REPORT OF INVESTIGATIONS

MINING PROGRAM, BUREAU OF MINES

OIL-SHALE PROJECT, RIFLE, COLO.

BY

E. D. Gardner
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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

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1/ The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 4269."

2/ Mining engineer, Bureau of Mines, and Chief, Oil Shale Mining Division.
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INTRODUCTION

The American petroleum industry is supplying the present domestic demand for liquid fuels. Known reserves of petroleum in the ground, however, are limited, and the cost per barrel of finding new oil pools is increasing. Any deficiencies of domestic production in the near future doubtlessly could be made up by imports. Dependence upon foreign oil for part of our industrial requirements is not necessarily cause for alarm, but in time of war an adequate, dependable, domestic source of liquid fuels is vital to the defense of the country. As a national defense measure, and to insure a future continuous oil supply for our economic machine, it would appear logical to take steps now to develop methods for producing petroleum substitutes within our own borders. This undoubtedly was in the mind of Congress when it passed the Synthetic Liquid Fuels Act (58 stat. 190; 30 U. S. C. Sup. Secs. 321-325), approved April 5, 1944. The title of the Law reads:

An Act authorizing the construction and operation of demonstration plants to produce synthetic liquid fuels from coal, oil shales, agricultural and forestry products, and other substances, in order to aid the prosecution of the war, to conserve and increase the oil resources of the Nation, and for other purposes.

Congress authorized $30,000,000 for a 5-year program and directed the Bureau of Mines to carry it out. The part of the program pertaining to oil shale is being conducted on Naval Oil-Shale Reserves Nos. 1 and 3 (fig. 1) at Anvil Points, near Rifle, Colo.

The development and construction phases of the oil-shale program largely have been completed (June 30, 1947); the authorized program has 2 more years to run. Roads have been built; a camp has been established; electrical, water, and sanitation facilities have been provided; offices, shops, laboratories, and other service buildings have been erected; a pilot retort plant has been built and is in operation, and a pilot refinery will soon be under construction. A mine has been developed to supply the retort with oil shale, which will be mined selectively from eight horizons of a 70-foot oil shale measure. A second set of workings is being developed, in which the most efficient practices will be selected, the best mining method will be ascertained, and the costs of mining the oil shale on a commercial scale will be established. Mining costs will be demonstrated on a one-unit scale; a commercial operation would comprise multiple similar units.
Figure 1. - Naval oil shale reserves Nos. 1 and 3, Garfield County, Colo.  
1 = plant site; 2 = camp site; 3 = mine site; A, B, C, and D = core holes. (Scale is in miles.)
Progress has been made in ascertaining the best mining method and in selecting the most efficient mining practices for producing the oil shale at the lowest practicable cost. The mining problems involved are being attacked both from the theoretical and practical standpoints. The product to be mined has a relatively low value, a fact that must be kept in mind constantly. Plans call for an uninterrupted flow of broken oil shale from the face in the mine, through crushers, through the retorts, and thence to the disposal dump. The combined aim of those in charge of mining and those in charge of retorting is to demonstrate that the shale oil can be produced at a cost per barrel corresponding to the current quotation for crude petroleum — or at least very close to it. It is hoped that work will lead to the establishment of an oil-shale industry in the United States.

The oil-shale mine site is about 5-1/2 miles by a mountain road from the plant site, which, in turn, is 2 miles from U. S. Highway 6 and 10 miles from Rifle, Colo. The highway parallels the Colorado River, the Denver & Rio Grande Western Railroad, and a 66,000-volt public utility power line.

This paper is in the nature of a progress report, up to June 30, 1947, of the work of the Oil Shale-Mining Division of the Office of Synthetic Liquid Fuels, Bureau of Mines.

ACKNOWLEDGMENTS

The evolvement of plans for exploiting the oil shale, the development of the underground workings, and the construction of the surface mining plant have been a cooperative effort of members of the Oil Shale-Mining Division. Tell Ertl assisted in the selection of the mine site and has been the engineer-in-charge of mining operations at Rifle since the beginning of the project. Carl Belser supervised a diamond-drilling program and is the mine engineer. Charles A. Kunke, as mine superintendent, is in direct charge of the underground work. Emery M. Sippelle is in charge of surface construction and surface operations, including transportation. Ernest E. Burgh and John R. Wagner have spent full time on mining investigations and mining research. Frederick D. Wright worked on theoretical aspects of the mining problem in the laboratories of Columbia University and now directs mining research at Rifle. Leonard Obert of College Park, Md., has cooperated with the Oil Shale-Mining Division on problems connected with strength of rocks; Herbert L. Teichman has made the detail seismic observations in the mine. Samples of the roof stone were tested at the Bureau of Mines station at Pittsburgh, Pa., by Dr. Irving Hartmann, for effects of temperature and humidity changes. Surface areas of drill cuttings also were determined at that station.

Boyd Guthrie, as supervising engineer, has had administrative charge of the whole oil-shale project.

Professor Philip B. Bucky of Columbia University, New York City, Charles N. Bell, mine operator, Ouray, Colo., and Lewis E. Young, consulting engineer of Pittsburgh, Pa., are consulting engineers to the Bureau of Mines and review general plans of operation. Bucky also supervised the work done by the Bureau of Mines at Columbia University.
The federal Geological Survey has furnished the Bureau of Mines with
topographic and geologic maps of Naval Oil-Shale Reserves Nos. 1 and 3.
D. C. Duncan and N. M. Denson, of the Survey, logged the cores of diamond-
drill holes put down by the Bureau of Mines on Naval Oil-Shale Reserve No. 1.
Core samples were assayed at the Bureau of Mines station at Laramie, Wyo.

Cre-dressing tests of the oil shale have been made at the Bureau of Mines
Metallurgical Experiment Station at Salt Lake City under the direction of S.
R. Zimmerley.

HISTORY

Oil-shale deposits have been exploited in various countries throughout
the world, but generally with governmental aid. The oil-shale industry of
Scotland perhaps is the oldest and best-known; the largest was conducted in
Manchuria by the Japanese during World War II as a source of liquid fuels for
military uses.

