P.L. (roughly 11.4 percent P_2O_5) but Gardner [26] later found that although the white coating forms on rocks containing more than 40 percent B.P.L. (18.3 percent P_2O_5), it may or may not form on rocks containing 4 to 40 percent B.P.L. (1.8 to 18.3 percent P_2O_5), depending partly upon their porosity and carbonate content. During the present investigation a faint coating was considered to represent a P_2O_5 content

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[25] Rubey, W. W., (Abstract of an informal communication): Washington Sci. Jour., vol. 23, p. 402, 1933.

[26] Gardner, [illegible], op. [illegible]

between 5 and 13.8 percent; a distinctly white coating to represent 13.8 to 23 percent P_2O_5; and a dense white coating to indicate more than 23 percent P_2O_5.

The fine-grained non-phosphatic, non-calcareous, and non-cherty rocks, termed siltstone or mudstone, are generally very carbonaceous, soft to medium hard, and moderately thin-bedded. However, some of them, especially the calcareous ones, are hard and thick-bedded. Most of the mineral particles are so fine-grained that they cannot be distinguished with the naked eye, but W. W. Rubey, who has studied many of the rocks microscopically, says that the grains are dominantly silt-sized and finer.

Soft, black, fissile shale is a common rock type in surface exposures, but it probably is not present in the phosphatic shale member where the rocks are totally unweathered. A good illustration of the development of fissility or very thin bedding, 27/ which defines a shale, was found at Sublette Ridge and in the Salt River Range. There the vanadiferous zone at the surface consists of soft shale or very thin-bedded siltstone, but beyond a distance of about 30 feet below the surface it is a very hard, massive siltstone containing only five to eight bedding planes in a thickness of 3.4 feet. The transition between the shale and siltstone, which is abrupt, takes place along a plane parallel to the surface. The rocks at Conda show a similar effect. In the section measured in the 509 crosscut only 11 feet were described as shale but in the ID trench over 50 feet of the section was found to be shale. Furthermore, a crosscut recently completed on the 300-foot level at Conda exposes no shale at all. In fact, all of the rocks are much harder and more massive than those on the higher levels. Most of the siltstone beds do not develop

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27/ In this report (see explanations to pls. 1-7) thick or massive bedding is defined as more than 0.2 foot thick; thin bedding as 0.05 to 0.2 foot; and fissile as less than 0.05 foot thick; so far as known to me these limiting dimensions have not been previously defined. That selected for fissile may be much higher than implied in ordinary usage of the term.

fissility on weathering. As suggested by Rubey [28] in studies of other rocks, the development of fissility is probably dependent on the presence of flat particles, oriented so that their long axes parallel bedding.

Most of the carbonate rocks are dense, thick-bedded, hard, and relatively resistant to weathering. In the Salt River Range, W. W. Rubey found, on microscopic study, that most of the carbonate rocks are dolomite. However, because they are so fine-grained that they effervesce with acid just as do limestone, they have not been differentiated in the field. Rocks described as calcareous are those that effervesce slightly or moderately on application of concentrated HCl; they thus include many rocks composed dominantly of other constituents, especially silt and clay.

Chert and cherty rocks are not abundant in the phosphatic shale, although they do form large portions of the Rex member in some places. Most of the chert and cherty beds are dense, thin-bedded, hard, and resistant to weathering.

Although moderate weathering modifies the hardness and structure of the rocks, it does not appreciably alter their color and chemical composition. They become softer, more clayey, some develop fissility, and the iron sulphide minerals are oxidized so that red, brown, yellow, and green stains are abundant. but the rocks retain their dark-brown or black color. Continued weathering, however, such as is found in the rocks beneath the Tertiary erosion surface, has pronounced effects on the appearance and composition of the rocks. The organic matter is completely oxidized and removed so that the rocks are white, light-gray, tan, or pink in color. The less soluble constituents, such as phosphate, are enriched as the more soluble ones, such as the carbonates, are removed; some of the more soluble ones, like vanadium, are carried down the dip of the beds and redeposited. Such a zone enriched in vanadium is present

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[28] Rubey, W. W., Lithologic studies of fine-grained Upper Cretaceous sediments of the Black Hills region: U. S. Geol. Survey Prof. Paper 165A, [illegible], 1930.

about 150 to 175 feet below the old erosion surface in the Paris-Bloomington area. The depth of weathering varies with the dip of the beds (greater where the beds are steeply inclined or vertical than where they are gently dipping) and with the texture of the rocks (greater in the oolitic rocks than in the siltstone or shale beds).

Topographic expression

Compared to the underlying and overlying rocks, the phosphatic shale member is extremely nonresistant to weathering. Generally its position is marked by a soil-covered valley between ledges of the more resistant Wells formation and Rex member of the Phosphoria. In the few places where it is exposed, the phosphatic shale member is readily recognized by its black or dark-brown color, but in most areas the unit must be identified by its stratigraphic position and topographic expression and by the presence of chips of dark-brown or black oolite and shale in the soil.

STRATIGRAPHY

The phosphatic shale member contains no major, well-defined units composed wholly of one rock type and continuous over the region without change in lithology, but for purposes of discussion it may be divided into a lower and upper part, each of which consists of a dominantly phosphatic and calcareous sequence overlain by less phosphatic, largely clastic or siliceous rocks. The lower part includes the vanadiferous zone and all beds below it; the upper part includes all the beds above the vanadiferous zone. The character and continuity of individual layers at 64 localities are shown by columnar sections on plate 1-7; in addition, the rocks at 13 of these localities are described in the appendix. Some of the areal differences in thickness and composition of the phosphatic shale and various portions of it are shown in figures 2-5.[29]

The correlations shown on plates 1-7 are based mainly on physical properties (thickness of beds, hardness, or resistance to weathering), composition (phosphate, carbonate, and vanadium content), and especially lithologic succession. Locally a few of the beds that are very fossiliferous (such as the "cap lime" in the Peale Mountains, the hanging-wall limestone in Sublette Ridge, and one of the phosphate beds in the upper part of the phosphatic shale in the Salt River Range) can be recognized on sight even though other beds are not exposed, but most of the beds cannot be identified or correlated from place to place unless several adjacent beds are exposed too.

Some of the correlations shown on plates 1-7 are believed to be exact, for many beds can be recognized from section to section over long distances, especially in a north-south direction and in the upper part of the phosphatic

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[29] The isopach lines on these maps are generalized to best show regional trends. They disregard local fluctuations and values which are considered not reliable. As drawn the isopachs are necessarily interpretative, but all data available have been shown to allow the reader to make other interpretations if desired.

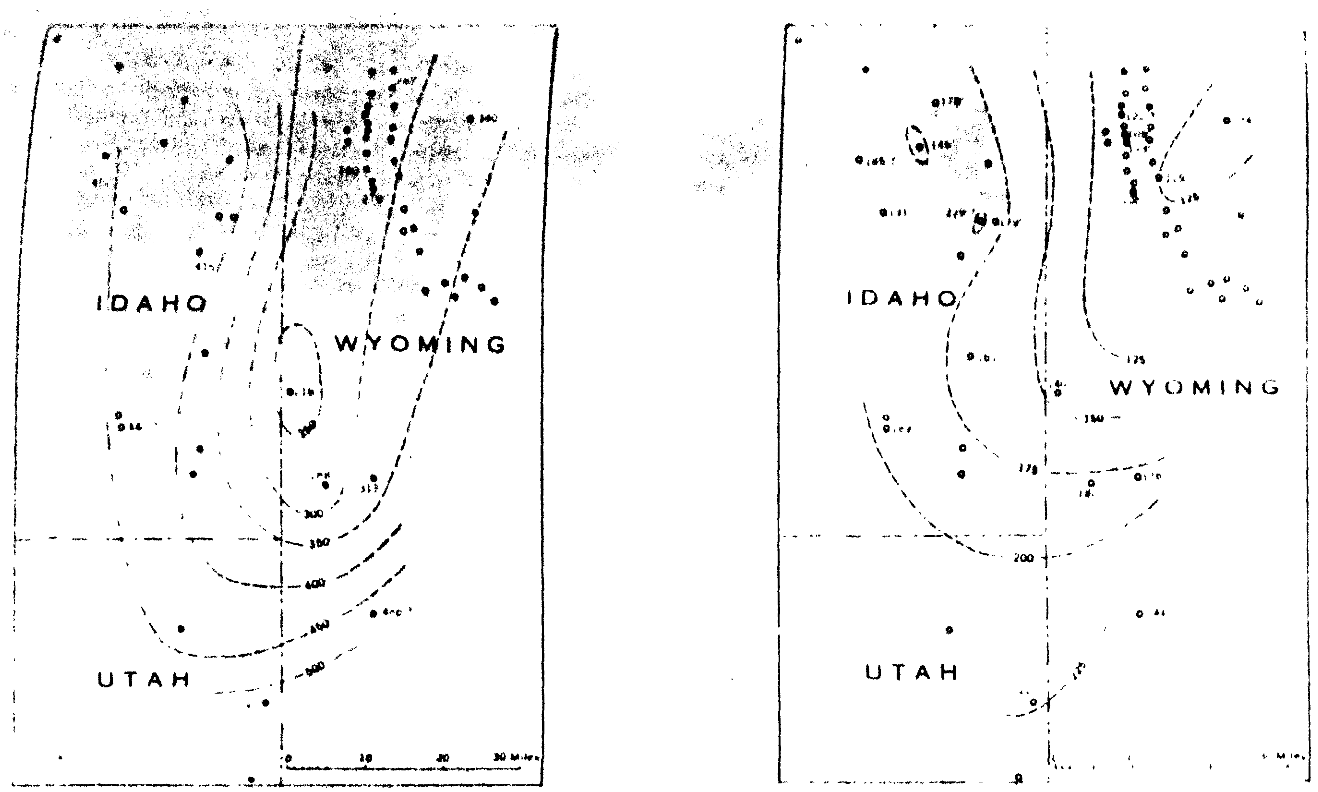
shale member. However, other correlations (shown by dashed lines) are approximate only and cannot be made more definite until more closely spaced sections are available or until detailed faunal studies are made.

Lower part of the phosphatic shale member of Phosphoria formation

The lower part, (that is, the part from the base of the member to the top of the vanadiferous zone) of the phosphatic shale member varies in thickness from a minimum of 65 feet in the Salt River Range, Wyo., to a maximum of about 165 feet in the Peale Mountains and Bear River Range in Idaho (fig. 2B). It consists of shale, siltstone, oolite, oolitic shale, oolitic siltstone, calcareous siltstone, silty limestone, and cherty limestone. The relative amounts of these rocks vary widely. In Idaho, nearly all of the rocks are phosphatic, and medium-and high-grade beds of phosphate are found throughout the section, although the thickest and best are restricted to the lowermost 50 feet of the section. Limestone and calcareous siltstone beds are subordinate, although they are conspicuous in exposures because of their hardness. In the Salt River Range cherty limestone or dolomite, siltstone, and shale predominate; phosphate in amounts greater than 10 percent is found only at three or four horizons and only one bed, about 25 feet above the base of the phosphatic shale, contains more than 25 percent P_2O_5. South of the Salt River Range, in Sublette Ridge, Tump Range, Dempsey Ridge and the Crawford Mountains, calcareous siltstone and cherty siltstone or limestone predominate and phosphatic rocks, non-calcareous siltstone and shale are subordinate.

Salt River Range

The lower part is 60 to 80 feet thick in the Salt River Range. A black shale marks the base of the phosphatic shale in some areas, but elsewhere the lowermost part of the phosphatic shale member, which consists of 25 to 35 feet of dark-gray-calcareous or dolomitic siltstone and a minor amount of cherty limestone and oolitic shale, is frequently mistaken for the Wells formation, the uppermost beds of which are also calcareous in this area.



A Phosphoria formation

B. Phosphatic shale member

Maps of western Wyoming, southeastern Idaho, and northern Utah, showing areal differences in thickness of the Phosphoria formation and the phosphatic shale member

A phosphate zone, about 3 feet thick, overlies the siltstone. Typically this unit is finely oolitic, but north of Afton, at the P and A trenches, it is non-oolitic and in parts of the Swift Creek, Dry Creek, and Labarge Creek areas it is coarsely oolitic or pisolitic and contains crystals of purple fluorite. Alternating beds of siltstone and shale overlie the phosphate. Two or three of the beds are generally phosphatic.

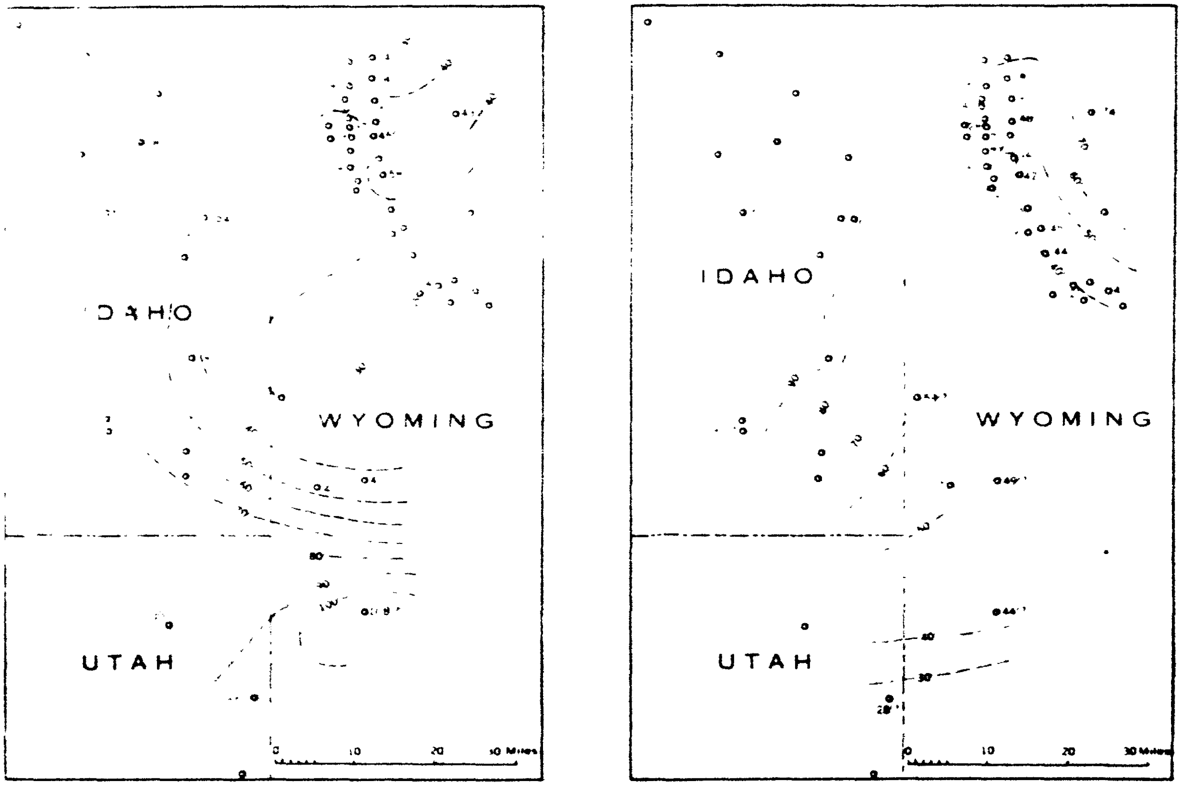
The vanadiferous zone, at the top of the lower part, is 3 to 5 feet thick; it is composed of six units which are 0.1 to 0.8 foot thick and contain 0.1 to 1.7 percent V_2O_5. These units are remarkably persistent in vanadium content in the Swift Creek, Dry Creek, and Cottonwood Creek areas, where the beds were sampled at intervals of 500 to 2,000 feet. They are differentiable in the field on the basis of physical properties but the distinctions between them are slight and were not recognized during the early work in other parts of the Salt River Range. Hence, although the vanadiferous zone as a whole has been identified at many localities over the entire Salt River Range, the individual units composing it have not.

<u>Sublette Ridge, Tump Range, Dempsey Ridge and Crawford Mountains</u>

The lower part of the phosphatic shale member is 90 to 150 feet thick in northeastern Utah and adjacent parts of Wyoming. Many of the units found in the lower part of the phosphatic shale in the Salt River Range are recognizable in the area to the south of the Salt River Range, in Sublette Ridge, Tump Range, Dempsey Ridge and the Crawford Mountains, but most of the units differ in thickness and general appearance.

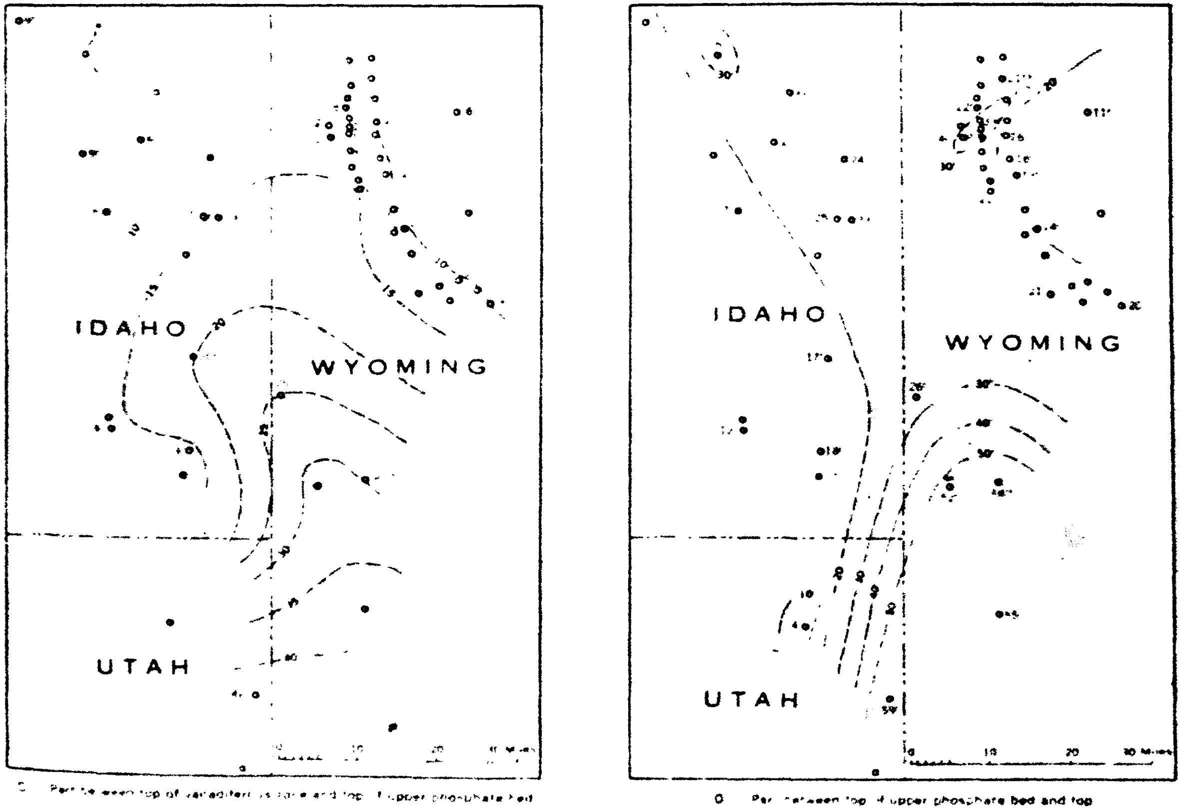
The basal calcareous siltstone of the Salt River Range has its counterpart in beds which increase in thickness southward from about 30 feet in Sublette Ridge to 85 to 100 feet in the Crawford Mountains and Dempsey Ridge (fig. 3a). Although these beds are predominantly calcareous they also contain several

FIGURE 3



A. Part equivalent to the basal siltstone and phosphate beds of the Salt River Range

B. Part between top of phosphate and top of vanadiferous zone



C. Part between top of vanadiferous zone and top of upper phosphate bed

D. Part between top of upper phosphate bed and top of phosphatic shale member

Maps of western Wyoming, southeastern Idaho and northern Utah showing areal differences in thickness of various parts of the phosphatic shale member phosphatic beds, so that the sequence does not stand apart from the beds above as it does in the Salt River Range. As in the Salt River Range the contact between the Wells formation is not easily defined in many places, for the gray calcareous siltstone beds at the base are not really typical of either the Wells or the Phosphoria.

The phosphate bed found at the top of the siltstone in the Salt River Range is also found to the south, but it is not a conspicuous unit because other phosphate beds occur above and below it. The portion above the phosphate bed ~~is~~ equivalent to that of the Salt River Range decreases in thickness southward from nearly 60 feet in Sublette Ridge to about 40 feet in the Crawford Mountains (fig. 3b). The layers of hard, massive siltstone are more calcareous and more conspicuous than in the Salt River Range.

The vanadiferous zone is lithologically almost identical with that in the Salt River Range. Seven individual beds are recognizable in the Sublette Ridge area and the amount and distribution of the vanadium is nearly the same as it is in the Salt River Range.

Southeastern Idaho

In southeastern Idaho the lower part of the phosphatic shale member of the Phosphoria is different from that in Wyoming and northern Utah. It is 125 feet to 165 feet thick (fig. 3a) and nearly all of the beds are phosphatic. The basal siltstone is not recognizable at all—in fact its correlatives can not be identified with certainty—and there are so many phosphatic beds that it is difficult to tell which are correlative with those in Wyoming. As in Wyoming, however, many of the individual beds composing the lower part of the phosphatic shale are recognizable over areas of several hundred square miles.

The boundary between the phosphatic shale and the underlying Wells formation is generally clear cut in southeastern Idaho. The top of the Wells formation is either massive, pale-yellow quartzite or white or light-gray limestone and the base of the phosphatic shale member is either dark-gray, fossiliferous limestone or phosphate rock.

The lower phosphate bed, which lies at or near the base of the phosphatic shale, is 4 to 8 feet thick and contains about 32 percent P_2O_5 over the whole of the southeastern Idaho region; it is not found at all in the Salt River Range, the Tump Range, Dempsey Ridge, or the Crawford Mountains but it may correlate with a 2-inch high-grade phosphate bed at the base of the phosphatic shale in Sublette Ridge and, interestingly enough, with a phosphate bed at the base of the section in the Wyoming Range, east of the Salt River Range. The fossiliferous "cap lime" overlying the lower phosphate bed extends over much of the Peale Mountains, although Deiss [30] recently found that it was lenticular in the Deer Creek-Wells Canyon area east of Georgetown. Other beds above the "cap lime" have a similar distribution and continuity.

The vanadiferous zone, which is present in southeastern Idaho, typifies the differences between the lower part of the phosphatic shale in southeastern Idaho and western Wyoming, for it is much thicker (8 to 12 feet) and much more phosphatic. The vanadiferous beds in the Paris-Bloomington area consist of three distinct lighologic units, each with a distinctive vanadium content: shale at the base, oolite in the middle, and siltstone at the top. Possibly the oolite and siltstone beds correspond to the beds just above those included in the vanadiferous zone in western Wyoming but because the beds in the two areas are so different in physical character there is little basis other than vanadium content on which to establish an exact correlation. Farther north in the Peale Mountains, the zone consists wholly of phosphatic shale which, except for its

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[30] Deiss, Charles, Phosphate deposits of the Deer Creek-Wells Canyon area, Caribou County, Idaho: U. S. Geological Survey, report in preparation.

higher vanadium content, much resembles adjacent beds and bears little resemblance to the vanadiferous zone in other parts of the region.

Upper part of the phosphatic shale member of the Phosphoria formation.

The upper part (that is, the part above the vanadiferous zone) of the phosphatic shale member increases in thickness southward from a minimum of about 30 feet in the Salt River Range to a maximum of about 100 feet in the Crawford Mountians. It is composed of two contrasting units, although they are not everywhere sharply defined; the lower half is dominantly phosphatic, but also contains beds of limestone and siltstone, some of which are cherty in Dempsey Ridge and the Crawford Mountains; the upper half contains a few phosphatic beds in a few areas but for the most part it consists of nonphosphatic siltstone, which, in the Salt River Range, is cherty or siliceous. Compared to the lower part, the beds of the upper part are very persistent over the region studied.

Salt River Range

In the Salt River Range, the lower, phosphatic portion of the upper part is 10 to 15 feet thick (fig. 3c). It consists of interbedded oolite, siltstone, and calcareous siltstone. Most of the oolite beds are phosphatic and although two at the top contain about 30 percent P_2O_5 they are too thin to be minable under present conditions. Most of the beds are remarkably persistent.

A black, soft, poorly consolidated oolite, 1 to 3 inches thick, overlies the vanadiferous zone throughout the Salt River Range and serves as a good marker in locating the vanadiferous zone. The two phosphate beds and the calcareous mudstone bed that separate them are also found throughout the region--in fact they, like the vanadiferous zone, extend over the entire area studied. The lower of the two phosphate beds contains abundant specimens of Orbiculoidea nearly everywhere in the Swift Creek, Dry Creek, and Cottonwood Creek areas.

The uppermost part of the phosphatic shale member of the Phosphoria is made up of hard, grey, thin-bedded, cherty or siliceous siltstone, or hard, gray, silty or cherty limestone that resembles rocks of the Rex member. Because the cherty siltstone is in places hard to distinguish from the Rex its thickness is not well known. In the Swift Creek, Dry Creek, and Cottonwood Creek areas, where the base of the Rex is marked by a conspicuous ledge of gray, hard, fossilfierous limestone, J. D. Love and L. E. Smith found the cherty siltstone to vary widely in thickness--absent altogether in places in the Swift Creek area and as much as 30 feet thick elsewhere (fig. 3d). No distinctive beds have been found in it in the Salt River Range, but a phosphatic oolite is found at the top of the division in the Wyoming Range and in parts of the Peale Mountains.

Although the cherty siltstone beds are lithologically more akin to the Rex than to the phosphatic shale in the Salt River Range, they are included in the shale member, partly because they seem correlative with soft carbonaceous siltstone in the Peale Mountains, but also because their contact with the phosphatic beds below is poorly exposed and therefore not mappable.

Sublette Ridge, Tump Range, Dempsey Ridge, and Crawford Mountains

The phosphatic portion of the upper part increases in thickness southward from a minimum of about 25 feet in Sublette Ridge to more than 40 feet in the Crawford Mountains (fig. 3c.) Most of the units are continuous with those in the Salt River Range but inasmuch as the units are all thicker and the calcareous siltstone partings are more calcareous and harder, the units are better defined and easier to identify from place to place than they are in the Salt River Range.

The oolite at the top of the vanadiferous zone in the Salt River Range is present also at Cokeville but it is absent in the other areas. However, [illegible] better one—a hard, massive, fossiliferous (*Chonetes* especially abundant) gray limestone, 1 to 3 feet thick, that is present in Sublette Ridge, Tump Range, Dempsey Ridge, and the Crawford Mountains, as well as at Cokeville, where it overlies the oolite. The upper phosphate beds and the calcareous siltstone parting are thicker than in the Salt River Range. The upper bed has been mined at Sublette Ridge, Cokeville, and in the Crawford Mountains.

