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Bulletin No. 290 - Phosphate in Utah

J. Stewart Williams

PHOSPHATE IN UTAH

by

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Bulletin 290
Utah Agricultural
Experiment Station

Acknowledgments

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(Logan, Utah, August 1939)

Summary

1. Phosphate tonnage estimates are offered for Uintah, Duchesne, Daggett, and Cache Counties. Partial estimates are made for Salt Lake, Wasatch, Summit and Utah Counties. No basis as yet exists for estimates for Weber and Morgan Counties. Tonnage estimates for Rich County have long been available in publications of the United States Geological Survey.

2. The principal items in Utah's phosphate reserve are:

By counties

County	Quality percent	Tonnage
Rich	70	96,750,000
Salt Lake and Wasatch	60	17,000,000
Utah	55	1,300,000
Daggett and Eastern Summit	50	119,000,000
Uintah	44	7,430,000
Uintah	40	1,500,000,000
Total		1,741,480,000

By quality of rock

Quality percent	Tonnage
70 or better	96,750,000
55 or better	115,050,000
50 or better	643,050,000
40 or better	1,741,480,000

3. Additional study will increase these figures but slightly. The probable increases are as follows:

(a) The Park City area in western Summit County is not likely to contain more than 10,000,000 tons of 60 percent rock, if that much.

(b) All evidence points to the conclusion that Weber and Morgan Counties are not likely to include more than 10,000,000 tons of about 50 percent rock, though they may contain a much larger tonnage of lower quality.

(c) It appears improbable that Utah County includes important undiscovered deposits.

4. In comparison with other states of the western field, Utah's reserves of phosphate rock are not large until rock of 50 percent grade is included. Utah's reserve is very largely in rock that is low grade according to present commercial standards.

5. Available data on land ownership, far from complete, are sufficient to indicate that most of the important phosphate deposits in Utah, those richest, largest or most accessible, are largely in private ownership.

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PHOSPHATE IN UTAH[1]

by

J. Stewart Williams[2]

Agitation for the development of the western phosphate field as part of the national program of conservation and economic rehabilitation has, in the last three years, focused public attention on the phosphate reserves of Idaho, Montana, Wyoming and Utah. In every conference or discussion on this subject, the minds of Utah's representatives have naturally turned to the question, "What is Utah's share in this great natural resource?" Obviously nature pays no heed to political boundaries, and neither does the prosperity of Utah's citizens depend solely upon that which is circumscribed within the state's boundaries. Nonetheless, it is necessary for Utahns to measure their own natural resources, that they may be prepared to participate in any possible future development that will benefit not only their state, but the whole Rocky Mountain region.

Utah agriculture has an immediate interest in the extent and location of the phosphate fields because many Utah soils are responsive to phosphate fertilizer. Those soils of which the phosphate rock forms a part of the parent material are usually quite rich in total phosphorus but, because of their basic or calcareous nature due to the arid climate, the phosphate is in many cases quite unavailable to plants. On such soils it is necessary either to add available phosphate as a fertilizer or to make available that which they already contain before the best possible crops can be grown. The addition of manure to such soils will usually render the phosphorus available, probably by means of the acids and carbon dioxide developed in decomposition which act similarly to the acid used at the fertilizer factory. Thus, on these soils, manure alone will often improve the yield and quality of crops especially responsive to phosphorus, such as alfalfa or sugar beets, more than phosphate fertilizer alone though the two together may be needed for maximum effect.

The soils of areas far removed from the phosphate deposits and which contain no phosphate rock as parent material have no such reserve supply of phosphorus. Manure alone is usually inadequate to build up such soils but actual additions of phosphate fertilizer are required for maximum production or best quality of crops (fig. 1). Probably because arid soils almost never contain any acid, simple rock phosphate such as is sometimes used on the acid soils of humid regions

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[1]Contribution from the Department of Geology, Utah State Agricultural College.

[2]Professor of geology.

Authorized for publication.

has very little if any effect on Utah soils but any form of superphosphate or metaphosphate gives outstanding results where phosphate is needed, and the beneficial effect of a heavy application has been observed to last in one instance for at least eleven years.

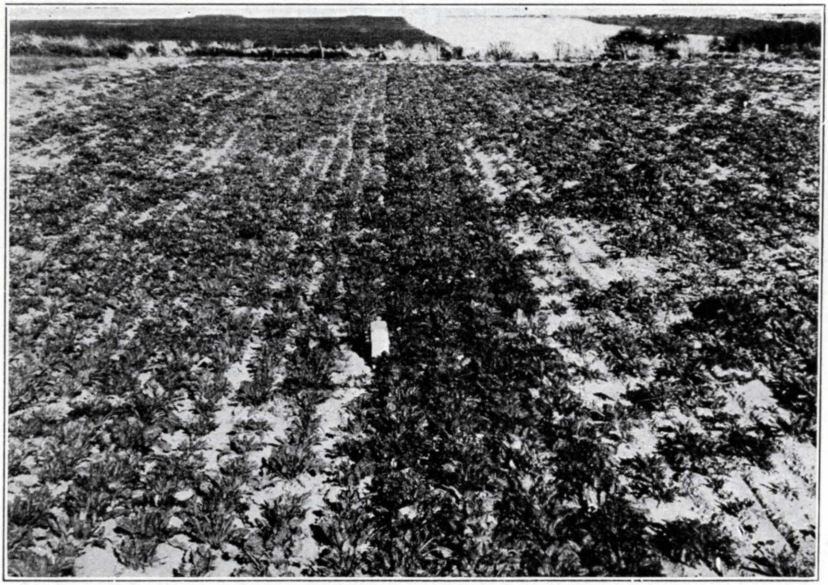

Fig. 1. Sugar-beet field contrasting results on strip where phosphate fertilizer was applied with the remainder of the field where no fertilizer was used. (Reproduced from Utah Agr. Exp. Sta. Bul. 233.)

In the manufacture of phosphate fertilizer from phosphate rock the rock is treated with sulfuric acid to render the phosphate in it soluble and therefore available to plants. In recent years progress has been made in developing processes wherein the rock is smelted in an electric or blast furnace, but such processes are not yet in commercial operation, and a supply of sulfuric acid remains, therefore, essential to the production of phosphate fertilizer from phosphate rock. Utah's smelters, treating sulfide ores, provide a large potential supply of sulfuric acid that might be utilized in the development of a phosphate-fertilizer industry in the state. The production figures for Utah's only present day sulfuric acid plant are included at the end of this paper, as data pertinent to a statement of the state's phosphate resources.

When this study was begun in the summer of 1936, there was little detailed information on Utah's phosphate reserves. Only the deposits in Rich County had been carefully mapped and estimated. The outcrops east of Ogden had been located by the reconnaissance of Blackwelder (1), and those around the Uinta Mountains had been located by Schultz's (7) rapid survey of 1912, but there were few analyses and measurements of thickness and no tonnage estimates for the counties other than Rich. It seemed most desirable, therefore, to obtain additional information on the quality and thickness of the phosphate-bearing beds in Utah.

The writer had made detailed measurements at eleven localities, collecting lithologic specimens and samples for analysis from each. These, together with those reported by Schultz (7), Blackwelder (1), and Gale and Richards (3), are sufficient to give at least a preliminary tonnage estimate for each of the counties in which the phosphate-bearing beds crop out. No detailed mapping has been done at any locality, but this has not been necessary since the structure is generally simple, the beds generally dip rather steeply, and the width of the outcrop is essentially the thickness of the bed; and the only quantity, in addition to thickness, needed for a tonnage estimate, is the linear extent of the outcrop. In the Uintah and Daggett County areas, where dip slopes on the Phosphoria formation cover wide areas, the geologic map in Schultz's (7) paper, supplemented with personal observations and some data from Humphrey's Phosphate Company, has been used to determine approximately the area of the outcrop. Analyses of the rock samples, absolutely essential to a study of this sort, have been made by the U. S. Geological Survey and the Bureau of Agricultural Chemistry and Engineering, U. S. Department of Agriculture.

In general, the phosphate beds in Utah are thin and lean. Most of the beds of oolitic (richer) rock are only a few inches thick, and few exceed one foot in thickness. This makes estimating tonnages difficult. In making estimates the regulations that govern the U. S. Geological Survey (5) in classifying phosphate lands have been adhered to, which are as follows:

"Lands underlain by beds of phosphates less than 1 foot in thickness or containing less than 30 percent tricalcium phosphate or lying at a depth greater than 5,000 feet below the surface shall be considered nonphosphate lands, except as hereinafter provided.

"A. Lands underlain by beds of phosphate 6 feet or more in thickness and containing 70 percent or more of calculated tricalcium phosphate shall be considered phosphate lands if the beds do not lie more than 5,000 feet below the surface. The depth limit for beds containing 70 percent of calculated tricalcium phosphate shall vary from 0 to 5,000 feet in direct ratio to the variation of thickness of bed from 1 foot to 6 feet. For beds containing less than 70 percent tricalcium phosphate the depth limit shall vary from 0 to the depth of a 70 percent bed of any given thickness in direct ratio to the variation in tricalcium phosphate content from 30 to 70 percent . . .

"D. Where the phosphate bed occurs at or near the surface so that the deposits may be readily mined by open-cut or stripping methods, the minimum thickness of a phosphate bed containing 70 percent or more of tricalcium phosphate shall be 3 inches. For beds containing less than 70 percent tricalcium phosphate the minimum thickness shall increase to 1 foot as the percentage of tricalcium phosphate decreases from 70 to 30 percent."

In effect these regulations constitute a definition of what is considered "minable phosphate". Beds actually mined at any particular future time under the pressure of economic need might well be thinner, or leaner, or might be pursued to greater depth than contemplated in these rules. Any tonnage estimate, however, based merely on examination of surface exposures, is impossible without certain limiting assumptions, though they be entirely arbitrary. Adoption of these regulations for the present estimates places them upon the same basis as those issued by the U. S. Geological Survey.

Generally, outcrops well enough exposed to permit detailed measurement and sampling are far apart, and thicknesses and qualities must be extrapolated to permit tonnage estimates for whole areas. Fortunately, in most areas the phosphatic shale member maintains a fairly constant character, so that the estimates, though based on comparatively few measurements, are believed fairly reliable, and the expense of trenching and sampling the outcrop at shorter intervals will not be warranted until the economic importance of the deposits has increased greatly. Admittedly, these estimates are approximations only, but all phosphate tonnage estimates for the western field are subject to most of the same limitations. They could be improved by additional field work, but at least, it is believed, they constitute a much closer measure of phosphate in Utah than has existed. The measured sections and analyses constitute data of permament value, regardless of the validity of the estimates based upon them.

There has been no opportunity to make a complete survey of the ownership of phosphate lands in the state, and had the time been available, the present small economic importance of western phosphate would hardly justify a thorough study of that phase of the problem. Those data readily available have been included. They are complete only for Uintah County, for which a map of land ownership, prepared by the Department of Agricultural Economics of the Utah Agricultural Experiment Station was at hand.

General Description

The phosphate rock of the Rocky Mountain region is sedimentary rock. It therefore occurs interlayered with other sedimentary rocks—shale, sandstone and limestone—as does coal. It is not a vein deposit, as are most of the metallic ores. It was deposited as sediments in a shallow sea that covered the northern Rocky Mountain region in Permian time, some 180,000,000 years ago.

Immediately after deposition these sediments must have constituted a thin but continuous sheet that extended from the area where the Uinta Mountains were to rise northward into what is now Canada, and from the belt where the Bighorn Mountains of Wyoming were to rise westward to the latitude of the western boundaries of Utah and Idaho. The sheet was not homogeneous throughout. Toward the middle of the sea, in an area that now centers in southeastern Idaho, the beds of phosphate rock are thicker and interlayered with beds of limestone. Toward the margins of the sea, in central Wyoming and northern Utah, where the coarser detrital sediments brought by the streams were deposited, the phosphate beds are thinner and intercalated with sandstones and terrestrial deposits of "red-beds". As time passed, continuing deposition in the Cordilleran area buried the thin sheet, rich in phosphate, under thousands of feet of other sediments and it was compacted into solid rock.

