Geochemistry and Stratigraphy of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation Near Hill Spring, Freeman Ridge Area, Caribou County, Southeastern Idaho

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By
Steven W. Moore[1]
R. David Hovland[2]

ABSTRACT

As part of a continuing effort to assess the phosphate resources on federal lands with leasing potential in southeastern Idaho, phosphate rock samples were obtained and analyzed from Hill Spring trench locality IP-1. This locality is in the southern part of the Freeman Ridge area of the Webster Range in southeastern Idaho.

The sampled stratigraphic section of the Meade Peak Phosphatic Shale Member (Meade Peak) of the Phosphoria Formation is composed primarily of siltstone, phosphorite, and claystone. At this locality, as throughout the western phosphate field, economically attractive phosphate beds (greater than 16 percent P_2O_5) are concentrated into upper and lower zones. The Meade Peak is about 165 feet (50 meters) thick at Hill Spring trench locality IP-1. The combined average phosphate grade of the upper and lower phosphate zones is 27.2 percent P_2O_5 with a thickness of 50.1 feet (15.3 meters). An MgO content of 0.30 weight percent, Fe_2O_3 + Al_2O_3 contents of 4.47 weight percent, and a CaO to P_2O_5 ratio of 1.44 are favorable for economic recovery and processing. An average vanadium content of 1,730 ppm for the combined phosphate ore zones implies some potential for vanadium as a by-product.

Geochemical and stratigraphic data from trench location IP-1, combined with other data in the Freeman Ridge area, will provide a basis for pre-lease resource estimates. Efficient development of this phosphate resource will require future drilling efforts to define the subsurface extent of alteration and overall characteristics of this deposit.

INTRODUCTION

This report is a product of the ongoing resource evaluation by the U.S. Bureau of Land Management in Idaho on

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the development potential of unleased federal phosphate areas in southeastern Idaho. The focus of the BLM evaluation is to determine characteristics of the phosphate resource at specific localities where sufficient data are lacking. The basic geologic data provide: (a) information for pre-lease resource and economic evaluation prior to competitive lease sales; (b) an improved inventory of federal mineral resources; and (c) a basis for guiding land-use decisions regarding phosphate development potential on federal mineral lands.

One area of study has been the Freeman Ridge area. Freeman Ridge is in Caribou County, 21 miles (33 km) east of Soda Springs in southeastern Idaho. The area is within the western phosphate field and is near several major operating phosphate mines in Idaho (Figure 1). Freeman Ridge lies on the western flank of the Webster Range and is located within the Stewart Flat 7.5-minute quadrangle. The sample locality, IP-1, described in this report, is on the eastern flank of Freeman Ridge, south of Hill Spring in SW1/4 SE1/4, sec. 15, T. 9 S., R. 45 E. (Figure 2).

This report includes chemical analyses, calculated thickness and grade of phosphate deposits, and stratigraphic descriptions for sampling units of the Meade Peak Phosphatic Shale Member of the Permian Phosphoria Formation at Hill Spring sample locality IP-1. The intent is to update the preliminary stratigraphic and geochemical data on locality IP-1 reported in Hovland and Moore (1986).

PREVIOUS WORK

Numerous publications, particularly by the U.S. Geological Survey, have contributed to understanding the geology, resources, and stratigraphy of the Phosphoria Formation in southeastern Idaho. Earlier work on the stratigraphy and phosphate deposits of the region culminated with the publication of Mansfield (1927). Continuing studies by the U.S. Geological Survey have resulted in numerous publications including those on stratigraphic descriptions, chemical analyses, and regional stratigraphy. McKelvey and others (1959) described the stratigraphy and provided the stratigraphic nomenclature of the Phosphoria Formation.

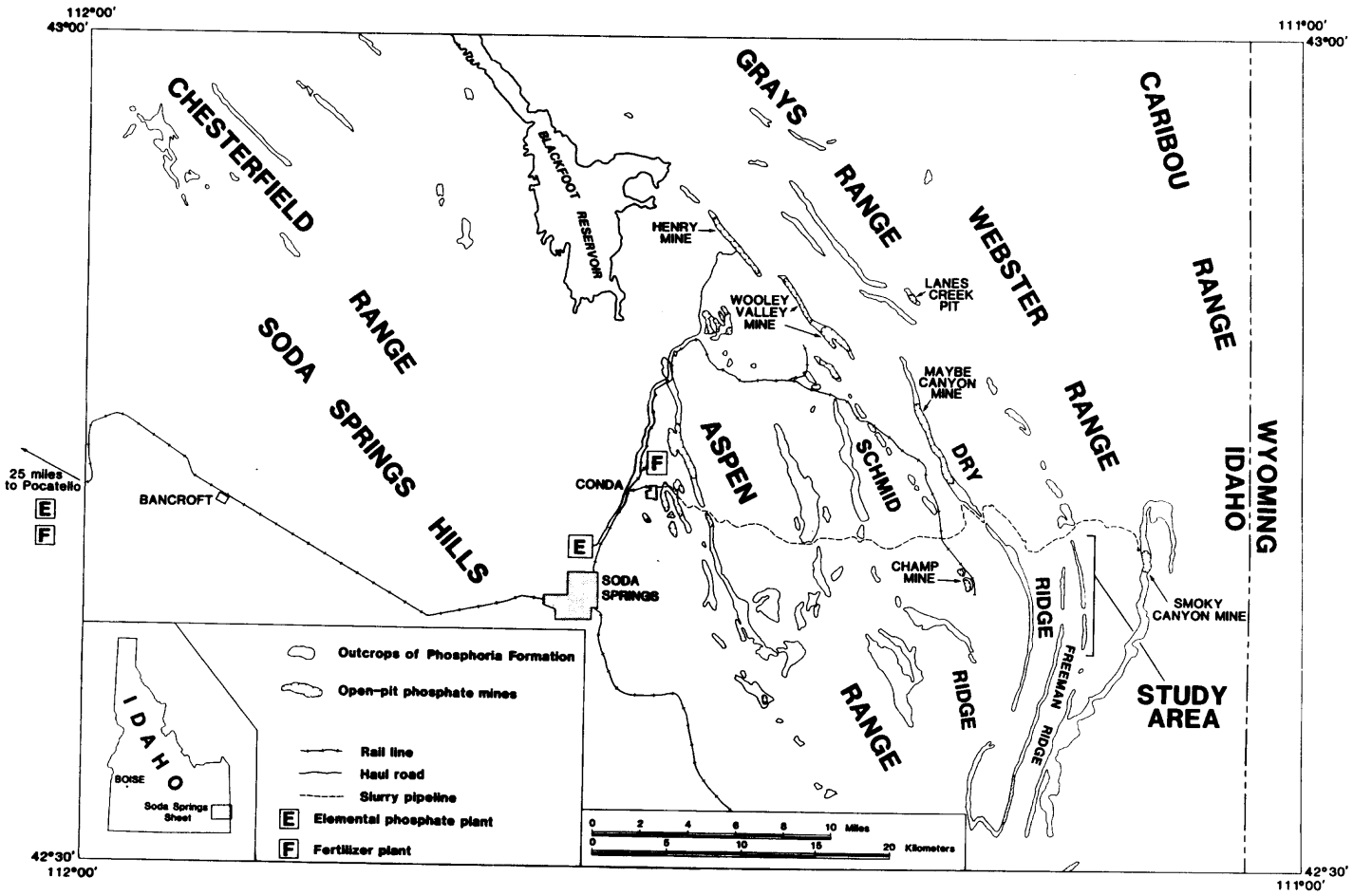

Figure 1. Index map showing location of Freeman Ridge area in southeastern Idaho.