The beds overlying the upper phosphate bed are generally concealed, despite the fact that they are hard and calcareous, even cherty in some places. Where they do crop out they do not form a wall or high ledge as does the cherty limestone of the overlying Rex. They increase in thickness from a minimum of about 25 feet in Sublette Ridge to about 60 feet in the Crawford Mountains (fig. 3d). A few thin phosphatic beds are present in Sublette Ridge, Cokeville, and Tump Range, but these do not continue southward. No other distinctive beds have been found, but as this part of the section has been incompletely studies, other marker beds may be found on further study.

Southeastern Idaho

The phosphatic portion of the upper part is 5 to 20 feet thick in southeastern Idaho (fig. 3c). In contrast with the lower part of the phosphatic shale, many of the beds of the upper part can be traced from western Wyoming into southeastern Idaho, although they differ somewhat in thickness and composition. However, the units are less well defined than in Wyoming because all are thinner, and the siltstone beds are softer, less calcareous, and more phosphatic than in Wyoming.

The oolite bed at the top of the vanadiferous zone extends over much of the area; the hanging-wall limestone bed can be traced into Idaho, but it is lenticular or concretionary there. The upper phosphate bed, the siltstone, and phosphate bed beneath are found in southeastern Idaho, but because the siltstone parting is thinner and more phosphatic, the individual phosphate beds are less pronounced than in Wyoming. The upper phosphate "bed" as it is mined at Conda includes not only the upper phosphate bed of the Salt River Range and Sublette Ridge but several lower beds as well and it is therefore best thought of as the upper phosphate zone.

The beds above the upper phosphate in southeastern Idaho are 12 to 35 feet thick (fig. 3d). They consist mostly of dark-brown, soft, non-calcareous, non-phosphatic siltstones which resemble the rest of the phosphatic shale member. Several thin, phosphatic zones persist over much of the Peale Mountains area, and one at the top, containing *Omphalotrochus*, is found throughout the region.

Because of their soft, carbonaceous nature the rocks of the upper part of the phosphatic shale are in most places clearly distinguishable from those of the Rex member.

AREAL VARIATIONS IN THE PHOSPHATIC SHALE MEMBER

Although many of the individual layers of the phosphatic shale member are continuous over areas of a few square miles, over larger areas discontinuities in certain layers and differences in others cause significant variations in the thickness and general composition of the phosphatic shale. Some of these areal variations in the phosphatic shale have already been mentioned but because they bear on its origin they deserve separate discussion and summary.

Unfortunately field observations on the composition of the rocks must be substituted for analytical data in comparing areal variations of most of the constituents. Comparisons made on the basis of such data are helpful in recognizing the general order of magnitude of the variations, but because of individual differences in the description of mixed rock types great confidence cannot be placed in the results, especially as to local details. 31/

Thickness

The thickness of the phosphatic shale member as a whole increases westward and southward from a minimum of about 100 feet in the Salt River Range to a maximum of about 200 feet in southeastern Idaho and 225 to 250 feet in Dempsey Ridge and the Crawford Mountains (fig. 2b). Although nearly every unit of the phosphatic shale is thinner, or at least no thicker in the Salt River Range than elsewhere in the region, a comparison of the thickness of various parts of the phosphatic member shows that the westward and southward

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31/ A study of the data leads to the feeling that the rocks of the phosphatic shale member, probably like those of other formations, vary much less than the description of them. Personal differences in description can bd minimized in future work if measurements are substituted for adjectives where possible and if various characteristics are systematically checked in describing each rock. The observations that appear most useful at this stage are those as to phosphate and vanadium content (which can be made by field tests), reaction of the rocks to concentrated HCl, abundance and size of oolites and fossils, thickness of bedding, and hardness or resistance of the rocks to weathering. Other details worthy of systematic observation in the field will doubtless be found on further work.

increase in thickness is not proportionately the same throughout the member. Thus a comparison of the thickness of the beds equivalent to the basal siltstone and phosphate and overlying phosphate bed of the Salt River Range, [32] shown in figure 3a, shows that these beds are thickest in the Crawford Mountains and Dempsey Ridge and are not greatly different in thickness in some places in southeastern Idaho than they are in the Salt River Range. The beds equivalent to those between the phosphate of the Salt River Range and the top of the vanadiferous zone in the Salt River Range, shown in figure 3b, are thickest in Idaho and actually decrease in thickness southward from Sublette Ridge. The thickness of beds between the top of the vanadiferous zone and the top of the upper phosphate bed (fig. 3c) is about the same in southeastern Idaho as in the Salt River Range, but increases regularly southward from the Salt River Range to the Crawford Mountains. This is true also of the thickness of beds above the upper phosphate bed (fig. 3d).

Composition

The major constituents of the phosphatic shale may be classed genetically as detritus, organic matter and chemical precipitates. Most of the difference in thickness in the phosphatic shale are cuased by differences in the relative amounts of these major constituents and particularly in the relative amount of the chemical precipitates.

Phosphate

The total amount of phosphate in the phosphatic shale increases westward. Enough beds have been chemically analyzed for phosphate at several localities

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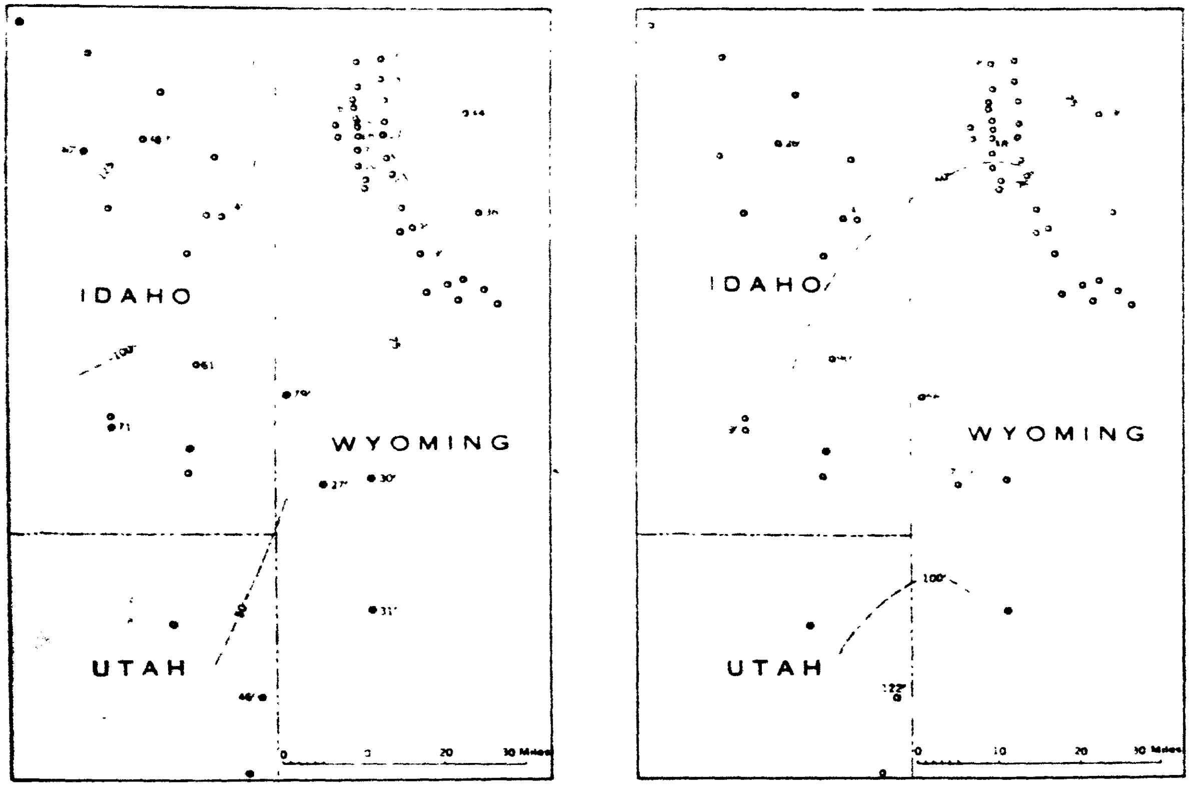
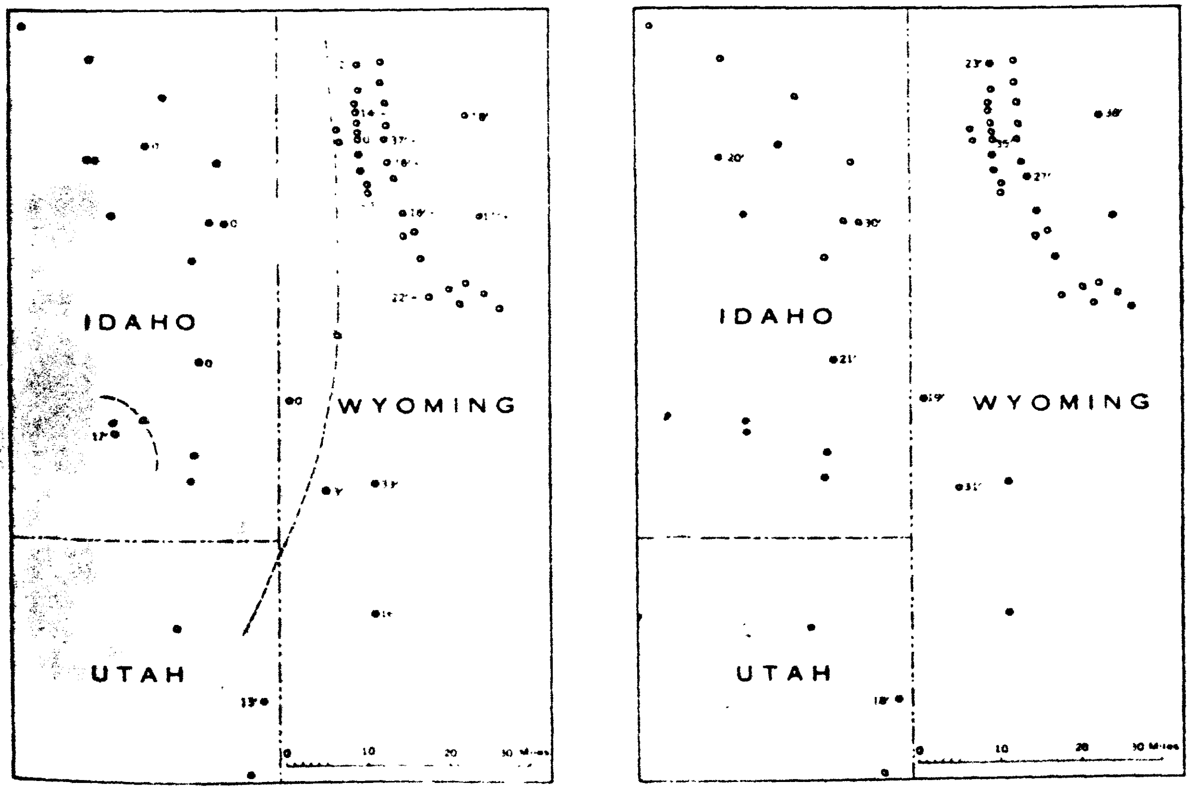
[32] Because the correlations of these beds in southeastern Idaho are uncertain the thicknesses shown in figures 3a and 3b are approximate only; they are believed to indicate general order of magnitude, however.



A. Phosphatic rocks (containing more than 5 percent P_2O_5)

B. Calcareous rocks.



C. Cherty rocks

D. Non phosphatic non calcareous, and non cherty rocks

Maps of western Wyoming, southeastern Idaho, and [illegible] showing areal differences in thickness of the principal rock types [illegible] shale member in the Salt River Range and the northern part of the Peale Mountains so that, by estimating the phosphate content of a few beds at each section, the average P_2O_5 content of part or all of the member can be estimated (table 6). These estimates show that the phosphate content in the northern part of the Peale Mountains is about double that in the Salt River Range.

The westward increase in total phosphate is brought about by an increase in the number and thickness of high-grade beds (table 6) and by a general increase in phosphate content of the other beds as well. (fig. 4a). Thus in the Salt River Range a total thickness of 5 to 13 feet contains more than 23 percent P_2O_5 compared to about 35 feet of more than 23 percent P_2O_5 in the northern part of the Peale Mountains. Similarly the thickness of beds containing more than 5 percent P_2O_5 (which has been taken as approximately the minimum amount that can be detected with the spot field test for phosphate) increases westward from about 7 to 38 feet in parts of the Salt River Range to about 140 feet at Conda (fig. 4a). 32/

The increase in phosphate content in the Peale Mountains over that found in the Salt River Range accounts for nearly half of the westward increase in thickness of the phosphatic shale member. Calculated as $10CaO.3P_2O_5.CaF_2CO_2$, which is believed to be the approximate composition of the phosphate minerals, and allowing for a difference in density of the phosphate mineral (assumed to be 2.9) from that of the other rocks (estimated at 2.4) the section at the A trench contains the equivalent of 12.2 feet of phosphate compared to 46 feet at ID. Calculated as phosphate rock, containing 35 percent P_2O_5, and making

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32/ On figure 4a the values shown at Conda, ID, A, C, D, F, I, H, and SCA are based largely on chemical analyses, supplemented by estimates, based on the description of the rock, on these samples not chemically analyzed. The figures shown at other localities represent the total thickness of rocks showing a positive reaction to the HCl spot test already described.

Table 6

Phosphate content of part or all of the phosphatic shale member of the Phosphoria formation at several localities in the Salt River Range and Peale Mountains.

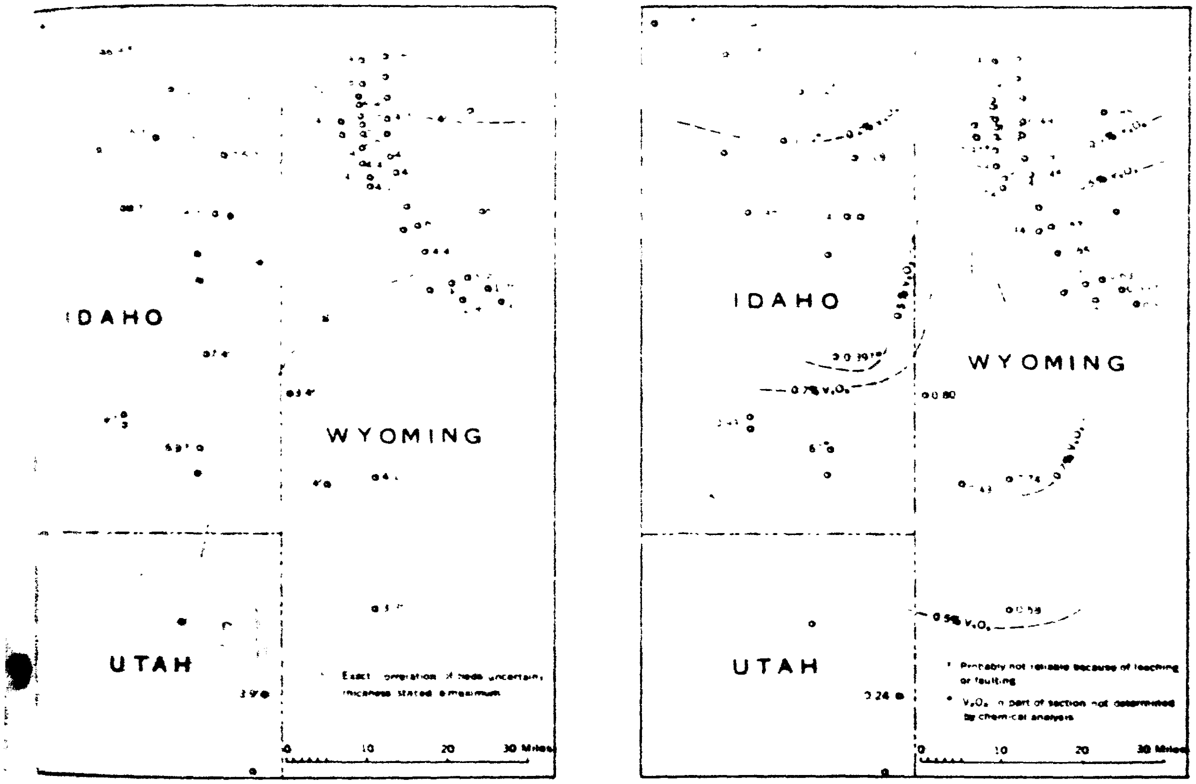
	Phosphatic shale, full thickness		Phosphatic shale, excluding beds above the upper phosphate		Total thickness of beds (feet) containing more P_2O_5 than:			
	Thickness (feet)	P_2O_5 (percent)	Thickness (feet)	P_2O_5 (percent)	5 percent	13.8 percent	23.0 percent	32.0 percent
Salt River Range								
A	99	5.6	78	6.9	37.7	9.2	7.0	—
F	95	5.6	81	6.4	26.9	13.2	5.1	3.9
I	121	6.7	99	8.0	36.2	26.1	13.3	1.1
H	94	5.3	73	6.5	17.3	12.3	8.2	4.5
C			76	8.9	36.2	18.5	13.0	—
D			84	8.0	30.9	19.7	13.4	—
Average			82	7.5				
Peale Mountains								
ID	179	11.9	158	12.8	114.0	60.1	34.4	11.9
Conda			161	12.9	140.6	42.3*	17.5*	13.8
Average			159	12.8				
Georgetown Canyon			129**	17.7	96.7	83.7	47.5	18.7

* The section in the 509 crosscut at Conda was sampled by the Anaconda Copper Mining Co. and published by G. R. Mansfield, Am. Inst. Min. Met. Eng. Tech. Pub. 1208, p.7, 1940. The section was sampled in large units so that thin, high-grade units, which are surely present, are masked by the lower-grade rocks with which they were included. The thickness of beds of more than 13.8 and 23.0 percent P_2O_5 appears to be lower, therefore, than it actually is.

** It is not known how much of the phosphatic shale member is included in this section; see Mansfield, G. R., op. cit., p. 274, 1927.

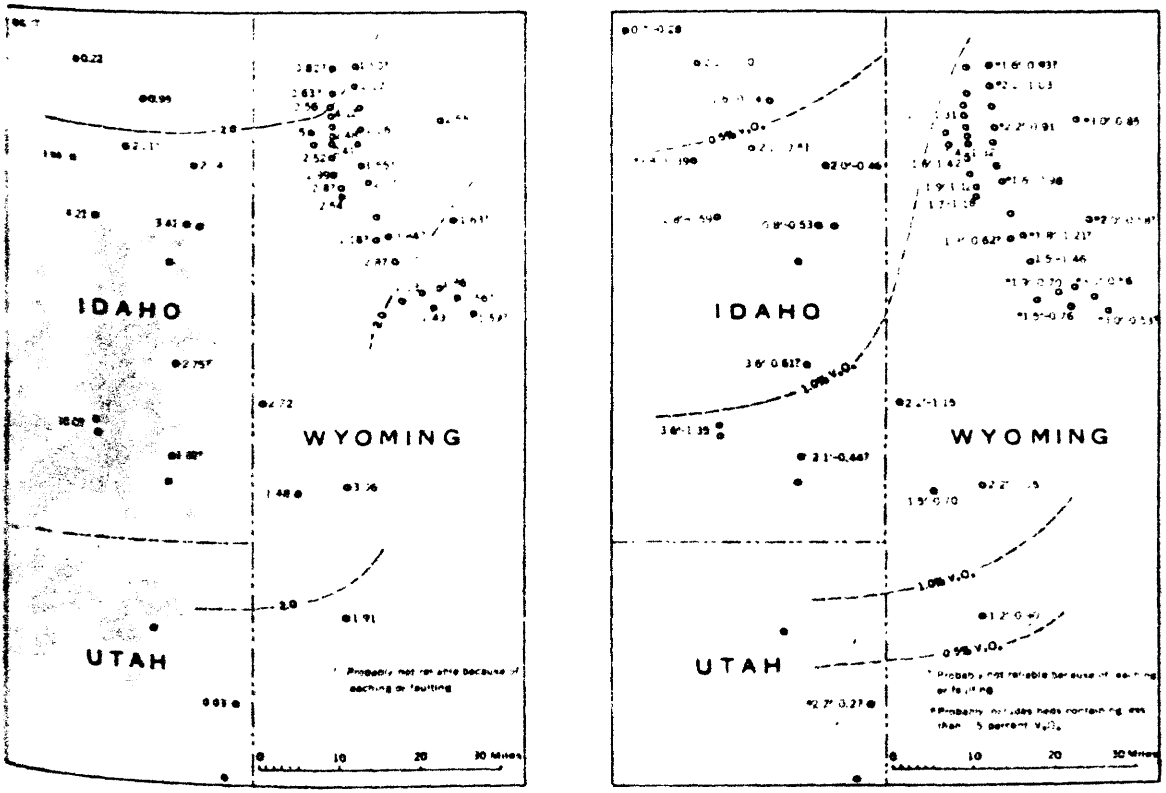
the same allowance for difference in density, the section at A contains the equivalent of 14 feet of phosphate rock compared to about 52 feet at ID. Therefore, of the difference in thickness between the two sections (about 80 feet) the phosphate alone accounts for 42 to 48 percent, depending upon which method of calculation seems most reasonable. The comparison may be strengthened by using the average of several sections, such as can be done if the beds above the upper phosphate bed are excluded. The Salt River Range sections (table 6) contain the equivalent of an average of about 13 feet of phosphate, calculated as $10CaO.3P_2O_5.CaF_2.CO_2$, or about 14 feet of 35 percent phosphate rock, compared to about 42 feet, calculated as $10CaO.3P_2O_5.CaF_2.CO_2$, or about 48 feet calculated as phosphate rock at Conda and ID. The phosphate thus accounts for 37 to 44 percent of the differences in average thickness between the two areas.

Areal variations in phosphate content similarly account for some of the areal variations in thickness of the vanadiferous zones. As shown in figure 5a the thickness of the vanadiferous zone increases westward from 3 to 5 feet in Wyoming to 6 to 12 feet in Idaho. The P_2O_5 content similarly increases from 1 to 2.5 percent in the Salt River Range to 10 to 23 percent in southeastern Idaho. At trenches H, I, M, and A in the Salt River Range the vanadiferous zone averages 3.4 feet in thickness and 1.3 percent P_2O_5. Calculated as before, but allowing for a lighter density of the vanadiferous rock (2.2) the phosphate constituent is equivalent to 0.09 to 0.1 foot. At Conda, where the vanadiferous zone is 12.1 feet thick and contains 17.7 percent P_2O_5, the phosphate is equivalent to 4.2 to 4.6 feet. Therefore, the phosphate alone accounts for 47 to 52 percent of the increase in thickness of the vanadiferous zone at Conda over that in the Salt River Range.



A. Thickness (feet)

B. Average V_2O_5 content (percent)



C. Total vanadium content (feet x percent V_2O_5)

D. Thickness and vanadium content of most vanadiferous part of vanadiferous zone, including all beds containing more than 0.5 percent V_2O_5

Maps of western Wyoming, southeastern Idaho, and northern Utah showing areal differences in thickness and vanadium content of the vanadiferous zone

Calcareous sediments

The total thickness of calcareous sediments increases southward, as shown in table 5 and figure 4b.[34] Moreover, the thickness of limestone or dolomite also increases southward: 0-5 feet in the northern part of the Salt River Range, 34 feet at Coal Canyon in Sublette Ridge, 40 feet at Cokeville, and 88 feet at Brazer Canyon. A study of plates 3 and 7 shows that the southward increase in thickness of various parts of the phosphatic shale, particularly the part above the vanadiferous zone, is caused in part by an increase in thickness of units which are dominantly carbonates and by the addition of others, such as the hanging-wall limestone, which are not present to the north. This is well shown on plate 7, where such beds as the hanging-wall limestone are seen to decrease in thickness westward, become lenticular, and finally pinch out.

The thickness of calcareous rocks found in the Ua section and in the trench at Montpelier Canyon may not be strictly comparable to that found at the other localities. The Ua section was measured at a natural exposure underneath a waterfall and the rocks there might contain secondary carbonate, or, on the other hand, the rocks might be less weathered and thus contain more of the lime originally present in the rocks than do those at other localities. Another waterfall exposure, at A (not shown in table 5 or fig. 4b but shown on pl. 1) also contains more calcareous beds (48 feet out of 98 feet exposed) than are found in adjacent areas. The rocks at Montpelier Canyon are [illegible] weathered and contain secondary

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[34] Calcareous rocks which are also cherty are not included in the values shown on figure 4b but are included with other cherty rocks shown in figure 4c.

lime (caliche) in the form of thin veinlets and coatings.

Chert

Chert and cherty beds are found only in the eastern and southern part of the region and are absent in the Peale Mountains (table 5, fig. 4c). Chert is a major rock-forming constituent of the Phosphoria formation, but it is of relatively minor importance in the phosphatic shale member. In most places it is restricted to the uppermost and lowermost parts of the phosphatic shale, but in the Paris-Bloomington area a hard, brittle, thin-bedded chert, 15 feet thick, which resembles chert of the Rex member of the Phosphoria in the same area, is found a few feet below the vanadiferous zone. A comparison of the sections in the Salt River Range shows that the thickness of cherty beds varies considerably over short distances.

Detritus and organic matter

Percentage-wise, the relative amounts of the non-phosphatic, non-calcareous and non-cherty rocks decrease westward and southward (table 5, fig. 4d). However, a comparison of the actual thickness of these sediments from place to place suggests that their thickness varies less than that of some of the other rocks and that the percentage variations result mainly from increases in other constituents, notably lime and phosphate. If the thickness of the non-calcareous, non-phosphatic, non-cherty sediments is a rough measure of the detritus and organic matter, it may be concluded that the amounts of these materials are more constant than those of the chemical precipitates.

Fluorine

The total amount of fluorine increases westward with increasing phosphate content but the fluorine-phosphate ratio seems to be higher in

Wyoming than in Idaho. Insufficient data are at hand to prove this conclusively but the evidence for it is twofold. Megascopic crystals of purple fluorite, which may be an index of a high fluorine-phosphate ratio, have been found at numerous localities in the Salt River Range, Sublette Ridge, and at Cokeville, both during the present investigation and during earlier work,[35] but none have ever been reported from the phosphatic shale in Idaho. In addition several analyses of phosphate rock show the fluorine-phosphate ratio to be higher at Cokeville (average 0.117) than at any of four Idaho localities (average 0.110 at Montpelier Canyon; 0.108 at Paris Canyon; 0.108 at Conda; and 0.108 at Georgetown).[36] These analyses are not strictly comparable because the Idaho samples are probably from the lower phosphate bed and the Cokeville samples are probably from the upper phosphate bed. However, the conclusion is further supported by 21 analyses of samples from beds of different phosphate content in the Salt River Range which show an average fluorine-phosphate ratio of 0.113, and by 57 analyses representing about 138 feet of the phosphatic shale at the ID trench in the Peale Mountains, which show an average of 0.104. Whether or not there is any relation between the lower average phosphate content in Wyoming and the excess fluorine is not known, but it is interesting to note that fluorite has also been found in the Montana phosphate rock[37] where the total P_2O_5 content of the section is also

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[35] Gale, H. S., and Richards, R. W., op. cit., Bull. 430, p. 464, 1910.

