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## OIL-SHALE TECHNOLOGY: A REVIEW

By H. M. Thorne, K. E. Stanfield, G. U. Dinneen,  
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UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

1964

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**UNITED STATES DEPARTMENT OF THE INTERIOR**  
Stewart L. Udall, Secretary

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# OIL-SHALE TECHNOLOGY: A REVIEW

by

H. M. Thorne,<sup>1</sup> K. E. Stanfield,<sup>2</sup> G. U. Dinneen,<sup>2</sup>  
and W. I. R. Murphy<sup>2</sup>

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## ABSTRACT

Oil shale, a potential source of products presently obtained from petroleum, is found in many countries. The most extensive known deposits from the standpoint of potential shale oil in place are those in Brazil and the United States of America. Mining methods used for oil shale range from open-pit operations for shallow deposits to room-and-pillar and longwall techniques for deposits with thick overburdens.

Oil shales from different sources vary greatly in the amounts and types of organic and inorganic constituents. By retorting, the organic material is converted to oil, gas, and coke. The largest percentages of oil are obtained from materials having the highest hydrogen content.

Over 2,000 retorting systems have been patented, but only a few have been used industrially, and no single process seems best for all types of shales or economic conditions.

Shale oils have different characteristics, depending on the source rock and method of retorting. They contain large quantities of olefinic hydrocarbons and more oxygen, nitrogen, and sulfur derivatives of hydrocarbons than most petroleum. Consequently, petroleum refining methods usually must be modified for shale oil. This is particularly true in catalytic processing. Hydrogenation, even under mild conditions, improves shale-oil refinability.

Several byproducts may be obtained from both the retorting and refining steps.

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## INTRODUCTION

Oil shale is an abundant fossil fuel of widespread occurrence throughout the world. This shale, though little used today, is a potential source of products presently obtained from petroleum. By heat, the organic material in the rock is converted to crude shale oil, which in turn may be recovered and processed to petroleumlike products.

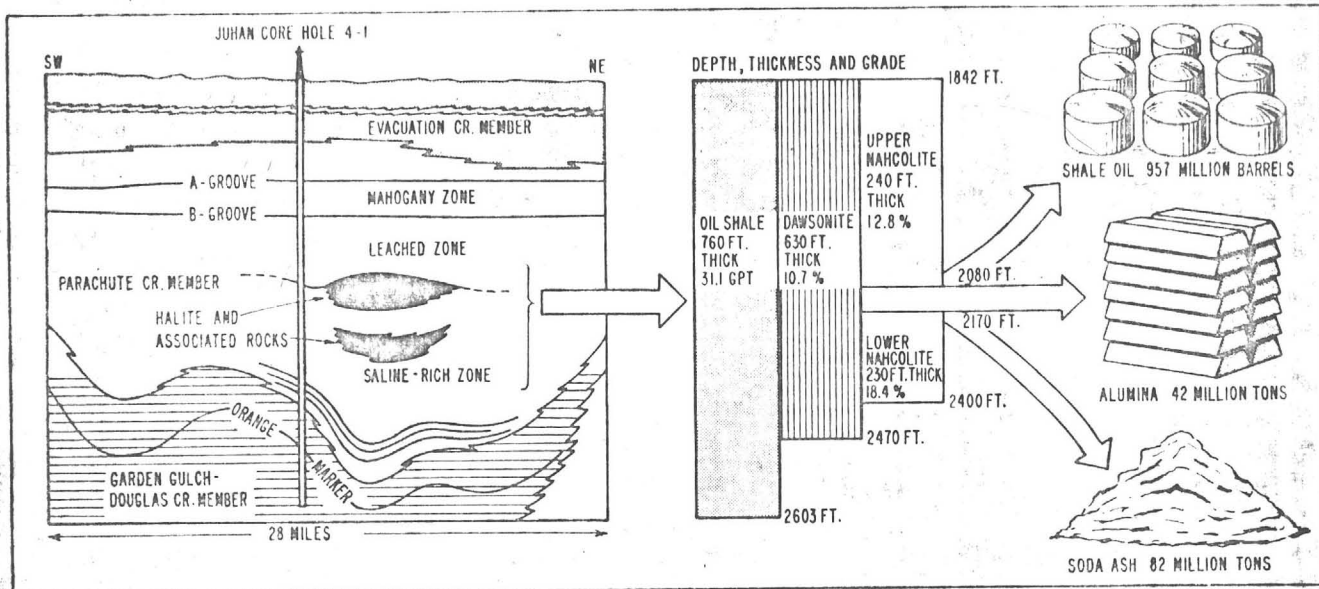
Oil shale was formed by the deposition and lithification of finely divided mineral matter and organic debris in the bottoms of shallow lakes and seas. The organic debris, predominantly in a gelatinous condition, resulted from the mechanical and chemical degradation of small aquatic algal organisms. This debris was intimately mixed and deposited with variable amounts of minerals and minor amounts of land plants, such as pollen and spores transported from adjacent land by streams and wind. During lithification the organic material was converted by polymerization and condensation into complex products of high molecular weight. The resulting oil shales of the same deposit may vary considerably in richness, and oil shales of different deposits may have widely different compositions and characteristics.