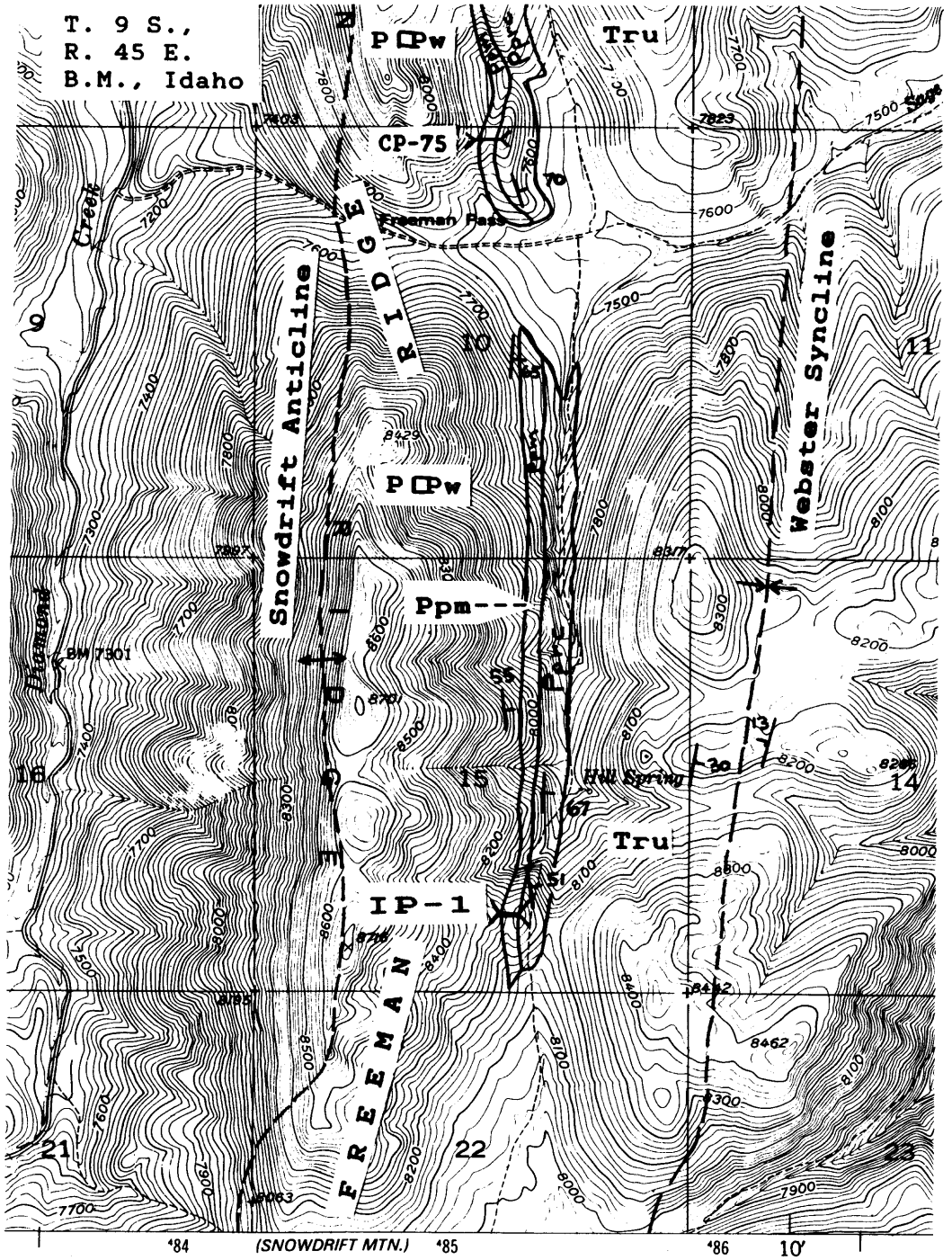

Figure 2.. Location and selected geology of Hill Spring sample locality IP-1. Portion of Stewart Flat 7.5 minute quadrangle. (Generalized geology modified from Montgomery and Cheney, 1967.)

MAP UNITS

Tru	**DINWOODY FORMATION and THAYNES LIMESTONE Undifferentiated (Lower Triassic)**
	PHOSPHORIA FORMATION (Permian):
Pprc	**Rex Chert and cherty shale members**
Ppm	**Meade Peak Phosphatic Shale Member**
PIPw	**WELLS FORMATION (Permian and Pennsylvanian), includes Grandeur Tongue of the Park City Formation**
>----<	**Trench locality**
30	**Strike and dip of bedding**

SCALE 1:24,000

0 0.5 1 Mi

0 2000 4000 Ft

0 0.5 1 Km

IDAHO

Gulbrandsen (1975) compiled a reference list of the main sources of analytical data on the Phosphoria through 1975. Other more recent information on geology and geochemistry of the southeastern Idaho phosphate deposits is included in reports by Powell and others (1975), Maughan (1975, 1976, and 1979a, b), Desborough (1977), Claypool and others (1978), Gulbrandsen and Krier (1980), Hovland (1983), Hovland and Moore (1986), and Oberlindacher and Hovland (1986). In addition to published information, active mining operations in the western phosphate field have contributed to the knowledge of chemical criteria for economically recoverable phosphate rock.

Published geologic mapping in the Freeman Ridge area includes that of Montgomery and Cheney (1967) and Cressman (1964). Derkey and others (1984) estimate an in-place phosphate resource of 68 million short tons (62 million metric tons) with less than 300 feet (91 m) of overburden in the Freeman Ridge area. Other nearby sample localities include USGS trenches at Timber Creek (lot 1310; Montgomery and Cheney, 1967) and at Freeman Pass (trench CP-75; Hovland and Roberts-Tobey, 1985; Figure 2). A preliminary report of the geology and phosphate resources of the Freeman Ridge area is given by Hovland and Moore (1986).

METHODS

The Meade Peak stratigraphic section, sampled and described at Hill Spring sample locality IP-1, is in a weathered (altered) zone. The principal effect of weathering is the loss of calcite, dolomite, and organic matter and thus the relative enrichment of P_2O_5 (Gulbrandsen and Krier, 1980, p. 10). Therefore, the P_2O_5 analyses of these weathered beds tend to be slightly higher than those of unweathered beds at depth (McKelvey and Carswell, 1956, p. 485).

The field investigation for this report consisted of the following activities: (1) siting the sampling trench; (2) clearing the trench site of brush and timber and stockpiling the topsoil with a bulldozer; (3) cutting the trench with a bulldozer and the inner trench with a backhoe; (4) measuring, describing, and sampling all units within the Meade Peak; and (5) backfilling and reclaiming the trench site to U.S. Forest Service (USFS) specifications. The trench incorporated a benched design and an inner, shallow backhoe trench for safety (Figure 3). The complete section of the Meade Peak was measured in the trench that was as much as 40 feet (12 m) wide (from the edges of the outermost bench), 20 feet (6 m) deep, and 200 feet (61 m) long. The trench was then backfilled, and the topsoil was replaced to the original surface. The cut trees were criss-crossed on the site to inhibit soil erosion, and the soil was reseeded by the USFS. The complete trenching project took place during the period of August 14 to September 7, 1984.

Figure 3. View of trench locality IP-1. Light-colored unit at the end of the trench is the Grandeur Tongue of the Park City Formation. For scale, ladder in trench is 8 feet (2.4 meters) high.

The methods of sampling and describing the units of the Meade Peak were discussed by Gere and others (1966) and Oberlindacher and Hovland (1979). The stratigraphy and nomenclature of the Phosphoria Formation used in this report follows that described by McKelvey and others (1959). Bedding thickness was described in accordance with Ingram (1954). Rock colors were determined by the National Research Council (Goddard and others, 1948) and Munsell Soil Color Charts (Munsell Color, 1975).

Phosphate allochems such as peloids, ooliths, and nodules were identified in the field with a hand lens. Grain-size distributions and rounding of these allochems were also determined in the field. "Peloid" is a general term for a subrounded to rounded grain 0.62 to 2.0 millimeters in diameter, and it is without internal structure or genetic interpretation. An oolith is a rounded accretionary grain 0.25 to 2.0 millimeters in diameter with internal concentric structure that formed around a nucleus. A nodule is an irregular shaped, mostly subrounded grain that is larger than 2 millimeters in diameter with no internal structure. Most nodules in trench IP-1 are 1 to 4 centimeters in diameter.

Under an interagency agreement, the Branch of Analytical Laboratories of the USGS analyzed samples from locality IP-1. Floyd Brown coordinated the analytical work. All samples were analyzed for P_2O_5 (by ICP, inductively coupled plasma or rapid rock technique) and acid-insoluble content. In addition, samples from the upper and lower phosphate zones were analyzed for all other major constituents using the rapid-rock technique. Loss on igni-

tion of water and volatiles and organic carbon content were determined for samples from the phosphate zones. Selected samples were also analyzed for vanadium.

GEOLOGY

The crest of Freeman Ridge coincides with the north-trending axis of the Snowdrift anticline. Upper Mississippian through lower Triassic marine sedimentary rocks are exposed along the flanks of Freeman Ridge. The stratigraphic sequence, in ascending order, consists of Upper Mississippian Chesterfield Range Group (Monroe Canyon Limestone), Permian and Pennsylvanian Wells Formation, Lower Permian Grandeur Tongue of the Park City Formation, Lower Permian Phosphoria Formation, and Lower Triassic Dinwoody Formation and Thaynes Limestone. The Phosphoria Formation dips from 45 to 70 degrees to the east along the eastern limb of Snowdrift anticline in the study area.

In the study area, the Phosphoria Formation is subdivided, in ascending order, into the Meade Peak Phosphatic Shale Member, the Rex Chert Member, and the cherty shale member (Montgomery and Cheney, 1967). The Meade Peak is composed predominantly of siltstone, phosphorite, and claystone. As is typical of the Meade Peak of southeastern Idaho, economically attractive phosphate rock is concentrated into upper and lower phosphate zones. In fact, as noted by McKelvey and others (1959, p. 22), the vertical sequence of the Meade Peak is "symmetrical—upper and lower halves are almost mirror images of each other."

Many of the siltstones and claystones are phosphatic and contain at least minor amounts of phosphatic peloids. For the lithologic description, the term "phosphorite" is used for rocks that are composed dominantly, in excess of 50 percent, of phosphate minerals (carbonate fluorapatite) in the form of peloids, nodules, phosphatic bioclasts, or other phosphatic allochems. Much of the unit qualifies as "phosphate rock" using a standard of equal or greater than 16 percent P2O5. The Meade Peak units are typically very thin- to thin-bedded and laminated, and they contain well-sorted phosphate peloids and ooliths. Many beds are carbonaceous, nodular, or bioclastic. Bioclasts include bivalves and gastropods. The generalized stratigraphy at sample locality IP-1 is shown in Figure 4 and in Table 1, with more detailed descriptions of the sample units provided in the Appendix.

PHOSPHATE ROCK CHARACTERISTICS AND GEOCHEMISTRY

At sample locality IP-1, the weighted average grade for the combined upper and lower phosphate zones for phosphate rock (equal to or greater than 16 percent P2O5) is 27.18 percent P2O5 over a thickness of 50.1 feet (19.8 m) (Figure 5). Weighted averages of P2O5 grade for individual phosphate zones are also shown in Table 2. Chemical composition, including all major elements, organic carbon, and the loss on ignition (H2O and volatiles), acid insoluble residue, and vanadium are shown in Tables 3 and 4.