Considerable interest began to be shown in western oil shales in 1916;
the peak of activities was in 1923. The Catlin operation, near Elko, Nev.,
perhaps was the nearest approach in this country to an oil-shale enterprise
on a commercial scale. Over 100 companies were formed, ostensibly for
exploiting the oil shale; a large share of them, however, proved to be stock
promotions only, which gave the embryo industry a black eye. The Bureau of
Mines operated an experimental oil-shale retort plant near Rifle, Colo., from
September 1926 to June 1927 and again from April 1928 to July 1929, after
which the plant was dismantled. By this time the East Texas oil field had been dis-
covered, and the country lost interest in substitute liquid fuels.

OIL-SHALE DEPOSITS

Oil shale is known to occur in about 20 States of the Union and in Alaska.
The most extensive deposits are in the Green River formation of Colorado, Utah,
and Wyoming; in the Chillicothe formation of Ohio; and in the Albany formation
in Indiana. The oil-shale deposits in the Green River formation are consid-
erably richer and thicker than those found elsewhere in the United States.

The Rocky Mountain deposits were described in 1923 by Winchester in U. S.
Geological Survey Bulletin 729/. In 1920, about 900,000 acres of public
domain in Colorado, 2,700,000 acres in Utah, and 500,000 acres in Wyoming
were classified as chiefly valuable for their oil shale. The land containing
oil shale on public domain in these three States was withdrawn from entry in
1930, except tracts covered by existing valid claims. The areal extent of the
Green River formation is shown in figure 2.

The oil shale of western Colorado generally is more amenable to exploita-
tion, more persistent, and apparently richer than elsewhere in the Rocky

\footnote{A paper on the oil-shale deposits of the Green River formation in Colorado,
Utah, and Wyoming, based upon later information, was presented by Carl
Belser in a paper before the September 1947 meeting of the A. I. M. E.
on Oct. 1, 1947.}
Figure 2. - Green River formation, Colorado, Utah, and Wyoming.
Figure 3. - Logs of core drills, Naval oil-shale reserve No. 1.
Figure 4. - Theoretical projection of oil-shale formation between holes A and C to hole D.
Mountain Region. About 1,000 square miles, or 640,000 acres, contain oil-shale beds of sufficient thickness and richness to be of potential economic importance. Private holdings in the Rifle-De Beque area comprise about 300 square miles.

Naval Oil-Shale Reserves Nos. 1 and 3 cover about 60 sections of oil-shale lands at the eastern end of the Rifle-De Beque area; the Green River formation here is about 2,000 feet thick. The oil shale measure that contains enough oil to be considered of commercial interest is near the top of the Green River formation and outcrops within the Reserve on the east and the southeast in a long line of cliffs near the top of a high escarpment about 3,000 feet above the Colorado River Valley. Individual beds are remarkably consistent. One bed, known as the "Mahogany bed," is persistent throughout the Rifle-De Beque area. An associated, easily identified band comprising a few inches of volcanic ash and known as the "Mahogany marker" is about 15 feet above the Mahogany bed. The marker generally is used as the geologic datum plane.

The oil shale of the Green River formation contains organic matter but no free oil or free carbon. The organic matter is broken down and volatilized by the application of moderate heat; the condensate is the shale oil, which looks like petroleum. The oil-shale measures on Naval Oil-Shale Reserve No. 1 comprise a tough, strong rock. "Shale" really is a misnomer, as the rock is a marlstone and has few of the qualities usually attributed to shale. The formation at the mine site has a $40^\circ$ dip into the hill; the dip flattens to the westward. The oil shale is not cut by faults and, as far as is known, has no local changes of dip and strike; it has relatively few jointing planes or vertical planes of weakness. Vertical master joints spaced several hundred feet apart will have to be given consideration in laying out mining plans. Some of the bedding planes constitute definite planes of weakness, but they are less evident as depth is attained. The specific gravity of the oil shale is relatively low; the average at the mine site is 15 cubic feet to the ton. About 6,000 tons of oil shale were mined by the Bureau of Mines in its first operation 4 miles from the present mine; this work indicated that the oil shale should stand well in open stopes.

Four core-drill holes were put down on Naval Reserve No. 1 during the summers of 1945 and 1946. The locations of the holes are shown on figure 1. Figure 3 is a log of the holes. A projection of the oil-shale formation from holes A and C to hole D is shown in figure 4. It is to be stressed that this projection is merely theoretical, and more holes would have to be drilled to prove the grade of the oil shale between the two holes. The continuation of the oil-shale formation appears fairly well assured. The heavy line on figure 1 near the boundary between Naval Oil-Shale Reserves No. 1 and No. 3 shows the outcrop of the top oil shale measure.

Geologic studies made by the federal Geological Survey indicate that two oil-shale measures occur below the one that outcrops. The logs of holes A and C show that these lower measures are not important at the mine site. Hole D stopped in the middle measure, which may be of economic interest some time in the future.
R.I. 4269

The oil-shale reserves are enormous. The top oil-shale measure of 500 feet thickness contains 850,000,000 tons of shale that could yield 300,000,000 barrels of oil per square mile, or 470,000 barrels to the acre, as indicated by core drilling at the mine site. The lower 70 feet of the measure contains 130,000,000 tons of oil shale, or a net of 100,000,000 tons of shale that could yield 70,000,000 barrels of oil to the section, or 100,000 barrels per acre, allowing for pillars that would be left in underground mining.

Assuming half of the 60 square miles of oil-shale formation on Naval Reserve No. 1 will be of the grade and thickness shown by the core drilling, the total shale oil on the Reserve from the full 500 feet of the upper oil-shale measure would be 9 billion barrels (the production of petroleum in the United States in 1946 was 1.7 billion barrels). The above estimate of shale oil on the Reserve is, of course, only indicative; considerable more drilling would be required to prove it. The Naval Reserve comprises only a small part of the known oil-shale lands in western Colorado.

MINE FACILITIES

The site for the oil-shale mine was selected in the spring of 1945; it is at the base of a cliff at the top of a long, steep talus slope, which in its upper reaches is too steep for horses to hold their footing. The mine site is 2,500 feet vertically and 9,000 feet horizontally from the plant site.

