

M. KING HUBBERT CENTER FOR PETROLEUM SUPPLY STUDIES

M. KING HUBBERT CENTER
Petroleum Engineering Department
COLORADO SCHOOL OF MINES
GOLDEN CO 80401-1887

LF (Buz) IVANHOE-Coordinator
CSM-M. King Hubbert Center
1217 Gregory St., OJAI CA 93023
805/646-8620; FAX:805/646-5506

SHALE OIL--THE ELUSIVE ENERGY

Walter Youngquist

An early settler in the valley of Parachute Creek in western Colorado built a log cabin, and made the fireplace and chimney out of the easily cut, locally abundant black rock. The pioneer invited a few neighbors to a house warming. As the celebration began, he lit a fire. The fireplace, chimney, and ultimately the whole cabin caught fire, and burned to the ground. The rock was oil shale. It was a sensational house warming!

Oil shales are reported to have been set afire by lightning strikes. The Ute Indians of northwestern Colorado told stories of "mountains that burned." Cowboys and ranchers of the region burned the dark rock in their fires, like coal. The flammable nature of the richer oil shales is basis for the title of a fascinating book by H. K. Savage (1967), *The Rock That Burns*. During oil shale enthusiasms in the early part of this century, stock promoters brought pieces of oil shale to Chicago street corners and set them afire. Clouds of smoke attracted crowds, and the promoters sold stock in oil shale companies.

Nature of oil shale. Shale oil comes from oil shale, but oil shale is a misnomer. It is neither a true shale nor does it generally have any oil in it. It is better identified as organic marlstone, marl being a mixture of clay and calcium carbonate. The organic material is kerogen, derived from myriad organisms, chiefly plants. Savage (1967) notes the term "oil shale" is a promotional term: "The magic word 'oil' would raise large sums of promotion money while organic marlstone wouldn't raise a dime."

The U. S. Geological Survey (USGS) defines oil shale as "organic-rich shale that yields substantial quantities of oil by conventional methods of destructive distillation of the contained organic matter, which employ low confining pressures in a closed retort system." (Duncan and

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Swanson, 1965). They further define oil shale for purposes of their report to "any part of an organic-rich shale deposit that yields at least 10 gallons (3.8 percent) of oil per short ton of shale..."

Organic-rich shales which would qualify as oil shales by the USGS definition exist in the geological column from Cambrian deposits formed more than 500 million years ago, to Tertiary deposits formed within the last 70 million years. They can form in shallow marine embayments or in lakes, ponds, and swamps. Grades of these deposits may range up to more than 100 gallons of oil per ton, although this is quite exceptional. Most average less than 40 gallons a ton.

World distribution of oil shale. Oil shale occurs in many parts of the world including Canada, Sweden, Estonia, Scotland, Spain, China, Russia, South Africa, Australia, Brazil, and France. The largest and some of the richest deposits are in the Piceance Basin of western Colorado, the Uinta Basin of eastern Utah, and the Green River Basin in southern Wyoming.

Oil shale development. Small scale oil shale industries developed in Europe in the 19th Century and have operated at various times in parts of Europe, Africa, Asia, and Australia. China has operated an oil shale plant for a number of years producing approximately 40,000 barrels of oil per day. Oil shale has been burned directly as a solid fuel for domestic purposes and small industrial operations. Estonia has used oil shale in solid form for fuel for electric power generation. The raw shale is simply shoveled into furnaces. Oil shale operations in Sweden and Scotland, each producing 500 to 700 thousand barrels per year, were closed in 1962. (Duncan and Swanson, 1965). Small oil shale deposits of Triassic age have been mined for several centuries in northern Italy, Austria, and Switzerland, to produce ichthyol, so-named because the beds are rich in fish remains.

Impressive resource figures. The numbers on oil shale resources around the world are nothing short of staggering. Most of the following estimates are drawn from Duncan and Swanson (1965) unless otherwise cited. Oil shale deposits of Late Permian age in southern Brazil have been estimated to contain 800 billion barrels oil equivalent in shale that yields 10 to 25 gallons per ton, and 3.2 trillion barrels in possible extensions. Resources that yield 5 to 10 gallons of oil per ton were estimated to hold 4 trillion barrels of oil equivalent in possible extensions. A 200 square-mile Middle Tertiary lake basin deposit in southwestern Montana has approximately 1000 feet of sediments which have not been appraised in detail but may contain tens of billion barrels of oil potential. Weeks (1960) stated "possible potential resources" of higher grade oil shale in the U. S. are approximately 2 trillion barrels of oil equivalent, and 12 trillion barrels in the world. Duncan and Swanson (1965) estimated a world oil shale resource of 2.1 quadrillion barrels.