In addition to the P2O5 content, other chemical constituents affect the quality of phosphate rock and its suitability for processing. In general, the more unweathered the phosphate rock, the less likely it is to meet the chemical criteria necessary for minable phosphate. According to Cathcart and others (1984, p. 23), the quality of phosphate rock in the western phosphate field depends on the CaO to P2O5 ratio, the combined ferric and aluminum oxide (Fe2O3 + Al2O3) content, the magnesium content, and the organic matter. The general criteria for economically recoverable phosphate rock are as follows (Cathcart and others, 1984; Stowasser, 1982; and Krauss and others, 1984):

CaO/P2O5 less than 1.55;
Fe2O3 + Al2O3 less than 5 percent;
MgO, maximum of 1.5 percent.

Based on weighted averages, the weathered phosphate rock sampled at locality IP-1 meets these criteria (Table 5). However, some individual units, particularly in the medium-grade range, have Al2O3 contents greater than 2 percent. This could be a problem for some processing techniques, although higher alumina phosphate rock could be handled by blending.

Excessive organic matter that causes problems in fertilizer processing by clogging filters and pipes is removed by calcining. Maximum limits for organic matter vary with the particular processing equipment involved. Phosphate rock from sample locality IP-1 has weighted average organic carbon contents that are considered "weathered" using a standard of 2.8 percent (Table 5; Gulbrandsen and Krier, 1980, p. 22).

Vanadium is a by-product of phosphate rock that is currently being recovered in the western phosphate field. At locality IP-1, vanadium concentrations from individual sampling units of the phosphate zones range from 270 to 4,300 ppm. Weighted averages of V2O5 from the phosphate zones at IP-1 (Table 5) exceed the average of 800 ppm for phosphate rock (greater than 18 percent P2O5) for the southeastern Idaho phosphate field (U.S. Departments of Interior and Agriculture, 1977).

CONCLUSIONS

Trench-sample data from IP-1 provide additional details on the stratigraphy and phosphate-rock characteristics of the

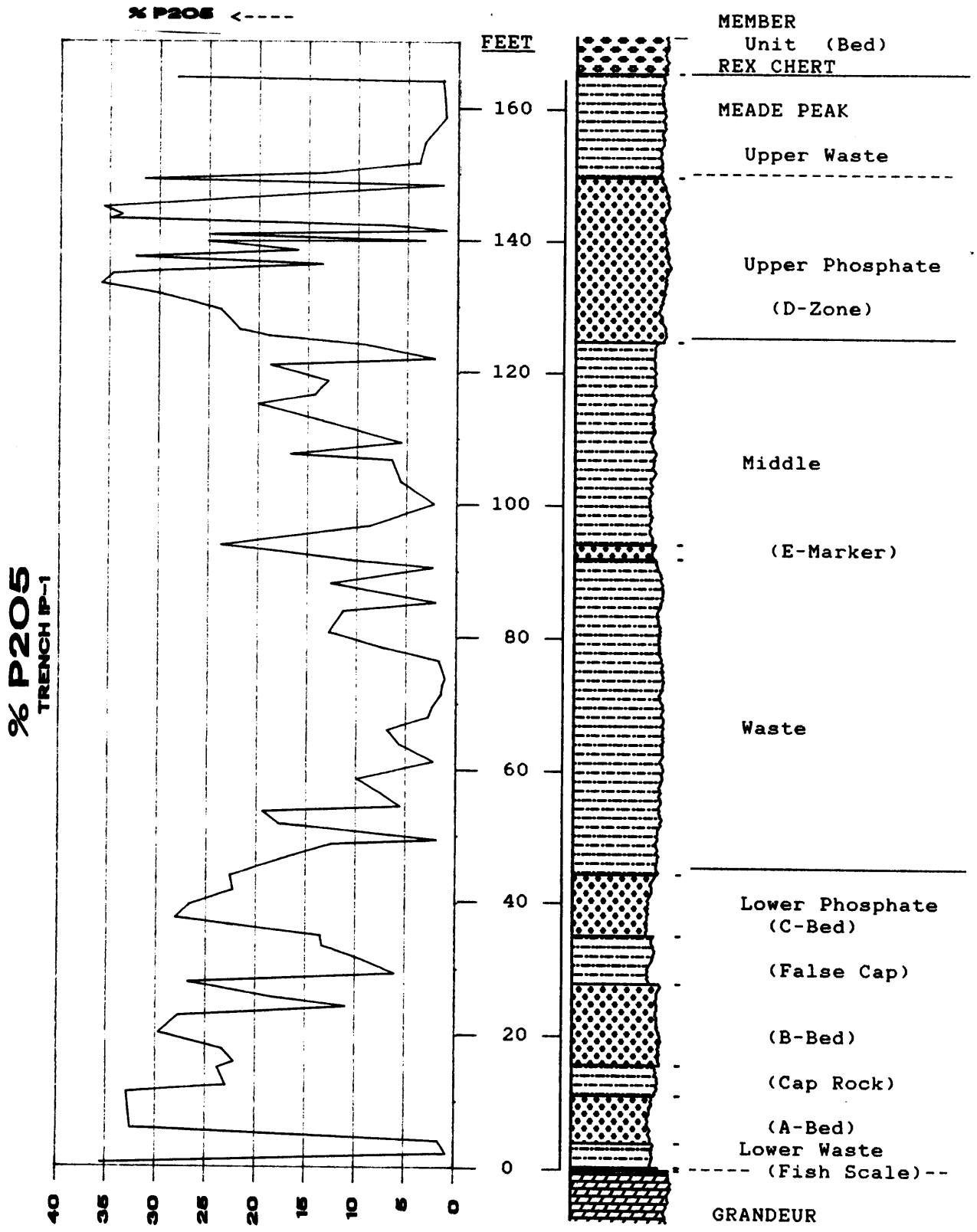

Figure 4. Generalized stratigraphic column and percent P_2O_5 for the Meade Peak Phosphatic Shale Member of the Phosphoria Formation at sample locality IP-1.

Table 1. General lithology, thickness, and phosphate analyses for Hill Spring trench IP-1.

TRENCH IP-1 Sample Number	Unit Number	General Lithology	Thickness (ft) Unit	Thickness (ft) Cumulative	Thickness (m) Unit	Thickness (m) Cumulative	Unit MEMBER Subunit	Bed thickness	P_2O_5 (wt %)
IP-1-91	R-1	chert					REX CHERT MEMBER		
IP-1-90	M-89	phosphorite	0.49	164.61	0.15	50.17	MEADE PEAK		28.20
IP-1-89	M-88	siltstone	2.62	164.12	0.80	50.02	Upper		1.50
IP-1-88	M-87	do	2.95	161.49	0.90	49.22	Waste		1.30
IP-1-87	M-86	do	3.71	158.54	1.13	48.32	15.58 ft		1.20
IP-1-86	M-85	do	3.28	154.83	1.00	47.19	4.75 m		3.30
IP-1-85	M-84	claystone, carbonaceous	1.57	151.55	0.48	46.19			3.90
IP-1-84	M-83	siltstone, phosphatic	0.95	149.97	0.29	45.71			13.40
IP-1-83	M-82	phosphorite, silty	0.79	149.02	0.24	45.42			31.50
IP-1-82	M-81	siltstone & phosphorite	3.41	148.24	1.04	45.18			1.50
IP-1-81	M-80	phosphorite, nodular	1.08	144.82	0.33	44.14			35.60
IP-1-80	M-79	phosphorite	0.69	143.74	0.21	43.81		D-Zone	33.80
IP-1-79	M-78	do	0.82	143.05	0.25	43.60			34.80
IP-1-78	M-77	siltstone, carbonaceous	0.79	142.23	0.24	43.35			6.60
IP-1-77	M-76	siltstone	0.72	141.44	0.22	43.11	Upper		1.20
IP-1-76	M-75	phosphorite, carbonaceous	0.79	140.72	0.24	42.89	Phosphate		24.80
IP-1-75	M-74	siltstone	0.26	139.93	0.08	42.65	24.84 ft		3.30
IP-1-74	M-73	phosphorite & siltstone	1.35	139.67	0.41	42.57	7.57 m		25.10
IP-1-73	M-72	do	1.02	138.33	0.31	42.16			16.10
IP-1-72	M-71	phosphorite	0.98	137.31	0.30	41.85			32.40
IP-1-71	M-70	siltstone & phosphorite	1.15	136.33	0.35	41.55			13.60
IP-1-70	M-69	phosphorite & siltstone	0.39	135.18	0.12	41.20			30.70
IP-1-69	M-68	phosphorite, nodular	1.44	134.78	0.44	41.08		-Buckshot Bed-	34.70
IP-1-68	M-67	phosphorite	1.64	133.34	0.50	40.64			35.80
IP-1-67	M-66	do	2.30	131.70	0.70	40.14			29.70
IP-1-66	M-65	do	2.92	129.40	0.89	39.44			23.80
IP-1-65	M-64	do	1.02	126.48	0.31	38.55	V	V	21.90
IP-1-64	M-63	phosphorite & siltstone	1.28	125.47	0.39	38.24			19.00
IP-1-63	M-62	siltstone & phosphorite	2.13	124.19	0.65	37.85			9.10
IP-1-62	M-61	siltstone	1.02	122.05	0.31	37.20			2.30
IP-1-61	M-60	siltstone & phosphorite	2.36	121.04	0.72	36.89			18.80
IP-1-60	M-59	phosphorite & siltstone	2.10	118.67	0.64	36.17			13.00
IP-1-59	M-58	do	1.44	116.57	0.44	35.53			14.30
IP-1-58	M-57	siltstone, nodular	2.56	115.13	0.78	35.09			20.00
IP-1-57	M-56	siltstone & phosphorite	3.22	112.57	0.98	34.31			13.50
IP-1-56	M-55	phosphorite & siltstone	1.77	109.36	0.54	33.33	Middle		5.60
IP-1-55	M-54	do	0.89	107.58	0.27	32.79	Waste		16.70
IP-1-54	M-53	siltstone & phosphorite	3.28	106.70	1.00	32.52	80.25 ft		6.50
IP-1-53	M-52	do	3.28	103.42	1.00	31.52	24.46 m		5.60
IP-1-52	M-51	do	3.28	100.14	1.00	30.52			2.30
IP-1-51	M-50	siltstone	3.05	96.86	0.93	29.52			8.60
IP-1-50	M-49	phosphorite	2.23	93.80	0.68	28.59		-E-Marker-	23.70
IP-1-49	M-48	siltstone	1.05	91.57	0.32	27.91			10.70
IP-1-48	M-47	siltstone & claystone	2.43	90.52	0.74	27.59			2.40
IP-1-47	M-46	claystone	2.85	88.09	0.87	26.85			12.60
IP-1-46	M-45	siltstone	1.35	85.24	0.41	25.98			2.10
IP-1-45	M-44	claystone	3.12	83.90	0.95	25.57			11.40
IP-1-44	M-43	do	2.33	80.78	0.71	24.62			12.80
IP-1-43	M-42	do	2.00	78.45	0.61	23.91			7.60
IP-1-42	M-41	siltstone, carbonaceous	2.66	76.45	0.81	23.30			1.70
IP-1-41	M-40	siltstone, bioclastic	1.05	73.79	0.32	22.49			1.10
IP-1-40	M-39	siltstone	1.35	72.74	0.41	22.17			1.40
IP-1-39	M-38	siltstone, bioclastic	1.94	71.39	0.59	21.76			1.50
IP-1-38	M-37	siltstone, carbonaceous	1.51	69.46	0.46	21.17			2.40
IP-1-37	M-36	siltstone, argillaceous	1.97	67.95	0.60	20.71			2.80
IP-1-36	M-35	do	2.17	65.98	0.66	20.11			6.90
IP-1-35	M-34	do	2.62	63.82	0.80	19.45	Middle		5.70
IP-1-34	M-33	do	2.66	61.19	0.81	18.65	Waste		2.30
IP-1-33	M-32	siltstone & phosphorite	2.17	58.53	0.66	17.84			9.90
IP-1-32	M-31	do	1.97	56.37	0.60	17.18			7.50
IP-1-31	M-30	siltstone, argillaceous	0.82	54.40	0.25	16.58			5.60
IP-1-30	M-29	siltstone & phosphorite	1.84	53.58	0.56	16.33			19.40