Toward the end of the Mesozoic era, some 120,000,000 years later, tremendous compressional forces in the earth's crust caused long belts in the Cordilleran region to rise in broad folds or be crushed and pushed up into broken piles, and the Rocky Mountains rose for the first time. As the slopes of the growing mountains steepened, and their crests grew higher to intercept increasing precipitation, the forces of erosion attacked their flanks with increasing vigor. Later, as the mountain-building forces dwindled, erosion became dominant and the crests of the ranges were slowly reduced. Where the phosphate-bearing strata crossed the upfolds or had been pushed up into the faulted mountain piles, they were removed by erosion. Where they lay in the down-folds between ranges, they were further buried under the accumulating debris from the adjacent mountains and preserved. Since the original Rockies were reduced to a plain by erosion, western North America has been reelevated and the rejuvenated streams, excavating the basins, have once more brought the ranges of the Cordilleran region into relief. These are the ranges we see today and, generally speaking, the outcrops of the phosphate-bearing beds follow along the flanks of the mountains, the edges of those parts of the sheet preserved beneath the basins, the limit of erosion that has removed the sheet from the upfolds and mountain piles. At least half of the original deposit has been thus destroyed.

The deposits of the Permian sea in the northern Rocky Mountains constitute the Phosphoria formation. It consists of two members, a phosphatic shale member, which contains the phosphate rock, and an upper member of cherty limestones and sandstones, called the Rex member. The formation as a whole varies from 200 to 400 feet in thickness, the phosphatic shale member from 20 to 200 feet in thickness.

In general, the phosphatic shale member consists largely of black or green shale with subordinate amounts of phosphate rock, and dark gray or black sandstone and limestone. No shale that the writer has seen and had analyzed has contained more than 12 percent P_2O_5 and most shales have contained between 5 and 10 percent P_2O_5. High-grade phosphate rock has an oolitic texture, that is, it is composed largely of small concretionary bodies about 1 millimeter in diameter, called oolites. The oolites in phosphate rock, together with larger nodules and concretionary masses, and the casts of small clam and snail shells, are composed of one or more flourine-bearing phosphate minerals, and are largely responsible for the phosphate content of the rock. The quality of the rock, then, varies with the concentration of oolites in it. Rock with a marked oolitic texture, composed of closely packed oolites, is of a high grade, with 30 to 35 percent P_2O_5; a rock with scattered oolites may be medium to fairly high grade; and rocks without oolitic texture, such as the common black or green shales of the phosphatic shale zone are low grade, or at least have been invariably so in the writer's experience, as has been pointed out.

Oolites of calcium carbonate are forming at the present time in the shallow waters of Great Salt Lake. The calcium carbonate, with which the water is saturated, is precipitated directly from solution about small grains of quartz or felspar, or fecal pellets, that act as nuclei for the oolites (2). Continuous agitation in the shallow water insures a uniform spheriodal growth for the small concretions. Similar conditions of depth are indicated for the Permian sea in which the phosphatic shale member of the Phosphoria formation was deposited, but the saturating substance was tricalcium phosphate and the shallow stagnant water, under the cool climate of the Permian, was generally rich in partly decomposed organic matter, which gives the typical phosphate rock of the western field its black color and fetid odor upon fresh fracture.

Conditions were far from uniform throughout this shallow sea, as has been indicated in a preceding paragraph. Toward the shore, particularly near the mouths of inflowing streams, the oolites were mixed with larger quantities of sand and silt, and the resulting rock is leaner, with but thin beds of high grade rock. In other areas, presumably some distance from shore, where little or no coarser detrital sediment was deposited, the shales and limestones are without oolites, and of low grade only. Hence there is considerable variation throughout the western field in the quality of the deposits. About the Wind River and Owl Creek Mountains in Wyoming, and the Uinta Mountains in Utah, areas that represent the shoreward facies of the formation, the beds are learn, with little oolite. The Wasatch Mountain area in Utah was near the center of the trough or sea, but with few exceptions it contains no important deposits. In the area of southeastern Idaho conditions were most favorable for phosphate deposition and there the beds reach a maximum in thickness and quality. In Montana the beds are somewhat thinner, but of good quality.

Phosphate-bearing beds occur in another and older formation in parts of northern Utah. The Brazer formation, of Late Mississippian age, consisting largely of calcareous sandstones and limestones, has as its basal member 200 feet of black phosphatic shale, in which thin beds and stringers of oolitic phosphate rock occur.

Outcrops of the Brazer formation are wide-spread in the Bear River range in Cache County, and they extend southward into the Central Wasatch and Oquirrh Mountains in Salt Lake and Tooele Counties (4). The phosphatic shale member is recognized in most localities where the formation crops out, but in none does it contain any considerable thickness of high-grade rock. The Mississippian phosphate constitutes the only phosphate deposits in Cache County, and will be discussed for the whole region when the deposits of that county are considered.

Although the exact chemical constitution of the phosphate mineral (or minerals) is not known, the phosphorus content of phosphate rock is usually expressed either as phosphorus pentoxide, P_2O_5, or as tri-calcium phosphate, $Ca_3(PO_4)_2$. According to present commercial standards, high-grade rock must contain about 65 to 75 percent $Ca_3(PO_4)_2$, or 30 to 35 percent P_2O_5. Few samples containing as much as 80 percent $Ca_3(PO_4)_2$ have been reported from the western field, and it is probable that little rock of such extraordinarily high quality exists. Typical high-grade rock contains about 70 percent $Ca_3(PO_4)_2$, and tonnage estimates are usually based upon rock of that quality. Utah has comparatively little rock of 70 percent grade and the tonnage estimates made in this paper are mostly for rock of 40 to 60 percent grade, the quality being given in each instance. A rock with a markedly oolitic texture will invariably test close to 70 percent. The lower grades are produced where the oolites are scattered through shale or limestone, or where thin beds of oolite must be averaged with thin intercalated beds of lean shale or sandstone.

Uintah County

Outcrops of the phosphate-bearing Phosphoria formation extend in an almost unbroken line from the western boundary of Uintah County to the Colorado state line (fig. 2). Westernmost of these is on Whiterocks River where the edges of the upturned beds are exposed for about a mile and a half on each side of the stream. The conglomerate that caps Mosby and Lake Mountains covers the line of outcrop for the next three or four miles, but east of Mosby Mountain the exposures are uninterrupted to Diamond Mountain, some twenty-five miles east. Diamond Mountain, like Mosby Mountain, is capped by a flat-lying conglomerate formation that buries the Phosphoria beds, and their next exposure is at a point north of Island Park. The strike of the beds emerging from beneath Diamond Mountain is southeasterly and they extend in that direction nearly to the Green River, where they are cut off by a fault trending northeast-southwest. Southeast of Island Park the outcrop reappears at the fault and is continuous in a great sigmoidal curve that can be traced westward around the Split Mountain anticline, eastward through the intervening Jensen syncline and thence westward around Section Ridge anticline and eastward to the state line. Of this comparatively long line of outcrop, however, only that on Whiterocks River and between Mosby and Diamond Mountains includes beds of phosphate-bearing rock that are of any possible future commercial value.

The Phosphoria formation in this region, consisting largely of

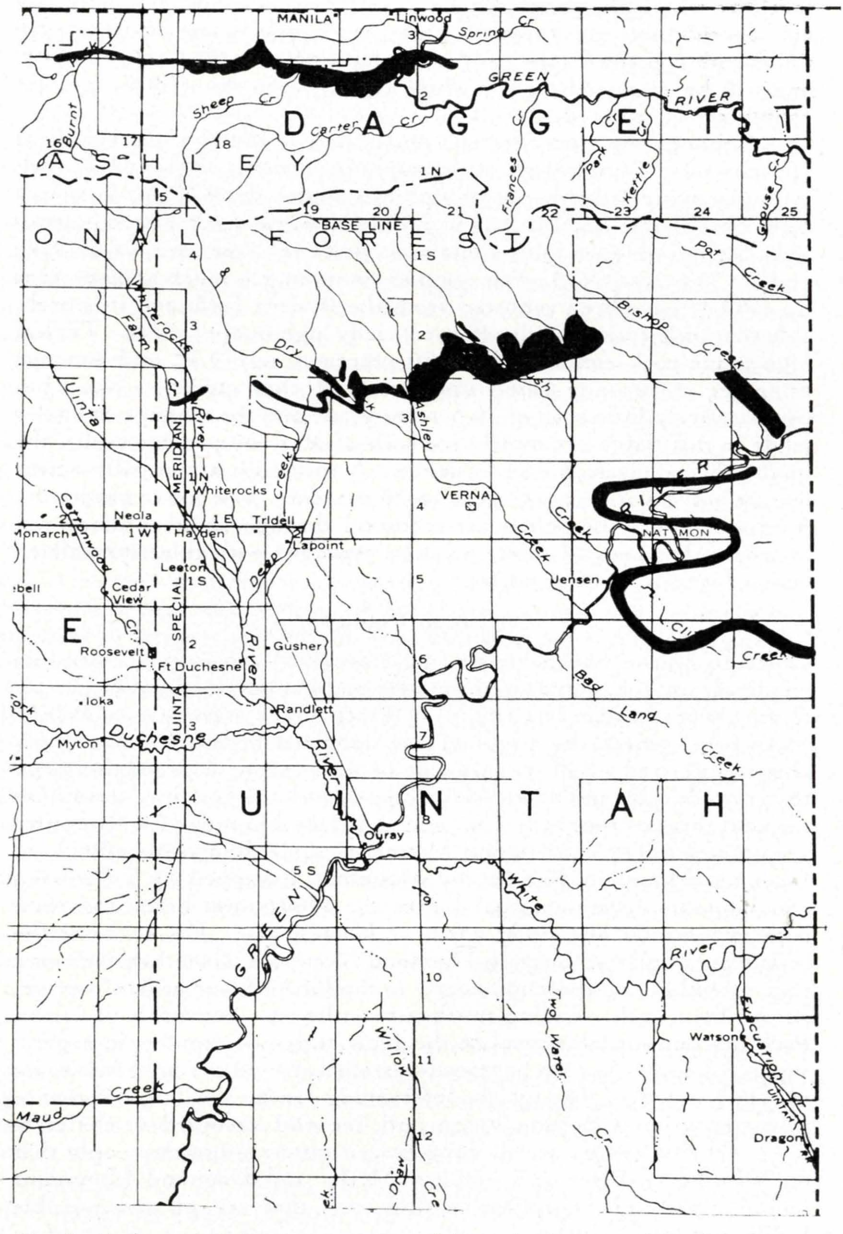

Fig. 2. Outline map showing outcrops of Phosphoria fm in Uintah, Daggett and eastern Summit Counties.

shales and thin-bedded sandstones, with some thick sandstone beds and some phosphate rock, is tripartite. It consists of three major members of shale, siltstone and thin-bedded sandstone, less resistant to erosion, separated by two thin subordinate members of thicker-bedded sandstones that are more resistant and, therefore, stand out as prominent ledges. The two upper shaly members are constituted of "red-beds"—gray and red shales, and thin-bedded siltstones and sandstones. The lower member, largely of green shale, contains the phosphate rock.

The Phosphoria formation stands in marked contrast to the formations above and below it. The formation below, the Weber sandstone, consists of several hundred feet of yellowish light-gray sandstone, strongly cross-bedded, and massive. Resistant to erosion, it stands in sheer walls along the streams that have cut gorges in it, producing the magnificent box canyons on Dry Fork, Ashley Creek, Little and Big Brush Creeks (figs. 3 and 4) and Green River. Directly on this massive formation lie the soft greenish shales at the base of the Phosphoria formation, forming gentle slopes rather than precipitous cliffs, the darker band that marks their outcrop distinctly visible along the rims of the gorges. Above the Phosphoria formation are "red-beds", thin-bedded sandstones, siltstones, and shales of a brick red color, such as those in Red Mountain north of Vernal, that contrast markedly with the predominantly light gray beds of the Phosphoria formation. Again more durable than the strata immediately beneath and capped by massive sandstones, they form a ridge that rises above the valley that coincides with the outcrop of the Phosphoria formation.