Road.

Soon after the site for the mine was selected, an application for a mine access road was made to the Bureau of Public Roads; construction began in midsummer. A pioneer grade reached the mine site in September 1945; grading and stabilization of the road bed with oil shale was finished in 1946. Surfacing of the road with river gravel was completed in the spring of 1947. The road has a grade generally below 10 percent, with a maximum grade of 14 percent on short rises; minimum width is 14 feet, and the sharpest curves have a radius of 40 feet. Intervisible turnouts are provided. The mine road starts at the plant; the first half mile was built through rough country to the bottom of a long ridge that extends from below the line of cliffs out into the valley. The road reaches the outermost point of the ridge in a long sweep; it then follows the top of the ridge for a distance and gains the final elevation in five switchbacks west of the ridge (see fig. 5). No serious slides have occurred in the road cuts to date (July 1947). A road patrol is run over the road after each snowstorm; about 3 hours were lost at the mine during the winter of 1946-1947 because of road conditions. Workmen are hauled to and from the mine in busses. Regular Bureau personnel use automobiles and jeeps. Oil shale is hauled over the road to the plant in 6-yard-capacity gasoline trucks, which make six trips per 8-hour shift and haul 7 tons per load. Diesel trucks of 15-ton capacity can make three trips per shift. It is expected that they could make four trips per shift if equipped with hydrotarders.

Water Supply

A water supply has been developed on the mesa above the mine. Water is brought into the workings through one of the diamond-drill holes put down for
Figure 5. - Mine site and upper part of mine road.
Figure 6. - Plan of oil-shale mine.
sampling. The minimum flow is 500 gallons per minute, which has proved adequate at the mine. Pipes on the surface and in the entrance of the workings have been buried in trenches below the frost line.

**Power**

Power is transmitted to the mine at 13,800 volts to two 500-kv.-a. primary transformers. Five outlets each at 2,400 volts are provided; one is for two electric compressors, one is for an electric shovel, and three are for secondary transformers. One bank of secondary transformers is in the substation, a second is in the haulage adit below the selective mine workings, and the third is at the portal of the upper adit of the room-and-pillar workings. The secondary transformers reduce the voltage to 480; all circuits of 480 volts or over are 3-phase. Numerous small transformers for reducing the voltage to 120 and to single-phase for lighting and other uses are located around the mine yards and throughout the mine.

**Telephone**

A telephone line was run from the plant switchboard to the mine in the fall of 1945; telephone extensions are installed in the mine office, in the warehouse, and in the shop.

**Buildings**

One building is the warehouse and mine office, a second is the changehouse, and the third will contain the air compressors and mine shops. The buildings are fire-resistant; their locations are shown in figure 6.

Consideration was given to placing all mine structures underground for safety. Cliffs above the mine site constitute a hazard, as rocks or icicles might be loosened by natural agencies and fall on the mine yards below. On the other hand, the oil shale is combustible. Open fires are required in a blacksmith shop, and heat would be necessary in the changehouse and mine office; the rock temperature is 520° F. The usual fire hazard exists in a building whether it is on the surface or underground, and a fire underground would be more dangerous to the occupants. Moreover, a building fire underground might set the oil shale afire. After weighing the relative hazards, it was decided to place the buildings on the surface. The mine entrances and buildings were located at points where the natural hazard of falling rocks appeared to be at a minimum. Loose rocks on the face of the cliff above the mine yards were rolled down, and some dangerous looking pinnacles were blasted down before operations began. A wire chain-link fence has been erected on a bench in the cliffs immediately above the yards to catch any rolling rocks or icicles that might become loosened above the bench. It was considered that heavy blasting in underground mine workings and near the surface might jar down loose slabs of rock in the face of the cliffs. Plans call for all rooms to be at least 250 feet from the surface; that is, a surface barrier of at least 250 feet will be left.
MINE EQUIPMENT

Early in 1945, orders were placed for equipment to be used in selective
mining workings. As this phase of the operation largely would follow con-
ventional practices, it was anticipated that no specialized equipment would
be required. The principal items acquired for the selective mining workings
are as follows:

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>920-cu. ft. electric air compressor.</td>
</tr>
<tr>
<td>1</td>
<td>430-cu. ft. electric air compressor.</td>
</tr>
<tr>
<td>4</td>
<td>3-inch automatic drifters.</td>
</tr>
<tr>
<td>2</td>
<td>3-1/2-inch automatic drifters.</td>
</tr>
<tr>
<td>2</td>
<td>Light stopers.</td>
</tr>
<tr>
<td>2</td>
<td>45-lb. Jackhammers.</td>
</tr>
<tr>
<td>2</td>
<td>50-hp. electric 3-drum hoists.</td>
</tr>
<tr>
<td>1</td>
<td>30-hp. electric 3-drum hoists.</td>
</tr>
<tr>
<td>1</td>
<td>7-1/2-hp. air 2-drum hoists.</td>
</tr>
<tr>
<td>1</td>
<td>Air-operated car loader.</td>
</tr>
<tr>
<td>1</td>
<td>1-1/2-ton battery locomotive.</td>
</tr>
<tr>
<td>8</td>
<td>24-cu. ft. cars.</td>
</tr>
<tr>
<td>1</td>
<td>15,000 cu. ft. ventilation fan.</td>
</tr>
<tr>
<td>2</td>
<td>1,500-cu. ft. air-driven blowers.</td>
</tr>
<tr>
<td>2</td>
<td>1,500-cu. ft. electric blowers.</td>
</tr>
<tr>
<td>1</td>
<td>Diamond drill.</td>
</tr>
<tr>
<td>1</td>
<td>160-cu. ft. portable gasoline compressor.</td>
</tr>
<tr>
<td>2</td>
<td>210-cu. ft. portable gasoline compressor.</td>
</tr>
<tr>
<td>1</td>
<td>310-cu. ft. portable gasoline compressor.</td>
</tr>
</tbody>
</table>

The portable compressors were used for supplying air for drilling until
electric power became available in the summer of 1947.

