Wyoming State Geological Survey
Gary B. Glass, State Geologist

Phosphate Rock Resources of the Wind River Indian Reservation, Wyoming

by Richard P. Sheldon

Reprinted from: Administrative Report to the Bureau of Indian Affairs
and Shoshone - Arapahoe Tribes
1982
United States Department of the Interior
Geological Survey

Reprint No. 57 • 1995

Laramie, Wyoming

People with disabilities who require an alternative form of communication in order to use this publication should contact the Editor, Wyoming State Geological Survey at (307) 766-2286. TDD Relay Operator 1(800) 877-9975.

This and other publications available from: Wyoming State Geological Survey
P.O. Box 3008, University Station
Laramie, Wyoming 82071-3008
(307) 766-2286 • FAX (307) 766-2605

This report is released to the Public by authority of the Joint Business Council (JBC 6-7-93) of the Shoshone and Arapahoe Tribes of the Wind River Reservation.

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PHOSPHATE ROCK RESOURCES OF THE WIND RIVER INDIAN RESERVATION, WYOMING

BY

Richard P. Sheldon

work done under
Field Mineral Studies of Indian Lands
Interagency Agreement No. 8

Administrative Report to the Bureau of Indian Affairs,

and Shoshone - Arapahoe Tribes

1982

This report is prelimary and has not been reviewed
for conformity with U.S. Geological Survey
editorial standards

Phosphate Rock Resources of the Wind River Indian Reservation

by Richard P. Sheldon

Introduction

Phosphate rock has been known for most of this century to exist in the Permian rocks exposed along the east flank of the Wind River Range. In the southern part of the Wind River Range, particularly in the Lander area and farther south, phosphate resources have been considered to be more valuable than those in the northern Wind River Range, which includes most of those in the Reservation itself. The southern area has been studied extensively (Condit, 1924; King, 1947; Rohrer, 1973), and phosphate resources have been fairly well defined. The northern area has been less well studied (Sheldon, 1963). This report assembles the available data on the phosphate deposits in the Wind River Indian Reservation and assesses the resources.

In addition to the work cited above on phosphate deposits, a stratigraphic study of the Park City Formation, which contains the tongues of the phosphate-bearing Phosphoria Formation, was made by Ahlstrand (1971), as a part of a Master of Science degree at the University of Montana under the direction of J. A. Peterson, financed in part by a National Science Foundation grant. Peterson (1980) synthesized Ahlstrand's work along with that of other areas by a number of other workers in his project. The stratigraphic nomenclature for the Permian rocks of the western phosphate field was defined by McKelvey and others (1959). A number of full or partial geologic maps of seven and one-half minute quadrangles containing phosphate rock in the eastern Wind River Range have been published (Rohrer, 1973; Murphy and Richmond, 1965), and others have been mapped by J. F. Murphy but have not been published and include the Kirkland Park, Hays Park, Blue Holes and Burris seven and one-half minute quadrangles. In the Owl Creek Range in the northern part of the Reservation, E. K. Maughan (oral comm., 1981) has shown that the Park City Formation contains tongues of the Phosphoria Formation, which contain phosphate rock but in such small amounts that they have not been considered in this report. W. R. Keefer (1970) has published an analysis of the structural geology of the Wind River Basin, which includes all of the Wind River Indian Reservation, and has summarized the geology of both the published and unpublished data.

This past work, combined with data collected during 4 weeks of field work by the author in the summer of 1981, is used as the basis of this report. The area covered by the report includes primarily the outcrop of Permian rocks on the east flank of the Wind River Range within the Reservation, and extending far enough to the north and south of the Reservation to include data on phosphate rock that is relevant to the phosphate deposits of the Reservation. In addition, the phosphate deposits of Black Mountain on the Reservation were studied and assessed.

Geologic setting

The Wind River Indian Reservation lies in part of the Wind River Basin, which is flanked on the southwest by the Wind River Range and on the north by the Owl Creek Mountains and their westward extension beneath Tertiary volcanic rocks. The Wind River Range represents a relatively simple geologic structure (Keefer, 1970) (fig. 1). The beds along the northeast flank of the Wind River Range strike about north 35-40° west and dip northeast 10-17°. This homocline is almost unbroken by smaller structural folding and faulting, although several structures of a few hundred feet amplitude or displacement occur. The Ervay Member of the Park City Formation, which forms a prominent