Table 1. Continued.

TRENCH IP-1 Sample Number	Unit Number	General Lithology	Thickness (ft) Unit	Thickness (ft) Cumulative	Thickness (m) Unit	Thickness (m) Cumulative	Unit MEMBER Subunit thickness	Bed	P_2O_5 (wt %)
IP-1-29	M-28	phosphorite & siltstone	2.36	51.74	0.72	15.77			17.80
IP-1-28	M-27	siltstone, argillaceous	0.66	49.38	0.20	15.05			1.90
IP-1-27	M-26	siltstone & phosphorite	1.90	48.72	0.58	14.85	V		12.50
IP-1-26	M-25	do	2.89	46.82	0.88	14.27			16.80
IP-1-25	M-24	phosphorite & siltstone	2.17	43.93	0.66	13.39			22.60
IP-1-24	M-23	do	2.20	41.77	0.67	12.73		C-Bed	22.30
IP-1-23	M-22	phosphorite & siltstone	1.97	39.57	0.60	12.06			26.70
IP-1-22	M-21	phosphorite, silty	1.05	37.60	0.32	11.46			28.10
IP-1-21	M-20	phosphorite, carbonaceous	1.67	36.55	0.51	11.14			22.80
IP-1-20	M-19	claystone, silty	1.54	34.88	0.47	10.63			13.50
IP-1-19	M-18	siltstone, carbonaceous	2.13	33.33	0.65	10.16		False	13.30
IP-1-18	M-17	do	2.00	31.20	0.61	9.51		Cap	9.20
IP-1-17	M-16	siltstone, sandy	1.38	29.20	0.42	8.90	Lower		6.10
IP-1-16	M-15	phosphorite & siltstone	2.23	27.82	0.68	8.48	Phosphate		26.80
IP-1-15	M-14	do	1.41	25.59	0.43	7.80	40.03 ft		18.30
IP-1-14	M-13	siltstone, bioclastic	1.41	24.18	0.43	7.37	12.2 m		11.00
IP-1-13	M-12	phosphorite, silty	2.62	22.77	0.80	6.94			27.80
IP-1-12	M-11	do	2.40	20.15	0.73	6.14		B-Bed	29.70
IP-1-11	M-10	claystone & phosphorite	1.90	17.75	0.58	5.41			23.30
IP-1-10	M-9	claystone, bioclastic	0.95	15.85	0.29	4.83		Cap	22.20
IP-1-9	M-8	siltstone, bioclastic	2.59	14.90	0.79	4.54		Rock	23.80
IP-1-8	M-7	do	1.15	12.30	0.35	3.75			23.00
IP-1-7	M-6	phosphorite	2.62	11.16	0.80	3.40			32.90
IP-1-6	M-5	do	2.62	8.53	0.80	2.60	V	A-Bed	32.70
IP-1-5	M-4	do	2.00	5.91	0.61	1.80			32.50
IP-1-4	M-3	siltstone	1.80	3.90	0.55	1.19	L. Waste		1.60
IP-1-3	M-2	do	1.64	2.10	0.50	0.64			0.80
IP-1-2	M-1	phosphorite, bioclastic	0.46	0.46	0.14	0.14		Fish-scale	35.50
IP-1-1	G-1	dolomite, bioclastic					GRANDEUR TONGUE OF THE PARK CITY FORMATION		

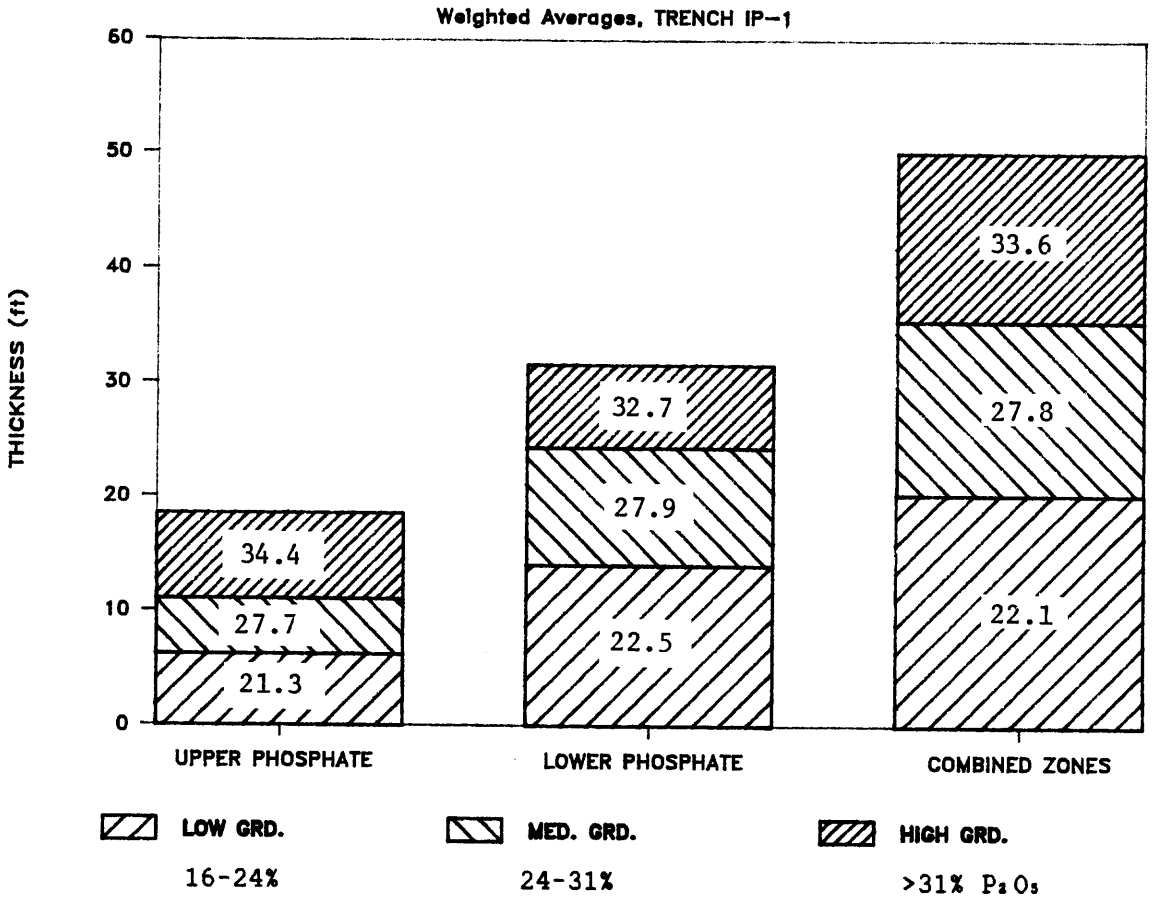

Figure 5. Phosphate-zone thicknesses and grades for sample locality IP-1. Numbers within columns are weighted averages of weight percent P_2O_5 content of high-, medium-, and low-grade phosphate units.

