The Green River formation of Colorado, Utah, and Wyoming contains the greatest potential reserves of oil in the world. The problem has been that of finding an economical method of extraction.

The first economic study of the oil shale in Utah started in 1913 (Woodruff and Day, 1914). Since that time sporadic attempts have been made to establish oil shale as an economic source of liquid fuels. Much activity took place during the interval from 1914 to 1920. D. E. Winchester (1923) published a comprehensive account of the oil shale deposits and the efforts to exploit them. Immediately after Winchester's bulletin was published, the discovery of rich petroleum fields in Texas, Oklahoma, and Kansas flooded the market with abundant oil and dampened enthusiasm for further research on shale oil for a generation to come.

However, the oil shale reserves of the Uinta and Piceance Basins have been steadily increasing in potential economic importance, even though there is presently no large scale operation that converts the oil shale to crude oil. There are several reasons why the oil shale reserves are becoming more important. First of all, many oil companies have gone abroad to increase their reserves in crude oil. The profits from the sales of those reserves have to be shared with the foreign country wherein the reserves are developed. The growing nationalism of most foreign countries is such that they are demanding a greater and greater proportion of the profit. The increased percentage of profits strengthens their economic power until they are rapidly reaching the point where they are able to explore and develop their own petroleum resources. Then, they no longer welcome U.S. companies. As a result, the U.S. companies must look more carefully at the potentials of our domestic resources, the largest of which is oil shale.

Secondly, oil shale is becoming more important because of the ever-rising exploration costs. The cost of finding new oil is already above the value of the oil found in many domestic oil provinces. Many companies are continuing to exist only because they are still producing oil that was found ten or more years ago at much lower costs. As that low-cost oil is gradually exhausted, the economic squeeze becomes more and more intense. If these companies are to perpetuate themselves, they must turn to a resource where the odds are much more favorable, even though the maximum profit margin may be somewhat smaller. The answer is the solid petroleum resources, such as oil shale and tar sands.

The recent, mandatory import controls must have a stabilizing and an encouraging effect on the domestic oil industry. If the still-growing demand for more power from oil is to be satisfied, then we must increase the available supply of oil from domestic sources at lower-risk capital costs. Since there would be no dry holes in oil shale crude development, the risk capital is minimized, even though it is admitted that substantial amounts of risk capital must be expended in the near future in research and technological developments to more efficiently extract and refine the oil from the oil shale.

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2. Formerly, Geologist, General Petroleum Corporation, assigned to special research on oil shale.
Finally, new developments in refining techniques (the possible application of nuclear energy to more economical mining and retorting "in situ", and the experimentations and developments that are in progress in other countries) all tend to place the oil shale industry on the threshold of reality. The potential of the industry is so great that once it gets under way it could grow so rapidly as to be reminiscent of the growth of the search for liquid crude oil after the discovery of the first commercial well near Titusville, Pennsylvania, on August 27, 1859. Only those companies that are aware of the potential and are well acquainted with the latest techniques through experienced personnel of their own can expect to be economically successful in a phase of the industry that is so foreign and so mingled with problems unfamiliar to their past background. Consequently, it is quite timely to consider what is known of the oil shale reserves of Utah.

**OIL SHALE ENVIRONMENT**

"Oil shale" isn't really shale at all. The rock is more nearly a limestone or mudstone formed eons ago in quiet lakes where there was abundant plant and animal life in shallow water. In addition to the plant and animal remains, the calcium-carbonate ooze was intermixed with the sand and clay brought into the lakes by the streams and rivers draining into them. This mixture, over a period of millions of years, was compressed into rocks. These rocks, known as oil shales, are more correctly called limestones, mudstones, or dolomites, depending on the relative amounts of calcite, clay, or dolomite in them. The foregoing conditions of sedimentation existed during the deposition of the Green River (Eocene) formation in the Uinta Basin. The shallow, lacustrine environment, uninterrupted for such a long period of time, made possible the accumulation of vast quantities of decaying organic material, commingled with the argillaceous and calcareous deposits of the lake. These materials were compressed into oil shale, whose richness, thickness, and extent are unique when compared to similar deposits in any other part of the world.