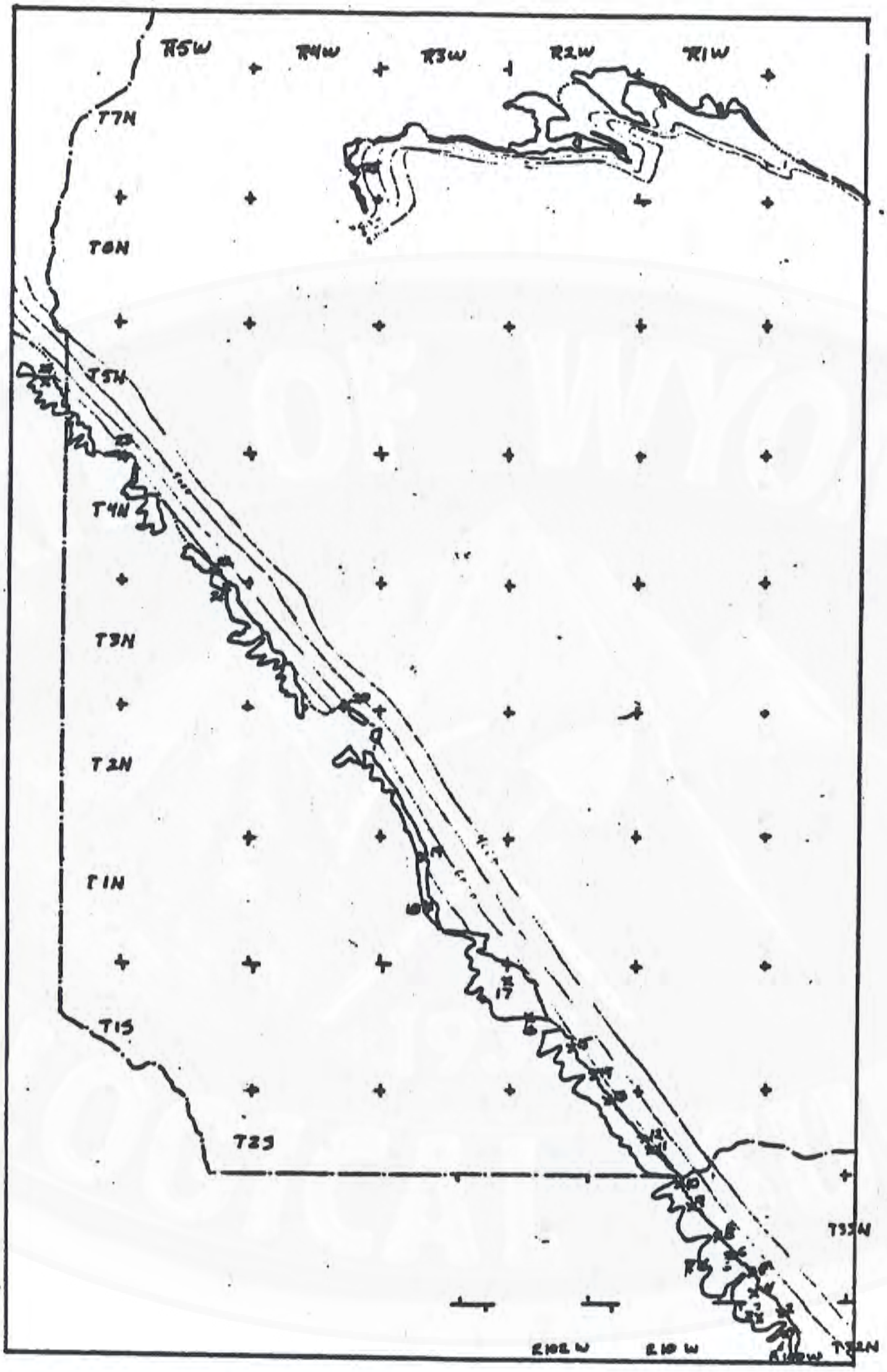
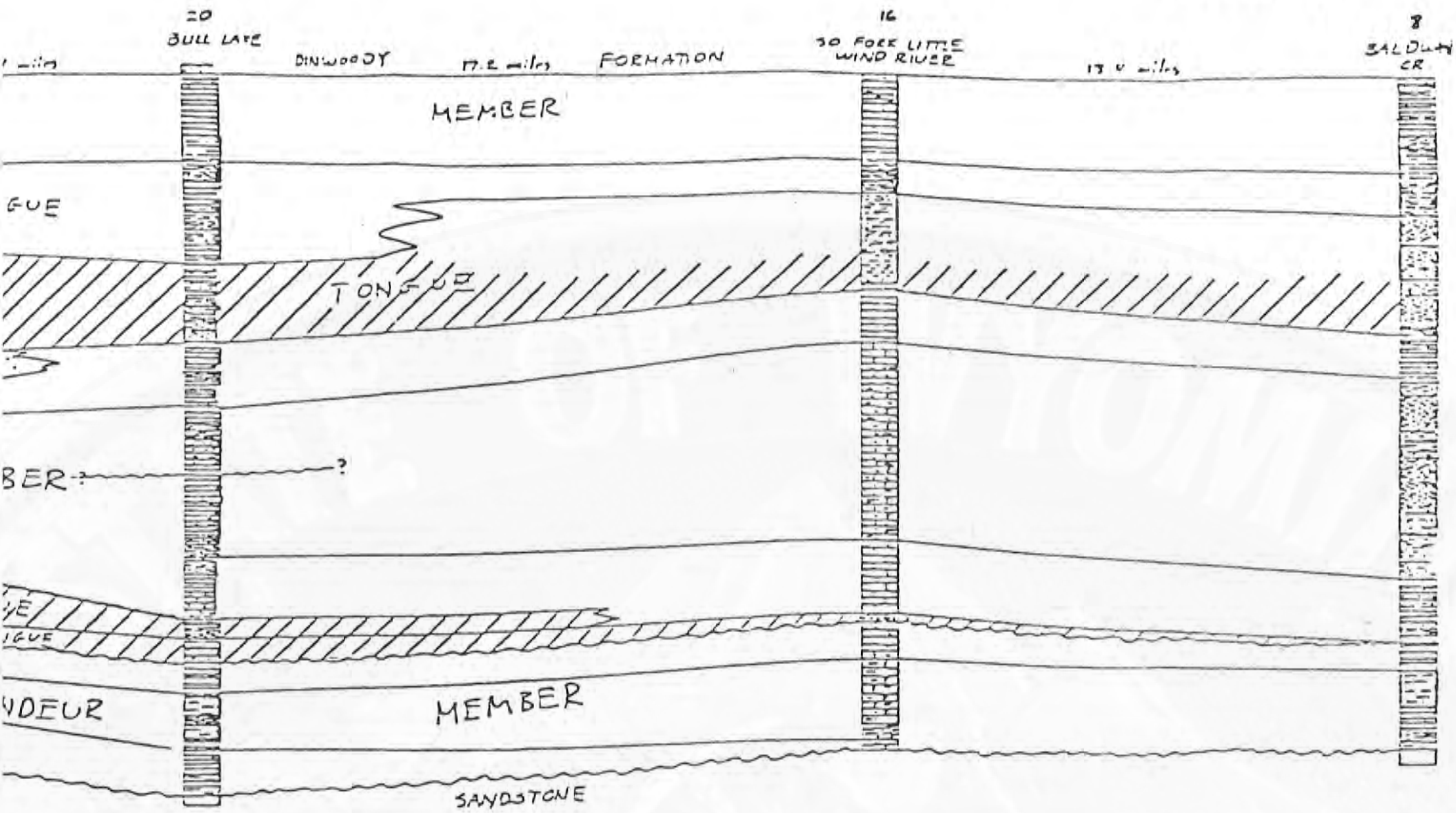


Fig. 1. Map showing outcrop of Park City Formation, location of sample localities and structure contours on top of Park City Formation After Keefer, 1970.

dip-slope on the mountain front, is composed of hard limestone that crops out at the surface, and its uppermost surface makes up most of the mountain front. The outcrop of the Ervay is commonly as much as one mile wide and in some places is over two miles wide. The irregularities of the outcrop of the Ervay are mainly due to erosion by valleys rather than by variations of geologic structure. Permian strata that underly the Ervay include intertongued members of the Phosphoria Formation, Shedhorn Sandstone, and other members of the Park City Formation (fig. 2). Beds of phosphorite within the Phosphoria have almost a flat surface dipping gently into the basin and are scalloped at their outcrop by valley erosion, which makes the calculation of the volume of phosphate rock simple and relatively accurate.

The northern flanks of the Wind River Basin have a much more complicated structure (Keefer, 1970) in the Owl Creek Mountains and its structural extension westward into the Black Mountain area. The Owl Creek Mountains comprise a complex east-west asymmetric uplift, whose southern limb is steeply dipping and in places overturned and reverse faulted, and with a secondary northwest-trending system of faults and folds. The Black Mountain section of the Park City Formation and intertongued phosphatic beds is located on the north side of the basin and is much more affected by folding and faulting than the Wind River Mountain outcrops. These structural differences between the regions are shown by the structure contours of figure 1 and Keefer's plate 3. The phosphate beds in the Black Mountain and Owl Creek regions are too thin to be considered economical resources, and reserve estimates have not been calculated for them.


20
BULL LAKE
DINWOODY
FORMATION
MEMBER
TONGUE
16
SO FORK LITTLE
WIND RIVER
8
BALDWIN
CR
MEMBER
SANDSTONE

ek, Wyoming.

Stratigraphy

The general stratigraphy of the rocks of the region is discussed in Keefer (1970), and only the stratigraphic relations of the Park City Formation are discussed here.

The Park City Formation is underlain by the Tensleep Sandstone of Pennsylvanian age. The Tensleep Sandstone is a massive cross-bedded sandstone, which contains a few beds of even-bedded dolomite. The formation commonly forms prominent cliffs and outcrops along valley walls, and also forms a prominent dip slope behind the Ervay dip slope. The contact between the two formations is ordinarily covered by debris. The Park City Formation is conformably overlain by the Dinwoody Formation of Triassic age.

The Park City Formation is divided into members by tongues of the Phosphoria Formation and the Shedhorn Sandstone (Sheldon, 1963) as shown in figure 2. Members of the Park City, from base to top are the Grandeur Member immediately overlying the Tensleep Sandstone, the Franson Member, and the Ervay Member at the top of the Permian sequence and overlain by the Dinwoody Formation. Separating the Grandeur and Franson Members are the Meade Peak and Rex Tongues of the Phosphoria Formation, and separating the Franson from the Ervay Member are the Retort and Tosi Tongues of the Phosphoria. In the northern part of the area the lower tongue of the Shedhorn underlies the Retort Tongue. These relationships are shown in figure 2 and are more completely discussed in Sheldon (1963).

