PHOSPHATE

IN

UTAH

UTAH GEOLOGICAL AND MINERAL SURVEY
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Phosphate In Utah 1980

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ACKNOWLEDGMENTS:

In June, 1978, the firm of Dames and Moore submitted a report to the U. S. Bureau of Land Management entitled "An Inventory and Market Analysis of the Phosphate Resources of Utah". This report was based upon a review of all available information from both public and industry sources including the files of Utah Geological and Mineral Survey. Because of the thoroughness of the Dames and Moore report and the useful information it contains, the Utah Geological and Mineral Survey has requested and received permission from the U. S. Bureau of Land Management to reproduce it. This circular is based on the Dames and Moore report edited, rearranged, and with minor changes and additions by Dr. Hellmut Doelling, Chief Economic Geologist of Utah Geological and Mineral Survey. The material on market analysis has been omitted.

PHOSPHATE IN UTAH

INTRODUCTION

Purpose

Phosphate rock has the principal use of being applied as a fertilizer in agricultural food production for which there can be no substitute. The demand continues to increase and all sources of supply need to be reexamined and reevaluated. Phosphates derived from phosphate rock are also used as animal feed supplements and in industrial and food grade products. This investigation has sought to identify the potentially economic phosphate resources in Utah, their extent and characteristics.

Scope

Dames and Moore have reviewed all existing publications relating to known phosphate occurrences in Utah. Geologic, sampling, analytical and processing information was obtained from public sources and industry contacts.

The location, extent and geology of all known phosphate rock outcrops in Utah were plotted on appropriate maps and land status and mineral ownership were determined for these areas. To provide a permanent and publicly available record of the information, this site data was reported to the U. S. Geological Survey's National Computer Resource Information Bank.

GEOGRAPHY

Location

Potentially important phosphate deposits in Utah occur in the Meade Peak phosphatic shale member of the Phosphoria Formation. Phosphatic rock in the Meade Peak is exposed in the Northern and Central Wasatch Range, Crawford Mountains, and Uinta Mountains, all in northeastern Utah. Figure 1 is a location map for the resource region. Other deposits are known in rocks of Mississippian age.

Transportation

The region in which the phosphatic rock deposits are found is served by limited transportation facilities. The Union Pacific Railroad has a spur in Wyoming that approaches within eight miles of the Crawford Mountains, with connections to Green River and Evanston, Wyoming and Ogden, Utah. Union Pacific spurs also traverse the southern and central Wasatch Mountains but rail service is lacking to the Vernal and Flaming Gorge areas.

A well dispersed network of state and county secondary roads, as well as a variety of Forest Service Roads, provide ready access to most phosphate occurrences. Electric power is furnished through a regionally interconnected grid supplied by the Utah Power & Light Company.

Climate

Climatic conditions change rapidly with altitude in the region. However, most phosphate occurrences of potential interest lie in an elevation range of 7,000 to 8,000 feet.

Within this range, climate is semi-arid and mean annual precipitation varies between 15 and 20 inches. Most precipitation occurs between November and March in the form of snow which often persists until late May.

Daily and annual variations in temperature show a wide range. July is the hottest month and January is the coldest. Extremes at 7,000 feet elevation may vary from a maximum of 100°F in July to -30°F in January. The period during which freezing temperatures might occur to affect surface mining, spans late October to early April.

GEOLOGY

Phosphate Distribution

Outcrops of phosphatic rock are distributed over an area of roughly 20,000 square miles in northeastern Utah. The study region is divided into seven resource areas, each characterized by similar deposit grades, stratigraphic and structural settings. Resource areas are illustrated on figure 1.

Physiography

Phosphate resource areas include portions of the Wasatch Range, Uinta and Crawford Mountains.

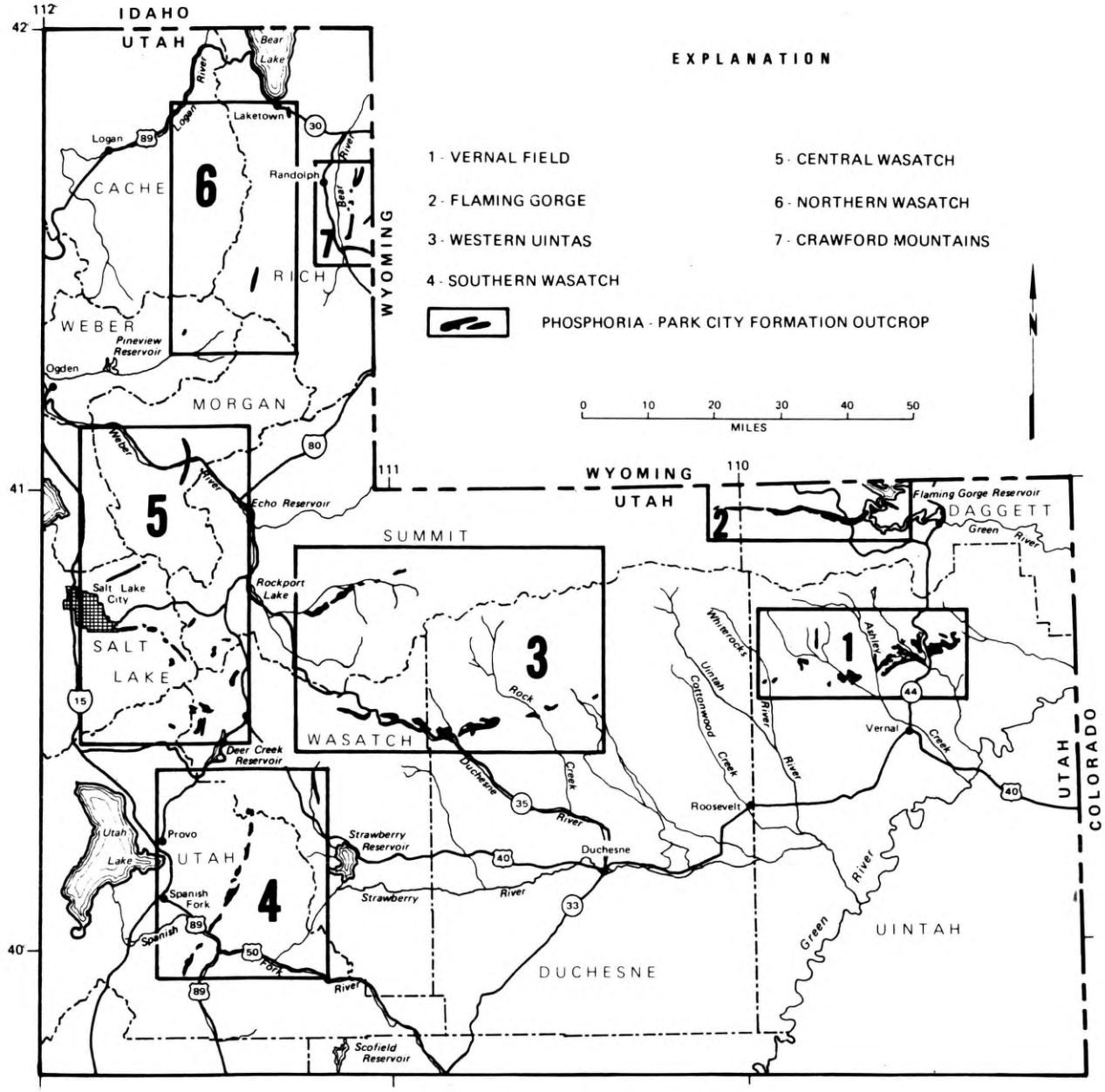
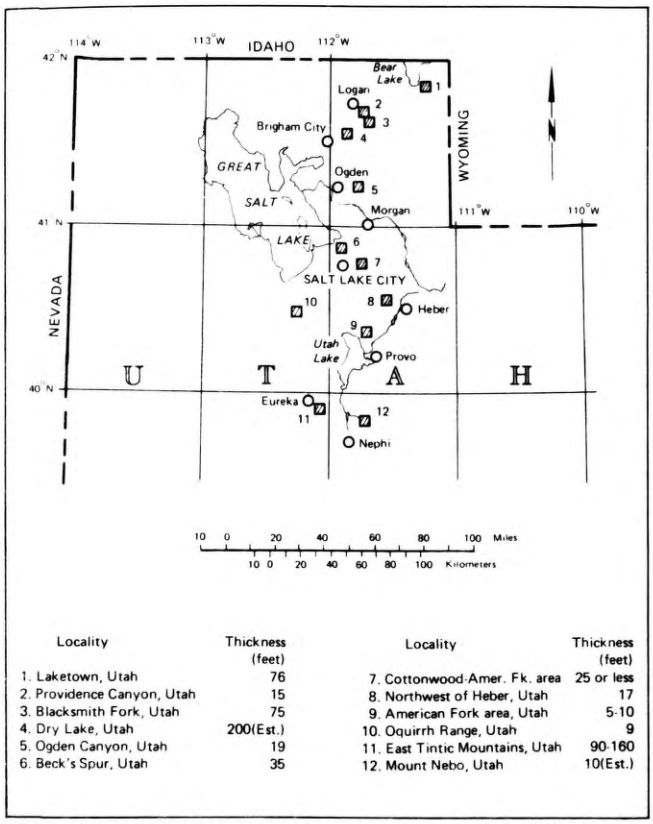


Figure 1. Utah phosphate occurrences.

Both the Wasatch Range and Uinta Mountains lie within the Rocky Mountain physiographic province. The east-trending Uintas and north-trending Wasatch Range are characterized by broadly folded strata cut by both high angle and thrust faults and dissected by drainages that are tributary to the Great Basin and Colorado River. Intrusive rocks are present in the vicinity of the intersection of the two ranges.

Rocks in the Uinta Mountains are arched over a broad, east-west-trending asymmetric anticline, the axis of which lies near the crest of the range. Dips of beds on the north limb of the anticline (Flaming Gorge area) are steep; beds dip gently across a wide plateau on the south flank of the anticline in the Vernal area.

In gross plan, the Wasatch Range is an eastward dipping homocline. However, the homoclinal nature of the range has been masked by the effects of Laramide synorogenic tectonism and later Basin and Range faulting.



Locality	Thickness (feet)	Locality	Thickness (feet)
1. Laketown, Utah	76	7. Cottonwood-Amer. Fk. area	25 or less
2. Providence Canyon, Utah	15	8. Northwest of Heber, Utah	17
3. Blacksmith Fork, Utah	75	9. American Fork area, Utah	5-10
4. Dry Lake, Utah	200(Est.)	10. Oquirrh Range, Utah	9
5. Ogden Canyon, Utah	19	11. East Tintic Mountains, Utah	90-160
6. Beck's Spur, Utah	35	12. Mount Nebo, Utah	10(Est.)

Figure 2. Index map showing general location and thickness of known occurrences of phosphatic shale of Mississippian age.

Topography and drainage in both the Wasatch Range and Uinta Mountains are mature, with the latest cycle of major stream retrenchment dating to the Eocene. Pleistocene glaciation is responsible for much of the topography in the central Uintas and locally in the higher Wasatch.

More rugged, youthful topography occurs along the western front of the Wasatch Range where a prominent, currently active hinge-line fault zone separates the Rocky Mountains from the Basin and Range physiographic province.

The Crawford Mountains, although within the Rocky Mountain physiographic province, border upon the Green River Basin in Wyoming and show some affinity to Great Plains physiography. Typical, broad Rocky Mountain region folding and faulting occur, but the area has escaped recent uplift and stream retrenchment and developed older, more subdued topography.

Stratigraphy

Phosphate beds occur in the Meade Peak Member of the Permian Phosphoria Formation. Phosphatic rocks are also found in the Mississippian Brazer Limestone, but these beds are thin and presently have no resource potential.

The Phosphoria and Park City Formations intertongue and are composed of four recognized members, as illustrated in figures 3a, 3b, 3c. The Meade Peak is the phosphatic member. The entire series rests on Pennsylvanian and Permian sandstone, quartzite and limestone.

In northeastern Utah, near the Idaho-Wyoming border, the Phosphoria Formation consists principally of the Meade Peak phosphatic shale member, about 210 feet thick, and the Rex Chert Member, about 220 feet thick. The Phosphoria is underlain by the Pennsylvanian Wells Formation, a cherty limestone, and overlain by the Triassic Dinwoody Formation, consisting of limestone, calcareous siltstone, and sandstone.

The Phosphoria Formation interfingers with the Park City Formation southward; only the Meade Peak Member is continuous and present throughout northern Utah. At its type locality, the Park City Formation is about 590 feet thick. It consists of a lower limestone member, (Grandeur) and an upper limestone (Franson) member. The Meade Peak Member of the Phosphoria tongues into the Park City Formation between these two members. This relationship exists in the southern part of the outcrop area farther north, along the Idaho border. The Meade Peak phosphatic member of the Phosphoria Formation is overlain by the Rex Chert Member of the Phosphoria. To the south the Grandeur is underlain by the Pennsylvanian Weber Quartzite and overlain by the Triassic Woodside Formation. Eastward, the Grandeur Limestone of the Park City Formation and phosphatic shale of the Phosphoria Formation become thin, are more clastic and finally tongue out into non-marine redbeds of the Permian Chugwater Formation in western Colorado.