Estimates of the volume of potential oil in the U. S. shale deposits have grown steadily since they were first studied in detail by the USGS in the early 1900's. Duncan (1981) states "The oil shale deposits of the United States can be considered collectively as an enormous low-grade source of oil, hydrocarbon gas, or solid fuel. Deposits with an estimated yield of 10 gallons or more oil per ton of rock contain more than 2 trillion barrels; their possible extensions may contain an additional 3 trillion barrels; and, speculatively, other unappraised deposits may contain several times as much oil."

A publication of the State of Utah (1980) reports "The potential of oil shale is enormous. While found throughout the world, nearly 62 percent of the world's potentially recoverable oil shale resource are concentrated in the United States...The largest of the U. S. oil shale deposits is found in the 16,500 square-mile Green River formation in northwestern Colorado, northeastern Utah, and southwestern Wyoming. The richest and most easily recoverable deposits are located in the Piceance Creek Basin in western Colorado and the Uinta Basin in eastern Utah...The deposits are estimated to contain 562 billion barrels of recoverable oil. This is more than 64 percent of the world's total proven crude oil reserves."

Enthusiasm in the popular press and investment publications was boundless in the 1960s as the U. S. began the attempt to unlock these great oil resources. An ad in the March 1, 1968 *Forbes* magazine read: "FANTASTIC--But True! Five trillion dollar U. S. shale oil treasure and 'ground-floor' investment potentials...An incredible mountain of oil--a veritable treasure of black gold...so plentiful it can supply this country's needs for at least 200 years." An Associated Press dispatch did even better stating "Tucked beneath the peaks and buttes of western Colorado lies enough oil to keep the United States rolling along at its current gas-guzzling rate for another 500 years."

Resources versus reserves. With these astounding estimates of world oil shale resources, why is it that so little oil has so far been produced? The answer in part lies in word definitions, the difference between "resources" and "reserves." Resources are the total amount of a given material in the Earth--copper, lead, gold, or organic material such as that in oil shale. Reserves are those resources which can now be economically recovered, and therein, as Shakespeare said, "ay, there's the rub." The resources of the organic material in oil shales are huge, but getting them out economically is another matter. There is an analogy in the gold "resources" in the ocean. There are thousands of tons of gold in sea water--huge resources. But the gold is in such dilute quantities that it probably can never be recovered economically--a resource which will never be a reserve. There seem to be oceans of oil shale resources around the world, but how much of all these deposits are oil reserves?

Oil shale interest--rise and fall. In the mid-20th Century the U. S. public was becoming aware of the huge western oil shale deposits. World War II had shown the critical importance of oil to both military and civilian operations. Gasoline was strictly rationed in the U. S. at that time. Immediately after the war in 1946, the U. S. Bureau of Mines began the Anvils Point oil shale demonstration project near Rifle, Colorado. The public for the first time saw the Government pursuing shale oil. Later, the peak of U. S. oil production was reached in 1970. For several years previously domestic oil supply had not met demand. Oil had begun to be imported. Long gasoline lines during the oil crises of 1973 and 1979 rudely awakened the public to the fact the U. S. was no longer self-sufficient in oil. What to do? The reported vast quantities of oil in oil shale seemed a logical venture.

Oil companies led the investigations. Leases were obtained and consolidated (some leases had been in effect for many years, and were merged into larger working blocks). Colony Development Corporation was formed to include Atlantic Richfield (now Arco), Ashland Oil Company, Shell Oil Company, and The Oil Shale Corporation. White River Shale Oil Corporation was formed by Phillips Petroleum Company, Sun Oil Company, and Standard Oil of Ohio. Gulf Oil Corporation and Standard Oil of Indiana (now Amoco) formed Rio Blanco Oil Shale Project. Phillips Petroleum Company and Sun Oil Company formed White River Shale Oil Development. Other players choosing to go independently included Union Oil Company of California (Unocal) which had a long-standing interest in oil shale, and in 1957 had built a small experimental plant near the community of De Beque, Colorado. Exxon and Occidental Petroleum also had independent operations. It was a premier group of companies, with excellent technical talent. And there was money to do the job. It remains the largest effort to commercially produce significant amounts of oil from shale the world has ever seen.