[36] Jacob, K. D., Hill, W. L., Marshall, H. L., and Reynolds, D. S., op. cit., p.36.

[37] Jacob, Hill, Marshall, and Reynolds, idem. Mansfield, G. R., op. cit., p. 366, 1940.

Vanadium

The vanadium content of the vanadiferous zone over the region as a whole ranges from less than 0.1 to more than 1.0 percent V_2O_5 (fig. 5b). Samples taken at intervals of 5 to 2,000 feet in the Paris-Bloomington, Sublette Ridge, and Swift Creek-Dry Creek-Cottonwood Creek areas show that variations of nearly this same magnitude are found locally as well as regionally (table 7). Plainly the nature of these local variations in vanadium content must be understood before the regional variations can be understood.

Local variations.—Only a small part of the variation in vanadium content can be charged to errors of analysis and sampling. Analytical errors were guarded against by making duplicate analyses, by the same method, of all samples collected during the intensive phase of the sampling program and by making repeat analyses when the results did not check within 0.05 percent V_2O_5; as a check on sampling, the Wyodak Coal and Manufacturing Co. collected 55 samples during the work at Sublette Ridge and the results showed that 30 percent of the samples contained identical amounts of vanadium; 80 percent differed by less than 0.10 percent V_2O_5; and none differed more than 0.30 percent V_2O_5.

Local differences in vanadium content are caused by weathering or deformation in some places, but variations attributable to these factors are not included in the variations described. Leaching and enrichment cause some of the differences in the vanadium content of the vanadiferous zone near the surface in the Paris-Bloomington area, where the phosphatic shale lies beneath the Tertiary erosion surface. However, such effects have not been found in the other areas and not all of the differences in vanadium content of the beds in the Paris-Bloomington area are secondary. Omission or repetition of beds through faulting causes variations in vanadium content of the zone as a whole

Table 7

Frequency distribution of vanadium content of the vanadiferous zone

	Western Wyoming, southeastern Idaho, northern Utah region		Sublette Ridge, Wyoming				Swift Creek, Dry Creek, and Cottonwood Creek areas, Wyoming			
			Trenches		Adit R7N		Trenches		Adit 8	
	Number of localities	Percent of total	Number of localities	Percent of total	Number of localities	Percent of total	Number of localities	Percent of total	Number of localities	Percent of total
0.00 - 0.10	1	2	—	—	—	—	—	—	—	—
0.11 - 0.20	4	9	—	—	—	—	—	—	—	—
0.21 - 0.30	6	13	—	—	—	—	—	—	—	—
0.31 - 0.40	3	6	—	—	—	—	3	5.2	—	—
0.41 - 0.50	8	17	1	2.6	2	3.8	3	5.2	—	—
0.51 - 0.60	4	9	5	13.1	13	24.5	14	24.1	1	4.5
0.61 - 0.70	7	15	5	13.1	22	41.5	14	24.1	5	22.8
0.71 - 0.80	6	13	9	23.7	11	20.8	14	24.1	10	45.3
0.81 - 0.90	3	6	9	23.7	1	1.9	6	10.4	3	13.7
0.91 - 1.00	1	2	8	21.0	4	7.5	0	0.0	3	13.7
1.01 - 1.10	2	4	1	2.6	—	—	0	0.0	—	—
1.11 - 1.20	1	2	—	—	—	—	1	1.7	—	—
1.21 - 1.30	0	0	—	—	—	—	—	—	—	—
1.31 - 1.40	1	2	—	—	—	—	—	—	—	—
	47	100	38	100	53	100	58	100	22	100
Average			3.4'-0.78%		3.3' - 0.69%		4.1' - 0.66%		3.0' - 0.76%	

because each of the individual beds of the vanadiferous zone is different in vanadium content. However, the effects of weathering are generally recognizable. In areas where the individual units of the vanadiferous zone can be recognized in the field omission and duplication of beds can also be detected.

Part of the variations result from differences in the relative thickness of the individual beds from one place to another. This effect may be produced by differences in the relative thickness of individual beds at the time of deposition or through later deformation, but that its contribution to the observed local differences is important was found in the Sublette Ridge area, where the vanadium content of the individual beds is much more constant than their thickness.

Except for variations due to weathering or deformation, most of the local variations are of a random nature and cannot be directly related to geological conditions. The variation in vanadium content seems to center about a mean; the smaller the area sampled, the less is the variation and the stronger the central tendency. This may be seen from a study of table 7. The variations in vanadium content over the region are nearly equally distributed from less than 0.1 to more than 1.0 percent, although about half of the samples fall within the range of 0.41 to 0.80 percent V_2O_5. In the Sublette Ridge area as a whole the range in V_2O_5 content is about 0.4 to 1.1 but about two-thirds of the samples fall within the range of 0.71 to 1.0 percent; in the Swift Creek, Dry Creek and Cottonwood Creek areas the vanadium content of the vanadiferous zone ranges from less than 0.4 to more than 1.1 percent, but more than two-thirds of the samples fall within the limits of 0.51 to 0.80 percent. Carrying the analogy to still smaller areas, in Adit R7N (580 feet in length) in Sublette Ridge the vanadium content ranges from 0.4 to 1.0, but about 69 percent of the samples range from 0.51 to 0.90 percent; and in Adit 8 ([illegible] feet long) in the Dry Creek area the vanadium content ranges from 0.5 to 1.0 percent, but 62 percent of the samples range from 0.61 to 0.90 percent V_2O_5.

The local differences in vanadium content tend to cancel each other, so that the average grade remains constant over areas of a few square miles. This is shown by table 8 which shows that the average vanadium content of the zone in component parts or blocks (defined on the basis of geological structure and geography) of the Swift Creek, Dry Creek, and Cottonwood Creek areas is not significantly different from the average of the zone over the area as a whole.

Table 8

Average vanadium content of the vanadiferous zone in component parts of the Swift Creek, Dry Creek, and Cottonwood Creek areas, Wyo.

Part	Number of samples	Length of outcrop (miles)	Average V_2O_5 content (percent)
A	10	2.0	.60
B	7	4.4	.64
C	4	1.2	.65
D	7	0.5	.70
E	6	1.2	.69
F	5	2.0	.77
G	10	2.8	.68
H	9	3.9	.65

__Significance of local variations in interpretation of regional variations.__- The wide range in vanadium content of the samples from the region as a whole and their weak central tendency reflect true areal variations in the vanadium content, but the variations in vanadium content of samples from small areas show that a minimum number of samples must be analyzed before the vanadium content may be determined in any area, regardless of its size. In the Sublette Ridge area, this minimum number of samples was found to be seven or eight, for where the average vanadium content is based on fewer samples the result differs appreciably from the average vanadium content based on all available samples.

Considered in this light, of the values for vanadium content over the region as a whole, those obtained at the Paris-Bloomington, Sublette Ridge, and Swift Creek, Dry Creek, and Cottonwood Creek areas, which are based on hundreds of samples can be accepted as representative of the vanadium content of the vanadiferous zone, but the values obtained at other localities cannot be taken as representative.38/ Some of them might prove to be close to the average for that area but most of them would deviate from that average appreciably. However, the average of several samples from an area of any particular size assumes more significance, increasingly so as the number of samples increases and as the range in vanadium content decreases. Where possible, therefore, it is better to consider the average vanadium content of groups or geographic clusters of samples rather than that of individual samples. This has been done in drawing the lines of equal thickness and vanadium content in figures 5a, b, c, and d; however, samples such as that from Brazer Canyon and the South Fork of Cottonwood Creek, which are geographically isolated, have necessarily had to be considered representative.

Regional variations.—The average grade of the vanadiferous zone, over the region as a whole, is highest in a belt that trends northeastward, and the

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38/ The values shown for Bloomington Canyon and Coal Canyon on figures 5a, b, c, and d are the averages of all samples available from those areas. The average values of all samples from the Swift Creek, Dry Creek, and Cottonwood Creek areas, which are not shown on these maps, are as follows: average thickness of zone, 4.1 feet; average V_2O_5 content, 0.71 percent; average feet x percent 2.90; average thickness of best portion of zone, 2.1 feet; average V_2O_5 content, 1.07 percent.

average grade decreases northwest and southeast of this belt (figs. 5a and b). However, the total amount of vanadium, as computed by multiplying the average V_2O_5 content by the thickness of the zone (feet-percent) is greatest in a belt that trends east and decreases northward and southward from this belt (fig. 5b). Thus the areal variations in vanadium content are both real and apparent. The actual pounds of vanadium deposited in the area encompassing Conda, Swan Lake Gulch, Caldwell Canyon, and Deer Creek in the Peale Mountains is approximately the same as, if not slightly more than, that deposited in the Swift Creek, Dry Creek, and Cottonwood Creek areas, but because the thickness of the zone is greater in the Peale Mountains than the Salt River Range (due in a large part to increased phosphate content, as already shown) the average grade is actually lower. But the total vanadium content (feet-percent) is also much greater in the Paris-Bloomington area than in either the Peale Mountains or the Salt River Range, and much less in the area encompassing the northern part of the Peale Mountains and Reservoir Mountain, the southeastern part of the Salt River Range, the Wyoming Range, and the Crawford Mountains.

Areal variations in vanadium in the vanadiferous zone are thus at least partly independent of variations in phosphate, but data are not available on the composition of the vanadiferous beds, (especially in areas where the average vanadium content is low and therefore of little direct economic importance) to provide a basis for comparing the areal variations of vanadium to that of other constituents.

In general, the vanadium content of the entire phosphatic shale member is high where the vanadium content of the vanadiferous zone is high and low where the vanadium content of the zone is also low (table 9). The occurrence of vanadium is thus analagous to that of the phosphate and carbonate, each of which are most abundant in those sections containing the thickest phosphate and the thickest carbonate beds.

Because of the relationship between the vanadium content of the vanadiferous zone and the vanadium content of the phosphatic shale as a whole, the areal variations in the vanadium content of the entire phosphatic shale member are similar to those of the vanadiferous zone (table 10)—the phosphatic shale member contains the most vanadium in a belt trending eastward through the center of the region and the vanadium content decreases to the south (data are not available to demonstrate the northward decrease in vanadium content found in the vanadiferous zone).

Table 9

Comparison of total vanadium content in the vanadiferous zone with that in the remainder of the phosphatic shale member of the Phosphoria formation 1/

Frequency class	Vanadiferous zone Feet x percent V_2O_5			Number of localities	Remainder of phosphatic shale member (including only those beds containing more than 0.1 percent V_2O_5)					
					Thickness (feet)			Feet x percent		
	Average	Maximum	Minimum		Average	Maximum	Minimum	Average	Maximum	Minimum
<1.50	1.1	1.48	0.63	6	12.3	20.3	3.6	1.9	3.03	0.46
1.51-2.50	2.2	2.48	1.91	5	12.3	18.7	1.3	2.7	4.66	0.26
2.51-3.50	2.8	3.01	2.52	6	32.7	44.1	19.4	7.2	10.1	3.26
>3.51	5.1	9.33	3.84	5	21.9	37.8	14.2	4.8	7.5	2.94

1/ Most of the beds of the phosphatic shale member, excluding the vanadiferous zone, have been tested only by the field test, which gives results consistently correct as to general order of magnitude when vanadium is present in amounts greater than about 0.1 percent V_2O_5. As there is thus no reliable method available for computing the vanadium content of the beds containing less than about 0.1 percent V_2O_5 they are not considered in this comparison. About two-thirds of the sections on which this comparison is based have been incompletely sampled, although probably most of those beds not sampled contain less than 0.1 percent V_2O_5.

Table 10

Total vanadium content of the phosphatic shale member of the Phosphoria formation at several localities in western Wyoming, southeastern Idaho and northern Utah 1/

	Feet	Feet x percent
Salt River and Wyoming Ranges, Wyoming		
South Cottonwood Creek	43.9	12.6
D	17.7	3.6
P	22.9	3.7
E	22.5	6.9
I	27.0	8.4
K	15.3	5.0
R	23.2	9.1
S	25.3	6.2
Ua	16.8	4.2
Z	25.5	7.3
AA	16.5	3.4
W	6.3	1.6
Sublette Ridge, Dempsey Ridge and Crawford Mts.		
Coal Canyon	44.8	10.7
Cokeville	18.2	3.5
KK	4.6	2.2
Brazer Canyon	10.1	2.0
Southeastern Idaho		
Conda	26.3	6.9
Caldwell Canyon	30.2	6.2
ID	41.8	11.7
Swan Lake Gulch	26.1	10.2
Montpelier Canyon	51.1	9.9
Bloomington Canyon	47.3	16.8

1/ Most of the beds of the phosphatic shale member, excluding the vanadiferous zone, have been tested only by the field test, which gives results consistently correct as to general order of magnitude when vanadium is present in amounts greater than about 0.1 percent V_2O_5. As there is thus no reliable method available for computing the vanadium content of the beds containing less than about 0.1 percent V_2O_5 they are not considered in this summation. About two-thirds of the sections listed have not been completely sampled, although probably most of those beds not sampled contain less than 0.1 percent V_2O_5.

ORIGIN

The origin of the phosphate deposits has aroused the curiosity of nearly all who have had occasion to study them. Without attempting to summarize the views of each, as has been ably done by Mansfield[39] and Pardee[40], it may be said that all now agree that the deposits are marine and that the phosphate deposits are syngenetic--that is, they were deposited on the sea bottom at the same time as the enclosing rocks. Most authors are further agreed that the Phosphoria accumulated slowly in a shallow sea of wide extent, but that poor circulation developed anaerobic conditions on the bottom at the time of deposition. Although opinion has diverged widely on the immediate source of the phosphate, its manner of precipitation, and deposition, nearly all have considered that organisms played an important part in its deposition and that the conditions which brought about its accumulation were peculiar in some way to the Phosphoria sea.

The origin of the trace elements, many of which have been recognized since 1912, has not been considered by earlier writers, except that Mansfield[41]

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[39] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 187-188, 361-367, 1927; The role of fluorine in phosphate deposition: Am. Jour. Sci., vol. 239, pp. 863-879, 1940.

[40] In Condit, D. C., Finch, E. H., and Pardee, J. T. Phosphate rock in the Three Forks-Yellowstone Park Region, Mont.: U. S. Geol. Survey Bull., 795, pp. 151-166, 172-176, 1927.

[41] Mansfield, G. R., op. cit., Prof. Paper 152, p. 212, 1927; op. cit., Am. Jour. Sci., 1940.

suggested that the chromium might have been derived from the erosion of a land area that contained basic igneous rocks or that it might have accumulated from cosmic dust; and that the fluorine might have been derived from volcanic activity in adjacent regions.

The origin of the phosphatic shale is a complex physico-chemical problem that will not be solved until the factors controlling and effecting the solution and precipitation of its various constituents are understood. The present work, which is largely a field study, contributes nothing new to the chemistry of deposition. However, a statement of the problem, by summary and discussion of the observed features of occurrence and distribution of the phosphatic shale that must be reckoned with by any comprehensive theory of origin, may contribute to an ultimate understanding of the origin.

Summary of features bearing on origin

1. The phosphatic shale is composed of a diverse assemblage of more than 30 elements, 29 of which are found in the vanadiferous zone.

2. Of these elements, lime, phosphate, silica, organic matter, magnesia, alumina, iron, and fluorine are most abundant, but others are found in amounts that are large by comparison with other sedimentary rocks. The thickness of the phosphatic shale is such that the total amounts of some of these constituents are very large. Thus in the Salt River Range the phosphatic shale contains 500 to 800 feet-percent P_2O_5 and in the Peale Mountains it contains 2,100 to 2,300 feet-percent P_2O_5. Similarly vanadium is found in amounts that range from about 5 to 25 feet-percent.

3. Minerals known to occur in the phosphatic shale are collophane, francolite, calcite, dolomite, fluorite, pyrite or marcasite, quartz, mica, [illegible] Other minerals are [illegible] to be pre[illegible] [illegible]

been identified. Vanadium is probably in the form of a hydromica or clay or possibly even in a complex organic compound; chromium and some of the other trace elements are probably in similar forms.

4. All of the mineral constituents of the phosphatic shale in southeastern Idaho, western Wyoming and northern Utah are fine-grained (silt-sized); sand, even as impurities in other rocks, is rare in the area studied, although it is found in the Phosphoria in central and southeastern Wyoming.

5. Well-rounded ~~oolites~~, ranging from a fraction of a millimeter to pellets [illegible] more than 2 centimeters in diameter, are characteristic of a large proportion of the rocks of the phosphatic shale member. Generally they are composed dominantly of phosphate, but some of them are principally carbonates or chert. Although ? most of the phosphate is in the form of ~~oolite~~ ?, some high-grade phosphate beds are not oolitic.

6. All of the common constituents are found in many rocks and their relative proportions vary over the entire possible range. However, the relative abundance of the various mixtures differs. Taken over the region as a whole, cherty oolite or phosphate is not as common as cherty siltstone, limestone or dolomite; calcareous phosphatic oolite or phosphate is less abundant than calcareous siltstone, calcareous shale, calcareous phosphatic shale or calcareous siltstone; organic matter is less abundant in the phosphate rock, chert, and limestone or dolomite than in the shale or siltstone. Judging from the distribution of vanadium, the only minor constituent which has been tested for in more than a few samples, the proportions of the minor constituents also varies from rock to rock. Many if not most of these trace elements are found to some extent in several different beds; however, vanadium is most abundant in the shale, siltstone, and phosphate rock and is least abundant in the limestone or dolomite and chert.

7. Concentrations of any one particular element are generally found at

more than one horizon in the phosphatic shale. In the case of phosphate, for example, there are two beds of sufficient width and phosphate content to be of value under present conditions, but there are many thinner beds as well. The total number of phosphate beds has never been counted because many of the beds are only a fraction of an inch thick, but at the ID section, described in great detail by Deiss,[47] a conservative estimate indicates that there are at least 100 units of oolite or phosphate rock which are separated from each other by less phosphatic or non-phosphatic material. A study of the stratigraphic sections shown on plates 1-7 shows that this is true of many of the other constituents as well.

8. The concentration of any one particular constituent in successive layers may increase or decrease either gradually or abruptly. Thus, the concentration of the vanadium in the vanadiferous zone in the Salt River Range and Sublette Ridge is greatest near the middle or upper part of the zone and decreases continuously above and below this point. On the other hand, sampling of individual layers or parts of layers shows differences between two adjacent layers of as much as 1.7 percent V_2O_5. Similarly contacts between lithologic units may be either sharp or gradational; shale grades into limestone or phosphate at some horizons but at others there is no transition between the two--and so with each of the other rock units.

9. Regional trends are found in the variations in the amounts of various constituents of the phosphatic shale. In general, the phosphate content increases westward and the lime content increases southward. Free fluorite is present in the phosphate rock in western Wyoming but has not been found in Idaho; the fluorine-phosphate ratio is apparently greater in Wyoming than in Idaho. Ch[illegible] in [illegible] in western Wyoming

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[47] Deiss, Charles, op. cit.

but are absent at most places in Idaho. The total vanadium content of the phosphatic shale member and of the vanadiferous zone decreases northward and southward.

10. The concentrations of phosphate, carbonate, and vanadium in the entire phosphate shale member are greatest at those sections which contain the thickest and highest-grade beds of phosphate, carbonate, and vanadiferous rocks.

11. Each of the rock types occurring in the phosphatic shale are at some horizon or other in contact with each of the other rock types. In other words, there is no definite succession of lithologic types. ?

12. The original area covered by phosphate deposits 1 feet or more thick has been estimated to be more than 175,000 square miles.[43] But the area containing the greatest total amount of phosphate was much less, possibly of the order of magnitude of 5,000 to 10,000 square miles.

13. The aggregate thickness of the Phosphoria formation is 100 to 500 feet over most of northern Utah, eastern Idaho, Wyoming, and west-central Montana. With local exceptions it increases generally westward, reaching a maximum thickness of about 900 feet in south-central Idaho, near Malta[44]

14. In the southeastern Idaho, northern Utah, western Wyoming region most of the variations in the thickness of the phosphatic shale member seem to be caused by variations in the thickness of the nonclastic constituents.

15. The lateral contimuity of most individual lithologic units is measured in miles and that of some units, especially near the top, is measured

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[43] Condit, D. D., Finch, E. H., and Pardee, J. T., op. cit., p. 172, 1927.

[44] Baker, A. A., and Williams, J. S., op. cit.

in scores of miles.

16. The lateral continuity of lithologic units is greater in the upper part of the phosphatic shale than in the lower.

17. Facies changes occur over shorter distances in an east-west direction than in a north-south direction.

18. The fossils of the phosphatic shale show that the length of time required for the deposition of the phosphatic shale is large, including at least parts of Leonardian and Guadalupian time.

19. Fossils are most abundant in limestone or calcareous units but are also locally abundant in the phosphate rock. They are rare in shale and shaly siltstone and in the bulk of the rocks of the phosphatic shale member. Fossils show some relation to lithology. Those in the phosphate rock are commonly fish remains and phosphatic brachiopods; depauperate faunas are also found in the phosphate rock.

20. Most of the species collected have been found in only one region, but there are a group of about 20 species, mostly brachiopods, which are widely distributed and which relate the fauna more to the Permian of Texas, Alaska, and Russia than to the Permian of the midcontinent.

21. Many local vertical discontinuities are found in the phosphatic shale. Inasmuch as some of these discontinuities are revealed by the lensing out of beds, many of them represent periods of nondeposition, although no evidence suggests periods of subaerial erosion.

Discussion

Time of deposition of phosphate and trace elements

The occurrence of vanadium and other trace elements is precisely analagous to that of the phosphate deposits, which have been recognized as syngenetic by most observers; but, lest there be some skeptics who would be inclined to attribute the trace elements found in the rocks to replacement by later percolating solutions, either hot or cold, a repetition of the evidence proving syngenetic origin seems justified:

1. Thin layers of various lithologic types and composition persist over areas of several square miles, and some layers, containing relatively uniform amounts of phosphate, vanadium, or other constituents, persist over areas of thousands of square miles.

2. Thin layers of markedly different composition, both in major and minor constituents, are interstratified.

3. Rocks which contain phosphate, vanadium, or other trace elements are as diverse in texture, permeability, porosity, and composition as those which contain none of these constituents.

4. The mineral particles are very fine-grained.

Source of sediments

Most of the elements in the phosphatic shale are believed to have been derived from the Phosphoria sea. The ultimate source of all the elements is of course igneous rocks, but this source must have been several erosion cycles removed from the immediate source of the phosphatic shale for no single igneous rock could supply such opposing groups of elements as chromium, cobalt, and nickel, which are characteristic of ultrabasic rocks; vanadium and titanium, which although found in rocks of diverse compositions, are comparatively abundant only in rocks of the gabbro family; copper, which although present in other rocks, shows a preference for the subsilicic ones; zinc, which is also found in other rocks but which is most abundant in those that are slightly more acidic; and molybdenum, tin, fluorine, and rare earths, all of which are generally most abundant in highly siliceous rocks.[45] Several other sedimentary rocks [46] (particularly carbonaceous and bituminous shales) contain a similar assemblage of elements; but to imagine another "phosphatic shale" as the source for the phosphatic shale merely transfers the problem to the older formation. Vanadium, tungsten, chromium, copper, molybdenum, and lead are found together in some vein deposits [47] (particularly

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[45] Clarke, F. W., The data of geochemistry; U. S. Geol. Survey Bull. 770, p. 40, 1924. Sandell, E. B., and Goldich, S. S., The rarer metallic constituents of some American igneous rocks: Jour. Geology vol. 51, p. 138, 1943.

[46] Only a few of the many references on this subject are given here. Carter, G. E. L., An occurrence of vanadiferous nodules in the Permian beds of South Devon: Mining Mag. vol. 22, pp. 609-613, 1931. DeGolyer, E., The occurrence of vanadium and nickel in petroleum: Econ. Geology, vol. 19, pp. 550-558, 1924. Fischer, R. P., Sedimentary deposits of copper, vanadium-uranium, and silver in southwestern United States: Econ. Geology, vol. 32, pp. 908-951. Hewett, D. F., Vanadium deposits in Peru: Am. Inst. Min. Met. Eng. Trans., vol. 40, p. 274, 1910. Jost, K., Über den Vanadiumgehalt der Sediment gesteine und sedimentaren Lagerstätten: Chemie Erde vol. 7, pp. 177-290, 1932. Lindgren, W., Mineral deposits, pp. 447-465, McGraw-Hill Book Co., New York, 1928. Schaller, W. T., The occurrence and properties of sincosite, a new vanadium mineral from Sincos, Peru: Am. Jour. Sci., vol. 8, pp. 462-460, 1924. Silbermintz, V. A., Occurrence of vanadium in fossil coals: Acad. Sci. U. R. S. S. Comp. rendu, vol. 3, pp. 117-120, 1935.

[47] Newhouse, W. H., The source of vanadium, molybdenum, tungsten, and chromium in oxidized lead deposits: Am. Mineralogist, vol. 19, pp. 209-220, 1934.

vanadinite and wulfenite ores) but deposits of this sort are characteristically small and could not have furnished the raw materials for a sedimentary deposit as large and widespread as the Phosphoria formation. Clastics derived from a terrain composed of several different rock types might of course contain many of these elements but that most of them, including those characteristic of acidic, intermediate, and basic rocks should be concentrated in amounts exceeding by several times the average found in igneous rocks seems out of the question, particularly inasmuch as the rock is not a concentrate of heavy detrital minerals. Furthermore, clastics form only a third of the phosphatic shale in southeastern Idaho. The bulk of it is composed of materials that are clearly not detrital. Admittedly the phosphate, lime, magnesia, and fluorine must have come directly or indirectly from the sea water; and because all the other elements but antimony are found in sea water today[49] it seems likely that most of the trace elements came directly from sea water.

