OIL SHALE IN WESTERN MONTANA, SOUTHEASTERN IDAHO, AND ADJACENT PARTS OF WYOMING AND UTAH.

By D. Dale Condit.

INTRODUCTION.

The presence of oil shale in the area near Dillon and Dell in southwestern Montana has been known for several years and was brought to the attention of the public in a recent publication by the United States Geological Survey.[1] It was noted with particular interest that although the shale is not phenomenally rich in oil as compared with the Eocene Green River shale of Utah and Colorado, some of the best of it is phosphatic.

A further investigation of the shales from western Montana southward to Utah has been made with two principal objects in view—first, a more detailed sampling of the phosphatic shales and associated phosphate beds in the Dillon-Dell area in the hope of demonstrating the presence of shales rich in oil and so intimately associated with beds of high-grade phosphate rock that the two products could be profitably worked in conjunction; second, a sampling of the thick black shales of the Phosphoria formation (Permian), which are persistent from the Dillon-Dell area southward through eastern Idaho into northern Utah, in the hope that some of the beds associated with the high-grade phosphate rock of those areas might prove to be rich in shale oil.

The results of the investigation may be briefly summarized as follows. In the Dillon-Dell area, where the Phosphoria oil shale is at its best, the richest beds of 3 feet or more in thickness yield 25 to 30 gallons of oil to the ton. The phosphate beds associated with the shale are thinner and contain considerably less phosphorus pentoxide than those mined near Montpelier, Idaho, and those known to occur in the Melrose and Garrison fields of Montana. Samples of the shales associated with the high-grade phosphate rock in the southeastern Idaho area yielded on distillation little more than a trace of oil.

In connection with the investigation of the phosphatic shales of the Phosphoria formation, attention was also given to bituminous shales of other formations that were convenient to the route of travel. Samples were taken at a number of localities of outcrop of the black shale in the Threeforks formation (Devonian) and Quadrant formation (Pennsylvanian and late Mississippian) of west-central Montana;

[1] Bowen, C. F., Phosphatic oil shales near Dell and Dillon, Beaverhead County, Mont.; U. S. Geol. Survey Bull. 661, pp. 315-320.

the Tertiary beds in the intermontane basins south of Dillon, Mont.; the Green River shale at Fossil, Wyo.; and Mississippian shales in northeastern Utah. No new localities that seem especially promising were discovered. The results are set forth in detail in the following pages.

The field work upon which this report is based was done in August and September, 1918. I was accompanied by Frank Reeves, assistant geologist, who rendered valuable aid. Thanks are due to the officials of the several phosphate mines visited and to the residents along the route traveled for courtesies too numerous to mention. Mr. J. H. Mackay, of Dillon, devoted several days to guiding us to the principal prospect pits in the Dillon-Dell area.

The chemical work for the determination of phosphorus pentoxide, nitrogen, and the composition of the ash was done in the laboratories of the United States Geological Survey by E. T. Erickson, R. C. Wells, and Benedict Salkover. The distillation tests for determination of the shale-oil yield were made by D. E. Winchester.

WEST-CENTRAL MONTANA.

GEOLOGIC SECTION.

The beds sampled for oil shale in west-central Montana lie in the Threeforks and Quadrant formations, whose positions and general character are shown in the following generalized geologic section, representative of the area between Whitehall and Logan:

Generalized section in west-central Montana.

	Feet.
Phosphoria formation (Permian):	
Chert and quartzite	0–50
Shale, sandy, with thin phosphate beds (position of oil-shale beds of Dillon field)	0–25
Quadrant formation (Pennsylvanian and late Mississippian):	
Sandstone, quartzitic	300
Impure limestone, shaly sandstone, and more or less black shale. Contains oil shale in western part of Meagher County.	0–60
Sandstone, impure limestone, and sandy shale, generally of brick-red color	75±
Madison limestone (Mississippian):	
Thick massive layers in upper part and thin platy layers toward bottom	1,000
Threeforks formation (Devonian):	
Shale, black	0–3
Sandstone	20–30
Shale, black to dark gray	5–15
Shale, sandy, greenish, interbedded with sandstone and fossiliferous limestone	30±
Limestone, gray	75±

Northward from Lombard, on Missouri River, the Phosphoria formation disappears and the underlying Quadrant formation thins, owing to an unconformity. On the North Fork of Musselshell River, in the Little Belt Mountains, the overlying Ellis formation of Jurassic age, rests upon limestones of the lower part of the Quadrant, the thick quartzitic sandstone member constituting the upper half of the Quadrant formation being absent. The shales in the lower portion are persistently carbonaceous, but most samples yielded on distillation no more than a trace of oil. The principal exception is in the western part of Meagher County, where the beds locally yield as much as 30 gallons of oil to the ton. This oil-shale facies of the Quâdrant formation is not persistent, being most conspicuous in the vicinity of Adell, Meagher County, and disappearing toward the south. Bituminous shales are present in the Little Belt Mountains, the Bridger Range, and farther south, but no samples yielded on distillation more than a trace of oil.

The black shales of the Threeforks formation were sampled in the Bridger Range and at a number of points to the west, near the head of Missouri River. None of the samples yielded more than a few gallons of oil to the ton.

SAMPLES FROM THE QUADRANT FORMATION.

The richest samples of oil shale from the Quadrant formation come from Meagher County, Mont., about 9 miles south of Adell post office, where shales identified by G. H. Girty on paleontologic evidence were sampled in several prospects by E. T. Hancock in 1917. Here and at various points as far east as the Bridger Range the black shales have been prospected for coal, and some of the pits dug years ago are still open for sampling. The Quadrant shales were investigated and sampled at several other localities, but the amount of oil obtained on distillation of the samples was insignificant. Descriptions of localities of the Quadrant shale visited are given below.

Samples **377–382.** About 9 miles south of Adell post office, Meagher County, Mont.; investigated by E. T. Hancock. Samples 377, 378, and 379 came from a landslide exposure at the head of Freeman Creek, on the F. C. Campbell ranch, near the line between secs. 28 and 33, T. 14 N., R. 2 E.

Sample **377** came from a thin bed near the base of the exposure. It was difficult to tell just how much of this material there is, for the beds are not very well exposed, but where the sample was taken the shale is about 2 feet thick. Possibly there are other beds of the same kind within the formation. Strike about N. 40° E.; dip about 50° SW. Results of test: Oil, 4 gallons to the ton; nitrogen, 0.17 per cent, equal to 16 pounds of ammonium sulphate to the ton.[1]

Sample **378** came from some fossiliferous beds about 25 feet below the top of the exposure. These beds are underlain by about 3 feet of fine-grained yellowish-brown sandstone, the joint planes of which are coated with a black substance resembling tar or asphalt. The highly fossiliferous beds are not much more than a foot in thickness and grade upward into the dark-brown shale represented in sample 379. Results of test: Oil, 2 gallons to the ton; nitrogen, 0.06 per cent, equal to 5.6 pounds of ammonium sulphate to the ton.

Sample **379** came from a bed of shale about 5 or 6 feet thick overlain by a hard bed of fine-grained sandstone. Near the middle of the shale bed are calcareous lenses,

[1] Determinations of nitrogen in all the samples listed in this report were made by E. T. Erickson.

containing shells and coatings of tar or asphalt. Results of test: Oil, 4 gallons to the ton; nitrogen, 0.22 per cent, equal to 20.7 pounds of ammonium sulphate to the ton.

Samples **380** and **381** came from the E. ½ sec. 32, T. 14 N., R. 2 E., near the head of the central branch of the north fork of Freeman Creek. At this point there is a landslide exposing the shale. The beds are so closely folded here that it is difficult to tell how much shale is present, but it is believed that at least 30 feet of shale is exposed. Sample 381 was taken near the top of the belt and sample 380 near the middle. Wherever seen the shale seems to be petroliferous, in that it gives off a very distinct odor of petroleum when fragments are rubbed together. The beds appear to have a general anticlinal structure, the axis passing in a general northwesterly direction at this locality, but the structure is complicated by minor folds. Without knowing the details of the structure, I suspect that samples 380 and 381 probably came from beds higher in the section than samples 377 and 379. Results of tests: Sample 380, oil, 7 gallons to the ton; nitrogen, 0.18 per cent, equal to 16.9 pounds of ammonium sulphate to the ton. Sample 381, oil, 19 gallons to the ton; nitrogen, 0.36 per cent, equal to 33.9 pounds of ammonium sulphate to the ton.

Sample **382** came from a prospect pit on the west fork of Crooked Creek, in sec. 36, T. 14 N., R. 1 E. From its relation to the overlying belt of white limestone, the shale is regarded as a part of the same belt as that at the head of Freeman Creek (samples 377–381). The prospect appears to be at the crest of an anticline, whose axis trends nearly due east. The beds dip steeply away from the opening on both the north and south sides. Above the shale on each side of the prospect is reddish-brown sandstone, overlain by gray limestone. The total thickness of the shale could not be determined, but from all appearances it must be between 30 and 70 feet. The sample represents a thickness of 3 feet exposed in the prospect. Except in the prospect pit the shale is not well exposed at this point. Results of test: Oil, 8 gallons to the ton; nitrogen, 0.39 per cent, equal to 36.7 pounds of ammonium sulphate to the ton.