Where strata in the south limb of the Uinta Mountain arch have gentler dips (around 10°), the two lower shaly members of the Phosphoria formation, protected by the uppermost of the two resistant sandstone beds, form wide outcrops between the streams. The more resistant formations that produce narrow ridges with steep faces toward the mountains and gentle backslopes toward the basin (hogbacks), along the south flank of the mountains, once extended completely across the area now occupied by the range and similar hogbacks, constituted by the same beds, face south along the north side of the mountains in Daggett County. As the mountains rose in a broad elongate dome, the forces of erosion removed the beds across the top and stripped them back to the present line of hogbacks. The backstripping continues, the less resistant beds yielding first, and causing the more resistant beds above them to fall back. In this ceaseless process the upper shaly member of the Phosphoria formation has proved less resistant than any beds for some distance above or below it, and as a result all beds above it are everywhere eroded nearly to the level of the basin floor, while the middle and lower shaly members, protected by the upper dividing member of resistant sandstone, cover wide areas (dip slopes) along the flank of the range. The gentler the slope, the wider this belt of outcrop of the Phosphoria formation. On Dry Fork the dip of the formation is about 20 degrees, but on Ashley

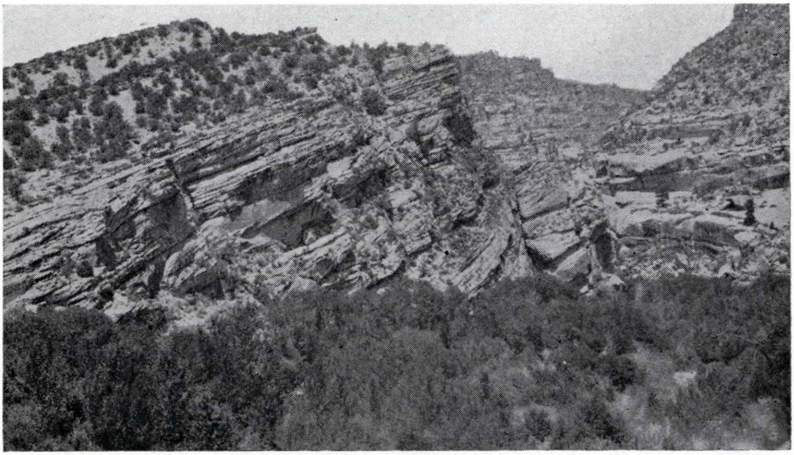

Fig. 3. Mouth of gorge on Ashley Creek, Uintah County, Utah, showing lower 95 feet of Phosphoria formation resting on Weber sandstone. Lower half of lower shaly interval is phosphatic shale member of Phosphoria formation. (Reproduced by courtesy of the American Association of Petroleum Geologists from a paper by the author published in the Bulletin of the Association.)

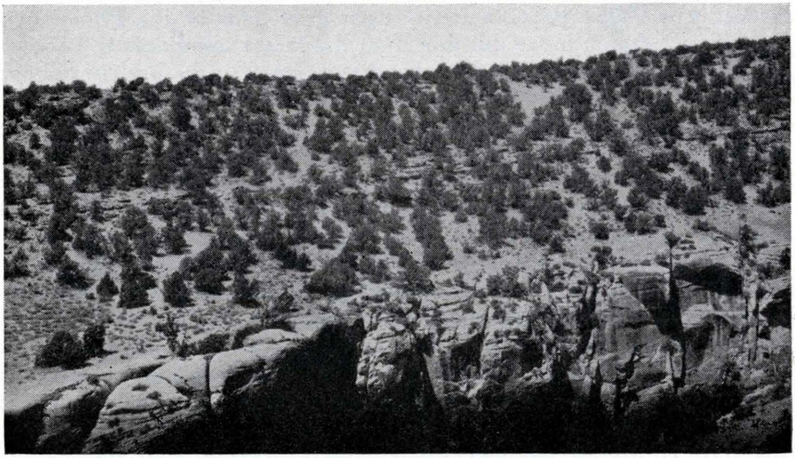

Fig. 4. Lower 95 feet of Phosphoria formation on tributary to Little Brush Creek, Uintah County, Utah. The basal 19 feet of the lower shaly member contain an average of 40 percent tricalcium phosphate and constitute the great phosphate reserve of Uintah County. (Reproduced by courtesy of the American Association of Petroleum Geologists from a paper by the author published in the Bulletin of the Association.)

Creek it is only 10 degrees and on Brush Creek about 8 degrees. Correspondingly, the width of the outcrop increases westwardly from Dry Fork until on Little Brush Creek it is as much as four miles on the divides between the stream valleys. In all, the outcrop of the Phosphoria formation between Dry Fork and Diamond Mountain covers some 24,000 acres. On Whiterocks River the beds are dipping steeply (70°) and the width of the outcrop equals only the thickness of the formation. On the north and south sides of Split Mountain the dips are about 40 degrees, but around the gently plunging nose of the anticline, on the west, the dips are more gentle and the upper resistant sandstone in the Phosphoria formation underlies dip slopes that are nearly a mile wide. There is little or no phosphate under these slopes, however.

Whiterocks River Area. The outcrop of the phosphoria formation crosses Whiterocks River just inside the mouth of the canyon about 7 miles due north of Whiterocks Indian School. It trends north 65 degrees east and extends about a mile and a half each way from the river. The beds dip steepng (73°) toward the southeast.

Following is a detailed description of the phosphatic shale member measured on the east side of the river. Those beds that were obviously too lean or too thin to be worthwhile were not sampled for analysis.

Section of the phosphatic shale member of the Phosphoria formation,
east side Whiterocks River, NE¼ Sec. 18 T2N R1E UB&M
Strike S 65° W Dip 73° S
U.S.A.C. Locality no. 64

Designation of bed	Description	Thickness ft.	in.	P_2O_5 (Moisture-free basis)	$Ca_3(PO_4)_2$	Minable depth feet
	Light greenish gray thin-bedded sandstone, with much nodularly bedded chert.					
N	Memium to light gray oolite	1	9	(Compare bed I)		
M	Greenish medium gray clay shale	4	0			
L	Medium gray shale		9			
K-1	Medium gray oolite		10			
K	Medium gray shale		9			
J	Brownish medium gray siliceous rock	1	0			
I	Black oolite grading upward into yellowish medium gray medium grained sandstone	1	6	26.68	58.27	270
H	Black to medium gray paper shales weathering with brownish tinge interrupted by thin seams of chert and one thin (1″) stringer of oolite	1	6			
G	Thin bedded medium gray oolite weathering greenish light gray, inrupted by two 8″ beds of greenish gray paper					

Designation of bed	Description	Thickness ft.	in.	P_2O_5 (Moisture-free basis)	$Ca_3(PO_4)_2$	Minable depth feet
	shale that are not included in the analysis	6	0	19.95	43.6	1,250
		(4	8)			
B-F	Greenish to brownish medium gray siliceous to slightly calcareous shales interrupted by two 3″ beds of chert	6	0			
A	Coarse grained sandstone		3			
A-2	Thin bedded light gray sandstone	1	3			
A-1	Light yellowish gray calcareous sandstone	1	6			
	Total	27				

Weber sandstone.

It will be noted that there are only three beds of phosphate rock in this section, and none is high grade. Bed N was not analyzed but megascopic examination indicates that it probably is no richer than bed I. Bed G includes a net thickness of 4 feet 8 inches of oolite after deduction is made for the two shale seams.

According to the above standards in use by the U. S. Geological Survey, beds N and I would be minable to a depth of about 300 feet and bed G to a depth of 1,250. The former, however, are barely over the limit of minimum thickness, they are not of high grade, and may be eliminated.

The line of outcrop in this area is approximately three miles long. The density of the oolite is nearly 180 pounds per cubic foot. On this basis the area contains 7,430,000 long tons of 44 percent rock.

Except for a narrow strip in the bottom of the canyon, which is privately owned, all land underlain by phosphate in this area, according to the best information available, is part of the Ashley National Forest. The ownership is divided approximately as follows:

Land ownership	Percentage of total	Corresponding phosphate tonnage
Private lands	8.5	630,000
National forest lands	91.5	6,800,000

Dry Fork-Brush Creek Area. Detailed information concerning the phosphatic shale member is available in two carefully measured sections in this area. The beds at the east side of the mouth of Ashley Creek gorge were studied by the writer, and the same beds on Little Brush Creek have been measured and analyzed by the engineers of the Humphrey's Phosphate Company of Denver, Colorado, whose claims cover over half the area under consideration.[3]

[3]Judson S. Hubbard, vice president of the Company, has kindly consented to the reproduction of its data in this report.

Section of phosphatic shale member of the Phosphoria formation
east side mouth of Ashley Creek gorge
NE¼ Sec 12 T3S R 20 E SLB&M
Strike N 65° W Dip 27° S
U.S.A.C. Locality no. 42

Designation of bed	Description	Thickness ft.	in.	P_2O_5 (Moisture-free basis)	$Ca_3(PO_4)_2$ (Moisture-free basis)	Minable depth feet
	Thick bedded yellowish light gray calcareous sandstone. Green paper shales grading upward into nodular chert.					
E	Green shale, some oolite	7	6	14.28	31.2	150
D	Ooolite and green shale	5	1	20.98	45.9	1,400
C	Lower 20″ or more green siliceous shale; toward top considerable oolite	3	5	14.52	31.7	100
B	Oolite with some green paper shale	2	9	19.96	43.6	600
	Gray sandstone		5			
A	Oolite and green paper shale	2	0	11.39		
	Total	21				
	Weber sandstone.					

It may be noted that through nearly 19 feet of this section the rock contains over 30 percent tricalcium phosphate. In this interval can be recognized 2 richer beds alternating with 3 leaner ones. If the richer beds B and D are considered alone, there are 7 feet 10 inches of 44 percent rock. The weighted average for the 19 feet is 36.5 percent. The figures for minable depth are of little significance in this area because the beds are nearly horizontal and the overlying formations have been stripped off a wide area. The overburden varies from 0 to 75 feet, but if the minable depth is measured perpendicular to the ground surface, rather than parallel to the bedding, all the phosphate rock under the area covered by the outcrop of the formation is well within the limit of depth for the leanest of the beds, that is 100 feet.

According to Humphrey's Phosphate Company, the depth of overburden on their land is distributed as follows:

Distribution of overburden on the claims of Humphrey's Phosphate Company north of Vernal, Utah, according to company reports

Overburden feet	Acreage	Phosphate tonnage
Very slight	300	16,000,000
0-10	1,200	96,000,000
10-12	1,500	120,000,000
20-50	3,500	280,000,000
Greater than 50	6,200	496,000,000

The detailed section of the phosphatic shale zone as measured on Little Brush Creek[4] is as follows:

[4]Made available for reproduction here through the courtesy of Mr. Hubbard.

Section of phosphatic shale member near Little Brush Creek on Cresson Claim no. 33 of Humphrey's Phosphate Company

(Beds numbered from top to bottom of section.)

Bed no.	Description	Thickness ft.	ins.	Strata analysis Percent Ins	Percent Sio_2	Percent P_2O_5	$Ca_3(PO_4)_2$	Percent Fe_2O_3	Percent CaO	Percent M_3O
	Limestone cap layer									
	Streaks phosphate rock									
1.	Limestone	5	0	27.11	25.75	1.40	3.05	2.52	24.00	1.00
2.	Shaly phosphate	2	0	72.62	65.44	1.33	2.90	5.72	8.10	0.52
3.	Foliated shales and plates of sandstone	1	0	51.37	48.36	3.26	7.05	2.34	15.47	2.26
4.	Coarsely oolitic rock	3	0	13.08	11.90	27.88	60.88	2.14	43.77	1.29
5.	Lumpy phosphate	1	0	25.40	21.22	20.07	43.83	1.90	34.65	1.07
6.	Yellow waste in hard streaks	0	9	69.82	65.98	4.17	9.11	5.58	10.90	0.77
7.	Lumpy shale	2	0	52.68	49.92	12.37	27.01	3.42	19.80	1.57
8.	Fine grained phosphate	5	0	12.18	11.00	28.64	62.55	1.40	43.75	0.56
9.	Cherty lime rock	0	6	74.33	69.67	2.25	4.92	6.35	8.00	0.47
10.	Phosphate shale	1	0	29.07	24.35	20.53	44.83	2.95	32.10	1.12
11.	Iron streak	0	1	18.23	16.96	22.68	46.20	17.26	34.90	0.59
12.	Soft phosphate brown and loose	1	4	8.50	7.83	29.51	64.45	2.18	47.00	0.39
13.	Limy slate	0	10	57.12	50.62	9.70	21.32	3.83	15.05	1.07
14.	Massive phosphate rock, hard, brown, grey	3	0	15.36	13.66	22.42	49.07	1.89	41.75	0.34
15.	Clay	0	6	51.75	26.50	10.54	23.02	5.15	1.77	1.61
	Total	27	0	--------	--------	--------	--------	--------	--------	------
16.	Quartzite stone	--	--	94.00	91.36	0.61	1.32	2.77	trace	000

If beds 1, 2, and 3, which contain only very small amounts of tricalcium phosphate, and bed 16, which is really the top of the Weber sandstone, are eliminated from consideration, this section, like the one on Ashley Creek, shows 19 feet of phosphate rock. The weighted average for the section is 45.6 percent tricalcium phosphate, however, compared with 36.5 percent for the other section. There are 9 feet 4 inches of rock containing 60 to 65 percent tricalcium phosphate in three beds separated by leaner material. Bed 8, the thickest and richest bed in the section, 7 feet 3 inches above the Weber sandstone, is equivalent in a general way to bed D of the Ashley Creek section, of the same thickness, and 8 feet 7 inches above the Weber sandstone. On these data the presence of a 5-foot bed of 50 percent rock throughout most of the area may be assumed.

