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OIL SHALE

Vernon C. Newton, Jr.* and Paul F. Lawson**

The United States has enormous deposits of oil shale which, if developed, could provide energy resources for centuries (Figure 1). Because of the vast size of these deposits, they are currently receiving a great deal of attention.

This issue of The ORE BIN is devoted to a discussion of oil shale -- what it is, how it formed, its distribution, methods of extracting the oil, economics of the industry, and the environmental impact of processing the shale.

What is Oil Shale?

Oil shale is a dark, organic, thin-bedded sedimentary rock. The source of the oil is kerogen, a mineraloid of indefinite composition consisting of fossilized organic material which was trapped in fine-grained bottom sediments during deposition in ocean and lake basins. Oil shale is also called "kerogen shale." Kerogen is insoluble in petroleum solvents and does not break down into oil until heated to more than 662°F.

Any organic shale that yields 10 gallons or more of oil per ton by distillation under low pressure is considered oil shale by the industry (Duncan and Swanson, 1965). Oil shale yielding 10 to 15 gallons per ton of oil is considered low grade; that yielding 25 to 100 gallons per ton makes up the high-grade deposits.

Oil shale is neither petroleum nor coal but an intermediate material. All three have similar origins, but the processes that formed them are complex. The existence of a chemical reducing or oxidizing environment during deposition of organic matter, the type of organic material, and the minerals present in rocks determines whether petroleum, coal, or kerogen will be formed (Levorsen, 1954).

It is believed that petroleum hydrocarbons form fairly soon after the sediments are deposited, whereas kerogen and coal represent residual organic

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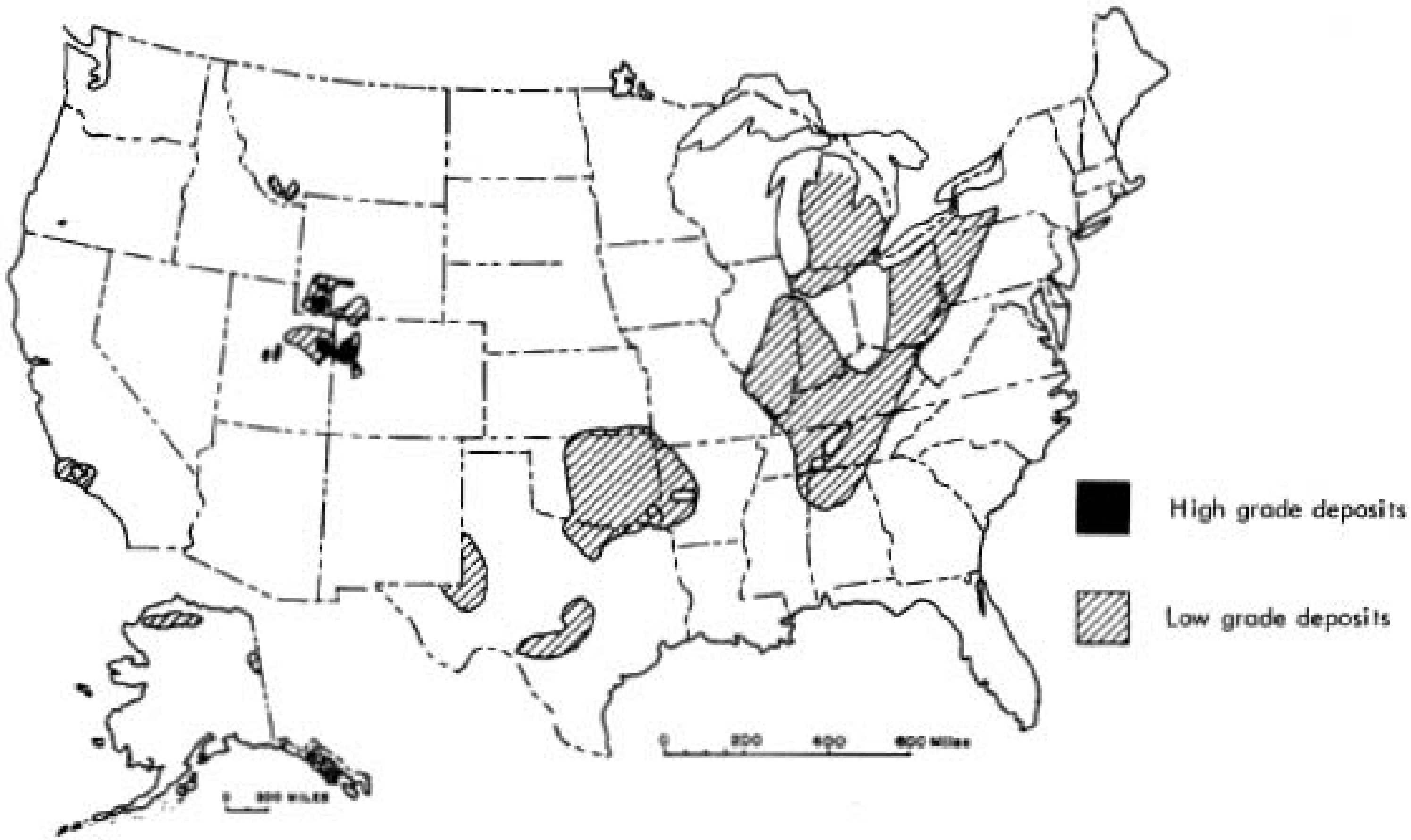


Figure 1. Principal oil-shale deposits in the United States (from Duncan and Swanson, 1965)

matter in the sediments. Kerogen and cannel coal are formed from sapropelic material (organic ooze consisting of bacterially decomposed microorganisms and plant remains); bituminous and anthracite coals are formed mainly from humic material.