Some oil-shale specimens, such as the rich torbanites of Australia that contain identifiable remains of preexistent algal organisms and minor amounts of mineral, are dark brown or black and exhibit comparatively little lamination. Most oil shales, however, contain more than one-third mineral matter intimately mixed with a structureless organic residue. Such specimens are commonly laminated and range from light gray to brown or black in proportion to the amount of organic material.

The Bureau of Mines, under its Organic Act, is obligated to promote the conservation of the Nation's petroleum resources, including the development of supplemental sources. The Bureau conducted research work on oil shales and erected two experimental retorts in the 1920's. In 1944, when wartime petroleum shortages prompted Congress to pass the Synthetic Liquid Fuels Act (30 U.S.C. 321-323), comprehensive investigations of mining, retorting, and refining on an engineering scale were started near Rifle, Colo. At the same time, supporting laboratory research and bench-scale experimental operations were begun at Laramie, Wyo. Reduced appropriations ended the operations at Rifle in 1956, but the plant has been maintained in standby condition since that time. Activities at Laramie have been continued with emphasis on studies of the characteristics and extent of oil-shale deposits, the composition of shale oils and the oil-shale organic constituent (kerogen), and laboratory and bench-scale process research. The process studies include the evaluation of uncommon methods for producing shale oil and gas from oil shale; in-situ retorting, including the possible application of nuclear explosives; and refining of shale oil.

Although this paper discusses the occurrence and estimated reserves of known oil-shale deposits throughout the world, the compositions of the shales and the oils that have been derived from them, and some of the methods that have been developed for utilizing them, emphasis is on the oil shale and technology of the United States of America. Unless otherwise stated, data

# The amazing Piceance mineral suite...



Theoretical resources of a square mile of the Piceance Basin are shown at right and based on thickness and grades of the center chart. Large amounts of oil shale overlie the

saline-rich zone as shown by diagram on left. The top of the salines is marked by a dissolution surface and above it soluble salts in the oil shale have been leached by water.

## ...and its industrial potential for ENERGY-OIL-METALS-CHEMICALS

Irvin Nielsen  
Consulting geologist

LONG NOTED FOR ITS OIL SHALE RESERVES, the discovery of sodium-rich salines within Colorado's Piceance Basin now suggests the possibility of developing one of the world's most unique and highly diversified industrial complexes.

The recent identification of dawsonite [ $\text{NaAlCO}_3(\text{OH})_2$ ] and nahcolite ( $\text{NaHCO}_3$ ) in central basin areas of the Green River formation a few years ago not only sparked a lease scramble and a great deal of legal maneuvering, it also broadened considerably the natural resource base of areas formerly looked upon solely as potential sources of shale oil.

Dawsonite was first viewed as a source of alumina. Then nahcolite stole the limelight as a relatively ideal and cheap reactant for removal of sulphur from stack gases. There was even a proposal to leave dawsonite in shale retorted to extract shale oil and to use the ash as a low-cost source of "alkalized alumina", another sulphur-removing chemical which is getting attention from the U.S. Bureau of Mines.

The same sodium-rich and kerogen-rich beds of the Green River Formation also host large reserves of halite, analcite (a zeolite-sodium aluminum silicate) and limestone. It seems almost inconceivable that such a useful suite of minerals could be stacked up in sedimentary strata in one area. The existence, however, opens the potential for a mine in the central portion of the Piceance Basin from which oil, alumina, lime and soda ash could be produced as a start (see the conceptual flowsheet on the following page).