There are two bases, then, for tonnage estimates for the Dry Fork-Brush Creek area; one a 5-foot bed of about 50 percent rock, the other a 19-foot bed of 40 percent rock. The density of the oolite is about 180 pounds per cubic foot, and that of the green shale about

165. Assuming that a 19-foot bed of 170 pound rock underlies the entire area of outcrop between Dry Fork and Diamond Mountain, 24,000 acres, there are roughly a billion and a half long tons of 40 percent rock in the area. If the 5-foot bed of richer rock is considered alone, there are 400 million tons of 50 percent rock.

The distribution of this rock among the various types of ownership is approximately as follows:

	Acres	50 percent rock millions of long tons	40 percent rock millions of long tons	Percent of total
Public lands	4,800	80	300	20.0
State lands	280	5	18	1.2
National forest	4,500	75	285	18.6
Private lands:				
Humphrey's Phosphate Company	12,600	210	790	52.4
Other	1,900	30	120	7.8
Totals	24,080	400	1,513	100.0

It may be noted that approximately 60 percent of this natural resource in this area is in private ownership, a little over one percent, belongs to the state, and the remainder is nearly equally divided between the public domain and the national forest. The outcrop between Dry Fork and Mosby Mountain has not been included because no detailed information is available on that section. While it very likely includes considerable rock of a quality equal to that east of Dry Fork, its omission tends to counterbalance the assumption of complete continuity of the beds throughout the area east of the stream.

Split Mountain Area. In the vicinity of Split Mountain, the Phosphoria formation is thinner than on Ashley and Brush creeks, due not only to an attenuation of all its members, but in part to non-deposition of the lower part of the phosphatic shale member. As a result, there is probably no phosphate rock of any importance in the area. Outcrops north of Island Park or southeast of Green River have not been visited, but it seems unlikely that they will show any beds of considerable thickness or quality.

Following is a section of the Phosphoria formation measured at the mouth of Split Mountain Canyon:

Section of the Phosphoria formation, mouth of Split Mountain Canyon, Sec 30 T4S R24E SLB&M. Strike S 87° E, Dip 44° S
U.S.A.C. Locality no. 62

Designation of bed	Description	Thickness ft.	in.	P_2O_5	$Ca_3(PO_4)_2$ (Moisture-free basis)
	"Red-beds"—Woodside shale ?				
	Gray and red shales and sandstones	100			
M	Yellowish brown sandstone	10			
L	Brownish light gray, evenly thin-bedded medium grained sandstone with some thin beds of white chert	14			
K	Medium gray medium grained calcareous sandstone with considerable chert (lower resistant bed)	12			
J	Greenish light gray siliceous shale packed with large septarian concretions of chert lavender and green on the outside. Cherty silicinate quartz sandstone	2	6	5.41	11.8
I	Thin, nodularly-bedded, greenish light gray chert	2	0		
H	Greenish light gray very cherty silicinate oolite with large concretions of gray chert lavender and green on the outside		6	21.53	47.1
G	Greenish gray chert, nodularly bedded; five grained silicinate quartz sandstone with much nodular greenish light gray chert		9		
F	Green siliceous shale	1	0	8.44	18.5
D-E	White thin-bedded chert	13	6		
C	Light gray medium grained siliceous limestone weathering brown	2	0		
B	Light gray medium grained calcareous sandstone	2	0		
A	Light gray siliceous limestone with pisolite-like nodules of chert	1	6		
	Total	160			

Weber sandstone

Where the outcrop of the Phosphoria formation crosses the west end of the Split Mountain anticline, the dip of the beds is as low as 6 degrees and the width of the outcrop as great as 2 miles along the axis of the fold. The lower resistant bed of the Ashley Creek section here forms the land surface. The lower shaly member is 15 feet thick, but contains little or no oolite. The section is very similar to that at the mouth of Split Mountain Canyon.

Section of the phosphatic shale member of the Phosphoria formation at west end of Split Mountain anticline, Sec 8 T4S R23W SLB&M
Strike N 30° E Dip 6° W

	feet
Cherty calcareous sandstone (lower resistant bed)	5
Covered. Float shows large lavender and green concretions chert and some green shale	15
Massive white chert stained brown and yellow on weathered surface	6
Brownish light gray sandstone. Weber sandstone	4
Total	30

Duchesne County

Wolf Creek, a tributary of the South Fork of the Duchesne River in western Duchesne County, follows down a valley eroded in the soft Woodside shale formation that immediately overlies the Phosphoria formation. As a result, the line of outcrop of the latter formation is north of the Heber-Duchesne road along Wolf Creek, and within a mile of the road for the greater part of the distance down to the South Fork of the Duchesne River. It crosses the South Fork about one and one-half miles above its junction with the North Fork, then crosses the united Duchesne River about one mile south of the forks, trending northeasterly from that point toward the summit of the divide between the Duchesne River and Rock Creek (fig. 5). This divide (Big Ridge) is capped by a conglomerate formation that covers the eroded edge of the Phosphoria formation for a mile or two across the crest.

Large lateral morains of the glacier that came down the valley of Rock Creek cover the line of outcrop where it crosses the latter stream, but the formation is well exposed in Dry Canyon one mile to the east, just inside the national forest boundary.

The line of outcrop is again covered by conglomerate in the ridge between Dry Canyon and the West Fork of Lake Fork, but it appears once more in the latter canyon and is well exposed on the east side, at the mouth of Mackentire Draw, a small tributary canyon. Beyond this point it passes once more beneath the Bishop (?) conglomerate, and is not exposed again in Duchesne County, the next outcrop being on Whiterocks River in Uintah County.

The sequence of sedimentary rocks that includes the Phosphoria formation is generally the same in this area as throughout north-

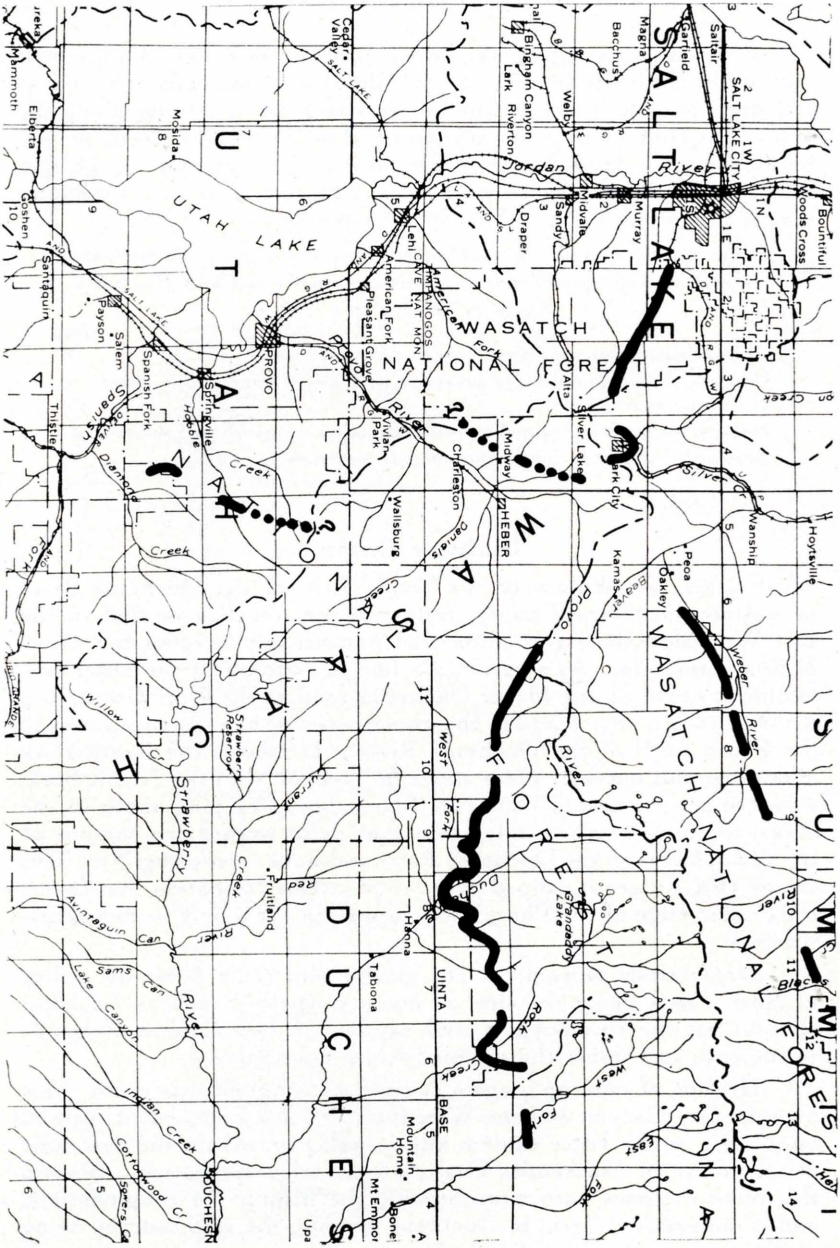

Fig. 5. Outline map showing outcrops of Phosphoria fm in western Summit, Duchesne, Salt Lake, Wasatch and Utah Counties.

eastern Utah. The Weber formation, not so strongly marked by cross bedding, is largely composed of quartzite and hence is more resistant to erosion than its equivalent of cross-bedded calcareous sandstone in Uintah County. The Weber quartzite forms a mighty hogback along the southwest flank of the range, and the Phosphoria formation can be found on the gentle backslope of the hogback. The "red-beds" immediately above the Phosphoria formation consist of two shaly formations separated by a more resistant limestone formation, namely (from bottom to top) the Woodside shale, the Thaynes limestone, and the Ankareh shales and sandstone. The Woodside formation, comparatively weak to erosion, forms a valley that brings into relief the Weber hogback to the north and the Thayne hogback to the south of it. It is not difficult to locate the Phosphoria formation between the strikingly different Weber quartzite below and Woodside shale above. In general the dips are steeper in this area than in Uintah County and the width of the outcrop is little more than the thickness of the formation.

The phosphatic shale member was measured in detail at two localities in Duchesne County as follows:

Section of the phosphatic shale member along the Forest Service trail, east side of the valley of Blind Stream
Sec 14 T1N R8W UB&M
U.S.A.C. Locality no. 36

Designation of bed	Description	Thickness ft.	in.	P_2O_5	$Ca_3(PO_4)_2$ (Moisture-free basis)	Minable depth feet
	Yellowish light gray sandstone. Greenish light gray nodularly bedded cherty siliceous shale. Includes some thin beds (2-4 inches) of oolite	40				
B	Black paper shales with some thin beds of fine grained dark gray sandstone. Chert nodules and geodes common	14		2.95	6.44	
	Light gray medium grained calcareous sandstone	3	6			
	Brownish light gray fine grained sandstone	1	5			
	Coarse grained phosphatc sandstone	1				
	Total	60				

Calcareous sandstone and quartzite.