These three hydrocarbon products are commonly associated. For example, oil and tar are often found in cracks and openings in oil shale; coal seams may be interbedded with oil shale. In many places, oil shale grades into cannel coal.

A comparison of the organic composition of petroleum, oil shale, and coal clearly indicates a close genetic relationship. The analyses show also the intermediated character of kerogen shale (Table 1).

Table 1. Average compositions of crude oil, oil shale, and coal

	Crude oil	Oil shale	Bituminous coal	Anthracite coal
Carbon	85	80.5	82	85
Hydrogen	12	10.3	5	4.5
Nitrogen	0.5	2.7	1.5	1.0
Oxygen	2	5.8	10.3	7.5
Sulfur	0.5	.7	1.2	2.0

Where is Oil Shale Found?

Oil shale is widely distributed throughout the world and is found in rocks of all ages from Cambrian through Tertiary. As mentioned above, it formed from organic debris deposited with bottom sediments in ocean and lake basins.

World reserves

The world's reserves of high-grade oil shale available with present technology amount to about 1.3 trillion barrels of oil. Nearly half of this (600 billion barrèls) occurs in the United States. Southern Brazil has an estimated 800 billion barrel reserve. Africa (mainly the Congo) has 100 billion barrels, Europe has 30 billion barrels, and Asia has 20 billion barrels (Duncan and Swanson, 1965).

The world's reserves of low-grade oil shale are estimated to be equivalent to 325 trillion barrels of oil. About 8 percent of these reserves are located in the United States.

United States reserves

Green River: The largest deposits of high-grade oil shale in the U.S. are in the adjoining parts of Colorado, Utah, and Wyoming (Table 2). They

Table 2. Green River oil-shale reserves

	Billions of barrels of oil in place			
	Colorado	Utah	Wyoming	Total
Intervals 10 ft. or more thick averaging 25 gal/ton or more of oil	480	90	30	600
Intervals 10 ft. or more thick averaging 10 to 25 gal/ton of oil	800	230	400	1,430
Total: Intervals 10 ft. or more thick averaging over 10 gal/ton	1,280	320	430	2,030

Dinneen and Cook, 1974

occur in the Green River Formation, an extensive lake deposit of early to middle Eocene age. The Formation is 1,800 to 5,000 feet thick and occupies several individual basins, mainly the Piceance, Green River, Uinta, and Washakie Basins (Figure 2).

The Green River oil shale is a "marlstone" deposited on lake bottoms as a mixture of clay, sand, and lime containing varying amounts of kerogen. The richest and thickest deposits occur near the central basin axis (Folsom, 1963) and are as much as 2,000 feet thick. In the Piceance Basin, overburden ranges from 25 feet in thickness along the edge of the basin to more than 1,000 feet near the center. The "Mahogany Ledge," which contains the richest oil shale in the Green River Formation, is 110 feet thick in the middle of the basin and yields an average of 42 gallons per ton (Oil and Gas Jour., 1964, p. 65). Other beds of high-grade oil shales in the Piceance Basin are more than 15 feet thick and yield 15 to 25 gallons of oil per ton.

Table 3 shows the inorganic content of the Green River oil shale and the high percentage of carbonate minerals. Of particular interest are dawsonite, an aluminum carbonate, and nahcolite and trona, sodium carbonates, which have significant by-product potential because of the large quantities of shale to be mined. There is an estimated 30 billion tons of nahcolite,

Table 3. Inorganic matter in Green River raw shale

Carbonates	50
Feldspar	19
Illite	15
Quartz	10
Analcite, et al.	5
Pyrite	1
(Weight percent inorganic	86.2)
(Weight percent organic	13.8)