Structure

The Phosphoria and Park City Formations lie in a number of different structural settings.

The predominant structural characteristic of the Uinta fields is that of simple uplift. On both the north and south flanks of the Uinta Mountains, phosphatic formations are affected by simple uplift with almost no influence by secondary folding. Dips on the north flank range up to 50 degrees, but the south flank is nearly horizontal (±8 degrees) in most of the areas where significant phosphate deposits occur.

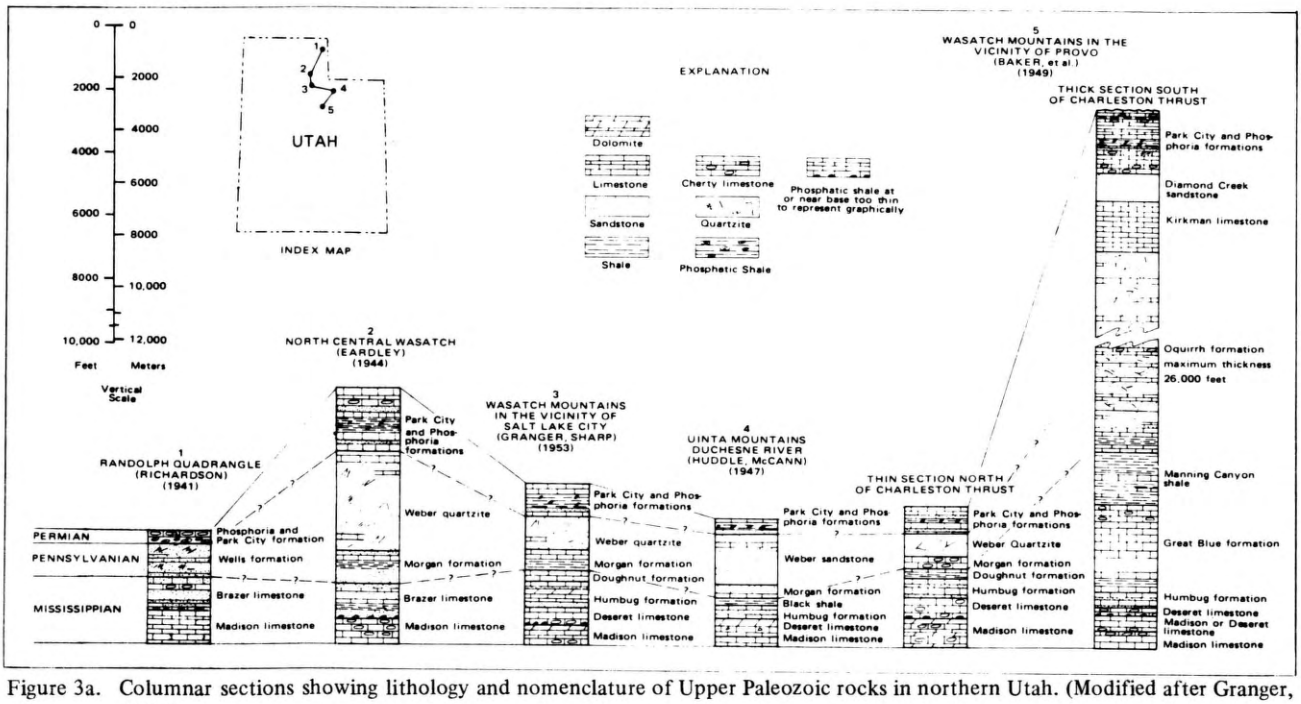


Figure 3a. Columnar sections showing lithology and nomenclature of Upper Paleozoic rocks in northern Utah. (Modified after Granger, 1953).

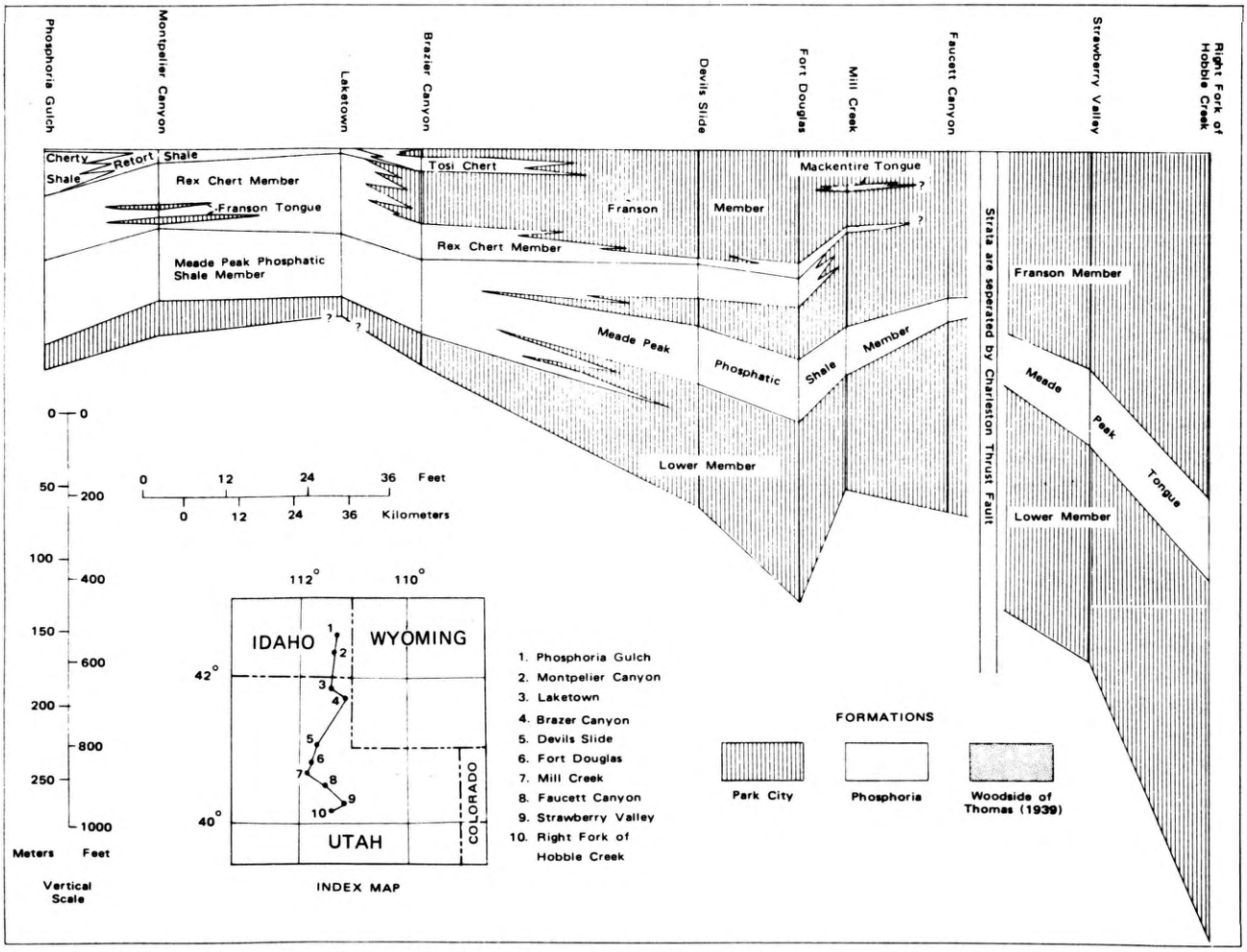


Figure 3b. Diagram showing nomenclature and intertonguing relationships of the Permian Phosphoria and Park City Formations, and the lower part of the Woodside Formation between Phosphoria Gulch, Idaho, and the Right Fork of Hobble Creek, Utah. (Sections at Faucett Canyon and Right Fork of Hobble Creek from Baker and others, 1949).

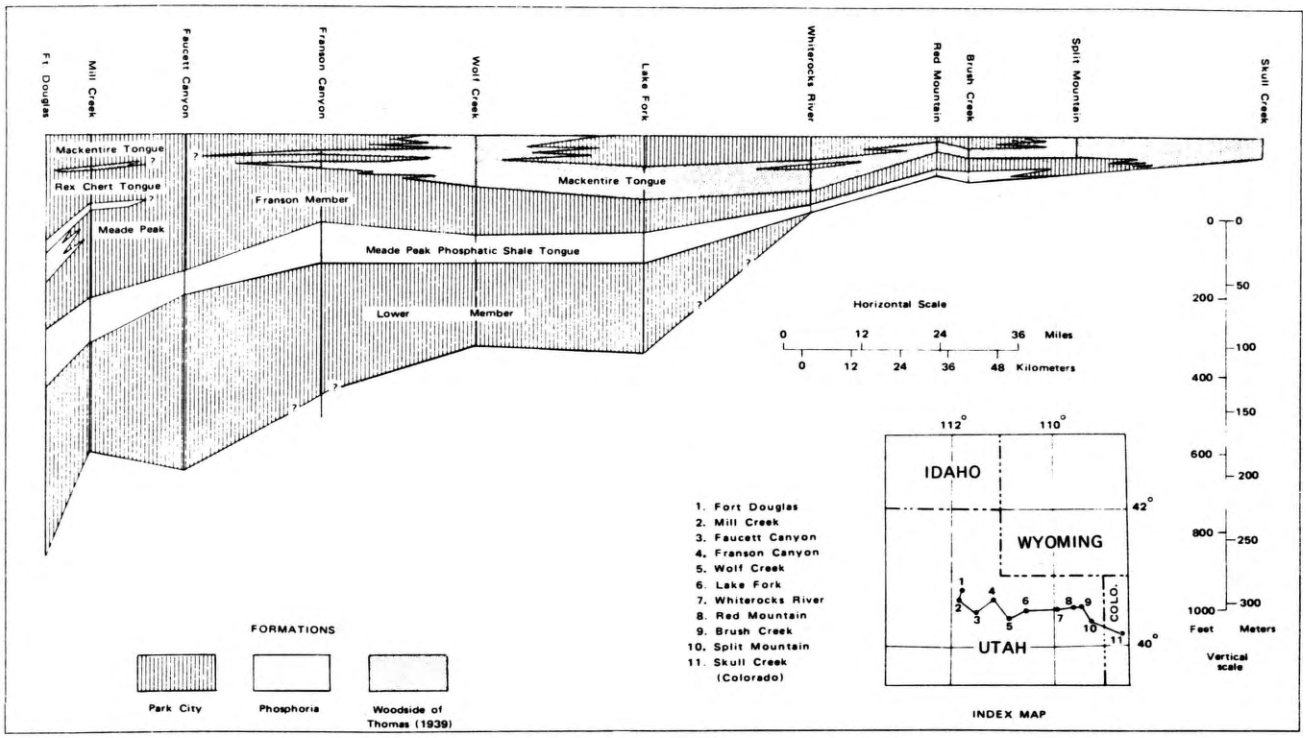


Figure 3c. Diagram showing nomenclature and intertonguing relationships of the Permian Park City and Phosphoria Formations, and the lower part of the Woodside Formation between Fort Douglas, Utah, and Skull Creek, Colorado. (Sections at Faucett Canyon from Baker and others, 1944; Whiterocks River and Red Mountain from Kinney, 1955; Skull Creek, Colorado from Thomas and Krueger, 1946).

In northern Utah, the western Wyoming fold and thrust belt extends southward to influence phosphate bed distribution. Permian rocks in the Crawford Mountains and northern Wasatch Range are generally highly folded with predominately steep dips and complex faulting. In many cases, upper Paleozoic strata rest upon major Laramide thrust plates.

The Laramide orogeny also affected phosphatic beds in the central Wasatch Range. Regional north-south strikes are interrupted by granitic intrusions which in some cases penetrate the Park City Formation. Thrust faults concentrate in mid-Paleozoic strata but locally transect Pennsylvanian and Permian Formations. Superimposed upon these structures are both Laramide and younger high-angle faults. The results are many broken, discontinuous outcrops of phosphatic rock with varying strikes and generally steep dips.

Structural complexity in the Wasatch Range diminishes southward. In the southern Wasatch, gentle folds with high angle faults of small displacement predominate. Twenty-five miles of outcropping phosphatic Park City Formation in the region strike north-south and dip at low to moderate angles eastward. Outcrop discontinuities stem more from stratigraphic onlaps than structural disturbances.