As preliminary studies were completed and the method for large-scale
mining was tentatively selected, the following equipment for the room-and-
pillar workings was ordered:

2 - 15-ton Diesel trucks
1 - 3-yd. electric shovel
1 - Tractor-mounted tunnel loader
2 - Wagon drills
1 - D7 caterpillar tractor
1 - 75,000-cu. ft. fan

At this writing, the tunnel loader and the electric shovel have not been
delivered. The fan has not yet been set up. The Diesel trucks have been
kept busy since they were delivered in 1945, mostly in hauling gravel for
surfacing the mine road and the yards at the plant and for general uses at
the plant. They are used occasionally for hauling oil shale to the plant.
**DESIGNATION OF MINABLE OIL-SHALE BEDS**  
OIL-SHALE DEMONSTRATION PLANT  
RIFLE, COLORADO

<table>
<thead>
<tr>
<th>Bed designation</th>
<th>Thickness (feet)</th>
<th>Distance from top of marker (feet)</th>
<th>Specific gravity</th>
<th>Cubic feet per ton</th>
<th>Yield gallons per ton</th>
<th>Caking tendency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>7</td>
<td>+14 to +21</td>
<td>2.28</td>
<td>14.03</td>
<td>16.68</td>
<td>None</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
<td>+ 7 to +14</td>
<td>2.04</td>
<td>15.79</td>
<td>31.91</td>
<td>Slight</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>- 1 to + 7</td>
<td>2.28</td>
<td>14.11</td>
<td>17.15</td>
<td>None</td>
</tr>
<tr>
<td>D</td>
<td>10</td>
<td>- 1 to -11</td>
<td>2.15</td>
<td>15.05</td>
<td>24.66</td>
<td>Very slight</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
<td>-11 to -15</td>
<td>1.70</td>
<td>18.96</td>
<td>61.98</td>
<td>Heavy</td>
</tr>
<tr>
<td>F</td>
<td>4</td>
<td>-15 to -19</td>
<td>1.84</td>
<td>17.52</td>
<td>47.43</td>
<td>Medium</td>
</tr>
<tr>
<td>G</td>
<td>12</td>
<td>-19 to -31</td>
<td>2.08</td>
<td>15.48</td>
<td>28.92</td>
<td>Slight</td>
</tr>
<tr>
<td>H</td>
<td>11</td>
<td>-31 to -42</td>
<td>2.16</td>
<td>14.84</td>
<td>23.52</td>
<td>Very slight</td>
</tr>
<tr>
<td>I</td>
<td>6</td>
<td>-42 to -48</td>
<td>1.95</td>
<td>16.50</td>
<td>38.28</td>
<td>Medium</td>
</tr>
<tr>
<td>J</td>
<td>4</td>
<td>-48 to -52</td>
<td>2.26</td>
<td>14.23</td>
<td>18.28</td>
<td>None</td>
</tr>
</tbody>
</table>

Figure 7. - Chart showing divisions of 70-foot section in accordance to coking qualities.
Figure 6. - Oil-shale mine.
The automotive equipment at the mine, in addition to items mentioned above, comprises:

2 - 6-yd. gasoline trucks
1 - 29-passenger bus
1 - 5-passenger automobile
3 - Jeeps
1 - Pick-up truck
1 - Cargo-carrier truck
1 - Stake-body truck
1 - Flat-bed 20-ton Diesel truck (on which drill carriage is to be mounted)

SURFACE EXCAVATION

Heavy excavation at the base of the cliffs was necessary to provide room for buildings and mine yards, as no flat areas whatever existed at the mine site. In all, a total of 72,617 cubic yards of material, of which 17,148 cubic yards was solid rock, was removed to provide 1 acre of yard room. The yards are shown in Figure 6. Because of switchbacks of the mine road below, little spoil could be dumped west of the ridge. Unlimited dump room is available just east of the ridge; the spoil rolls down the mountainside 1,500 feet before coming to rest. The surface excavations were completed in the fall of 1946.

MINE DEVELOPMENT

Underground Development

Selective Mining Workings

A decision was made early in the program that the 70 feet at the bottom of the top oil-shale measure offered the greatest promise for commercial exploitation, at least under present conditions. Samples from individual beds in this 70-foot section behave differently when treated in retorts. The shale of the higher-grade beds has a tendency to coke when heated to the retorting temperature; that is, it becomes sticky and is prone to cling to the sides of the retort or to form a mass that is difficult to handle. The 70-foot section has been divided into eight divisions, classified in accordance to coking qualities. (Fig. 7.)

A mine has been developed to produce shale from any of the eight divisions of the 70-foot section for delivery to the plant as requested. It comprises a haulage adit started below the bottom of the beds to be mined and a ventilation adit 70 feet above; the adits are connected with raises (see fig. 8). At the end of June 1947, two stopes 40 feet wide had been opened up and three other stopes started from the first of two vertical raises; similar stopes also will be developed from the second raise. The development work to June 30, exclusive of stope preparation, comprises 1,585 feet of drifting and 415 feet of raising.
Track haulage was used in running the haulage and ventilation adits; a storage-battery motor was used in the haulage adit. Broken material was loaded with an air-operated loader on both levels. Before production began, the track was removed and the haulage adit enlarged from an 8- by 9-foot section to 12 by 15 feet to permit the egress of trucks; they are loaded from chutes at the bottoms of the raises.

Drilling was done with 3- and 3-1/2-inch automatic pneumatic drills. Holes were started at 2-1/8 inches; changes were 1/8-inch. Drilling speed ranged from 15 to 25 inches per minute. Blasting, generally, was with 40-per-cent gelatin dynamite. Stoping rounds are drilled with the same equipment that was used in development. The broken shale is dragged into the raise with 60-inch scrapers pulled by 35- or 50-horsepower electric scraper hoists.