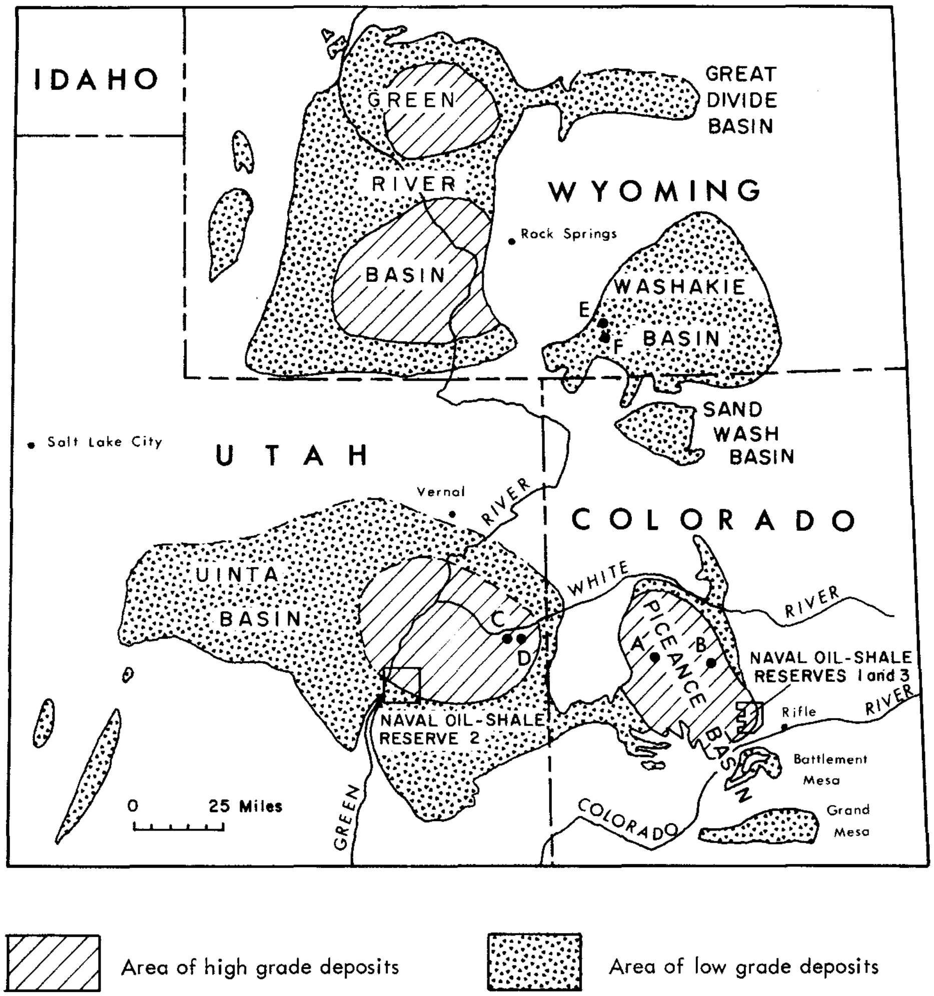


Figure 2. Green River oil shale deposits (from Duncan and Swanson, 1965). Tracts A through F shown in Table 4.

100 billion tons of trona, and 27 billion tons of dawsonite, containing 9.5 billion tons of alumina, in the Piceance Basin of Colorado and Green River Basin of Wyoming. These by-products represent major reserves of alumina and soda ash (American Mining Congress, 1968).

Other U.S. reserves: Oil shale occurs in 27 other states in the Union, and the character of the deposits varies widely. Most of the oil shale other than that in the Green River Formation was deposited in a marine environment. These deposits are mainly low grade and not minable under present economic conditions. However, yields up to 42 gallons of oil per ton of shale have been obtained on tests of the Barnett shale of Mississippian age in central Texas (Oil and Gas Jour., March 1967). Mississippian oil shales are also found in the south-central states. The Ohio shale of Devonian age underlies the eastern coal fields and extends from central Alabama through Tennessee and West Virginia. It extends west of the Appalachian coal fields, across central Ohio, through central Kentucky, across a portion of Illinois and underlies most of Michigan (see Figure 1). Diatomaceous Miocene shales in southern California contain significant oil shale reserves. Marine oil shales occur in Alaska in Jurassic and Triassic rocks.

Oil shale in Oregon: A small deposit of oil shale occurs in the Western Cascades of Oregon 10 miles northeast of Ashland. The deposit is interbedded with tuff of the Little Butte Volcanics of Oligocene age (Figure 3), and represents a local fresh-water lake environment where organic material and volcanic ash accumulated. The thickest layer of oil shale is about 4 feet, and the total thickness of the oil shale beds is about 10 or 15 feet. Assays by the U.S. Bureau of Mines yielded 35 to 37 gallons of oil per ton of shale. The extent of the deposit is not known but is probably small and is estimated to contain less than a million tons of kerogen shale.

Development of the shale deposit began in the 1930's with construction of a mill, a retort, and a small settlement of 32 cabins. The shale was first mined and processed for oil, which was noncommercial, and later

Figure 3. Exposure of high-grade oil shale near Ashland, Oregon.

was reportedly marketed as a medicinal tonic, a soil conditioner, and a cattle-feed additive.

Organic shale of possible potential value is present in beds of varying thickness in the lacustrine Payette and Succor Creek Formations of Pliocene age in southeastern Oregon. Tests made thus far, however, have yielded only half a gallon of oil per ton.

What is the History of Commercial Development?

Foreign Countries

The first commercial oil-shale operations began in France in 1838 and in Scotland around 1850. Oil-shale industries were later established in Russia, Sweden, Spain, Manchuria, South Africa, and Germany. By 1950, all except Russian and Manchurian operations were shut down because they could not compete with petroleum fuels (Schramm, 1970).

The Soviet oil-shale industry has been unprofitable, at least until recently. In the past, the major portion of mined shale in Estonia and north Leningrad Province was burned as raw fuel for Baltic area electric power generation. Production from Estonian and Leningrad deposits totalled 21.5 million tons in 1965. Shale gas production was approximately 100 million cubic feet per day during the same year (Oil and Gas Jour., October 1965). Although Russia now recognizes the value of extracting oil from oil shale rather than burning the raw material, future emphasis will probably be on petroleum resources.

Not much is known about the Chinese oil-shale operations, which are principally at Fushun, Manchuria. The Fushun project is producing at the present time. The Manchurian shales were an important source of oil during World War II and reportedly produced 40,000 barrels per day in 1961.

Brazil is going ahead with a major oil-shale development at Sao Paulo, where high-grade deposits are to be mined from the Iraty shale of Late Permian age.

United States

Prior to the 1869 discovery of oil in Pennsylvania, about 60 shale and coal distillation plants functioned in northeastern United States, 25 of which were in Ohio. The plants operated on shale which yielded between 8 and 20 gallons of oil per ton (McKee, 1925). The oil-shale industry became noncompetitive when the petroleum industry was established. Since that time, no significant amount of oil shale has been mined and processed in the United States.