Table 2. Summary of weighted average grades and thicknesses for Hill Spring trench IP-1.

GRADE:	HIGH	MEDIUM	LOW	H+M+L	OVERALL
(Process Grade):	(Acid)	(Furnace)	(Beneficiation)	---	---
P_2O_5:	(>=31%)	(>=24-31%)	(>=16-24%)	(16%+)	($\%P_2O_5$)
ALL BEDS SAMPLED:					
P_2O_5 (weight %)	33.61	27.81	20.83	25.40	13.97
Thickness (ft)	15.16	15.58	35.40	66.14	164.61
(m)	4.62	4.75	10.79	20.16	50.17
UPPER PHOSPHATE:					
P_2O_5 (weight %)	34.36	27.70	21.25	28.21	22.13
Thickness (ft)	7.45	4.82	6.23	18.50	24.84
(m)	2.27	1.47	1.90	5.64	7.57
LOWER PHOSPHATE:					
P_2O_5 (weight %)	32.72	27.85	22.47	26.57	23.24
Thickness (ft)	7.25	10.27	14.04	31.56	40.03
(m)	2.21	3.13	4.28	9.62	12.2
WEIGHTED AVERAGE OF UPPER AND LOWER PHOSPHATE ZONES:					
P_2O_5 (weight %)	33.55	27.80	22.09	27.18	22.81
Thickness (ft)	14.70	15.09	20.28	50.07	64.87
(m)	4.48	4.60	6.18	15.26	19.77

Table 3. Chemical composition of the upper phosphate zone of the Meade Peak Phosphatic Shale Member at sample locality IP-1.

Unit Number	Thickness (ft)	Thickness (m)	Chemical Composition (weight percent) P_2O_5	Al_2O_3	Fe_2O_3	MgO	CaO	SiO_2	Na_2O	K_2O	H_2O+	H_2O-	TiO_2	MnO	CO_2	C org	V_2O_5	Total	LOI	AI	Calculated $Fe_2O_3 + Al_2O_3$	Calculated CaO/ P_2O_5
UPPER PHOSPHATE--Top																						
M-82	0.79	0.24	31.50	1.30	0.52	0.14	44.90	11.30	0.46	0.25	1.10	1.00	0.07	0.01	1.30	1.70	0.030	95.58	5.10	11.81	1.82	1.43
M-81	3.41	1.04	1.50	---	---	---	---	---	---	---	---	---	---	---	---	1.20	---	---	---	85.35	---	---
M-80	1.08	0.33	35.60	0.32	0.15	0.07	50.00	4.20	0.23	0.06	1.00	0.86	0.01	<0.01	1.30	1.70	0.086	95.59	4.60	4.62	0.47	1.40
M-79	0.69	0.21	33.80	1.10	0.49	0.17	47.90	4.00	0.28	0.24	1.30	1.40	0.06	<0.01	1.40	3.00	0.150	95.29	7.80	5.14	1.59	1.42
M-78	0.82	0.25	34.80	0.59	0.32	0.07	49.00	7.90	0.28	0.12	0.90	0.46	0.04	<0.01	1.30	0.46	0.052	96.29	2.60	8.64	0.91	1.41
M-77	0.79	0.24	6.60	9.00	3.00	0.43	9.00	62.90	1.50	1.50	2.20	1.20	0.64	0.06	0.23	0.59	0.062	98.91	4.10	74.48	12.00	1.36
M-76	0.72	0.22	1.20	11.70	4.10	0.50	1.60	70.50	2.30	1.70	2.20	1.80	0.76	0.14	0.03	0.27	0.082	98.88	4.60	86.89	15.80	1.33
M-75	0.79	0.24	24.80	3.80	1.40	0.24	35.60	23.80	0.62	0.74	1.50	0.95	0.26	0.01	0.99	1.10	0.036	95.85	4.40	27.84	5.20	1.44
M-74	0.26	0.08	3.30	11.40	3.80	0.66	4.70	65.30	1.40	2.10	2.90	1.50	0.77	0.05	0.11	1.00	0.100	99.09	5.60	80.82	15.20	1.42
M-73	1.35	0.41	25.10	3.60	1.20	0.25	35.80	24.80	0.61	0.66	1.40	1.00	0.25	0.01	0.98	1.00	0.066	96.73	4.30	28.56	4.85	1.43
M-72	1.02	0.31	16.10	6.60	2.20	0.44	23.10	39.90	0.83	1.30	2.10	1.50	0.45	0.01	0.64	1.70	0.120	96.99	6.30	47.74	8.80	1.43
M-71	0.98	0.30	32.40	1.40	0.57	0.15	45.70	8.90	0.27	0.31	1.30	1.20	0.09	0.01	1.20	2.10	0.110	95.71	6.00	9.29	1.97	1.41
M-70	1.15	0.35	13.60	7.00	2.50	0.40	19.60	44.90	1.00	1.40	2.20	1.40	0.49	0.02	0.54	1.60	0.120	96.77	6.00	53.69	9.50	1.44
M-69	0.39	0.12	30.70	1.90	0.69	0.15	43.40	12.40	0.37	0.36	1.20	1.40	0.11	0.01	1.20	1.90	0.057	95.85	5.90	13.72	2.59	1.41
M-68	1.44	0.44	34.70	1.00	0.39	0.12	48.80	5.60	0.20	0.22	1.00	0.90	0.06	<0.01	1.30	1.10	0.160	95.55	4.00	5.92	1.39	1.41
M-67	1.64	0.50	35.80	0.58	0.24	0.11	50.10	3.30	0.18	0.14	0.98	1.20	0.03	<0.01	1.40	1.60	0.170	95.83	4.90	3.44	0.82	1.40
M-66	2.30	0.70	29.70	1.80	0.77	0.23	42.60	8.60	0.20	0.43	1.60	2.40	0.10	0.01	1.20	5.30	0.430	95.37	12.30	9.28	2.57	1.43
M-65	2.92	0.89	23.80	3.70	1.40	0.36	34.50	17.70	0.27	0.85	1.70	3.40	0.22	0.01	1.00	5.30	0.310	94.52	13.60	21.82	5.10	1.45
M-64	1.02	0.31	21.90	4.00	1.70	0.34	32.00	19.90	0.31	0.90	2.10	2.80	0.22	0.01	0.87	6.10	0.220	93.37	14.70	24.12	5.70	1.46
M-63	1.28	0.39	19.00	5.20	1.30	0.42	27.90	27.50	0.35	1.20	1.60	4.10	0.30	0.01	0.86	4.30	0.140	94.18	12.90	32.64	6.50	1.47
UPPER PHOSPHATE--Bottom																						

NOTES: C org = organic carbon. LOI = loss on ignition. AI = acid insoluble.
Analyses by Z. Brown and J. Marinenko, U.S. Geological Survey, Reston, VA.

Table 4. Chemical composition of the lower phosphate zone of the Meade Peak Phosphatic Shale Member at sample locality IP-1.