Not only is it probable that the minor elements of the Phosphoria came from sea water, it is possible that they came from sea water similar in composition (as far as the trace elements are concerned) to that of the present

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[49] Sverdrup, H. U., Johnson, M. W., and Fleming, R. H., The oceans, pp. 220, 229. Prentice-Hall, Inc., New York, 1942. Antimony is one of the rarest elements of those found in the phosphatic shale, (Clarke, F. W., and Washington, H. S., The composition of the earth's crust: U. S. Geol. Survey, Prof. Paper 127, p. 21, 1924). Therefore it is not surprising that it has not been reported from sea water, but it is not to be denied that, like all other elements, some of the antimony eroded from the surface of the earth must reach the sea in solution and may be present there, even though in very small quantities.

day. In a study not yet published, W. W. Rubey has attempted to test the hypothesis that the phosphate in amounts found in the Phosphoria could accumulate with present sea water composition, atmospheric CO_2, oceanic salinities, temperatures, currents; slow detrital sedimentation; and approximate stability of the sea floor. Without discussing Rubey's data or conclusions some comparisons can be made that tend to support Rubey's hypothesis as applied to vanadium as well as phosphate.

The similarity in age (Permian and Mesozoic) of some notable sedimentary deposits [49] of trace elements is striking indeed. At first glance it might appear that these represent some sort of a metallogenic epoch; that, if the minor elements came directly from sea water, the sea water at least contained greater concentrations of those elements than it does today. But phosphate deposits are found on the present sea bottom and in rocks of many other ages. Moreover, vanadium, chromium and molybdenum are found in deep sea deposits of the present day [50] and recent tests [51]

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[49] Perhaps the most notable of these is the Permian Kupferschiefer of Germany but Lindgren (op. cit.) lists many other occurrences of ores of vanadium, copper, lead, silver, and zinc in Permian and Mesozoic rocks.

[50] Oana, Shinya, Chemical investigations of deposits, VIII: Vanadium, chromium, and molybdenum content of deep-sea deposits, II: Chem. Soc. Japan, J. vol. 61, no. 10, pp. 1060-1062, 1940 (in Japanese). See chem. abstracts vol. 35, p. 1277, 1941.

[51] Bogvad, Richard, and Nielsen, A. H., Dansk. geol. Foren. Medd., vol. 10, pp. 532-540, 1945, (0.2-0.4 percent V_2O_5 and small amounts of chromium in Cambrian and Ordovician shales); Johnson, A. C., and Davis, C. W., War development proves large vanadium reserves: Eng. and Min. Jour., vol. 146, no. 4, pp. 105-107, 1945, (the Bureau of Mines discovered vanadium in a thin layer of carbonaceous shale of Mississippian age in northern Utah.)

show vanadium and chromium in carbonaceous shales of other ages. The similarity in general lithology of the various deposits suggests that similarity in conditions of deposition may have been of more importance in the concentration of minor elements than an unusually high concentration of the elements in the sea water.

The tremendous volume of the various minor elements in the phosphatic shale member might also suggest that the Phosphoria sea contained unusually high concentrations of them. Others[57] have regarded the amount of minor elements in sea water of ordinary composition as inadequate to form similar deposits in other rocks and have suggested that the sea water in which such deposits were formed was enriched by solutions derived from eruptives. This conclusion is understandable when, as pointed out to me by H. E. Hawkes, it is considered that the vanadium below 1 square meter of surface of the vanadiferous zone is equivalent to all the vanadium in a column of sea water (of present-day composition) 1 meter square and 32 million meters high. However, the phosphate in the lower phosphate bed is equivalent to the phosphate contained in a column of sea water 6 million meters high and even the calcium in that same 5-foot bed would require for its deposition all the calcium in a column of sea water 3,300 meters high, which is almost certainly a greater thickness of water than was present in the Phosphoria sea. Plainly even thin layers of the most common chemical precipitates require a long time for their accumulation. Instead of comparing the volume of an element in even a thin bed with the amount present in sea water at any given instant it is therefore necessary to compare the deposit with the amount of material in the sea over the period required for its deposition.

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[57] Lindgren, op. cit., p. 465.

A comparison (based on what may be a shaky pyramid of assumptions) of the amount of phosphorous, calcium, and vanadium in the Phosphoria with the amounts of these elements that might have been in the Phosphoria sea during Permian time suggests that the disparity between the two is not great. On the basis of a comparison of the total amount of sodium in the sea and in sedimentary rocks, Goldschmidt[53] has concluded that 600 grams of igneous rocks must have been weathered for each kilogram of water in the ocean (table 11). This igneous rock must have contributed to the sea amounts of the various elements proportional to their average content in igneous rocks; the amounts not found in the sea water must have been deposited in its sediments. The vanadium, phosphorous, and calcium in the sea constitute only 0.0005, 0.02, and 1.9 percent, respectively, of the potential supply (table 11), and the amounts of most other elements (except those such as sodium, magnesium, and sulphur, which have very soluble compounds) in the sea are similarly small in comparison with the amount brought to the sea throughout geologic time. Dietz, Emery, and Shephard,[54] who have described phosphate deposits on the present sea bottom off the coast of California, have presented data on the solubility of tri-calcium phosphate in sea water which suggest that "sea water deeper than a few hundred meters is essentially saturated

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[53] Goldschmidt, V. H., The principles of distribution of chemical elements in minerals and rocks: Chem. Soc., Jour. pp. 655-673, 1937. See also Sverdrup, Johnson, and Fleming, op. cit., pp. 220-222.

[54] Dietz, R. S., Emery, K. O., and Shephard, F. P., Phosphorite deposits on the sea floor off southern California: Geol. Soc. America Bull. vol. 53, p. 836, 1942.

with tri-calcium phosphate. If the ocean is saturated, it follows that an amount equal to all the phosphate annually carried to the sea must be deposited as phosphate minerals or as organic matter." Whether the concentrations of the minor metals in the sea is similarly limited by the solubility of their compounds or by biological activity or other factors is unknown, but whatever the cause, the fact that the amounts of these elements is but a fraction of the "potential supply" suggests that the sea is in effect saturated with them. If it can be assumed that over a long period of time these elements were brought to the sea and deposited at a more or less constant rate, then the amounts brought to the sea during the Permian might have been proportional to the ratio of Permian time to all of geologic time. As may be seen from table 11 (line F) the amounts of phosphorous, calcium, and vanadium thus brought to the Permian ocean are much greater than found in the Phosphoria formation (table 11, line I). These figures are of little direct significance except that when added to the amounts of the various elements present in the ocean at the beginning of the Permian[55] they might be a measure of the total amounts of these substances that could have been deposited in all Permian rocks.

What part of the volume of these elements brought to the Permian ocean was available for deposition in the Phosphoria sea is difficult to estimate for it depends upon many factors, among which are area and volume of the Phosphoria sea, rate of inflow to it from adjacent seas, the composition of the terrain bordering the Phosphoria sea, and the volume of elements received from

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[55] The sea at the beginning of the Permian would presumably have contained some amount of these various elements. If their maximum concentration is controlled by their solubilities then the ocean at that time might well have contained as much of these elements as it does today.

Table 11

Phosphorous, calcium, and vanadium content of the sea compared to that of the Phosphoria formation 1/

	P	Ca	V
A. Mg. per kg. in sea water.	0.1	408	0.0003
B. Potential "supply" of elements (in mg. per kg. of sea water), according to Goldschmidt's conclusion that for each kg. of sea water 600 g. of primary rocks have been supplied to the sea.	470	22,000	60
C. Percentage remaining in solution: = mg. per kg. in sea water divided by potential supply x 100 = line A/line B x 100	0.2	1.9	0.0005
D. Tons (metric) in ocean today: = (mg. per kg. in sea water x kgs. of ocean water) divided by mgs. per ton = (line A x 1.42×10^{21})/(1×10^9)	1.4×10^{11}	5.8×10^{14}	4.3×10^{8}
E. Tons brought to ocean during all of geologic time: = (Potential "supply" of elements in mg. per kg. of sea water x kgs. of ocean water) divided by mgs. per ton = (line B x 1.42×10^{21})/(1×10^9)	6.7×10^{14}	3.1×10^{16}	8.5×10^{13}
F. Tons brought to ocean during Permian; assumed to be directly proportional to the ratio of Permian time (30 million years) to geologic time (2 billion years): = (3.0×10^7)/(2.0×10^9) x line E	1.0×10^{13}	4.6×10^{14}	1.3×10^{12}
G. Tons brought to Phosphoria sea if in same proportion as area of Phosphoria sea (4.5×10^5 sq. km.) is to area of the ocean (assumed to be same as area of ocean today--3.6×10^8 sq. km): = (4.5×10^5)/(3.6×10^8) x line F.	1.3×10^{10}	6.0×10^{11}	1.7×10^{9}
H. Tons brought to Phosphoria sea if in same proportion as volume of Phosphoria sea (assumed to be same as volume of Black sea - 5.0×10^{14} cu. m.) is to the rest of the ocean (assumed to be same as today--1.37×10^{18} cu. m): (5.0×10^{14})/(1.37×10^{18}) x line F	3.6×10^{9}	1.7×10^{11}	4.7×10^{8}
I. Tons in water circulating through the Phosphoria sea during Permian if its size and rate of ocean water inflow were the same as that of the Black sea (5.8×10^{18} cu. m. in 30 million years) and its composition were the same as today: = (cu. m. of water x mgs. per cu. m) divided by mgs. per ton = (5.8×10^{18} x 1.04 x 1 x 10^3 x line A)/(1×10^9)	6.0×10^{11}	2.4×10^{15}	1.8×10^{9}
J. Tons in the Phosphoria formation, assumed to have been 30 m. thick over an area of 4.5×10^{11} sq. m.; to contain 2.18% P,			

Table 11 (cont'd.)

	P	Ca	V
5.17% Ca in phosphate mineral, and 0.03% V; and to be 2.65 in density: = (area x thickness x density x percent of element in rock) divided by 100 = (4.5×10^{11} x 30 x 2.65 x percent)/(1×10^2)	7.8×10^{11}	1.9×10^{12}	1.1×10^{10}
K. Tons in the lower phosphate bed; assumed to have been 1.5 m. thick over an area of 6.5×10^9 sq. m. to contain 14.0% P and 33.1% Ca; and to have a density of 2.9: = (area x thickness x density x percent of element in rock) divided by 100 = (6.5×10^9 x 1.5 x 2.9 x percent)/(1×10^2)	3.9×10^9	9.3×10^9	-----
L. Height in meters of column of sea water of present-day composition containing amount of P and Ca equivalent to that in lower phosphate bed; assumed to be of same area.	6.0×10^6	3.3×10^3	-----
M. Tons in the vanadiferous zone; assumed to have been 1 m. thick over an area of 7.2×10^9 sq. m.; to contain 0.45% V; and to have a density of 2.2: = (area x thickness x density x percent) divided by 100 = (7.2×10^9 x 1 x 2.2 x percent)/(1×10^2)	-----	-----	7.1×10^7
N. Height in meters of column of sea water of present-day composition containing amount of V equivalent to that in the vanadiferous zone; assumed to be of same area.	-----	-----	3.2×10^7

[1] Lines A, B, and C from Sverdrup, H. U., Johnson, M. W., and Fleming, R. H., The Oceans: p. 220, New York, Prentice-Hall, Inc., 1942.

it. One approach that could be made to the problem would be to assume that the amounts of these elements delivered to the Phosphoria sea would be in the same proportion as either the area or the volume of the Phosphoria sea was to the area and volume of the whole ocean. Calculated on this basis, the Phosphoria sea would have received amounts of phosphorous, calcium, and vanadium (table 11, lines G and H) one to two orders of magnitude lower than the amounts[56] assumed to be present in the Phosphoria.

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[56] With regard to calcium, only that in the phosphate mineral has been considered.

These calculations make no allowance for the fact that some part of the volume of elements brought to the Permian ocean would have been brought and deposited in the form of detritus and would therefore never have been dissolved in sea water and available for deposition in the Phosphoria. On the other hand, the calculations make no allowance for oceanic circulation, which would much increase the volume of the various elements available for deposition in the Phosphoria sea, but they suggest that such circulation is required if the deposits of the phosphatic shale were derived directly from the Phosphoria sea.

How much inflow the Phosphoria sea received from adjacent seas is also difficult to estimate but the problem may be approached by analogy with the Black Sea, which is similar in size to the Phosphoria sea (420,000 square kilometers, average depth 1,200 meters) and has been compared[57] to the

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[57] Blackwelder, E., The geologic role of phosphorous: Am. Jour. Sci. vol. 42, p. 293, 1916.

Phosphoria sea because of the similarity of its black muds to those that must have existed on the bottom of the Phosphoria sea. The Black Sea is noted for its poor oceanic circulation--ocean water enters only through the narrow Bosphorous[59]--but even so, at the present rate of inflow (6,100 cubic meters per second) over a period of 30 million years 5.8×10^{18} cubic meters of sea water (more than 4 times the volume of the present ocean) would enter the Black Sea from the Mediterranean. If all of this water contained amounts of phosphorous, calcium, and vanadium similar to those in present-day sea water, then the total amount of calcium available for deposition during that period would have been much greater than is assumed to be present in the phosphate in the phosphatic shale; the phosphate would have been about the same, and the vanadium would have been slightly less than one order of magnitude lower.

The similarities of the Phosphoria fauna to that of other Permian rocks in Russia, Alaska, California and Texas show that the Phosphoria sea had more and doubtless larger connections with the ocean than does the Black Sea. Therefore, circulation of ocean water through it must have been proportionately greater, as were the amounts of the various elements available for deposition in the Phosphoria sea. Admitting the frailties of the arguments presented they nevertheless appear to justify the conclusion that the Phosphoria sea, given a sufficient period of time, normal contributions from chemical denudation, and normal oceanic circulation, was an adequate source of the phosphate and minor elements found in the Phosphoria formation and probably in many other formations as well.

Factors causing concentration of elements

Rate of deposition.--The abnormally slow deposition of other sediments

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[59] Sverdrup, H. U., Johnson, M. W., and Fleming, R. H., op. cit., p. 649.

is probably the most important single factor leading to the concentration of the phosphate and minor elements in the Phosphoria formation. The notion that at least the phosphate was concentrated through slow deposition of other constituents receives some support from occurrences in other rocks, where it is associated with unconformities and periods of nondeposition.[59] The comparisons made between the amount of vanadium, phosphorous, and calcium in the sea with the vanadium in the vanadiferous zone and the phosphorous and calcium in the lower phosphate bed illustrate how slow must have been the deposition of these materials.

However slow the deposition of phosphate and carbonates may have been, the deposition of clastics and organic matter was even slower. This is shown by the fact that the principal changes in thickness of the phosphatic shale are caused by variations in the thickness of phosphate and carbonate beds and that the thickness of the non-phosphatic and non-carbonate rocks remains relatively constant over the region; and also by the fact that the principal areal differences in thickness of the vanadiferous zone (which is composed largely of clastics and organic matter) are caused by variations in the amount of phosphate.

WHAT ABOUT WEATHERING (LEACHING) OF
CARBONATE FRACTION

Clearly no concentrations of phosphate or trace elements would exist in the Phosphoria formation if it were diluted with a volume of other sediments comparable to the 3,000 to 5,000 feet deposited in the Leonard and Word formations of Texas, which are believed to be equivalent in age to the Phosphoria. Of interest is the fact that if these formations contain 0.15 percent P_2O_5 and 0.01 percent V_2O_5, which are the average amounts found in sedimentary

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[59] Goldman, M. I., Basal glauconite and phosphate beds: Science, new ser., vol. 56, pp. 171-173, 1922. Pettijohn, F. J., Intraformational phosphate pebbles of the Twin City Ordovician: Jour. Geology vol. 24, p. 373, 1926.

rocks[60] then they contain 450 to 750 feet-percent P_2O_5 and 30 to 50 feet-percent V_2O_5. These amounts compare favorably with those contained in the Phosphoria. The phosphate content of the Word and Leonard formations would be about the same as that of the Phosphoria over most of its outcrop, but it would be only a fifth or a third of that found in southeastern Idaho, where it is most phosphatic. Their vanadium content would be about the same as that in the Phosphoria in small areas where it is richest in vanadium, but it would be much higher than that found in the region as a whole.

Physical, chemical, and biological factors.--Slow deposition is by no means the only factor effecting concentration of the phosphate and trace elements in the phosphatic shale, for the total amounts of these various elements vary laterally in individual layers and in the phosphatic shale as a whole. Moreover, as shown in preceding paragraphs, the Phosphoria sea must have drawn on the resources of the rest of the ocean to form its deposits and therefore conditions for deposition of these elements must have been more favorable in the Phosphoria sea than in many other places.

It is evident, therefore, that although the sea may have been essentially saturated with phosphate, vanadium, and other elements, their actual precipitation was subject to the control of factors which varied from place to place and from time to time. Whatever these controlling factors were, they must have been such that the process of precipitation of the various elements could be repeated many times to bring about the concentrations of the various elements at several, even many, horizons. Fur[illegible], they must have been such that

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[60] Clarke and Washington, op. cit. The value for the average V_2O_5 content of the earth's crust is selected more or less arbitrarily. According to Clarke and Washington the earth's crust contains about 0.03 percent; the content of sediments is somewhat lower.

the process of precipitation could operate with varying efficiency, for the amounts of each of the various elements increases or decreases gradually or abruptly in successive layers. These characteristics do not fit those of a catastrophic event, such as the mass killing of fish or other organisms, but they do fit processes whose operations depend upon slight fluctuations in salinity, pH, carbon dioxide content, temperature, pressure and other physical, chemical, and biological variables of the sea. A discussion of the relation of these factors to the precipitation of the various elements is beyond the scope of this paper.[61]

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[61] A thorough discussion of the relation of these factors to the precipitation of phosphate will be presented by W. W. Rubey as a part of the study to which reference has already been made.

Environment of deposition

The environment of deposition must have influenced the operation of the processes of precipitation directly or indirectly, and at least some of its characteristics can be stated. The Phosphoria sea must have been of wide extent, for phosphate deposits 1 foot or more thick are scattered over an area of about 175,000 square miles. It must have had connections to waters in central and eastern Nevada, southern California, Texas, Alaska and Russia, for the Phosphoria fauna is related to Permian faunas of those regions. The sea floor must have been flat over larger areas in southeastern Idaho, western Wyoming, and northern Utah, but there may have been a low submarine ridge or other topographic feature in the vicinity of the Salt River Range during the deposition of the lower part of the phosphatic shale, for the rocks of the lower part in the Salt River Range are thinner, more calcareous, and cherty than those to the east (in the vicinity of South Cottonwood Creek) and west (in the Peale Mountains) which are similar and are most phosphatic. The sea floor must have been below wave base because ripple marks, cross laminations, and other wave marks are lacking in the sediments of the phosphatic shale.[62] This is also suggested by the presence of large amounts of organic matter which could hardly have been preserved under oxidizing conditions in any shallow sea of wide extent.

The Phosphoria sea has been generally thought to be shallow, but if "shallow" means less than a few hundred feet the evidence for this supposition is not clear. Oolites sometimes form under conditions permitting rotation of the nucleus so that uniform accretion of mineral matter takes place on all sides. If the oolites of the phosphatic shale formed in this manner, their presence indicates that the bottom was shallow enough to be affected by currents or wave motion of some kind, but inasmuch as oolites are known to form under conditions not requiring rotation of the nucleus,[63] and as phosphatic oolites are found on the present sea bottom to depths of 6,400 feet,[64] their presence does not necessarily mean that the sea floor was shallow enough to be affected by CURRENTS OR WAVES.

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[62] Wave marks would not be expected in the fine-grained shales and siltstones, even if these sediments were above wave base at the time of their deposition, but such marks might have formed in the coarse oolites had they been above wave base when deposited.

[63] Bradley, W. H., Algal reefs and oolites of the Green River formation: U. S. Geol. Survey Prof. Paper 1540, pp. 222-223, 1928.

Davidson, S. C., and McKinstry, H. E., "Cave Pearls," oolites and isolated inclusions in veins: Econ. Geology vol. 26, pp. 289-294, 1931.

[64] Dietz, R. S., Emery, K. O., and Sheppard, F. P., op. cit.

The configuration of the sea bottom or shoreline very likely was such that conditions of equal depth, distance from shore, and other physical conditions of the sea were similar in a north-south direction in the southeastern Idaho, western Wyoming, northern Utah region, for lithologic units are more continuous and facies changes less abrupt in a north-south direction than in an east-west direction.

CONCLUSION

The phosphate deposits and other trace elements very likely were derived directly from the Phosphoria sea by inorganic or organic precipitation or a combination of both. Physical, chemical, or biological factors, largely unknown, controlled their precipitation and deposition. Their concentration was made possible, in part, by the nondeposition of other materials.

The occurrence and apparent origin of minor elements in the phosphatic shale has an important bearing on future prospecting for minor metals. Additional sampling of beds of the Phosphoria formation may disclose:

1. Areas to the east or northeast in which the beds of the vanadiferous zone are thinner but higher grade.
2. Areas to the west in which the beds of the vanadiferous zone are thicker and more phosphatic but where the average vanadium content of the beds will be lower.
3. Areas beneath Tertiary sediments, such as near Dingle or Laketown, in which the vanadiferous zone may be secondarily enriched as it is in the Paris-Bloomington area.
4. Other beds which contain significant amounts of other minor metals besides vanadium. Nickel, molybdenum, and zinc especially deserve further prospecting, for they have been found in amounts which approach commercial value (assuming of course that they can be extracted from the rock economically) but others also may be found in significant amounts.

Sea water has long been recognized as a tremendous potential source of minor metals, but if Goldschmidt's inferences concerning the proportion of the minor metals that have come to the sea but have passed through it into sediments are correct, then sedimentary rocks like the Phosphoria contain a far greater potential supply of these metals than does the sea. Conditions which led to the concentration of some of these metals in the Phosphoria formation were unusual, but it seems probable that they were duplicated, in part at least, during the deposition of other formations. Some of the other metalliferous sedimentary formations already referred to are probably examples of such deposits and others may be found on further prospecting.

A better understanding of the chemistry of deposition of the Phosphoria and similar deposits will come eventually and will be of considerable value in prospecting for new deposits of minor metals. In the meantime, the search for minor metals in other formations might be guided by present knowledge of their occurrence in the Phosphoria, which suggests that concentrations of minor metals (as primary deposits of wide extent) will most likely be found in fine-grained, carbonaceous, largely non-calcareous, marine rocks which have accumulated slowly. In prospecting for them it will not suffice to test a few specimens from a formation or to test samples representing large thicknesses of the rocks, for one or several of the metals may be concentrated in beds only a few inches or, at most, a few feet thick. And, with the philosophy of looking for bears where bears are known to be, deposits known to contain one metal should be tested for possible presence of others.

APPENDIX

Measured sections

The foregoing description of the phosphatic shale in western Wyoming, southeastern Idaho, and northern Utah is based on about 200 measured sections, 60-odd of which are shown in some detail on plates 1-7. The volume of these data precludes their inclusion here, but several sections, spaced over the region, that may be taken as representative are given in the following pages.

Unless otherwise stated the V_2O_5 and P_2O_5 determinations were made by the Geological Survey. The V_2O_5 values followed by "c" were determined by chemical analysis; those followed by "s" were determined spectrographically; the others were determined by field test, which sometimes detects vanadium in amounts as low as 0.05 percent V_2O_5 but generally not in amounts below about 0.01 percent V_2O_5. Samples showing no vanadium by field test are indicated by "0.0." The P_2O_5 values determined by chemical analyses are stated as percent but those determined by field test are stated as "very low," "low," "medium," or "high." Rocks termed "very low" are those that show no phosphate by field test, which is taken, somewhat arbitrarily, to mean that phosphate is not present in amounts greater than 5 percent P_2O_5; those termed "low" are taken to indicate a P_2O_5 content of 5 to 13.8 percent; those termed "medium," 13.8 to 23.0 percent; and those termed "high," more than 23 percent P_2O_5. Samples not analyzed by any method are shown by "n.d."

At Conda, Coal Canyon, Cokeville, and Montpelier Canyon some of the determinations were made on samples representing two or more of the lithologic units described separately. The limits of these samples are shown by brackets.

South Cottonwood Creek, Wyoming

Complete section of the phosphatic shale member of Phosphoria formation in trench on South Cottonwood Creek-Sheep Creek divide, SW¼, SE¼, sec. 29, T. 33 N., R. 115 W., Lincoln County, Wyoming (pl. 5): measured by John Rodgers.