ORIGIN

The Phosphoria and Park City Formations were deposited on marginal shelves of a sea which occupied a broad epeirogenic basin on the Cordilleran Miogeosyncline during the Permian Period. Stratigraphic evidence suggests that the Phosphoria Sea was surrounded on the west, north, and east by low-lying lands that produced little detrital material. To the south and south-west was a connection with the open ocean. The basin of deposition seems to have been deepest in southwestern Idaho and western Utah, from which area the bottom shallowed gradually in all directions.

Surrounding lowlands undergoing limited erosion, gradually sloping marine shelves, and the impeded connection of the Phosphoria Sea with the open sea all contributed to the concentration of phosphate on the Basin floor.

High pressure and low temperature in deeper portions of the sea

Phosphate minerals are unstable in high pressure low temperature environments as found in the deeper portions of seas. These conditions caused the chemical precipitates and skeletal remains of animals to dissolve

as they sank into the depths. On the shallow marine shelves, limestone was precipitated which either diluted the phosphate minerals or left them in solution. Still farther toward shore where major rivers flowed into the Phosphoria Sea, clastic deposition totally masked phosphate precipitation. The areas in which these paleoenvironmental conditions existed, shifted frequently during Phosphoria time. However, the predominate distribution of depositional environments can be interpreted from gross lithologic assemblies during Phosphoria time. This is presented in figure 4.

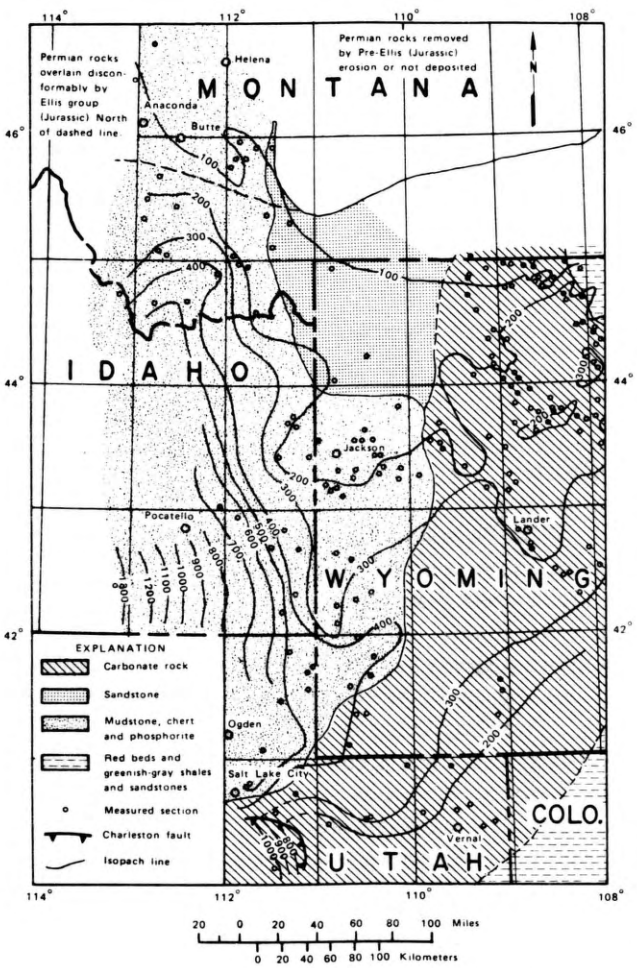


Figure 4. Dominant lithology and thickness of Phosphoria Formation and its stratigraphic equivalents.

Although phosphate may have been precipitated everywhere in the Phosphoria Basin during Meade Peak time, its concentration and preservation in significant amounts was restricted to intermediate depths on the shelf of the Phosphoria Sea.

ECONOMIC GEOLOGY

Phosphate Distribution

The thickness of the phosphatic Meade Peak Member of the Phosphoria Formation in Utah's phosphate provinces are:

Province	Thickness (feet)
Uintas	
North Flank	45-95
South Flank	20-80
Wasatch Range	
Northern	90[1]-263
Central	20-26[1]
Southern	5-10[1]
Crawford Mountains	100-130

[1] Above 10 percent P_2O_5 cutoff.

Isopach maps for the Meade Peak phosphate beds and higher grade portions at various cutoffs are presented in figures 5 through 8.

On the south flank of the Uinta Mountains in the vicinity of Brush Creek, the phosphate content of the entire Meade Peak Member (±20 feet) is farily homogeneous as a minable section. In the Crawfords and northern Wasatch, however, phosphate enrichment occurs at the base and top of the member. The lower portion typically contains a 5- to 10-foot section of phosphatic shale with up to 20 percent P_2O_5. Overlying this is a thick sequence of minor grade limestone and mudstone which may locally hold one or two beds of low grade rock. The upper or hanging wall ore zone consists of a top layer 5 to 7 feet thick of high grade ore ("A" Bed) with up to 31.5% P_2O_5, underlain by 7 to 13 feet of medium grade phosphatic shale named the "B" and "C" Beds. The "B" and "C" Beds average 24 to 26 percent P_2O_5. The hanging wall zone persists but becomes thinner and of lower grade southward; the lower zone disappears or contains only low grade rock to the south. An average northern Wasatch Meade Peak section from Brazer Canyon, relating percent P_2O_5 to stratigraphy, is shown in figure 9.

PETROGRAPHY

Phosphate in the Meade Peak Member of the Phosphoria and Park City Formations occurs principally

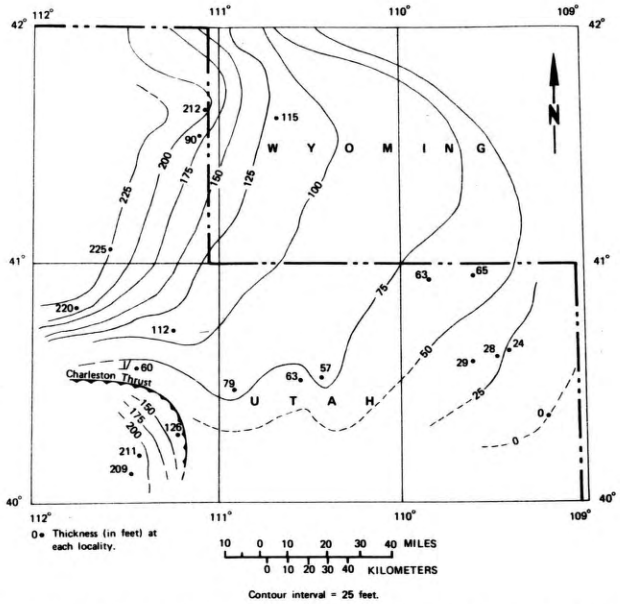


Figure 5. Map showing thickness (in feet) of the Meade Peak phosphatic shale tongue of the Phosphoria Formation.

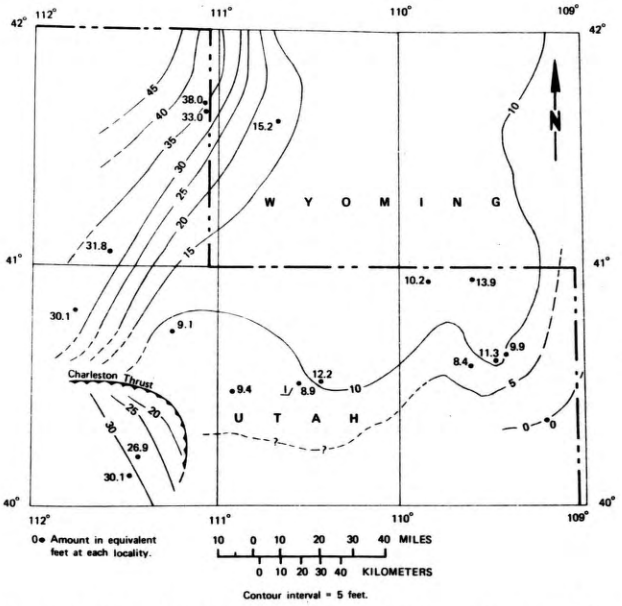


Figure 6. Map showing equivalent thickness and amount (in feet) at each sample locality of the total carbonate-fluorapatite in the Meade Peak phosphaitc shale tongue of the Phosphoria Formation. 1/ a few feet of phosphatic sandstone at base of member was not sampled so this figure is slightly low.

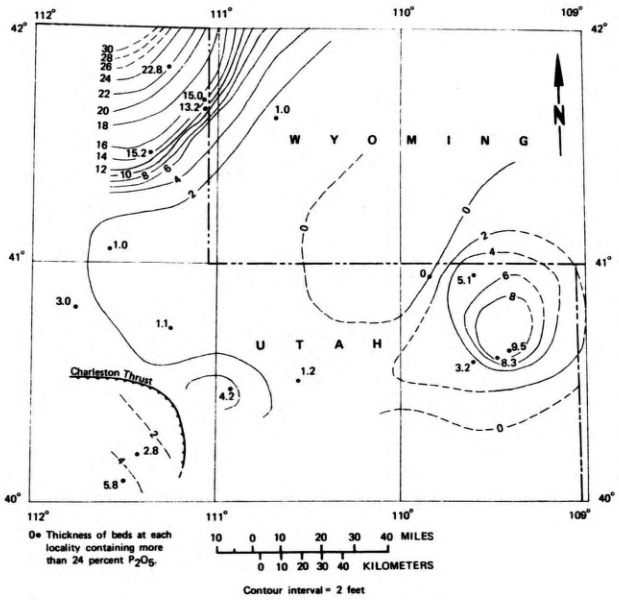


Figure 7. Map showing the total thickness (in feet) of beds in the Meade Peak phosphatic shale tongue of the Phosphoria Formation that contain more than 24 percent P_2O_5 in the Uinta Mountains.

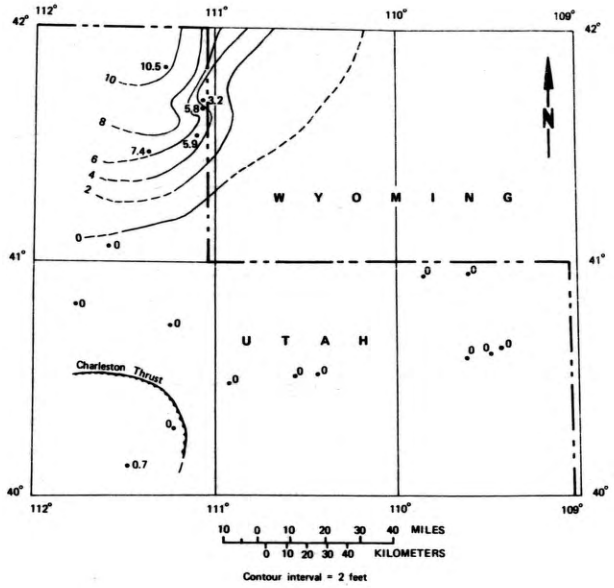
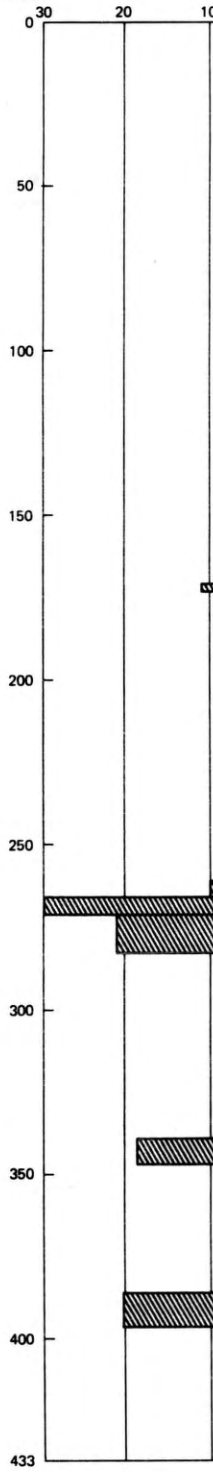


Figure 8. Map showing total thickness and amount (in feet) of beds in the Meade Peak phosphatic shale tongue of the Phosphoria Formation that contain more than 31 percent P_2O_5.

in phosphatic shale and phosphorite rock with thin interbeds of shale, limestone, and chert.