Sample **383** was taken on the North Fork of Musselshell River about 4 miles east of Delpine, in T. 9 N., R. 11 E., from black fossiliferous shale in the lower part of the Quadrant formation. The bed sampled is 7 feet thick and is exposed along an irrigation ditch on the north side of the valley. The beds are overturned and dip steeply westward. Result of distillation: Oil, none.

Sample **384** was taken on the west side of Ross Peak, in the Bridger Range, in T. 2 N., R. 6 E., from a bed of black shale 2½ feet thick, probably of Quadrant age, lying between quartzitic sandstone layers. Result of distillation: Oil, none.

Samples **385** and **386** came from a point half a mile northwest of Lombard station, along the Northern Pacific Railway, in the Missouri River valley, in T. 4 N., R. 2 E. Here the lower part of the Quadrant formation contains much black shale and shaly limestone in which prospect pits have been dug for coal. Some of the rock when freshly broken emits an oil odor. Neither of the samples on distillation gave any oil. About half a mile northwest of the Quadrant exposures is an abandoned coal mine in the Kootenai formation.

SAMPLES FROM THE THREEFORKS AND OTHER FORMATIONS.

The Threeforks formation is exposed at several places in west-central Montana. Samples from this and other formations were obtained as described below. Some other exposures were visited but not sampled.

Samples **387** and **388** were obtained on the south side of Jefferson River at the east end of the canyon, about 4 miles east of Jefferson station, where nearly vertical and considerably sheared black shales of the Threeforks formation contain a layer of coal several inches thick along which a shaft was sunk to a depth of more than 30 feet many years ago. Sample 387 was taken from the weathered coal near the outcrop; sample 388 represents hard pieces of coal picked from the dump. Results of test: Sample 387, no oil; sample 388, oil, 10 gallons to the ton; nitrogen, 0.43 per cent, equal to 40.5 pounds of ammonium sulphate to the ton.

Sample **389** was taken in the bottom of a small ravine 4 miles N. 20° W. of Logan, in T. 2 N., R. 2 E., at the bottom of a prospect pit, 20 feet beneath the surface, in soft dark-brown shale 3 feet thick dipping 40° N. This shale, which is of Threeforks age, is separated from the Madison limestone by 30 feet of shaly sandstone. Result of distillation: Oil, none.

Samples **390** and **391** were collected from the Threeforks formation at the west side of Ross Peak, in the Bridger Range, in T. 2 N., R. 6 E., at an elevation of about 7,700 feet. The section at this locality is as follows:

Geologic section on west side of Ross Peak, Mont.

	Ft.	in.
Madison limestone, in thin platy layers.		
Threeforks formation:		
Shale, black, tough; emits oil odor when freshly broken (sample 390)	2	6
Sandstone, shaly, calcareous and fossiliferous in lower portion.	30	
Shale, black; emits oil odor when freshly broken (sample 391).	10	
Shale, sandy, unmeasured.		

Results of tests: Sample 390, oil, 1 gallon to the ton. Sample 391, oil, 2 gallons to the ton; nitrogen, 0.22 per cent, equal to 20.6 pounds of ammonium sulphate to the ton.

Sample **392** represents a coal bed of Cretaceous age in the railroad cut at Chestnut station, 7 miles east of Bozeman.[1] In the same vicinity are abandoned coal mines. The thickness of the beds sampled is about 10 feet, including coal and black shale and excluding a layer of gray shale 1½ feet thick near the base. Results of test: Oil, 12 gallons to the ton; nitrogen, 0.22 per cent, equal to 20.6 pounds of ammonium sulphate to the ton.

On the north side of the valley of Sixteenmile Creek, along the Chicago, Milwaukee & St. Paul Railway about 2 miles east of Lombard, there are complete exposures of the upper half of the Threeforks formation, consisting of greenish to dark-gray shaly sandstone and sandy shale with no beds of promising appearance as oil shale.

In a ravine on the north side of Gallatin River opposite Logan village complete exposures of the Threeforks formation show the following beds, none of which warrants sampling for oil shale:

Section near Logan, Mont.

	Ft.	in.
Madison limestone, in thin layers, unmeasured.		
Threeforks formation:		
Sandstone, dark brown	1	6
Shale, black, sandy	2	
Sandstone, grayish brown, in even layers	25	
Clay shale, dark gray, fragile	11	
Sandstone, shaly, fossiliferous	17	
Limestone, dark gray, fossiliferous	6	
Shale, greenish, grading down into sandstone	30	
	92+	

[1] For a description of the Chestnut district see Calvert, W. R., The Livingston and Trail Creek coal fields, Park, Gallatin, and Sweetgrass counties, Mont.: U. S. Geol. Survey Bull. 471, pp. 384–405, 1912.

On the North Fork of Musselshell River near Delpine, in T. 10 N., R. 11 E., a search was made along the outcrop of the Threeforks formation, but no black shale was found.

DILLON-DELL AREA, SOUTHWESTERN MONTANA.

GENERAL GEOLOGY.

PHOSPHORIA FORMATION.

In the Dillon-Dell area the formation of chief interest as a bearer of oil shale is the Phosphoria. The same formation contains phosphate beds which persist northward to the Garrison field, near Helena, and southward through southeastern Idaho into Utah, where the rocks are included in the Park City formation. Although the phosphate beds in the Dillon-Dell area are fairly rich and possibly of minable thickness, they do not compare favorably with the deposits now mined in southeastern Idaho.

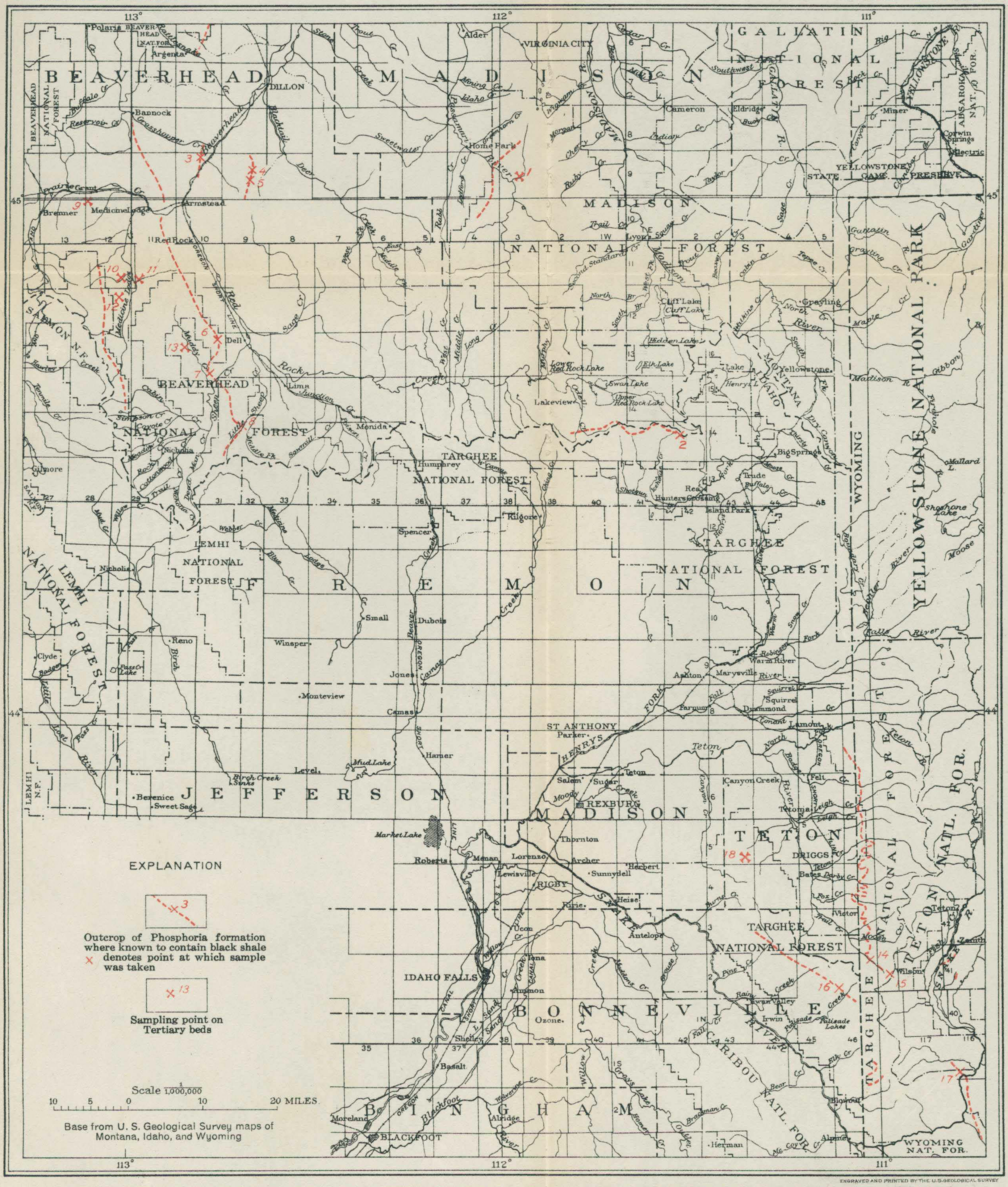
From Dillon eastward into Yellowstone Park and the west-central Montana area the Phosphoria beds change in character and the phosphatic black shale member disappears. The accompanying map (Pl. III) shows approximately the extent of the Phosphoria outcrop in the Dillon-Dell area and also at points to the east and southeast where it is known to contain black shale. Throughout the region the Phosphoria shales crop out along the principal mountain fronts, and are in general steeply dipping and extensively faulted.[1] The formation has never been completely mapped in the Dillon-Dell area, and Plate III therefore indicates only the extent of the outcrop as ascertained during the course of the present work. Detailed mapping in the future will disclose further outcrops, especially in the southern portion of the area, along the Idaho State line.