	Thickness (feet)	V_2O_5 (percent)	P_2O_5 (percent)
Rex member			
Dolomite: light, well-laminated, with numerous thin tabular masses of chert and drusy quartz, the druses filled with calcite.	40	n.d.	n.d.
Phosphatic shale member			
Phosphate rock: slightly calcareous, cherty, fine white marks.	1.5	0.01	32.20
Chert: massive, black.	3.0	n.d.	n.d.
Dolomite: cherty, massive, light blue to medium gray: middle third almost completely replaced by massive black chert. Contains large masses of white calcite.	5.2	n.d.	n.d.
Chert: massive, black.	1.0	n.d.	n.d.
Limestone: fine-grained, hard, light gray.	0.5	n.d.	n.d.
UPPER PHOSPHATE BED			
Oolite: hard.	0.5	n.d.	n.d.
Oolite: hard, calcareous.	0.5	n.d.	n.d.
Oolite: hard.	1.3	0.02	32.55
Siltstone: soft, calcareous, tan.	1.0	n.d.	n.d.
Oolite and clay-shale: soft, jet black.	1.0	0.17	19.27
Siltstone: soft, flaky, non-calcareous, dark brownish gray to black.	1.1	n.d.	n.d.
Siltstone: calcareous, medium hard, massive, blocky, light gray, weathers buff tan. Cherty calcite, ½ inch thick, at base.	0.9	n.d.	n.d.
VANADIFEROUS ZONE			
Shale: fissile, soft, brownish-black, weathers medium bluish gray.	3.0	0.85	3.22
Similar to shale above.	0.5	0.02	35.79
Similar to shale above.	3.3	0.37	1.93

	Thickness (feet)	V_2O_5 (percent)	P_2O_5 (percent)
Siltstone: calcareous, medium hard, massive, blocky; light gray, weathers buff tan.	1.5	n.d.	n.d.
Siltstone: medium hard, blocky, non-calcareous, brownish black.	1.2	0.04	3.62
Siltstone: blocky, non-calcareous, light gray, weathers buff to tan.	1.6	n.d.	n.d.
Siltstone: medium hard, blocky, non-calcareous, brownish black.	1.0	n.d.	n.d.
Chert: very calcareous, hard, much jointed, dark gray.	10.0	n.d.	n.d.
Chert: slightly calcareous, much jointed, medium to light gray.	3.7	n.d.	n.d.
Limestone: cherty, hard, medium to dark gray, weathers light buff gray.	1.5	n.d.	n.d.
Covered.	0.7		
Siltstone: slightly calcareous, soft, tan.	3.7	0.02s	0.69
Siltstone: similar to siltstone below but darker and more fissile; upper half softer and sub-oolitic.	5.0	0.30s	7.31
Siltstone: medium soft, blocky, non-calcareous, brownish black.	6.7	n.d.	n.d.
Siltstone: medium hard, blocky, non-calcareous, brownish to greenish, weathers pale buffy gray.	4.0	0.02s	0.99
Like siltstone above.	4.2	n.d.	n.d.
Covered	2.6		
Oolite and shale: fissile, soft, non-plastic, non-calcareous, black; shale is sub-oolitic.	3.2	n.d.	n.d.
Like oolite and shale above.	3.0	0.12s	6.59
Siltstone: hard, calcareous, blocky, medium buffy gray: contains several thin (2- to 3-inch) layers of soft, slightly calcareous, fissile, brownish gray shale.	3.1	n.d.	n.d.
Like siltstone above.	3.0	0.12s	2.43
Shale and siltstone: calcareous, fissile to chippy, black.	3.5	0.12s	6.17

	Thick-ness (feet)	V_2O_5 (per cent)	P_2O_5 (per-cent)
Like shale and siltstone above.	3.6	n.d.	n.d.
Oolite: soft, earthy, jet black.	3.3	0.30s	8.58
Shale: fissile, soft, sub-oolitic, jet black.	4.5	0.36	13.43
Siltstone: sandy, somewhat cherty, hard, calcareous, medium gray, weathers light brownish gray. Alternates with black, calcareous, softer silstone in beds 6-12 inches thick.	3.5	0.05s	1.32
Like siltstone above.	3.5	n.d.	n.d.
Shale: fissile, soft, non-calcareous, jet black; two 1-inch soft oolite beds in lower part~~s~~.	3.0	0.24s	3.84
Siltstone: hard, massive, jointed, calcareous, brownish black.	1.0	n.d.	n.d.
Shale: soft, fissile, jet black, non-calcareous; not very plastic; lustrous bedding surfaces.	2.0	n.d.	n.d.
Siltstone: medium hard, slightly calcareous, brownish black.	2.2	n.d.	n.d.
Siltstone: non-calcareous, sub-oolitic, soft, plastic, black.	3.6	0.18s	7.96
Oolite: soft, non-calcareous, jet black; becomes increasingly clayey upward.	2.5	n.d.	n.d.
Like unit above.	2.5	0.19	25.92
Siltstone: soft, somewhat fissile, sub-oolitic, slightly calcareous, jet black; contains thin, harder, more massive beds.	2.4	0.08	25.84
Siltstone: hard, chippy, massive, jointed, non-calcareous, brownish black.	2.8	n.d.	n.d.
Like unit above.	3.0	0.02s	2.01
Oolite: soft, non-calcareous, black.	1.8	0.05	28.99
LOWER PHOSPHATE BED ?			
Phosphate rock; hard, black, cherty, calcareous, with pisolites, pale tan to gray, 1/8-¼ inch in diameter.	1.3	0.02	32.46
Wells formation			
Limestone: hard, medium- to fine-grained, medium gray, weathers light gray; hackly surface caused by fracturing and recementation. Makes top of Wells cliff.	10	n.d.	n.d.

Swift Creek, Wyoming.

Complete section of the phosphatic shale member of Phosphoria formation and part of underlying Wells formation in Trench K near the Geyser on West Swift Creek in T. 32 N., R. 118 W., Lincoln County, Wyoming (pls. 2, 5): measured by W. W. Rubey:

	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Rex member			
Limestone: hard, dense, massive, dark gray: makes vertical wall. Dips 90° N 85° E.	25+	0.0	very low
Limestone: fine-grained to dense, massive but fractured, dark gray to black fresh, light buff-gray weathered.	1.8	0.0	very low
Siltstone: clayey (?), soft, fine-grained to dense, platy to blocky, dark brownish gray to black fresh.	1.4	0.0	very low
Siltstone: calcareous, hard, dark brownish gray fresh, pale buffy gray weathered.	0.2	0.0	very low
Siltstone: slightly calcareous; hard, massive, dark gray; grades into siltstone bed above.	1.2	0.0	very low
Shale: relatively soft, fissile, black; grades into siltstone bed above.	1.0	0.0	very low
Siltstone: medium hard, dense, dark gray; abundant veinlets of calcite.	0.2	0.0	very low
Siltstone: calcareous, medium hard, massive, fossiliferous, black.	2.0	0.0	very low
Siltstone: soft, chippy, black.	1.3	0.0	medium?
Siltstone: calcareous, hard, much jointed (water-seep): hardest 1 to 2 feet above base.	4.0	0.0	very low
Siltstone: calcareous, medium hard, much jointed, black, weathers pale buffy gray; grades into bed above.	1.8	0.0	very low
Siltstone: calcareous, relatively soft, massive but much jointed (water-seep in lower 2 feet), black.	4.8	0.0	very low
Siltstone: hard, chippy, black; grades into siltstone above.	1.0	0.0	very low
Dolomite: hard, light gray; dips 70° N 85° E.	0.7	0.0	medium?

	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Siltstone: soft, black.	0.8	0.0	low
Siltstone: calcareous, hard, fossiliferous, black fresh, light gray weathered.	1.0	0.0	medium?
Siltstone: soft, black.	0.2	0.0	low
Siltstone: calcareous, hard, very fossiliferous (<u>Orbiculoidea</u>?), black fresh, light gray weathered.	0.5	0.0	medium?
Siltstone: calcareous, soft, blocky, black.	1.1	0.0	very low
Phosphate rock: hard, massive, fossiliferous, non-calcareous, black fresh, light gray weathered.	0.6	0.0	high
Siltstone: medium hard, black; white calcite veins.	0.8	0.0	very low
Siltstone: calcareous, hard, fine grained to dense, dark gray fresh, very light gray weathered.	1.0	0.0	very low
Siltstone: slightly calcareous, relatively hard, dense, blocky, black.	3.2	0.0	very low
Siltstone: slightly calcareous, hard, granular texture, concretionary?, massive, black.	0.3	0.0	very low
Siltstone: relatively hard, dense, blocky, black.	1.5	0.0	very low
Siltstone: calcareous, cherty, very hard, dense, black; contains a few 1/8-inch to ¼-inch softer, non-calcareous partings. Pale bluish film on hardest joint faces--may be both chert and calcite.	5.6	0.0	very low
Siltstone: slightly calcareous, relatively hard, dense, chippy, black.	6.0	0.0	very low
Siltstone: slightly calcareous, dense, blocky, black; contains a few ¼-inch calcite veinlets parallel to bedding.	3.6	0.0	very low
Siltstone: hard, dense, medium bedded to massive, black.	1.9	0.0	very low
Siltstone: slightly calcareous, relatively hard, dense, thin bedded to chippy, black.	1.6	0.0	very low
Oolite: calcareous, relatively soft, fine grained.	1.0	0.0	very low

	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Siltstone: calcareous, medium hard, fine-grained, blocky, medium brown.	1.1	0.0	low?
Oolite: calcareous, relatively soft, massive, black.	1.4	0.0	high
Oolite: relatively soft, massive.	1.8	0.0	high
Siltstone: calcareous, relatively soft, fine-grained, massive, tan.	1.5	0.0	low?
Oolite: soft, black; brown stains on surface.	0.2	0.0	medium
Siltstone: calcareous, relatively soft, fine-grained, massive, black fresh, medium brown weathered; micaceous in lower part.	1.5	0.0	low?
Siltstone: soft, clayey, conspicuously micaceous, brown; ½ inch black, oolitic 2 inches below top.	0.7	0.0	low?
Oolite: slightly calcareous, soft, coarse, black.	0.4	0.0	very low
Siltstone: hard, dense, black, concretionary?, non-calcareous.	0.2	0.0	very low
Oolite: soft, coarse, black.	0.2	0.0	medium
Siltstone: calcareous, soft, massive, micaceous, dark brown.	0.6	0.05	very low
Oolite: soft, clayey, non-calcareous, black; a few ¼-inch to ½-inch hard, non-calcareous, ferruginous beds.	0.8	0.06c	very low
VANADIFEROUS ZONE			
Clay: soft, non-calcareous, black.	1.0	0.32c	very low
Siltstone: hard, non-calcareous, concretionary; reddish-brown stain on weathered surfaces; many minute crystal faces visible.	0.6	0.97c	very low
Shale: soft, fissile, black; contains 1-inch hard layer 0.3-0.4 foot above base.	0.8	1.58c	very low
Siltstone: hard, massive, dense to fine-grained, non-calcareous.	0.6	0.24c	very low
Oolitic shale: soft, fissile, black.	0.6	0.23c	low?

	Thick-ness (feet)	V_2O_5 (per-cent)	P_2O_5
Siltstone: hard, black, non-calcareous.	1.1	0.0	very low
Siltstone: blocky, medium to dark brown, non-calcareous.	1.4	0.2	very low
Oolite: soft, very thin bedded, black.	0.2	0.0	very low
Shale: soft, fissile, brown.	0.2	0.0	very low
Siltstone: blocky, medium tan, non-calcareous.	3.0	0.0	very low
Shale: soft, brown, ferruginous.	0.8	0.0	very low
Shale: soft, brown, ferruginous.	2.3	0.0	very low
Shale: soft, fissile, shiny, micaceous, black.	2.2	0.0	very low
Siltstone: calcareous, siliceous, very hard, slabby, gray to black.	1.7	0.0	very low
Mudstone: earthy, thin bedded (2-inch beds), brown.	1.3	0.0	very low
Mudstone: soft, slightly micaceous, fine-grained.	1.2	0.0	very low
Mudstone: moderately soft, slightly micaceous.	1.7	0.0	very low
Mudstone: calcareous, relatively hard, massive, dark brown to black.	0.9	0.0	very low
Shale: soft, slightly calcareous, black.	0.5	0.0	very low
Mudstone: calcareous, relatively soft, massive, dark brown.	1.0	0.0	very low
Mudstone: soft, massive?, dark brown (partially obscured by spring).	1.5	0.1	very low
Siltstone: relatively soft, medium brown.	0.7	0.2	very low

	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Oolite: clayey, very soft, massive, black.	1.7	0.2	very low
Siltstone: soft, massive, tan.	2.2	0.05	very low
Shale: soft, fissile, slickensided, black.	1.0	0.13c	very low
Shale and siltstone: beds of black, fissile shale, slickensided, alternating with beds of hard, blocky siltstone.	2.9	0.33c	very low
Siltstone: blocky to massive, dark brown to black.	2.6	0.13c	very low
Shale: soft, fissile to blocky, black.	2.5	0.05	very low
Oolite: soft, black.	1.5	0.0	very low
Shale: fissile, slickensided; more massive in lower part.	2.6	0.0	very low
Siltstone: calcareous, medium hard, blocky to massive, dark brownish gray to black; grades into shale above.	1.4	0.0	very low
Shale: fissile, dark brown, non-calcareous.	0.3	0.05	low
Siltstone: calcareous, massive, medium to dark brown.	2.4	0.0	very low
Oolite: soft, black; contains some clay beds.	0.6	0.2	very low
Shale: slightly calcareous, soft, fissile, dark brown to black fresh, medium brown weathered.	0.7	0.2	very low
Oolite: calcareous, hard, coarse grained, medium to light gray fresh and weathered in upper 2½ feet; gradational downward into fine-grained, black fresh and weathered. Only slightly calcareous in lower 1½ feet. Fluoritic.	4.0	0.05	very low
Siltstone: medium soft, platy to blocky, medium brown.	2.0	0.0	very low
Siltstone: slightly calcareous, medium hard, platy, oolitic at base and sub-oolitic throughout, black.	1.1	0.0	medium

	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Shale: soft, fissile, dark brown.	0.2	0.05	very low
Shale and oolite interbedded: soft, dark brown shale alternating with oolite. At very base contains what appears to be a rounded pebble of quartzite 1½ inch in diameter set in oolite matrix.	0.6	0.0	medium
Siltstone: medium hard, blocky, dark brown fresh, medium brown weathered.	4.5	0.0	very low
Siltstone: slightly calcareous, medium hard, thin bedded, dark brown fresh, medium brown weathered. Similar in appearance to siltstone above.	5.0	0.0	very low
Siltstone: like bed above but becoming more blocky and massive below.	4.2	0.0	low
Siltstone: calcareous, massive to blocky, dense, dark brown to black; grades into siltstone above.	4.0	0.0	very low
Siltstone: calcareous, dense, blocky to massive black; like bed above but contains numerous 1/8- to ¼-inch white vugs lined with terminated quartz crystals.	2.0	0.0	very low
Siltstone: calcareous, platy, medium to dark brown.	1.1	0.0	low
Oolite: slightly calcareous, black, soft.	0.2	0.0	medium
Calcareous siltstone or silty limestone: hard, brittle, dense, chippy, medium gray fresh, light bluish gray weathered.	1.9	0.0	very low
Siltstone: calcareous, relatively hard, dense, chippy, black fresh, dark brown weathered.	3.1	0.0	very low
Siltstone: calcareous, hard, sub-oolitic, black.	0.2	0.0	very low
Shale: calcareous, platy and medium to dark brown in upper half, soft and black in lower half.	3.6	0.0	very low
	30.6		
Wells formation			
Limestone: medium soft, dense to medium grained, medium gray fresh, light gray weathered.	5.7	0.0	low?
Limestone: hard, dense, medium gray fresh.	0.7	0.0	very low

	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Limestone: dense, much jointed, medium gray; in beds 2 to 4 inches thick alternating with four beds 1/8 to ½ inch thick of soft black calcareous clay.	1.0	0.0	very low
Siltstone: slightly calcareous, massive to thin bedded; upper 1 inch soft, gritty, non-calcareous.	7.3	0.0	low?
Dolomite: hard, dense, light gray.	0.4	0.0	very low
Siltstone: calcareous, massive, tan.	2.3	0.0	low?
Limestone: hard, granular, massive, dark gray; vugs lined with chert on upper surface.	2.2	0.0	very low
Calcareous siltstone or silty limestone: soft, massive, medium to light brown.	2.6	n.d.	n.d.
Sandstone or siltstone: porous, iron-stained; contains some nodular (remnants?) of dark gray granular limestone. Unit is bright tan to ochre to dull brown. In upper 1 foot many small open vugs lined with dark brown mammilary limonite.	4.7	n.d.	n.d.
Limestone and siltstone interbedded; medium gray, medium-grained limestone alternating with tan, non-calcareous siltstone.	1.4	n.d.	n.d.
Limestone: nodular, dark gray; and yellow to reddish brown clay and hard chips.	1.5	n.d.	n.d.
Siltstone or fine sandstone: massive, non-calcareous, tan to medium brown fresh, pale buffy gray weathered with some reddish and pink tints.	5.9	n.d.	n.d.
Limestone: relatively hard, massive, granular, medium gray fresh, pale buffy gray weathered.	11.4	n.d.	n.d.
Limestone: relatively soft, pale gray; pink and tan stains.	2.5	n.d.	n.d.
Limestone: relatively hard, dense, light gray.	1.0	n.d.	n.d.
Dolomite: soft, massive, dense, light gray; gradational from bed below.	4.5	n.d.	n.d.
Limestone and dolomite: medium hard, beds 4-12 inches thick, fine grained, medium to light gray.	9.8	n.d.	n.d.
Dolomite: hard, fine-grained, light gray; beds 3-12 inches thick. A few ½-inch beds of light gray slightly calcareous softer fine-grained sandstone.	4.3	n.d.	n.d.

	Thickness (feet)
Sandstone and dolomite interbedded: alternation of soft thin-bedded, fine-grained, tan non-calcareous sandstone in beds 1-3 inches thick and hard, fine-grained, medium gray dolomite in beds 4-8 inches thick.	4.4
Dolomite: hard, medium gray fresh; beds 1 foot thick.	2.7
Dolomite: hard, fine-grained, light gray fresh; beds 2-15 inches thick.	12.9
Sandy (or cherty)limestone or dolomite: very hard, massive, makes vertical wall; pale yellowish to buffy gray weathering. Dips 85-90° N 85-90° E.	15+

Corral Creek, Wyoming

Complete section of phosphatic shale member of Phosphoria formation naturally **exposed at waterfall** near Cottonwood Creek–Corral Creek trail, T. 31 N., **R. 117 W., Lincoln** County, Wyoming (pl. 1): measured by W. W. Rubey.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Rex member				
Phosphatic shale member				
Limestone: hard.		9.0	n.d.	n.d.
Siltstone: calcareous, hard, massive, dark gray to black.		4.5	n.d.	n.d.
UPPER PHOSPHATE BED				
Oolite: highly calcareous, hard, black.	Ua22	1.3	0.0	low
Siltstone: highly calcareous, oolitic to sub-oolitic, hard, black.	Ua23	1.2	0.0	low?
Oolite: highly calcareous, hard, black to dark gray.	Ua24	2.8	0.0	medium
Siltstone: highly calcareous, oolitic to sub-oolitic, hard to medium hard, black.	Ua25	1.3	0.0	Very low
Siltstone: highly calcareous, very hard, dense to sub-oolitic, black.	Ua26	2.3	0.0	very low
Oolite: highly calcareous, coarse, hard, black.	Ua27	0.35	0.0	low
Mudstone: calcareous, hard, dense, black.	Ua28	0.25	0.0	very low
Oolite: highly calcareous, soft, black.	Ua29	0.35	0.0	very low
Mudstone: calcareous, dense to sub-oolitic, hard, massive, black.	Ua30	0.8	0.0	very low
Clay shale: slightly calcareous, thin bedded, soft, black.	Ua31	0.3	0.0	very low
Oolite: highly calcareous, hard, massive, black.	Ua32	0.3	0.0	very low
Oolite: medium soft, shaly, black.	Ua33	0.6	0.10c	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
VANADIFEROUS ZONE				
Shale: soft, very thin bedded, slickensides, black; makes pronounced re-entrant in waterfall cliff.	Ua34	1.2	0.19c	very low
Mudstone: highly calcareous, hard, dense, black.	Ua35	0.6	0.80c	very low
Siltstone: non- to slightly calcareous, soft, thin bedded, black.	Ua36	1.0	1.09c	very low
Mudstone: highly calcareous, medium hard, dense, massive, black.	Ua37	1.0	0.16c	very low
Shale: soft, thin bedded, slickensided, black.	Ua38	0.9	0.17c	very low
Siltstone: highly calcareous, hard, massive, black.	Ua39	1.9	0.0	very low
Shale: slightly calcareous, soft, black; contains a few hard beds; grades laterally to hard massive ledge.	Ua40	2.2	0.0	very low
Siltstone: calcareous, hard, massive, black.	Ua41	2.2	0.0	very low
Siltstone: hard and soft, thin bedded to massive, black.	Ua42	0.8	0.0	very low
Siltstone: highly calcareous, hard, massive, black.	Ua43	2.3	0.0	very low
Shale: soft, slickensided, black.	Ua44	0.25	0.1	very low
Mudstone: calcareous to slightly calcareous, relatively hard, black.	Ua45	0.35	0.05	very low
Clay shale: soft, non-calcareous, black; resembles graphite; forms prominent re-entrant at base of vertical falls.	Ua46	0.6	0.1	very low
Mudstone: slightly calcareous, medium hard, massive to thin bedded, black.	Ua47	1.5	0.0	low
Siltstone: highly calcareous, hard, massive to thin bedded, black.	Ua48	2.2	0.0	very low
Shale: soft, fissile, black.	Ua49	0.65	0.0	very low

Siltstone: highly calcareous, hard

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Siltstone: sub-oolitic, relatively soft, thin bedded, black.	Ua51	0.7	0.1	very low
Siltstone: hard, massive, black.	Ua52	0.3	0.05	very low
Siltstone: sub-oolitic, relatively soft, thin bedded, black.	Ua53	2.4	0.1-0.2	very low
Siltstone: calcareous, hard, massive, black.	Ua54	5.0	0.0	very low
Shale: soft to relatively soft, thin bedded, graphitic appearance; contains a few thin hard beds in upper 1 foot.	Ua55	3.8	0.2	very low
Siltstone: calcareous, hard, thin bedded, dense, black.	Ua56	0.9	0.1	very low
Shale: soft, "graphitic," black; a little "roll" in the structure.	Ua57	3.0	0.05	very low
Mudstone: calcareous, hard, massive, dark brownish gray.	Ua58	0.8	0.0	very low
Shale: oolitic, graphitic appearance, soft, black.	Ua59	2.9	0.0	low
Oolite: medium hard, lustrous, non-calcareous.	Ua60	1.5±	0.0	low
Shale: soft, pronounced graphitic appearance.	Ua61	2.8	0.05	very low
Siltstone: hard, massive, medium brownish gray.	Ua62	1.3	0.05	very low
Siltstone: soft, thin bedded, dark gray to black.	Ua63	0.35	0.0	low?
Mudstone: calcareous, hard, massive, medium brownish gray.	Ua64	2.1	0.0	very low
Oolite: calcareous, medium hard, very coarse in upper 2 inches.	Ua65	1.0	0.0	low?
Oolite and dense mudstone: soft to medium hard, dark gray to medium brownish gray.	Ua66	2.1	0.0	low
Oolite: calcareous, hard, massive, black.	Ua67	2.0	0.0	low
Oolite: very hard, massive, gray, non-calcareous.	Ua68	0.8	0.0	low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Mudstone; very hard, dense, medium gray, non-calcareous; oolitic, softer and darker in lower part.	Ua69	1.9	0.0	medium
Mudstone: very hard, dense, medium gray, non-calcareous.	Ua70	0.5	0.0	very low
Pisolite: hard, medium gray.	Ua71	1.2	0.0	high
Siltstone: highly calcareous, hard massive, medium gray; cross bedded?		2.6	n.d.	n.d.
Siltstone: relatively soft, thin bedded, dark gray.		0.5	n.d.	n.d.
Siltstone: highly calcareous, hard, massive, medium brownish gray.		5.0	n.d.	n.d.
Mudstone: slightly calcareous, hard but much jointed, light to medium gray.		4.5	n.d.	n.d.
Siltstone: highly calcareous, very hard, massive to thin-bedded, medium to dark gray.		11.0	n.d.	n.d.
Siltstone: much like that above but light brownish gray weathered; very hard.		10.0	n.d.	n.d.
Siltstone; medium hard, non-calcareous, massive, medium tan; much jointed; softer in lower part.		4.2	n.d.	n.d.
Siltstone: medium soft, non-calcareous, massive, medium brownish gray.		2.8		
Wells formation				
Calcareous siltstone or silty limestone: medium soft, bright tan.		2.0		
Limestone: medium soft, cherty?, light ash gray.		2.0		
Sandy dolomite: hard, massive to thick bedded, somewhat cherty?, light buffy gray; dips 25-30° S, 65-70° W.		35.0		

Coal Canyon, Wyoming

Complete section of phosphatic shale member of Phosphoria formation exposed in U. S. Geological Survey trench on south side of Coal Canyon in Sublette Ridge, sec. 6, T. 26 N., R. 119 W., Lincoln County, Wyoming. Portion above upper phosphate bed measured by Gale and Richards;[1] remainder described by W. W. Rubey and V. E. McKelvey. P_2O_5 chemical analyses after Gale and Richards.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5 (percent)
Rex member				
Limestone: cherty, hard, massive, fossiliferous, gray; forms wall.			n.d.	n.d.
Phosphatic shale				
Limestone: shaly and shattered.		1.8	n.d.	n.d.
Limestone: blocky.		3.1	n.d.	n.d.
Limestone: shaly, oolitic, crushed.		1.9	n.d.	n.d.
Limestone: shattered, fossiliferous, black.		9.7	n.d.	n.d.
Phosphate rock: shaly, oolitic, impure.		0.4	n.d.	n.d.
Limestone: granular, black; and shale, sandy appearance in part.		7.7	n.d.	n.d.
Siltstone: hard, massive, gray.	184	1.8	0.0	very low
UPPER PHOSPHATE BED				
Oolite: massive, hard, black, weathers gray.	185	2.2	0.05	high
Shale: fissile, soft, black, alternating with beds (1-4 inches) of blocky siltstones; shale more abundant in upper part; all finely oolitic.	186-187	4.5	0.25	high
Limestone: dense, hard, dark gray, buff-gray weathered.	188	1.9	0.1	very low
Silt: dense, soft, brown.	189	0.1	0.0	high
Oolite: blocky, soft, black.	190	0.8	0.0	high
Limestone: concretionary, hard, dark gray.	191	0.4	0.0	high
Oolite: blocky, soft, black.	192	2.6	0.0	high

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[1] Gale, H. S., and Richards, R. W., op. cit. Bull. 430, p. 502.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Siltstone: blocky, clayey, dense to medium grained, dark brown.	193	1.4	0.0	low
Oolite: soft, fossiliferous, black.	194	1.0	0.0	medium
Mudstone: calcareous, medium hard, dark brown.	195	0.1	0.1	16.3%
Siltstone: blocky, calcareous, hard, buff-gray.	196	1.7	0.0	16.3%
Oolite: soft, black.	197	0.6	0.0	16.3%
Siltstone: medium hard, dark brown.	198	0.7	0.0	16.3%
Oolite: clayey, soft, black.	199	0.4	0.0	16.3%
Limestone: granular, soft, light gray.	200	0.1	0.0	16.3%
Siltstone: calcareous, oolitic, dark gray.	201	1.1	0.0	16.3%
Limestone: concretionary, dark gray.	202	0.4	0.0	16.3%
Siltstone: soft, dark gray.	203	0.4	0.0	16.3%
Oolite: soft, black.	204	0.5	0.05	16.3%
Limestone: hard, dense, concretionary, black.	205	0.2	0.0	16.3%
Siltstone: soft, fissile to blocky, dark gray to black.	206	3.7	0.05	16.3%
Limestone: hard, very fossiliferous, dark gray, buff-gray weathered.	207	1.2	0.06c	very low
VANADIFEROUS ZONE				
Shale: soft, blocky to fissile, dark brownish gray. Conspicuous dark red and yellow stains.	208	2.6	0.98c	very low
Shale: soft, fissile, dark brown.	209	1.1	0.16c	very low
Limestone: hard, fossiliferous, dark gray, buff-gray weathered.	210	1.0	0.03c	very low
Shale: soft, fissile to chippy, black.	211	1.4	0.05c	11.3%
Siltstone: medium hard, massive, black.	212	1.8	0.0	very low
Shale: soft, fissile, black.	213	0.8	0.0	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Limestone: hard, massive, buff-gray.	214	1.8	0.0	very low ↓
Shale: soft, fissile, black.	215	0.7	0.0	16.8%
Limestone: fine grained, dark gray.	216	0.1	0.0	16.8%
Shale: soft, fissile, black.	217	2.5	0.05	16.8%
Limestone: hard, concretionary, gray.	218	0.4- 0.6	0.0	16.8%
Shale: soft, fissile, black.	219	4.1	0.25	16.8% ↑
Limestone: hard, massive, dark gray fresh, pale buffy gray weathered, upper 0.8 foot less resistant.	220	2.5	0.0	very low
Siltstone: calcareous, medium hard, massive at top, platy at base, dark gray, buff gray weathered.	221	2.2	0.05	↓ 16.4%
Shale: soft, fissile, dark gray.	222	3.0	0.2	16.4%
Siltstone: calcareous, massive, dark gray, buff-gray weathered.	223	1.0	0.1	16.4%
Shale: fissile, clayey, soft, black.	224	2.4	0.05	16.4% ↑
Siltstone: medium hard, dark gray, buff-gray weathered.	225	1.2	0.0	↓ 12%
Shale: clayey, soft, fissile, black.	226	1.3	0.0	12%
Siltstone: calcareous, medium hard, massive, dark gray, buff-gray weathered.	227	1.3	0.0	12% ↑
Oolite: soft, platy to fissile, dark gray.	228	2.7	0.05	↓ 26%
Siltstone: medium hard, massive, dark gray.	229	0.6	0.0	26%
Siltstone: oolitic, soft, fissile to blocky, black; grades into mudstone below.	230	1.3	0.1	26% ↑
Mudstone: calcareous, medium hard, massive, black, buff-gray weathered.	231	1.3	0.0	↓ 19.6%
Oolite: soft, massive, black.	232	1.3	0.0	19.6%
Shale: oolitic, dense, soft, fissile, black; top forms east wall of old tunnel.	233	1.2	0.0	19.6%