Twenty-four stratigraphic complete or partial sections of the Park City Formation have been measured in or near the Wind River Indian Reservation on the east flank of the Wind River Range. The location of these sections is shown on figure 1 and along with their publication source are listed in table 1. Three of these sections were measured for this report, including Black Mountain, Little Red Creek and Meadow Creek, and are given in tables 4, 5 and 6.

Two phosphatic zones occur. The lower is in the Meade Peak Tongue, and the upper is in the Retort Tongue of the Phosphoria Formation. For the most part, these two zones are made up of continuous beds of phosphatic rock; however, compositional changes occur from north to south. These variations in thickness and grade result from the variations of a number of factors. There is a natural variation due to original sedimentation of the amount and composition of the sediment. Additional variation may be due to different amounts of recent chemical weathering. Also, there are variations or errors inherent in measuring the thickness of the beds in outcrop and in determining the percentage of phosphate from samples in the bed. Some of these measurement errors may be systematically biased between stratigraphers, which include Condit, King, Ahlstrand, Peterson, and Sheldon and his co-workers, or between chemists or chemical laboratories, or due to sampling errors of the phosphate beds. The sum of all of these factors gives the variations between stratigraphic sections in figure 3. It is impossible now to try and separate the relative errors due to the different factors. However, a consistency of the measurements appears when all measurements are plotted, as shown in figure 3, and the data included within a band having parameters representative of maximum and minumum values obtained from the several sources of information. These bands were drawn by inspection and were not calculated statistically. The bands approximate a spread of two standard deviations about the mean, which itself is varying along outcrops.

Table 1.--Section number, location, name and source of stratigraphic sections used in this report

Section number	Location	Section Name	Reference _/
1a	center sec. 8, T. 32 N., R. 100 W.		Condit
1b	S1/2NW1/4NW1/4, sec. 9, T. 32 N., R. 100 W.		King, sec. C
2	NE1/4, sec. 5, T. 32 N., R. 100 W.		Condit
3	SE1/4, sec. 6, T. 32 N., R. 100 W.		King, sec. J and K
4	center sec. 35, T. 33 N., R. 100 W.		Condit
5	center sec. 29, T. 33 N., R. 100 W.	Squaw Creek	Condit
			King, sec. F.
6	SW1/4, sec. 19, T. 33 N., R. 100 W.		King, sec. G.
7a	NW1/4, sec. 25, T. 33 N., R. 101 W.		King, sec. H.
7b	N1/2SE1/4, sec. 25, T. 33 N., R. 101 W.		King, sec. I.
8	SW1/4, sec. 18, T. 33 N., R. 100 W.	Baldwin Creek	Condit
			King, sec. B
			Ahlstrand, sec. 16
9	NE1/4, sec. 11, T. 33 N. R. 101 W.	Mexican Creek	Condit, p. 22
10	SW1/4NW1/4, sec. 2, T. 33 N., R. 101 W.		Condit
11	NW1/4SE1/4, sec. 18, T. 2S N., R. 1 W.		Condit
12	NW1/4NW1/4, sec. 18, T. 2S, R. 1 W.		Condit
13	center sec. 2, T. 2 S, R. 2 W.	S. Fork, Trout Creek	Condit, p. 20
14	NW1/4NW1/4, sec. 32, T. 1 S, R. 2 W.		Condit
15	center east line, SE1/4, sec. 21, T. 1 S, R. 2 W.		Condit
			Ahlstrand, sec. 12
16	center east line, SE1/4, sec. 18, T. 1 S., R. 2 W.	S. Fork of Little Wind River	Condit, p. 11-12
			Ahlstrand, sec. 18
17	SE1/4SE1/4, sec. 1, T. 1 S., R. 3 W.		Condit
18	center NW1/4, sec. 21, T. 1 N., R. 3 W.	Pevah Creek	Condit
			Ahlstrand, sec. 9
19	center west line, SW1/4, sec. 4, T. 1 N., R. 3 W.		Condit
20	SE1/4, SW1/4, sec. 35, T. 3 N., R. 4 W.	Bull Lake	Sheldon, sec. 82
21	center NW1/4, sec. 2, T. 3 N., R. 5 W.	Meadow Creek	Ahlstrand, sec. 7
			Sheldon, this report
22	NW1/4SW1/4, sec. 35, T. 4 N., R. 5 W.	Bob Creek	Ahlstrand, sec. 7
23	NW1/4NW1/4, sec. 6, T. 4 N., R. 5 W.	Dinwoody Lake	Sheldon, sec. 75
24	NW1/4SW1/4, sec. 21, T. 40 N., R. 105 W.	Little Red Creek	Sheldon, this report
25	SE1/4, sec. 26, T. 7 N., R. 4 W.	Black Mountain	Sheldon, this report
			Blackwelder, 1911

_/ references are to Ahlstrand, 1971; Condit, 1924; King, 1947; and Sheldon, 1963.