The gradual subsidence of the Uinta Basin under the load of the accumulating organic and inorganic rock materials, without major diastrophism, made possible the preservation of the oil shale formed by compression and burial. The oil shale deposition was interrupted only by short periods of volcanism which spread thin tuff and ash blankets over the lake floor. Those blankets are preserved as analcitized tuff beds in the Green River section. They are remarkably continuous, even though they rarely exceed a few feet in thickness. The gradual burial of structures in the lower Green River section and in the Wasatch without unconformity or disconformity is indisputable evidence of the constant and continued accumulation of organic and inorganic material, together with gradual subsidence.

Following Eocene deposition of the oil shale, the accumulation of sediments in the Uinta Basin became mainly fluviatile in response to the greater uplift of the Uinta Mountains. In spite of the terrestrial origin of most of the sediments of the Uinta formation, lacustrine deposition continued to take place in the center of the lake, so that in the vicinity of Duchesne there are in excess of 10,000 feet of lacustrine beds. The widespread deposition of the Uinta formation and the overlying Duchesne River formation preserved the underlying rich oil shale deposits of the Green River from erosion over the northern two-thirds of the basin. The oil shales are either exposed, near exposure, or have been eroded away on the remaining one-third of the basin.
STRATIGRAPHY

A lengthy discussion of the stratigraphy of the Green River formation, wherein the bulk of the oil shale is deposited, is adequately covered in the literature by Picard (1955, 1957), Abbott (1957), Cashion and Brown (1956), Cashion (1957), Dane (1955), and by others. The bulk of the rich oil shale deposits occur in the Parachute Creek member of the Green River formation, with minor amounts occurring in the Evacuation Creek member, above. Near Soldier Summit, where Abbott (1957) reports 2,000±feet of the lower black-shale facies of the Green River, the total thickness includes "some rich oil shale." To the west and northwest, the Parachute Creek member and the Evacuation Creek member change gradually by lithologic variation and become part of the saline facies of the central Uinta Basin. In general, the oil shales are thickest and richest near the depositional axis of the basin. Consequently, it would seem that they would be present in even greater amounts northward from the Sun Oil Company's Ouray well in sec. 22, T-9-S, R-20-E. The lithologic variation to a saline facies limits such a generalization to the west. It is probable that the oil shales give way to saline beds by gradual interfingering in the deeper parts of the basin. The lack of core analysis on oil and gas test wells to the west and northwest of the Sun Oil Company's Ouray well makes it difficult to do more than extrapolate the possible lithologic variations through detailed study of the electric logs.

The most notable bed of the Parachute Creek member is the Mahogany Ledge. Mapped by Cashion and Brown (1956) throughout the eastern part of the basin, it contains the thickest and richest oil shale zone in the Green River formation, and is a very persistent and an extremely useful marker bed. It thins to the south and thickens westward from the Colorado-Utah line. It can be traced to the Green River, but has not been recognized as a separate unit west of the river.

RECENT DEVELOPMENTS AND ECONOMICS

The lengthy research project on the refining of shale-oil crude at Rifle, Colorado, by the Bureau of Mines, and the construction of a production retort plant at Grand Valley, Colorado, by Union Oil Company of California, have paved the way for favorable economic competition between shale-oil crude and normal crude oil. Union Oil Company officials have stated that they were able to reduce the cost of refining to 75 cents per barrel of shale crude. Continued efforts and research are bound to reduce that cost even further. It is the opinion of the authors that the "heated ball" retorting method of the Aspeco process, developed by the Denver Research Institute, is a step in the right direction toward increased efficiency and lower refining costs. It would seem logical that, if the retorting takes place in an "air-free" environment without combustion, the volatiles emitted would have a B.T.U. value equal to, or nearly equal to, pipeline standards. The gases emitted by the combustion retort are diluted by air, carbon dioxide, water vapor, and other possible products of combustion. These gases must then be filtered and enriched to meet pipeline standards.

Mining

The cost of mining the oil shale and transporting it to the refinery are the other major factors contributing to the total cost of shale-oil crude, as compared to the cost of exploring for and developing new reserves of normal crude. It would appear that those areas where the oil shale is mineable by open-pit methods offer the most favorable economics. A complete mining-cost study undertaken recently by
one company indicated that the oil shale could be stripped and mined for a cost of slightly less than 50 cents a barrel, based on an average richness of 30 gallons per ton, as determined by laboratory analysis of cores.