Section of the phosphatic shale member, West Fork of Lake Fork east side of valley, Sec 34 T2N R5W UB&M. Strike S 85° E, dip 35° S. U.S.A.C. Locality no. 40

Designation of bed	Description	Thickness ft.	in.
G	Greenish light gray, thin nodularly bedded, fine gray sandstone	8	6
F	Brownish black shale, weathering bluish light gray, grading upward into medium gray fine grained sandstone	2	6
E	Black shale grading upward through medium gray, fine grained, sandy shale into medium gray dense sandstone in beds 1 foot thick	10	
D	Fine grained medium gray sandtone	1	
C	Black shale	3	
B	Bituminous sandstone, medium to coarse grained; not well sorted	10	
	Total	35	

Weber sandstone

As will be seen from these sections, there are no beds of oolite, other than thin seams a few inches thick, in this area. The black shale is so low grade as to be of little commercial promise, even for the remote future.

Schultz collected four samples for analysis in Duchesne County. Two (nos. 13 and 14) were collected on the South Fork of the Duchesne one and one-half miles above the forks. On examination the section at this locality has been found to be very similar to the one on Blind Stream. It does not contain a 6-foot bed of black chert described in Schultz's report, nor a basal bed in the shale member that looked richer than the ordinary run of black shales in the region. The 4-foot bed (no. 10) reported from the west side of the Duchesne River below Stockmore Ranger Station is richer than any black shale ever collected by the writer and is not represented in the Blind Stream or South Fork sections. Schultz's (7) analyses (nos. 15 and 16) for the West Fork of Lake Fork locality indicate that part, at least, of the bituminous sandstone (bed B) is phosphatic (3 feet analyzing 12.28 percent P_2O_5, 26.89 percent $Ca_3(PO_4)_2$), while the black shale is very lean (6 feet analyzing 4.15 percent P_2O_5, 9.09 percent $Ca_3(PO_4)_2$).

In summary, the phosphatic shale member of the Phosphoria formation in Duchesne County consists of about 15 feet of black shale, with thin beds of fine grained medium gray sandstone, containing an average of about 10 percent $Ca_3(PO_4)_2$. In the greenish gray nodularly bedded shales and sandstones immediately above the black shales there are thin discontinuous beds of oolite but they are not thick enough (average 2 to 4 inches) to be of any possible economic value. The basal few inches of the black shales are, in places, richer, perhaps by secondary enrichment from the beds above, but this basal bed is likewise of little possible value.

Daggett County

The outcrop of the Phosphoria formation along the north flank of the Uinta Mountains extends from a point in Sec 4 T2N R21E SLB&M, about three miles east of the Green River, eastward to the divide between Burnt Fork and the East Fork of Beaver Creek, a distance of about 30 miles (fig. 2). At the east end it is terminated by the North Flank fault, and at the west end it passes beneath a cover of younger rocks. The beds everywhere dip toward the north, more gently in the eastern half of the area, more steeply in the western half. In the vicinity of Green River the dip is about 7 degrees and at the Bennett Ranch, where Lodgepole Creek joins Sheep Creek and highway U-44 crosses the outcrop, about 20 degrees. At the Nebeker Ranch in Conner Basin higher up on Lodgepole Creek, and between Birch Creek and Burnt Fork, the dip is about 42 degrees.

Here, as in Uintah County to the south, the formation is tripartite, with three shaly members separated by two resistant members of cherty sandstone. All members here are thicker, however, than in th area on the south flank of the range. The massive cross-bedded Weber sandstone below and the "red-beds" above are similar to the equivalent beds in the Vernal area. Here, also the alternation of more resistant and less resistant beds produces hogbacks separated by valleys that follow the strike of the formation. Lodgepole Creek below Conner Basin and Sheep Creek below its junction with Lodgepole Creek, to within a mile of its mouth, follow a valley eroded in the upper shaly member of the Phosphoria formation and the lower part of the overlying "red-beds."

Along the south side of this valley the two resistant members of the formation form wide dip slopes along the north flank of the range, slopes that widen on the interstream areas and contract at the mouths of canyons cut by streams across the strike of the beds. Between Green River and Bennett Ranch these slopes are a mile to a mile and a half wide. West of the ranch, up Lodgepole Creek, they narrow as the dip steepens. Opposite Phil Pico Mountain, the nearly flat-lying younger rocks of the Wyoming Basin encroach upon and nearly cover the upturned edges of the Phosphoria beds. South of Conner Basin the beds dip more steeply than the surface of the ridge and the edges of the more resistant strata stand out as transverse ribs on the slope. Across the valley drained by Birch Creek, from Phil Pico Mountain to the end of the outcrop, the phosphatic shale member lies along the backslope of a continuous hogback formed by the Weber sandstone. Exposures are poor and the member could not be measured at any place, but there was no indication in the float or otherwise that formation is different here than at the Nebeker Ranch, where it was measured in detail.

From Flaming Gorge, cut in the hogback of "red-beds" that overlie the Phosphoria formation, to the mouth of Sheep Creek, the Green River swings in a series of great bends that occupy the valley on the upper shaly member of the Phosphoria formation, or cut into the hogback of Weber sandstone, in the steep-walled gorges of Horseshoe and Kingfisher Canyons. Between these bends, on the backslope of the Weber hogback, one or the other of the resistant members of the Phosphoria formation forms wide gentle dip slopes.

Section of the phosphatic shale member of the Phosphoria formation
west side of Sheep Creek gorge at Bennett Ranch
Sec 2 T2N R19E SLB&M
Strike S 87° E, Dip 18° N
U.S.A.C. Locality no. 59

Designation of bed	Description	Thickness ft.	in.	P_2O_5	$Ca_3(PO_4)_2$ (Moisture-free basis)	Minable depth feet
	Massive white chert (Bed I)					
H	Beds composed of small irregular bodies of white chert, alternating with beds of dark gray oolite, green shale, and dense medium gray siliceous rock. Sample from 3 thickest beds of oolite 6, 12 and 8 inches respectively	20	0	18.29	40.0	
G-8	Light gray and medium gray oolites, weathering greenish light gray; some shale and sandstone, the latter increasing toward the top	3	2	15.01	32.8	150
G-7	Black shale	5	9	6.34	13.8	
G-6	Brownish medium gray medium grained sandstone	1	1			
G-5	Greenish gray oolite with some black shale	1	7	14.84	32.4	35
G-4	Medium gray medium grained silicinate quartz sandstone	1	0			
G-3	Black shale	1	10	8.86	18.3	
G-2	Brownish dark gray fine grained sandstone or					

Designation of bed	Description	Thickness ft.	in.	P_2O_5	$Ca_3(PO_4)_2$ (Moisture-free basis)	Minable depth feet
	silt stone		10	1.70	3.7	
G-1	Black shale; lower 6 inches oolite with abundant casts of small shells; some of higher beds brownish dark gray sandstone	2	9	25.96	56.6	1,150
	Total	38				

Medium grained brownish gray calcareous sandstone (Bed F).

Of the three beds (G-1, G-5 and G-8) that exceed the minimum limits for quality and thickness, as set by the U. S. Geological Survey in the classification of phosphate lands[5], only the basal bed is thick or rich enough to be worthy of any consideration. An examination of the analyses from Conner Basin, about six miles to the west, shows a basal bed of substantially the same quality and thickness present there.

Section of the phosphatic scale member of the Phosphoria formation, east side of the Lucerne Valley Canal, just inside the forest boundary, SW ¼ Sec 2 T2N R18E SLB&M, south of Nebeker Ranch, Conner Basin

Strike S 80° W, Dip 42° N
U.S.A.C. Locality no. 61

Designation of bed	Description	Thickness ft.	in.	P_2O_5	$Ca_3(PO_4)_2$ (Moisture-free basis)	Minable depth feet
	Massive white chert					
K	Greenish light gray paper shales, with 3 6-12″ beds of greenish light gray medium grained cherty sandstone, and near the top, 2 6-12″ beds of oolite. Sample omits cherty sandstone	20		10.02	21.9	
J	Light gray oolite	1	0	21.53	47.0	
I	Sandstone	1	0			
H	Thin bedded fine-grained dark gray sandstone	2	0	6.08	13.3	
G	Dark gray fine-grained sandstone weathering brownish gray	1	10			
F	Black shale	1	8	6.47	14.1	
E	Dark gray fine-grained sandstone weathering					

[5]See p. 5.

Designation of bed	Description	Thickness ft.	in.	P_2O_5	$Ca_3(PO_4)_2$ (Moisture-free basis)	Minable depth feet
	brownish gray	1	2			
D	Black shale with 3 inches of oolite at base	3	6	11.00	24.1	
C	Medium gray medium grained sandstone	2	1			
B	Mostly black and brownish dark gray shale with some thin beds of brownish dark gray sandstone. At the top 12″ of black paper shales followed by 4″ of oolite	7	6	15.47	33.8	350
A	Dark gray oolite with abundant casts of small shells	1	0	33.14	72.4	
	Total	43	9			

Medium-grained calcerous sandstone

This section contains a 1-foot basal bed of high grade (72.4 percent) rock, succeeded by 7½ feet of shale of 32.8 percent grade. If 1 foot 9 inches of this shale were taken with the basal bed, this section would show a 2 foot 9 inch bed of 57.4 percent grade, compared with 2 feet 9 inches of 56.6 percent rock at the base of the section on Sheep Creek. The Phosphatic shale member east of the Bennett Ranch was not sampled, but samples taken by Schultz above Horseshoe Canyon in T3N R21E SLB&M (nos 32 and 33) indicate a basal bed about four feet thick of 60 percent rock. Schultz's (7) analyses consistently run higher than the writer's for the same beds, but in the absence of more data these samples may be taken as the basis for assuming at least a 2 foot 9 inch basal bed of 50 percent rock in the eastern half of the area. The area of gentler dips east of the west boundary of R19E SLB&M contains approximately seventeen square miles of outcrop of the formation where the over-burden does not exceed 200 feet and where if minable depth is measured perpendicular to the ground surface, the basal bed is everywhere well within the limit of 1,150 feet. The line of outcrop west of this point is approximately fifteen miles long, seven miles being in Summit County. For this part of the area where the dip exceeds 40 degrees, the minable depth may be assumed to be measured down the dip. On this basis there are 9,000,000 long tons of 170 pound rock of 50 percent grade west of the west boundary of R19E in Daggett County, and 100,000,000 long tons of the same rock east of this line, a total of 109,000,000 tons for Daggett County.

Cache County

The Phosphoria formation of Permian age, in which lies the great phosphate reserve of the western field, is not present in Cache

County. Though there is little doubt that it once covered this area, it has long since been completely removed by erosion, and an older formation of Mississippian age, with a member of phosphatic shale at its base, admits this county to the list of Utah counties having phosphate deposits. Known as the Brazer formation, it underlies the Bear River range east of Cache Valley from a point opposite Smithfield southward to East Canyon, opposite Avon (fig. 6).

The Brazer formation in this region is nearly 2,000 feet thick. The section measured on the north side of the canyon of Blacksmith Fork fairly represents the formation in the Bear River range.

Section of the Brazer formation north side of Blacksmith Fork
NE¼ Sec. 4 T10N R2E SLB&M

Description Wells formation (?)	Thickness in feet
Medium to light gray medium gray crystalline dolomite, with sporadic black chert	160
Fine grained to dense, gray limestones, generally massive. In upper 50′ chert, in a variety of colors, common	670
Medium to light gray, medium-grained sandstone weathering brown	60
Gray quartzitic sandstone weathering light yellowish gray	85
Medium-grained bluish medium gray sandstone with common seams and stringers of calcite	75
Thin bedded medium to light gray quartzitic sandstone weathering light yellowish gray	20
Black fetid medium-grained crystalline crinoidal limestone with numerous corals	20
Medium gray coarsely crystalline crinoidal limestone, massive	110
Fine to medium-grained blue black to dark gray calcareous sandstone, beds of medium thickness	15
Thin bedded, coarse to fine grained, bluish gray calcareous sandstone	450
Thin bedded, dark gray, dense cherty limestone	60
Medium gray, medium-grained sandstone; crossbedded	70
Phosphatic shale with beds of black limestone and brownish gray sandstone. Thin lenses and stringers of phosphatic oolite	75
Total	1,870

Madison formation. Massive light gray cherty dolomite.