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Oolite: soft, massive, black. Base forms west wall of old tunnel.	234	2.4	0.2	19.6%
Siltstone: medium hard, massive, but much jointed, dark gray.	235	3.5	0.0	very low
Siltstone: soft, chippy, dark gray.	236	2.3	0.0	very low
Siltstone: moderately calcareous, concretionary, dark gray.	237	1.3	0.0	very low
Siltstone: moderately calcareous, hard, dense, dark gray.	238	0.3	0.0	medium
Shale: soft, fissile, dark brown.	239	0.2	0.0	medium
Siltstone: medium hard, chippy, dark gray.	240	3.9	0.05	medium
Siltstone: medium hard, thin bedded, black.	241	0.3	0.05	medium
Oolite: medium hard, thin bedded, black.	242	0.8	0.07c	medium
Shale: clayey, oolitic, soft, fissile, black.	243	0.9	0.42c	medium
Siltstone: slightly calcareous, medium hard, chippy, dark brown.	244	1.7	0.15c	medium
Oolite: soft, fissile to chippy, black.	245	2.9	0.25c	medium
Limestone: silty, medium hard, blocky, grayish brown.	246	1.6	0.06c	very low
Shale: calcareous, medium hard, chippy to fissile, black.	247	3.2	0.22c	medium
Shale: clayey, calcareous, soft, fissile.	248	0.3	0.10c	very low
Siltstone: moderately calcareous, medium hard, dense, thin bedded, grayish brown.	249	3.0	0.15c	high
Shale: oolitic in lower half, soft, fissile, dark gray.	250	2.0	0.11c	medium

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Siltstone: calcareous, oolitic, medium hard, massive to blocky, dark grayish brown.	251	1.2	0.0	very low
Shale: soft, dark brown.	252	1.3	0.0	high
Siltstone: calcareous, hackly, fractured, gray-brown.	253	0.7	0.0	medium
Shale: soft, fissile, dark brown.	254	0.5	0.0	very low
Limestone: silty, medium hard, hackly to blocky, grayish brown.	255	2.3	0.0	very low
Siltstone: slightly calcareous, medium hard, thin bedded, dense.	256	3.2	0.1	medium
Shale: oolitic in upper part, medium hard, fissile, black.	257	1.0	0.2	medium
Shale: soft, dense, dark brown; deep orange stains at base.	258	2.2	0.2	very low
Siltstone: calcareous, hard, massive, grayish brown.	259	2.7	0.2	very low
Shale: soft, micaceous, fissile, dark brown.	260	1.8	0.05	very low
Oolite: coarse, hard, dark gray; grades into limestone below.	261	0.3	0.0	very low
Wells formation				
Limestone: hard, massive, dark gray, weathers light gray.	261	5.8	0.0	very low
Limestone: silty, hard, thin bedded, buff gray.	262	1.3	0.0	very low
Limestone: silty, hard, massive, buff gray.	263	0.9	0.0	very low
Sand: poorly consolidated, yellow-brown.	264	0.3	0.0	very low
Limestone: massive, dark gray.	265	0.5	0.0	very low
Sand: calcareous, unconsolidated, finely laminated in part, purplish gray and yellowish.	266	2.7	0.0	very low
Siltstone: [illegible], [illegible] soft [illegible]	267	1.[illegible]	[illegible]	[illegible]

Cokeville, Wyoming

Nearly complete section of the phosphatic shale member of the Phosphoria formation exposed in U. S. Geological Survey trench on the hillside above mine 2½ miles northeast of Cokeville, sec. 4, T. 24 N., R. 119 W., Lincoln County, Wyoming (pls. 3, 7); measured by V. E. McKelvey. P_2O_5 chemical analyses after Gale and Richards.1/

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Rex member.				
Limestone: cherty, hard, massive, gray: forms ledge			n.d.	n.d.
Phosphatic shale member				
Limestone: hard, thin bedded to massive, gray.	426	4.0	0.0	very low
Shale: soft, thin bedded, brown.	425	3.4	0.0	very low
Limestone: hard, massive, dark gray.	424	3.6	0.0	very low
Limestone: hard, thin bedded to massive, gray.	423	4.2	0.0	very low
Limestone: hard, massive, dark gray.	422	1.7	0.0	very low
Shale: calcareous, hard, fissile, dark gray.	421	5.5	0.0	very low
Shale: hard, fissile, brown.	420	1.8	0.0	very low
Limestone: hard, dense, blocky, black.	419	1.4	0.0	very low
Shale: hard, fissile, dark brown.	418	2.2	0.0	very low
Oolite: fossiliferous, dark brown.	417	0.6	0.0	low
Limestone: hard, thin bedded, dark brown.	416	0.2	0.0	very low

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1/ Gale, H. S., and Richards, R. W., op. cit., Bull. 430, p. 505.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Shale: soft, thin bedded, brown.	415	0.6	0.0	very low
Limestone: hard, fossiliferous, brown.	414	0.5	0.0	very low
Shale: calcareous, medium hard, thin bedded, dark brown.	413	1.4	0.0	very low
Shale: like shale above.	412	3.0	0.0	very low
Shale: soft, thin bedded; a few thin hard layers.	411	2.5	0.0	very low
Oolite: hard, fossiliferous, massive, dark gray.	410	1.2	0.0	high
Shale: calcareous, soft, fissile, brown.	409	1.3	0.0	very low
Shale: calcareous, soft, fissile, brown.	408	0.9	0.0	very low
Shale: calcareous, medium hard, dark brown.	407	1.0	0.0	very low
Concretion: calcareous, shaly, black.	406	1.2	0.0	very low
Shale: calcareous, soft, brown.	405	0.7	0.0	very low
Shale: calcareous, brown: contains calcareous concretions.	404	0.7	0.0	very low
Siltstone: calcareous, massive, brown; contains a few coarse oolites.	402	1.0	0.0	very low
Siltstone: soft, massive, dark brown.	401	0.5	0.0	very low
Siltstone: calcareous, thin bedded, dark gray.	400	1.8	0.0	very low
Siltstone: soft to medium hard, thin bedded, dark brown.	399	1.6	0.0	very low
Limestone: hard, oolitic, fossiliferous, dark gray.	398	1.3	0.0	22.2%
Oolite: hard, coarse, dark gray.	397	0.7	0.0	22.2%

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Limestone: hard, oolitic, massive, fossiliferous, dark brown.	396	1.5	0.0	12.6%
UPPER PHOSPHATE BED				
Phosphate rock: coarsely oolitic, hard, blocky, dark gray.	427	3.1	0.1	37.0%
Phosphate rock: oolitic, soft to medium hard, thin bedded, dark brown.	428	2.1	0.25	33.2%
Shale: oolitic, soft, fissile, black.	429	0.9	0.1	29.5%
Shale: soft, thin bedded, brown.	430	0.8	0.1	very low
Limestone: massive, earthy weathering, light brown.	431	2.3	0.0	very low
Shale: oolitic, soft to medium hard, dark gray.	432	1.2	0.0	33.4%
Oolite: thin bedded, dark brown.	433	1.0	0.0	19.5%
Oolite: thin bedded, dark brown.	434	1.2	0.0	high
Oolite: coarse, massive, fossiliferous, gray.	435	0.7	0.0	high
Oolite: thin bedded, gray.	436	1.4	0.0	medium
Oolite: coarse, massive, gray.	437	0.6	0.0	high
Oolite: coarse, massive, gray; fluoritic.	438	1.1	0.0	medium
Siltstone: hard, light brown.	439	0.2	0.0	very low
Limestone: silty, earthy weathering, yellowish brown.	440	0.9	0.0	very low
Limestone: hard, massive, dark gray.	441	1.4	0.0	very low
Shale: soft, fissile, gray-brown.	442	0.2	0.0	very low
Siltstone: hard, massive, brown.	443	0.5	0.0	low
Oolite: soft, coarse, shaly, black.	444	0.1	0.0	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Limestone: hard, buff-gray.	445	0.1	0.0	very low
Oolite: soft, coarse, shaly, black.	446	0.5	0.0	very low
Limestone: hard, dense, dark gray.	447	0.3	0.0	very low
Oolite: shaly, dark brown.	448	1.0	0.0	very low
Limestone: hard, massive, gray.	449	1.1	0.0	very low
Shale: soft, fissile, black.	450	0.6	0.0	low
Limestone; hard, nodular, gray.	451	0.6	0.0	low
Shale: finely oolitic, soft, dark brown.	452	0.5	0.0	low
Siltstone: calcareous, hard, gray.	453	0.1	0.0	very low
Shale: oolitic, soft, fissile, brown.	454	0.4	0.0	very low
Limestone: hard, gray.	455	0.2	0.0	very low
Shale: oolitic in part, fissile, dark gray.	456	2.2	0.0	very low
Limestone: silty, hard, massive, brown.	457	1.8	0.0	very low
Limestone: hard, massive, fossiliferous, dark gray.	458	1.8	0.0	very low
Oolite: coarse, hard, gray.	459	0.6	0.04c	medium
VANADIFEROUS ZONE				
Shale, soft, fissile, dark brown.	460a	0.5	0.41c	very low
Shale: like shale above.	460b	0.4	1.21c	very low
Shale: like shale above.	460c	1.1	0.51c	very low
Shale: like shale above.	460d	0.9	0.19c	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Shale: like shale above.	460c	0.5	0.11c	very low
Limestone: hard, massive, fossiliferous, gray.	461	0.7	0.0	very low
Siltstone: soft, thin bedded to massive, brown.	462	1.0	0.0	very low
Shale: soft, fissile, black.	463	0.7	trace	very low
Siltstone: medium hard, massive, brown.	464	2.6	trace	very low
Siltstone: soft, massive, yellowish brown.	465	2.7	trace	very low
Shale: medium hard, dark brown.	466	1.2	0.0	low
Shale: soft, dark brown.	467	2.9	0.0	very low
Siltstone: calcareous, hard, blocky, brown.	468	2.2	0.0	very low
Shale: oolitic, fissile, black.	469	0.5	0.0	low
Limestone: oolitic in part, hard, massive, dark gray.	470	1.1	0.0	very low
Shale: calcareous, oolitic, soft, fissile, dark brown.	471	3.0	0.0	very low
Limestone: hard, massive, dark gray.	472	1.1	0.0	very low
Shale: soft, thin bedded, dark gray.	473	0.7	trace	low
Limestone: hard, massive, dark gray.	474	0.6	0.0	very low
Oolite: soft, thin bedded, dark gray.	475	0.8	0.35	very low
Siltstone: medium hard, massive, brown.	476	0.7	0.1	very low
Shale: oolitic in part, soft, dark brown; contains a few hard calcareous layers.	477	3.2	0.05	very low
Shale: like shale above.	478	3.4	0.05	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Shale: locally oolitic, soft, fissile, dark brown to black.	479	1.8	0.05	very low
Shale: like shale above.	480	3.4	0.0	very low
Shale: like shale above.	481	3.4	0.1	very low
Limestone: hard, much fractured, light gray.	482	1.2	0.0	very low
Shale: medium hard, thin bedded, dark brown.	483	2.8	0.0	medium
Limestone: hard, thin bedded, blue-gray.	484	5.6	0.0	very low
Limestone: locally oolitic, cherty, hard, thin bedded, dark gray.	485	2.6	0.0	very low
Siltstone: oolitic, shaly, brown.	486	1.6	0.1	very low
Limestone: silty, medium hard, massive, brown.	487	7.5	0.0	very low
Walls formation ?				
Limestone: hard, massive, light gray. Possibly a large talus block, not in place.			0.0	very low
Covered		32	n.d.	n.d.
Walls formation				

Pine Creek, Wyoming

Complete section of phosphatic shale member of Phosphoria formation exposed in U. S. Geological Survey trench about 100 feet north of east end of the Cokeville Power Plant ditch on Pine Creek, sec. 35, T. 25 N., R. 118 W., about 7 miles east of Cokeville, Lincoln County, Wyoming (pl. 7): measured by J. D. Love.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Rex member				
Limestone: slightly cherty, coarse-grained, massive, slightly fossiliferous, bluish-gray.		8.0	n.d.	n.d.
Phosphatic shale member?				
Limestone: hard, very fine-grained, poorly bedded, shaly, with a few very shaly tan slabby layers, tan on weathered surfaces, gray on fresh surfaces; contains some unoriented masses and nodules of dark-gray chert.		38.0	n.d.	n.d.
Phosphatic shale member				
Phosphate rock: calcareous, impure, hard, very fine-grained, black.		1.2	n.d.	n.d.
Limestone: hard, fine-grained, massive, bluish-gray to tan; contains unoriented masses of black, granular chert.		8.5	n.d.	n.d.
Covered interval, containing in lower part at least 1 foot of hard massive phosphate underlain by 3 feet or more of earthy yellowish mudstone. Upper phosphate bed is somewhere in this interval.		20.0	n.d.	n.d.
Phosphate rock: hard, fine-grained, blocky, massive, black.		2.5	n.d.	n.d.
Covered		1.6	n.d.	n.d.
Phosphate rock: silty, soft, greenish-black.		2.5	n.d.	n.d.
Mudstone: very earthy, dull, massive, light-gray; contains numerous phosphate grains.		3.0	n.d.	n.d.
Oolite: phosphatic, soft, moderately coarse, black.	JJ-52	0.4	0.0	high
Mudstone: hard, massive, blocky, gray to brown; ferruginous stain.	JJ-51	2.2	0.0	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Oolite: soft, fine-grained, black.	JJ-50	0.4	0.0	low
Mudstone: blocky, gray.	JJ-49	0.6	0.0	very low
Shale: oolitic, black and rusty.	JJ-48	0.4	0.0	low
Mudstone: blocky, gray.	JJ-47	1.1	0.0	very low
Phosphate rock: oolitic, soft, bedded, black; grades downward into black shale, slightly ferruginous.	JJ-46	1.3	0.0	high
Mudstone: hard, blocky, gray.	JJ-45	3.4	<0.06c	very low
VANADIFEROUS ZONE				
Shale: fissile, black, stained yellow to orange.	JJ-44	2.2	1.16c	very low
Shale: fissile, black, and black shaly soft blocky mudstone, both with orange-yellow stain.	JJ-43	2.1	0.26c	very low
Mudstone: massive, blocky, gray.	JJ-42	1.2	0.0	very low
Shale: fissile near base, blocky near top, black.	JJ-41	2.1	0.0	low
Mudstone: massive, blocky, gray.	JJ-40	3.0	0.0	very low
Shale: fissile, silty, black.	JJ-39	3.0	0.0	low
Mudstone: massive, blocky, gray.	JJ-38	2.7	0.0	low
Shale: fissile, black.	JJ-37	0.8	0.0	medium
Mudstone: blocky, hard, except near base where it is shaly, dark-gray.	JJ-36	1.6	0.0	low
Shale: fissile, silty, black.	JJ-35	2.2	0.12	very low
Shale: fissile, black.	JJ-34	1.4	0.23c	low
Shale: fissile, flaky, black.	JJ-33	1.4	0.46c	medium

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Mudstone: hard, massive, blocky, black; shaly bed in middle.	JJ-21	1.5	trace.	very low
Shale: fissile, black; contains silty layers.	JJ-22	3.3	0.0	very low
Mudstone: hard, blocky, dark-gray.	JJ-23	1.0	0.0	very low
Shale: oolitic, fetid, black.	JJ-24	0.7	0.0	Medium
Mudstone: slabby, gray.	JJ-25	0.7	0.0	low
Shale: fissile to plastic, oolitic, slightly ferruginous, black.	JJ-26	0.9	trace.	very low
Mudstone: oolitic, fossiliferous, black to brown; black chert at base.	JJ-27	1.6	0.0	very low
Mudstone: phosphatic, soft, brown.	JJ-28	0.6	0.0	low
Phosphate rock; coarse, fetid, black.	JJ-29	1.2	0.0	medium
Mudstone: phosphatic, very hard, blocky, shaly, fetid, brown.	JJ-30	2.5	0.0	medium
Mudstone: siliceous, very hard, blocky to fissile, brown to black; only partly exposed.		5.8	n.d.	n.d.
Covered interval. A few inches of brown phosphatic shale exposed at base.		4.0	n.d.	n.d.
Phosphate rock: hard, fine, slabby, shaly, coarser near base, black.	JJ-53	2.0	n.d.	n.d.
Mudstone: soft, brown.		0.3	n.d.	n.d.
Chert: black, in irregular beds, 2 to 4 inches thick; interbedded with shaly, dark-gray, hard limestone in about equal amounts. Shaly layers cause slope to be terraced.		4.3	n.d.	n.d.
Covered interval		6.4	n.d.	n.d.
Mudstone: very hard, massive, dark-bluish-black.		1.0	n.d.	n.d.
Covered interval.		7.0	n.d.	n.d.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Chert: brittle, massive, white to bluish-black, irregularly bedded in layers up to 3 feet thick; interbedded with gray to yellowish, very hard fine-grained limestone.		20.0	n.d.	n.d.
Wells formation?				
Dolomite (?); limy, hard, massive, fine, vuggy, yellow.		7.0	n.d.	n.d.
Wells formation				
Quartzite: fine-grained, brecciated, yellowish.		5.0+	n.d.	n.d.

Dempsey Ridge, Wyoming

Complete section of phosphatic shale member of Phosphoria formation (pl. 3). Lower part exposed in U. S. Geological Survey trench KK on fault block on north side of draw, about one-half mile east of Rock Creek, 2 miles north of Nugget Station, in sec. 28, T. 22 N., R. 118 W., Lincoln County, Wyoming. Upper part exposed on crest of anticline about one-quarter of a mile northeast. Measured by J. D. Love.

	Thickness (feet)
On crest of anticline	
Rex member?	
Dolomite: vuggy, porous, gray, phosphatic with oolite grains in lower part, fossiliferous and cherty near top.	4.2
Phosphatic shale member	
Phosphate: hard, massive, medium-grained, fetid, black.	1.5
Limestone or dolomite: phosphatic, with numerous oolite grains, vuggy, poorly bedded, gray.	4.7
Phosphate: hard, bedded, massive, medium to coarse, black, slightly fossiliferous, with some geodes.	1.5
Dolomite: medium to thick-bedded, weathering coarse-grained, vuggy, with numerous geodes, more dense in lower part, gray, darker in lower part.	24.2
Chert: soft, very vuggy, gray, non-calcareous	0.25
Siltstone: hard, medium-bedded, gray, with vuggy chert.	1.2
Chert, hard, vuggy, gray to white.	0.55
Siltstone: thin to medium-bedded, gray, non-calcareous, with vuggy chert. Irregular shale near base.	4.0
Shale, very soft, black to brown.	0.15
Siltstone: hard, cherty, medium-bedded, fine, gray.	2.3
Siltstone: thin-bedded, dark-gray, non-calcareous.	1.6
Siltstone, hard, fine, massive, fossiliferous, black to dark-gray. Fossils replaced by white calcite. [illegible] paleontological possibilities.	1.2

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Covered interval. On fault block		17	n.d.	n.d.
Limestone: hard, silty, fine-grained, coarsely bedded, mouse-gray. Dip is 32° NE, strike N 35° W.		1.5	n.d.	n.d.
Shale: siliceous, phosphatic, black.	KK-1	0.2	0.0	high
Limestone: siliceous, hard, shaly, bluish-gray.		0.3	n.d.	n.d.
Shale: fissile, black.	KK-2	0.1	0.0	medium
Limestone: siliceous, hard, fine-grained, coarsely bedded, dark bluish-black.		4.2	n.d.	n.d.
Chert: brittle, bedded, black; interbedded with black fissile shale in about equal amounts.	KK-3	0.3	0.0	high
Limestone: hard, fine-grained, massive, structureless, possibly brecciated, light bluish-gray; some phosphatic material in lower half.		4.1	n.d.	n.d.
UPPER PHOSPHATE BED				
Phosphate rock; moderately soft, fine-grained, impure, poorly bedded, fossiliferous, black.	KK-4	3.0	trace	medium
Limestone: cherty, siliceous, hard, massive, gray.		1.9	n.d.	n.d.
Chert: brittle, thin-bedded, black; interbedded with black fissile shale.	KK-5	2.8	0.0	very low
Chert: brittle, thick-bedded, black.		1.8	n.d.	n.d.
Phosphate rock: siliceous, hard, highly fossiliferous, black.	KK-6	0.6	0.0	high
Limestone: hard, coarse- to fine-grained, massive, dove-gray to black; interbedded with chert, well bedded, black; numerous dark shale partings. Limestone beds moderately fossiliferous and slightly phosphatic near base.		7.8	n.d.	n.d.
Mudstone: oolitic and shaly near top, dark-gray; conspicuous orange-yellow stain.	KK-7	2.2	0.0	very low
Mudstone: very massive, gray.		2.1	n.d.	n.d.
Oolite: soft, black.	KK-8	0.5	0.0	high

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Mudstone: blocky, gray, slightly ferruginous; brown shale partings.	KK-9	3.0	0.0	very low
Oolite: soft, black.	KK-10	0.7	0.0	high
Mudstone: blocky, gray.	KK-11	1.2	0.0	very low
Shale: slightly oolitic, micaceous, black, ferruginous.	KK-12	0.7	0.0	low
Mudstone: moderately soft, slabby, black.	KK-13	1.7	0.0	low
Shale: slightly oolitic, very soft, black.	KK-14	2.5	0.0	medium
Shale and mudstone:;soft, black; about equal amounts of each.	KK-15	1.8	0.0	very low
Mudstone and silty limestone: hard, blocky, slightly fossiliferous, gray.	KK-16	2.5	<0.06c	very low
VANADIFEROUS ZONE				
Shale: fissile, black, ferruginous.	KK-17	1.2	0.90c	very low
Shale: silty, black, sulfur-yellow stain on surfaces.	KK-18	2.1	0.39c	very low
Mudstone: blocky, gray, ferruginous.	KK-19	1.6	0.0	very low
Shale: silty, black; yellow stain on surfaces.	KK-20	1.1	0.0	very low
Mudstone: hard, blocky, gray.		3.5	n.d.	n.d.
Shale: fissile, black, slight ferruginous stain.	KK-21	2.4	0.0	high
Mudstone and shale: black; shale has yellow stain on surfaces.	KK-22	1.7	0.0	very low
Shale: silty, black.	KK-23	1.0	0.0	very low
Mudstone: massive, black.		2.3	n.d.	n.d.
Shale: fissile, black.	KK-24	2.7	0.0	low
Shale: fissile, silty near base, black.	KK-25	1.8	trace	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Mudstone: blocky, black.		1.2	n.d.	n.d.
Shale: soft, oolitic, fissile, black.	KK-26	1.3	0.24	very low
Mudstone: massive, dark-gray.		3.6	n.d.	n.d.
Shale: fissile, black.	KK-27	2.1	0.0	low
Shale: silty, black; contains mudstone concretions.	KK-28	2.3	trace	very low
Fault, probably of small displacement.				
Shale: fissile, black.	KK-29	1.8	0.0	very low
Mudstone: blocky, black.		1.2	n.d.	n.d.
Shale: slightly oolitic near base, fissile, black.	KK-30	2.5	0.0	low
Shale and mudstone: black.	KK-31	1.4	0.0	very low
Shale: slightly oolitic, graphitic appearance, bluish-black.	KK-32	2.7	0.0	low
Limestone: hard, very fine-grained, massive (forms a conspicuous ledge), black. Coarse phosphate pellets and some fossils near top.		2.6	n.d.	n.d.
Phosphate rock; oolitic, coarse- to fine-grained, soft, fetid, black.	KK-33	3.6	0.0	low
Shale: silty, phosphatic, black.	KK-34	2.6	0.0	medium
Mudstone: blocky, dark-gray to black.		16.4	n.d.	n.d.
Shale: fissile, black; slightly ferruginous in lower part; very silty and blocky near top.	KK-35	2.9	0.0	low
Mudstone: blocky, dark-gray to black.		10.0	n.d.	n.d.
Mudstone: shaly, or silty shale, blocky, black.		1.1	n.d.	n.d.
Mudstone: blocky, black to dark-gray; black siliceous shaly limestone interbedded near base.		7.6	n.d.	n.d.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Approximate interval between bottom of trench and apparent top of Wells, fine; hard, gray, limestone. Interval consists almost entirely of hard, blocky, gray mudstone.		63.7	n.d.	n.d.
Wells formation.				

Brazer Canyon, Utah.