Table 4. Federal prototype oil-shale leases

Company	Tract	Type operation	Reserves (tons) (20-30 gpt)	Bonus paid (millions)	Lease sale date
Gulf Oil Co. and Standard of Indiana	A.* Piceance Basin, Colorado	Underground or surface mine	1.86×10^9	$210.3	Jan. 1974
Atlantic-Richfield and partners	B. Piceance Basin, Colorado	Underground mine	1.01×10^9	117.8	Feb. 1974
Sun Oil Co. and Phillips Petrol.	C. Uinta Basin, Utah	Underground mine	342×10^9	75.6	March 1974
White River Shale Corp. and partners	D. Uinta Basin, Utah	Underground	372×10^9	45.0	April 1974
(received no bids when offered)	E. Washakie Basin, Wyoming	In situ	354×10^9	---	May 1974
(received no bids when offered)	F. Washakie Basin, Wyoming	In situ	352×10^9	---	June 1974

*See Figure 2 for tract locations

What is the Status of the U.S. Oil Shale Development?

Economics

For the past 20 years, mineral resource experts have been giving increasing attention to United States oil-shale deposits. During this period more than 20 private firms were involved in oil-shale research. Thus far, petroleum, because of its relatively low price, has kept shale oil (kerogen) off the market. It has been estimated that under 1973 economic conditions high-grade oil shale can compete with petroleum at $8 a barrel, whereas liquefaction of coal probably becomes competitive only when petroleum reaches $10 per barrel. These potential sources of hydrocarbons should have the effect of holding prices of petroleum to around $8 a barrel.

Shale oil would be low-sulfur premium fuel oil and be in great demand in metropolitan areas. A one-million barrel per day underground operation or strip mine would require approximately $4 to $5 billion in capital investment. In-situ combustion technique would take considerably less capital. However, the latter technology is still in the research stage (West, 1974).

A depletion allowance of 15 percent on raw shale oil is allowed under Federal tax laws. The reduction of depletion on petroleum from 27 percent to 22 percent improved the competitive position of shale oil.

Federal lands opened

The Federal government controls 80 percent of the rich oil-shale reserves in the Green River Formation; thus development of this resource depends upon government policy. Hundreds of mining claim titles, many pre-1920, had to be cleared before the Federal lands could be offered for lease. Clearing of titles and revisions to the mining law involved several years of litigation.

In June 1971, Secretary of the Interior, Rogers Morton, initiated a prototype leasing program on Federal lands in Colorado, Utah, and Wyoming. The program called for six leases of 5,100 acres each to establish commercial oil-shale facilities. The plan was to field test current technology in order to determine the actual economics and impact of the industry. The program envisaged construction of the six commercial-scale plants with an estimated production of 250,000 bbl/d to be on line in the 1980's. Each plant would require $200 million to $250 million capital investment.

After an assessment of environmental impact was completed, the first shale lease was offered for bid in January 1974. The last of the six tracts was offered for lease in June 1974 (Table 4 and Figure 2). No bids were received for the two low-grade deposits in Wyoming.

How is Oil Removed from Oil Shale?

Extraction techniques

There are two methods of recovering oil from kerogen shale: mining the shale and above-ground retorting, or in-situ (underground) combustion. A generalized flow sheet illustrating the entire oil-shale mining operation is shown in Figure 4.

If the deposit is to be mined, depth of the kerogen shale beds below the surface determines whether underground or strip mining will be used. Experiments in underground mining with the room-and-pillar method have been done; ideally about 75 percent of the shale is removed and 25 percent is left as supporting pillars.

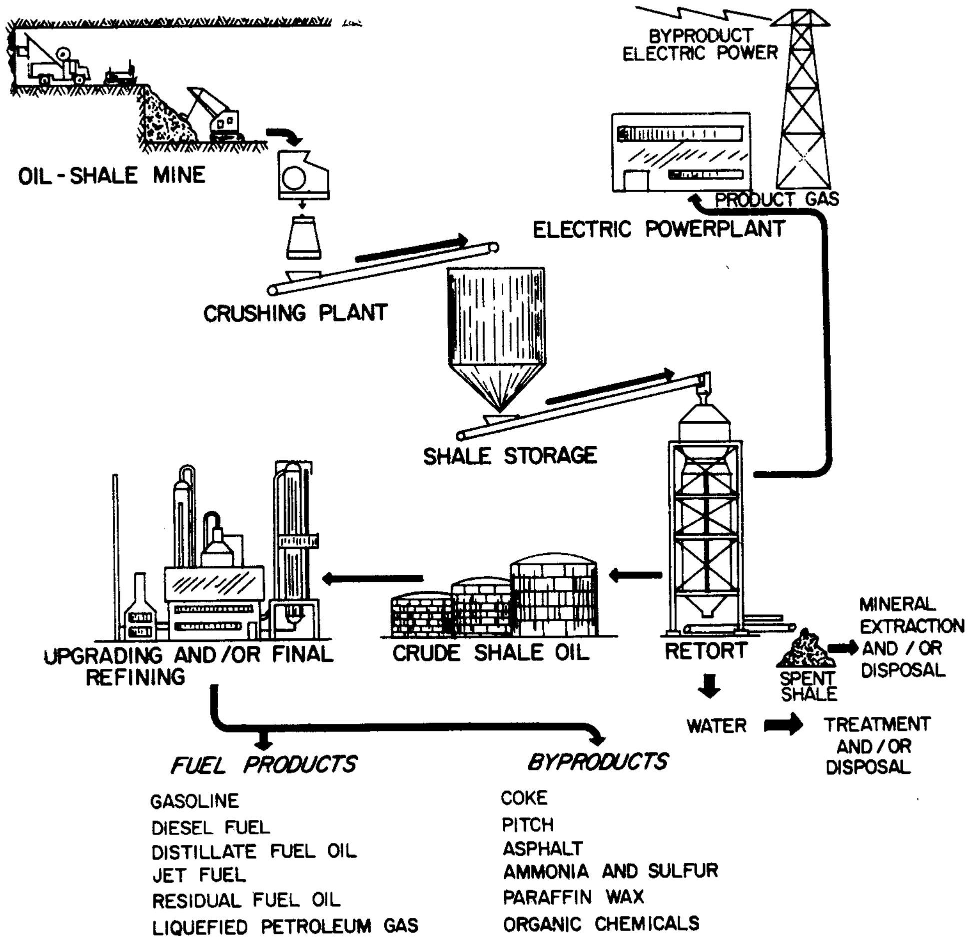


Figure 4. Surface processing system for oil shale from mine to products and byproducts (American Mining Congress, 1968).