The sedimentary rocks in the front or western ridge of the Bear River Range have been folded into a large open synclinal structure with axis paralleling the general trend of the ridge. Each successively younger formation in the sequence underlies, therefore, a smaller area in the range. The Wells formation, youngest and atop the pile, constitutes only the higher peaks such as Logan, Birdneau and Millville that rise above the general level of the range top, which is formed on the massive limestones and dolomites at the top of the Brazer formation. The phosphatic shale member, lying over a thousand feet below and protected by these limestones, underlies an area of

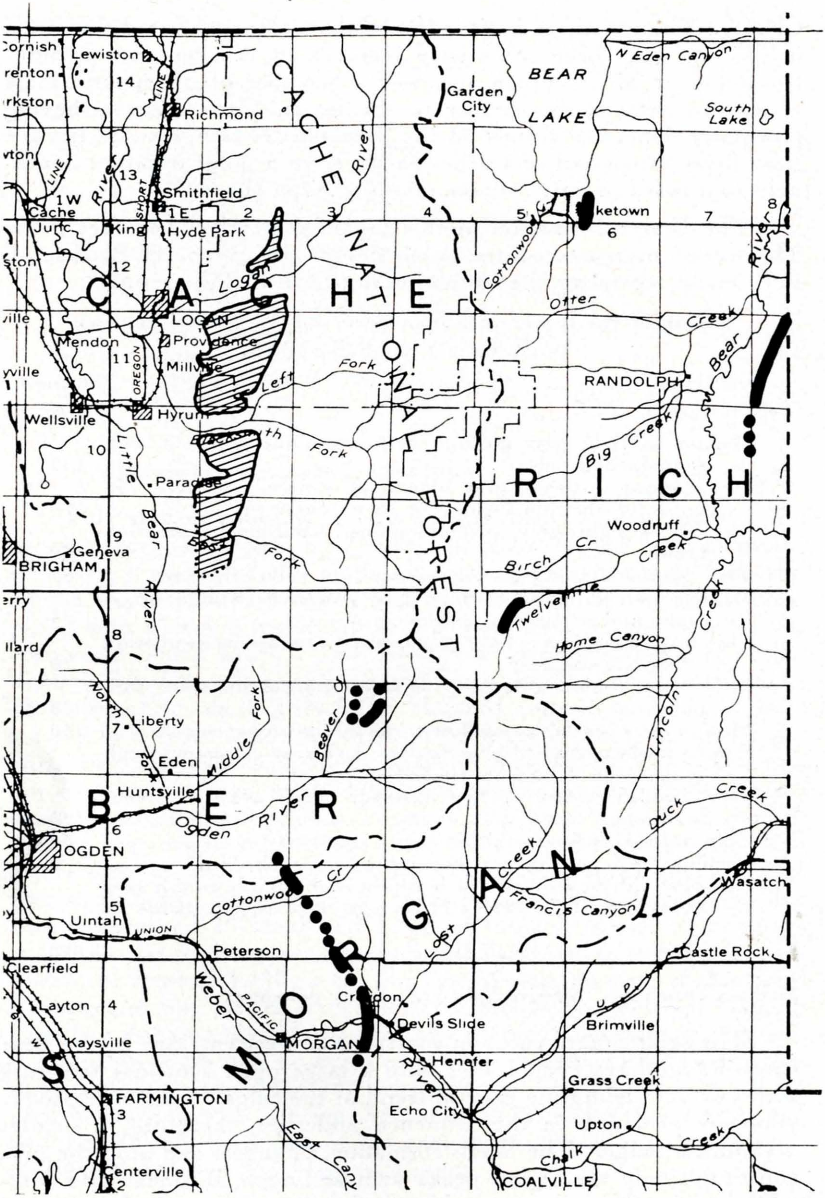

Fig. 6. Outline map showing area underlain by Brazer fm in Cache County and outcrops of Phosphoria fm in Rich, Weber and Morgan Counties.

approximately 48 square miles, separated into three parts by the canyons of Logan River and Blacksmith Fork.

Where the axis of the syncline crosses Logan and Blacksmith Fork Canyons, about three and five miles above their respective mouths, the outcrop of the phosphatic shale is 1,500 to 2,000 feet above the road. Both east and west from these positions the beds rise at the limbs of the syncline are ascended. North of Logan River the line of outcrop circumscribes Birdneau Peak with rather long extensions corresponding to the high ridges that extend northeast and southwest from the highest point. Between Logan and Blacksmith Fork Canyons it parallels the Left Fork of Blacksmith Fork and Richards Hollow and Card Canyon, along the east side of the ridge, and on the north and west sides, crosses Spring Hollow and Providence and Millville Canyons about halfway to their heads. South of Blacksmith Fork Canyon the outcrop has not been traced but the general regional features of the geology indicate that it does not extend far south of East Canyon.

The phosphatic shale member varies from 50 to 200 feet in thickness. It includes considerable sandstone and limestone, and the beds of oolitic phosphate rock are thin and discontinuous. Few beds of oolite are more than a few inches thick, and it is probable that little if any of the shale contains as much as 30 percent tricalcium phosphate. Fairly thick and rich beds of shale, such as no. 4 in the following detailed section, are not repeated in other sections, showing their limited lateral extent.

A detailed section of the phosphatic shale member in Providence Canyon[6], is as follows:

Details of the lower part of the phosphatic shale zone in Providence Canyon.
(Beds are numbered from top to bottom)

No. of bed	Description	Thickness in inches	Percent $Ca_2 (PO)_3$
	Dark gray limestone	36	
2	Phosphatic shale	18	30.10
3	Shaly phosphate rock	12	16.71
4	Dark shaly phosphate rock	48	65.43
	Gray limestone	24	
5	Shale, some layers phosphatic	48	14
6	Black shale	11	8.41
7	Shale, oolitic phosphate, in bands	30	21.30
	Sandy limestone	24	
9	Phopshate rock, shaly	38	33.01
	Chert	18	
	Black shale	12	
10	Phosphate rock	30	35.83
11	Phosphate rock	12	46.34
	Black chert	2	

[6]Measured by William Peterson in 1914, and reproduced from Science n. s. 40:755-756. 1914.

No. of bed	Description	Thickness in inches	Percent $Ca_2(P0)_3$
12	Black shale	48	3.91
	Black chert	6	
13	Black oolitic phosphate rock	21	65.76
	Black chert	1	
14	Black shaly phosphate rock	12	21.40
15	Brown oolitic phosphate rock	18	68.59
	Bedding planes		28.31
	Shale	6	
16	Shale showing phosphate in	6	
	Chert	2	
17	Shaly phosphate rock	4	27.12
	Sandy limestone	20	
18	Brown oolitic phosphate rock	18	66.9
	Black shale	12	
	Black shale with bands of chert	16	
	Brown oolitic phosphate rock	5	52.22
	Shale	7	
	Oolitic phosphate rock with much hematite	2	

Limestone ledge

If and when phosphorus becomes sufficiently scarce to warrant the exploitation of extremely low grade rock, this area may become important as a phosphate reserve. But in the present view it is insignificant, the unused billions of tons of 70 percent rock in other parts of the western field and in the southeast barring almost indefinitely its future economic value.

The phosphatic shale member of the Brazer formation is present in the Wellsville Mountain across its north end. It crops out in Beck's Spur north of Salt Lake City where it is 35 feet thick[7], and at numerous places in the Oquirrh Range, where it consists of 9 feet of black, red-weathering shale with a thin bed of phosphate oolite at the top (4). The Brazer formation crosses Weber Canyon between the town of Morgan and Round Valley, and although the upper members of the formation are closely similar to those in the Bear River Range, the phosphatic shale member is not present, at least near the bottom of the canyon. Outcrops of the formation in Big Cottonwood Canyon do not show a phosphatic shale member. The phosphatic shale member in rocks equivalent to the Brazer formation has not yet been reported from the central Wasatch Mountains east of Provo, but it may be present there. There is nothing to indicate that the phosphatic shale member of the Brazer formation is any richer at any of these localities than it is east of Cache Valley. It is, therefore, probably of no future economic importance.

Rich County

The Phosphoria formation outcrops at three widely separated localities in Rich county: in Laketown Canyon, east of Laketown, in the

[7]Personal communication from Phyllis Wilcken, University of Utah.

Crawford Mountains east of Randolph, and in a small area on Twelvemile Creek west of Woodruff. The phosphatic shale member is richer at these places than at other outcrops in the state. Consequently, they received rather detailed study at a comparatively early date, and tonnage estimates by the U. S. Geological Survey are available for them. The following summary of the salient facts regarding these deposits is taken from the report of Gale and Richards (3).

Laketown Area. The Phosphoria formation outcrops in two parallel belts that cross Old Laketown Canyon about one mile east of Laketown in Sec 32 T13N R6E. These belts of outcrop are in the two eroded limbs of a rather closely folded north-south anticline that is slightly overturned toward the east and truncated by erosion. The phosphate bed on the west limb is partly overridden by a block of limestone thrust over it from the west. The whole thickness of the bed is not represented in the outcrops and no attempt has been made to estimate the tonnage on that side of the anticline. The Phosphoria formation in the east limb is but little disturbed, and its outcrop extends from a point some 3,500 feet north of the canyon, where it is terminated by an east-west fault, to a point about the same distance to the southeast, where it passes under a cover of younger rocks.

A section of the phosphatic shale member is as follows:

Section of phosphate rock in Sec 32 T13N R6E

Field no. of specimen		P_2O_5 percent	Equivalent to $Ca_3(PO_4)_2$ percent	Thickness ft.	in.
134-A	Cherty limestone, phosphate rock, gray, coarse to medium, oolitic	36.3	79.5	1	5
	Shale, brown				4
134-B	Phosphate rock, gray, coarse, oolitic, friable	37.3	81.7		5
134-C	Phosphate rock, gray, fine oolitic	26.4	57.0		5
134-D	Phosphate rock, gray, coarse, oolitic, weathers into flat concretions up to 1 inch in diameter	36.7	80.4		6
134-E	Phosphate rock, fine grained, oolitic, weathered	26.0	56.5		8
134-F	Phosphate rock, gray, fine to medium, oolitic	34.1	74.7	2	10
	Total			6	7

The total thickness of phosphate rock in this section is 6 feet 3 inches, excluding the 4 inches of brown shale near the top, and it averages about 73 percent $Ca_3(PO_4)_2$. The length of the outcrop in the eastern limb is about 7,000 feet. Assuming a 6-foot bed for this distance, minable to a depth of 2,000 feet, Gale and Richards estimate that there are 6,750,000 long tons of 70 percent phosphate rock in the area.

Crawford Mountain Area. The Crawford Mountains are a small north-south trending range, only about 15 miles long and 2 or 3 miles wide, lying between Bear River and the Wyoming state line, opposite the town of Randolph. The essential structure of the phosphate is a shallow, narrow syncline whose axis trends with the range. The syncline is closely folded and slightly overturned toward the east at the north end of the range, but more open and symmetrical in the middle and toward the south end. In part of the southern half the Phosphoria formation has been completely removed from the syncline by erosion. Prospects, and later mines, at the north end of the area were among the first to be opened in the western field. The ore was trucked to the railroad at Sage, Wyoming, about 12 miles distant. A section of the phosphate-bearing beds in Brazer Canyon near the north end of the area, is as follows:

Section of phosphate and associated beds in Brazer Canyon, "Otto claim," approximately in NE¼ Sec 19 T11N R8E

Field no. of specimen		P_2O_5 percent	Equivalent to $Ca_3(PO_4)_2$ percent	Thickness ft.	in.
	Main bed				
97-A	Phosphate, dark gray or black, massive, coarsely oolitic	34.9	76.4	3	2
97-B	Phosphate, shaly, brown, weathered, oolitic	23.7	51.9		8
97-C	Phosphate, dark, almost black, oolitic	36.8	80.6	1	2
97-D	Phosphate, brown, shaly, finely oolitic	31.0	67.9	5	8
	Interval concealed, probably shaly			4	8
97-E	Phosphate, or limestone, dark gray or black, massive	26.8	58.7	1	8
	Limestone, cherty			8	
97-F	Phosphate, dark gray, massive, calcareous	28.7	62.8	1	2
	Interval concealed			71	6
	(ft. in.) Shale, brown 1 ft. 5 in.;				
98-A	Phosphate, gray, oolitic 4 in.;	23.4	51.2	2	9
	Shale, brown 1 ft.				
98-B	Phosphate, brown, earthy material	27.8	60.3	1	7
	Total			102	1

Gale and Richards (3) estimate that there are 113,000 linear feet of outcrop of phosphate-bearing strata in the area. Assuming a 5-foot bed of 70 percent rock minable to a depth of 2,000 feet along this outcrop they arrive at a general estimate of 90,000,000 long tons. No exact data on land ownership are available, but it is known that a large part, perhaps well over half of the outcrop, is covered by patented claims obtained prior to 1908 when all remaining phosphate lands were withdrawn from entry.