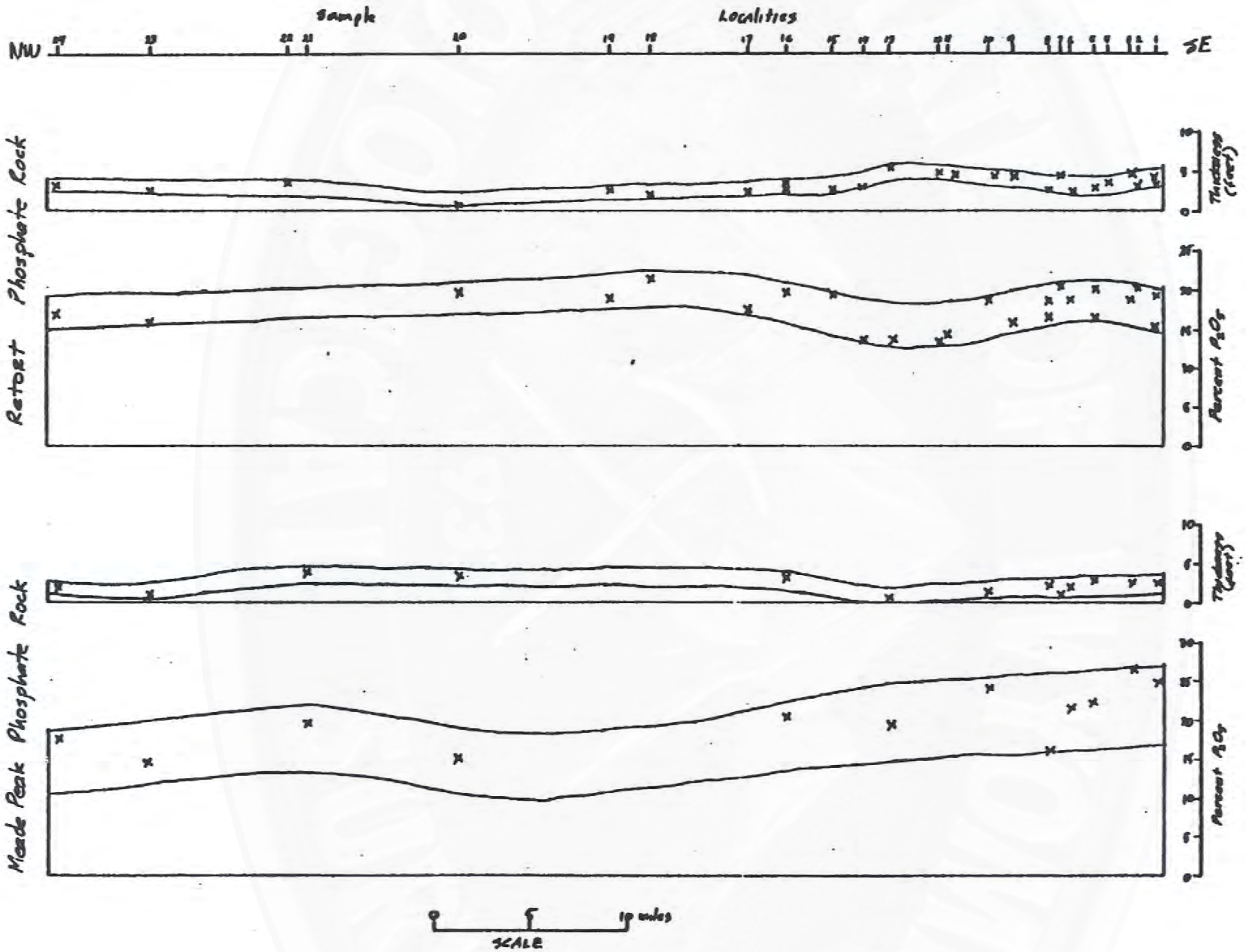


FIGURE 3. Variations in thickness and percent P_2O_5 of Meade Peak and Retort phosphate rock beds in the central eastern Wind River Range, Wyoming. For location of measurements, see figure 1.

Several broad relationships are shown in figure 3. There seems to be an inverse regional relationship between the statistical mean for both thickness and grade. The Meade Peak and Retort phosphorites, in general, are highest grade where they are thinnest and lowest grade where they are thickest, which suggests that phosphate grade is partly a function of dilution by other sediments, including clastic quartz and clay and biochemical carbonate grains. This pattern of thickness and grade is superimposed on a general northwestward decrease along outcrop in the total amount of phosphate irrespective of grade, a parameter that is measured by the feet times percent P_2O_5 of the beds (table 2 and 3). These changes are discussed for each unit below.

The Meade Peak phosphate beds are composed of pelletal phosphate rock in the southern part of the Wind River Range (King, 1947, figure 4), and are composed of fragments of shells of the originally phosphatic inarticulate brachiopod, Orbiculoidea Utahensis in the northern part of the Range. The transition from the one facies to the other is gradual from north to south. The thickness and percent P_2O_5 of the beds of phosphate rock in the Meade Peak that make up the potentially economic sequence are shown in figure 3 and listed in table 2. The beds are more than three feet thick along much of the outcrop, but south of bed 13 and north of bed 23 the beds are less than three feet thick. Over most of the outcrop where the thickness is high, the P_2O_5 grade is low, as particularly well shown at section 20. There is a general decrease in phosphate content from about 22 percent mean P_2O_5 at the south to about 14 percent at the north. Accompanying this change is the change of the character of the phosphate from pelletal to bioclastic. Also the percentage of quartz sand increases to the north. There is a general decrease of feet percent times P_2O_5 from about 60 in the south to about 40 in the north.

Table 2.--Thickness, percent P_2O_5 and feet times percent P_2O_5 of the Meade Peak Tongue of the Phosphoria Formation in the central Wind River Range.

Meade Peak phosphate thickness and grade

Section number	thickness	$\%P_2O_5$	Feet x $\% P_2O_5$
1	2.8	24.8	69
3	2.7	26.5	72
5	2.9	22.1	64
6	2.0	21.5	43
7	1.0	29.7	30
8	2.3	16.1	37
10	1.5	24.0	36
13	0.6	20.1	12
16	3.0	20.5	61
20	3.1	15.0	46
21	3.4	20.4	69
23	0.9	14.7	13
24	1.6	17.8	28

Table 3.-- Thickness, percent P_2O_5 and feet time percent P_2O_5 of the Retort Tongue of the Phosphoria Formation in the central Wind River Range.

Retort Phosphate thickness and grade

Section number	thickness	$\%P_2O_5$	Feet x $\%P_2O_5$
1	3.6	19.2	69
2	3.6	20.0	72
3	4.9	18.9	93
4	3.8	-	-
5	3.2	16.7	53
	3.1	20.0	62
6	2.3	18.7	43
7	4.5	20.2	91
8	2.8	18.4	51
9	4.4	15.9	70
10	4.4	18.6	82
11	4.5	14.1	63
12	4.9	13.4	66
13	5.3	13.6	72
14	2.8	13.5	38
15	2.8	19.2	54
16	2.8	19.4	54
	3.5	-	-
17	2.3	17.2	40
18	2.0	21.1	42
19	2.5	18.8	53
20	0.8	18.4	15
22	2.4	-	-
23	2.4	15.9	38
24	3.1	16.7	52
25	1.6	13.0	21

The Retort phosphate beds are pelletal over most of the outcrop (King, 1947, fig. 5). In the vicinity of sections 9 through 14, the Retort increases to a mean thickness over 4 feet, but the grade decreases to below 17 percent P_2O_5. There may be a decrease of thickness to below 3 feet between sections 17 and 21 accompanied by an increase in grade to above 21 percent P_2O_5, although this is far from certain from the data. The feet times percent P_2O_5 shows a gradual decrease along outcrop from about 70 on the south to about 30 on the north.

Resources of phosphate rock

The U.S. Geological Survey and the U.S. Bureau of Mines classify phosphate rock as economic or subeconomic resources dependent on mining requirements, whether surface or underground. The lower limit of strippable subeconomic resources is defined as phosphate rock that is thicker than 3 feet and has a P_2O_5 content greater than 15 percent. This gives a minimum feet times percent P_2O_5 of 45 feet percent. The lower limit of strippable economic resources is 5 feet and 18 percent P_2O_5. The lower limit of underground subeconomic resources is 3 feet thick and 24 percent P_2O_5, or 72 feet percent. An upper limit on underground subeconomic resources is not pertinent, because it is uneconomic to mine phosphate rock underground in the western phosphate field.

The phosphate strippable deposits of the Wind River Indian Reservation are subeconomic resources, but the thickness and tenor of the underground deposits fall below the limits for subeconomic resources. Even the strippable phosphatic beds barely fall within the lower limit for subeconomic resources, and in some local areas fall below this limit. Compared with the phosphate deposits in other parts of the western phosphate field, the deposits on the Reservation are clearly much leaner and thinner and probably could not be competitively mined in the foreseeable future. An additional unfavorable feature of the phosphate rock of the Reservation is a relatively high iron and alumina content. Glauconite, which contains iron and alumina, is a common accessory mineral in the phosphate rock. Although no chemical analyses have been made for the iron and alumina, visual estimates of combined iron and alumina of the phosphorites indicate an excess of the generally accepted three percent maximum. Glauconite has about the same specific gravity and mineral grain size as apatite, the mineral that contains the phosphate, so that its separation from the apatite grains is difficult.

An advantage of the Reservation deposits is their easy mineability. There are few structural complexities to the deposits, and some rock is available for strip mining on the dip slope of the mountain front. Also, large volumes of rock are available above the lowest entry level for mining, which occurs at the points where the phosphate beds are intersected by stream level.