Complete section of phosphatic shale member of Phosphoria formation exposed in U. S. Geological Survey trench on the north side of Brazer Canyon, sec. 18, T. 11 N., R. 8 E., Rich County, Utah (pl. 3): measured by V. E. McKelvey.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Rex member				
Chert: hard, massive, dark gray to black; contains some limestone.	1265		0.0.	very low
Phosphatic shale member?				
Limestone: hard, massive, fine-grained, a few coarsely crystalline zones, dark gray.	1266	4.5	0.0	very low
Chert: hard, massive, black.	1267	6.3	0.0	very low
Limestone: hard, massive, contains nodular layers of black chert, dark gray.	1268	5.7	0.0	very low
Chert: hard, thin bedded, black; contains some limestone.	1269	1.9	0.0	very low
Limestone: hard, locally oolitic, massive, dark gray.	1270	7.5	0.0	very low
Siltstone: calcareous, medium hard, massive, finely laminated, olive.	1271	1.1	0.0	very low
Limestone: hard, blocky, dark gray.	1272	2.9	0.0	very low
Limestone: hard, massive, dark gray.	1273	3.5	0.0	very low
Limestone: hard, thin bedded (2-4 inches), blocky, dark gray.	1274	2.3	0.0	very low
Limestone: silty, medium hard, massive, buff-gray.	1275	4.5	0.0	very low
Limestone: like limestone above.	1276	5.0	0.0	very low
Limestone: Silty, hard, blocky, dark gray, yellowish brown weathered.	1277	2.0	0.0	very low
Limestone: silty, medium hard to hard, massive to blocky, buff gray.	1278	3.2	0.0	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Limestone: like limestone above but contains a brown-weathering zone at top (1 foot thick).	1279	3.9	0.0	very low
Phosphatic shale?				
Limestone: phosphatic, oolitic, hard, massive, black; forms natural outcrop.	1280	1.3	0.0	medium
Limestone: oolitic near top, silty, hard, massive, buff.	1281	3.0	0.0	very low
UPPER PHOSPHATE BED				
Phosphate rock: oolitic, hard, massive, black, with blue bloom.	1282	1.8	0.0	high
Phosphate rock: like phosphate rock above.	1283	1.7	0.05	high
Siltstone: calcareous, oolitic, medium hard, massive fresh, shaly weathered, brown.	1284	0.5	trace	very low
Phosphate rock: oolitic, hard, massive, black, with blue bloom.	1285	1.5	0.1	high
Shale: moderately calcareous, oolitic, soft, brown.	1286	1.5	0.29c	low
Oolite: moderately calcareous, soft, thin bedded, dark brown.	1287	1.4	0.19c	medium
Oolite: like oolite above, but shaly in upper 0.6 foot, moderately calcareous.	1288	1.8	0.15	medium
Limestone: hard, massive, buff.	1289	2.9	0.0	very low
Oolite: medium hard, shaly, gray.	1290	0.9	0.0	medium
Siltstone: oolitic, medium hard, fairly massive, brown.	1291	1.8	0.0	medium
Phosphate rock: oolitic, cherty, hard, dark gray.	1292	2.2	0.0	high
Chert: hard, massive, but well laminated, black; basal 1.2 feet shaly and calcareous.	1293	3.5	0.0	very low
Limestone: hard, blocky to massive, gray; oolitic in basal 1½ feet.	1294	5.7	0.0	very low
Limestone: hard, massive, gray, buff weathered.	1295	2.2	0.0	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Shale: medium hard, dark brown.	1296	0.4	0.0	medium
Siltstone: calcareous, hard, blocky, brown.	1297	2.2	0.0	very low
Shale: oolitic, soft, black.	1298	1.2	0.05	very low
Siltstone: calcareous, soft, massive, buff gray.	1299	0.6	0.0	very low
Shale: moderately calcareous, oolitic, soft, black.	1300	1.0	0.0	very low
Limestone: hard, massive, dark gray.	1301	1.0	0.0	very low
Shale: slightly calcareous, medium hard, black.	1302	1.2	0.0	low
Limestone and shale interbedded: limestone hard, dark gray; shale soft, dark brown.	1303	0.7	0.0	very low
Shale: somewhat oolitic, black; contains a few calcareous layers.	1304	1.8	0.0	low
Limestone: hard, massive, fossiliferous, dark gray.	1305	2.9	0.0	very low
VANADIFEROUS ZONE				
Siltstone: medium hard, blocky, black; numerous red and yellow stains.	1306	0.7	0.25c	very low
Shale: soft, brown, numerous red and yellow stains.	1307	2.7	0.26c	very low
Shale: like shale above, but contains a few small concretions.	1308	0.5	<0.06c	very low
Limestone: hard, blocky, fossiliferous, gray.	1473	1.2	0.0	very low
Shale: upper part calcareous, chippy, dark brown.	1474	0.7	0.0	very low
Siltstone: blocky, hard, dark gray to black, numerous iron stains.	1475	0.7	0.0	very low
Siltstone: calcareous, hard, blocky, dark gray, a few red and yellow (iron) stains: concretionary weathering.	1476	3.1	0.0	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Shale: chippy, dark gray.	1477	1.0	0.0	very low
Shale: dark gray; contains limestone concretions.	1478	0.6	0.0	very low
Shale: soft, chippy; dark gray, red and yellow stains; contains secondary gypsum.	1479	0.9	0.0	very low
Siltstone: calcareous, hard, massive, dark gray.	1480	1.4	0.0	very low
Shale: soft, chippy, black, a few red and yellow stains.	1481	1.2	0.0	very low
Shale: soft, dark gray; contains calcareous concretions.	1482	0.6	0.0	low
Shale: locally oolitic, soft, dark gray; contains a few calcareous concretions and thin, hard calcareous layers.	1483	3.2	0.0	very low
Limestone: hard, silty, thin bedded, dark gray.	1484	1.4	0.0	very low
Shale: oolitic, soft, black.	1485	0.3	0.0	low
Limestone: hard, thin bedded, dark gray.	1486	0.6	0.0	very low
Shale: medium hard, chippy, iron stained, black; contains some secondary gypsum.	1487	1.4	0.0	very low
Shale: soft, much weathered, dark gray; contains much secondary gypsum.	1488	1.0	0.0	low
Siltstone: somewhat oolitic, hard, blocky, gray.	1489	0.6	0.0	low
Shale: oolitic, chippy to fissile, black; contains a limestone concretion 6 inches in diameter 1 foot from top.	1490	2.4	0.0	medium
Nodular oolite: hard but crumbly, dark gray; nodules up to 1 inch in diameter.	1491	0.7	0.0	low
Limestone: oolitic, hard, thin bedded, weathered, dark gray, (probably massive fresh).	1492	1.0	0.0	very low
Oolite: crumbly, numerous white (lime) coatings, shaly, dark gray.	1493	1.4	0.0	high
Limestone: hard, fossiliferous, gray; irregular in thickness, possibly because of concretionary structure or folding.	1494	1.5	0.0	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Shale: soft, chippy in lower half, dark gray.	1493	3.0	0.0	low
Siltstone: calcareous, hard, blocky, gray.	1496	3.3	0.0	low
Siltstone: like siltstone above, but weathers brown instead of gray.	1497	2.3	0.0	very low
Siltstone: hard, dark gray.	1498	2.0	0.0	very low
Limestone: hard, massive, dense, black, weathers buff gray.	1499	2.1	0.0	very low
Siltstone: calcareous, hard, blocky, dark gray.	1500	2.3	0.0	very low
Limestone: hard, dense, massive, black, weathers gray.	1501	2.4	0.0	very low
Siltstone: calcareous, hard, chippy to blocky, dark gray.	1502	3.7	0.0	very low
Limestone: hard, dense, massive, dark gray.	1503	2.2	0.0	very low
Siltstone: hard, shaly to blocky, grayish brown; contains a few calcareous layers.	1504	3.8	0.0	very low
Limestone: hard, dense, massive, dark gray.	1505	1.2	0.0	very low
Shale: oolitic, medium hard, chippy, dark grayish brown.	1506	2.7	0.0	very low
Limestone: silty, hard, massive, dark gray.	1507	1.5	0.0	very low
Shale: medium hard, chippy, dark gray.	1508	0.9	0.0	very low
Shale: like shale above but contains limestone concretions.	1509	0.6	0.0	very low
Shale: medium hard, chippy, grayish brown.	1510	1.7	0.0	medium
Limestone concretion: hard, weathers grayish brown.	1511	0.7	0.0	very low
Shale: calcareous, medium hard, chippy to fissile, dark grayish brown.	1512	1.5	0.0	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Siltstone: calcareous, hard, massive, grayish brown.	1513	1.6	0.0	low
Shale: finely oolitic, medium hard, chippy to fissile, dark brown.	1514	1.9	0.0	medium
Limestone: hard, dense, massive, black, buff gray weathered.	1515	1.4	0.0	very low
Shale: locally finely oolitic, medium hard, chippy, dark brown to black.	1516	9.1	0.0	medium
Limestone: hard, dense, massive, dark gray.	1517	0.4	0.0	very low
Limestone: like limestone above, but more oolitic and more massive.	1518	2.2	0.0	medium
Limestone: hard, massive, gray, buff weathered.	1519	0.6	0.0	very low
Oolite: hard, blocky, grayish brown.	1520	0.7	0.0	medium
Limestone: hard, dense, massive, weathers buff, dark gray.	1521	1.7	0.0	very low
Siltstone: hard, blocky, black.	1522	0.7	0.0	medium
Shale: medium hard, chippy, dark gray.	1523	1.5	0.0	medium
Limestone: oolitic, hard, blocky, buff gray.	1524	0.4	0.0	very low
Shale: locally oolitic, hard, chippy, dark gray.	1525	1.3	0.0	medium
Limestone: hard, dense, massive, black; gray weathered.	1526	2.7	0.0	low
Shale: oolitic, medium hard, chippy, dark gray.	1527	0.7	0.0	high
Wells formation?				
Limestone: hard, massive, (contains shaly-weathering zones), dark gray.	1528	15.5	0.0	very low
Covered: one outcrop of dark-gray, hard limestone about in center of interval		18	n.d.	n.d.
Wells formation		n.d.	n.d.	n.d.

Conda mine, Idaho

Partial section of the phosphatic shale member of Phosphoria formation measured largely in the 509 cross-cut of the Anaconda Copper Mining Company mine at Conda, Caribou County, Idaho (pl. 5). Beds dip about 45° N 78° E. P_2O_5 and V_2O_5 determinations were made by Anaconda Company.1/ Section described by W. W. Rubey and V. E. McKelvey: thickness of units adjusted to section surveyed and sampled by Anaconda.

	Thickness (feet)	V_2O_5 (percent)	P_2O_5 (percent)
Rex member			
Phosphatic shale member			
Covered	?		
UPPER PHOSPHATE ZONE			
Phosphate rock: oolitic, medium hard, brown, in beds 0.8-1.5 feet thick, interbedded with soft, brown fracture-cleavage clay in beds 0.2-0.6 foot thick.	7.0	0.09c	33.6
Clay: soft, tan.	1.1	0.15c	27.9
Oolite: soft, massive, black.	0.3	0.15c	27.9
Clay: soft, tan.	0.4	0.15c	27.9
VANADIFEROUS ZONE (upper and lower limits uncertain)			
Siltstone: soft, fissile and thin-bedded, interbedded black and brown.	1.9	0.21c	27.9
Siltstone: hard, fine-grained, thin-bedded but massive, black.	3.8	0.39c	16.6
Siltstone: generally soft, thin-bedded, brown and black; some layers fractured; contains hard 12-inch concretion.	3.5	0.34	14.2
Siltstone: hard, fine-grained, thin-bedded: 1-inch fissile shale at top.	2.3	0.34	14.2
Siltstone: soft, black.	0.2	0.34	14.2

1/ Mansfield, G. R., Recent studies of reserves of domestic phosphate: Amer. Inst. Min. Met. Eng. Tech. Pub. 1208, p. 7, 1940.

	Thickness (feet)	V_2O_5 (percent)	P_2O_5 (percent)
Siltstone: very hard, dense.	0.2	0.0[2]	13.6
Siltstone: medium hard, thin-bedded, dense; many slickensided surfaces.	0.7	0.0	13.6
Siltstone: granular texture, very thin-bedded.	0.1	0.0	13.6
Shale: hard, dense; many slickensides; almost slate.	0.3	0.0	13.6
Siltstone: hard, massive, dense, fine-grained, grades into siltstone above.	1.0	0.0	13.6
Concretion: very hard siltstone(?).	0.2	0.0	13.6
Siltstone: hard, thin-bedded.	0.2	0.0	13.6
Concretion: very hard siltstone (?).	0.4	0.0	13.6
Siltstone: hard, thin-bedded, black.	0.1	0.0	13.6
Siltstone: soft, thin-bedded, black.	0.6	0.0	13.6
Siltstone: hard, massive, black.	1.8	0.09c	16.6
Siltstone: hard, (softer weathered), very massive, black.	2.0	0.09c	16.6
Siltstone: somewhat softer than above, thin to slaty bedded.	2.5	0.09c	11.0
Siltstone: relatively soft, black; some calcite veins near base, some stained red.	2.7	0.09c	11.0
Siltstone: hard, massive, medium-grained to dense, black.	3.7	0.09c	11.0
Siltstone: relatively soft, much fractured, dense to medium-grained; abundant iron (?) stains on irregular joint surfaces in lower part.	3.2	0.09c	1.5 ft.- 11.0 1.7 ft.- 9.8

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[2] This bed, 9.8 feet of beds above it and 3.6 feet of beds below it were grouped together in one sample which was found to contain 0.20 percent V_2O_5; the 9.8 feet of beds above this sample were subsequently analyzed separately and found to average 0.36 percent V_2O_5—slightly more total vanadium than present in the 13.6 feet of beds, as determined by the other analysis. Admitting an error in sampling or analysis, I am assuming that apparently all of the vanadium in the 13.6 feet of beds is contained in the upper 9.8 feet and that the lower 3.8 feet is barren.

	Thickness (feet)	V_2O_5 (percent)	P_2O_5 (percent)
Siltstone; soft, massive, fractured, black (almost blue black): grades into siltstone above.	0.5	0.09c	9.8
Siltstone: brittle, hard, dense, black; fissile shale at base.	1.4	0.09c	9.8
Siltstone: hard, dense, brown stains on joints 1 foot below top; soft black shale partings 2 feet above base.	4.6	0.09c	9.8
Siltstone: soft, massive, brown-stained.	1.8	0.04c	4.2
Clay: soft, laminated, tan.	1.9	0.04c	4.2
Shale: medium soft, thin-bedded.	1.7	0.07c	11.2
Shale: thin-bedded, brown, alternates with harder, dense, black siltstone.	2.1	0.07c	11.2
Siltstone: hard, dense.	0.2	0.07c	11.2
Shale: soft, brown.	2.2	1.0 ft. -0.07c 1.2 ft. -0.05c	1.0 ft. -11.2 1.2 ft. -7.0
Shale, harder than above.	0.8	0.05c	7.0
Shale: soft, black	0.2	0.07c	4.0
Siltstone: hard, dense, black; becomes harder and denser toward base.	6.2	0.07c	4.0
Clay (?): liesegang banding, brown.	1.4	0.07c	4.0
Siltstone: very hard; 2-inch black seam 1 foot below top.	2.9	1.0 ft. -0.07c 1.9 ft. -0.05c	1.0 ft. -2.0 1.9 ft. -12.0
Clay (?): brown, contains 1-inch concretion.	0.8	0.05c	12.0
Siltstone: hard, massive, black.	8.1	0.05c	6.0 ft. -8.8 1.8 ft. -11.8 0.3 ft. -6.4
Siltstone: black, slickensided, lenticular.	0.2	0.05c	6.4
Siltstone; hard, thin-bedded.	0.5	0.05c	6.4

	Thickness (feet)	V_2O_5 (percent)	P_2O_5 (percent)
Siltstone: soft, crystalline, black.	0.3	0.05c	6.4
Siltstone: hard, dense.	2.0	0.05c	6.4
Siltstone: soft, lenticular.	0.2	0.05c	1.4
Siltstone: hard.	0.1	0.05c	1.4
Siltstone: soft, concretionary.	1.2	0.05c	1.4
Siltstone: hard, crystalline.	0.3	0.05c	1.4
Mudstone: hard.	1.9	0.05c	1.4
Mudstone: hard.	0.8	0.05c	6.4
Mudstone: hard.	0.4	0.05c	6.4
Siltstone: very soft, thin-bedded.	0.1	0.05c	6.4
Siltstone: hard, thin-bedded.	0.8	0.05c	6.4
Mudstone: leached (altered?), brown.	2.3	0.05c	6.4
Siltstone: hard, concretionary, black, brown weathered.	0.1	0.05c	6.4
Siltstone: soft, black.	0.1	0.05c	6.4
Siltstone: very hard, massive, dense, black.	1.6	0.05c	6.4
Siltstone: medium hard, dark brown.	0.5	0.05c	6.4
Shale: soft, slickensided, black.	0.5	0.05c	6.4
Siltstone: hard, concretionary, dark gray; alternates with ½-inch beds of soft, tan clay.	3.7	0.05c	6.4
Siltstone: medium soft, banded to massive, lower 2 feet harder than upper 3 feet, tan.	5.0	0.05c	12.8
Siltstone: hard, massive.	1.0	0.05c	9.9
Siltstone: hard, nodular, hackly fracture.	0.2	0.05c	9.9
Siltstone: hard, massive; brown iron stains and bands inside fresh rock.	1.5	0.05c	9.9
Siltstone: thin-bedded, alternating soft and hard, brown, dark gray and black; contains some massive dense beds and soft brown clays.	0.9	0.05c	10.8

	Thick-ness (feet)	V_2O_5 (per-cent)	P_2O_5 (per-cent)
Siltstone: very hard, massive, dark brown.	0.2	0.05c	10.8
Siltstone: medium hard, hackly, medium brown.	0.1	0.05c	10.8
Siltstone: dense, hard, medium- to thin-bedded, black.	0.5	0.05c	10.8
Clay: soft, liesegang banded, massive, tan.	1.5	0.05c	13.5
Siltstone: hard, thin-bedded; alternates with soft black layers 1-4 inches thick.	2.0	0.05c	13.5
Siltstone: hard, thin-bedded, yellow-stained.	1.3	0.09c	8.1
Siltstone: soft, crumpled, black.	1.0	0.09c	8.1
Siltstone: hard, thin- to medium-bedded; alternates with occasional 2- to 3-inch beds of soft, black siltstone.	11.4	0.09c	3.5 ft. -8.1 3.7 ft. -9.3 4.2 ft. -10.9
Siltstone: soft, thin-bedded, dark brown to black.	1.0	0.09c	9.5
Clay: soft, massive, tan to black; irregularly splotched in color and clearly secondary.	2.0	0.09c	9.5
Siltstone: hard, dense, massive, black.	2.7	1.8 ft. -0.05c 0.9 ft. -0.02c	1.8 ft -4.0 0.9 ft. -9.1
Clay: soft, black.	0.2	0.02c	9.1
Siltstone: very hard, dense to fine-grained, massive black.	3.1	0.02c	2.0 ft. -9.1 1.1 ft. -10.6
Siltstone: hard, thin- to medium-bedded.	2.3	0.02c	10.6
Siltstone: hard, thin, chippy; alternates with soft black layers.	0.4	0.02c	10.6
Silt: soft, unconsolidated, black; a few inconspicuous brown stains.	1.5	0.02c	10.6
Siltstone: thin- and medium-bedded, chippy.	0.7	0.02c	10.6
Siltstone: soft, thin-bedded, black.	0.2	0.02c	10.6

	Thickness (feet)	V_2O_5 (percent)	P_2O_5 (percent)
Siltstone: hard, thin- to medium-bedded.	1.2	0.02c	10.6
Clay: soft, diffusion banded, massive, tan.	0.7	0.02c	10.6
Siltstone: hard, fine-grained, thin-bedded; alternates with subordinate soft, black ¼-inch layers.	2.3	0.02c	10.6
Shale or mudstone: hard, chippy, thin-bedded.	0.9	0.02c	18.7
Shale: fissile to thin-bedded, black; lustrous gummy clay seam at top.	1.1	0.02c	18.7
Shale: soft, clayey, thin-bedded to fissile.	2.2	0.02c	18.7
Siltstone: hard, thin-bedded, dark brown.	0.5	0.02c	18.7
Siltstone: massive, medium to dark brown.	2.6	1.3 ft. -0.02c 1.3 ft. -0.02c	1.3 ft. -18.7 1.3 ft. -3.9
Siltstone: soft, massive, tan secondary discoloration.	0.7	0.02c	3.9
Clay: soft, massive, medium to dark brown.	0.4	0.02c	3.9
Siltstone: medium hard, thin-bedded, black.	1.5	0.02c	3.9
Siltstone: medium hard, laminated, tan to medium brown.	0.9	0.18c	21.4
Clay: soft, massive, tan.	0.1	0.18c	21.4
Siltstone: medium soft to hard, medium- to thin-bedded, laminated, dark brown, tan, and black; more massive above.	2.1	0.18c	21.4
Clay: laminated, soft, tan.	0.7	0.18c	21.4
Clay: soft, tan.	0.7	0.18c	21.4
Shale: lustrous, dark brown.	0.1	0.18c	21.4
Clay: soft, lenticular, tan.	0.2	0.18c	21.4
LOWER PHOSPHATE BED •			
Phosphate rock, granular (oolitic?), dark gray; tan partings.	1.3	0.25c	33.2
Phosphate rock: oolitic to fine-grained.	3.9	0.25c	33.2
Phosphate rock: dense to fine-grained, black.	1.6	0.25c	33.2
Clay: soft, laminated to fissile, brown.	0.2	0.16c	6.8

	Thick- ness (feet)	V_2O_5 (per- cent)	P_2O_5 (per- cent)
Siltstone: hard, fine-grained, massive, dark gray.	1.0	0.16c	6.8
Clay: grades into siltstone above.	0.5	0.02c	1.8
Clay: soft, tan.	0.5	0.02c	1.8
Clay: massive, medium hard, tan.	1.3	0.02c	1.8
Clay: soft, thin dark gray streaks.	0.3	0.02c	1.8
Chert(?): medium hard, gray.	0.3	0.02c	1.8
Breccia: probably black chert and tan clay.	0.5	0.02c	1.8
Wells formation			
"Rice lime"; fine-grained, tan, dolomite.	5.0±	2.2 ft. -0.02c	2.2. ft. -1.2

Total thick 141.3

Caldwell Canyon, Idaho

Nearly complete section of the phosphatic shale member of the Phosphoria formation exposed in U. S. Geological Survey trench on the north side of Caldwell Canyon, sec. 7, T. 8 S., R. 44 E., Caribou County, Idaho (pl. 5): measured by V. E. McKelvey.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Rex member.				
Chert: calcareous, hard, blocky, light gray.	1529	n.d.	0.0	very low
Covered.		3.9		
Phosphatic shale member.				
Siltstone: soft, shaly, brown; soil admixed, possibly not in place.	1530	2.1	0.0	very low
Shale: calcareous, soft, platy, dark brown; much weathered.	1531	1.9	0.0	very low
Siltstone: calcareous, hard, blocky, fossiliferous, brown.	1532	3.5	0.0	very low
Siltstone: medium hard, thin-bedded, brown; grades into siltstone above.	1533	1.4	0.0	very low
Siltstone: soft to medium hard, shaly, dark brown.	1534	2.6	0.0	very low
Siltstone: hard, dark brown; contains nodules about 1 inch in diameter.	1535	0.4	0.0	very low
Siltstone: locally oolitic, hard, thin bedded, brown; contains elliptical concretions 2 inches in diameter. Grades into siltstone above.	1536	0.5	0.0	very low
Oolite: nodular, hard but crumbly, black.	1537	0.4	0.0	very low
Shale: soft, a few nodules in upper part, black; grades into oolite above.	1538	1.6	0.0	very low
Siltstone: calcareous, soft (local hard layers), fossiliferous, yellow-brown. Possibly weathered limestone.	1539	2.3	0.0	very low
UPPER PHOSPHATE ZONE				
Oolite, hard but crumbly, thin bedded, gray; yellow stains parallel to bedding.	1540	2.4	0.0	high

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Shale: oolitic, soft, brown; light brown 1-inch bed at base.	1541	1.5	0.05	very low
Oolite: hard but crumbly, shaly, black.	1542	0.8	trace	low
VANADIFEROUS ZONE (lower limit indefinite) Shale: oolitic, soft, black.	1543	2.2	0.42c	very low
Shale: like above.	1544	2.0	0.29c	very low
Shale: like above.	1545	2.1	0.16c	very low
Shale: like shale above but contains a few nodules and small concretions.	1546	1.2	0.0	very low
Shale: like shale above but contains many small nodules and concretions.	1547	1.3	0.0	very low
Shale: soft, black; contains many elliptical concretions (medium hard) up to 3 inches in diameter.	1548	2.7	0.0	very low
Siltstone: medium hard, shaly to blocky, dark brown; contains elliptical nodules up to 6 inches in diameter—probably formed by weathering.	1549	3.1	0.0	very low
Shale: nodular and oolitic, brown, red stains.	1550	3.3	0.0	very low
Siltstone: medium hard, chippy, brown, yellow-brown weathered.	1551	1.1	0.0	very low
Shale: finely oolitic, medium hard, chippy to blocky (cross fractured), black.	1552	2.2	0.0	very low
Shale: medium hard, fissile to chippy, dark brown.	1553	2.0	0.0	very low
Siltstone: medium hard, blocky, brown.	1554	0.7	0.0	very low
Siltstone: soft and earthy to medium hard, brown.	1555	2.4	0.0	very low
Siltstone: locally oolitic, soft, shaly, dark brown.	1556	2.3	0.0	very low
Silt: calcareous, soft, earthy, brown.	1557	2.6	0.0	very

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Shale: soft, dark brown.	1558	0.8	0.0	very low
Siltstone: soft to medium hard, shaly to blocky, brown.	1559	2.6	0.0	very low
Oolite: soft, black; contains hard nodules.	1560	0.4	0.0	low
Siltstone: somewhat oolitic, soft, contains many small medium hard concretions, shaly, brown.	1561	1.6	0.0	very low
Siltstone: calcareous, hard, massive, brown.	1562	0.6	0.0	low
Siltstone: somewhat oolitic, soft, shaly, brown: contains many small medium hard concretions.	1563	0.8	0.0	very low
Siltstone: moderately calcareous, hard, massive, brown, light brown stains.	1564	0.7	0.0	very low
Siltstone: medium hard, shaly to blocky, brown.	1565	0.9	0.0	very low
Siltstone: calcareous, hard, chippy, brown to gray, contains a few small nodules; grades into siltstone above.	1566	3.8	0.0	very low
Silt: soft, earthy, massive, yellowish brown; contains a few hard fragments of same material.	1567	1.4	0.0	very low
Siltstone: calcareous, hard, blocky, dark grayish brown, reddish yellow stain.	1568	1.4	0.0	very low
Siltstone: hard, thin-bedded, greenish black; a few brown streaks.	1569	4.2	0.0	very low
Siltstone: like shale above.	1570	2.6	0.0	very low
Silt: soft, earthy, yellow brown.	1571	1.6	0.0	very low
Shale: soft, much weathered, black; contains small hard nodules.	1572	0.7	0.0	very low
Siltstone: medium hard, shaly to massive, dark brown; light brown earthy zones at top and base.	1573	4.2	0.0	very low
Shale: calcareous, soft, weathered, black.	1574	2.1	0.0	very low
Siltstone: soft to medium hard, brown; possibly not in place.	[illegible]	[illegible]	[illegible]	[illegible]

	Sample No.	Thickness (feet)	V_2O_5 (per cent)	P_2O_5
Silt: massive, very light in weight, light yellowish brown.	1576	1.0	0.0	very low
Shale: somewhat oolitic, soft, black; much weathered.	1577	1.3	0.0	very low
Shale: soft to medium hard, gray brown.	1578	2.0	0.0	very low
Shale: somewhat oolitic, soft, dark brown; much weathered.	1579	3.6	0.0	very low
Shale: like shale above.	1580	2.9	0.0	very low
Limestone: hard, blocky to massive, gray.	1581	11.5	0.0	low
Shale: medium hard, dark gray.	1582	1.9	0.0	low
Limestone: hard, blocky to massive, gray.	1583	4.7	0.0	very low
Shale: oolitic, soft, chippy to fissile, black.	1584	3.0	0.15	low
Limestone: silty, hard, blocky, gray.	1585	1.0	0.0	very low
Oolite: soft, black.	1586	3.5	0.25	medium
Shale: oolitic, soft, black.	1587	2.2	0.10	very low
Siltstone: medium hard, blocky to massive, brown.	1588	0.8	0.05	very low
Shale: oolitic, soft, black.	1589	1.0	0.10	medium
Limestone: hard, blocky to massive, gray.	1590	0.7	0.0	very low
Shale: oolitic, soft, black.	1591	2.9	0.0	medium
Limestone: oolitic, hard, gray; possibly lenticular.	1592	2.2	0.0	very low
LOWER PHOSPHATE BED				
Oolite: medium hard, shaly, black.	1593	0.4	0.05	low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Siltstone: calcareous, oolitic, hard, massive, brown.	1594	0.6	<0.06c	very low
Oolite: medium hard, shaly, black.	1595	3.6	0.27c	medium
Oolite: like above.	1596	3.2	0.25c	low
Shale: clayey, soft, reddish brown.	1597	0.2	0.86c	very low
Oolite: hard, massive, gray.	1598	0.2	0.0	low
Wells formation.				
Limestone: hard, massive, gray.	1599	n.d.	n.d.	n.d.