Moving a step further, it is possible to tap the energy

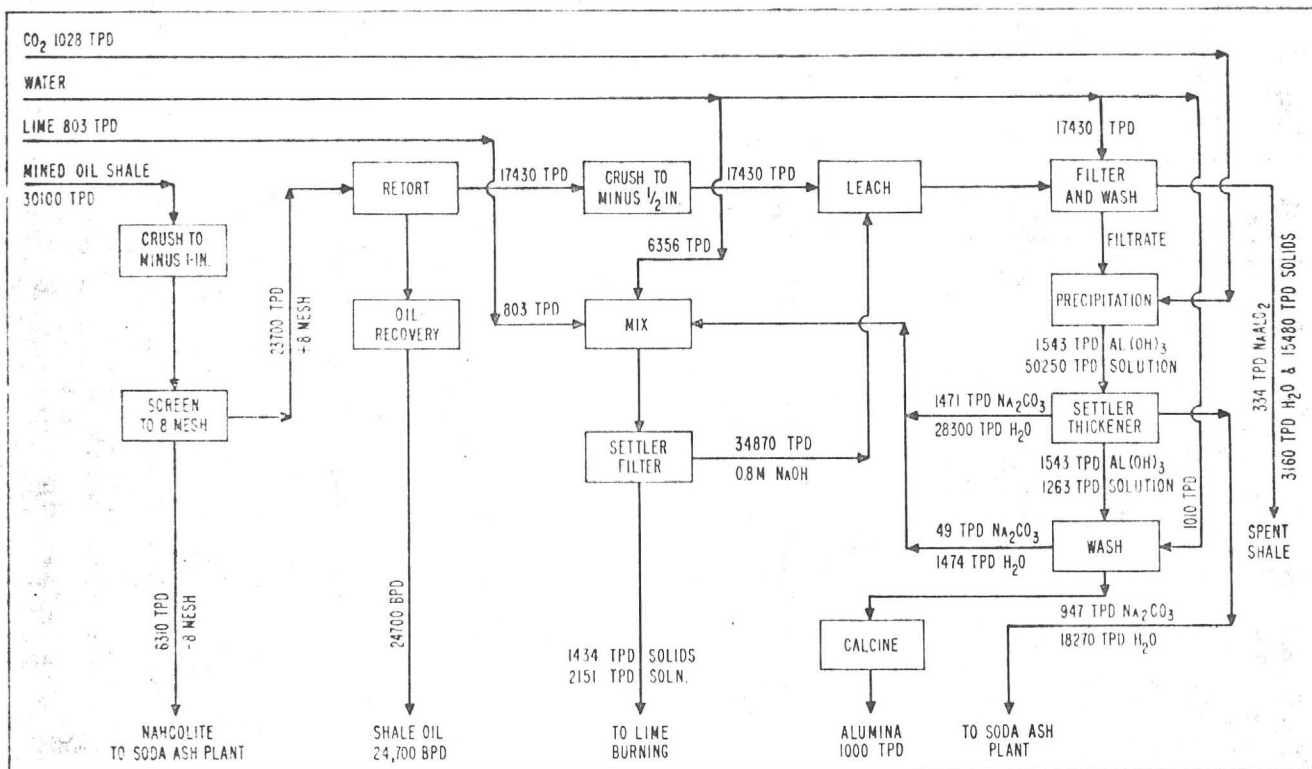
of a hydrogenated shale oil base for support of an aluminum smelter. The unique mineral assembly also presents interesting opportunities for production of other primary products such as: Caustic soda; quicklime; sodium bicarbonate; cement; sulphur; sulphuric acid; ammonia; chlorine; hydrochloric acid; sodium sulphate; sodium chloride; calcium chloride and others. The secondary chemicals that could be made from these basic building blocks are too numerous to mention.

While many technical problems stand in the path of a multi-product industrial complex, it takes a little imagination to think of what might evolve from specialized research on utilization of these deposits. There is an open-end opportunity to provide a new domestic source of aluminum, perfect an economic oil recovery process, and produce reactants useful in correcting air pollution problems.

### The oil shale and saline environment

The Piceance Basin of northwest Colorado has long been known for its Mahogany ledge oil shale deposits that outcrop around the rim of the basin. A 60-ft-thick interval in the area of Parachute Creek can be mined to produce a 38-gal-per-ton upper lift and a 35-gal-per-ton lower lift. It is the upper section that has been mined in demonstration plants. Oil field drilling and diligent assay work by the U.S. Bureau of Mines was responsible for the finding of a thick "oil shale" sequence near the center of the basin. Later, core drilling and assay work determined that the rocks that gave such high "shale oil" assays were not really so rich but had a high concentration of sodium minerals that dissolved in oil well drilling fluids and in effect, the cuttings were upgraded by removal of the soluble minerals.





Flowsheet shows how mined rock from saline sections can be used to recover multiple products. It was developed by Den-

ver consultants, Cameron & Jones, for Wolf Ridge Minerals Corp., a company interested in the Piceance sodium potential.

The minerals are located in what is now known as the saline section of the Green River formation. The rock here is peculiar. It is composed of varying amounts of nahcolite, dawsonite, potassium feldspar, calcite, dolomite, free silica, minor amounts of iron sulphide and organics or "kerogen", the naturally-occurring hydro-carbon yielding shale oil.

Elsewhere in the Green River formation thick beds of halite and analcite are found. Above the analcite beds are sand, shales, and limestones that may be used as silica, clay, and calcium carbonates for various industrial products.

The saline or sodium minerals are most concentrated in the area coincident with that covered by the two principal halite beds shown in an accompanying map. Apparently, these beds delineate the deepest portion and maximum salinity of the various water layers of an ancient lake, and consequently, maximum concentrations of nahcolite and dawsonite.

#### Make-up of the saline beds

The sodium mineral-bearing rock containing dawsonite is generally composed of the following minerals and kerogen and in the following approximate percentages:

Nahcolite	20%
Dawsonite	12%
Authigenic potash feldspar	12%
Calcite	3%
Dolomite	14%
Silica	24%
Kerogen	15%
	100%

The minerals were apparently precipitated chemically from a high pH water that dissolved all incoming sediments. The waters were also reducing and conducive to growth and preservation of organisms such as plankton or algae. Dawsonite, silica, calcite, dolomite, and feldspar were precipitated or grew as an intergranular matrix.

Nahcolite, however, tended to grow into megascopic crystals, nodules, rosettes or layered strata. The large accumulations of nahcolite give most of the rock a texture or appearance similar to phenocrysts in a porphyry.

Kerogen, or solid organic material, is incorporated in the matrix of the rock. It is possible to mechanically and chemically separate nahcolite from the rock without altering the kerogen or other matrix minerals. Once the nahcolite is removed, the kerogen can be distilled off as gases and condensable hydrocarbons, without detrimental effects on the dawsonite or other inorganic portions of the rock.