Underground methods of mining materially increase the cost, and such methods will be required on those deposits which are too far removed from the outcrop to be economically stripped. The Bureau of Mines has been able to estimate a total cost of 75 cents per ton at the Rifle mine. The Union Oil Company's costs at the underground mine up Parachute Creek have been much higher because of unfavorable roof conditions. It is felt that underground mining conditions must be very carefully analyzed at each locale before mining is attempted. The initial development should be restricted to open-pit mining because of the reduced costs. Underground mining methods can be further studied after the initial problems of retorting, hydrogenation, and ash disposal have been worked out to yield the most "sweet" crude from the least amount of mined shale.

The possible application of nuclear energy to reduce over-all mining costs, as proposed by the Atomic Energy Commission, is a most important consideration. Such an experiment should have the support of all the oil companies. The possible success of the experiment would have a far-reaching significance. It could bring the oil shale industry into reality overnight.

"In Situ" Methods

There can be no doubt that the full potential of the oil shale reserves in Utah can be developed only when we have learned to retort and produce the oil from the shale in place. Otherwise, we are limited by the percentage of oil shale that can be removed from an underground mine and by the depth that we can economically mine and lift the oil shale. Then too, the disposal of the ash becomes an enormous and costly problem.

The major problem in preventing the early development of "in situ" retort methods is the complete lack of natural porosity and permeability of most oil shale deposits. The porosity and permeability must be created ahead of and prior to the distillation of the oil from the shale. If this porosity and permeability could be created by an underground nuclear explosion, then the distilled oil would be free to move to the production well. "In situ" retort methods would immediately become feasible because of the successful experiments already completed or under operation in permeable sand reservoirs. Field experiments based on the proper spacing and configuration of input and output wells insure complete "sweeping" of the reservoir and indicate that 90 per cent or more of the original oil in place could be recovered. It follows that the percentage of the total possible oil recovery from the oil shale is limited, principally, by the practical aspects of creating the proper permeability throughout the oil shale section.

The development and adoption of suitable "in situ" techniques would obviate the necessity of disposing of the enormous quantities of ash. "In situ" techniques would permit the recovery of the oil from the richest beds which lie far below practical mining depths. Moreover, no pillars would have to be left to support the roof, as is necessary in a mining operation.

To give an illustration of the tremendous potential of the "in situ" methods, it is necessary only to point out that oil shale which yields 30 gallons per ton is equivalent to 2,000 bbls. per acre foot. In comparison, a sandstone reservoir that has a porosity of 20% and a water saturation of 30% would have originally
about 1,000 bbls. of oil per acre foot in place. At best, one could not expect to recover more than 500 bbls. per acre foot by the usual methods of primary and secondary recovery. "In situ" methods might recover as much as 940 bbls. per acre foot from the sandstone reservoir and 1,880 bbls. per acre foot from the oil shale. It would seem that the oil shale has about twice the potential of a good sandstone reservoir.

For instance, let us assume that a 160-acre tract is underlain by an oil shale bed having a thickness of 50 feet and a yield of 30 gallons per ton. The quarter-section would contain 16,000,000 bbls. of oil in place. If a 500-foot, hexagonal well-spacing program was set up so as to obtain 100% sweep efficiency, it would require 55 wells to properly cover the quarter-section. If five of the 5-spot patterns were "fired" at once, then the entire section could be "swept" in five successive moves. On the basis of past experimentation, it appears that a practical rate of advance of the distillation front would be about 0.35 foot per day. The yearly rate of advance would be 125 feet per year. It would not be necessary to advance the front more than 80% of the 500-foot distance between the input and output wells before the move to the adjacent set of 5-spot patterns could take place, for there would be enough preheat left in the formation to insure that the sweeping agent would be able to complete the "sweep-cycle." Consequently, a move could be made every four years, and the entire 160 acres could be "swept" in 20 years. During that time 16,000,000 bbls. of oil would be produced at the rate of 800,000 bbls. per year, or more than 2,000 bbls. per day. On one section of oil shale property of moderate thickness and richness such an operation could be carried on for 80 years.