High-grade phosphorite in the member is dense and characteristically oolitic or nodular, with pellets ranging from 0.5 mm to 3 cm in maximum diameter. It is carbonaceous, black to brownish-black in color, and gray to light gray when weathered, surface exposures or outcrops weather light bluish-gray to nearly white. Weathered rock is higher in P_2O_5 content because of the reduced amount of carbonate. High-grade rock has a specific gravity of 2.80 to 2.95 and its hardness varies from medium hard to relatively soft. Where phosphorite has been metamorphosed by close folding



THICKNESS IN FEET	AVERAGE P_2O_5 IN PERCENT	DESCRIPTION
		Dinwoody formation
9	1	Limestone: argillaceous hard, medium-gray, thick-bedded; very fossiliferous.
4	6	Limestone: argillaceous hard, medium-gray, thin-bedded; contains few irregular chert masses.
16	3	Chert: calcareous, hard, black, thick-bedded; upper 9 feet contains irregular limestone beds or lenses.
13	8	Chert: phosphatic, hard, black, thick-bedded.
4	4	Limestone: argillaceous, hard, light brownish-gray, massive.
21	4	Dolomite: argillaceous, hard, light-gray, massive.
35	1	Dolomite and chert: 60 percent is medium-hard, medium-gray, massive dolomite; 40 percent is hard, black, nodular, thick-bedded chert.
17	1	Dolomite: hard, medium-gray, massive; contains chert nodules.
33	1	Dolomite: argillaceous, hard, medium-gray, massive.
17	0	Chert and limestone: upper 10 feet is dolomitic hard, medium-gray, massive chert; lower 7 feet is argillaceous, hard, dark-gray, thin-bedded limestone.
2	11	Limestone: phosphatic, cherty, hard, dark-gray, thick-bedded, nodules.
6	1	Limestone and chert: upper 3 feet is argillaceous, hard, light-gray, thick-bedded limestone; lower 3 feet is hard, black, thick-bedded chert.
20	0	Chert and dolomite: 60 percent is hard, black, thick-bedded chert; 40 percent hard, light-gray, thick-bedded dolomite.
23	1	Limestone and chert: 30 percent is hard, black, nodules lenses, and irregular masses of chert; 30 percent is hard, dark-gray, thick-bedded limestone.
38	0	MEADE PEAK MEMBER Mudstone: 40 percent is calcareous, hard, medium, brownish-gray, thin-bedded; 60 percent is dolomitic, hard, brownish-gray, thin-bedded.
4	10	Mudstone: phosphatic, calcareous moderately oolitic, hard, brownish-gray, massive.
5	30	Phosphate rock: abundant oolites, hard, black, thick-bedded.
12	21	Phosphate rock: argillaceous, abundant oolites, medium-hard, brownish-black, fissile.
8	1	Chert and dolomite: 60 percent is hard, black, thick-bedded chert; 40 percent is hard, brownish-black, thick-bedded dolomite.
15	8	Mudstone: 60 percent is phosphatic, moderately oolitic, hard, black, thin-bedded mudstone; 40 percent is calcareous, dolomitic, hard, brownish-black, thin-bedded.
12	2	Mudstone: medium-hard, black, thick-bedded.
21	9	Mudstone: 80 percent is phosphatic, moderately oolitic, soft, brownish-gray, thin-bedded; 20 percent is calcareous, soft, brownish-gray, thick-bedded.
7	18	Phosphate rock: argillaceous, abundant oolites, soft, black fissile.
24	2	Limestone and mudstone: 60 percent is argillaceous, medium-hard, grayish-brown, thin-bedded limestone; 40 percent is dolomitic, medium-hard, brownish-black, thin-bedded mudstone.
16	8	Mudstone: phosphatic, moderately oolitic, medium-hard, brownish-black, thin-bedded; contains limestone concretions.
10	20	Phosphate rock: argillaceous, abundant oolites, hard, black, fissile.
17	6	Limestone and mudstone: 60 percent is argillaceous, hard, dark-gray, thin-bedded limestone; 40 percent is phosphatic, moderately oolitic, hard, brownish-black, thin-bedded mudstone.
8	2	Limestone: argillaceous hard, black, thin-bedded.
8	2	Dolomite: argillaceous, hard, brownish-gray, thick-bedded.
8	8	Mudstone and phosphate rock: 70 percent is calcareous, soft, brown, thick-bedded mudstone; 30 percent is argillaceous, medium-hard, grayish-brown, thick-bedded, phosphate rock.
		Wells formation

Figure 9. Generalized section of the Phosphoria Formation in northeastern Utah.

or igneous intrusions, it is sometimes hard and brittle. Usually, hardness increases with depth and decreases with weathering.

Phosphatic shales are fine-grained argillites or shales of varying thickness with interbedded limestone and mudstone. Color varies from dark brown to light shades of yellow and gray. Thin seams of high-grade phosphorite contained in the shales are mainly responsible for P_2O_5 grade.

MINERALOGY

Phosphatic nodules and pellets are composed chiefly of collophane, a cryptrocrystalline, opaline, dense, layered or colloform mineral aggregate with an approximate composition of $5.4\ Ca_3(PO_4)_2 \times 2\ CaF_2 \times CaCO_3$.

Most collophane pellets are structureless, but some in the middle-size range are concentrically laminated. Many of the larger nodules are composed of cemented fine pellets. In a few layers, collophane is in the form of phosphatized brachiopod shells and fish scales.

Phosphate nodules and pellets are generally well cemented with collophane, clay, carbonaceous matter, silica or basic carbonates. The P_2O_5 content ranges up to 38 percent for nearly pure collophane, but phosphorite beds of minable thickness generally contain less than 32 percent P_2O_5. Dilutents are: detrital matter, chiefly clay and silt size quartz, mica and feldspar; chemical precipitates are mainly chert, calcite and dolomite. Carbonaceous matter gives the rock a prevailing dark brown to black color.

CHEMISTRY

Chemical analyses of phosphate ore from the Meade Peak Member of the Phosphoria Formation throughout the Crawford Mountains and Vernal are presented in table 1. The composition of the ore varies widely, owing to differences in matrix characteristics. However, phosphate pellets, having formed everywhere under similar marine environmental conditions, exhibit a relatively constant composition. Average major constituents in 100 samples of segregated phosphate pellets are presented in table 2.

A comparison of table 1 with table 2 shows SiO_2, Al_2O_3 and Fe_2O_3 to be dominantly matrix constituents, diminished by pellet concentration, with a consequent upgrading of CaO and P_2O_5.

ENRICHMENT BY WEATHERING

In some phosphate occurrences, a surface zone of enrichment in P_2O_5 results from the leaching of more soluble constituents, notably $CaCO_3$ and iron oxides from the matrix. Locally, the P_2O_5 content of a high grade bed may be five percent higher in leached surface outcrops than at 500 feet depth. Weathering also serves to free phosphatic pellets and nodules from matrix material, rendering ore amenable to simple screening and washing beneficiation.

The extent to which surface enrichment is responsible for the reported grades of Utah's phosphate occurrences cannot be assessed from available data. Most reported assays are from surface outcrops or shallow trench samples; little drilling has been done and no drill sample assay returns have been made public. Outcrop characteristics which serve to identify leaching enrichment have been identified (limestone dissolution, carbon loss resulting in bleaching), but these are largely subjective and have not been applied systematically to Utah occurrences.

The only reliable evidence for the presence or absence of surficial enrichment in Utah ores is provided by present and past mining operations. At Stauffer's Vernal mine, phosphate rock protected by five feet or more of overburden is found to be fresh and requires milling and flotation concentration. Stauffer reports no consistent change in ore grade between surface outcrops and maximum overburden mining depths of roughly 85 feet.

In the Crawford Mountains, past mining operations found ore in the upper Meade Peak phosphorite horizon to be weathered. The ore was concentrated by simple crushing, screening and washing. The Meade Peak phosphorite is also reportedly highly weathered at Laketown, 14 miles northwest of the Crawfords, where weathering appears to be related to an old erosion surface a few tens of feet above the phosphate and at the base of the overlying Tertiary Wasatch Formation. P_2O_5 grade changes with depth have not been reported for either Laketown or the Crawfords.

Geologic and geographic settings provide the only clues to potential weathering and enrichment elsewhere in the state. Deposits on the east flank of the northern Wasatch Mountains, although within the Rocky Mountain tectonic province, are at the margin of the stable Green River Basin and geographically near Laketown and the Crawford Mountains. Weathering, as affecting

Table 1. Chemical composition - Weight% - Western phosphate ore.

	1	2	3	4	5	6	7
SiO_2	14.8	5.4	14.1	3.6	14.6	14.3	12.26
Al_2O_3	2.2	0.79	1.8	0.64	2.2	3.0	1.75
Fe_2O_3	1.1	0.73	1.6	0.56	2.0	1.4	1.09
MgO	1.0	0.30	0.16	0.15	0.34	0.56	0.36
CaO	40.9	49.0	43.7	51.1	41.5	42.0	43.77
Na_2O	0.90	1.1	0.60	0.87	0.46	0.47	0.68
K_2O	0.69	0.20	0.46	0.13	0.63	0.94	0.46
H_2O^{total}	2.1	1.1	1.1	0.84	2.8	2.8	2.2
H_2O^-	0.7	0.1	0.1	<0.05	1.5	1.3	0.6
TiO_2	0.20	0.10	0.17	0.05	0.09	0.14	0.15
P_2O_3	26.9	31.7	27.4	30.4	27.8	27.2	29.79
CO_2	3.17	4.07	4.65	8.22	1.30	2.21	2.49
SO_3		2.81	1.34		4.84	3.63	2.17
Cl					0.02		
F	2.90	3.50	2.55	2.98	2.83	2.78	2.99
Organic matter[4]	3.0	1.5	0.8	0.9	0.5	1.0	2.31
Oil	0.14	0.14	0.15	0.10	0.12	0.10	0.12
U	0.008	0.010	0.004	0.013	0.002	0.002	0.009
eU	0.010	0.011	0.004	0.013	0.003	0.004	0.009
Ag	0.0003	0.0003	0.0003	0.0003	<0.00001	<0.00001	0.001-0.0003
As	0.002	0.001	0.002	0.001	0.001	0.002	0.004
B	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ba	0.03	0.01	0.01	0.01	0.01	0.01	0.01
Be	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Cd	0.01	<0.005	<0.005	0.01	<0.005	<0.005	<0.005
Co	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cu	0.01	0.003	0.003	0.003	0.003	0.001	0.01
Ga	0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
La	0.01	0.01	0.03	0.01	0.01	0.01	0.01
Mn	0.003	0.003	0.01	0.01	0.003	0.003	0.003
Mo	0.01	0.003	0.003	<0.0005	0.001	0.001	0.01
Nd	0.03	<0.006	0.03	<0.006	<0.006	<0.006	0.03
Ni	0.03	0.01	0.01	0.01	0.01	0.003	0.01
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sb	0.0007	0.0005	0.0004	0.0003	0.0003	0.0007	0.0007
Sc	0.001	<0.0005	0.001	<0.0005	0.001	0.001	0.001
Se	0.001	0.001	0.0003	0.0001	0.0007	0.0005	0.0015
Sr	0.1	0.1	0.1	0.1	0.03	0.03	0.1
V	0.1	0.03	0.01	0.03	0.001	0.001	0.03
Y	0.03	0.03	0.03	0.03	0.03	0.01	0.03
Yb	0.001	0.0003	0.0003	0.0003	0.0003	0.0003	0.001
Zn	0.03	0.01	0.01	0.01	<0.008	<0.008	0.03
Zr	0.003	0.003	0.01	0.001	0.001	0.003	0.003

1. Pellet phosphorite. Sample no. VEM-130, lab. no. 7132. Meade Peak Phosphatic Shale Member. Brazer Canyon section, Rich County.
2. Pellet phosphorite. Sample no. RAH-111, lab. no. 1784. Meade Peak Phosphatic Shale Member. Brazer Canyon section, Rich County.
3. Pellet phosphorite. Sample no. MAW-3837, lab. no. 25217. Meade Peak Phosphatic Shale Member. North Crawford section, Rich County.
4. Pellet phosphorite. Sample no. VEM-3926, lab. no. 25250. Meade Peak Phosphatic Shale Member. North Crawford section, Rich County.
5. Pellet phosphorite. Sample no. DMK-7, lab. no. 1649. Meade Peak Phosphatic Shale Member. Brush Creek Gorge section, Uintah County.
6. Pellet phosphorite. Sample no. DMK-13, lab. no. 1655. Meade Peak Phosphatic Shale Member. Brush Creek Gorge section, Uintah County.
7. Average phosphorite of Meade Peak Phosphatic Shale Member of Phosphoria Formation.

Table 2. Chemical analysis of oolites.

	Range	Mean	Std. Deviation
P_2O_5	35.2 - 36.8	35.9	0.6
CaO	49.2 - 52.1	50.7	1.3
SiO_2	0.1 - 6.4	3.0	3.2
Al_2O_3	0.3 - 2.5	1.1	0.9
F_2O_3	0.2 - 0.4	0.3	0.06
F	3.0 - 4.9	3.5	0.9
CO_2	1 - 3	2.0	--
H_2O	1	1	--
Total		97.5	
CaO/P_2O_5	1.4 - 1.44	1.42	0.0
L.O.I.	4.8 - 6.1	5.1	0.0

The balance of 2.5 percent is represented by other elements, such as Na_2O = 0.7, MgO = 0.2, S = 0.6, U_3O_8, V_2O_5, Cr, MnO and Sr, and other more minor elements.

beneficiation characteristics, may be expected, but surficial grade enrichment is indeterminate. All of the Uinta Range occurrences and those in the southern Wasatch Province bear similar geologic histories. Fresh rock conditions found at Vernal may be expected throughout these areas.