A rock having this unusual composition, physical appearance and unique genetic origin is truly a new type and warrants a unique name.

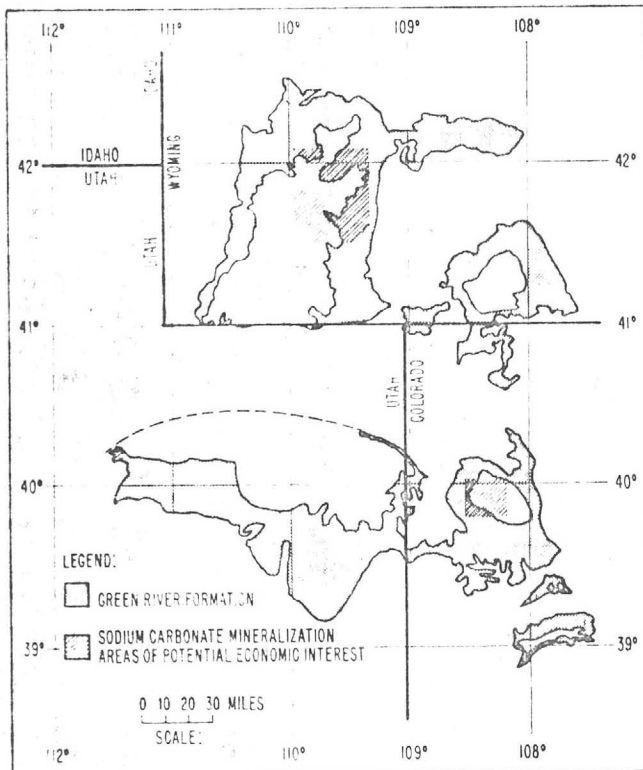
#### The multi-purpose slant

The U.S. Bureau of Mines, Union Oil Co. of California, Colony Development Corp., and a combine of Humble, Socony, Phillips, Sinclair, Texaco, and Conoco have all

Table 1. Shale oil cost estimated at \$1.59 a bbl

	Cost (per ton)	Cost (per barrel)
Mining	55¢	76¢
Retorting	25¢	35¢
General Expense, Ash Disposal, Depreciation, Amortization	35¢	48¢
<b>Total</b>	<b>\$1.15</b>	<b>\$1.59</b>
Value at site*		\$1.75
Cost at site		\$1.59
<b>Profit per barrel</b>		<b>.16</b>

\*Assumes no hydrogenation or pipelining to market which would be necessary to command the near \$3.00 price ordinarily paid for oil. Other assumptions: room and pillar mining method; a shale assaying 38 gal per ton; a 30,000 bbl per day output; and no by-product credits.

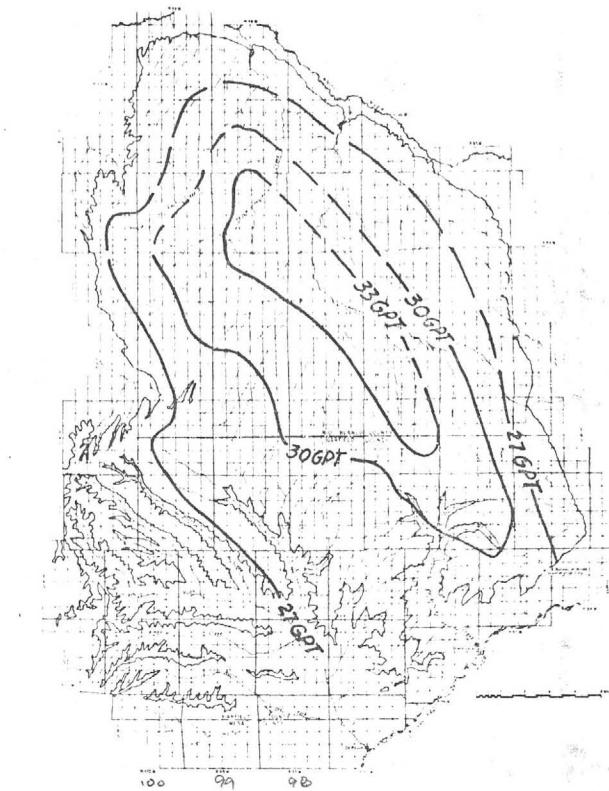


Major basins of the Green River formation occur in three states. Cross-hatching indicates sodium mineralized areas.

operated oil shale demonstration plants. To date no shale oil is being produced commercially. It must be concluded that all these efforts failed to prove conclusively that an oil company could invest its risk capital to produce shale oil and make more profit than it could by investing its risk capital to find oil at home or in foreign countries under today's lease and depletion conditions.

The indicated economics for a 30,000 bbl per day shale oil operation reveal a potential profit of \$0.16 per bbl as shown in Table 1. This situation would prevail for a room and pillar mine with a shale oil assay of 38 gal per ton and where overall mine and plant recovery amounted to 80%. If the shale oil was hydrogenated and pipelined to metropolitan areas it might command the \$3.00 (plus or minus) price ordinarily paid for oil, but this would necessitate a large quantity of product.