Unit Number	Thickness (ft)	Thickness (m)	Chemical Composition (weight percent) P_2O_5	Al_2O_3	Fe_2O_3	MgO	CaO	SiO_2	Na_2O	K_2O	H_2O+	H_2O-	TiO_2	MnO	CO_2	C org	V_2O_5	Total	LOI	AI	Calculated $Fe_2O_3 + Al_2O_3$	Calculated CaO/P_2O_5
LOWER PHOSPHATE--Top																						
M-24	2.17	0.66	22.60	5.80	1.10	0.49	32.70	20.70	0.40	1.40	2.60	1.90	0.27	<0.01	0.76	4.50	0.027	95.25	11.80	26.79	6.90	1.45
M-23	2.20	0.67	22.30	5.20	1.30	0.54	32.70	18.20	0.35	1.30	2.70	2.30	0.25	<0.01	0.89	5.80	0.039	93.87	14.40	24.13	6.50	1.47
M-22	1.97	0.60	26.70	3.40	2.30	0.28	38.10	14.80	0.47	0.93	2.20	1.30	0.18	<0.01	0.99	2.90	0.050	94.60	8.40	18.33	5.70	1.43
M-21	1.05	0.32	28.10	2.80	1.20	0.32	40.20	12.60	0.47	0.72	1.80	1.50	0.13	<0.01	0.99	3.60	0.080	94.51	9.30	15.24	4.00	1.43
M-20	1.67	0.51	22.80	4.10	1.80	0.39	32.90	23.70	0.30	1.10	2.20	1.60	0.22	0.03	0.93	3.10	0.140	95.31	9.10	28.51	5.90	1.44
M-19	1.54	0.47	13.50	7.60	2.50	0.28	19.60	43.40	0.36	2.30	2.80	1.20	0.40	0.10	0.49	1.80	0.066	96.40	7.30	52.92	10.10	1.45
M-18	2.13	0.65	13.30	8.50	2.30	0.46	19.40	42.60	0.50	2.80	3.20	1.00	0.43	0.01	0.72	1.70	0.052	96.97	7.00	54.37	10.80	1.46
M-17	2.00	0.61	9.20	9.90	2.80	0.54	13.70	49.40	0.47	3.20	3.50	1.20	0.51	0.01	0.47	1.50	0.064	96.46	7.00	63.91	12.70	1.49
M-16	1.38	0.42	6.10	10.60	3.10	0.31	8.60	60.00	0.86	2.80	3.40	1.20	0.65	0.04	0.24	0.92	0.068	98.89	5.70	74.28	13.70	1.41
M-15	2.23	0.68	26.80	2.90	0.85	0.23	38.40	20.70	0.33	0.85	1.70	0.90	0.17	<0.01	1.10	1.60	0.160	96.69	5.40	23.13	3.75	1.43
M-14	1.41	0.43	18.30	5.70	1.70	0.32	26.10	36.00	0.50	1.60	2.40	1.00	0.40	<0.01	0.76	1.50	0.210	96.49	5.90	42.60	7.40	1.43
M-13	1.41	0.43	11.00	---	---	---	---	---	---	---	---	---	---	---	---	0.92	---	---	---	61.80	---	---
M-12	2.62	0.80	27.80	2.80	1.10	0.27	39.50	16.00	0.36	0.84	1.90	1.10	0.16	<0.01	1.20	2.30	0.220	95.55	7.10	18.12	3.90	1.42
M-11	2.40	0.73	29.70	2.40	0.87	0.25	42.60	12.80	0.39	0.70	1.80	0.96	0.12	<0.01	1.30	1.90	0.240	96.03	6.20	13.94	3.27	1.43
M-10	1.90	0.58	23.30	4.70	1.70	0.38	33.60	23.70	0.43	1.40	2.20	1.10	0.26	0.01	1.00	2.10	0.200	96.08	7.10	28.10	6.40	1.44
M-9	0.95	0.29	22.20	4.90	1.40	0.41	32.00	26.50	0.39	1.30	2.30	1.20	0.20	0.03	0.97	1.70	0.100	95.60	6.80	31.66	6.30	1.44
M-8	2.59	0.79	23.80	3.90	1.20	0.36	34.50	24.00	0.50	1.20	2.10	0.99	0.19	0.01	1.10	1.80	0.052	95.70	6.60	28.11	5.10	1.45
M-7	1.15	0.35	23.00	4.60	2.10	0.35	33.00	25.30	0.51	1.00	2.50	1.10	0.24	0.02	0.77	1.10	0.110	95.70	5.60	29.03	6.70	1.43
M-6	2.62	0.80	32.90	1.10	0.36	0.20	47.00	4.90	0.79	0.32	1.80	1.10	0.05	<0.01	1.60	2.80	0.190	95.11	8.00	5.56	1.46	1.43
M-5	2.62	0.80	32.70	0.94	0.42	0.21	46.40	5.00	0.82	0.32	1.90	1.10	0.05	<0.01	1.70	2.70	0.310	94.57	8.00	5.26	1.36	1.42
M-4	2.00	0.61	32.50	1.00	0.65	0.22	46.40	5.40	0.90	0.36	1.60	0.92	0.05	0.01	1.80	2.00	0.320	94.13	6.90	5.90	1.65	1.43
LOWER PHOSPHATE--Bottom																						

NOTES: C org = organic carbon. LOI = loss on ignition. AI = acid insoluble.
Analyses by Z. Brown and J. Marinenko, U.S. Geological Survey, Reston, VA.

Table 5. Weighted averages of selected chemical criteria for phosphate zones in Hill Spring phosphate trench IP-1.

ZONE (units >=16% P_2O_5)	P_2O_5	MgO	Fe_2O_3 + Al_2O_3	CaO/ P_2O_5	Organic Carbon	V_2O_5
Units:	|<----------(wt %)---------->					(ppm)
UPPER PHOSPHATE	28.21	0.24	3.49	1.43	3.02	1858
LOWER PHOSPHATE	26.57	0.30	4.47	1.44	2.64	1602
COMBINED ZONES	27.39	0.27	3.98	1.43	2.83	1730

Meade Peak Phosphatic Shale Member of the Phosphoria Formation at the southern part of Freeman Ridge. Data from sample locality IP-1 represent a weathered (altered) section of the Meade Peak that meets chemical criteria for mining and processing as does the data from two other trenches at Freeman Ridge (see Hovland and Moore, 1986; Hovland and Roberts-Tobey, 1985). Trench data are useful as a basis for preliminary phosphate resource estimates at Freeman Ridge. However, a comprehensive drilling program would be required to determine the subsurface extent of alteration and structural complexities that directly affect the mining approach and economic viability.

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APPENDIX

Detailed lithologic descriptions of sampled units of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation in Hill Spring phosphate trench IP-1.

(Refer to Tables 1, 3, and 4 for thickness and chemical data associated with each sample unit. A generalized lithologic column is provided in Figure 4.)

Unit No.	Lithologic Description
	—Conformable contact with Rex Chert Member above. Top of Meade Peak Phosphatic Shale Member (upper waste zone).—
M-89	Phosphorite, peloidal, brownish-gray (10YR 4/1), hard, mostly composed of peloids 0.1 to 0.5 mm in diameter; rare nodules as much as 3 cm in diameter. Unit has a sharp irregular contact with unit below.
M-88	Siltstone, light yellowish-brown (10YR 6/4) to moderate yellowish-brown (10YR 4/4), medium hard, thickly laminated to very thin-bedded, shaly habit; gradational contact with unit below.
M-87	Siltstone; same as unit M-88.
M-86	Siltstone; same as unit M-88 except thin bedded.
M-85	Siltstone; same as unit M-88 except has blocky weathering and is thinly laminated to thin bedded.
M-84	Claystone, carbonaceous, brownish-black (10YR 2/1) to medium yellow-brown (10YR 4/4), soft, poorly defined, laminated, mottled beds; sharp planar contact with unit below.
M-83	Siltstone, phosphatic, nodular, peloidal, grayish-brown (2.5YR 3/2) to pale brown (10YR 5/3), hard, laminated to thin-bedded. Peloids are well rounded and moderately well sorted. Nodules that comprise 4 percent of this unit are phosphatic, well rounded, and oriented along bedding planes. Unit has fetid odor and is very thin bedded. Sharp planar contact with unit below.
	—Top of upper phosphate zone ("D-zone").—
M-82	Phosphorite, silty, peloidal, brown-gray (10*YR* 4/1), hard- to medium-hard, very thin-bedded to thin-bedded, limonite staining; peloids are less than 0.5 mm in diameter, well rounded, and well sorted; sharp planar contact with unit below.
M-81	Siltstone, with minor phosphorite interbeds (that comprise 5 percent of unit). Siltstone is petroliferous, locally carbonaceous, medium yellow-brown (10*YR* 5/4), to very dark gray-brown (10*YR* 3/4); medium hard to hard, thickly laminated to very thin-bedded, shaly habit. Phosphorite interbeds are peloidal, very dark yellow-brown (10*YR* 4/2), silty, medium hard to hard, 5 mm to 1 cm thick beds; peloids in the phosphorite interbeds are well rounded, less than 0.5 mm, and suspended in a silty matrix. Sharp planar contact with unit below.
M-80	Phosphorite, peloidal, nodular, brownish-gray (10*YR* 4/1) to light brownish-gray (10*YR* 6/2), medium hard to hard, thickly laminated to thin-bedded. Peloids are as much as 1.0 mm in diameter and medium to well sorted. Nodules oriented along bedding planes are 1-2 cm in diameter. Sharp planar contact with unit below.
M-79	Phosphorite, carbonaceous, peloidal, brownish-gray (10*YR* 4/1) to brownish-gray (10*YR* 3/1), medium hard, thickly laminated to very thin-bedded, shaly habit (in part); peloids less than 0.3 mm, well rounded, well sorted. Sharp planar contact with unit below.
M-78	Phosphorite; same as unit M-80.
M-77	Siltstone, carbonaceous, slightly phosphatic, peloidal, nodular, medium yellow-brown (10*YR* 5/6) to brownish-gray (10*YR* 3/1), medium hard to hard, laminated to very thin-bedded; peloids less than 0.5 mm, well rounded, disseminated in siltstone matrix; nodules, 0.5 to 1.0 cm in diameter, are common along bedding planes; sharp irregular (wavy) contact with unit below.
M-76	Siltstone, moderate yellowish-brown (10*YR* 5/6), to light yellowish-brown (10*YR* 6/4),

mottled, soft, beds indistinct; gradational contact with unit below.

M-75 Phosphorite, peloidal, carbonaceous, nodular, brownish-gray (10YR 3/1) to dark gray (7.5YR 3/0), silty, hard, very thin-bedded to thin-bedded, laminated. Peloids are 0.2 to 0.5 mm in diameter, well rounded, and well sorted. Nodules are common, phosphatic, subrounded, and as much as 3 cm in diameter.

M-74 Siltstone, peloidal, slightly phosphatic, medium yellow-brown (10YR 4/4) to dark brown (10YR 3/3), medium hard, very thin-bedded. Peloids are rare, less than 0.25 mm in diameter and well rounded. Sharp planar contact with unit below.

M-73 Phosphorite and siltstone. Phosphorite constitutes 90 percent of unit and is peloidal, silty, very dark grayish brown (10YR 3/2) to brownish gray (10YR 3/1), hard, very thin bedded to thin bedded. Peloids are as much as 2 mm in diameter, subrounded to well rounded, and are moderately well sorted. Siltstone interbeds are carbonaceous, phosphatic, peloidal, dark yellow-brown (10YR 4/2) to brownish-gray (10YR 3/1), thickly laminated to very thin bedded. Gradational contact with unit below.

M-72 Phosphorite and siltstone; same as unit M-73, except that phosphorite comprises 60 percent of the unit.

M-71 Phosphorite, peloidal, dark gray (7.5YR 3/0) to light brownish-gray (10YR 5/1), medium hard to hard, thickly laminated to very thin-bedded; has prismatic cleavage. Peloids are 0.1 to 1 mm in diameter, rounded to subrounded, and moderately well sorted. Sharp planar contact with unit below.