In the tectonically active Central Wasatch Range, uplift in general should have kept pace with erosion, preventing the accumulation of any thick, laterally persistent weathered phosphate zones or surficial enrichment. However, the presence of numerous faults in the area may have facilitated ground water circulation which would locally accelerate weathering and promote leaching enrichment. Consequently, phosphate ore from the Central Wasatch may be mixed in nature. Further metallurgical complexity may have been introduced by local and regional metamorphism accompanying granitic intrusion in the area.

HISTORY OF THE PHOSPHATE MINING IN UTAH

Phosphate production did not begin in Utah until 1907, when about 12,000 tons were shipped from the Arickaree Mine in the Crawford Mountains. This activity continued on a limited basis until 1920, and no further production was reported until 1953, when the San Francisco Chemical Company started development of the Arickaree, Pawnee, and Mandan Mines and later, the Tuscarora and Emma Mines in the Crawford Mountains. Most of these mines produced briefly and were closed by 1958; the Cherokee Mine, developed in 1955, maintained a production of 375,000 to 400,000 tons per year until closure in 1975. Limited surface trench mining continues in the Crawfords.

The newest and principal phosphate mine in Utah is at Vernal. The San Francisco Chemical Company began building plant and mine facilities at the Humphreys Phosphate Company property, about 12 miles north of Vernal, in 1960. A 500-ton-per-day capacity mine and flotation plant went on stream in 1961. The Stauffer Chemical Company acquired total interest in the plant and mine in 1969 and has since expanded the facility to process 1,000 tons of ore per day. All production from the plant goes to Stauffer's fertilizer complex at Salt Lake City.

Several other companies, as well as individual prospectors, have shown much interest in Utah phosphate deposits. The most recent active exploration program was completed by the U.S. Steel Corporation near Stauffer's Vernal Mine in 1965.

BENEFICIATION

Introduction

Phosphate rock can be used in the production of fertilizers or for industrial uses in the form of either high quality phosphoric acid or as elemental phosphorus. Although some high grade phosphate rock is pulverized and used directly as fertilizer, the vast majority of phosphatic fertilizers are produced through the acidulation of phosphate rock with sulfuric, nitric or phosphoric acid. Phosphoric acid can be manufactured by either the wet-process method which uses phosphate rock and sulfuric acid, or by the method of hydration of elemental phosphorus. The latter method produces a higher purity phosphoric acid but requires the use of elemental phosphorus which is produced from phosphate rock through the use of energy-intensive electric furnaces.

Phosphate rock used for fertilizer, either directly or after acidulation, must be high grade to allow for a market-quality product. Also, phosphate rock used for wet-process phosphoric acid (WPA) must be high grade and sufficiently low in impurities to permit efficient operation of the WPA process. Although standards can vary, the industry generally accepts a minimum P_2O_5 content of around 31 percent for phosphate rock to be used for acidulation or WPA.

A lower grade phosphate rock can be used by electric furnace smelting of phosphate rock, silica and coke to produce elemental phosphorus. Generally accepted standards for furnace grade rock are 24 to 31 percent P_2O_5 content. Although the elemental phosphorus product can be hydrated to produce phosphoric acid which could be used for fertilizer manufacture, economics generally dictate that high-quality acid produced from elemental phosphorus be used either for industrial purposes or food supplements rather than for fertilizer manufacture.

Potential by-products

Three possible by-products of beneficiation of phosphate rock are: fluorine, vanadium and uranium. At the present there is no evidence that any of these can be recovered economically.

The most recent estimates of Utah's phosphate resources by the U. S. Bureau of Mines (Coffman & Service, R.I. 6934) are presented in table 3. The Bureau of Mines estimates were based upon a minimum three feet of rock *in situ* which may or may not be profitably recovered depending upon changing technologic and economic conditions in the near or distant future.

VERNAL FIELD

Geology

In the Vernal Field (figure 10) phosphate outcrops dip off the south flank of the Uinta Mountains at attitudes that normally range between 6 degrees and 10 degrees; local dips are as much as 25 degrees. There are a few faults in the main part of the field but these are

Table 3. Summary inventory of phosphate rock - Vernal Field[1] (million short tons).

Location	Overburden (feet) -43	+43 -78	+78-100	100 feet to stream level	Stream level to 1,000 feet below	Total Resources
T 3 S, R 20 E	17.2	16.9	21.8	21.4	76.3	153.6
T 2 S, R 21 E	91.8	140.7	307.0	85.0	9.7	634.2
T 3 S, R 21 E	19.8	21.7	77.0	112.5	183.2	414.2
T 2 S, R 22 E	136.7	220.0	366.0	56.2	266.0	1,044.9
T 3 S, R 22 E	--		--	--	36.2	36.2
T 2 S, R 23 E	3.9		21.2	80.0	83.5	196.8
Total	269.4		793.0	355.1	654.9	2,479.9
Cumulative Total	269.4	676.9	1,469.9	1,825.0	2,479.9	--

[1]Percent P_2O_5 varies between 16.4 and 23.0.

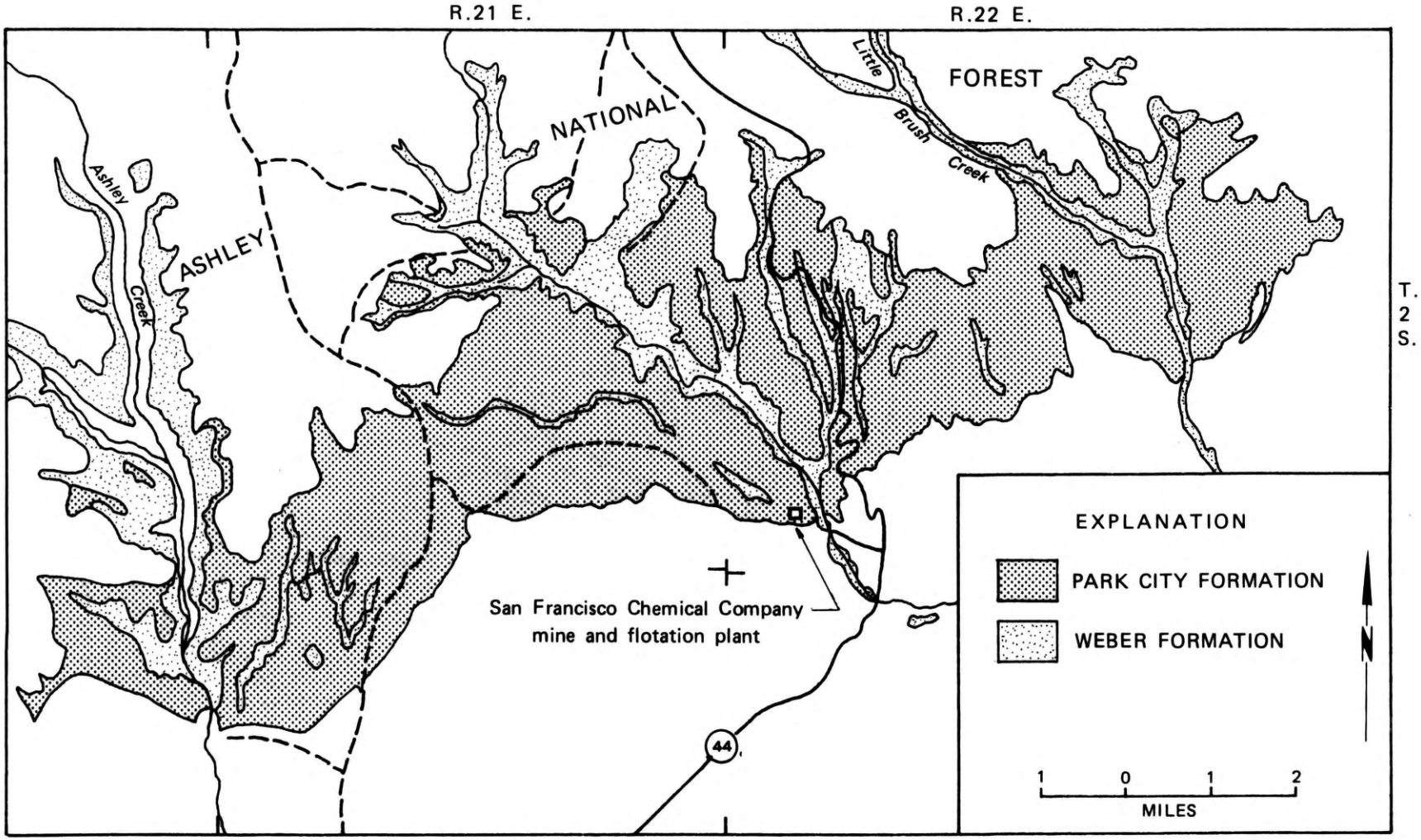


Figure 10. Vernal Field, eastern part. (Modified from D. M. Kinney, plate 1).

simple, normal faults with small displacements. Toward the western part of the area, the faulting becomes more severe as it approaches the large shear area of the South Mountain fault zone. Faulting in this zone becomes fairly intense between Ashley Creek and its dry fork. The faulting displaces the Park City into series of small fault slices. To the west the formation is covered by Tertiary conglomerate.

The Meade Peak Member varies in thickness between the approximate limits of 18 to 22 feet in the Vernal Field, and for the most part, it rests on the hard quartzite and sandstone of the Weber Formation. The Meade Peak is a fairly hard unit, although the coherency is mainly attributed to chert, carbonates and mudstone within the member. The lime and magnesia contents of the beds is not known. These beds are generally of lower phosphate content and are interbedded with softer zones of higher phosphate content. Because of the relative thinness of the individual beds within the member, it appears unlikely that selective mining would be used. Kinney has weighted the sample data from three trenches in the Vernal Field which indicates an increase in grade of P_2O_5 from west to east.

Inventory

Total resources in the Vernal Field computed by Kinney are shown in table 3 and represent the area from Ashley Creek east to the end of the outcrop. The grade of the Meade Peak Member decreases at Ashley Creek (Rock Creek Canyon) to a point where no beds more than three feet thick can be placed in the +18 percent P_2O_5 category. When weighted with adjacent parts of the field, however, the overall grade is 20 percent P_2O_5.

Grade in the Meade Peak west of Ashley Creek, well beyond the area evaluted by Kinney, is only 14.1 percent P_2O_5 in a 12-foot section, below the cutoff established for this analysis. No grade control exists for faulted rock immediately east and west of Ashley Creek, areas also excluded from Kinney's tabulation. However, based upon the grade in Rock Creek Canyon, a grade of 16 percent P_2O_5 is arbitrarily assumed for a 12-foot section, adding 132 million tons to the inventory. Accordingly, total phosphatic rock for the field above stream level is 1.93 billion tons. The weighted average phosphate occurrence is 18 feet thick and contains 20 percent P_2O_5.

CRAWFORD MOUNTAINS

Geology

The beds of the Crawford Mountains (figure 11) are highly folded and faulted. A number of folds are outlined by the Phosphoria Formation, but the major structural feature of the mountains is a syncline on strike with the general trend of the mountains. This structure is outlined by the Phosphoria outcrop as mainly a doubly plunging syncline with the beds exposed very near the trough in the north.

The Phosphoria Formation in this area has been mapped as an approximate 400-foot-thick unit. This is divided into the lower Meade Peak Member and the upper Rex Chert Member which varies from about 125 to 200 feet.

The total Meade Peak thickness (including the Grandeur Member) in the Crawford Mountain ranges from the measured thickness of 145 feet to 212 feet. The thickness and grade of the phosphate enrichment zone changes considerably from place to place. In the northern part of the range the entire section is phosphatic. Here a trench exposed 127 feet that analyzed +11 percent P_2O_5 with comparatively rich beds near the base and the top. Farther south, the middle part of the Meade Peak becomes relatively lean. At the southern end of the Crawford Mountains the upper phosphatic zone of the Meade Peak was found to contain 8.9 feet of +31 percent P_2O_5 rock. The lime and magnesia contents of the above samples were not reported.

Inventory

Table 4 shows phosphate resource estimates for the Crawford Mountains to be 438 million short tons in 1967. Table 5 duplicates the critical inventory values. These estimates were based upon total in-place rock and did not consider blocks that had been mined out; neither did they allow for open-pit vs. underground minability.

The computations of open-pit minable resources, minus past production are presented in table 5. Open-pit extraction is regarded as the only method economically feasible at any foreseeable commodity price level.

A graph relating ore tonnage and grade to stripping ratios for the entire Crawford Mountain district is presented in figure 12.