Proponents of in-situ combustion methods (Figure 5) point out that the cost of mining, milling, and retorting can be eliminated by retorting underground. Waste is not a problem because the spent shale remains in place. This method of recovery involves drilling a pattern of wells so that the shale can be hydraulically fractured. Fuel must be pumped into the holes and burned until the temperature reaches 850°F to 900°F, at which temperature the shale will ignite and continue burning. Air must also be supplied to keep the shale burning. Thus far, none of the pilot projects using in-situ burning has been successful. Use of nuclear explosives to fracture and retort oil shale underground appears to be feasible. The type of radioactive byproducts can be controlled to a certain extent by design of the explosive. The system involves detonation of many underground charges so that seismic ground motion appears to be the main problem. In this method, also, air must be introduced through wells to support underground combustion of the fractured shale (Lekas and Carpenter, 1965).

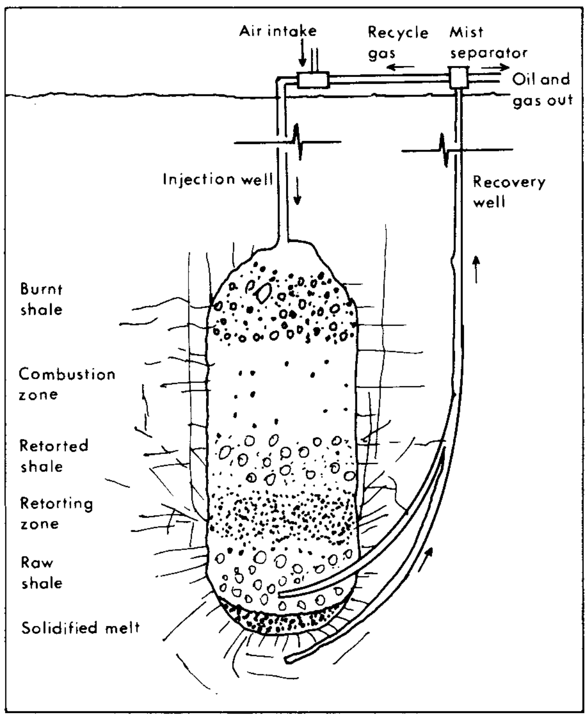


Figure 5. In-situ recovery using nuclear explosives (from Lombard and Carpenter, 1967).

Retorting technology

Experimental models of retorts have developed significantly over the past 20 years (Figure 6). The U.S. Bureau of Mines used a modified gas-combustion retort (Figure 6-a) operating on a downflow of shale and upward circulation of hot gas. Hydrocarbons leave the retort in a gaseous state. The Union Oil Company project at Grand Valley, Colorado operates on the exact opposite basis (Figure 6-b). It uses a downdraft of air with raw shale fuel being fed at the bottom and rammed upward by a piston. Oil Shale Corporation (partner with Atlantic-Richfield) introduced the Tosco Process utilizing hot ceramic balls to convey heat to the oil shale (Figure 6-c). The kerogen vaporizes and is condensed in a cooler. Advantage of the process is that the shale gas is not polluted by air. The Tosco Process has given the highest yields thus far of any of the retorting methods (Oil and Gas Jour. 1964).

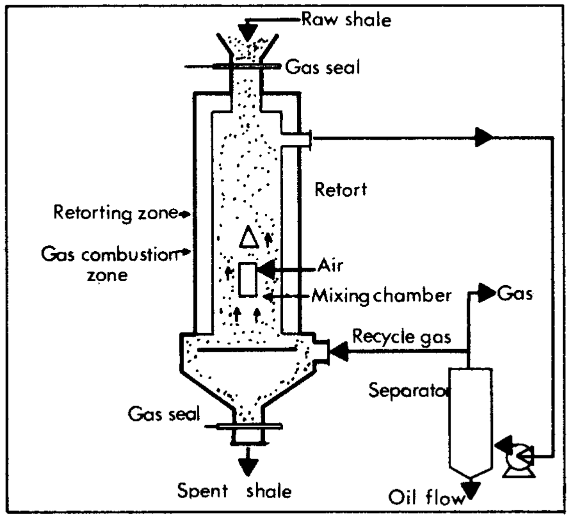
Pour point of the crude shale oil ranges between 85° and 95°F, API gravity is 17° to 22°, and viscosity approximately 300 Saybolt seconds. This means that the crude shale oil has to be heated to above 90°F to pump through a pipe line. The sulphur content is below 0.75 percent.

The extractable energy in oil shale by normal destructive distillation includes 80 percent oil, 6 percent gas, and 4 percent coke and char. The character and amount of liquids and gas can be varied by introducing hydrogen under high pressure. Approximately 65 percent of the oil can be converted to shale gas by hydrogenolysis. However, the added refining in the hydrogen processes takes nearly half of the available energy in the shale. The gas obtained has a heating value of 1,000 BTU/$F+^3$. Theoretically, 1 gallon of oil will yield 100 $F+^3$ of gas by adding hydrogen under pressure (Duncan and Swanson, 1965).