M-70 Siltstone and phosphorite; same as unit M-73 except that phosphorite comprises only 40 percent of the unit. Sharp irregular contact with unit below.

M-69 Phosphorite with minor phosphatic siltstone near base. Phosphorite is brownish black (10YR 2/1), soft to medium hard, and very thin bedded. Peloids are 0.25 to 0.50 mm in diameter, subrounded to well rounded, and well sorted. Siltstone is phosphatic, peloidal, dark yellow-brown (10YR 4/2), medium hard, and thickly laminated. Sharp planar contact with unit below.

M-68 Phosphorite, peloidal, nodular, brownish-black (10*YR* 2/1) to very dark grayish-brown (10*YR* 3/2); the top 5 cm is soft and friable with the remainder hard to medium hard; very thin bedded to thin bedded. Many companies refer to this bed as the "buckshot bed" because of its texture and friability. Peloids are 0.2 to 1 mm in diameter, subrounded to rounded, with sorting variable throughout unit. Nodules are subrounded, 2.5 cm long, elongate, and phosphatic. Sharp planar contact with unit below.

M-67 Phosphorite, peloidal, silty, brownish-gray (10*YR* 4/1) to brownish-gray (10*YR* 3/1), thickly laminated to very thin-bedded, medium hard. Peloids range from 0.2 to 0.5 mm in diameter, well rounded, and well sorted. Gradational contact with unit below.

M-66 Phosphorite, silty, argillaceous, peloidal, brownish-black (10*YR* 2/1) to brownish-gray (10*YR* 3/1), medium hard; beds are thickly laminated to very thin bedded. Peloids are mostly less than 0.25 mm, well sorted, and subrounded to rounded. Limonite staining, strong brown (7.5*YR* 5/6) throughout unit. Gradational contact with unit below.

M-65 Phosphorite; same as unit M-66.

M-64 Phosphorite, peloidal, brownish-black (10*YR* 2/1), soft, friable, no distinctive stratification; peloids are 0.2 to 0.5 mm in diameter, well rounded, and well sorted. Sharp planar contact with unit below.

M-63 Phosphorite with minor siltstone interbeds. Phosphorite is peloidal and brownish black (10*YR* 2/1). Peloids in the phosphorite are less than 0.25 mm in diameter and are well rounded and well sorted. Siltstone comprises 15 percent of unit and is phosphatic and dark brown (10*YR* 3/3). Unit is medium hard and thickly laminated. Gradational contact with unit below.

—Top of middle waste zone.—

M-62 Siltstone and interbedded phosphorite. Siltstone is phosphatic, brownish black (10*YR* 2/1) to medium yellowish brown (10*YR* 5/4), and

medium hard. Phosphorite comprises 25 percent of unit and is peloidal, silty, brownish black (10*YR* 2/1), and medium hard. Unit is thickly laminated to thinly bedded. Sharp planar contact with unit below.

M-61 Siltstone, argillaceous, punky, weakly phosphatic, very dark gray (5YR 3/1) to moderate brown (7.5YR 4/4), soft, no internal stratification distinguishable. Sharp planar contact with unit below.

M-60 Siltstone and interbedded phosphorite. Siltstone is peloidal, phosphatic, dark brown (7.5YR 3/2) to strong brown (7.5YR 4/6), and medium hard to soft. Forty percent of unit is rhythmically interbedded phosphorite, which is peloidal, locally silty, very dark grayish brown (10YR 3/2) to moderate yellowish brown (10YR 3/4), and medium hard. Peloids are mostly less than 0.25 mm in diameter, well rounded to subrounded, and well sorted. Unit is very thin to thin bedded. Gradational contact with unit below.

M-59 Phosphorite and siltstone; same as unit M-60, except that phosphorite comprises 70 percent of the unit. Elongated phosphate nodules, 1 to 1.5 cm long, are locally present. Gradational contact with unit below.

M-58 Phosphorite and siltstone; same as unit M-59.

M-57 Siltstone, nodular, phosphatic, dark gray (7.5YR 3/0) to strong brown (7.5YR 5/6), hard to medium hard, thickly laminated to medium-bedded. Common, elongated, irregular-shaped phosphatic and peloidal nodules comprise 8 percent of unit. Nodules are as much as 4 cm long, with the elongate direction of nodules parallel to bedding. Gradational contact with unit below.

M-56 Siltstone and interbedded phosphorite; same as unit M-60 except that phosphorite comprises 30 percent of unit. Sharp planar contact with unit below.

M-55 Phosphorite and interbedded siltstone. Phosphorite is peloidal, brownish black (10YR 2/1) to very dark grayish brown (10YR 3/2), medium hard, and thickly laminated to very thin bedded; has prominent Liesegang banding. Peloids range from 0.2 to 0.5 mm across and are well rounded and moderately sorted. Siltstone is phosphatic, peloidal, dusky yellowish brown (10YR 2/2) to moderate yellowish brown (10YR 4/6), soft to medium hard, and laminated. Gradational contact with unit below.

M-54 Phosphorite and interbedded siltstone. Phosphorite (70 percent of unit) is peloidal, dark brown (7.5YR 3/2) to brownish black (10YR 2/1) medium hard to hard, and very thin bedded. Siltstone is argillaceous, grayish brown (7.5YR 4/2) to very dark grayish brown (10YR 3/2), phosphatic, and peloidal. Gradational contact with unit below.

M-53 Siltstone and interbedded phosphorite. Siltstone (80 percent of unit) is carbonaceous in part, slightly phosphatic, grayish brown (7.5YR 4/2) to dark brown (7.5YR 3/2), soft to medium hard, thickly laminated to medium bedded, with shaly partings and Liesegang banding. Abundant crusty, pale yellowish orange (10YR 8/6) to reddish yellow (5YR 6/8) coating. Phosphorite is silty, peloidal, brownish gray (10YR 3/1) to dark brown (10YR 3/3), medium hard, mostly very thin bedded. Peloids are as much as 1 mm across, subrounded to well rounded, moderately well sorted to well sorted. Sharp planar contact with unit below.

M-52 Siltstone and interbedded phosphorite; same as unit M-53 except that phosphorite beds are 15 percent of unit and unit is more carbonaceous.

M-51 Siltstone and interbedded phosphorite; same as unit M-52.

M-50 Siltstone, peloidal, silty, black (2.5YR 2/0) to grayish-brown (2.5YR 3/2), soft to medium hard, thickly laminated to thin-bedded, common splitting along shaly partings. Peloids are 0.2 to 1 mm across, subrounded to well rounded, and moderately well sorted. Pale yellowish-orange (10YR 8/8) crusty coating is present along fractures and bedding planes. Gradational contact with unit below.

M-49 Phosphorite (E-marker bed); same as M-50 except less silty; shaly planar contact with unit below.

M-48 Siltstone, phosphatic, silty, peloidal, dark gray (2.5YR 4/0) to brownish-black (5YR 2.5/1),

hard, very thin-bedded; breaks into angular blocks and has fetid odor. Other characteristics are similar to unit M-50. Sharp planar contact with unit below.

M-47 Siltstone and interbedded claystone. Siltstone is mottled, phosphatic, moderate brown (7.5YR 4/4) to dark yellowish orange (10YR 6/8), soft, friable, indistinct stratification, well sorted. Claystone, located 0.22 to 0.48 m from base of unit, is peloidal, phosphatic, very dark grayish brown (10YR 3/2) to brownish gray (10YR 3/1), and medium hard; breaks into irregular fragments; Liesegang banding. Peloids are concentrated in thin laminations and are 0.1 to 0.5 mm in diameter, subrounded (and flattened), and well sorted. Sharp planar contact with unit below.

M-46 Claystone; similar to unit M-74 except bioclastic, common bivalves. Sharp planar contact with unit below.

M-45 Siltstone; same as unit M-47. Sharp planar contact with unit below.

M-44 Claystone, silty, carbonaceous, mottled, slightly phosphatic, peloidal, very dark gray (5YR 3/1) to strong brown (7.5YR 4/6), soft, weakly laminated, poorly defined bedding. Peloids are subrounded, 0.2 to 0.5 mm across, and well sorted. Gradational contact with unit below.

M-43 Claystone; same as unit M-44 except that it contains a well-defined 3-cm-thick phosphate interbed. Gradational contact with unit below.

M-42 Claystone, silty, slighty phosphatic, peloidal, bioclastic, carbonaceous, brownish-black (5YR 2.5/1) to strong brown (7.5YR 5/6), medium hard, finely laminated, fissile. Peloids are 0.5 to 3 mm across, disseminated in clay matrix, and subrounded. Common but poorly preserved bivalves are present. Sharp planar contact with unit below.

M-41 Siltstone, carbonaceous, argillaceous, slightly fetid odor, pale brown (10YR 6/3) to dark brown (7.5*YR* 3/2). The upper 0.23 m of this unit is soft and friable, and displays no obvious internal stratification. In contrast, below this, the siltstone is medium hard, very thin to thin bedded, and horizontally laminated (carbonaceous laminations as much as 2 mm wide); has Liesegang banding. Jointing is perpendicular to bedding. Rare bioclasts present are bivalves that average 13 mm across. Sharp planar contact with unit below.

M-40 Siltstone, bioclastic, grayish-brown (7.5*YR* 3/2), thin-bedded. Bioclasts are common (brachiopods and bivalves) but poorly preserved. Sharp planar contact with unit below.

M-39 Siltstone, mottled, moderate yellowish-brown (10*YR* 3/6) to dark yellowish-brown (10*YR* 4/2), very soft and friable; no internal stratification is obvious. Gradational contact with unit below.