The full 70-foot section outcrops in the cliff. Consideration was given to opening rooms on the various beds directly from the surface. The expected expense of getting the shale from the stopes to a place where it could be loaded into trucks made this type of operation appear uneconomical. Moreover, blasting in stopes near the surface would increase the hazard of rocks falling from above. The haulage level could have been started at the bottom of the 70-foot interval. The oil shale, however, dips about 40° into the mesa from the outcrop. This grade down dip is too steep for track haulage of outgoing loads. Moreover, the workings would not drain by gravity, should the workings be run down the dip.

During May and June 1947, 1,100 tons of regularly stoped oil shale was delivered to the retort plant. A total of about 600 tons had been mined previously, principally from development headings in both sets of workings, and shipped from Rifle for testing purposes.

**Room-and-Pillar Workings**

The oil shale from the full thickness of the measure being exploited would have to be retorted as mined at a commercial oil-shale operation; the cost per ton of mining the oil shale selectively underground would be at least twice as high as mining the full thickness as a unit. A retorting technique doubtless will be developed to handle the run-of-mine oil shale.

As will be discussed later, it has tentatively been decided that the lowest underground mining cost for exploiting the oil shale commercially could be obtained in room-and-pillar workings. A location was selected in 1946 for the room-and-pillar workings about 1,500 feet from the selective mine workings (see fig. 6). The development work to July 1, 1947, consisted of an upper entry 18 by 25 feet in section, 230 feet long, and a lower entry of the same cross section and 122 feet long. About 75 feet of raises and drifts also have been run from these entries in mining samples of oil shale for testing.
MINING PROBLEMS

General

A commercial oil-shale enterprise would comprise a mine, a retorting plant, and a refinery. All three phases, of course, would have to be integrated and be of sufficient magnitude that minimum over-all costs could be obtained. The scale of operations probably would be governed by the refinery, which it is considered would have a minimum capacity of 10,000 barrels of oil per day, with a 7-day week. An underground mine to match a refinery of this size would have to produce 20,000 tons per day during a 5-day week; an open pit would have about twice this capacity, as the grade of the oil shale would be about half that from an underground mine. In any event, a mine of either type would have full advantage of size in regard to over-all costs.

Although mining costs are calculated on a per-ton basis, the cost per barrel of shale oil delivered to the refinery will be a determining factor in the establishment of an oil-shale industry. Mining and retorting must be considered together in arriving at a cost for producing the oil.

Selection of a Mining Method

A study of the log of hole A (fig. 2) shows that the grade of the oil shale varies greatly from foot to foot in the vertical column. The following five groupings of beds suggest themselves for consideration in making a choice as to the best interval of the column for exploitation.

<table>
<thead>
<tr>
<th>No.</th>
<th>Location in column, distance from marker, feet</th>
<th>Thickness, feet</th>
<th>Average grade, gallons per ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>1...</td>
<td>447 to -53</td>
<td>500</td>
<td>15</td>
</tr>
<tr>
<td>2...</td>
<td>263 to -53</td>
<td>315</td>
<td>17</td>
</tr>
<tr>
<td>3...</td>
<td>21 to -49</td>
<td>70</td>
<td>29</td>
</tr>
<tr>
<td>4...</td>
<td>-4 to -49</td>
<td>45</td>
<td>34</td>
</tr>
<tr>
<td>5...</td>
<td>-9 to -161/</td>
<td>8</td>
<td>55</td>
</tr>
</tbody>
</table>

1/ Mahogany bed.

The shale probably could be mined at less cost per barrel by exploiting the full oil-shale measure as an open-cut mine than by exploiting the 70-foot interval by underground methods. The retorting cost per ton, however, would be nearly the same in both cases, and the over-all cost per barrel of oil probably would be higher from the surface workings. The distance from transportation, availability of water, and convenience for the retorting plant also would affect the selection of a site for a commercial mine. It is taken for granted that the retorting plant would have to be near the mine to save the cost of transporting the oil shale from the mine to the plant.

The oil shale can be beneficiated by a sink-and-float treatment. A test made of the 70-foot interval indicated that 75 percent of the oil in this particular grade of shale could be concentrated in a product equal to 50 percent of the tonnage treated. If the lower-grade intervals of the 500-foot
measure could be beneficiated to produce a relatively high-grade concentrate without too large a loss in the rejects, open-cut mining would be preferable. Arrangements have been made to make preliminary tests of the lower-grade shale of the top measure at the Bureau of Mines laboratory at Salt Lake City. A final decision between open-cut and underground mining can not be made until the cost of retorting can be closely approximated.

The 100 feet of overburden at hole A is absent in other areas, and in places the upper part of the 500-foot series has been eroded. Moreover, areas of mineable size may exist where relatively little of the formation is left above the 70-foot series. Present plans do not call for any mining work to be done specifically to establish open-pit costs. Considerable information, however, will be obtained in the underground operations that could be applied to open-pit mining. A pencil study is being made of the general problem. The geological and topographic maps made by the Geological Survey will be used in laying out mine sites for exploiting the oil shale on Naval Oil-Shale Reserve, No. 1.

Undercut block caving would be considered for mining the oil shale under deep cover; no rock just like the oil shale, however, has been mined. The toughness of the stone and the relative lack of vertical planes of weakness would be handicaps in block caving. The writer is inclined to believe, however, that a procedure for block caving could be worked out, but it would take more time and money than are now available to the oil-shale project for this purpose. At any rate, work on block caving is being held in abeyance until more pertinent data are at hand.

As the bottom 70 feet of the top-oil-shale measure now appears to constitute the most promising portion of the measure for commercial exploitation, the research work on retorting and mining is being confined to this interval. This part of the measure would have to be included in an open-cut mine for the operation to be commercially feasible; the overlying shale by itself would be too low-grade to be exploited in the foreseeable future. Moreover, the existence of open stopes 70 feet high below an open pit would present a mining hazard. Prior mining of the 70-foot series would be less of a handicap in block caving than in open-pit mining. The pillars left in open stopes could be blasted down to provide an undercut area in a caving method.

The 8-foot interval, which includes the so-called Mahogany bed, averages 55 gallons, or 1.3 barrels of oil per ton. This series alone probably would give the largest money return per ton of shale mined, provided this high-grade material could be retorted alone as cheaply as when mixed with lower-grade beds. At the time of writing, research at the retort plant has not progressed far enough to ascertain the feasibility of retorting this high-grade bed by itself.