**OIL SHALE RESERVES IN THE UINTA BASIN**

The contour map, Figure 62.1, attempts to illustrate the total oil in the shales of the Green River and lacustrine Uinta formations within the Uinta Basin of Duchesne and Uintah Counties, Utah. The data used in the construction of the map comes from the U.S. Bureau of Mines Report of Investigation No. 5081, "Oil Yields of Sections of Green River Oil Shale in Colorado, Utah, and Wyoming, 1945-1952."

"The total oil is represented in millions of barrels of oil per square mile, and the contour interval is 100 million barrels. The total oil content map is not restricted to minimum yields of 15 gallons per ton, such as are the oil shale maps that are already published. As a consequence, the total oil reserve of the oil shales in the Uinta Basin is crudely estimated at 1,300 billion barrels, instead of 26 billion barrels. Is such an approach practical? How can we deny the practicality of one billion barrels per square mile such as is present in Humble's Rosemary Lloyd No. 1 well in sec. 24, T-1-S, R-1-E, U.S.M.? This well penetrated an oil shale section in excess of 2,500 feet that was all oil bearing, yet only 60 feet of it yielded more than 15 gallons per ton. Whenever it becomes possible to distill the oil from the shale "in situ", then the entire 2,500 feet becomes important and not just the 60 feet.

"The two areas of greatest total oil reserve need some explanation. The Ute Trail area in T-9-S, R-21 and 22-E, shows a possible reserve of 1,000 million barrels per square mile, while the south Duchesne area in T-5-S, R-3 and 4-W, U.S.M., shows a possible reserve of 700 million barrels per square mile. The thickness of the Green River in the Ute Trail

1. Figure 62 and explanation are adapted from an article by the senior author and published in Petrogram, September, 1961.
TOTAL OIL IN THE OIL SHALE
UINTA BASIN, UTAH

CONTOUR INTERVAL—100 MILLION BARRELS
INCOMPLETE SECTION
0.355 MILLION BARRELS PER SQUARE MILE

GAS FIELD
OIL FIELD

Figure 62.
area is approximately 3,500 feet while the thickness of the Green River and lacustrine Uinta in the south Duchesne area exceeds 7,000 feet. It follows then, that the richness ingallons per ton is several times greater in the Ute Trail area than it is in the south Duchesne area, even though the total oil is comparable.

"It must not be presumed that the map will remain unchanged when more information becomes available. In fact, it is probable that several of the oil companies have information on hand that would materially alter the map and particularly change its zero limits.

"The map was not constructed to show the possible total "shale oil" reserve alone, but rather to show the possible relationship between the occurrence of the Green River and Wasatch oil and gas fields, and the total oil in the oil shales. The relationship is rather striking. All the oil and gas fields are concentrated in or near areas of greatest "shale oil" reserve. Is not this concrete evidence of the indigenous nature of the oil and gas in Green River reservoirs? The Red Wash field, in T-7-S, R-22-23-24-E, extends beyond the limits of "shale oil" because of the delta sands in the Green River. Oil and gas migration has taken place from the rich source beds nearby into the reservoir sands deposited along the ancient river delta. Future exploration and development in the Uinta Basin is expected to give more support to the postulation that oil and gas will be found in paying quantities where the reservoir beds occur in the proximity of large "shale oil" reserves.

"In spite of the technical breakthroughs reported in the extraction of tar-sand oil, oil shale in the Uinta Basin must wait! One needs only to see the location of the present oil and gas fields in relation to the greatest shale oil reserves to know that no development of the oil shale can take place. Multiple use of the same area for the production of oil and gas by two entirely different extraction techniques would not be possible. The cost of immunizing one technique from harm by the other would be prohibitive. Still, it is most encouraging to know that the Uinta Basin, and its neighboring basins, the Piceance Basin and the Green River Basin, contain a natural resource that will provide adequate supplies of hydrocarbons for a continually growing market for many generations to come."

**CITED REFERENCES**


OIL AND GAS POSSIBILITIES OF UTAH, RE-EVALUATED

Compiled and Edited by Arthur L. Crawford

Pure Oil Company Big Flat Wildcat Well. Return cuttings and water from well pile up at end of blooey line. (Photograph courtesy of "Oil and Gas Journal", Dec. 4, 1961, p. 125.)

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