What Will be the Effect on the Environment?

The environmental effect of a shale-oil industry in the Green River, Washakie, and Unita Basins has been estimated by the U.S. Department of Interior in a statement issued in August 1973. Water requirements for the 250,000 bbl/d prototype projects will be between 8,000 and 11,500 acre feet per year. For a mature shale-oil industry producing 1 million bbl/d of shale oil, the requirement will be between 121,000 and 189,000 acre feet per year, according to an August 30, 1973 news release of the U.S. Department of the Interior.

Water resources in Utah and Wyoming are believed to be adequate to support a mature plant but a shortage could develop in Colorado as water use increases in other sectors. Construction of additional hydro-facilities or importation of new supplies into the Colorado River basin may be necessary (Schramm, 1970). Downstream pollution may occur if all the water is supplied by the Colorado system. Waste effluent containing organic substances could add to pollution if not properly processed and water salinity at Hoover Dam could increase to approximately 15 mg/liter or 1.5 percent from a mature shale-oil industry.



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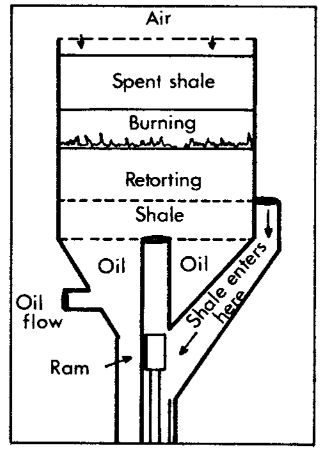

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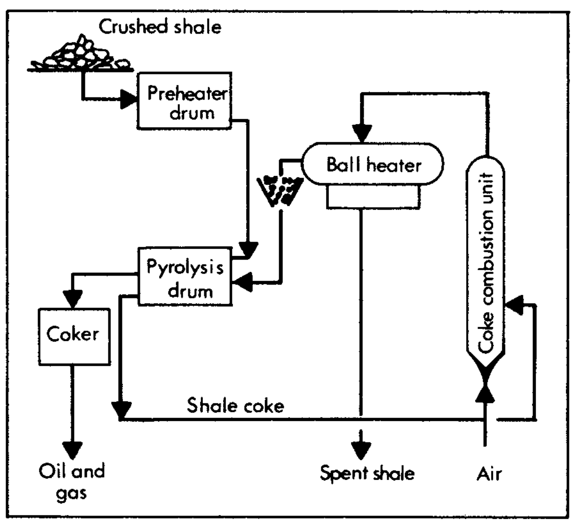

C.

Figure 6. Above-ground retorting methods: A. U.S. Bureau of Mines gas-combustion process; B. Union Oil Co. down-draft retort; C. Tosco Process used by Oil Shale Corp.

Air quality will be affected locally and clarity and visibility reduced. Some fine particulate matter will likely be emitted, along with small amounts of hydrogen sulfide. There is a potential for atmospheric inversions 20 days per year, according to the August 1973 U.S. Department of Interior news release. Influx of population due to the prototype operations will be approximately 34,000 persons to an area where 119,000 now live. There will be some impact on wildlife. Introduction of a mature industry into the region would reduce deer population, in some localities as much as 10 percent, according to the U.S.D.I.

Perhaps the most significant environmental problem is the handling of spent shale wastes. For the average grade shale to be mined, it will take 1.7 tons of shale to produce 1 barrel of oil. Therefore 1.7 million tons of spent shale will be accumulated every day the plant produces 1 million barrels of oil, or a total of 620 million tons per year. The problem is compounded by the fact that the shale expands approximately 25 percent by volume during retorting.

The terrain where mining will take place is rugged and relief is high; some operations may be able to take care of wastes by filling nearby arroyos. The wastes can be compacted, shaped, and terraced. Studies by the U.S. Bureau of Mines indicate that the spoils can be vegetated after three years of weathering. In other instances, the waste shale can be returned to the mined-out area. Large waste piles, though symmetrical, would not be aesthetically pleasing.

What is the Outlook for the Industry?

The Federal program involving six prototype shale leases in Colorado, Utah, and Wyoming is projected to produce 250,000 barrels a day by 1980. Development of private properties, along with a full-scale operation on additional Federal leases, may reach 1 million barrels a day before 1990.

If the industry is able to expand its production to 2 million barrels of shale oil a day by the year 2,000, the amount will equal or possibly exceed the estimated domestic production of petroleum from wells. In light of the potential for the oil-shale industry to help offset our declining petroleum resources, it appears that we should no longer delay this development. The impact of the industry on the environment should be closely studied and the undesirable side effects reduced as much as possible.

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LINN COUNTY ENVIRONMENTAL GEOLOGY REPORT PUBLISHED

"Environmental Geology of Western Linn County, Oregon" is the latest of the Department's bulletins dealing with environmental geology. The authors are John D. Beaulieu, Department stratigrapher and environmental geologist, and Paul W. Hughes and R. Kent Mathiot, both of Hughes and Associates, Inc., consulting geologists.

Western Linn County is characterized by the foothills of the Western Cascades, terraced valleys, and the extremely flat lowlands of the Willamette Valley. As part of the environmental geology program, the study was initiated to provide pertinent information on geologic hazards to planners and developers in the County. The bulletin discusses geologic units, engineering geology, soils, flooding, mass movement, erosion, and other hazards in addition to natural resources.