M-38 Siltstone; same as unit M-40.

M-37 Siltstone, carbonaceous, slightly phosphatic, pale brown (10*YR* 5/3) to brownish-black (10*YR* 2/1), hard, thin-bedded; Liesegang banding; rare, poorly preserved bivalves. Gradational contact with unit below.

M-36 Siltstone, argillaceous, carbonaceous and phosphatic, laminated, dark brown (7.5*YR* 3/4) to brownish-gray (10*YR* 3/1) and dark gray (10*YR* 3/1); soft to medium hard; very thin to thin-bedded; Liesegang banding. Phosphatic material is concentrated in thin laminations composed of peloids less than 0.5 mm; rare, poorly preserved bivalves present. Sharp planar contact with unit below.

M-35 Siltstone; same as unit M-36.

M-34 Siltstone; same as unit M-36.

M-33 Siltstone; same as unit M-36. Sharp planar contact with unit below.

M-32 Siltstone with minor interbeds of phosphorite. Siltstone is carbonaceous, dark gray (7.5*YR* 3/2) to pale brown (10*YR* 5/3), medium hard, thickly laminated to very thin bedded; Liesegang banding. Phosphorite is 5 percent of unit, brownish gray (10*YR* 3/1), and medium hard; peloids are well rounded, 0.2 to 0.5 mm across and well sorted.

M-31 Siltstone with minor interbeds of phosphorite; same as unit M-32.

M-30 Siltstone, argillaceous, mottled, slightly phosphatic, rare peloids, dark brown (10*YR* 3/3) to

moderate yellowish-brown (10YR 5/6), soft, no internal stratification; bioclasts, common but poorly preserved. Gradational contact with unit below.

M-29 Siltstone with minor phosphorite beds; same as unit M-32.

M-28 Phosphorite with interbedded siltstone. Phosphorite is carbonaceous, silty, brownish black (5YR 2.5/1), thickly laminated, medium hard to soft. Siltstone comprises about 40 percent of unit and is dark brown (7.5YR 3/2), medium hard to soft; peloids occur both as laminae and as disseminated particles. Sharp planar contact with unit below.

M-27 Siltstone, argillaceous, bioclastic, light brown (5YR 5/8) to grayish-brown (7.5YR 3/2); very thin-bedded, soft; common gastropods and spherical nodules 1-5 cm in diameter. Nodules are phosphatic, randomly oriented, and probably concretionary around a fossil nucleus. Sharp planar contact with unit below.

M-26 Siltstone with minor beds of phosphorite; same as unit M-32.

M-25 Siltstone with minor beds of phosphorite; same as unit M-32, except that phosphorite is 20 percent of the unit.

—Top of lower phosphate zone.—

M-24 Phosphorite and minor siltstone. Phosphorite is 90 percent of unit and silty, peloidal, brownish black (10YR 2/1), soft, and thickly laminated to very thin bedded. Siltstone, 10 percent of unit, is moderate yellowish brown (10YR 5/8), phosphatic, peloidal, and carbonaceous. Peloids are in lenses and thin beds. This unit is at the top of the "C-bed." Gradational contact with unit below.

M-23 Phosphorite and minor siltstone; same as unit M-24.

M-22 Phosphorite with minor siltstone interbeds. Phosphorite is silty, peloidal, carbonaceous, brownish black (10YR 2/1), soft to medium hard, thickly laminated to very thin bedded. Peloids are 0.2 to 0.5 mm across, subrounded, and well sorted. Gradational contact with unit below. Siltstone comprises 20 percent of unit, has Liesegang banding, is medium yellowish brown (10YR 4/6) and soft to medium hard. Gradational contact with unit below.

M-21 Phosphorite, silty, peloidal, dark brown (7.5YR 3/2) to dusky yellowish-brown (10YR 2/2), soft, thickly laminated to very thin bedded. Peloids are 0.2 to 2 mm across, well rounded, and medium to well sorted. Gradational contact with unit below.

M-20 Phosphorite, carbonaceous, argillaceous, brownish-black (10YR 2/1) to very dark grayish-brown (10YR 3/2), mottled, soft, very thin-bedded. Peloids are 0.2 to 1.0 mm across, subrounded to rounded, moderately to well sorted. This unit is the bottom unit of the "C-bed." Gradational contact with unit below.

M-19 Claystone, silty, slightly peloidal, phosphatic, greasy, dark brown (7.5YR 4/2) to yellowish-brown (10YR 5/8), mottled, soft, lacks internal stratification. This bed is considered the top of the "false cap." Sharp planar contact with unit below.

M-18 Siltstone, carbonaceous, locally peloidal, argillaceous, dark brown (7.5YR 3/2), to moderate yellowish-brown (10YR 4/3), soft to medium hard, thickly laminated to very thin-bedded. Peloids are 0.1 to 0.5 mm across and well sorted. Gradational contact with unit below.

M-17 Siltstone, carbonaceous, local peloidal concentrations, clay rich; color is same as unit M-18.

M-16 Siltstone, sandy, poorly stratified, laminated; sand is very fine grained and well sorted. This unit is at the bottom of the "false cap." Gradational contact with unit below.

M-15 Phosphorite and phosphatic siltstone. Phosphorite comprises 60 percent of unit and is peloidal, silty, very dark gray (2.5YR 3/0), medium hard to hard, and mostly very thin bedded. Peloids are 0.1 to 0.25 mm across, well rounded, and well sorted. Siltstone is peloidal, strong brown (7.5YR 5/6), and medium hard to hard. This unit is at the top of the "B-bed." Sharp planar contact with unit below.

M-14 Phosphorite and siltstone. Phosphorite is 70 percent of unit and silty, peloidal, very dark gray (N3), medium hard, very thin bedded. Siltstone is peloidal, phosphatic, light yellowish brown (10YR 6/4), and medium hard. Sharp planar contact with unit below.

M-13 Siltstone, peloidal, phosphatic, bioclastic, medium yellowish-brown (10YR 3/1) to pale brown (10YR 5/2), medium hard, very thin-bedded; well-sorted and well-rounded peloids. This relatively low P2O5 content seam within the "B-bed" is sometimes referred to as the "5th horizon." Sharp planar contact with unit below.

M-12 Phosphorite, silty, carbonaceous, peloidal, brownish-gray (10YR 3/1) to pale brown (10YR 5/2), medium hard, very thin-bedded. Sharp planar contact with unit below.

M-11 Phosphorite; same as unit M-12.

M-10 Claystone and interbedded phosphorite. This unit is at the bottom of the "B-bed." Claystone is 70 percent of unit, dark brown (10YR 3/3) to brownish gray (10YR 3/1), and very thin bedded. Unit may contain buddingtonite (ash bed). Sharp planar contact with unit below.

M-9 Claystone, bioclastic, silty, phosphatic, dark brown (7.5YR 3/2) to moderate yellowish-brown (10YR 4/6), soft, no apparent internal stratification; bioclasts are bivalves. This unit is at the top of the "Cap rock." Gradational contact with unit below.

M-8 Siltstone, bioclastic, phosphatic, peloidal, carbonaceous, brownish-black (10YR 2/1) to moderate yellowish-brown (10YR 4/4), soft to medium hard, thickly laminated to very thin-bedded. Carbonaceous material is concentrated in darker laminae. Rare nodules as much as 1 cm in dia-meter; bioclasts are bivalves; limonite staining along fractures. Gradational contact with unit below.

M-7 Siltstone, bioclastic, phosphatic, peloidal, dark brown (10YR 3/3), soft, no internal stratification. Bioclasts are bivalves. This unit is at the bottom of the "Cap rock." Sharp planar contact with unit below.

M-6 Phosphorite, peloidal, silty, very dark gray (2.5YR 3/2) to brownish-gray (10YR 4/1), soft to medium hard, very thin-bedded to thickly laminated. Peloids are subrounded to rounded, 0.2 to 1 mm across, and well sorted. This unit is at the top of the "A-bed." Sharp planar contact with unit below.

M-5 Phosphorite; same as unit M-6.

M-4 Phosphorite; same as unit M-6. This unit is at the bottom of the "A-bed."

M-3 Siltstone, dark brown (10YR 3/3), soft to medium hard, thickly laminated to very thin-bedded; bioclasts are bivalves. This unit is at the top of the "Lower waste." Sharp irregular contact with unit below.

M-2 Siltstone; same as unit M-3.

M-1 Phosphorite, bioclastic, peloidal, slightly calcareous, dark gray (7.5YR 3/0) to brownish-gray (10YR 4/1), hard, very thin-bedded. Abundant bioclasts in this "fossil hash" (brachiopod, and bivalve shell fragments) are 1 to 2 mm across. The upper 4 to 5 cm of this unit is composed of round to oblong peloids that are 3 mm to 2 cm across. This distinctive bed is informally known as the "fish-scale bed." Sharp irregular contact with unit below.

—Contact with the Grandeur Tongue of the Park City Formation. Unconformable contact (disconformity).—

G-1 Dolomite, bioclastic, calcareous, petroliferous, light gray (2.5YR 7/2) to light olive-gray (5YR 6/1), very hard, no apparent internal stratification; recrystallized, medium- to coarse-grained texture. Bioclasts include bryozoans and brachiopod fragments. Continuous veinlets of calcite, 2-3 mm thick, and chert nodules are common in unit. The Grandeur Tongue is a prominent ledge-forming unit. Top 0.1 m is more granular and possibly represents a weathered horizon on top of the Grandeur.

—End of measured section, Trench IP-1.—