Swan Lake Gulch, Idaho

Complete section of phosphatic shale member of Phosphoria formation exposed in U. S. Geological Survey trench on the north side of Swan Lake Gulch, sec. 29, T. 9 S., R. 43 E., Caribou County, Idaho; measured by V. E. McKelvey.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Rex member.				
Chert: hard, thin-bedded (2-4 inches), gray to black.	1316		0.0	very low
Phosphatic shale member.				
Oolite: moderately calcareous, hard, thin-bedded (shaly at base), gray.	1317	0.5	0.0	very low
Siltstone: moderately calcareous, soft, massive, yellow brown.	1318	0.8	0.0	very low
Shale: soft, much weathered (lime coating along joints), dark brown.	1319	1.4	0.0	very low
Siltstone: medium hard, massive, yellow brown.	1320	0.7	0.0	very low
Siltstone: hard, massive, in upper 0.7 foot, thin-bedded below, yellow to medium brown.	1321	1.7	0.0	low
Siltstone: hard, massive, yellow to medium brown.	1322	3.1	0.0	very low
Shale: medium hard, brown.	1323	0.8	0.0	very low
Siltstone: hard, massive, yellow brown.	1324	0.1	0.0	very low
Shale: soft, a few thin, hard limy beds in basal 0.8 foot, brown.	1325	1.8	0.0	very low
Siltstone: medium hard, blocky, dark brown.	1326	2.3	0.0	very low
Siltstone: medium hard, much weathered, shaly to blocky, brown. Softer and darker in lower 0.4 foot. Grades into siltstone above.	1327	2.3	0.0	very low
Shale: oolitic, medium hard, black.	1328	0.3	0.2	medium
Siltstone: fluor-like, yellow brown; contains many hard calcareous fragments. Possibly weathered limestone.	1329	1.1	0.05	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
UPPER PHOSPHATE ZONE				
Oolitic shale: soft, black; contains hard layers of oolite.	1330	1.4	0.05	medium
Shale: oolitic, soft, much weathered (lime coating along joints), brown.	1331	1.2	0.4	very low
Limestone: oolitic, blocky, brown.	1332	1.1	0.0	very low
Shale: locally oolitic, soft to medium hard, much weathered (lime coating along joints) in upper 0.8 foot, brown.	1333	2.7	0.35	very low
Oolite: soft and hard layers interbedded, dark brown to black.	1334	1.4	0.25	low
VANADIFEROUS ZONE (lower limit indefinite)				
Shale: soft, dark gray; contains a few limestone concretions (one 4 x 8 inches) and a few thin limestone beds at base.	1335	1.9	0.51c	very low
Shale: like shale above.	1336	1.6	0.39c	low
Limestone; hard, dark gray.	1337	0.2	<0.06c	very low
Shale: soft, dark gray.	1338	2.2	0.47c	very low
Shale: soft, fissile, black; a few limestone concretions and thin limestone seams (1½ inches) at top and bottom.	1339	2.8	0.59c	very low
Shale: finely oolitic, soft, black; weathered (lime cement); 4 x 10 inch limestone concretion at base.	1340	3.2	0.0	low
Shale: soft to medium hard, dark brown. Grades into shale above.	1341	3.3	0.0	very low
Siltstone: soft, massive, light yellowish brown.	1342	0.6	0.0	very low
Shale: soft, weathered (lime cement) dark brown; 6 x 12 inch lime concretion at base.	1343	1.4	0.0	very low
Siltstone: medium hard to hard, blocky, brown.	1344	4.3	0.0	low
Siltstone: medium hard to hard, thin-bedded, light brown.	1345	1.1	0.0	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Siltstone: medium hard, blocky, dark brown; contains numerous small nodules.	1346	1.7	0.0	very low
Siltstone: medium hard, blocky, dark brown; contains many small nodules.	1347	1.1	0.0	very low
Siltstone: medium hard, blocky, brown.	1348	3.2	0.0	very low
Shale: soft, much weathered, black.	1349	0.7	0.0	low
Siltstone: medium hard, massive, brown.	1350	0.7	0.0	very low
Siltstone: medium hard, shaly, brown.	1351	2.6	0.0	very low
Covered.		3.1	n.d.	n.d.
Siltstone: brown, much weathered; possibly not in place.	1352	0.7	0.0	very low
Shale: somewhat oolitic, much weathered, black.	1353	0.3	0.0	very low
Siltstone: medium hard, massive, yellow brown.	1354	0.6	0.0	very low
Shale: locally oolitic, medium hard, black.	1355	1.9	0.0	very low
Shale: slightly oolitic, soft, fissile, black; 8-inches light brown shale in middle.	1356	2.4	0.0	low
Shale: soft to medium hard, black; contains numerous nodules; grades into shale above.	1357	0.7	0.0	low
Siltstone: medium hard, shaly to blocky, yellow brown to brown.	1358	3.2	0.0	very low
Siltstone: medium hard, shaly to blocky, yellow brown to brown; weathered, possibly not in place.	1359	5.0	0.0	very low
Shale: slightly oolitic, soft, black; numerous iron stains; contains a few medium hard layers.	1360	2.3	0.0	very low
Siltstone: flour-like, light yellow brown in upper 0.6 foot; medium hard, medium brown in lower part.	1361	2.2	0.0	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Silt: flour-like, very light in weight, massive, light yellow brown; a few layers of medium brown siltstone. Possibly weathered limestone.	1362	4.9	0.0	very low
Limestone: hard, blocky, brown.	1363	1.5	0.0	very low
Nodular oolite: crumbly, black.	1364	0.5	0.0	medium
Shale: soft to medium hard, black, numerous iron stains.	1365	1.5	0.0	low
Siltstone: hard, massive, brown.	1366	3.4	0.0	very low
Siltstone: like siltstone above.	1367	2.4	0.0	very low
Nodular oolite: massive but crumbly, dark gray; numerous iron stains.	1368	1.1	0.0	very low
Siltstone: calcareous, soft, massive, light tan.	1369	1.0	0.0	very low
Oolite: medium hard, massive, black.	1370	1.0	0.0	low
Siltstone: locally oolitic, medium hard, blocky, brown, grades into oolite above.	1371	4.1	0.0	very low
Oolite: soft, massive, black.	1372	1.2	0.0	low
Siltstone: hard, blocky, brown; contorted possibly because of spheroidal weathering.	1373	3.7	0.0	very low
Siltstone: like siltstone above.	1374	3.2	0.0	very low
Shale: soft, much weathered, dark brown.	1375	2.7	0.0	very low
Siltstone: soft, much weathered, thin-bedded, dark brown.	1376	3.0	0.0	very low
Shale: crumbly, black; contains oolitic nodules.	1377	0.5	0.0	very low
Siltstone: medium hard, massive, brown.	1378	1.2	0.0	very low
Silt: massive, contorted, light yellow brown. Thickness approximate.	1379	1.0	0.0	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Shale: soft to medium hard, light brown; much weathered, not entirely in place.	1380	2.2	0.0	very low
Shale: oolitic, much weathered, black.	1381	2.5	0.0	very low
Shale: dark brown; contains numerous small elliptical concretions.	1382	1.4	0.0	very low
Shale: soft, light brown.	1383	0.8	0.0	very low
Shale: dark brown to black. Grades into shale above.	1384	1.5	0.0	low
Silt: soft, massive, medium brown.	1385	0.8	0.0	very low
Shale: locally oolitic, soft, dark brown to black.	1386	3.1	0.0	low
Siltstone: soft, shaly, brown.	1387	0.5	0.0	low
Shale: soft, fissile, black; much weathered, possibly not in place.	1388	3.9	0.0	low
Shale: locally oolitic, soft, fissile, black.	1389	3.7	0.0	low
Shale: oolitic, soft, much weathered, black.	1390	3.0	0.0	very low
Covered.		38.0		
LOWER PHOSPHATE BED				
Oolite: hard but crumbly, shaly, black.	1391	3.4	0.24c	medium
Oolite: like oolite above.	1392	2.7	0.45c	medium
Oolite: hard but crumbly, thin bedded, black.	1393	3.2	0.38c	medium
Shale: soft, much weathered, dark brown.	1394	1.4	0.63c	very low
Siltstone: light brown, weathered, fairly massive; possibly weathered limestone. Grades into shale above.	1395	1.4	0.25	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Oolite: hard, shaly, gray.	1396	0.3	trace	high
lls formation.				
Limestone: hard, massive, in upper 2 feet, gray; grades downward into yellowish sandy limestone (weathered).	1397	4.0	n.d.	n.d.

Montpelier Canyon, Idaho

Complete section of phosphatic shale member of Phosphoria formation exposed in U. S. Geological Survey trench on the north side of Montpelier Canyon, sec. 31, T. 12 S., R. 45 E., Bear Lake County, Idaho (pl. 7); lower phosphate bed and beds below described from natural exposure at the south end of Waterloo Hill, on the south side of Montpelier Canyon. Section measured by V. E. McKelvey.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Rex member.				
Cherty limestone: hard, massive, light to dark gray.	574	2.0	0.0	very low
Phosphatic shale member.				
Siltstone: soft, massive, light brown.	573	0.4	0.0	very low
Shale: soft, brown.	572	1.3	0.0	very low
Siltstone: calcareous, locally oolitic, medium hard, light brown; beds about 0.3 foot thick.	571	6.5	0.0	very low
Siltstone: locally oolitic, medium hard, massive, light brown, weathers light gray.	570	2.9	0.0	very low
Siltstone: locally oolitic, calcareous, medium hard, thin bedded, dark brown.	533	2.4	0.15	high
Siltstone: medium hard, massive, brown.	532	3.6	0.1	very low
UPPER PHOSPHATE BED				
Oolite: slightly calcareous, coarse to fine, thin bedded, gray; cherty?	531	2.4	0.05	medium
Oolite: cherty?, hard, much fractured, gray.	530	1.4	0.0	high
Siltstone: medium hard, fairly massive, brown.	529	1.2	0.1	very low
Oolite: cherty ?, soft, much fractured, gray.	528	1.9	0.1	low
Siltstone: slightly calcareous, soft, brown.	527	1.6	0.1	low
Fault?				
Oolite: calcareous, hard but much fractured, thin bedded, gray.	526	1.2	0.0	low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Siltstone: calcareous, oolitic in part, massive, brown.	525	0.8	0.1	high
Oolite: coarse, hard but much fractured, thin bedded, gray; contains a 6-inch limestone concretion.	524	2.9	0.25	high
Silt: soft, brown.	523	0.2	0.25	medium
Siltstone: calcareous, coarsely oolitic in lower part, finely oolitic in upper part, massive, brown.	522	1.0	0.25	medium
Shale: finely oolitic, brown; interbedded with coarse soft oolite.	521	1.0	0.25	medium
Oolite: calcareous, coarse, soft, thin bedded, gray.	520	0.5	0.25	low
Limestone: oolitic, hard, massive, brown.	519	0.8	0.0	very low
Shale: slightly calcareous, oolitic, medium hard, but much fractured, thin bedded, dark brown.	518	2.3	0.25	very low
Calcareous concretion: hard, brown.	517	0.8	0.0	very low
VANADIFEROUS ZONE (lower limit indefinite)				
Siltstone: oolitic, soft, thin-bedded, gray to brown.	575	0.8	0.79c	very low
Siltstone: like siltstone above.	576	1.3	0.57c	very low
Siltstone: like siltstone above.	577	1.5	0.55c	low
Siltstone: like siltstone above.	578	1.4	0.32c	very low
Siltstone: like siltstone above.	579	1.4	0.05	very low
Siltstone: like siltstone above.	580	1.0	0.05	low
Siltstone: oolitic, soft, thin bedded, gray to brown.	387	4.8	0.1	low
Siltstone: like siltstone above.	386	3.5	trace	very low
Siltstone: blocky, yellowish brown.	385	0.8	0.05	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Siltstone: oolitic, moderately calcareous, medium hard, brown.	384	3.5	trace	very low
Oolite: medium hard, grayish brown.	383	1.4	0.0	very low
Siltstone: slightly calcareous, medium hard, massive, brown.	382	0.5	0.1	very low
Siltstone: thin bedded, medium hard, dark grayish brown.	381	6.1	0.1	very low
Siltstone: slightly calcareous, soft to medium hard, brown.	380	2.2	0.1	very low
Shale: soft, blocky, dark gray.	379	1.2	0.0	very low
Siltstone: hard, massive, dark gray to black.	378	1.6	0.05	medium
Siltstone: soft, massive, brown.	377	0.8	0.0	very low
Shale: slightly calcareous, locally oolitic, medium hard, thin bedded, dark gray.	376	4.8	0.0	low
Limestone: hard, much fractured, buff gray.	375	8.2	0.0	very low
Shale: slightly calcareous, soft to medium hard, thin bedded, dark gray.	374	5.2	0.0	very low
Limestone: hard, concretionary, dark gray.	373	0.4	0.0	very low
Shale: slightly calcareous, soft, thin bedded, black.	372	1.2	0.0	very low
Limestone: hard, much fractured, dark gray.	371	0.6	0.0	very low
Shale: calcareous, finely oolitic, soft, thin bedded, black.	370	6.2	0.0	low
Limestone: hard, gray; possibly concretionary.	369	0.2	0.0	very low
Shale: calcareous, soft, clayey, finely laminated, dark brown.	368	0.7	0.0	low
Limestone: hard, much fractured, buff gray; light gray weathered.	367	10.3	0.0	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Shale: slightly calcareous, clayey, soft, thin-bedded, black.	366	3.2	0.0	very low
Shale: slightly calcareous, medium hard, thin-bedded (1-2 inches), dark gray.	365	0.6	0.0	very low
Siltstone: calcareous, soft, massive, brown.	364	0.8	0.0	very low
Shale: moderately calcareous, finely oolitic (contains small limestone concretions), soft, black.	363	2.3	0.0	very low
Shale: calcareous, medium hard, thin-bedded, gray; light gray weathered.	362	1.7	0.0	very low
Shale; slightly calcareous, fissile, soft to medium hard, dark gray.	361	1.8	0.0	very low
Limestone concretions: isolated within the shale; hard, dark gray.	360	0.4	0.0	very low
Shale: slightly calcareous, sub-oolitic, soft to medium hard, fissile, dark gray.	359	3.9	0.0	low
Siltstone: calcareous, much fractured, granular, medium hard, dark gray to black.	358	0.6	0.05	very low
Shale: sub-oolitic, calcareous, clayey, soft, dark brown to black.	357	1.0	0.0	very low
Limestone: hard, much fractured, grayish brown, light gray weathered.	395	2.0	0.0	very low
Shale: moderately calcareous, thin-bedded, dark gray.	394	3.5	0.0	medium
Limestone: hard, blocky, grayish brown.	393	2.2	0.0	high
Shale: medium hard, fissile, black.	392	3.3	0.0	very low
Limestone: hard, dense, concretionary, dark gray.	391	1.7	0.05	low
Shale: thin-bedded, dark brown; hard 8-inch limestone concretion at top.	390	3.2	0.15	medium
Shale: like shale above.	389	2.4	0.15	medium
Siltstone: slightly calcareous, massive, dark brown.	355	0.7	0.15	medium

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Shale: moderately calcareous, soft, dark gray to black.	354	1.8	0.1	medium
Limestone: hard, beds 2-6 inches thick, dark gray.	353	1.5	0.0	very low
Shale: fissile to thin bedded (1-2 inches), dark gray; oolites up to 3 mm. in diameter irregularly distributed throughout.	352	2.4	0.0	high
Cap lime: limestone, oolitic, hard, massive, except for upper 0.4-0.6 foot which is shaly; fossiliferous, buff gray fresh, light gray weathered.	351	2.1	0.0	low
Measured at the south end of Waterloo Hill				
LOWER PHOSPHATE BED				
Oolite: soft to medium hard, thin-bedded (beds 0.1-0.3 foot thick), brownish black to black. Oolite grains range from about 1/16 to 1/8 inch in diameter. Vertical joints are conspicuous and are coated with white carbonate.	1646	2.0	0.23c	34.8% [1]
Oolite: like oolite above except more shaly (beds 0.02-0.2 foot thick).	1645	1.7	0.55c	34.8
Oolite: medium hard, massive in lower 0.4 foot (one bed), shaly in upper 0.2 foot (beds 0.01-0.05 foot thick), brownish black to black fresh (oolite grains are black, matrix is brownish black), pale brown weathered.	1644	0.6	0.07c	34.8
Oolite: soft, black.	1643	0.3	0.12c	34.8
Oolite: hard, massive, thick-bedded, brownish black to black fresh, pale brown weathered.	1642	0.9	0.10c	34.8
Shale: soft, non-oolitic, beds 0.01-0.02 foot thick, brownish-black.	1641	0.5	0.62c	n.d.
Siltstone: soft, non-oolitic in lower 0.3 foot, moderately oolitic in upper 0.1 foot, shaly (beds 0.1 foot thick), brownish black.	1640	0.4	0.17c	nd.

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[1] Analyses of entire lower phosphate bed from U. S. Geological Survey Prof. Paper 152, p. 280.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Limestone: silty, hard, massive, prominently fractured perpendicular to bedding, fossiliferous, brownish gray to brownish black fresh, light brownish gray weathered.	1639	2.0	n.d.	n.d.
Limestone: hard, shaly, brownish gray to brownish black fresh, light brownish gray weathered; not well exposed.	1638	0.5	n.d.	n.d.
Oolite: hard, fine-grained, fossiliferous, black, conspicuous bluish-white bloom on upper surface.		0.3	n.d.	n.d.
lls formation.				
Limestone: very hard, coarse-grained, dense, massive, fossiliferous, gray.	1637		n.d.	n.d.

Total thick MP = 190 ft.

Bloomington Canyon, Idaho

Composite section of phosphatic shale member of Phosphoria formation measured in Consolidated mine cross-cut and in 9-S cross-cut in draw joining Bloomington Canyon about 2 miles from Bloomington, Idaho, sec. 23, T. 15 S., R. 43 E., Bear Lake County, Idaho; section in 9-S cross-cut measured by A. L. Slaughter, that in Consolidated mine by V. E. McKelvey. The vanadium and phosphate analyses of the vanadiferous zone represent the average of several made by the Wyodak Coal and Manufacturing Company, agent for the Metals Reserve Company.

	Sample No.	Thickness (feet)	V_2O_5 (per-cent)	P_2O_5
Measured in Consolidated mine cross-cut				
Rex member (chert).	731	0.4+	0.0	very low
Phosphatic shale member.				
Oolite: soft, fine, gray.	730	0.7	0.05	medium
Siltstone: medium hard, light tan.	729	0.8	0.05	very low
Siltstone: hard, massive, dark brown.	728	1.8	0.05	very low
Siltstone: soft, weathered, massive, light brown.	727	3.6	0.25	very low
Silt: clayey, soft, massive, reddish, brown.	726	2.2	0.3	very low
Siltstone: soft, massive, brown.	725	3.2	0.35	very low
UPPER PHOSPHATE ZONE				
Oolite: soft, coarse, gray; red clay near top.	724	2.4	0.1	medium
Oolite: soft, coarse, gray.	723	1.4	0.1	medium
Oolite: soft, coarse, gray.	722	2.6	0.1	medium
Oolite: soft, massive, light gray.	721	3.0	0.5	medium
Clay: oolitic, soft, dark brown.	492	0.7	0.45c	medium
Oolite: soft, light gray.	491	0.6	0.21c	medium

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Siltstone: clayey, oolitic in places, light brown.		3.5	0.32c	very low
VANADIFEROUS ZONE (thickness and V_2O_5 content based on average of many measurements in north and south drifts)				
Siltstone: medium hard, well-bedded, (beds range from 2 to 8 inches in thickness), blocky, dark brown; a soft, black slickensided siltstone at top.		4.4	0.94c	3.3%
Siltstone lenses: locally calcareous, soft to hard, massive, black; included in either siltstone bed or oolite depending upon local character. Thickness is <u>not</u> in addition to that of oolite and siltstone bed.		1.1	0.48c	23.4%
Oolite: hard, coarse, black; thin layers of siltstone interbedded in upper half.		2.1	0.57c	11.0%
Shale: soft, shiny, black; contains thin oolitic layers in upper 1 foot; lower 6-10 inches is locally thicker bedded and harder; contains lenses of black, massive, siltstone which are either soft and noncalcareous or hard and calcareous and which generally occur near the base of the oolitic shale at the top of the bed.		3.0	1.31c	n.d.
Measured in 9-S cross-cut				
Siltstone and clay: soft, yellow to brown.		0.5	n.d.	n.d.
Siltstone: soft, massive, gray to tan.		0.6	0.11c	n.d.
Siltstone: soft, massive, bedded, tan to gray; streaks of red and yellow clay along bedding.		12.0	0.23c	n.d.
Siltstone: soft, tan; contains abundant flattened concretions.		1.4	n.d.	n.d.
Siltstone: soft, massive bedded, tan to gray.		6.2	n.d.	n.d.
Siltstone: hard, light gray to tan, red stained and cherty in part.		3.8	n.d.	n.d.
Siltstone: soft, gray to tan.		1.0	n.d.	n.d.
Oolite: gray, stained brown along fractures and along some beds.		1.4	n.d.	n.d.
Siltstone: soft, massive bedded, dark brown; contains red clay seams.		5.2	n.d.	n.d.

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Oolite: gray.		0.4	n.d.	n.d.
Chert: massive, bedded, fractured, light gray to tan; contains reddish clay seams and pockets.		3.0	n.d.	n.d.
Chert:		13.0	n.d.	n.d.
Oolite: hard, gray brown.		0.4	n.d.	n.d.
Siltstone: soft, dark brown.		0.2	n.d.	n.d.
Nodules: ½ to 1 inch in diameter, hard.		0.4	n.d.	n.d.
Siltstone: soft, massive, tan to brown.		3.1	n.d.	n.d.
Nodular oolite: cherty?, hard.		0.4	n.d.	n.d.
Siltstone: soft, massive, light gray.		2.0	n.d.	n.d.
Nodular layer.		0.3	n.d.	n.d.
Siltstone: soft, massive, gray to tan.		1.6	n.d.	n.d.
Nodular layer:		0.4	n.d.	n.d.
Siltstone: massive, light brown.		1.8	n.d.	n.d.
Siltstone: soft massive nodular layers interbedded.		5.2	n.d.	n.d.
Siltstone: dark brown; oolite; interbedded; medium hard.		2.1	n.d.	n.d.
Siltstone: soft, white.		0.8	n.d.	n.d.
Siltstone: oolitic, soft, black.		1.0	n.d.	n.d.
Siltstone: soft, white.		0.3	n.d.	n.d.
Shale: medium hard, black; contains several layers of black siltstone.		25±	n.d.	n.d.
Measured in Consolidated mine cross-cut (tie to above section only approximate).				
Limestone: hard, silty, massive, dark gray.	311	4.1	0.0	very low
Siltstone: calcareous, cherty, hard, dense, fractured, dark gray; contains veins of gypsum.	310	0.7	0.0	low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Limestone: hard, massive, but broken, dense, dark gray.	309	4.6	0.0	very low
Limestone: carbonaceous, hard, banded, dark gray.	308	1.9	0.0	very low
Fault.				
Siltstone: calcareous, hard, dark gray.	306	5.8	0.0	medium
Limestone: hard, dense, laminated, massive.	297	1.9	0.0	very low
Limestone: hard, dense, much fractured, dark gray.	296	3.5	0.05	very low
Siltstone: hard, massive, finely laminated, dark gray.	294-5	5.5	0.0	low
Siltstone: soft, granular, platy.	293	0.1	0.0	very low
Siltstone: hard, dense; interbedded with soft, granular.	292	2.0	0.0	low
Siltstone: micaceous, granular.	291	0.2	0.0	low
Siltstone: hard, dense.	290	1.0	0.0	very low
Siltstone: calcareous, hard, dense, dark gray; a few granular layers interbedded.	288	3.3	0.0	medium
Siltstone: calcareous, hard, hackly, brown.	287	1.4	0.1	low
Siltstone: hard, shaly to massive, black.	285-6	0.7	0.0	medium
Siltstone: tan with brownish streaks of carbonaceous matter; thin bedded to massive; soft, sandy appearance.	284	1.6	0.25	very low
Siltstone: finely laminated, thin bedded to massive, light gray to tan.	283	3.4	0.2	very low
Siltstone: hard, massive, dense, sandy appearance, light gray to yellow.	282	2.3	0.05	very low

	Sample No.	Thickness (feet)	V_2O_5 (percent)	P_2O_5
Siltstone: clayey, soft, reddish brown, gray and yellow streaks.	281	2.5	0.05	very low
Siltstone: sandy appearance, light gray to brown.	280	3.3	0.05	very low
Siltstone: sandy appearance, massive, light gray; a few hard calcareous layers.	279	1.4	0.3	very low
Siltstone: calcareous, thin bedded, sandy appearance, light gray.	278	1.3	0.3	very low
Siltstone: calcareous, massive, pinkish gray.	277	1.4	0.2	very low
LOWER PHOSPHATE BED Phosphate rock: oolite, gray.		5.5	n.d.	n.d.
Wells formation				
Quartzite; hard, but much broken, light gray; thin cherty layers near top.		n.d.	n.d.	n.d.