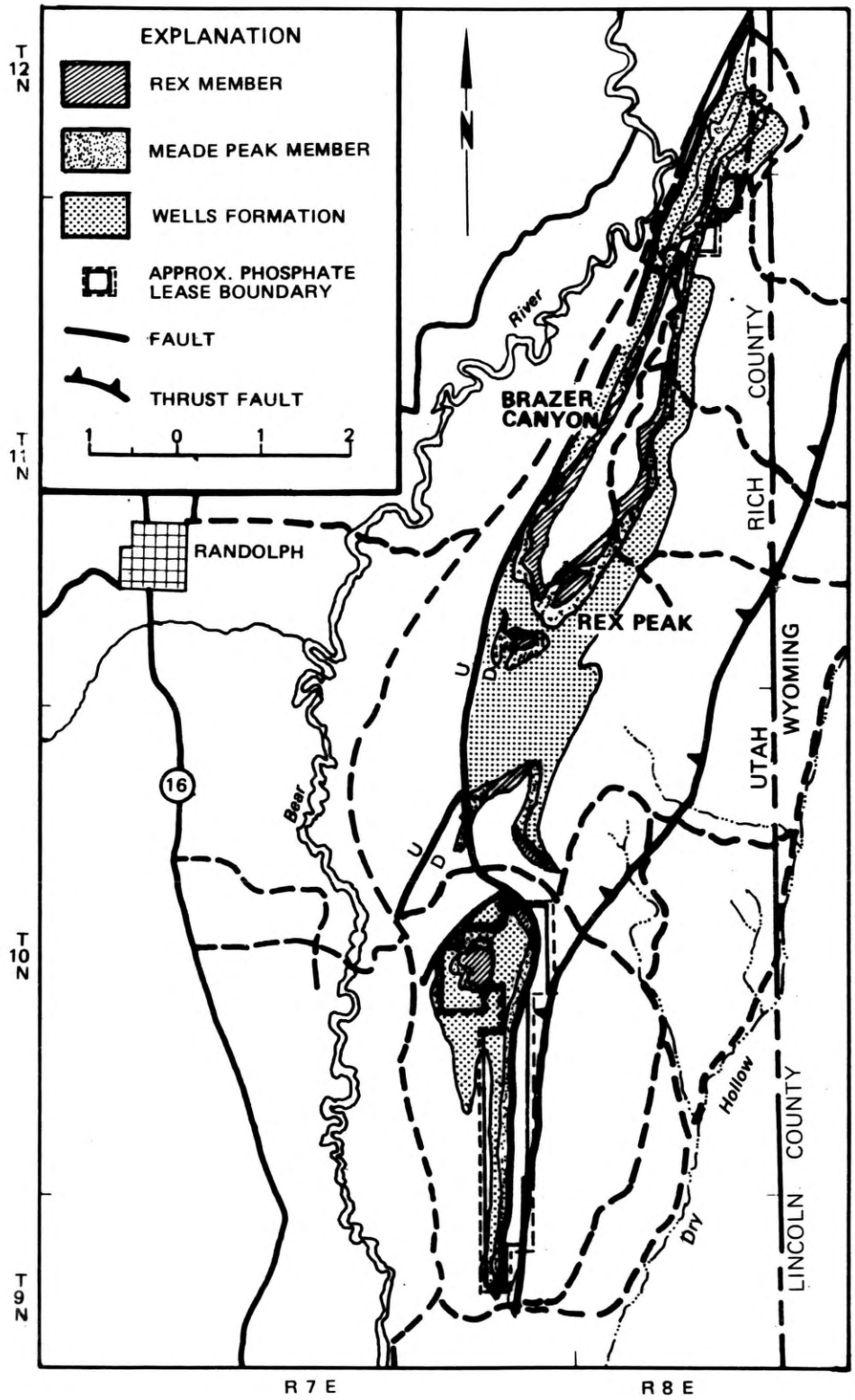


Figure 11. Crawford Mountains district.

Table 4. Phosphate resources of Utah (millions of short tons).

Phosphate Districts	+ 31 Percent P_2O_5		+ 24 percent P_2O_5[1]		+ 18 percent P_2O_5[2]	
	Above Drainage Level Entry	First 100 Feet Below Entry	Above Drainage Level Entry	First 100 Feet Below Entry	Above Drainage Level Entry	First 100 Feet Below Entry
Uinta Range:						
Vernal Field	–	–	–	–	1,825.0	65.5
Flaming Gorge	–	–	83.9	3.2	107.0	4.4
Western	–	–	–	–	203.5	–
Total Uinta Range	–	–	83.9	3.2	2,135.5	69.9
Wasatch Range:						
Little Diamond Creek[3]	–	–	5.0	0.4	5.0	0.4
Dry Bread Hollow	–	–	10.6	1.5	13.4	1.9
Woodruff Creek	–	1.9	–	3.7	–	3.7
Laketown	–	0.6	–	1.9	–	3.5
Total Wasatch Range	–	2.4	15.6	6.7	18.4	8.1
Total Crawford Mountains	32.7	5.8	122.3	22.0	217.1	38.1

[1]Includes + 31% resources.

[2]Includes + 31% and + 24% resources.

[3]Grade information is available only on selected beds.

Table 5. Phosphate resource estimate – Crawford Mountains, Utah.

Land Status	Waste: Ore 2:1		Waste: Ore 5:1	
	Tons at 30% P_2O_5	Tons at[1] 24% P_2O_5	Tons at 30% P_2O_5	Tons at[1] 24% P_2O_5
Private	4.88×10^6	11.20×10^6	10.85×10^6	26.23×10^6
Federal	$.97 \times 10^6$	1.92×10^6	2.13×10^6	$4.32 \times 10_6$
Total	5.85×10^6	13.12×10^6	12.98×10^6	30.55×10^6

[1]Includes 30% P_2O_5 resources.

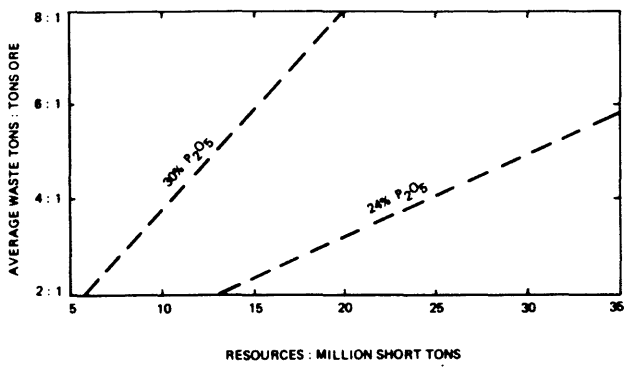


Figure 12. Resource vs. stripping ration, Crawford Mountains Phosphate.

WESTERN UINTA FIELD

The Park City Formation is exposed for about 40 miles on the western end of the Uinta Range in a discontinuous outcrop pattern (figure 13). Comparatively widespread areas on the north flank of the range are covered by Quaternary glacial deposits. According to available data, only two areas, both on the eastern end of the south flank, contain potential phosphate deposits.

In Mackentire Draw, a tributary of Lake Fork Creek, an 11.7 foot zone at the base of the Meade Peak Member was found to contain 14.1 percent P_2O_5. The strike length of this outcrop is approximately one mile and the beds dip about 35 degrees south. About eight miles west the formation crops out on the flanks of Rock Creek Valley. In the wide valley floor it is covered by alluvium, and on the crests of the ridges it is overlain by other Tertiary and Quaternary deposits. Total strike length of this outcrop is roughly six miles, with about one and one-half miles covered by alluvium. The dip is between 20 degrees and 25 degrees south, and the beds are displaced by two faults. The Geological Survey trenched and sampled a section of the Meade Peak Member in Dry Canyon, exposing a 4.8-foot zone averaging 18.1 percent P_2O_5.

Tertiary sediments cover an area a few miles to the west before the Park City crops out again in Wedge Hollow and continues in a discontinuous outcrop pattern around the western nose of the Uinta anticline. Total strike length of the exposures is about 35 miles. The Geological Survey excavated two trenches in this area; one in Wolf Creek on the south flank and the other in Franson Canyon on the north flank of the anticline. The Wolf Creek Trench exposed 6.1 feet of +18 percent PO_5 in two beds separated by a 1.5-foot carbonate rock bed. The Franson Canyon trench exposed two beds separated by about 2 feet of carbonate rock. The total phosphatic zone here was measured at 13.8 feet of +11 percent P_2O_5 rock. The lime and magnesia contents of the above samples were not reported.

Inventory

On the basis of the foregoing grade and thickness information, the Bureau of Mines produced the following inventory:

	Million short tons
South flank (6.1 feet), +18% P_2O_5	198
North flank (13.8 feet), +11% P_2O_5	305

The highest grade section of the inventory was sampled in Dry Canyon, where 3 feet of +25 percent material may be available. However, diluted to a practical mining thickness of five feet, the section would provide only 14 to 15 percent rock. Neither this, nor any other known occurrence in the field, offers sufficient grade and thickness to warrant economic analyses at current or paramarginal price levels.

FLAMING GORGE

Geology

In the eastern part of the north flank of the Uinta Mountains, the Meade Peak Member extends nearly 30 miles in east-west trending, north dipping outcrops. The Park City Formation in the area (figure 14) forms broad exposures on the slopes of the ridges north and south of Sheep Creek.

Access to the area is through Manila, Utah, and several good gravel roads off Sheep Creek. The nearest rail facility is at Green River, Wyoming, about 50 miles north. Almost all of the phosphate exposures lie within the boundaries of Ashley National Forest.

The dips of the Meade Peak Member exposures range from about 8 degrees to 35 degrees north; the most gentle dips are on the eastern end. There is one comparatively wide exposure on the west side of the Flaming Gorge Reservoir, however, that dips consistently at about 8 degrees. Where the Park City Formation crosses Sheep Creek the dip is about 20 degrees; the majority of the attitudes are between 15 degrees and 20 degrees. Throughout practically the entire length of the outcrops, the Meade Peak Member either dips off a hill or just under a crest. The structure of the phosphate belt is simple except in the extreme eastern end where it is faulted off against the Uinta thrust zone.

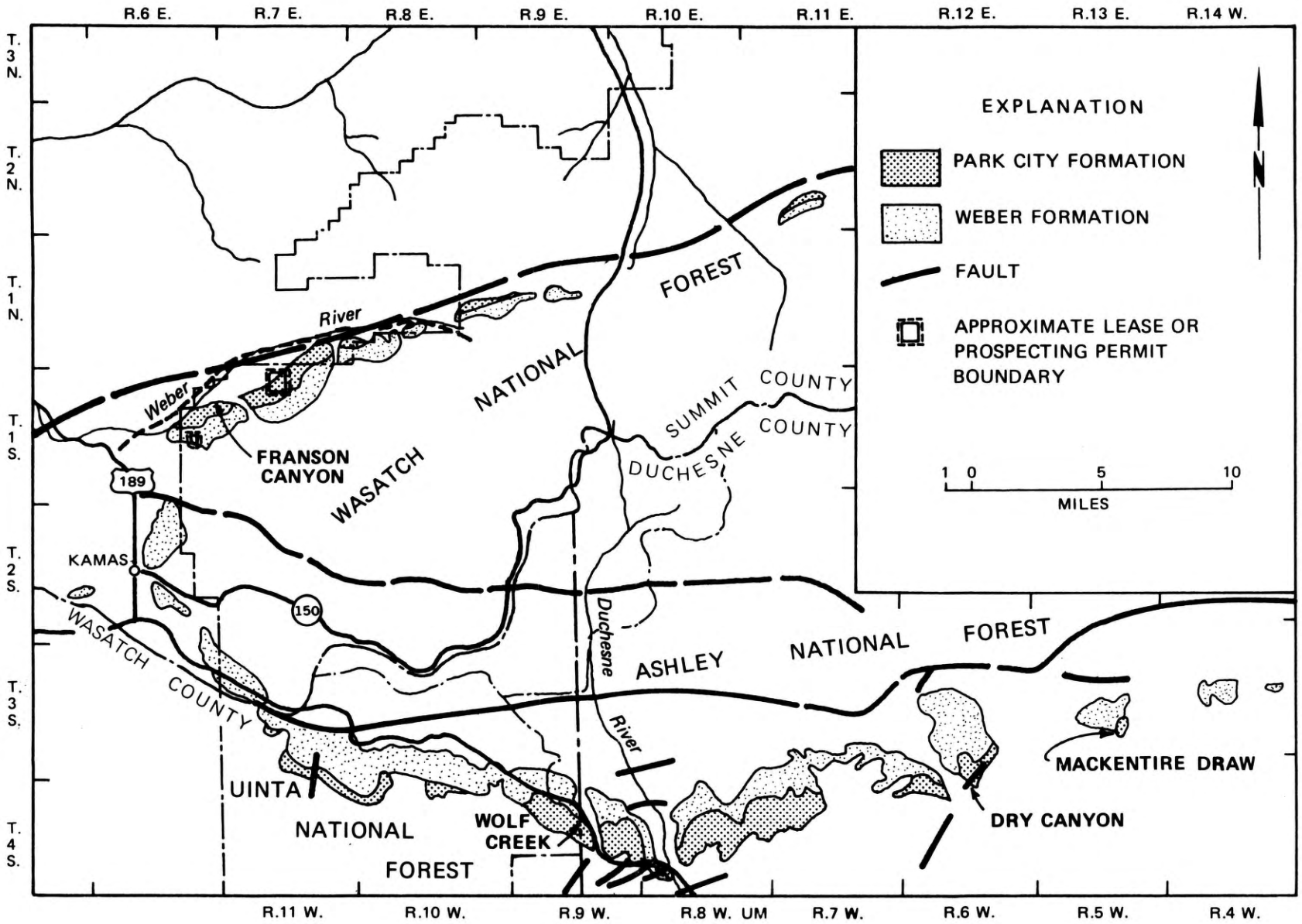


Figure 13. Western Uinta Range. (Modified from W. L. Stokes).