In the detailed descriptions of beds sampled are given measurements of the phosphatic shale beds and associated phosphate rock, and it is only necessary to give here a general outline of the stratigraphy showing the associated formations.

Generalized section of Phosphoria and associated formations in Dillon-Dell area, Mont.

	Feet.
Triassic beds:	
Limestone and sandstone, shaly, generally brownish on weathered surface, containing characteristic fossils including *Lingula*	350
Shale, sandy, yellowish brown; weathers readily to light-yellowish soil	100
Phosphoria formation:	
Quartzite, cherty, grading down into bedded chert alternating with quartzite layers	125–150
Shales, black, containing shale oil, more or less phosphatic, interbedded with thin layers of gray and shaly brown oolitic phosphate	50–75

[1] For a description of the Phosphoria and Quadrant formations in the Threeforks-Yellowstone Park region see U. S. Geol. Survey Prof. Paper 120, pp. 111-121, 1918.



MAP SHOWING DILLON-DELL AREA, IN SOUTHWESTERN MONTANA, AND ADJACENT PARTS OF IDAHO AND WYOMING

	Feet.
Quadrant formation:	
Sandstone and impure limestone	75- 125
Quartzitic sandstone, equivalent to middle portion of Quadrant quartzite of Yellowstone Park section; estimated thickness	700
Limestone and sandstone with shaly beds, reddish in lower portion and with one or more thin beds of black clay shale (nonpetroliferous); estimated thickness	200
Madison limestone (gray, massive beds forming rugged escarpment along principal mountain fronts)	800-1200
Threeforks formation (sandy and more or less carbonaceous; locally a graphitic schist where sheared and affected by intrusive rocks).	

TERTIARY FORMATIONS.

Between the principal mountain ranges are broad valleys with rolling topography made up of gently dipping strata of Tertiary age, which contain oil shale. These strata are of moderate extent, and were deposited in the basins which they now occupy. The rocks

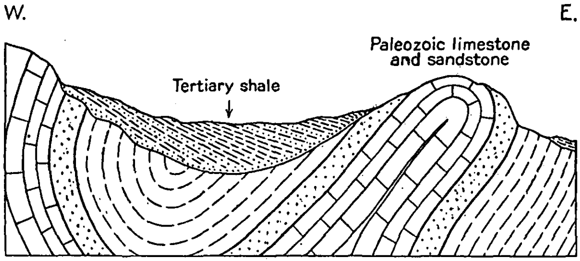


FIGURE 2.—Geologic cross section of a Tertiary basin and surrounding mountains of Paleozoic rocks.

consist of sandy shale, sandstone, impure lignitic coal, brown oil shales, and a considerable amount of shaly to conglomeratic material of volcanic origin. At the base is a conglomerate made up of limestone, shale, sandstone, granite, and quartz pebbles derived from the adjacent mountain slopes.

Figure 2 is a hypothetical cross section of an intermontane basin such as that of Muddy Creek west of Dell, showing the Tertiary beds of the basin and their probable relation to the older rocks of the surrounding mountains.

DRILLING FOR OIL.

To one with even a superficial knowledge of geologic conditions in Beaverhead County, Mont., the improbability of discovering commercial deposits of oil is evident. Nevertheless drilling has been carried on almost continuously in this area for several years, and when the field was visited in 1918 there were at least five companies selling stock. The possibility of discovering small amounts of oil in the Tertiary lake-basin rocks is not denied, and it is even possible, though not probable, that small amounts may be found in the Paleozoic strata. The geologic evidence is, however, almost wholly unfavorable.

The presence of oil shale has been assumed by many persons to be proof of itself that oil can be obtained by drilling into the shale-bearing rocks, an assumption which is without truth. This belief has doubtless led to the persistent efforts to find an oil pool near Dillon. It can be stated positively that the presence of shale which will yield oil on distillation has but little bearing on the probability of the occurrence of free petroleum in commercial quantities in the same rocks.

The geologic structure of the area presents an irrefutable argument as to the improbability of the occurrence of pools of oil in this part of Montana. The region has been subjected to intense folding and faulting, and the beds are so shattered and jointed that any inclosed oil or gas would have found its way to the surface long ago. The structural deformation has been accompanied by intrusions of igneous rock with accompanying mineralization that has formed the ore deposits for which the region is best known.

OIL SHALE OF PHOSPHORIA FORMATION.

PROPERTIES.

The Phosphoria shale is black or deep brown, gives a brownish streak, and ranges in texture from smooth to oolitic. All the shale is more or less phosphatic, but the richest portion is that containing the most oolites. The oolites resemble fish roe, are grayish to black, and in composition are probably in large part phosphate of lime with less amounts of alumina and iron. The phosphatic character is evident in the weathered rock, the surface of which assumes a peculiar bluish-white color. Some of the layers show impressions and casts of fossils that are believed to indicate marine origin. On fracture surfaces the shale commonly shows what appear to be slipping planes, which have a glistening, oily, or waxy-looking luster, with a slight iridescence in places. When rubbed a freshly broken surface emits an unmistakable odor of petroleum, and when placed in a fire the shale will burn to a gray ash. Some of the joint planes show thin films of a black pitchlike substance. Pyrite and other sulphides are present only as minute particles in some of the samples, and on weathering films of gypsum appear along joint and bedding planes. The oil, nitrogen, and phosphorus contents of the individual shale samples are shown in the following pages. A few samples were subjected to more detailed chemical analysis, and the results appear on page 36.

SECTIONS AND SAMPLES.

The detailed measurements of the beds as sampled at the several localities are tabulated on pages 24–26. Supplementary notes are given herewith. Attention is called to the illustrative sections of the shale in figure 3 (p. 35). The locality numbers refer to points designated on the map (Pl. III).

Locality 1 (samples **524** and **524A**): Warm Spring Creek, tributary of Ruby River, sec. 15, T. 9 S., R. 3 W. At this point the Phosphoria beds are exposed along the crest of a small anticline that is cut across by Warm Spring Creek. The oil shale here is only 1½ feet thick, and none appears in outcrops along the neighboring mountain front to the east.

Locality 2 (sample **517**): Centennial Mountains, Idaho-Montana State line, sec. 16, T. 14 N., R. 42 E., Idaho. The exposures here are at an elevation of about 9,000 feet and dip gently southward. The total thickness of the carbonaceous shale is only 4 feet.

Locality 3 (samples **393–396**): Daly Spur, Oregon Short Line Railroad, sec. 2 (?), T. 9 S., R. 10 W., about 13 miles southwest of Dillon. Considerable prospecting was done here for coal by Marcus Daly 23 years ago. The tunnel, which is still open, cuts across the beds, which strike N. 35° E. and dip 30° NW. The outcrop can readily be traced for about half a mile. To the north and south a distance of about a mile are igneous rocks. The samples compare favorably with those collected about 6 miles to the east in Smallhorn Canyon.

Locality 4 (samples **403–404**): Smallhorn Canyon, secs. 14 and 23, T. 9 S., R. 9 W. The samples were collected on the property of the Dillon Oil Co., where a retort apparatus has been installed that is said to handle 50 tons of shale a day. It is planned to haul the product in trucks to the railroad. The principal phosphate bed, which is 5½ feet thick, contains a little oil and, although somewhat shaly, shows on analysis 19.85 per cent of P_2O_5. The strike of the beds is approximately N. 15° E. and the dip 30°–40° NW. The outcrop extends southward with no faulting to be seen for a mile or so but is probably interrupted by a fault a short distance north of the edge of sec. 14. The richest shale sample (No. 403), representing a thickness of 5½ feet from the tunnel in sec. 14, gives on distillation 21 gallons of oil to the ton. A sample representing a thickness of 5 feet, from the same tunnel, collected by Bowen,[1] yielded 24 gallons to the ton. A small sample selected to include the richest appearing material on the dump gave 30 gallons.

Locality 5 (samples **397–402**): Shallow trench on a hilltop 1 mile south of the tunnel mentioned above (locality 4). Here the shale is weathered, and the results are therefore not representative. The beds, which are completely exposed, show a thickness of nearly 50 feet with the principal phosphate bed a little below the middle.