The fundamental concept of a multi-products plant in the accompanying flowsheet assumes an idealized underground mine working strata containing 21% nahcolite,



Average grade of oil shale in Mahogany Ledge member of the Piceance Basin in Western Colorado is indicated on the map.

12% dawsonite, and 16% organics.

From the flowsheet materials consumed are: (1) Carbon dioxide, 1,028 tpd; (2) water, 1,010 tpd; (3) lime, 803 tpd; and (4) mined rock 30,100 tpd. The products recovered include: (1) Nahcolite, 6,310 tpd; (2) oil, 24,700 bbl per day (3,900 tpd); (3) alumina, 1,000 tpd; and (4) soda ash from dawsonite, 947 tpd.

If the 1,000 tpd alumina is refined to aluminum on site, then the 24,700 bbl per day oil would supply the fuel to produce 14-million kwh electric energy. Since each pound of aluminum requires 10 kwh for electrolytic reduction from alumina, a total of 10-million kwh will be used in the electrolytic plant. Therefore, 70% of the oil would be consumed if the oil were used as fuel. As a result, the material input-output balance would become:

**Consumed:** (In addition to lime, water, CO<sub>2</sub> and ore)

Oil	17,290 bbl per day
Alumina	1,000 tpd

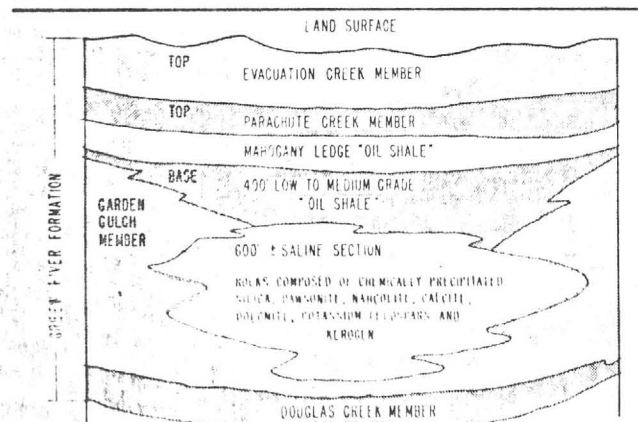
**Products:**

Nahcolite	6,310 tpd
Soda Ash	947 tpd
Aluminum	500 tpd
Oil	7,410 bbl per day

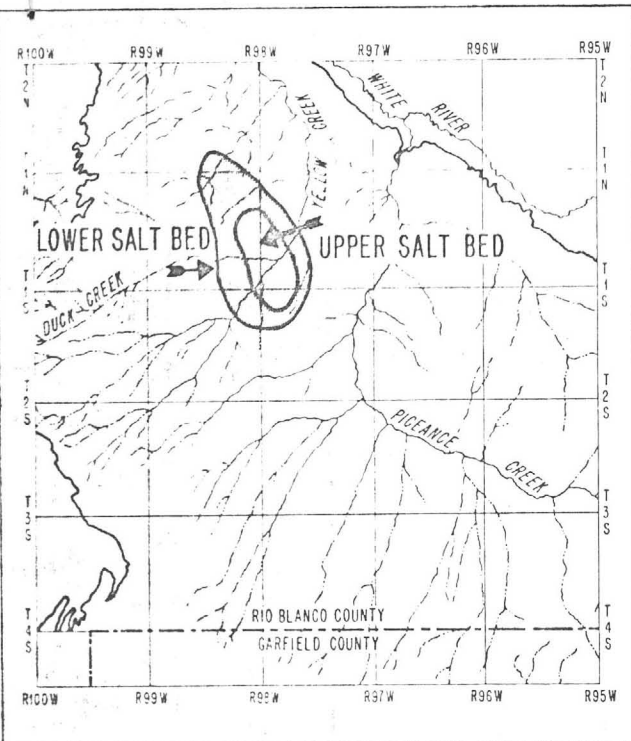
The operator may option to produce oil and burn locally available coal or produce soda ash instead of nahcolite. He may also produce any of the basic inorganics previously mentioned and/or a host of organic chemicals.

The mine could be designed to increase product flexibility by selecting minable horizons having varying ratios of dawsonite, nahcolite, and shale oil. Dawsonite can be varied from 0 to 18%, nahcolite from 0 to 90% and shale from 20 to 46 gal per ton.

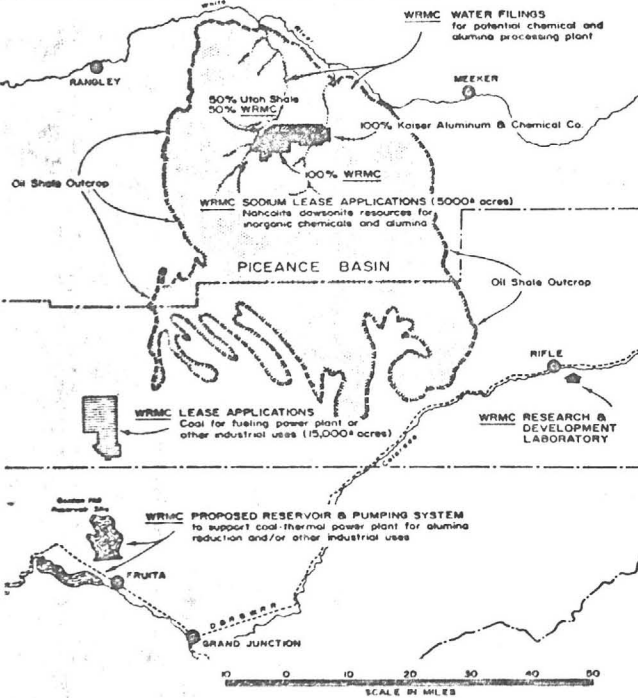
What about economics? One would find little argument from oil shale—experienced companies that shale oil can be produced at a cost less than its value at many sites in Colorado, though perhaps not at a profit sufficient to attract risk capital to build a plant. The questions preventing development are largely political and legal, in-