Flat, horizontal, stratified deposits under 75 or 100 feet thick in a formation that will stand well without support generally can be exploited at the lowest mining cost per ton by an open-stope method. Moreover, deposits of this type favor low underground mining costs. The oil-shale deposits fit this classification, and an open stope method has been selected for exploiting the 70-foot interval of oil shale.
Many variations exist in the application of the open-stope principle of mining. The manner of laying out an open-stope mine will depend largely on the haulage system and other mining practices to be followed. Most of the mining practices, in turn, will be governed by the maximum spans that the back will stand without spalling or caving. The size of pillars will, of course, be governed by the requirements for supporting the roof. The pillar pattern, however, in part may be arranged for convenience of operation.

For an oil-shale mine to be commercial, at least in the immediate future, unusually low mining costs will be necessary. To attain this end, an unusually large output per man-shift will be required, as wages will be the major item of expense. Present plans call for using units of equipment as large as underground conditions will permit. Low retorting costs, of course, also will be necessary in a commercial installation.

In general, the unit costs of mining in open cuts are less than in underground mines. Open-cut or quarry costs must be approached to make the exploitation of the oil shale commercial. The aim, therefore, has been to take a quarry underground and adapt as many surface-mining practices as practicable to underground conditions.

Pencil studies of methods for mining the oil shale from the 70-foot section began in July 1945. The first tentative mining scheme was laid out around a belt-conveyor haulage system. A panel system was designed with haulage adits at the bottom and ventilation drifts at the top of the ore body to be mined; rooms the length of the panel, with rib pillars between, were projected. A top heading 8 or 10 feet high would have been run directly under the roof stone from a ventilation adit at the back of the panel. The lower 50 or 62 feet of oil shale would have been broken by blasting vertical holes put down with diamond drills.

The oil shale breaks, on blasting, into relatively large fragments. Two bolt manufacturers expressed the opinion that the expected coarse oil shale could be handled on bolts; the makers of conveying equipment, however, wanted the shale crushed before loading on bolts. Crushing in stopes would not be practicable, and the idea of conveying the oil shale on bolts underground was abandoned reluctantly, or at least receded, until blasting experiments were further advanced. This system of mining would have many operating advantages, as the drilling and blasting would be on one level and loading and hauling on another. It would fit other methods of transportation, but further consideration of the plan was recessed for the further reason that the expected relatively high cost per foot of diamond drilling apparently would more than offset the expected operating advantages. A diamond drill was purchased later and confirmed the anticipated high relative drilling costs as compared to drilling with pneumatic drills.

Systems of mining with haulage drifts under the ore body to be mined have been considered. The cost of the development work, however, would be about the same as the direct cost of mining the shale where all workings are confined to the interval being mined. In a commercial operation, starting on the outcrop, very little work coming under the classification "development" would be required. Shafts would be necessary, of course, for underground mines back on the mesa.
It has been decided that the 70-foot interval could be mined at lowest cost per ton by the room-and-pillar adaptation of the open-stope method of mining. The decision was based upon balancing a number of factors. After pencil studies, revisits to lead and copper mines where flat, relatively thick deposits were mined, and visits to underground limestone mines, the system of mining shown in figure 9 was evolved. Huge tonnages of limestone are mined underground for industrial uses of the stone; substantial tonnages are sold for such purposes as railroad ballast and road metal. The system of mining planned for exploiting the oil shale is analogous to that employed in the underground limestone mines.

The workings, as depicted in figure 9, are now in course of development at the Anvil Points mine. The two 18- by 26-foot entries (fig. 6) will be extended about 100 feet farther and then opened out into rooms. The principal mining investigations will be made in these workings. It is planned to develop only two benches in the experimental mine and confine the work to the upper two-thirds of the 70-foot interval. In a commercial operation, the full 70 feet, of course, would be exploited, and a third and lower entry would be run from the surface. The top heading in the experimental mine will be 25 feet high and the other bench 22-1/2 feet high; the third bench, if run, also would be 22-1/2 feet high. The blast holes in the top bench will be drilled horizontally; vertical, downward, parallel holes probably will be used in the lower benches. All drilling in this phase of the experimental work will be done with air drills. The breaking costs in the advance heading will be higher than in the lower benches, because the top rounds will have only one free face to which to break, whereas rounds on benches would have only two free faces. As mining conditions on the second bench at the experimental mine would be the same as a third or lower bench, it is considered that practices and costs demonstrated on the middle bench could be applied with confidence to the lower one.

The lay-out of the Anvil Points mine corresponds largely to that used in most underground limestone mines, with the exception that the advance heading will be at the top. This top advance heading appears to be an innovation. The principal disadvantage is that haulage roads will have to be maintained on three levels instead of one. The advance heading at the top was chosen mainly as a matter of safety. The back of this heading will be the final roof of the mine. It can be trimmed to better advantage and tested in a room 25 feet high than it could be when 70 feet from the floor. Moreover, if the advance heading were at the bottom, two temporary roofs would have to be made safe, thus increasing the expense of trimming the back. Another point in favor of the top heading is that observation has shown that narrow beds of the oil shale within the 70-foot interval have a tendency to peel after about six months when exposed to the surface air. The roof stone is more massive and, so far, has shown no tendency in this regard. Samples of roof stone have been submitted to rigorous tests at the Pittsburgh station under Dr. Irving Hartmann of the Bureau of Mines. It is apparently unaffected either by dry air or moist air or by normal temperature variations. The oil shale is relatively dense; fresh stone in place contains 0.5 to 1 percent free moisture.
Figure 9. - Air-Vu drawing of proposed room and pillar workings.
A number of plans for ventilating are under consideration; doubtless, considerable experimental work will be required before a final selection is made. A fan of 75,000 capacity has been purchased; it will be set up in one of the entries with a door, to prevent short circuiting of the air currents. In a commercial mine, an advance heading would be extended to the back of the block of ground to be mined. The end of this heading would be connected to a shaft; the main ventilation fan for the workings would be installed at the collar of the shaft. Stoping would retreat from the block boundary, and the haulage entries would be the air intakes.