Bulletin 84 has 116 pages, 78 figures and photographs, 18 tables, and 22 full-color maps (geology, soils, hazards) on a scale of 1" to the mile. It can be obtained from the Department offices in Portland, Grants Pass, and Baker. Price is $8.00.

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NEWPORT-WALDPORT MAP REPRINT AVAILABLE

"Geology of the Newport-Waldport area, Lincoln County, Oregon," by H. E. Vokes, Hans Norbisrath, and P. D. Snavely, Jr., published in 1949 as U.S.G.S. Oil and Gas Investigations Map OM-88, has long been out of print. Because of the demand for the map and accompanying fossil check lists and text, the Department has made blue-line ozalid prints that can be purchased at the Portland office for $2.50 each. Although geologic interpretations have been revised in more recent publications, this version contains considerable useful information.

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FEA SETS PROJECT INDEPENDENCE HEARINGS

The Federal Energy Administration is holding 10 regional hearings on Project Independence focusing on local, regional, and national energy concerns. Project Independence is a program to evaluate the growing U.S. dependence on foreign sources of energy and to develop positive programs to reduce our vulnerability to future oil cutoffs and price increases. Hearings in west coast states are: Seattle, Sept. 5-7; San Francisco, Oct. 7-10.

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POTASSIUM ARGON AGES OF VOLCANIC ROCKS COMPILED

All available potassium-argon age measurements on volcanic rocks in Oregon are given in a recent publication by the U.S. Geological Survey. The compilation, MF-569, is in two sheets consisting of a map of Oregon showing location of rocks sampled and a tabulation which gives alphabetically by county the location of each sample, formation, rock type, material analyzed, age, and source of information. MF-569, entitled "Compilation of potassium-argon ages of Cenozoic volcanic rocks of Oregon," is by G. W. Walker, G. B. Dalrymple, and M. A. Lanphere. The publication is for sale by the U.S. Geological Survey, U.S. Court House, Room 678, West 920 Riverside Ave., Spokane, WA 99201. The price is $1.00.

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COASTAL AND OFFSHORE EARTHQUAKES LISTED

A recent publication issued by Oregon State University lists 2,220 earthquakes that have occurred in historic time (1853 to 1973) along and off the Pacific Northwest coast. Information given includes the date, time, location of epicenter, location of highest intensity reported, observed and computed magnitude, and focal depth. A map showing the general distribution of the earthquake epicenters is included. The compilation provides data to assess the potential effects of coastal and offshore earthquakes on coastal areas, particularly in selection of sites for nuclear installations and large construction projects.

The 67-page book, "Coastal and offshore earthquakes of the Pacific Northwest," prepared by Richard Couch, Linda Victor, and Kenneth Keeling, School of Oceanography, OSU, was done in cooperation with the Oregon Department of Geology and Mineral Industries. Copies of the publication are available from Geophysics office, School of Oceanography, Oregon State University, Corvallis, 97331.

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MINED LAND RECLAMATION HEARINGS IN SEPTEMBER

Mined land reclamation hearings will be held late in September to consider revisions to administrative rules proposed by the Department. Information on time and place of the hearings will be available by calling or writing Oregon Department of Geology and Mineral Industries at its Portland office, 1069 State Office Building, or phone 229-5580.

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GEOTHERMAL GROUP VISITS HOT SPOTS

A 6-day field trip June 24 to 29, 1974, showed 32 persons interested in geothermal development several areas in Oregon and Washington where geothermal fluids are known or thought to be present. The tour was led by R. G. Bowen, Department Economic Geologist, assisted in particular areas by Paul Hammond, PSU, and Department geologists R. E. Corcoran, H. C. Brooks, and N. V. Peterson. In Washington, the places visited were Government Mineral Springs and Trout Lake in the Cascades. In Oregon, the group visited Hot Lake near La Grande, Snake River Canyon, Vale-Owyhee region, Diamond Craters, and hot springs in the Alvord area and in the Oregon Cascades. The group were shown practical applications of geothermal energy for space heating in Lakeview and Klamath Falls.

Back row, left to right: H. J. Olson, D. Pilkington, AMAX; J. H. Robison, U.S.G.S.; K. H. Koenen, Geophysical consultant; M. Millis; L. Garrett, Shell; R. G. Detrick; W. H. Lee, U.S.G.S.; W. D. Michell, Reynolds; A. Alpha, Mobil; C. W. Jordan, Burlington Northern; W. S. Cox, Ore. Div. State Lands; G. W. Berry, Consulting geologist; E. Kurtz, O.I.T.; D. F. Finn, Geothermal Energy Inst.; R. J. Rossetter, Gulf; R. M. Sanford, Hunt Oil; P. E. Hammond, P.S.U.; P. M. Scott, Gulf. Front row, left to right: F. Dellechaie, AMAX; E. P. Kiver, E.W.S.C.; A. L. Strasfogel, Int'l Paper; N. J. Beskid, Argonne Nat'l Lab.; C. Isselhardt, Union Oil; E. H. Haynes, Chevron; P. Birkhahn, Woodward-Gizienski; R. M. Normark, EXXON; R. G. Bowen, Ore. Dept. of Geology and Mineral Industries.

Geothermal group visited Mickey hot springs near Alvord Desert in Harney County.

Geothermal group searched for volcanic bombs at Harney County aggregate pit in Diamond Craters area.