Locality 6 (samples **405–405A**): Dry Canyon, sec. 12, T. 13 S., R. 10 W., about 3¾ miles west of Dell station. The beds along the mountain front consist of Triassic limestone and sandstone overturned and dipping under the Phosphoria formation and Quadrant quartzite, which form the higher part of the mountain. The folding, together with more or less faulting, has sheared the black shale so that it is greatly slickensided and resembles coal and as a result has been extensively prospected. All the tunnels are caved in, and the samples were collected in a trench recently dug in the location of an oil-shale claim. The rock, although comparatively fresh, can hardly be regarded as representative. The richest sample, from 8 feet of shale, gives 17 gallons to the ton. No exposure of the phosphate rock was found.

Locality 7 (samples **405–408**): Big Sheep Creek canyon, T. 13 S., R. 10 W. Years ago a tunnel was dug here for coal on the north side of the valley and about 1,200 feet above it. The beds are for the most part well exposed, and the rock is comparatively

[1] Bowen, C. F., U. S. Geol. Survey Bull. 661, p. 318, 1918.

unweathered. The structure is complicated, there being one or more large faults in the neighborhood and minor faults that involve the rocks in the tunnel. The beds dip steeply northward and may be overturned. The principal phosphate bed is exposed at the mouth of the tunnel, but its thickness is exaggerated by shearing. The samples were taken in the tunnel. A single hand specimen selected to represent the richest portion of sample 406 gave on distillation 26 gallons of oil to the ton.

Locality 8 (samples **409–411**): South Fork of Little Sheep Creek, sec. 4, T. 15 S., R. 9 W. The beds dip 18° W. The samples were collected in a shallow prospect pit dug for coal. Only the lower portion of the shale is represented. It is improbable that the phosphate bed 1½ feet thick is the principal one, although no other was discovered owing to poor exposures. The shale is considerably weathered and would no doubt give a richer yield if sampled where fresh.

Sections and yield of samples from Phosphoria formation in Dillon-Dell area, Mont.

[Chemical analyses by E. T. Erickson, R. C. Wells, and Benedict Salkover.]

No. on map.	Locality.	Character.	Thickness. Ft.	Thickness. in.	Sample No.	Oil (gallons per ton).	Phosphorus pentoxide (P_2O_5) (per cent).	Nitrogen. Per cent in shale.	Nitrogen. Theoretical equivalent in ammonium sulphate (pounds per ton).
1	Warm Spring Creek, sec. 15, T. 9 S., R. 3 W.	Phosphate rock, black, oolitic.	1	8	524				
		Clay		5					
		Shale, black	1	8	524A	3	....	....	a 7.85
		Shale, sandy, brown							
2	Idaho-Montana State line, 4 miles southwest of Mount Sautelle, sec. 16, T. 14 N., R. 42 E., Idaho.	Cherty shale	8	0					
		Shale, black, bony	4	0	517	6	....	....	a 2.09
		Phosphate rock, gray, oolitic.		8					
		Sandstone and shale.							
3	Daly Spur, Oregon Short Line R. R., sec. 2 (?), T. 9 S., R. 10 W.; old "coal" prospect tunnel.	Shale, cherty, phosphatic.	9+						
		Shale, dark brown, bony.	4	8	393	14	3.26	0.50	47.1
		Phosphate, dark, oolitic, interbedded with oolitic shale.	4	7	394	....	19.41	.20	18.9
		Shale, black, bony	14	0	395	17	1.72	.77	72.6
		Shale, brownish gray	1	0					
		Shale, dark brown, bony.	10	0	396	13			
		Lower strata not exposed.							
4	Smallhorn Canyon, sec. 14, T. 9 S., R. 9 W.; Dillon Oil Co. property, old "coal" prospect tunnel.	Roof of bony black shale.							
		Shale, hard, bony, black.	5	6	403	21	....	.63	59.3
		Argillite, soft, phosphatic.		5	404	17			
		Shale, bony		7					
		Argillite, soft, phosphatic.		7					
		Shale, bony	1	8					
		Phosphate rock, gray, oolitic.		3					
		Shale, dark		9					
		Phosphate rock, gray, oolitic, shaly.	1	4					
		Shale, dark		7					
		Phosphate rock, shaly, oolitic.		9					
		Shale, black, soft	1	2					
		Phosphate rock, gray, oolitic.		4					
		Shale, dark with thin oolitic bands to floor of mine.	4	2					

a Ammonium sulphate determined from fixed gas and does not represent the total nitrogen content of the shale.

Sections and yield of samples from Phosphoria formation in Dillon-Dell area, Mont.—Continued.

No. on map.	Locality.	Character.	Thickness.	Sample No.	Oil (gallons per ton).	Phosphorus pentoxide (P_2O_5) (per cent).	Nitrogen. Per cent in shale.	Nitrogen. Theoretical equivalent in ammonium sulphate (pounds per ton).
			Ft. in.					
5	Divide at head of Smallhorn Canyon, sec. 23, T. 9 S., R. 9 W.; prospect trench.	Quartzitic sandstone and chert.	50+					
		Shale, dark, bony in lower part.	10 0	402	Trace.			
		Shale, black, with three layers of phosphate rock each 4 inches thick.	5 0	401	4	19.20	0.27	25.4
		Shale, black, tough....	11 0	400	15	1.68	.53	49.9
		Phosphate rock with three black shaly layers.	5 6	399	2	19.85	.19	17.1
		Shale, brownish gray, phosphatic.	10 0	398	Trace.			
		Shale, brownish gray, slightly phosphatic.	6 0	397	Trace.			
		Sandstone.						
6	Dry Canyon near Dell, sec. 12, T. 13 S., R. 10 W.; prospect trench.	Shale, black, top not exposed.	1+					
		Phosphate rock, oolitic.	1 0					
		Shale, black, soft, greatly slickensided.	8 0	405	17	5.94	.73	68.9
		Shale, brownish black.	10 0	405A	2	....	.14	13.2
		Limestone............	8					
		Shale, sandy, brown..	6+					
7	Big Sheep Creek Canyon, T. 13 S., R. 10 W., near old coal prospect tunnel.	Shale..................	2+					
		Phosphate rock, black, oolitic.	2 5					
		Shale, black, much slickensided.[a]	2 11					
		Sandstone, dark brown.[a]	4	408	......	9.34	.22	20.7
		Phosphate rock, black, oolitic.	4+					
	Section in tunnel at locality 7.	Phosphate rock, oolitic (tunnel mouth).	2+					
		Clay shale [a]...........	3	407	......	24.10	.20	18.9
		Phosphate rock, oolitic.	1 3					
		Clay, hard, gritty [a]....	1 6					
		Shale, dark brown [a]...	5 0					
		Clay shale, gray [a].....	1 0					
		Shale, black...........	8					
		Phosphate rock [a]......	1 0					
		Shale, black..........	1 2					
		Clay, gray, gritty [a]....	1 6					
		Phosphate rock, gray [a]	9					
		Shale, black..........	1 2					
		Clay, hard, gritty [a]....	1 3					
		Shale, black..........	1 0	406	13	5.58	.68	63.9
		Clay shale, gritty [a]....	3 2					
		Shale, black..........	1 8					
		Phosphate rock........	5					
		Clay, hard, gritty.....	9					
		Phosphate rock, oolitic, black.	1 1					
		Shale, black..........	1 3					
		Clay, brown, gritty....	2 2					
		Shale, black (back end of tunnel).	6					

[a] Not included in sample.

Sections and yield of samples from Phosphoria formation in Dillon-Dell area, Mont.—Continued.

No. on map.	Locality.	Character.	Thickness.	Sample No.	Oil (gallons per ton).	Phosphorus pentoxide (P_2O_5) (per cent).	Nitrogen. Per cent in shale.	Nitrogen. Theoretical equivalent in ammonium sulphate (pounds per ton).
			Ft. in.					
8	Little Sheep Creek, sec. 4, T. 15 S., R. 9 W.; prospect pit dug for coal.	Shale, bony, black, with limestone concretions.	14 0	409	16	5.57	0.68	63.9
		Clay shale, hard, gritty.	2 6					
		Shale, black, bony....	4 0	410	a 12	a 10.28	a 66	a 62.2
		Phosphate rock, gray, oolitic.	1 6	411	....	13.7		
		Shale, hard, black.....	2 6	410	a 12	a 10.28	a 66	a 62.2
		Rocks not exposed....	8 0					
		Limestone, unmeasured.						

a Sample 410 included material from two beds.

TERTIARY SHALE.

EXTENT AND CHARACTER.

The Tertiary shale beds, as stated on a preceding page, are of small extent, occupying narrow, elongated basins between the mountains. The rocks are diverse in character, and individual layers can not be traced for any considerable distance. In fact, the alternating beds of coarse and fine sandstone, sandy shale, and lignite are just such as one would expect to be deposited in such basins.

The principal belt of these lake beds extends from a point near Bannack, in Grasshopper Valley, south to Horse Prairie, and thence up Medicine Lodge Creek, the length of the belt being about 28 miles. Although the beds have not been traced continuously for the entire distance, coal prospect pits are found at numerous places along the belt. Many of these pits reveal either lignite or brown shale which on distillation yields more or less oil.