**Size of Rooms**

One of the first things to know in laying out an open-stope mine is the safe width for rooms to prevent caving or spalling of the roof stone. The only underground work on oil shale in the district was done by the Bureau of Mines in the "twenties" at Cottonwood Point to obtain material for testing. A room 59 feet in diameter, within the 70-foot interval, has stood in the Cottonwood Point workings with no evidence of failure except that a thin layer of oil shale has started to peel at the room neck. The physical qualities of the formation at Anvil Points indicated that the roof stone would stand over fairly wide spans; this observation, supported by the experience at Cottonwood Point, was the basis for deciding upon an open-stope method. It was thought at that time (1945) that 50-foot rooms could be used safely, but no definite evidence was at hand. The problem was first attacked theoretically. Arrangements were made with Columbia University to have aerodynamic tests of samples of the oil shale made in the laboratory, under the direction of Professor Philip B. Bucky. This work has been completed and a publication by Bucky and Frederick D. Wright describing the procedure and results is forthcoming. The Bucky-Wright conclusion regarding safe spans has been verified by Dr. Leonard Ober of the Bureau of Mines at College Park, Md. The results at Columbia and Collège Park indicate that rooms may be run safely 60 feet wide. To check the theoretical results, a rest room 50 feet wide by 100 feet long, directly under the roof stone, was completed in mid-December 1946 in the selective mine workings (see fig. 8) and was widened to 60 feet in June 1947. It has stood without evidence of spalling to the time of writing (August 1947). Later, it will be progressively widened to 70, 80, 90, and 100 feet, or until failure occurs. The roof of the test room is kept under careful observation. The sag is measured daily with an accurate gage reading to 0.0001 inch. Measurements are made from a plug in the immediate roof stone and from one in a drill hole 12 feet above the roof. The sag to date follows the theoretical pattern; from March 9, when the gaging stations were put in, to July 1 it was 0.05 inch.

Four instruments, using the geophone principle, have been set up in the top stone above the four corners of the original room. These devices are connected electrically to other instruments that make a visual record of the rock noises. Stresses being set up in the rock cause readjustment of rock crystals (or molecules), which, in turn, cause noises that can be heard and recorded by the instruments. To date, only normal rock noises have been recorded. It is expected that as the room is widened the instruments will indicate at which width stresses in the roof stone will be set up that might cause spalling or failure.
As stated, work to July 1947 indicated that rooms 60 feet wide may be worked safely. A definite decision, however, has not yet been made in the matter. An electric shovel that has been ordered requires a minimum of 50 feet between walls to be able to load trucks on one side only; with 60 feet, it can load on both sides and thus be more efficient.

When completed, the rooms will be 70 feet high. The back of such a room is admittedly high; rooms up to 90 feet high, however, are carried safely in underground limestone mines. A commercial mine would be laid out so that areas could be completed and then abandoned before time could affect the roof stone.

Bucky and Wright determined the theoretical size of pillars required to support the roof. Oertt, at College Park, is now working on the problem. The size and shape of pillars, or pillar arrangement, have not yet been decided. It is expected, however, that about 75 percent of oil shale will be extracted in mining.

**Loading**

Where the necessary working space is available, the most efficient loading unit is an electric shovel. This type of loader (electric or Diesel drive) is used almost universally in open-pit metal mines and hard-rock quarries; electric shovels also are commonly used in underground rock mines. The ability and efficiency of a shovel to handle coarse material increase with the size of the unit; moreover, the tons per man-shift handled increase with the size of the shovel. It was developed at conferences with shovel manufacturers that a standard 2-1/2-yard shovel was the largest practical unit that could be worked in the shale mine. As the oil shale has a relatively low specific gravity, a 3-yard dipper can be used on the 2-1/2-yard model. As digging is expected to be tough, a Ward-Leonard control on the shovel is considered desirable and necessary. A shovel of the above specifications, with a special front end that will permit working under a 25-foot roof, has been ordered. The 25-foot height of the top bench is a compromise. The standard model requires 27-1/2 feet of headroom, and the most desirable height, from the mining standpoint, would be 23-1/3 feet (one-third of 70). A special front end could be designed for the shovel to work under a 23-1/3-foot height, but the shoveling efficiency, particularly in handling coarse material, apparently would be decreased to an extent that would more than offset the gain that would result in working a 23-1/3-foot advance heading instead of one 25 feet high.

**Underground Haulage**

Three standard methods of haulage are used in underground rock mines: (1) cars running on tracks, (2) trucks, and (3) belt conveyors. Mines are laid out to fit the haulage system, and haulage practices must fit the manner of loading. Broken rock can be moved on conveyors at the lowest cost per ton-mile, but there is a limit to the size of material that can be handled economically on belts; and the oil shale undoubtedly will break into coarse sizes. Moreover, a power shovel cannot load material as blasted down directly onto a main-line conveyor; an intermediate step would be necessary.
Where large tonnages can be loaded at a single point, a lower cost per ton-mile can be obtained by rail haulage than with trucks; rail haulage, however, does not lend itself to room-and-pillar mining. Shovels commonly load freshly blasted material in open-pit mines into railroad cars. In such cases the track runs parallel to the bench, and a train of cars can be loaded, one after another, without switching. In underground workings, however, stub tracks are necessary to get the cars to the face; and only one or, at the most two, cars can be loaded without switching. The cost of switching and loss of capacity of a shovel while waiting for cars appear to offset any advantage of costs that would be gained with rail haulage instead of trucks. As stated, a decision has been made to use Diesel trucks for hauling the oil shale; two 15-ton Diesels are on hand.

**Drilling and Blasting**

The daily capacity of the shovel used for loading the broken oil shale and the size of the dipper will influence the type and depth of stope rounds. A round should provide enough broken stone for a full shovel shift; the stone should be broken down in primary blasting to a size that will pass through the shovel dipper. The capacity of the shovel is tentatively being taken as 1,200 tons per shift; the inside dimensions of the dipper are 40 by 59 inches.