The above considerations of the feasibility of economic mining of the Reservation phosphate deposits are based on minimal thickness and quality values currently accepted by the mining industry. New technology, however, may permit use of these low-grade phosphate deposits, such as in a small-scale phosphate and nitrate fertilizer generator currently under development at Kettering Research Laboratory at Yellow Springs, Ohio (Treharne and others, 1980). This generator, by using the arc process of producing nitric acid, reacts nitric acid with limestone or phosphate rock to produce calcium nitrate or calcium nitrate and phosphoric acid, both valuable fertilizers. The generator can accept a feed rock of much lower tenor (grade) than the current large phosphorus fertilizer manufacturing plant. The presence of iron is not necessarily deleterious, as ferrous iron is a commonly needed trace metal in agricultural lands. Also, calcium or calcium-magnesium carbonate, common contaminants of the Reservation phosphate rock, are not a problem for the N-P fertilizer generator in that calcium nitrate or calcium-magesium nitrate is produced by the reaction of this feed rock to the generator. The Kettering N-P fertilizer generator is designed to run on a 3-kilowatt electric generator to produce several tons of fertilizer a year. Because electrical power can be produced from renewable energy sources, such as microhydropower, solar energy or wind energy, all three of which are abundant on the Reservation, it is conceivable that the phosphate deposits could be utilized to produce fertilizer to increase the productivity of hay and other crops of the Reservation. If the N-P generator becomes feasible, the phosphatic and glauconitic limestone of the Ervay and Franson Members of the Park City Formation should be evaluated. These rocks, composed of calcium carbonate with large amounts of apatite and glauconite, would also be an excellent feed rock for the Kettering generator. That would produce a mixed fertilizer of nitrate, phosphate, potash and ferrous iron.

The tonnage of phosphate rock of both the Meade Peak and Retort beds has been roughly estimated. Only that phosphate rock above entry level has been considered because of the minimal thickness and grade. To determine the volume of the phosphate rock, the area of the Park City above entry level was planimetered from the 1:250,000 map of Keefer (1970) and corrected for dip. This areal value is approximately correct for the Meade Peak but tends to overestimate the Retort area somewhat, because the Retort beds do not extend over the full area considered. The average thickness and grade of each bed was estimated from tables 2 and 3 for the stratigraphic sections on the reservation between localities 9 and 24 (fig. 1). As was stated above, the grade of both the Meade Peak and Retort phosphate rock tends to decrease somewhat from south to north; hence, the tonnage in the south will tend to be somewhat underestimated and in the north somewhat overestimated.

In summary, about 710 million tons of phosphate rock exist within the southwestern part of the Reservation above entry level. This is rock in the ground, and if mined from underground, about half of this would be recoverable, or about 350 million tons could be produced. In practical terms, large-scale mining probably will never take place, but the estimation shows that abundant underground deposits exist for small-scale mining and production of phosphate-nitrate fertilizer. The amount of strippable phosphate rock cannot be estimated with presently available information, but it would only be a small fraction of the amount of rock above entry level.

References Cited

Ahlstrand, Dennis C., 1971, Permian carbonate facies, Wind River Mountains and Western Wind River Basin, Wyoming: Masters Thesis, University of Montana, p. 104.

Blackwelder, Eliot, 1911, A Reconnaissance of the phosphate deposits in Western Wyoming: U. S. Geological Survey Bulletin 470, p. 452-481.

Condit, D. C., 1924, Phosphate deposits in the Wind River Mountain, near Lander, Wyoming: U. S. Geological Survey Bulletin 764, 39 p.

Keefer, William R., 1970, Structural Geology of the Wind River Basin, Wyoming: U. S. Geological Survey Professional Paper 495-D, p. D-1-D35.

King, R. H., 1947, Phosphate deposits near Lander, Wyoming: Wyoming Geological Survey Bulletin 39, 84 p.

McKelvey, V. E., Williams, J. S., Sheldon, R. P., Cressman, E. R., Chene, T. M., and Swanson, R. W., 1959, The Phosphoria, Park City, and Shedhorn formations in the western phosphate field: U. S. Geological Survey Professional Paper 313-A, p. 1-47.

Murphy, John F., and Richmond, Gerald M., 1965, Geologic map of the Bull Lake West Quadrangle, Fremont County, Wyoming: U. S. Geological Survey Geologic Quadrangle Map 432.

Peterson, James A., 1980, Depositional history and petroleum geology of the Permian Phosphoria, Park City, and Shedhorn Formations, Wyoming and southeastern Idaho: U. S. Geological Survey Open-File Report 80-667, 42 p.

Rohrer, Willis, L., 1973, Geologic map of the phosphate reserve in the Lander area, Fremont County, Wyoming: U. S. Geological Survey Mineral Investigations Field Studies Map MF-305.

Sheldon, Richard P., 1963, Physical Stratigraphy and Mineral Resources of Permian Rocks in Western Wyoming: U. S. Geological Survey Professional Paper 313-B, p. 49-273.

Treharne, W. R., Moles, D. R., Bruce, M. R. M., and McKibben, C. K., 1980, Non-conventional manufacture of chemical fertilizers: Small-scale fertilizer production technology, p. 55-64, in Sheldon, R. P., Ahmed, S., and Yang, Y. H., 1980, Fertilizer raw material resources, needs, and commerce by Asia and the Pacific, Resource Systems Institute, East-West Center, Honolulu, Hawaii, p. 1-406.

Table 4.--Stratigraphic Section of the Park City Formation at Black Mountain, Wyoming.

Park City Formation measured and sampled at a natural exposure in a small intermittent tributary to Red Creek on Black Mountain in the SE 1/4 of section 26, T. 7 N., R, 4 W. Rocks crop out in cliff as well as in stream bed. Beds sampled from base to top along stream bed and cliffs near stream bed, so bed numbers ascend upwards in section. Section measured by R. P. Sheldon, assisted by C. R. Sheldon in August, 1981.

Bed	Thickness in feet (meters)	Description
D-132		Dinwoody Formation
D-131	14.8 (4.5)	Covered. Contains definite float of Dinwoody Formation.
D-130	19.7 (6.0)	Covered. Contains float of fine-grained carbonate rock. Formation uncertain.
Ervay Member of Park City Formation.		
E-129	24.6 (7.5)	Limestone, hard, thick-bedded to massive, fine-grained, contains abundant fossils including bryozoans. Upper portion contains scattered chert nodules and calcite filled geodes.
E-128	5.0 (1.52)	Limestone, hard, massive, coarse-grained.
E-127	5.0 (1.52)	Limestone, hard, thick-bedded, fine-grained to aphanitic.
E-126	2.1 (0.64)	Limestone, glauconitic, hard, thick-bedded, slightly phosphatic. Composed of abundant bryozoans and other fossils, glauconite and apatite occur as casts of bryozoan zoecia. Unit contains scattered chert nodules.
E-125	.7 (0.2)	Mudstone, soft, fissile to thin-bedded, slightly glauconitic, contains scattered fossils, light olive gray 5Y6/1.

Table 4 (continued).

Bed	Thickness in feet (meters)	Description
E-124	3.4 - 5.0 (1.05 - 1.52)	Chert, hard to medium hard, thin- to medium, knobbly bedded. Contains thin shale unit near top.
E-123	.6 (0.2)	Limestone, hard thick-bedded. Contains bryozoans and other fossil fragments.
E-122	2.0 (0.6)	Mudstone, dolomitic, medium-hard, thin-bedded. Dolomite occurs as nodules and undulant thin beds in mudstone. Unit contains a bed of undulant chert 0.1 meter thick in middle of unit.
Tosi Chert Tongue of the Phosphoria Formation.		
T-121	4.9 (1.5)	Chert, hard, thin, knobbly bedded.
T-120	9.0 (2.74)	Chert, hard, tubular structures.
T-119	1.6 (0.5)	Chert, argillaceous, dolomitic, thick-bedded, hard, light gray N7.
T-118	3.3 (1.0)	Chert, hard, tubular structures. Composed of two beds.
T-117	21.6 (6.6)	Chert, hard, thin- to medium-, undulant bedded. Contains bed of dolomite 0.6 feet (0.2 meters) thick, 6.6, feet (2.0 meters) from base. Contains shale partings.
Retort Tongue of the Phosphoria Formation.		
R-116	1.6 (0.5)	Limestone, phosphatic, medium hard, thin-, irregularly bedded; calcite microcrystalline; apatite fine to medium pellets and fine to coarse brachiopod bioclasts. Light olive gray 5Y4/1 to olive gray 5Y4/1 near top. Apatite grains in part floating in micrite matrix. Gradational contact with unit below. Unit contains 13.0 percent P_2O_5.