The Muddy Creek basin is smaller, being at most only 3 miles wide and about 12 miles long. A well drilled for oil near the center is said to have reached a depth of 1,000 feet without encountering hard rocks, and it seems probable that the bottom of the lake beds was not reached. The supposed relation of the Tertiary beds of Muddy Creek to the underlying older formations is shown by the cross section, in figure 3 (p. 35).

The oil shale as exposed in the Muddy Creek basin occurs about the middle of the Tertiary beds. This shale is light brown when fresh and weathers to a cocoa color or nearly white. In the process of weathering the shale breaks up into thin, flexible laminae or flakes resembling manila paper. The richer shale is characterized by a low specific gravity. It contains an abundance of vegetable remains and some well-preserved leaves, chiefly of *Sequoia*. This shale, like that from the Phosphoria, will burn when exposed to a strong flame but does not give an odor of petroleum on freshly broken surfaces. On distillation, richer looking layers as much as 5 feet thick yield about 24 gallons of oil to the ton. Thinner beds occur in other parts of the section, some of which contain thin streaks of lignite. In fact, except for its lighter color, the shale has very much the aspect of an ordinary carbonaceous shale, such as is commonly associated with coal beds. Many of the samples collected along Medicine Lodge Creek are actually impure lignite, and the richest sample collected in the area (yielding 36 gallons of oil to the ton) comes from such a bed.

At most of the collecting localities described in the following table the samples were taken in old coal prospects, few of which were extended far enough under cover to give unweathered samples. All the samples of lignitic coal, however, may be regarded as fairly representative. No prospecting has been done in the brown shale beds, and the samples were taken from weathered outcrops where the shale has disintegrated to flexible papery layers. It is believed that the same shale well below the surface would prove to be much richer. The outcrop of the brown oil shale is easily recognized, because these beds do not favor the growth of vegetation and as seen from a short distance appear whiter than the associated rocks.

SECTIONS AND SAMPLES.

Sections and yield of samples from Tertiary shale in Dillon-Dell area, Mont.

No. on map.	Locality.	Character.	Thickness.	Sample No.	Oil (gallons per ton).	Nitrogen. Per cent in shale.	Nitrogen. Theoretical equivalent in ammonium sulphate (pounds per ton).
			Ft. in.				
9	Near Grant, sec. 6, T. 10 S., R. 12 W.	Shale, lignitic, bony	1 10	412			
		Sandstone [a]	2		3	0.98	92.4
		Shale, lignitic, bony	1 10	412			
10	Swartz Creek, sec. 26, T. 11 S., R. 12 W.	Shale, sandy	6				
		Shale, bony, brown	3 6	413	1	.74	69.8
		Clay shale.					
11	Medicine Lodge Creek, sec. 30, T. 11 S., R. 11 W.	Coal, lignitic, bony	3	414	1		
		Clay shale, sandy	40				
		Coal, bony, lignitic	1 3				
12	Keystone Creek, sec. 2, T. 12 S., R 12 W.; coal prospect.	Coal	1 3				
		Clay [a]	3				
		Coal	10	415	36	1.02	96.1
		Clay, sandy [a]	3 8				
		Coal, bony	2 1				
		Clay	4				
	Keystone Creek, sec. 2, T. 12 S., R. 12 W., about 500 feet northeast of coal prospect at locality 12.	Shale, sepia-brown, weathers to flexible paper layers.	3	416	11	.56	52.8
	Keystone Creek, sec. 3, T. 12 S., R. 12 W.; coal prospect near locality 12.	Coal, lignitic, bony	1 4				
		Clay [a]	3				
		Coal, lignitic, bony	6				
		Clay [a]	6	417	4	.41	38.6
		Coal, shaly	2 1				
		Clay [a]	1				
		Coal, shaly	2 8				
		Clay.					
13	Muddy Creek basin, T. 13 S., R. 10 W. (unsurveyed, probably sec. 17); outcrop sampled.	Sandstone.					
		Shale, brown and black, with thin clay bands.	10	418	0		
		Beds not well exposed.	60				
		Shale, brown	3 4	419	4	.13	12.2
		Shale, sepia-brown	2 1	420	24	.20	18.9
		Clay shale	1 3				
		Shale, black	8				
		Shale, sandy [a]	2				
		Shale, black	8	421	4	.35	32.9
		Shale, brown [a]	3 4				
		Shale, black	5				

[a] Not included in samples.

SOUTHEASTERN IDAHO AND ADJACENT PARTS OF WYOMING AND UTAH.

GEOLOGIC SECTION.

From the Idaho-Montana State line southeastward for a distance of 75 miles there are no outcrops of the Phosphoria formation. The rocks reappear in the Teton and Bighole mountains along and near the Idaho-Wyoming State line and thence southward are to be seen in most of the mountains all the way to Ogden, Utah. They crop out along the Salt River Range in Wyoming and also encircle the Uinta Mountains of northeastern Utah. Throughout the region brown or black shale is associated with the phosphate rock in beds whose thickness ranges from 50 to more than 200 feet. Wherever these black shales crop out they were prospected by the early settlers for coal. More recently new openings have been made at a few points for the mining of phosphate rock. Unweathered samples of the shales were obtained in the mines and prospects at numerous places that can be regarded as representative of the area. The negative results from the distillation of the samples collected from these areas, therefore, prove that the black shale of the Phosphoria formation in southeastern Idaho and adjacent parts of Wyoming and Utah is not oil shale, there being but few samples that yield as much as 1 gallon of oil to the ton.

In all the above-mentioned mountain ranges the Phosphoria formation probably includes beds of phosphate rock that is sufficiently low in iron and alumina to meet commercial requirements. Chemical analyses of the phosphate rock from MacDougall Pass, in the Salt River Range, Wyo., and from Palisade Creek, in T. 2 N., R. 45 E., Idaho, are given in the table on page 36.[1] Farther south the phosphate rock is mined in a commercial way at a number of points, and its character is well known. Most of the outcrop has been described in reports of the United States Geological Survey.

Detailed measurements of the Phosphoria beds show considerable variations from place to place. The following section published in a report by Richards and Mansfield [2] illustrates well the general character of the formation as exposed in Georgetown Canyon, Idaho. Although carbonaceous shales make up a large part of the section at this point no samples on distillation yielded more than a trace of oil.

[1] For a description of phosphate in the Salt River Range see Mansfield, G. R., U. S. Geol. Survey Bull. 620, pp. 331-349, 1916; and for a description of the adjacent area to the north in both Wyoming and Idaho see Schultz, A. R., U. S. Geol. Survey Bull. 680, 1918.

[2] Richards, R. W., and Mansfield, G. R., Preliminary report on a portion of the Idaho phosphate reserve: U. S. Geol. Survey Bull. 470, pp. 387-388, 1911.

Section of Phosphoria formation in Georgetown Canyon, Idaho.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
		Per cent.	*Per cent.*	*Ft.*	*in.*
144-A	Shale, calcareous, or muddy limestone, brown, weathering into irregular chip fragments; effervesces vigorously	3.5	7.7	25	6
144-B	Phosphate rock, oolitic, weathering brown or gray; effervesces slightly; lower 1½ inches somewhat cherty	35.8	78.4		6
144-C	Shale, hard, brown, calcareous at the top; effervesces vigorously	Trace.	....	1	
144-D	Phosphate rock, coarsely oolitic, gray; effervesces vigorously	37.6	82.3	2	11
144-E	Shale, brownish, earthy, containing 6 inches of phosphate; effervesces considerably	10.0	21.9	1	
144-F	Phosphate rock, including— *Ft. in.*				
	(a) Phosphate rock, oolitic, hard, gray, calcareous.... 7				
	(b) Phosphate rock, medium, gray, oolitic.... 6	21.9	48.0	1	5
	(c) Shale, phosphatic, light brown.... 4				
	(Sample shows considerable effervescence.)				
144-G	Phosphate rock, including—				
	(a) Phosphate rock, coarsely oolitic, gray, brittle.... 1 2				
	(b) Phosphate rock, finely oolitic, brownish gray.... 4				
	(c) Phosphate rock, coarsely oolitic, dark gray.... 2				
	(d) Phosphate rock, finely oolitic, brownish gray.... 4	33.3	72.9	4	2
	(e) Phosphate rock, coarsely oolitic, gray.... 7				
	(f) Phosphate rock, finely oolitic, thin bedded.... 3				
	(g) Phosphate rock, coarsely oolitic, gray.... 1 4				
	(Sample effervesces slightly.)				
144-H	Phosphate rock, including—				
	(a) Phosphate rock, medium to finely oolitic, brownish gray.... 7				
	(b) Shale, phosphatic, brownish, somewhat oolitic.... 10	29.3	64.1	1	10
	(c) Phosphate rock, coarsely oolitic.... 2				
	(d) Phosphate rock, shaly, brown.... 3				
144-I	Phosphate rock, including—				
	(a) Phosphate rock, coarsely oolitic, brownish-black streaks.... 1 1				
	(b) Phosphate rock, shale, brown, thin bedded.... 5	34.7	76.0	4	10
	(c) Phosphate rock, coarsely oolitic, crumbly.... 4				
	(d) Phosphate rock, medium to coarsely oolitic.... 3				
	(Sample effervesces considerably.)				
144-K	Shale, brownish to black, earthy composition, thin bedded, with a few limestone lenses; effervesces slightly	24.2	53.0	8	9
	Limestone, dark, compact, fetid	....	....	1	9
144-L	Shale, brownish to black, earthy; effervesces slightly	11.7	25.6	12	
144-M	Shale, including—				
	(a) Shale, brownish black, earthy.... 7				
	(b) Concealed, not included in sample (probably same as a and c).... 4 7	15.1	33.1	17	
	(c) Shale, brownish black, earthy.... 5 5				
144-N	Shale, black, earthy; effervesces slightly	19.9	43.6	12	
144-O	1. Shale, brownish black, earthy.... 4				
	2. Limestone, single stratum (not sampled).... 2	21.2	46.4	12	
	3. Shale, brownish black, earthy.... 4				
	4. Limestone, single stratum (not sampled).... 2				
144-P	Shale, black and dark brown, calcareous, earthy; effervesces considerably	25.8	56.5	6	
144-Q	Shale, black and dark brown, calcareous earthy; effervesces considerably	24.6	53.9	12	
144-R	Limestone, shaly, brownish gray; effervesces vigorously	17.8	39.0	4	10
	Limestone, single stratum	....	....		11
	Limestone ("cap lime"), fine, dark gray, fossiliferous	....	....	2	3
144-S	Phosphate rock, main bed prospected, coarse to medium, oolitic, gray; contains two or three minor streaks of shaly material; effervesces slightly	36.8	80.6	6	4
144-T	Shale, brown, earthy; effervesces slightly	3.7	8.1		9
	Limestone, massive, underlying the phosphatic series. Thickness not determined.				
				139	9