Stratigraphy of saline section of Piceance Basin. Sodium minerals are at depth in central portion of basin.



Aerial extent of two salt beds which delineate the area of maximum saline mineral deposition within Piceance Basin.



Piceance Basin map shows various projects related to sodium development. It was prepared by Wolf Ridge Minerals Corp.

volving depletion allowance, land titles, tax treatment, royalties, public domain land availability, etc.

**The cost advantage of a multi-product plant**

As an idealized illustration, a comparison is made of two kerogen-bearing properties—one without and the other with nahcolite. The economics of the first case are as indicated in Table 1—a pre-tax profit of 16¢ a bbl.

For the second case, the same production rate is as-

sumed; however, the mining occurs in the deep saline section which will require shaft hoisting. Both shale oil and nahcolite can be recovered. For the production of shale oil, the costs based on a pro-rata per ton are as follows: \$0.65 for mining and crushing, \$0.25 for retorting, and \$0.40 for general expense, ash disposal, depreciation, and amortization. However, the feed to the retort is 45 gal-per-ton after removing the nahcolite. At an 80% recovery, 1.17 tons are required to produce a barrel of oil. On a per-barrel basis and before taxes, royalty, and interest, the total cost amounts to \$1.52. On the same aforementioned basis, the profit is \$0.23 per barrel or \$0.21 per ton.

For the production of nahcolite, the mining and crushing cost remains at \$0.65 per ton, but the mechanical recovery, stockpiling and loading amounts to \$0.75 per ton, and general expense, depreciation, and amortization, are \$0.25 per ton. Nahcolite may be sold for as little as \$6.00 per ton, f.o.b. mine site, for use as an air pollution control reactant or for other uses. Total costs are \$1.65 per ton nahcolite produced. Value is \$6.00 and profit per ton nahcolite is \$4.35 before taxes, royalties, and interest. Profit on each ton of rock mined due to sale of the contained 420 pounds of nahcolite would be \$0.91, which exceeds any logical profit expectations from sale of crude shale oil from the same rock.

**Current investigations of the salines**

Wolf Ridge Minerals Corp., one of the companies that claim preference right leases to sodium deposits in the Piceance by virtue of discovery of sodium minerals on issued U.S. sodium prospecting permits, has done considerable research on the salines. This has ranged from making alumina from dawsonite, to soda ash from nahcolite, and glass from the inorganic constituents of the mineral zone.

Investigation of nahcolite from Wolf Ridge's sodium discovery cores shows that it is fully as reactive as synthetic sodium bicarbonate in removing sulphur compounds from stack gas, and sodium bicarbonate is considered ideal for treatment at low temperatures (300°F.) of stack gas discharge. The company has been in touch with the U.S. Dept. of Health, Education, and Welfare with regard to the use of nahcolite in air pollution control.

The Health Dept. process envisions injecting powdered nahcolite into stack gas streams where it reacts with sulphur oxides in the hot gas to form granular sodium sulphate or sodium bisulphate. The latter is the most desirable since only one atom of sodium combines with one of sulphur. The solid sulphates are then removed by means of a baghouse filter. Wolf Ridge is now mining several tons of nahcolite to use in a pilot plant scale test designed by the Health Dept's research group.

The company has also studied the approximate costs of transcontinental and transoceanic freight rates. These rates and review of nahcolite production costs show that a crude powdered form of the mineral may be delivered by unitized trains to all major cities of the eastern U.S. for \$16 per ton or less. Delivery to the Gulf and West Coast seaports may be as low as \$11 a ton, and therefore nahcolite can be shipped to Europe or Japan for about \$15 a ton. No chemical known is as suited for low temperature stack gas reaction as nahcolite, and there is no other major deposit of this mineral known in the world.

Wolf Ridge has also devised and tested a method to make glass from the saline section of the Green River formation. In making oil, gas and glass the only additives required for glass are additional silica, additional sodium carbonate and sodium sulphate.

Credit for work on the use of Colorado's vast nahcolite reserves should be given to Richard Herrington, James F. Durham, and especially, Robert Borgwardt.

for the United States pertain to shales from the Mahogany zone of the Green River formation in Colorado.