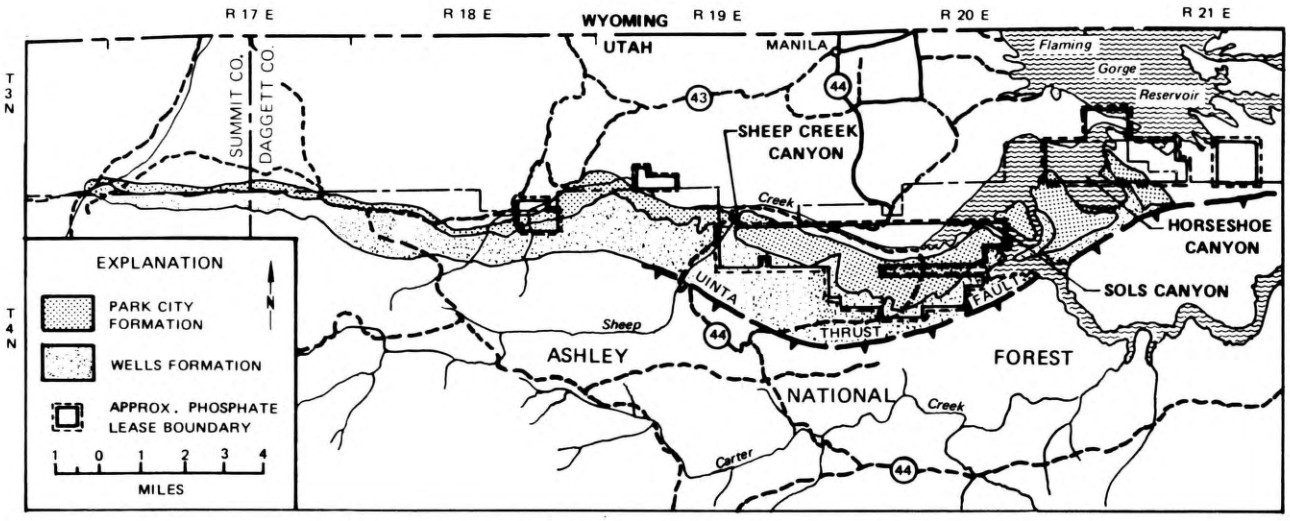


Figure 14. Flaming Gorge. (Modified from Anderman, Hansen and Stokes).

The eastern end of the Meade Peake Member outcrop belt was sampled by the Geological Survey in Horseshoe Canyon where a little more than 6 feet of +24 percent P_2O_5 rock was found (table 6). Farther west, in Sols Canyon, the grade of the basal zone was found to decrease to about 6.6 feet of +14 percent P_2O_5 rock. At Sheep Creek, the basal zone thins to about 2.8 feet of +25 percent P_2O_5 rock. Another 3.2-foot bed of +15 percent P_2O_5 occurs about 12 feet above this zone. The lime and magnesia contents of the above samples were not reported. Since this is an area of low dip and broad outcrops, the above-drainage level bed area is comparatively large.

Using thicknesses and grades in the sections at Horseshoe Canyon and Sheep Creek, the above- and 100 feet below-drainage resources were calculated by the U.S. Bureau of Mines (RI 6934) as follows in millions of short tons:

Table 6. Meade Peak section in Horseshoe Canyon, Daggett County.

Lithology	Thickness (feet)	Grade $\%P_2O_5$
Carbonate rock and mudstone	7.7	6.2
Argillaceous phosphate rock, carbonate rock, and mudstone	5.5	12.1
Mudstone	7.2	8.8
Mudstone, phosphate rock, and carbonate rock	8.9	12.2
Phosphate rock	3.4	22.1
Mudstone and phosphate rock	3.4	9.2
Phosphate rock	6.1	24.1
Mudstone	0.5	7.9

Using thicknesses and grades in the sections at Horseshoe Canyon and Sheep Creek, the above- and 100 feet below-drainage resources were calculated by the U. S. Bureau of Mines (RI 6934) as follows in millions of short tons:

Grade $\%P_2O_5$	Above Drainage Entry	100 Feet Below
+ 24	83.9	3.2
+ 18	107.0	4.4

Grade $\%P_2O_5$	Above Drainage Entry	100 Feet Below
+24	83.9	3.2
+18	107.0	4.4

At the nearest sampling point beyond Sheep Creek Canyon, roughly 1.5 miles west, the Meade Peak contains no +3-foot sections with a grade of 18 percent P_2O_5 or better. The phosphatic horizon diminishes still more further west, so the volume and grade of the material was not inventoried.

Economics

Relatively steep topography and interference by the Flaming Gorge reservoir would prohibit the development of sufficient open-pit minable reserves in the vicinity of the higher grade Horseshoe Canyon mineralization. Thickness and grade in the Meade Peak farther west preclude economic consideration of open-pit or underground mining at either current or paramarginal price levels at the present time.

SOUTHERN WASATCH

Geology

The southern part of the Wasatch Range (figure 15) contains about 25 miles of Park City Formation outcrops, beginning on the ridge south of Spanish Fork Canyon and continuing intermittently to a short distance north of the Utah-Wasatch County line. The exposures are interrupted by faulting toward the southern end, but most of the breaks are caused by unconformably overlying sediments of the Upper Cretaceous Price River Formation. All exposures on this trend are east dipping, except at the north end where the Park City swings into a north plunging syncline for a short distance.

The Meade Peak phosphate member has been trenched and sampled by the Geological Survey at four localities. The southern trench, located in a small, inactive mine on the ridge north of Little Diamond Creek, exposed a 5.8 foot bed of +28 percent PO_5. It is not known how much rock was shipped from this pit.

A little farther north, in Wanrhodes Canyon, another trench exposed a basal, 3.7-foot bed of +20 percent P_2O_5. In the other two trenches, one on the right fork of Hobble Creek and the other in Strawberry Valley, the phosphatic content was not localized except in negligible amounts. At Strawberry Valley there are two +12 percent P_2O_5 zones totaling 7.3 feet and a 3.1-foot zone of +16 percent P_2O_5. At Hobble Creek there are no +3-foot zones of +10 percent P_2O_5 rock. The lime and magnesia contents of the above samples were not reported.

Inventory

Phosphate resources of the Little Diamond Creek area have been estimated at 1.3 million tons of +25 percent P_2O_5 rock in a 5-foot bed taken to a depth of 2,500 feet. This was calculated on a relatively short strike length of 600 to 800 feet. which is the approximate length of the knob where the mine is located. Extending this zone to the nearest practical drainage entry point at Little Diamond Creek would give roughly 5 million tons above and 350,000 tons 100 feet below entry.

Economics

Insufficient volumes of ore are available for open-pit development at Little Diamond Creek, the most favorable southern Wasatch locale, to support operation of economic size at either current or paramarginal price levels.

CENTRAL WASATCH

Geology

The central Wasatch Mountains (figure 16) include the general area east of Salt Lake City to the Provo River Valley and extend north to Huntington Creek. The topography is rugged but the area is accessible because it is within the Park City Mineral Belt and is close to population centers.

The geology of the area is complex and the predominate feature is a central igneous mass that cuts through a Mesozoic and Paleozoic sedimentary belt. The majority of the sediments on the immediate slopes of Salt Lake Valley show an east-west strike typified by most of the valleys east of Salt Lake City. This is only local, and the structure changes abruptly with the influence of numerous faults and igneous bodies.

The Weber Quartzite is a comparatively resistant formation. For some distance it forms the north wall of Mill Creek Canyon and is cut at several points by igneous rocks.

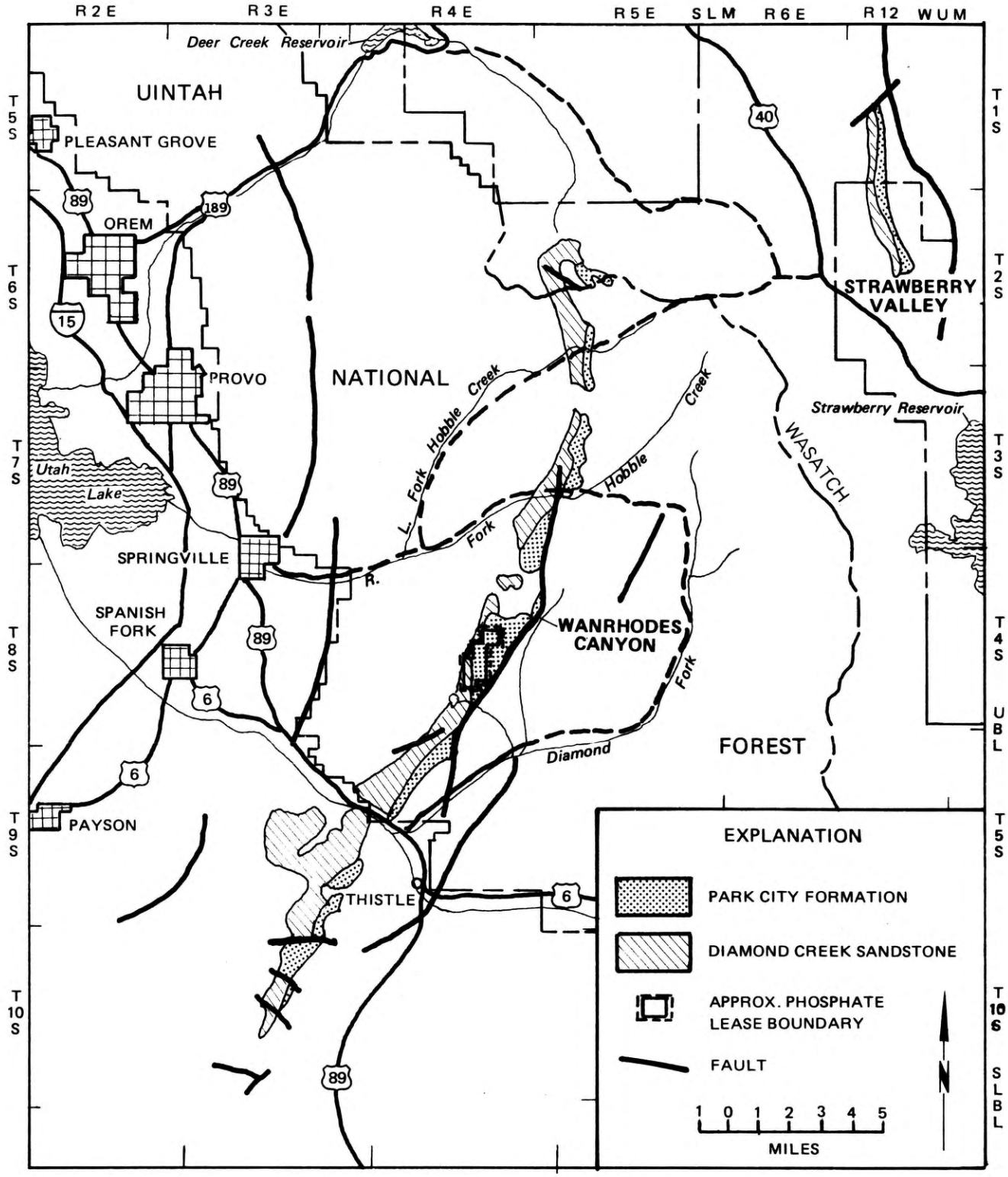


Figure 15. Southern Wasatch Range. (Modified from Baker and Stokes).