Woodruff Creek Area. The Phosphoria formation crops out along Woodruff Creek and its tributary, Sugar Pine Creek, about 14 miles west-southwest of Woodruff. The beds strike generally east-northeast, parallel to Woodruff Creek (before it joins its tributary), but outcrops of the phosphatic shale zone are limited and discontinuous due to the presence of a fault developed in them and the shales of the overlying Woodside formation. The principal prospects are in sections 4 and 16, T8N R5E. In view of the poor exposures and difficult structure, Gale and Richards could find no satisfactory basis for an estimate of tonnage. The few samples they were able to obtain did not show particularly high quality. The area is of special, if casual, interest in being that in which the phosphate rock of the western field was first discovered.

Weber and Morgan Counties

The phosphate deposits in the valleys of the Ogden and Lower Weber Rivers are known only from a reconnaissance report prepared by Blackwelder (1) in 1910. This report serves, however, to locate the outcrops of the Phosphoria formation in the area, and gives a measured section, with analyses, of the most important outcrop—that on the Weber River about one mile below Devil's Slide. As shown on the accompanying map (fig. 6), the Phosphoria formation crops out northeast of Huntsville on Beaver and Dry Bread Creeks, tributaries to the South Fork of the Ogden River, and southeast of the same town, on the ridges west of Sheepherd Valley, a small valley also tributary to the Ogden River Valley. South of this exposure the beds are covered for some distance by younger rocks, but four or five miles north of Weber Canyon the cover becomes discontinuous, and the formation may be traced into the bottom of the canyon, which it crosses just above the railroad tunnel and about one mile below Devil's Slide, at the old Robison ranch. The beds dip steeply toward the east at this locality. The phosphate-bearing zone is thick but the rocks are lean; there is much black limestone but little black shale and little oolite. Following is part of the section measured by Blackwelder (1):

Section of beds near Robison's ranch, Weber Canyon

Description	Thickness feet	$Ca_3(PO_4)_2$ Percent
Limestone, dense, black, and cherty	2	
Shale, black and phosphatic	6	
Limestone, dense, black, and cherty	5	
Phosphate rock, black, partly oolitic	13	46.1
Limestone, phosphatic, black, cherty	5	21.9
Chert, hard and blocky, black	1	
Limestone, black, with black chert nodules	4	
Phosphate rock, rather uniform, dense black rock with many nodular and oolitic layers	10	39.2
Limestone, black and cherty	10	
Limestone, gray, hard and blocky	8	8.8
Limestone, black, with much chert, interbedded with layers of shaly phosphate rock 1 to 4 inches thick	40	15
Limestone, black and phosphatic	3	9.6
Limestone, black, rather siliceous and hard	1	8.8
Limestone, black, cherty	2	15.3
Limestone, black, hard, and siliceous	1	11.8
Limestone, dark gray, with great masses of black chert	157	

This section shows two rather rich beds, one 13 and the other 10 feet thick (tricalcium phosphate average 46.1 and 39.2 percent respectively). This section has been examined in detail, but no analyses were made to serve as a check. The shale and black limestones look exceedingly lean and pieces of oolite are difficult to discover. The existence in this section of members 10 feet thick that will yield an average of over 30 percent tricalcium phosphate is doubted. Accordingly no tonnage estimate is attempted, and further analyses from this locality are desirable.

The outcrop of the Phosphoria formation extends southwestward beyond the bottom of the canyon and there passes again beneath the cover of younger rocks.

As has been stated in connection with a description of the phosphate deposits of Cache County, the Brazer formation crops out in both Ogden and Weber Canyons. The phosphatic shale member of this formation was seen at each of the localities in Ogden Canyon by Blackwelder (1), but is not present in the section along the bottom of Weber Canyon, as has been pointed out. There has been no report of any kind to indicate that the Brazer phosphatic shale in this area is any richer than in Cache County, to the north.

Salt Lake, Wasatch and Summit Counties

The outcrop of the Phosphoria formation in Salt Lake County ends in the escarpement of the Wasatch Range front in the vicinity of the mouth of Neff's Canyon (fig. 5). From the Wasatch front it strikes east-southeastward into Big Cottonwood Canyon, crossing the divide between the two canyons above Mill A basin and approaching within a few hundred feet of the highway in "Section Ridge," about three miles below Brighton. From this point the strike continues southeasterly for a mile or two until the formation is cut off by the Cottonwood batholith, just west of the crest of the range. The outcrop of the Phosphoria formation partly encircles the town of Park City with a U-shaped configuration open to the south. It reappears, separated from the main area by faults and intrusive bodies, in the southeast corner of the district in Sec 36 T2S R4E. From here it follows southward around Bonanza Peak toward Midway, in Provo Valley. At a point due north of this village the line of outcrop is terminated at the edge of the valley, although the formation may be continuous beneath the deposits of the valley fill. Phosphate deposits have been reported in the area southwest of Midway, so there is little doubt that the outcrop reappears on that side of the valley, continuing an unknown distance toward the heads of Deer Creek and American Fork Canyons.

Exposures of the phosphatic shale member are poor across the brush-covered crest of the mountains. In the section on "Section Ridge" in Big Cottonwood Canyon, however, Gale and Richards[8] measured a 3-foot bed, near the base of the member, which, they report, contains 32.6 percent P_2O_5, equivalent to 71.39 percent $Ca_3(PO_4)_2$. The black shales also crop out in and about the town of Park City, but there is no detailed information concerning them at this place.

At the outcrop on the edge of Provo Valley, due north of Midway, in a small pit 300 to 400 feet above the valley floor and about 100 yards west of the east boundary of Sec 22 T3S R4E the phosphatic shale member was measured as follows:

Section of phosphatic shale member of Phosphoria formation due north of Midway, Utah, Sec 22 T3S R4E SLB&M, U.S.A.C. Locality no. 32

Field designation of bed	Description	Thickness ft.	in.	P_2O_5	$Ca_3(PO_4)_2$
	Covered				
I	Dense fine grained brownish black fetid sandstone	1	0		
H	Brown shale	4	0		
G	Brown fetid sandstone		8		
F	Brown and black shale with a few thin seams of oolite	4	0		
E	Brown calcareous sandstone		4		
D	Brown shale	1	6		
C	Oolite, with bluish gray bloom	1	0		
B	Cherty fetid brown fine-grained sandstone	2	0		
A	Sandy oolite with pale bloom	3	6	26.74	58.40
	Total	18	0		
	Quartzite and sandstones				

[8] In Shultz, (7).

It will be noted that the basal 3 feet of both of these sections are fairly high grade rock, say 60 percent tricalcium phosphate. Such a bed, according to the standards of the U. S. Geological Survey is minable to a depth of 1,500 feet, and each linear mile of outcrop, if the minable depth is measured down the dip, represents 1,800,000 long tons of 170 pound rock. The degree of continuity that this bed possesses along the strike of the formation from the Wasatch Front to Provo Valley, through Salt Lake, Summit and Wasatch Counties, is not known, since it has been seen at only two places.

The similarity in thickness and quality of the basal bed at these two points suggests that it is continuous, but such a conclusion, on such scanty evidence, is not warranted, particularly in view of the known variability of the phosphatic shale member of the formation. The outcrop north-northeast of the pit north of Midway is probably continuous for three miles, to the north boundary of the township. The outcrop west of Midway is perhaps half as long, at least. These would credit Wasatch County with four and one-half miles of linear outcrop and 8 million tons of 60 percent rock. This estimate represents, of course, only the first approximation, and would be improved by additional field work in the area.

There are approximately ten miles of linear outcrop in Salt Lake County between Wasatch Front and the Summit County line where the outcrop terminates against the igneous rock of the Cottonwood batholith. As a first approximation this could be credited with 18 million long tons of 60 percent rock, but a conservative estimate will divide this at least by two.

The Daggett County outcrop of the phosphate-bearing beds continues for about seven miles into extreme eastern Summit County, across the valleys of Birch Creek and Burnt Fork to a point where it passes beneath the flat-lying cover of younger rocks. From this point the outcrop of the Phosphoria formation is completely covered with the exception of a short distance on the divide between Blacks Fork and the East Fork of Bear River, as far west as R9E on the West Fork of Bear River. Westward from this locality the outcrop is nearly continuous, though poorly exposed, to the edge of Rhodes Valley, east of Oakley, where the formation is either truncated by a fault, or passes beneath the valley fill.

Near Holiday Park the Phosphoria beds are in the North Flank fault zone, steeply dragged down and much disturbed. East or west of the river below this resort an outcrop of the phosphatic shales could not be located, although the beds above and below them were easily recognized. Between Holiday Park and the mouth of Smith and Morehouse Canyon, the Weber quartzite forms the south wall of the canyon, and the outcrop of the Phosphoria formation occupies a line near the bottom of the wall, a locus heavily covered with talus and morainic material, and densely overgrown with brush and forest. There is no exposure then until the steeper and barer slopes at the mouth of Smith and Morehouse Canyon are reached. Here the shale member can be distinguished, but it is too heavily covered to permit the collection of samples.

The line of outcrop crosses the South Fork of Weber River just south of the junction of that stream and Noblet Creek. Here the formation as a whole is fairly well exposed, but the phosphatic shale member cannot be easily measured and sampled.

The formation is probably exposed in Swifts Canyon, which has not been visited, for it is well exposed in Franson Canyon farther west. The Franson Canyon exposure is by far the best along the upper Weber River. The Phosphoria formation underlies the narrow ridge between Franson and Weber Canyons, dipping 35 degrees to the north. The phosphatic shale member can be completely exposed by shallow trenching, and the following section was obtained at this locality:

Section of the phosphatic shale member of the Phosphoria formation at the mouth of Franson Canyon, NE ¼ of NE ¼ of NW ¼ of Sec 22 T1S R6E SLB&M
U.S.A.C. Locality no. 27-R

Description	Thickness ft.	in.	P_2O_5	$Ca_3 (PO_4)_2$
Medium gray dense quartzite with much chert				
Dark brown to black shale with an occasional bed, 4″ to 2′ thick, of fine-grained dark brown sandstone. Toward the top the shale becomes more siliceous. Basal 6″ bed of oolite	50		8.63	18.85
Total	50			

Gray dense quartzite, thin bedded

In a prospect hole in a gully just north of the mouth of Seymour Canyon, near the center of Sec 22, a sample (L 27-A) was taken of the lowest 4 feet of the phosphatic shale member, including the basal oolite, and values of 13.33 percent P_2O_5 or 29.11 percent $Ca_3 (PO_4)_2$ were obtained. In the prospect tunnel of C. A. Hall and J. O. Gibbons of Oakley, in SE ¼ of NW ¼ of Sec 22 a sample (L 27-B), representing the upper part of the phosphatic shale member, was collected and yielded on analysis 2.39 percent P_2O_5 or 5.22 percent $Ca_3 (PO_4)_2$. These analyses indicate clearly that there is nothing but low grade rock in the section, even the basal 4 feet failing to reach 30 percent $Ca_3 (PO_4)_2$.

In the float east of this locality where the exposures are poor, a few pieces of oolitic rock were seen, but no other indications that the formation may contain richer sections than that at Franson Canyon. It seems quite certain, therefore, that this area may be recorded as containing only rock of little or no possible future commercial value.

Outside, then, of possible small outcrops of phosphatic shale close to Park City, Summit County is without phosphate deposits of importance unless the outcrop that extends westward 7 miles from the Daggett County line contains the basal 2 foot 9 inch bed of 50 percent rock observed in Conner Basin at the Nebeker Ranch. If this bed is continuous for the full length of the outcrop, Summit County may be credited with 10 million long tons of 50 percent rock.