#### DEPOSITS AND RESERVES

Oil shales are widely distributed throughout the world in sedimentary rocks of geological periods from Cambrian to Recent. Deposits occur in many countries, but only those of Australia, Brazil, China (particularly Manchuria), Estonia, France, Germany, the Republic of South Africa, Scotland, Spain, and Sweden have been exploited commercially for the production of shale oil. However, oil shales of Bulgaria, Canada, Italy (Sicily), New Zealand, Thailand, the United States, and Yugoslavia have been processed experimentally or on a minor commercial scale. Other deposits are reported in Arabia, Argentina, Austria, Burma, Chile, Czechoslovakia, England, India, Ireland, Israel, Lebanon, Nicaragua, Norway, Panama, Peru, Switzerland, Syria, Turkey, Uruguay, Wales, and Yemen (21).<sup>3</sup>

Estimates of oil-shale and shale-oil reserves vary greatly, depending upon the method of computation as well as the availability of pertinent information on the deposits. Such estimates range from measured reserves based on detailed appraisals of deposits to indicated reserves based on meager geologic and analytical data. Both types of estimates are summarized in table 1 showing roughly the magnitude of major shale-oil reserves of the world.

The most extensive oil-shale deposits from the standpoint of potential shale oil in place are those in Brazil and the United States. The Irati (or Iraty) deposit of Permian age in the States of São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul in Brazil has been mapped along 1,000 miles of outcrop, but has not been completely explored by drilling (18).

The most important oil shale in the United States occurs in the Green River formation of Eocene age which underlies approximately 16,500 square miles in the States of Colorado, Utah, and Wyoming. By cooperative effort, extensive information has been obtained on the oil-yield potential of this shale. Studies included oil-yield assays by the modified Fischer retort method (43) of more than 90,000 core and drill-cutting samples provided by companies engaged in evaluating oil-shale properties and drilling for oil and gas (7). Continuous oil-shale sections 15 to 2,000 feet thick, which average 15 gallons of oil per ton, underlie 1,380 square miles in Colorado. These sections represent more than one trillion barrels of oil in place and contain richer sections, averaging 25 gallons of oil per ton, that represent 400 billion barrels of oil. Present information indicates that sections averaging 25 gallons of oil per ton in Utah are 15 to 150 feet thick and represent 120 billion barrels of oil in place, and those in Wyoming are 15 to 80 feet thick and represent 12 billion barrels of oil (17).

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<sup>3</sup>Underlined numbers in parentheses refer to items in the list of references at the end of this report.

TABLE 1. - Major shale-oil reserves<sup>1</sup>

Country or area	Oil in place, million bbl <sup>2</sup>
Australia.....	200
Brazil.....	342,000
Bulgaria.....	200
Burma and Thailand.....	17,100
Canada.....	34,200
China: <sup>3</sup>	
Fushun, Manchuria ( <u>27</u> ).....	2,000
Other deposits.....	2,700
England.....	1,400
Estonia ( <u>49</u> ) <sup>4</sup> .....	17,300
France.....	1,400
Germany (West).....	2,000
Israel ( <u>19</u> ).....	20
Italy.....	34,200
Malagasy Republic.....	200
New Zealand ( <u>51</u> , <u>52</u> , <u>53</u> ).....	200
Republic of the Congo (former Belgian Congo).....	103,000
Republic of South Africa.....	30
Scotland.....	600
Spain.....	300
Sweden.....	2,800
United States ( <u>17</u> ).....	1,132,000
U.S.S.R. <sup>4</sup> .....	6,800
Yugoslavia.....	1,400
<b>Total.....</b>	<b>1,702,050</b>

<sup>1</sup>Except as noted by citations, estimates are based on descriptive pamphlet of Swedish oil-shale operation by Claes Gejrot: Svenska Skifferolje, AB, Orebro, Sweden, 1958, 33 pp. Underlined figures in parentheses refer to items in list of references at end of report.

<sup>2</sup>Conversion to barrels of 42 U.S. gallons each is based on shale oil having an assumed specific gravity of 0.92 at 60° F (27.8° C).

<sup>3</sup>According to George Rosu in World Petroleum, November 1959, pp. 94-99, after discoveries in 1958 and 1959, proved oil-shale reserves (yielding 6 to 20 percent oil) are 60 billion tons, and probable oil-shale reserves are 360 billion tons.

<sup>4</sup>U.S.S.R. Ministry of Geology and Conservation, publication Coal and Fuel, 1958, p. 180, reports larger reserves estimated at 172 billion tons of oil shale; grade is not stated.

Black oil shales, mostly of marine origin, also occur in the Appalachian, Midcontinent, and Rocky Mountain regions of the United States. Though widespread, these deposits are of low grade and have not been thoroughly evaluated. Beds 15 feet or more in thickness seldom average as much as 15 gallons of oil per ton by assay. In 1928, Winchester (54) estimated that the Devonian black shales in Indiana and Kentucky alone represented about 18 billion barrels of oil.

## CHARACTERISTICS OF OIL SHALES

The characteristics of oil shales and torbanites are described in the literature and have been summarized or referred to in papers presented at the Oil Shale and Cannel Coal Conferences of the Institute of Petroleum (25, 26). Several properties of samples from different sources are compared in table 2. Specimens from different deposits vary greatly in the amounts and types of the organic and inorganic constituents. The minerals range from predominantly argillaceous, calcareous (dolomitic), or arenaceous materials to mixtures of these materials.