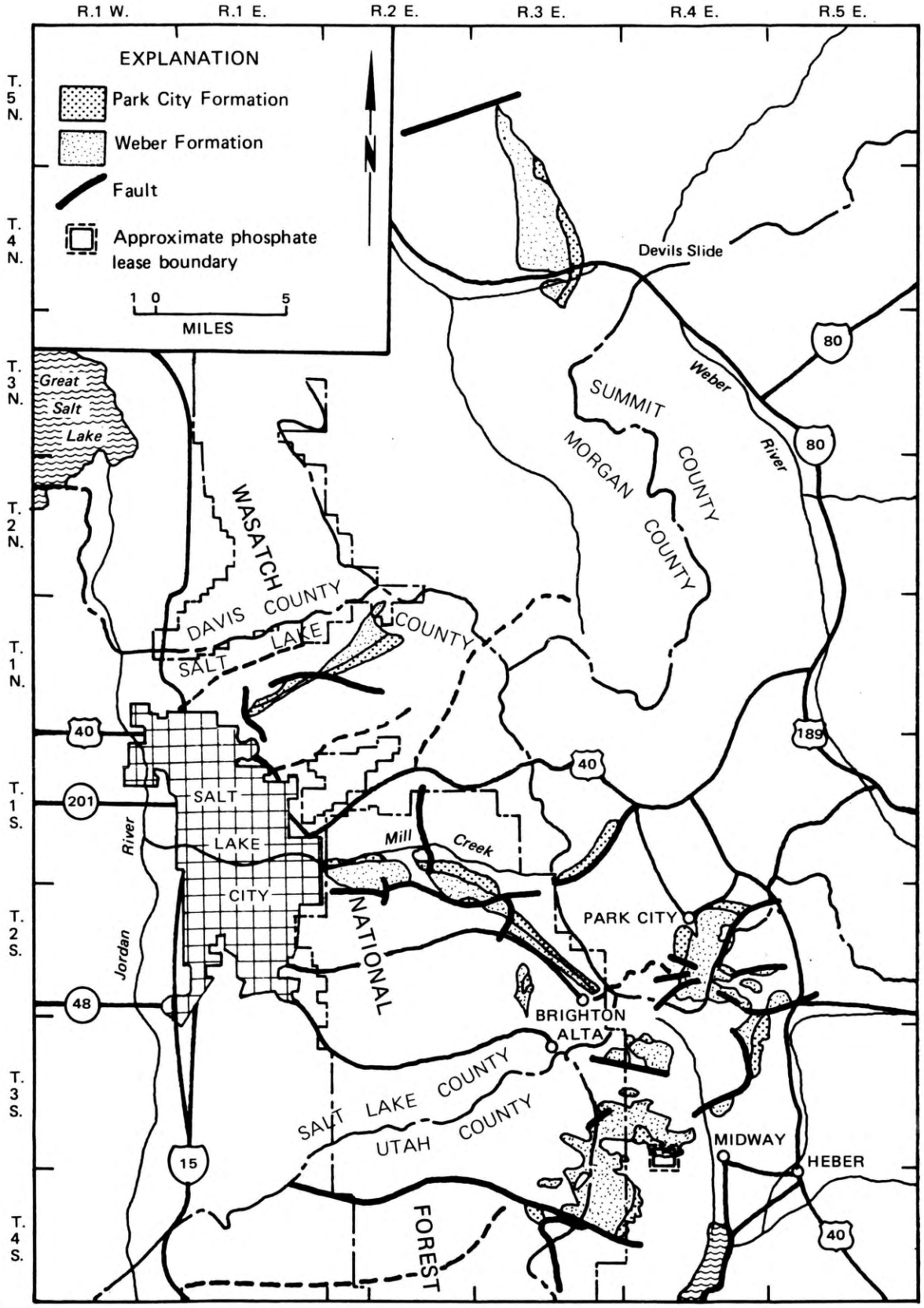


Figure 16. Central Wasatch Range. (Modified from Baker, 1961, Geological Survey unpublished preliminary maps, Mullen, Stokes).

The longest, continuous outcrop of Meade Peak in the region extends from the mouth of Mill Creek to Scotts Pass in a wide arc, to where it is faulted out against the Cottonwood batholith, a strike distance of nearly 14 miles. This exposure is faulted off, displaced, and covered by later sediments at several places. Dips are 30 degrees to 60 degrees to the north and northeast. While this outcrop is quite long, it was found to be very lean where sampled in Big Cottonwood Canyon. The phosphate was confined to several beds only a few inches thick and normally containing less than 15 percent P_2O_5.

Another outcrop of the Park City Formation extends about 4.5 miles in a northeast direction in the upper plate of a thrust that brings the Park City Formation over Jurassic sediments. While this outcrop also contains a considerable amount of bed area, there is no information concerning grade or thickness of any possible phosphatic zones.

Near Midway and Park City, the Park City Formation crops out for a total strike length of approximately 16 miles. One bed has been sampled northeast of Park City and analyzed +14 percent P_2O_5 over a thickness of 5.9 feet. Another zone was sampled on the 1,300 level of the Silver King Mine, southwest of town, and measured 10.7 feet of +13 percent P_2O_5.

Another trend of the Park City Formation begins near the Salt Lake City limits and extends about 7.5 miles in a north-easterly direction before it is covered by later Tertiary gravels (Almy conglomerate). The beds dip 60 degrees to the south and at the west end of the formation dip off the hill on the north side of a dry gulch. The central part of the outcrop is accessible by a road up Red Butte Creek.

The outcrop was trenched and sampled near the eastern end by the Geological Survey. There are several thin phosphatic zones in the section. The highest grade bed is 3 feet thick and contains +26 percent P_2O_5. This zone occurs about 300 feet above the base and is the lowest phosphate bed in the section. The thickest phosphate zone is a 14-foot bed of +17 percent P_2O_5. The lime and magnesia contents of the above samples were not reported.

Inventory

Based upon the above grade information, the Bureau of Mines (RI 6934) produced the following inventory for the central Wasatch:

Percent P_2O_5	Thickness	Million Short
+24	3.0	12.5
+18	4.7	18.1

This inventory accrues to the Meade Peak just northeast of Salt Lake City, the only occurrence in the central Wasatch with sufficient grade and thickness to warrant evaluation.

Economics

Aside from environmental restraints attached to any operation in the vicinity of Salt Lake City, insufficient volumes of open-pit ore are available at necessary grades and allowable stripping ratios for economic consideration under either current or paramarginal price levels.

NORTHERN WASATCH

Geology

The northern Wasatch Mountains (figure 17) contain three widely scattered, small exposures of the Park City Formation and Meade Peak Member. The region is typically covered over great expanses by Tertiary sediments (Eocene Knight conglomerates) and, as a result, the two northern outcrops are exposed in valleys with small above-drainage bed areas. The southern exposure occurs higher up on a valley wall but is still covered by Tertiary conglomerates and does not crop out for any great distance.

The southernmost exposure occurs as an east limb of a north-plunging syncline in Dry Bread Hollow, a north-trending valley off the south fork of the Ogden River. The exposure is roughly 20 miles by paved and gravel roads and 2 miles by trail from the city of Ogden. In 1963 the section was trenched and sampled by the Geological Survey, and the following total phosphatic section was exposed:

Percent P_2O_5	Feet
+31	2.0
+24	46.4
+18	81.6

The sampled bed dips 26 degrees to the west and has an approximate outcrop length of 5,000 feet.

About 13 miles northeast of Dry Bread Hollow, the Phosphoria Formation crops out for about 3.5 miles across the Woodruff and Sugarpine Creek drainages.

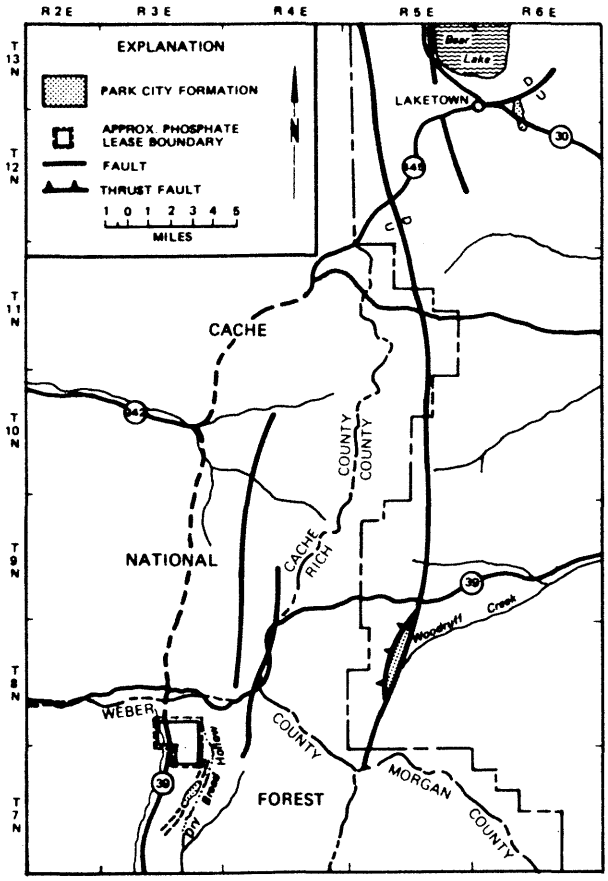


Figure 17. Northern Wasatch Range. (Modified from Richardson, Schell and Stokes).

The geology of the Woodruff Creek area is characterized by faulting, overturned beds and Tertiary erosion surfaces on upturned Mesozoic and Paleozoic sediments. The phosphatic shales and adjacent strata occur on the overturned west limb of a syncline that strikes nearly north-south and are exposed in the deep canyons of Sugarpine and Woodruff Creeks. The east limb of the syncline does not crop out. The phosphatic shales are bound by faults on both sides and are in contact with the Cambrian Brigham Quartzite on the west and the Jurassic Nugget Sandstone on the east. Both of these horizons are overturned.

To the west, the Brigham Quartzite is overturned and occurs in an overriding thrust block. In the intervalley areas, the Paleozoic and Mesozoic rocks are covered by the flat-lying Tertiary Wasatch Formation on a relatively extensive Tertiary erosion plane. This erosion surface is the most obvious geologic feature of the area.

The phosphatic section in this area is comparatively thick, mainly because of pre-Wasatch erosion and enrichment of beds near the surface. The geological Survey measured and sampled a total of 24.1 feet of +24 percent P_2O_5 rock which is dipping 55 degrees and was overturned to the west.

This section appears rich. However, the available resources are comparatively small since the Meade Peak Member only crops out in the valleys; it is covered on the hills. Vertical relief is quite small and there are almost certain to be faulting complications at depth. There is the possibility that this grade may be surficial and limited to depths of less than 25 to 50 feet below the surface.

About 20 miles north of Woodruff Creek the Phosphoria Formation crops out in an overturned section 1.5 miles east of Laketown. This area is similar to the Woodruff Creek area in several ways; the structure is overturned (50 to 60 degrees to the west), a wide expanse of Tertiary sediments cover the area and the Meade Peak crops out only in the topographic lows and, finally, the phosphatic section is comparatively rich.

The Meade Peak Member was trenched and sampled at this locality and 90 feet were exposed with zones of phosphate enrichment at the base and the top; the entire section averaged +14 percent P_2O_5. The lime and magnesia contents of this sample were not reported. The basal zone is a series of thin beds totaling a little over 14 feet of +20 percent P_2O_5 rock. This zone can be separated into smaller units of higher and lower grade material. There have been attempts to develop this deposit on a small scale, but the amount of production, if any, is not known.

The upper phosphate zone, a little richer, totals 23 feet of +24 percent P_2O_5 rock, including a fairly definite 9.5-foot bed of +31 percent P_2O_5 rock. Considering both phosphate zones and selecting the boundaries to delineate beds of all grades, the total thicknesses would be; 9.5 feet of acid-grade, 32.1 feet of furnace-grade, 65.4 feet of beneficiation-grade and 90.4 feet (the entire section) of low-grade (+14 percent P_2O_5) rock.

Inventory

The following inventory was prepared by the Bureau of Mines (RI 6934):

Dry Bread Hollow - To 300-Foot Depth Below Outcrop.

Percent P_2O_5	Million Short Tons
+24	10.6
+18	13.4 (Cumulative)

Woodruff Creek - To 300-Foot Depth Below Outcrop.

+31	5.7
+24	11.1 (Cumulative)

At the Laketown occurrence, topographic relief on the Meade Peake Member is low and no significant tonnage occurs above drainage level. The outcrop is at an elevation of about 7,000 feet and the resources for each 100 feet below drainage level in the respective grades would be:

	Million Short Tons
Acid	0.6
Furnace	1.9
Beneficiation	3.5
Low	4.8

Economics

Further exploration may serve to locate additional acid-grade phosphate resources in a shallow environment in the northern Wasatch. However, typically steep dips and disturbed rock conditions preclude economic open-pit or room-and-pillar mine development at this time. Extraction would of necessity be through shrink or open-stope methods. Neither current, 20-year predicted nor paramarginal price levels would support this production method.

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