Yet, one by one, these organizations gave up their oil shale interests. (Gulliford, 1989, Symonds, 1990). The last company to do so was Unocal (Turner, 1991), and in the Parachute Creek Valley a short distance north of the town of Parachute (earlier called Grand Valley) there is a \$650 million abandoned Unocal shale oil plant as a monument to this endeavor. Why has shale oil been such an elusive energy source? A brief examination of geological and technological factors may reveal some answers.

Geological setting. The oil shales of the western U. S. are in the Green River Formation of Eocene age, and are lake deposits, showing seasonal varves. From a study of this record, Picard (1963) concluded that Lake Uinta persisted for more than 13 million years. Ten depositional environments are recognized, forming a great variety of lithologies ranging from organically barren salt deposits to rich organic oil shale muds. Histograms of well logs show that oil content differs greatly in closely adjacent beds, ranging in some cases from more than 50 gallons a ton to less than 5 gallons a ton within 10 feet vertically. Only a few beds are thick enough to mine efficiently. Also, the worthwhile oil shale strata are almost all buried so deeply that they have to be mined by underground methods, which is much more expensive than strip mining. Even in the *in situ* method of oil recovery, some underground excavation has to be done.

Shale oil recovery methods. Oil shale must be drilled and blasted. If it is to be processed other than *in situ* (the method tried by Occidental Petroleum near De Beque), the blasted rock must be loaded and hauled to the processing plant where it is crushed, and then heated. The organic material in oil shale is kerogen. Kerogen can be the first stage of nature's way of producing oil, but it has not gone through the "oil window" of heat, and therefore, to be changed to an oil-like substance, it must be heated to approximately 900 degrees F. By this process the organic material is converted into a liquid, which must be further processed to produce an oil which is said to be better than the lowest grade of oil produced from conventional oil deposits, but of lower quality than the upper grades of conventional oil.

Colorado's shale oil is chemically "kerogen" – not petroleum. It is not the equivalent of "heavy oil" or "tar", which are hydrocarbons. An additional hydrogen (H) atom is required to convert kerogen into a hydrocarbon that can be refined into gasoline and other petroleum products. The missing hydrogen is usually supplied from water (H₂O) and requires a "pre-oil" plant plus large quantities of water – which is rare in the oil shale regions of semiarid Western Colorado. In order to release hydrogen from water, energy must be supplied. This two-step refining procedure makes the production of gasoline from shale oil prohibitively expensive for practical purposes. The original untreated kerogen shale oil is good only to burn as boiler fuel or as a base for some plastics and other petroleum by-products.

When heated, oil shale tends to expand, so the resulting volume, even after the oil has been removed, may be as large or larger than it was originally. This material must be disposed of, and for a shale oil plant of significant size (e.g. 500,000 barrels/day), the amount of waste material would be enormous. This has to be transported to a proper disposal site. It must be stabilized so it will not contaminate areas beyond the disposal site, because the spent shale has a variety of undesirable mineral compounds which rain will leach. The waste material must be watered and vegetated so it does not blow around.

Two other procedures have been tried to recover oil or gas from oil shales. (Note that small amounts of oil and gas are now recovered by wells from a few places in oil shales. Montgomery and Morgan, 1998). Occidental developed an underground operation, which involved excavating a series of small rooms to provide space for oil shale rubble formed by blasting. This was set afire with temperatures reaching 900 degrees F, cracking the kerogen into oil which drained down through the rubble pile into a sump. (Chew, *in* Murray 1974). The Rio Blanco project was designed to test the use of nuclear blasts to fracture a gas-bearing sandstone in the Green River Formation, and place it into production. Three 30-kiloton nuclear devices were simultaneously exploded in a well at depths of 5,840; 6,230; and 6,690 feet. (Weichman, *in* Murray, 1974). But the results were not economic.

Much study and effort. The volume of literature from around the world on shale oil recovery is huge. Clearly there has been no lack of talented effort. Colorado School of Mines scientists and engineers, with the huge oil shale deposits virtually in their back yard, have been most diligent in pursuing all aspects of this problem. (Sladek, 1975; Williamson, 1965; and many others not listed in the bibliography).