Table 4 (continued).

Bed	Thickness in feet (meters)	Description
R-115	2.6 (0.8)	Limestone sandy, medium hard to hard, thin-bedded, slightly phosphatic and glauconitic. Contains abundant brachiopods. Possible scour-and-fill structures. Olive gray 5Y4/1. Becomes more phosphatic and glauconitic towards top. 2.3 feet from base occurs a thick-shelled pelecypod 8 cm wide and 5 mm thick, possibly indicating a beach environment. Very fine to fine grained sand; fine to coarse bioclastic apatite and glauconite.
R-114	2.3 (0.7)	Limestone, cherty, hard, coarse-grained, slightly phosphatic with brachoiopod fragments, slightly glauconitic, medium-grained glauconite and fossil molds; chert occurs as nodules and cement, contains sponge spicules; rock is light olive gray 5Y6/1.
Lower tongue, Shedhorn Sandstone.		
LS-113	1.1 (0.35)	Sandstone, calcareous, medium hard, thin-knobbly bedded, very fine grained sand, light olive gray 5Y6/1.
LS-112	2.0 (0.6)	Sandstone, calcareous, cherty, medium hard, thin irregular bedded, very fine to fine grained sand, chert is nodular in most of unit but one crude bed in center of unit which contains abundant sponge spicules, sandstone is light olive gray 5Y6/1 and chert is yellowish gray 5Y8/1.
LS-111	9.2 (2.8)	Sandstone, hard, massive, medium scale cross-bedded, fine-grained, contains scattered brachiopods, slightly phosphatic, bioclastic apatite increasing towards top.
LS-110	4.9 (1.5)	Sandstone, cherty, hard, massive, fine-grained sand, chert occurs as vertical tubular concretions, and chert contains sponge spicules. Unit contains rare brachiopods. Light olive gray 5Y6/1.

Table 4 (continued).

Bed	Thickness in feet (meters)	Description
LS-109	6.8 (2.09)	Sandstone, calcareous, similar to unit LS-108, but contains much more abundant brachiopods. Olive gray 5Y4/1.
LS-108	4.1 (1.25)	Sandstone, calcareous, hard, thin-bedded, very fine-grained sand, contains scattered fossils, amount of calcite and quartz about equal, light-olive gray 5Y6/1 to olive gray 5Y4/1.
Franson Member of Park City Formation.		
F-107	6.0 (1.7)	Limestone, phosphatic, thick-bedded, weathers thin-bedded, hard, coarse-grained calcarenite, contains bryozoan and other fossils cast with apatite, slightly glauconitic, glauconite also forms fossil casts, light olive gray 5Y6/1.
F-106	1.2 (0.4)	Mudstone, medium hard, thin-bedded, light olive gray 5Y6/1.
F-105	1.3 (0.4)	Limestone, cherty, sandy, hard, medium-bedded, very fine-grained calcarenite and quartz sand grains, olive gray 5Y4/1, contains very fine apatite pellets. Chert occurs as nodules, many of which appear to be relict fossils, light olive gray 5Y6/1.
LS-8	4.9 (1.5)	Sandstone, calcareous, medium hard, knobbly thin-bedded, very fine-grained sand, slightly phosphatic, medium to coarse pellets and fossil casts, contains calcite brachiopods, light olive gray 5Y6/1.
F-7	2.9 (0.9)	Limestone, hard, thick-bedded, weathers thin bedded, medium- to coarse-grained, slightly phosphatic and glauconitic, apatite and glauconite occur as casts of bryozoans, contains fragmented brachiopods, light olive gray 5Y6/1.

Table 4 (concluded).

Bed	Thickness in feet (meters)	Description
F-6	5.9 (1.8)	Limestone, hard, thin-bedded, fine to coarse grained calcarenite, contains abundant bryozoans, upper 0.6 feet consists of bryozoan coquina, contains brachiopods, slightly phosphatic and glauconitic, apatite and glauconite casts, light olive gray 5Y6/1.
F-101	3.9 (1.2)	Limestone, phosphatic hard, thick-bedded medium to coarse grained calcarenite, are coarse grained and apatite grains consist of fossil casts.

Note: Beds of F-1 through LS-8 series measured in cliff exposure, and beds of F-101 through R-116 measured from gully bottom. The sequence described above are in correct continuous stratigraphic order even though bed numbers go from one series to another. Correlations were made on outcrop.

Bed	Thickness in feet (meters)	Description
F-5	22.8 (6.9)	Covered. Actual covered interval between F-4 and F-6 is 26.7 feet.
F-4	1.5 (0.5)	Siltstone, calcareous, hard, medium-bedded, has a relict granular structure, light gray N/6.
F-3	7.7 (2.3)	Chert, hard, thin-bedded to laminated, olive black 5Y2/1 to olive gray 5Y4/1, upper 1.0 feet is undulant bedded. Laminated beds are argillaceous.
F-2	0-1.0 (0-0.3)	Dolomite, medium hard, medium grained pelletal, cross-bedded, light olive gray 5Y6/1. Compensation for changes in bed thickness apparently taken up by underlying unit. Slightly glauconitic, glauconite occurs as matrix films and silt sized grains.
F-1	5.9 (1.8)	Dolomite, hard to medium hard, medium-bedded planar bedded, obscure pelletal texture, fine to medium sized pellets, covered below.

Table 5.--Stratigraphic Section of the Park City Formation at Little Red Creek, Wyoming

Park City Formation measured and sampled at a natural exposure and several short hand trenches on a cliff overlooking Little Red Creek from north on the northwest 1/4, southwest 1/4 section 21, T. 40 N., R. 105 W. Upper part of section, from E-101 to E-105 measured 1/2 mile downstream from lower part of section. Bed E-101 immediately overlies bed E-44. Beds sampled from base to top so the numbers ascend upwards in section. Section measured by R. P. Sheldon, assisted by C. R. Sheldon in July and August, 1981.

Bed	Thickness in feet (meters)	Description
Ervay Member of the Park City Formation		
E-105	5.6 (1.7)	Limestone, hard massive, calcarenite. Overlain by Dinwoody Formation.
E-104	7.0 (2.15)	Carbonate rock, argillaceous, aphanitic, knobbly texture, makes poor outcrop. Contains scattered silica concretions.
E-103	5.6 (1.7)	Limestone, hard, thin- to thick-bedded, calcarenite, contains abundant fossils, slightly phosphatic and glauconitic, both occur as casts of fossil voids, yellowish gray 5Y8/1.
E-102	2.3 (0.7)	Limestone, massive, calcarenite, medium- to very coarse grained calcite sand, contains scattered fossils, yellowish gray 5Y6/1.
E-101	2.3 (0.7)	Limestone, hard, thin-bedded, lower 1.0 foot fine-grained, upper 1.3 feet bryozoan coquina, slightly glauconitic and phosphatic, both occur as casts of fossil voids and as rounded medium to very coarse grains, light-olive gray 5Y6/1.
E-44	2.8 (0.8)	Limestone, cherty, calcarenite, similar to bed E-42, contains abundant spirifers. Overlain by thin-bedded platey limestone.
E-43	0.8 (0.21)	Limestone, hard bryozoan coquina, contains brachiopods, matrix is argillaceous limestone, fine- to medium-grained slightly glauconitic, light brownish gray 5Y6/1.