SAMPLES FROM PHOSPHORIA FORMATION.

ALONG IDAHO–WYOMING STATE LINE.

Sections and yield of samples from Phosphoria formation along and near Idaho-Wyoming State line south of Yellowstone Park.

No. on map.	Locality.	Section.	Thickness.	Sample No.	Oil (gallons per ton).	Nitrogen.	
						Per cent in shale.	Theoretical equivalent in ammonium sulphate (pounds per ton).
			Ft. in.				
14	North of Victor-Jackson road, 2 miles east of State line in Wyoming, T. 41 N., R. 119 W.; prospect tunnel.	Shale, cherty	5+				
		Shale, brown, phosphatic	5 6	422	0		
		Shale and chert	1 1				
		Phosphatic rock, soft, oolitic	2 0	423	0		
		Shale and chert	3 7				
		Shale, black, phosphatic	2 10	424	0		
		Phosphate rock, hard, black	1 0				
		Chert	3+				
15	Black shale outcrop along road on west side of Teton Pass, Wyo., in T. 41 N., R. 19 W.	Shale, black	5 0	425	0		
16	Palisade Creek, T. 2 N., R. 45 E., Idaho.	Black shale, limestone, and phosphate, all greatly sheared; thickness apparently over 100 feet; samples represent lithologic variations.	150 (?)	426	3	0.70	65.8
				427	3	.76	71.7
				428	3	.85	80.1
				429	3	.41	38.6
17	Count's ranch, upper end of Snake River canyon, below mouth of Hoback River, T. 39 N., R. 116 W., Wyo.	Chert	20+				
		Shale, phosphate, and sandy beds, all black; shaly layers included in sample.	27 3	430	Trace.		
		Shale and phosphate interbedded with limestone; shaly layers sampled.	21 1	431	Trace.		

SOUTHEASTERN IDAHO.

Sample **432.** Black shales of Phosphoria formation over phosphate bed, Georgetown Canyon, Idaho; sec. 25, T. 10 S., R. 44 E. Material selected after visiting several prospect tunnels and trenches. Result of distillation: Oil, trace.

Samples **433-441.** Phosphatic black shales of Phosphoria formation about 40 feet thick, associated with phosphate bed in Waterloo mine, near Montpelier, Idaho; sec. 6, T. 13 S., R. 45 E. Result of distillation: Trace of oil in only one sample; others barren.

Samples **442-447.** Phosphatic black shales of Phosphoria formation about 18 feet thick, associated with phosphate beds at Paris mine of Western Phosphate Co., near Paris, Idaho; sec. 8, T. 14 S., R. 43 E. Result of distillation: No oil.

Samples **448-449.** Bloomington Canyon, Idaho; NW. ¼ sec. 21, T. 14 S., R. 43 E. Black phosphatic shales of Phosphoria formation. Thickness of beds sampled 75 feet. Result of distillation: Trace of oil in four samples.

SOUTHWESTERN WYOMING.

Sample **450–454.** Near McDougall Pass, Salt River Range, Wyo., T. 33 N., R. 117 W., unsurveyed sec. 16. Phosphatic black shales of Phosphoria lying between two principal phosphatic beds. Thickness of beds sampled about 17 feet. Result of distillation: Oil, none. The chemical composition of the phosphate beds is shown in the table on page 36.

Sample **455.** McDougall Pass, Salt River Range, Wyo., T. 33 N., R. 117 W., unsurveyed sec. 9. Black shale 10 feet thick at top of Phosphoria formation. Result of distillation: Oil, none.

Sample **456.** Raymond Canyon, Wyo., NE. ¼ sec. 6, T. 26 N., R. 120 W. Black phosphatic shales from prospect tunnel in Phosphoria formation. Result of distillation: Oil, none.

Samples **457–458.** Phosphate mine in T. 24 N., R. 119 W., 1 mile northeast of Cokeville, Wyo., Black shale associated with phosphate bed of Phosphoria formation. Thickness of beds sampled about 4 feet. Result of distillation: Oil, none.

NORTHEASTERN UTAH.

In the Crawford Mountains east of Randolph, Utah, several phosphate mines and prospects afford excellent exposures of the black shaly beds accompanying the phosphate rock, but none of the shale of the Phosphoria formation appeared sufficiently promising to warrant testing for oil.

At the Robinson ranch, in Weber Canyon, 1 mile below Devils Slide, Utah, in T. 4 N., R. 3 E., practically complete exposures of beds representing the Phosphoria formation were found to contain almost no black shale.[1]

MISCELLANEOUS SAMPLES FROM OTHER FORMATIONS.

Samples **459–461.** Taken in coal field on Brown Bear Creek, about 12 miles west of Driggs, Idaho, in the SE. ¼ sec. 25, T. 5 N., R. 43 E.; locality 18 on map, by Frank Reeves. Age of beds Cretaceous.

Section in tunnel of Teton Valley Coal Co. west of Driggs, Idaho.

	Thickness.		Sample No.	Oil (gallons per ton).	Nitrogen.	
					Per cent in shale.	Theoretical equivalent in ammonium sulphate (pounds per ton).
	Ft.	*in.*				
"Brown Bear" coal bed: Coal	3	5	461	20	0.59	55.5
"Brown Bear" coal bed: Clay[a]		5				
"Brown Bear" coal bed: Coal	1	3				
"Brown Bear" coal bed: Bone		3				
Shale	30	0				
Coal		10				
Shale, black	2	0	459	2	.07	6.5
Shale	20	0				
Coal		8				
Shale, black	1	4	460	4	.25	23.5

[a] Not included in sample.

[1] For stratigraphic section see U. S. Geol. Survey Bull. 430, pp. 545–546, 1910.

Sample **462.** Taken in Boise opening of "Boise" coal bed at north edge of sec. 36, T. 5 N., R. 43 E., Idaho, by Frank Reeves. Sample represents coal bed 3 feet 5 inches thick. Cretaceous age. Results of test: Oil, 38 gallons to the ton; nitrogen, 0.77 per cent, equal to 72.4 pounds of ammonium sulphate to the ton.

Sample **463.** Black shale from bank of Bear River about 4 miles south of Soda Springs, Idaho, in sec. 29, T. 9 S., R. 42 E. Bed over 4 feet thick; lies nearly flat and extends under basalt flow. Quaternary age (?). Results of test: Oil, 20 gallons to the ton; nitrogen, 0.93 per cent, equal to 87.7 pounds of ammonium sulphate to the ton.

Samples **464–465.** Half a mile east of phosphate mine, near Cokeville, Wyo., in T. 24 N., R. 119 W. Impure coal and bony shale in Bear River formation. Sample 464 from bed 3 feet thick; sample 465 from prospect dump. Results of test: Sample 464, oil, 1 gallon to the ton; sample 465, oil, 1 gallon to the ton.

Sample **466.** Impure bony coal in Bear River formation at abandoned slope mine near Sage station, Wyo., in T. 21 N., R. 119 W. Sample taken from dump. Result of test: Oil, 11 gallons to the ton; nitrogen, 0.65 per cent, equal to 61.2 pounds of ammonium sulphate to the ton.

Samples **467–472.** About 2 miles southwest of Fossil, Wyo., on Oregon Short Line Railroad, in T. 21 N., R. 117 W. Green River formation.

Section near Fossil, Wyo.