But to date, commercial oil in significant quantities from oil shale remains a fond hope, subject to wry statements including: "Shale oil--fuel of the future and always will be." In 1946, a real estate promoter erected a sign along what is now U. S. 70, regarding the minor shale oil boom at the time: "Get In On the Ground Floor." It is still not too late to get in on the ground floor. But all plans to do so have been at least temporarily discontinued. Perhaps oil shale will eventually find a place in the world economy, but energy demands of blasting, transport, crushing, heating, adding hydrogen, and the safe disposal of huge quantities of waste material are large. There appears to be a positive net energy recovery from oil shale processing (Penner and Icerman, 1984), but it is low

and does not compare with net energy from conventional oil well drilling. The large amount of water needed to support any major oil shale operation along with the supporting infrastructure of housing is also a difficult problem. The western U. S. oil shales are in the headwaters of the Colorado River, which already has more water rights against it than it can meet. Most of the time it now no longer reaches the Gulf of Lower California.

It now seems unlikely that shale oil recovery operations can be expanded to the point where they could make a major contribution toward replacing the daily consumption of 73 million barrels of oil worldwide, or the 19 million barrels used in the U. S. Perhaps some day some now unknown technology can do it. On a small scale with good geological and other favorable conditions, such as water supply, oil shale may make a modest contribution. Suncor of Canada is now beginning an oil shale operation in Australia.

But in the western U. S., the scope of the problems to make shale oil a significant energy source gradually became apparent. One cannot fault those who have enthusiastically promoted oil shale, for they were joined by some of the world's largest petroleum enterprises. It was a learning process, and the most recent attempt in the Piceance Basin of western Colorado has been the most expensive lesson ever in oil shale economics, costing billions of dollars. The future of this elusive energy source remains uncertain. For the moment at least, industry has gone home to continue to pursue conventional oil, leaving the deer and elk still in possession of the realm of oil shale.

Still a national treasure. A treasure of oil may not yet be proven, but calling the western U. S. oil shales a national treasure is surely justified. The very fine-grained deposits have preserved in delicate detail a wonderful record of life during the Eocene Epoch in this region. Pollen grains tell of the vegetation, and myriad insects are preserved to the degree that the compound eyes of even very tiny specimens are intact. (Bradley, 1931). Many vertebrate fossils have been found, most famous of which are the exquisitely preserved fossil fish, which grace museums the world over. These fish are the reason for Fossil Butte National Monument near Kemmerer, Wyoming. Oil shales are a natural library of geological history second to none, but their oil potential remains elusive.

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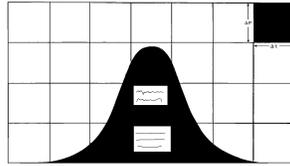
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AUTHOR: Walter Youngquist received a Ph.D. in geology from the University of Iowa. He has both domestic and overseas oil experience with Exxon Corporation, and has been consultant to Sun Oil Company, Shell Oil Company, and Amoco. Beyond petroleum, his interest has been in alternative energy sources. He first visited the Colorado Plateau oil shale country in 1946, and has followed developments there ever since. He is the author of numerous articles and nine books including *GeoDestinies: The Inevitable Control of Earth Resources Over Nations and Individuals* (1997).

Walter Youngquist
P. O. Box 5501
Eugene, OR 97405
Phone: 541/343-9768

H.C. NEWSLETTER



The M. KING HUBBERT CENTER FOR PETROLEUM SUPPLY STUDIES

Located in the Department of Petroleum Engineering
Colorado School of Mines
Golden, Colorado

The Hubbert Center has been established as a non-profit organization for the purpose of assembling and studying data concerning global petroleum supplies and disseminating such information to the public.

The question of WHEN worldwide oil demand will exceed global oil supply is stubbornly ignored. The world's oil problems, timing and ramifications can be debated and realistic plans made only if the question is publicly addressed. A growing number of informed US and European evaluations put this crisis as close as the years 2000 - 2014. The formation of this center is to encourage a multi-field research approach to this subject.

For further information contact:

Hubbert Center Chairman
Prof. Craig W. Van Kirk
Head of Petroleum Engineering Dept.
Colorado School of Mines
Golden CO 80401-1887
Phone: 1-800-446-9488
Fax: 1-303-273-3189
Internet Address: <http://hubbert.mines.edu>

Hubbert Center Coordinator
L. F. Ivanhoe
1217 Gregory St.
Ojai CA 93023-3038
Phone: 1-805-646-8620
Fax: 1-805-646-5506

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