Table 5 (continued).

Bed	Thickness in feet (meters)	Description
E-42	4.8 (1.4)	Limestone, cherty, hard, calcarenite, medium-grained, contains abundant bryozoans, slightly phosphatic and glauconitic, both occur as casts of bryozoan zoecia and as rounded medium sized grains, chert occurs as nodules containing sponge spicules, nodules may in part be sponges, greenish gray 5GY6/1.
E-41	1.1 (0.3)	Mudstone, calcareous, similar to bed E-39, contains spirifers.
T-40	2.6 (0.8)	Chert, similar to bed T-38. Conodont sample W81-427 taken from top of bed.
E-39	4.6 (1.4)	Mudstone, calcareous, contains small fossil fragments in part composed of apatite, contains grains and coatings of glauconite, soft, fissile to thin-bedded. Upper part burrowed and contains geodes up to 0.4 feet in diameter filled with coarse calcite crystals and rimmed with quartz and chalcedony, greenish gray 5G6/1.
Tosi Chert Tongue of the Phosphoria Formation		
T-38	16.9 (5.2)	Chert, hard, thick undulant bedded, medium gray N5, nodular in part, contains abundant sponge spicules up to 1 mm in length, contains irregularly shaped tubular concretions, light olive gray 5Y6/1.
T-37	20.6 (6.28)	Interbedded cherty mudstone (70%) and shale, calcareous (30%). Thinly interbedded. Calcareous shale is fissile soft, olive gray 5Y4/1; cherty mudstone is undulant bedded and in part nodular, olive gray 5Y4/1.

Table 5 (continued).

Bed	Thickness in feet (meters)	Description
R-36	1.0 (0.3)	Interbedded argillaceous phosphatic rock and mudstone. Bed A at base. C 0.3' Phosphate rock, argillaceous, similar to bed A. B 0.4' Mudstone, medium hard, brownish gray 5YR4/1. A 0.3' Phosphate rock, argillaceous, medium hard, thin bedded, fine-grained pellets, scattered medium- to coarse-grained pellets, olive gray 5Y4/1.
T-35	4.0 (1.2)	Mudstone, cherty, hard, thin to medium bedded, contains thin beds of fissile shale, light olive gray 5Y6/1.
Retort Phosphatic Shale Tongue of the Phosphoria Formation		
R-34	2.0 (0.6)	Shale, similar to Bed R-32
R-33	0.4 (0.1)	Dolomite, argillaceous, hard, medium dark gray N4.
R-32	10.2 (3.1)	Shale, soft, fissile, brownish gray 5Y4/1. Contains two beds of argillaceous phosphate rock, one bed 0.1 feet thick 2.6 feet from base and the other 0.2 feet thick 6.2 feet from base. Argillaceous phosphate rock is medium hard, fine-grained pellets, brownish gray 5Y4/1.
R-31	3.1 (0.95)	Phosphate rock, calcareous, argillaceous, medium hard to soft, thin bedded, fine to medium grained pellets, contains scattered coarse to very coarse pellets, slightly sandy, very fine to fine quartz grains, contains coarse-grained scattered apatite brachiopod shell fragments, calcite occurs in matrix, sharp contact with unit blow, mostly covered but exposed in small hand trench. Conodont sample W81-426. Unit contains 16.7% P_2O_5.

Table 5 (continued).

Bed	Thickness in feet (meters)	Description
Lower tongue of the Shedhorn Sandstone		
LS-30	2.0 (0.6)	Sandstone, calcareous, hard, thick-bedded, fine-grained, slightly phosphatic, contains scattered fine to medium grained apatite brachiopod shell fragments and pellets, becomes more phosphatic toward top, olive gray 5Y4/1, abundant burrowing, burrows 0.06 feet in diameter and 0.6 feet long.
LS-29	4.0 (1.2)	Sandstone, calcareous, medium hard, indistinct bedding, fine- to medium-grained sand, calcite composed of coquina of productoid and other brachiopods and as matrix of sandstone, contains scattered apatite brachiopods shell fragments and pellets, medium light gray N6, burrows up to 0.1 feet in diameter and 1.0 feet long. Conodont sample W81-425.
LS-28	3.6 (1.1)	Sandstone, medium hard, thin-bedded, very fine grained, contains rare brachiopods, light olive gray 5Y6/1.
Franson Member of the Park City Formation		
F-27	2.3 (0.7)	Limestone, argillaceous, hard, thin-bedded, contains abundant brachiopods, abundant brachiopod spines in matrix along with much other fossil debris, micrite matrix, light olive gray 5Y6/1, gradational contact with unit below. Conodont collection W81-424.
F-26	2.2 (0.7)	Mudstone, calcareous, soft, thin-bedded, light olive gray 5Y6/1. Unit contains scattered brachiopods, gradational contact with unit below.
F-25	1.3 (0.4)	Dolomite, argillaceous, medium hard, thin-bedded, light olive gray 5Y6/1, contains scattered brachiopods, some of which are silicified.
F-24	3.2 (1.0)	Limestone, medium hard, coquina of large, unabraded brachiopods, micrite matrix containing abundant brachiopod spines, light olive gray 5Y6/1, forms obscure outcrop. Conodont collection W81-423.

Table 5 (continued).

Bed	Thickness in feet (meters)	Description
F-23	5.5 (1.7)	Dolomite, argillaceous, medium hard, nodular, contains rare bryozoans cast by apatite and apatite brachiopods, light olive gray 5Y6/1.
F-22	0.5 (0.15)	Limestone, glauconitic, phosphatic, hard, calcarenite, medium-grained contains bryozoans cast by apatite and glauconite greenish gray 5GY6/1.
F-21	5.6 (1.7)	Limestone, phosphatic, glauconitic, hard, thick-bedded, coarse to very coarse grained, contains bryozoans cast by apatite and glauconite as well as large bryozoans up to 0.2 feet long, greenish gray 5GY6/1, sharp contact with unit below.
F-20	4.3 (1.3)	Carbonate rock, hard, medium-bedded, algal lamination, white N9.
F-19	3.6 (1.1)	Limestone, cherty, sandy, hard, medium-bedded, fine grained calcarenite, very fine-grained sand, chert occurs as beds of nodules up to 0.4 feet thick, light olive gray 5Y6/1.
F-18	8.3 (2.5)	Carbonate rock, sandy, hard, massive, finely crystalline, very fine-grained sand, contains an irregular zone of chert at base 0.7 to 1.0 feet thick, light olive gray 5Y6/1.
F-17	9.1 (2.8)	Dolomite, hard, thick-bedded, aphanitic, slightly phosphatic rare medium-grained apatite fossil casts and pellets, contains burrows filled with calcite 0.1 by 0.5 feet.
F-16	10.3 (3.1)	Unit consists of three beds, which are described below, bed A being at the base.
		C 5.7' Interbedded argillaceous dolomite (80%) and dolomitic mudstone (20%). Dolomite is medium hard, medium-bedded, yellowish gray 5Y8/1; Mudstone is soft, pinkish gray 5R8/1.