Utah County

The presence and location of phosphate-bearing beds in Utah County has only recently been made known.[9] In general, the line of outcrop of the Phosphoria or "Park City" formation strikes southward from the vicinity of Round Valley (Wallsburg) across the upper reaches of the two forks of Hobble Creek to Diamond Fork, where it terminates against an east-west fault. Generally speaking, the line of outcrop is covered on the high areas between the canyons, where erosion has not yet removed the cover of younger rocks, and is exposed in the stream valleys. The outcrops on the Right Fork of Hobble Creek and on Little Diamond Creek have been visited, but no detailed information on possible exposures north of these localities has been obtained. These, however, are the most accessible, perhaps also the richest deposits in the county.

The Phosphoria or "Park City" formation crosses the Right Fork of Hobble Creek just below the Balsam forest camp in Sec 20, T8S R5E. The strike is north 25 degrees east and the beds dip steeply to the east. A section of the phosphatic shale member at this point is as follows:

Section of the phosphatic shale member of Phosphoria or "Park City" formation on Righ Fork Hobble Creek, just below Balsam forest camp, Sec 20 T8S R5E SLB&M. Strike N 25° E, Dip 78° E.
U.S.A.C. Locality no. 68

Designation of bed	Description	Thickness ft.	in.	P_2O_5 (Moisture-free basis)	$Ca_3(PO_4)_2$	Minable depth feet
	Gray and reddish gray limstone					
P	Covered. Presumably shale with limestone in part	120	0			
O	Black shale with 3 2-3″ beds of oolite. Large concretions common	19	0			
N	Black oolite		8	19.17	41.85	
M	Black shale with coquina bed at base	3	4			
L	Medium gray, medium bedded, nodular limestone with large round concretions common	11				
J	Black shale	9	6	11.87	25.91	

[9]Through the work of A. A. Baker on the Strawberry quadrangle.

Designation of bed	Description	Thickness ft.	in.	P_2O_5	$Ca_3(PO_4)_2$ (Moisture-free basis)	Minable depth feet
I	Ooolite	1	0	21.12	46.13	
H	Medium gray thin-bedded siliceous limestone, weathering with a slightly greenish cast and with nodulary bedding distinct	28	0			
G	Black oolite with 3″ seam of black shale	3	0	17.59	38.42	420
F	Medium gray to black shale	22	0			
E	Black siliceous limestone grading upward into medium gray to black shale	6	0	7.11	15.52	
D	Black and gray oolite (8″) and black shale	2	0	14.38	31.41	
C	Black limestone with concretionary structures	1	0			
B	Black shale	3	0	3.43	7.50	
A	Covered interval, presumably shale	44				
	Total	275				

It will be seen that there is very little oolite in this comparatively thick black shale member. Bed G is the only minable bed according to the standards previously described. It would be minable to a depth of 420 feet. No information is at hand on the extent of the outcrop north or south of the canyon bottom, and no probable tonnage estimate will be attempted.

Some seven miles south-southwest, in Sec 22, T8S R4E, on the peak to the right of the head of Little Diamond Creek, the sequence of beds in the phosphatic shale member is generally similar to that on Hobble Creek but the basal oolite bed has thickened to produce a rather high grade deposit, though one of comparatively limited extent. Following is the section measured at this locality:

Section of the phosphatic shale member of Phosphoria or "Park City" formation on top of peak 7,943, Sec 22 T8S R4E SLB&M Strawberry Quadrangle, U.S.A.C. Locality no. 70.

Designation of bed	Description	Thickness ft.	in.	P_2O_5	$Ca_3(PO_4)_2$ (Moisture-free basis)	Minable depth feet
	Covered					
	Ooolite		6			
	Shale		12			
	Ooolite		6			
	Shale with large round concretions	70				
A-2	Ooolite	5	0	25.91	56.57	2,500
A-1	Medium gray oolitic (?) limestone	2	8	8.42	18.40	
	Medium gray limestone.	Total	80			

The main bed of oolite at this locality is remarkably homogeneous and without intercalations of shale or sandstone. Near the south end of the outcrop it is 11 feet thick but it thins rapidly northward to 5 feet near the top of the peak, and less than 2 feet a short distance farther north. The estimated length of the outcrop is approximately one-fourth mile. On the basis of the three samples taken (L 70, L 70A-2, L 70B) at about equal distances along the exposure, the rock is very uniformly of about 55 percent grade (25 percent P_2O_5, 55 percent $Ca_3 (PO_4)_2$.

In each case, however, the whole thickness of oolitic rock was included in one sample, and perhaps richer beds of less thickness can be distinguished in the section. Near the south end of the exposure the beds dip only 20 degrees to the east, more gently than the mountain slope, and are therefore probably removed by erosion on the lower slopes of the peak. Near the north end the dip is 40 degrees, and the beds are perhaps preserved to the base of the peak.

A 5-foot bed of 55 percent rock is minable to a depth of 2,500 feet, according to the regulations that have governed the estimates in this bulletin. Assuming that the length of the outcrop is 1,300 feet, and ignoring the probable removal by erosion to the southeast, the deposit contains 1,300,000 long tons of 55 percent rock.

In addition to containing a substantial body of rock of good quality, this deposit is one of the most accessible in the state, and will perhaps be one of the first to receive attention when future demands cause the development of new properties in the western field.

Summary of Tonnage Estimates by Areas

Area	Quality of rock Percent $Ca_3(PO_4)_2$	Reserve long tons	Nature of estimate	Reference to footnotes
Uintah County				
Whiterocks River	44	7,430,000	S	
Dry Fork—Brush Creek	40	1,500,000,000	S	
Dry Fork—Brush Creek	(50)	(400,000,000)	S	
Split Mountain		none	SR	a
Duchesne County		none	S	
Daggett County	50	109,000,000	S	
Cache County		none	S	
Rich County				
Laketown	70	6,750,000	S	b
Crawford Mountains	70	90,000,000	S	b
Woodruff Creek		none	S	b
Weber County	?	?	U	c
Morgan County	?	?	U	d
Salt Lake County	60	9,000,000	P	e
Wasatch County				
North of Midway	60	5,300,000	SR	
Southwest of Midway	60	2,700,000	P	f
Summit County				

Area	Quality of rock Percent $Ca_3(PO_4)_2$	Reserve long tons	Nature of estimate	Reference to footnotes
Upper Weber River		none	S	
Park City District	?	?	U	g
Burnt Fork	50	10,000,000	P	
Utah County				
Right Fork Hobble Creek	40	very small	P	i
Little Diamond	55	1,300,000	P	j
Between Right Fork Hobble Creek and Round Valley	?	?	U	h

Nature of estimate
S=satisfactory.
SR=fairly satisfactory.
U=no basis for satisfactory estimate.
P=first approximation only.

Notes

a. Further study of Diamond Mountain-Island Park outcrop desirable.
b. Estimates by Gale and Richards, U. S. Geological Survey Bul. 430. 1910.
c. Further study of outcrops on Ogden River drainage necessary.
d. Careful measurements and check analysis of section in Weber Canyon necessary before estimate can be made.
e. Further study of Big Cottonwood outcrops necessary.
f. Further study southwest of Midway necessary.
g. No study yet made of phosphatic shale member in Park City district.
h. No information on possible outcrops in this area available.
i. Further information on linear extent of outcrop necessary.
j. Very preliminary estimate by author.

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Appendix A

Analyses of phosphate rock by U. S. Geological Survey
Washington, D. C., November 1937

No.	Insol. in aqua regia	P_2O_5	Equiv. $Ca_3(PO_4)_2$	F	$(Al,Fe)_2O_3$	As_2O_5	V_2O_5	Organic matter
L 27 A	45.12	13.33	29.11	1.6	4.96	.002	(b)	3.60
L 27 B	47.96	2.39	5.22	----	------	------	------	------
L 27 R	39.12	8.63	18.85	----	------	------	------	------
L 32	16.46	26.74	58.40	2.2	2.50	(a)	(b)	0.55
L 36	41.90	2.95	6.44	----	------	------	------	------

(a) Less than 0.001 percent.
(b) Less than 0.02 percent.
F, As_2O_5 and V_2O_5 determined by J. G. Fairchild.

Analyses of phosphate rock by Phosphate Section, Fertilizer Research Division, Bureau of Agricultural Chemistry and Engineering, U. S. Department of Agriculture, Washington, D. C.
November 1938

(The results are not calculated to the moisture-free basis)

U.S.A.C. Lacality no. and bed	Total P_2O_5	Fluorine	F / P_2O_5	Moisture at 105°C	CaO	Fe_2O_3	Al_2O_3	Material insoluble in 1:1 HCL
	percent	percent		percent	percent	percent	percent	percent
L41A	11.32	1.30	.1148	0.56	-------	------	------	-------
L41B	19.86	2.21	.1113	0.52	29.78	1.96	2.56	38.52
L41C	14.45	1.66	.1149	0.51	-------	------	------	-------
L41D	20.86	2.25	.1079	0.55	34.10	1.47	2.44	29.81
L41E	14.21	1.66	.1168	0.47	-------	------	------	-------
L59B-1	1.22	0.30	.2459	0.57	-------	------	------	-------
Lb9B-2	0.41	0.20	.4878	0.38	-------	------	------	-------
L59G-1	25.72	2.87	.1116	0.93	40.80	0.87	2.04	16.00
L59G-2	1.70	0.27	.1588	0.23	-------	------	------	-------
L59G-3	8.75	1.00	.1143	1.21	-------	------	------	-------
L59G-5	14.73	1.69	.1147	0.71	-------	------	------	-------
L59G-7	6.29	0.78	.1240	0.75	-------	------	------	-------
L59G-8	14.94	1.55	.1037	0.44	-------	------	------	-------
L59H	18.08	1.90	.1051	1.15	31.76	1.62	3.17	24.97
L61A	32.89	3.62	.1101	0.76	48.28	0.66	0.72	6.66
L61B	15.19	1.64	.1080	1.78	-------	------	------	-------
L61D	10.88	1.28	.1176	1.06	-------	------	------	-------
L61F	6.40	0.80	.1250	1.05	-------	------	------	-------
L61H	6.01	0.72	.1198	1.21	-------	------	------	-------
L61J	21.47	2.29	.1067	0.30	38.00	0.94	0.58	24.46
L61K	9.93	1.12	.1128	0.85	-------	------	------	-------
L62F	8.35	0.86	.1030	1.06	-------	------	------	-------
L62H	21.48	2.37	.1103	0.23	34.66	1.39	1.14	29.61
L62J	5.35	0.69	.1290	1.18	-------	------	------	-------
L64G	19.90	2.13	.1070	0.27	33.24	1.36	1.22	33.08
L64I	23.60	2.44	.1034	0.34	36.54	1.04	1.47	26.79
L68B	3.40	0.51	.1500	1.06	-------	------	------	-------
L68D	14.28	1.51	.1057	0.71	-------	------	------	-------
L68E	7.05	0.75	.1064	0.82	-------	------	------	-------
L68G	17.50	1.62	.0926	0.54	29.30	1.46	2.14	38.92
L68I	21.05	2.23	.1059	0.35	35.84	1.10	1.42	29.37
L68J	11.80	1.23	.1042	0.56	-------	------	------	-------
L68N	19.06	1.77	.0929	0.55	32.06	1.34	2.42	35.93
L70	25.50	3.04	.1192	0.40	40.12	0.90	0.96	20.50
L70A1	8.41	1.08	.1284	0.17	-------	------	------	-------
L70A2	25.82	3.09	.1197	0.33	45.62	1.04	0.89	11.24
L70B	24.19	2.86	.1182	0.31	43.34	0.74	1.13	14.44

AMERICAN SMELTING AND REFINING COMPANY
Garfield Plant

Garfield, Utah,
October 28th, 1937.

Mr. J. Stewart Williams,
Head, Dept. of Geology,
U. S. A. College,
Logan, Utah.

Dear Mr. Williams:

I believe this is the only sulphuric acid producing company in the State of Utah. The following figures are the tons produced by us for the years you asked in your letter of October 19th, 1937:

Year	Quantity tons	Concentration
1927	13,043	60.0 Be.
1928	15,250	" "
1929	13,840	" "
1930	15,230	" "
1931	10,250	" "
1932	17,996	" "
1933	10,550	" "
1934	9,335	" "
1935	11,045	" "
1936	15,805	" "
6 mo. 1937	9,440	" "
4 mo. 1937	7,604	100%

During the next five years we will produce about 180,000 tons of 100 percent sulphuric acid.

Yours very truly,

Garf. Chem. & Manufg. Corp.
P. H. Hutchinson, Supt.

P.H.H.:WF.