No actual experimental work has yet been done on the type and depth of stope rounds because of the lack of working places. Moreover, for the same reason, no experimental work has been done with explosives to be used in the stope rounds. A jumbo with wagon-drill mountings is being developed to hold a battery of drills for horizontal drilling. Wagon drills probably will be used on the lower benches.

Drilling apparently will be the largest individual item of expense. Work to date in development headings indicates that about 24 inches per minute is drilled with 3-1/2-inch piston machines with an air pressure of 95 pounds per square inch in holes up to 6 feet deep. The drilling rate, however, decreases to 14 inches per minute in holes 18 feet deep. This latter rate is not satisfactory; the rate in the first part of the hole could be considered satisfactory, but an increase would be desirable.

It has been found that commercial detachable bits are dulled principally by losing gage and have to be changed after about 5 feet of drilling. As deep holes will be used in all rounds, the drilling cost would be too high for our purposes if bit changes were required every 5 feet. Moreover, the rapid loss of gage would tend to cause drill rods to stick in the long holes. Plans call for drilling 22-1/2-foot holes with no more than one change of drill rods and with only one man on a machine. A bit has been developed at Rifle that will drill over 100 feet without serious loss of gage. The use of this bit has reduced the drilling cost; although there is a reduction of cost of bit per foot of hole, the great saving is in labor. The development of the bit has been described in R. I. 4177, "The Development of a Successful Hard Surfaced Bit for Drilling Oil Shale" by Tell Ertl, John R. Wagner, Jr., and Ernest E. Burgh.
In an effort to lower drilling costs, a fundamental study is being made of the whole drilling problem. Apparently there is a speed of rotation of the drill that will give optimum results in the oil shale; this is being investigated. Work is also progressing on the shape and form of bits to increase drilling speed. As other investigators have found, grinding drill cuttings in a hole reduces drilling speed. Increasing the water supply in a standard drill increased the drilling speed, doubtless by flushing the drill cuttings away faster. The aim is to develop a bit that will make a 'minimum of fines' in cutting the shale. Drilling speed depends directly upon the air pressure; with too high a pressure, however, drill and bit breakage offsets the advantage of the faster rate. Some curves have been drawn, but the final answer has not yet been obtained; the range apparently is 95 to 105 pounds per square inch at the drill. The decrease in drilling speed with depth is a serious factor. Present studies are mostly in the theoretical stage. Alloy steel tubes are to be tried as drill rods; these lighter rods should require less energy to overcome their inertia. As stated, experimental work has been done with a diamond drill, but with discouraging results. Other types of rotary drills or augers are to be tried.

Inherent Hazards

The oil shale is combustible and can be ignited if kindling is used. The workings of a full-scale mine would require no support; no timber structures would be erected underground, and the use of other inflammable material would be kept to a minimum. A fire hazard, however, does exist, and adequate precaution to prevent igniting the oil shale must be taken.

The possibility of dust explosions is recognized. A sample of the Mahogany bed, after grinding to a fine powder, was shown to be explosive about 20 years ago at the Pittsburgh station of the Bureau of Mines. Although the oil shale is tough, considerable dust is made by blasting; relatively little dust is stirred up in handling shale. Heavy blasting with gelatin dynamite in a small development heading in the Mahogany bed gave no indication that the dust in the mine atmosphere made by blasting was sufficiently concentrated to be explosive. The Mahogany bed contains up to 76 gallons of oil per ton; the average of the 70-foot interval is 30 gallons. Samples of the settled dust from the various beds of the 70-foot section will be collected and forwarded to Pittsburgh for further testing. So far, one dust sample has been collected; this was from the test room. The dust of this sample, suspended in a cabinet, could not be ignited with an electric arc or a blow torch. Very little settled dust is evident in any of the present workings. In regular mining operations the Mahogany bed would be included in a bench with other beds of the oil shale; vertical downward holes would be drilled. Relatively little of the dust from blasting such a bench would come from the high-grade interval. Judging from the behavior of the oil-shale outcrop, the toughness of the rock seems to vary with the richness of the shale.

All broken shale is wet down before handling, and all blasting is done electrically after the workmen have left the mine. A dust explosion is not considered likely, but, if one did occur, only property damage would result.
Figure 10. - Organic content of oil shale from demonstration mine, Rifle, Colo.
Figure 9, prepared by K. E. Stanfield of the Laramie petroleum station of the Bureau of Mines, shows, in percentages, the organic content of oil shale of various grades. One of the recommendations made by The American Engineering Standards Committee for rock-dusting coal mines is:

In all places where rock dust is distributed, enough shall be used so that the percentage of inflammable material in the samples of dust collected in the places shall be maintained at least 55 percent. Along room entries or gangways, where methane gas is found in the ventilating current, the amount of inflammable material above specified shall be raised 10 percent for each 1 percent of gas.

It will be noted from figure 10 that even the richest sample of oil shale contains over 55 percent inflammable constituents.

Routine tests are made in the workings for methane with a methane detector; no methane has been indicated by the detector. From a geological standpoint, it does not seem likely that a dangerous amount of methane could be found in the workings. The structure of the formation on Naval Reserve No. 1 is not favorable for the accumulation of gas in reservoirs. Moreover, the oil shale has very little porosity, and the hydrocarbons in the rock are inert at normal rock temperatures.

Adequate ventilation is planned, primarily to dilute the exhaust gases of Diesel trucks to be used for haulage; moreover, a good ventilation system will be required to evacuate the gases from blasting from the mine. The same system, of course, would remove from the mine any methane that might be encountered as well as fine dust made in blasting.

Summary

The principal job of the Oil Shale Mining Division is to select methods and devise practices for producing the oil shale on a commercial scale at the lowest practicable cost. The preliminary thinking on the problem largely has been done, the method for mining the shale has been decided upon, and the loading device and the haulage equipment have been selected. Considerable major research remains to be done on drilling and blasting problems, on integrating breaking of the shale with loading and with haulage, and in establishing costs. Mining research to date has been determining how long the oil shale will stand with safety in open rooms, as well as drilling problems. The work is well organized, and procedures for finishing the job have been outlined.