Table 5 (continued).

Bed	Thickness in feet (meters)	Description
		B 1.3' Sandstone, calcareous, medium hard, fine to coarse grained, light brownish gray 5Y6/1.
		A 3.3' Interbedded argillaceous dolomite (80%) and dolomitic mudstone (20%), similar to unit C above.
		Unit covered in natural section and exposed in hand trench.
F-15	10.0 (3.0)	Interbedded dolomite mudstone (50%) and argillaceous dolomite (50%), soft to medium hard, thin to medium bedded, very finely crystalline, light olive gray 5Y6/1. Conodont sample from top, W81-422. This unit exposed in hand trench.
F-14	2.5 (0.8)	Dolomite, hard, medium bedded, upper part laminated and perhaps algal, contains scattered quartz sand and small fossils (ostracods or snails), yellowish gray 5Y8/1.
Rex Tongue of the Phosphoria Formation		
R-13	9.5 (2.9)	Chert, hard, medium bedded, nodular, brecciated, light olive gray 5Y6/1, sharp contact with unit below.
R-12	5.2 (1.6)	Carbonate rock, hard, massive, microcrystalline, light olive gray 5Y6/1, unit contains thin beds rich in apatite braciopod clasts, bed at base 0.2 feet thick contains chert nodules up to 0.03 feet in diameter. Conodont sample from top of bed.
Meade Peak Tongue of the Phosphoria Formation		
MP-11	1.1 (0.3)	Sandstone, phosphatic, medium hard to soft, finegrained sand, apatite brachiopod fragments up to 10 mm in diameter, upper half of bed has fewer and finer grained apatite brachiopod fragments than lower, yellowish gray 5Y8/1 to light olive gray 5Y6/1. Conodont sample. Unit contains 16.7 percent

Table 5 (continued).

Bed	Thickness in feet (meters)	Description
MP-10	1.4 (0.4)	Sandstone calcareous, medium hard, fine- to medium-grained, sparry calcite cement, slightly phosphatic and glauconitic, apatite brachiopod clasts and pellets, light gray N7, gradational contact with unit below.
MP-9	3.2 (1.0)	Carbonate rock, hard, weathers soft, very finely crystalline, contains rare apatite brachiopod clasts, yellowish gray 5Y8/1.
MP-8	1.6 (0.5)	Phosphorite, glauconitic, medium hard to soft, fine to medium grained, apatite is pelletal and bioclastic, glauconite is pelletal, greenish gray 5GY6/1, sharp contact with unit below. Unit contains 17.8 percent P_2O_5.
MP-7	2.6 (0.8)	Carbonate rock, hard, weathers soft, very finely crystalline, contains bryozoa and and other fossils cast with glauconite and apatite, yellowish gray 5Y8/1.
Grandeur Member of the Park City Formation		
G-6	5.4 (1.66)	Sandstone, hard to medium hard, thin-bedded, small-scale cross bedded, fine-grained sand, slightly phosphatic, apatite bioclasts, contains thin beds of carbonate rock which may be algal in origin, very pale orange 10YR8/2 to light gray N7.
G-5	6.0 (1.8)	Chert, hard, massive, brecciated, light gray N7, contains thin beds of carbonate rock, contains sponge spicules, brecciation is probably due to carbonate solution, sharp and irregular contact with unit below.
G-4	7.8 (2.4)	Carbonate rock, hard to medium hard, thick-bedded, microcrystalline, very pale orange 10YR8/2.

Table 5 (concluded).

Bed	Thickness in feet (meters)	Description
C-3	3.8 (1.2)	Interbedded carbonate rock and chert, hard, thin- to medium-bedded, carbonate rock is yellowish gray 5Y8/1, chert is pinkish gray 5R8/1, slightly sandy, covered contact with unit below.
C-2	3.4 (1.0)	Sandstone, calcareous, hard, medium-bedded, fine-grained, well-sorted, yellowish gray 5Y8/1, sharp contact with unit below.
Tensleep Sandstone (upper beds only)		
T-1	32.0 (9.7)	Sandstone, hard, massive, cross-bedded, fine-grained, well-sorted, yellowish gray 5Y8/1, unit forms prominent cliff in bottom of gully. Additional Tensleep exposed upstream.

Table 6.--Stratigraphic Section of the Meade Peak Tongue of the Phosphoria Formation at Meadow Creek, Wyoming

Meade Peak Tongue of the Phosphoria Formation measured and sampled at a natural exposure and a hand trench on a cliff overlooking Meadow Creek from the north. Stratigraphic section is located in the center of the northwest quarter, section 2, T. 3 N., R. 5 W. Beds strike north 70° west and dip 10° east. Beds measured from base to top so that bed numbers ascend upwards in the section. Section measured by R. P. Sheldon in July, 1981.

Bed	Thickness in feet (meters)	Description
Rex Chert Tongue of the Phosphoria Formation.		
R-7	21.4 (6.53)	Mudstone and chert. Chert occurs as beds and nodules with some nodules up to .3 feet (0.1 m) in diameter. Unit is more shaly in lower half. Greenish brown color. Unit is poorly exposed in trench, and is overlain by poorly exposed carbonate rock of the Franson member (equivalent to the Minnekahta Member of Goose Egg Formation).
Meade Peak Tongue of the Phosphoria Formation.		
M-6	.3 (0.1)	Dolomite, similar to M-1
M-5	3.3 (1.0)	Sandstone, phosphatic, medium hard to hard, fine-grained sand; apatite composed both rounded grains and bioclasts of brachiopod shell fragments. Unit contains cherty layers near top. Unit contains 7.7 percent P_2O_5.
M-4	1.9 (0.58)	Phosphorite, sandy, hard, apatite occurs as abraded brachiopod bioclasts up to 15 mm in diameter and as rounded grains; fine-grained sand; slightly glauconitic with rounded glauconite grains same size as sand grains. Brachiopod bioclasts occur in lenses. Unit is thick-bedded and is in part indistinctly cross bedded. Unit contains 23.1 percent P_2O_5.

Table 6 (continued).

Bed	Thickness in feet (meters)	Description
M-3	0.4 (0.13)	Carbonate rock, slightly phosphatic and glauconitic, similar to M-1. Unit contains 4.7 percent P_2O_5.
M-2	1.1 (0.33)	Phosphorite, glauconitic, medium hard, moderate yellowish brown 10YR 5/4, fine to medium grained apatite composed of bioclasts and rounded grains; rounded glauconite grains same size as apatite. Unit is thin-bedded and poorly exposed. Unit contains 21.6 percent P_2O_5.
M-1	10.3 (3.15)	Carbonate rock, hard, pale red 5R6/2, slightly sandy, silty, phosphatic and glauconitic. Carbonate rock is a grainstone. Sand and silt occur in separate layers. Glauconite occurs toward top of unit. Apatite is mainly bioclastic, but some is pelletal or rounded bioclasts of brachiopods. Unit contains Orbiculoidea brachiopods and bryozoan fragments. Unit is thick-bedded and probably weathered to pink. Sharp contact with underlying brecciated chert unit. This is a shallowing-upward sequence. 0.4 miles to the east along discontinuous outcrop M-1 is represented by a sandy calcarenite 11.3 feet (3.45 meters) thick, which has small-scale, low-angle cross bedding. No phosphate or glauconite occurs in unit. Units M-2 through M-4 represented by 3.2 feet (1.0 meters) of sandy phosphate rock similar to M-4. Thus in detail continuity of beds in the Meade Peak is low. Underlain by Grandeur Member of Park City Formation.