	Thickness.		Sample No.	Oil (gallons per ton).	Nitrogen.	
					Per cent in shale.	Theoretical equivalent in ammonium sulphate (pounds per ton).
Shale forming hilltop.	*Ft.*	*in.*				
Shale; weathers purplish gray; curly laminae	2	0				
Shale, brown, calcareous [a]	7	0	467	37	0.35	33.0
Shale, brown, weathering purplish		10				
Shale, sandy to calcareous	7	6				
Shale, brown, slightly calcareous and sandy near base	7	1	468	6	.03	2.8
Sandstone, orange color		2				
Shale, fissile, dark gray	5	0	469	4	None.	
Shale, brown, weathering purplish gray	3	0	470	7	.09	8.4
Shale, fissile, papery layers where weathered	5	0	471			
Sandy limonite		6				
Shale, sandy and calcareous	2	4				
Clay	2	0				
Shale, tough, gray, with fine brown laminae	3	10				
Limestone, argillaceous, gray	4	2				
Shale, brown and gray laminae, with thin limestone layers	3	6				
Shale, brown with gray laminae	3	4				
Clay [a]		7				
Shale, brown, laminated, calcareous, rich in fossil fish	1	0	472	15	.14	12.9
Shale, tough, brown, laminated	4	2				
Lower strata not exposed.						

[a] Not included in sample.

Sample **473.** Abandoned coal mine at Almy, about 4 miles northwest of Evanston, Wyo., in T. 16 N., R. 120 W. Sample includes 5 feet of impure coal and black shale above main coal bed. Cretaceous age. Results of test: Oil, 5 gallons to the ton, nitrogen, 0.51 per cent, equal to 47.8 pounds of ammonium sulphate to the ton.

Sample **474.** Laketown Canyon, 1 mile east of Laketown, Utah, in the NW. ¼ sec. 32, T. 13 N., R. 6 E.[1] Prospect pit in phosphatic brown shale 3 feet thick lying in Mississippian limestone. Result of distillation: Oil, trace.

Sample **475.** "The Oaks" resort, Ogden Canyon, Utah, in T. 6 N., R. 1 E. Black phosphatic calcareous shale in Mississippian limestone outcropping along public road. Bed 3 feet thick sampled. Result of distillation: No oil.

PRACTICAL CONSIDERATIONS.

The commercial extraction of oil from shale in America is still in the experimental stage. Although dozens of companies have been organized to operate in Utah and Colorado, only half a dozen have begun to install machinery, and none of the machinery has been sufficiently tested to prove its efficiency. Meanwhile the United States Bureau of Mines, at its stations at Salt Lake and Denver, has conducted experiments and cooperated in many ways in the effort to determine the best methods of distilling shale. The investigations are still in progress, but it will possibly be several years before the technologic problems involved in the production of shale oil are thoroughly understood and perhaps still longer before the Green River shale can be worked for oil on a large commercial scale.

PHOSPHATIC SHALES.

A comparison of the phosphatic oil shale of the Dillon-Dell region, in southwestern Montana, with the rich Green River oil shales of western Colorado, northeastern Utah, and southwestern Wyoming gives scant encouragement to the hope that the shale of the Dillon-Dell area can be successfully exploited for its oil yield. Its richest beds of workable thickness yield little more than 20 gallons of oil to the ton, or less than half the yield of much of the Green River shale. The expense of mining the phosphatic shale must necessarily be a handicap. Nearly everywhere the beds dip steeply, and their attitude will permit only small operations by stripping and open cuts; ultimately underground work will be required. The faults and joints in the shale beds, by interrupting their continuity, add further difficulties and will lead to expensive timbering.

The thickness of the phosphatic shale beds and their content of oil and phosphoric acid at the several localities where samples were taken is shown in figure 3. Daly spur and Smallhorn Canyon (localities 3, 4, and 5) furnished the most complete exposures within easy access to the railroad and are therefore of chief interest.

At Daly spur the principal shale bed is 14 feet thick and yielded on distillation 17 gallons of oil to the ton. Above it is a phosphate bed 4 feet 7 inches thick with two thin shale bands, the whole containing 10.7 per cent of phosphorus pentoxide. Above the phosphate bed is 4½ feet of shale yielding 14 gallons of oil to the ton.

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[1] For map of area see U. S. Geol. Survey Bull. 430, pl. 12, 1910.

On the divide at the head of Smallhorn Canyon, where the complete section is exposed in a prospect trench, the principal shale bed, which is 15 feet thick, yielded 15 gallons of oil to the ton, and a sample selected from the richest portion, 5½ feet thick, gave 21 gallons. Beneath this shale bed is a layer of phosphate 5½ feet thick which on analysis gave 19.85 per cent of phosphorus pentoxide. Select specimens from the tunnel in Smallhorn Canyon yielded 30 gallons, and a sample from a bed 5 feet thick taken by Bowen yielded 24 gallons. The ash residue remaining after distillation of the several

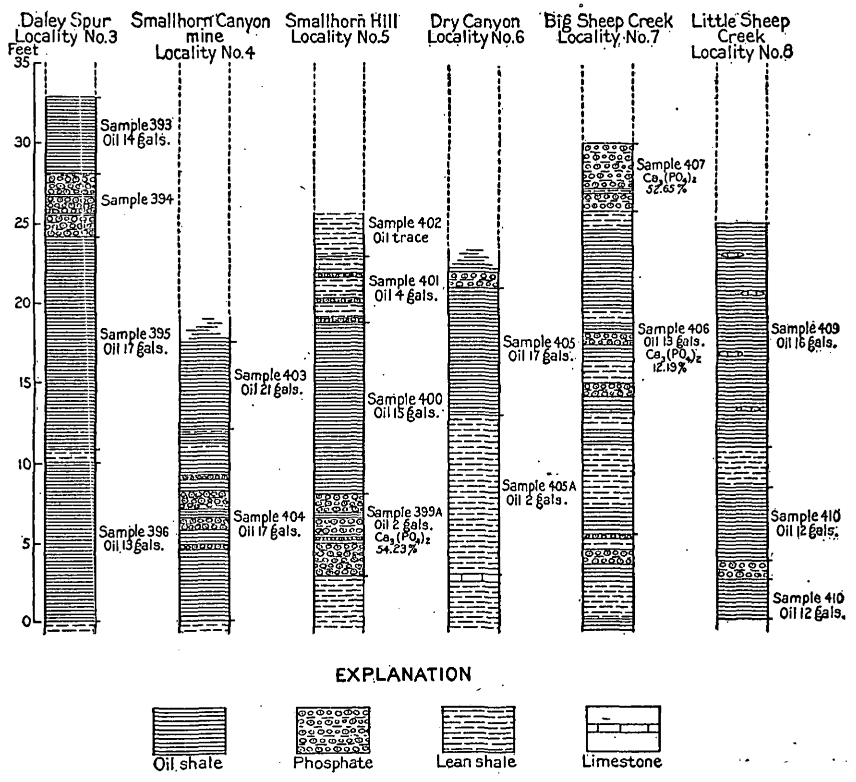

FIGURE 3.—Sections of oil shale and associated phosphate beds in Dillon-Dell area, Mont.

oil-shale samples was found to contain 4 to 11 per cent of phosphorus pentoxide.

The examination of the phosphatic oil shales, as already stated, did not bear out the hope that the phosphate beds associated with the oil shale might be of immediate importance for use in the manufacture of commercial fertilizer. The phosphate rock occurs in beds of fair thickness and yielding a fair percentage of phosphorus pentoxide, but it is suspected that further chemical analysis may show that the rock at some localities is high in iron and alumina, an objectionable feature for the reasons stated below.

The usual process of treating the raw phosphate rock in the manufacture of superphosphates, as practiced in America, consists in mixing the finely powdered rock with sulphuric acid and then drying. It is said that in factory practice the product of the acid process sometimes remains moist and gummy, so that it is difficult to handle, and that it tends to eat the cloth bags in which it is placed for shipment. Iron and alumina are supposed to be the cause of this undesirable property in the manufactured product, as their sulphates show a tendency to take up moisture in a damp atmosphere. The combined percentage of the two radicles computed in the oxide form should, according to the manufacturers, not be more than 5 per cent.

Another process of treatment practiced in Italy and elsewhere in the Mediterranean region consists in heating the finely ground phosphate rock to 600° or 700° C. with a mixture of calcium, magnesium, and sodium carbonates. The calcined mass is then moistened and diluted with earth or sand until the phosphoric acid content is about 20 per cent. The product, a "tetraphosphate," is said to be equal to the ordinary superphosphate in fertilizing power and is also cheaper to produce. The beneficial results from the use of the "tetraphosphate" as manufactured in Italy have been questioned by certain chemists. If on further investigation the merits of the product are established the process could readily be carried on in conjunction with the distillation of the oil shales in the Dillon-Dell area.

The following table of chemical analyses shows the composition of the phosphate rock at two localities (Nos. 399A and 411) in the Dillon-Dell area. It will be noted that in several samples the content of phosphorus pentoxide is more than 25 per cent, equivalent to about 55 per cent of tricalcium phosphate. In the samples from the Salt River Range in western Wyoming and from Palisade Creek, Idaho, the analyses of which are inserted for comparison, the percentage of phosphorus pentoxide is considerably greater. In all the samples the alumina and iron content is within the limits required for use in commercial fertilizer.