DEPARTMENT LABORATORY SCHEDULE OF ANALYTICAL FEES REVISED

Sample preparation:

1.	Drying of wet samples	$1.00
2.	Crushing of large (over 3" diameter) samples	2.00

Spectrographic analyses:

1.	For 3 elements (excluding the precious metals)	$ 5.00
2.	For the precious metals only	15.00
3.	For 62 elements (excluding the precious metals)	10.00
4.	For 62 elements plus gold and silver	16.00
5.	For 70 elements (including the precious metals)	20.00

20% discount in groups of 3 or more samples at one time

Chemical analyses:

Gold and silver	$ 8.00	Phosphorous	$ 8.00
Alumina	12.00	Platinum metals:	
Antimony	12.00	As a group	25.00
Barium	12.00	Platinum	20.00
Calcium oxide	10.00	Palladium	20.00
Chromium	12.00	Iridium	20.00
Cobalt	12.00	Rare Earths (total) ..	30.00
Copper	7.00	Silica	10.00
Iron	8.00	Tin	12.00
Lead	8.00	Titanium	15.00
Magnesium	10.00	Tungsten	15.00
Manganese	10.00	Uranium	15.00
Mercury	8.00	Vanadium	12.00
Molybdenum	12.00	Zinc	9.00
Nickel	8.00	Loss on ignition ...	3.00

25% discount for the same element in groups of 3 or more samples at one time

Atomic absorption analyses:

Prices on request.

There is no limitation on the number of samples, and information concerning the legal description or ownership of the property is not required. Fees for all analyses must accompany the samples. A convenient assay request blank will be provided upon request. Analytical results will be reported as promptly as possible after receipt of sample and fee.

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AVAILABLE PUBLICATIONS

(Please include remittance with order; postage free. All sales are final - no returns. Upon request, a complete list of Department publications, including out-of-print, will be mailed)

BULLETINS

8. Feasibility of steel plant in lower Columbia River area, rev. 1940: Miller . . .	$0.40
26. Soil: Its origin, destruction, preservation, 1944: Twenhofel	0.45
33. Bibliography (1st suppl.) geology and mineral resources of Oregon, 1947: Allen. .	1.00
35. Geology of Dallas and Valsetz quadrangles, Oregon, rev. 1963: Baldwin. . . .	3.00
36. Papers on Tertiary foraminifera: Cushman, Stewart & Stewart. vol. 1 $1.00; vol. 2	1.25
39. Geology and mineralization of Morning mine region, 1948: Allen and Thayer . .	1.00
46. Ferruginous bauxite deposits, Salem Hills, 1956: Corcoran and Libbey	1.25
49. Lode mines, Granite mining district, Grant County, Oregon, 1959: Koch . . .	1.00
52. Chromite in southwestern Oregon, 1961: Ramp	3.50
57. Lunar Geological Field Conf. guidebook, 1965: Peterson and Groh, editors . . .	3.50
58. Geology of the Suplee-Izee area, Oregon, 1965: Dickinson and Vigrass	5.00
60. Engineering geology of Tualatin Valley region, 1967: Schlicker and Deacon . . .	5.00
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64. Geology, mineral, and water resources of Oregon, 1969	1.50
66. Geology, mineral resources of Klamath & Lake counties, 1970: Peterson & McIntyre	3.75
67. Bibliography (4th suppl.) geology and mineral industries, 1970: Roberts	2.00
68. The Seventeenth Biennial Report of the State Geologist, 1968-1970	1.00
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76. Eighteenth Biennial Report of the Department, 1970-1972	1.00
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79. Environmental geology inland Tillamook Clatsop Counties, 1973: Beaulieu . . .	6.00
80. Geology and mineral resources of Coos County, 1973: Baldwin and others . . .	5.00
81. Environmental geology of Lincoln County, 1973: Schlicker and others	7.50
82. Geol. hazards of Bull Run Watershed, Mult. Clackamas Cos., 1974: Beaulieu . .	5.00
83. Eocene stratigraphy of southwestern Oregon, 1974: Baldwin	in press
84. Environmental geology of western Linn Co., 1974: Beaulieu and others	8.00
85. Environmental geology of coastal Lane Co., 1974: Schlicker and others	in press

GEOLOGIC MAPS

Geologic map of Oregon west of 121st meridian, 1961: Wells and Peck	2.15
Geologic map of Oregon (12" x 9"), 1969: Walker and King	0.25
Geologic map of Albany quadrangle, Oregon, 1953: Allison (also in Bulletin 37) . .	0.50
Geologic map of Galice quadrangle, Oregon, 1953: Wells and Walker	1.00
Geologic map of Lebanon quadrangle, Oregon, 1956: Allison and Felts	0.75
Geologic map of Bend quadrangle, and portion of High Cascade Mtns., 1957: Williams	1.00
GMS-1: Geologic map of the Sparta quadrangle, Oregon, 1962: Prostka	1.50
GMS-2: Geologic map, Mitchell Butte quad., Oregon: 1962, Corcoran and others . .	1.50
GMS-3: Preliminary geologic map, Durkee quadrangle, Oregon, 1967: Prostka . . .	1.50
GMS-4: Gravity maps of Oregon, onshore & offshore, 1967: Berg and others [sold only in set] flat $2.00; folded in envelope	2.25
GMS-5: Geology of the Powers quadrangle, 1971: Baldwin and Hess	1.50
GMS-6: Prelim. report, geology of part of Snake River Canyon, 1974: Vallier . . .	in prep.

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Landforms of Oregon: a physiographic sketch (17" x 22"), 1941 . . . . 0.25
Geologic time chart for Oregon, 1961 . . . . free
Postcard - geology of Oregon, in color . . . . . 10¢ each; 3 - 25¢; 7 - 50¢; 15 - 1.00
Oregon base map (22 x 30 inches) 0.50
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