Analyses of phosphatic shales and phosphate rock from Montana, Idaho, and Wyoming.

Sample No.	Insoluble in acid.	$(AlFe)_2O_3$.	CaO.	MgO.	P_2O_5.	Equivalent in $Ca_3(PO_4)_2$.	CO_2.
399A	29.8	4.7	33.4	0.3	25.2	55.0	0.7
411	8.5	2.3	45.5	2.9	13.7	29.9	22.6
524	17.8	2.9	38.3	.3	28.8	62.9	1.8
429	39.3	2.7	25.9	1.2	15.8	34.5	3.7
450	16.2	2.6	39.3	.9	26.5	57.9	4.8
454	11.7	1.7	44.7	.2	30.5	66.6	3.1

399A. Smallhorn Canyon, 12 miles south of Dillon, Mont.
411. Little Sheep Creek, sec. 4, T. 15 S., R. 9 W., Mont.
524. Warm Spring Creek, sec. 15, T. 9 S., R. 3 W., Mont.
428. Palisade Creek, T. 2 N., R. 45 E., Idaho.
450 and 454. McDougall Pass, Salt River Range, T. 33 N., R. 117 W., Wyo.

The ash remaining after distillation of most of the black phosphatic shales in closed crucibles was black, but when heated in an open vessel to a bright-red heat it lost its black carbonaceous material and turned grayish yellow. The ash from most samples on being tested qualitatively gave reactions for potash.

TERTIARY SHALES.

There is little to be said in favor of the Tertiary shales in the Muddy Creek basin, Medicine Lodge Valley, and other parts of Beaverhead County, Mont. The samples that yielded the largest amounts of oil came from impure earthy lignite beds that were formerly mined or prospected for coal. The richest sample was taken in a prospect tunnel at locality 12 (see Pl. III), on Keystone Creek, a branch of Medicine Lodge Creek, It represents a bed about 8 feet thick divided into two benches by a layer of sandy clay about 3½ feet thick. Distillation of a sample of the coal excluding the numerous clay bands gave 36 gallons of oil to the ton and an amount of nitrogen equivalent to 96.1 pounds of ammonium sulphate to the ton. This yield is similar to that of the average sample of lignite from other parts of the Rocky Mountains. Possibly the time may come when the low-grade lignite beds of Montana will be mined and distilled for their gas and oil content, but it will be many years before deposits of inferior thickness such as these, remote from large cities and railroad lines, will be utilized. An investigation of the methods of possible utilization of American lignites has recently been made by the United States Bureau of Mines.[1]

TECHNOLOGY OF SHALE OIL.

The following data concerning the preparation of oil shale for distillation, the machinery used for distillation, and plant costs, are taken from papers by D. E. Winchester[2] or from a paper by the Bureau of Mines:[3]

PREPARING OIL SHALE FOR DISTILLATION.

After oil shale is mined and brought down to the plants for the manufacture of shale oil, it will need to be crushed before it is subjected to distillation, and the fineness to which it is crushed will depend on the method of treatment to which it is to be submitted. The existing machinery for crushing rock may need to be remodeled to handle efficiently and economically this tough, almost rubbery shale, which is inclined to pack rather than to crush, but this is a minor mechanical detail which can easily be adjusted.

[1] Babcock, E. J., Economic methods of utilizing western lignites: Bur. Mines Bull. 89, 1915.

[2] Oil shale and its development in the United States: Railroad Red Book, vol. 36, No. 1, pp. 21-25, published by Denver & Rio Grande Railroad, 1919.

[3] Some concise information on oil shale—its possibilities and needs: Railroad Red Book, vol. 36, No. 2, pp. 217-218, published by Denver & Rio Grande Railroad, 1919.

DISTILLING MACHINERY.

At the present time there are no commercial shale operations in this country, although there is a great amount of activity, particularly in the States of Colorado, Utah, and Nevada, where there are large and easily accessible deposits of rich oil shale and where geographic and transportation conditions are such as to favor the production of oil in these States.

The manufacture of the shale oil and by-products from oil shale requires heat, and many types of apparatus are being designed and tried. In July, 1918, there were at least 20 processes for the extraction of oil from shale. It is to be expected that some, probably most, are doomed to be discarded, not because they will fail to produce the oil, but because they either will not produce the best oil or will not produce any oil at a cost sufficiently low to allow the sale of the products at a profit. The experiments now being carried on should, within a short time, prove the value of many of the ideas that have been advanced, and if the successes and failures of one experimenter are made available for the use of others who are attempting to produce the same results, some efficient shale distilling plants may be in operation in the oil-shale fields within the next few years. The history and experience of the oil-shale companies of Scotland, where there is an oil-shale industry of 60 years' standing, is available for the guidance of the American experimenter, and this information should be fully utilized. It appears that little change has been made in the Scottish oil-shale retorts for a decade, but prior to that time certain principles of distillation were tried and found unsatisfactory, while others were proved to be more efficient and were adopted for use with the Scottish oil shale. Inasmuch as there are certain differences in character and richness between the Scottish oil shales and those to be retorted in the United States, it stands to reason that the processes of handling the American oil shale will probably be considerably different from those used in Scotland.

In order to obtain the maximum amount of ammonia in the shale it is necessary to heat the shale to incandescence and then to introduce steam. The steam dissociates in the presence of fixed carbon which has been formed in the process of heating, liberating free hydrogen which combines with the nitrogen, forming ammonia. In this country, where our most favorable shale deposits are very much richer in oil but contain less nitrogen than the Scottish shales, it may prove advantageous to neglect more or less the ammonia production and to increase the capacity of a plant by shortening the time and temperature of heating.

Theoretically, all the products now obtained from both crude petroleum and from coal tar are possible from shale oils. The

Scottish operators have never made many different products from their shale oil, marketing it as motor spirit, naphtha, burning oil, gas and fuel oil, lubricating oil, and paraffin wax. This is probably largely due to the fact that they have well-established markets for these products and for this reason find it more profitable to confine themselves to them. It must be realized that no little skill and experience will be necessary in making many different marketable products from shale oil.

COSTS.

At the present time there is no exact information regarding the cost of mining oil shale, delivering it to the retorts, crushing and retorting it, or of refining the shale oil after it is extracted. The cost of mining oil shale will probably be as great as that of the mining of coal in the same general region under similar conditions, if not greater, and underground mining will therefore cost at least $1 a ton.

Reliable general estimates of the cost of shale-oil operations can not be made, as most of the costs are dependent largely on local and individual conditions. Some of the shale deposits are such that the shale can be mined with a steam shovel. This, of course, is a much cheaper method of mining than the stope and pillar or other methods where the shale must be brought from underground. Thirty-five cents per ton is considered by some as a reasonable figure for the average steam-shovel mining and $1.15 per ton as an average figure for underground mining.

The delivery of oil shale to the retorts will in most places necessitate the installation of tramway systems. Crushers of special types will be needed to reduce the oil shale to proper fineness for retorting. The original cost as well as the cost of operation of crushers will depend largely on the degree of pulverization demanded by the retorts in which the shale is to be distilled, but in any case the cost will not be small.

The estimates of cost of installing the various retorting systems range from $300 to $2,500 per ton of shale to be handled daily. These figures represent preliminary estimates, and in the present state of the industry they are the best available. Accurate figures relative to the costs of operating the retorting machinery will not be available until plants of commercial size are put into operation. The cost, in Scotland, of a commercialized Pumpherston plant complete with retorts, condensers, and ammonium-sulphate house was estimated by Mr. Henderson [1] at pre-war prices (before 1909) to be at least $350 per ton of shale to be treated daily.

[1] Ells, R. W., Joint report on bituminous or oil shales of New Brunswick and Nova Scotia, p. 29, Canada Dept. Mines, 1909.

After the oil shale has been mined, prepared, and retorted, the product is crude shale oil, which, like crude oil-well petroleum, must be refined before its value will be fully realized. A refining plant must therefore be available, and tank cars or trucks will be needed for transporting the crude shale oil to the refinery, as there seems to be ample indication that it will be impractical to convey shale oil by pipe line because of the fact that the oil may be thick or almost solid, at least in cold weather. The shale oil manufactured in Scotland is too thick for piping at ordinary temperatures.

It is evident, therefore, that the installation of a commercial oil-shale plant means the expenditure of no less than half a million dollars and probably much more, and such a plant must be operated with the greatest efficiency and at a minimum cost in order to produce shale oil and other oil-shale products at a profit. The production of shale oil in paying quantities will require plants capable of treating great amounts, perhaps 1,000 tons of shale a day. If it is assumed that the average oil shale treated will yield approximately 1 barrel of shale oil per ton of shale, it will be necessary to install and operate a great number of such plants to enable the shale-oil industry to replace in any great degree the vanishing supply of petroleum in this country.

Finally, it must be realized that the production of oil from oil shale is in fact a large, low-grade manufacturing project rather than the application of an intricate chemical process, and that for oil-shale operations to be commercially successful a large amount of capital and both engineering and technical ability will be necessary.