By thermal treatment, torbanites, such as those from Australia and the Republic of South Africa, commonly yield more than 50 gallons of oil per ton. In one instance, a high-grade sample from Coolaway Mountain, Australia, yielded 200 gallons of oil per ton (38). Except for thin beds, most oil shales, however, seldom yield more than 50 gallons of oil per ton.

The organic materials in different oil shales, while possessing some similar properties, such as insolubility in oil solvents and thermal conversion to oil, are apparently different members of a continuous series that grades from low-hydrogen, coallike materials (such as those in shale from Kvarntorp, Sweden, and Chattanooga shale of the United States) to high-hydrogen materials (such as that in Green River shale of the United States). Materials of high-hydrogen content are more completely converted to oil by thermal treatment. The conversion of organic material to oil (table 2), based on organic carbon balance, for different oil shales ranges from 26 to 71 percent (38).

Most experimental studies of Green River oil shale have been conducted on the richest oil-shale interval, which is known as the Mahogany zone. This zone varies in thickness and oil yield, but in Colorado it reaches a thickness of more than 100 feet. Individual 1-foot samples yield up to 95 gallons of oil per ton, but the average oil yield is about 25 gallons of oil per ton. Composite studies, published (40, 41) and currently in progress, show that sections of this zone averaging 25 gallons of oil per ton are remarkably uniform over a wide area. The average organic and mineral compositions of these sections are shown in table 3. The major inorganic elements in the oil shale are aluminum, calcium, iron, magnesium, potassium, silicon, and sodium. The principal trace elements include boron, barium, chromium, copper, gallium, lithium, manganese, nickel, lead, rubidium, strontium, titanium, vanadium, and zinc.

Characterization of the organic material in shale is complicated by the presence of large quantities of mineral matter. Hence, numerous techniques have been proposed to separate these two materials. Partial separations have been achieved, but in no known instance has complete separation been accomplished. A series of treatments that reduces the mineral content to a few tenths of 1 percent is as follows: Leaching with dilute hydrochloric or acetic acid to remove carbonates and soluble material; grinding in a cetane-water mixture to remove most other minerals (39); reduction with lithium aluminum hydride to remove pyrite; and finally, treatment with cold dilute hydrofluoric acid to remove most of the remaining minerals.

TABLE 2. - Properties of oil shales and torbanites<sup>1</sup>

	Australia, Glen Davis <sup>2</sup>	Brazil, Tremembé- Taubate <sup>2</sup>	Canada, Nova Scotia <sup>3</sup>	France, Autun <sup>3</sup>	Israel, Um Barek <sup>3</sup>	Lebanon <sup>3</sup>	Manchuria, Fushun <sup>3</sup>
<b>Modified Fischer assay:</b>							
Oil.....gal/ton	82.9	31.3	51.4	25.8	15.6	61.5	7.6
Oil.....percent	30.9	11.5	18.8	9.7	6.4	24.8	3.0
Water.....do...	0.7	6.2	0.8	3.2	2.2	11.0	4.9
Spent shale.....do...	64.1	78.4	77.7	84.0	88.4	56.5	90.3
Gas and loss.....do...	4.3	3.9	2.7	3.1	3.0	7.7	1.8
Conversion of organic material to oil <sup>4</sup> .....do...	66	59	<sup>5</sup> 60	44	48	-	33
<b>Rock characteristics:</b>							
Specific gravity, at 60° F.....	1.60	1.70	-	2.03	-	-	2.29
Heating value.....Btu/lb	8,100	3,520	5,420	3,810	-	-	1,460
Ash.....percent	51.6	71.4	62.4	70.8	60.0	18.8	82.7
Organic carbon.....do...	39.7	16.5	26.3	18.8	10.6	-	7.9
<b>Assay oil:</b>							
Specific gravity, at 60° F.....	0.89	0.88	0.88	0.90	0.97	0.96	0.92
Carbon.....percent	85.4	84.3	-	84.9	79.6	83.2	85.7
Hydrogen.....do...	12.0	12.0	-	11.4	9.8	10.3	10.7
Nitrogen.....do...	0.5	1.1	-	0.8	1.4	0.6	-
Sulfur.....do...	0.4	0.2	-	0.3	6.2	1.5	-
<b>Ash analysis, percent:</b>							
SiO <sub>2</sub> .....	81.5	55.8	61.1	55.1	<sup>6</sup> 26	-	62.3
Al <sub>2</sub> O <sub>3</sub> .....	10.1	26.7	30.1	27.6	-	-	26.7
Fe <sub>2</sub> O <sub>3</sub> .....	3.0	8.5	5.0	9.3	-	-	6.1
CaO.....	0.8	2.8	1.1	1.7	<sup>6</sup> 45	-	0.1
MgO.....	0.8	3.7	1.6	1.9	-	-	1.8
Other oxides.....	3.8	2.5	1.1	4.4	-	-	3.0
	New Zealand, Orepuki <sup>3</sup>	Scotland, Westwood mine <sup>2</sup>	South Africa, Ermelo <sup>2</sup>	Spain, Puertol- lano <sup>3</sup>	Sweden, Kvarntorp <sup>2</sup>	Thailand, Maesod <sup>3</sup>	United States, Colorado <sup>2</sup>
<b>Modified Fischer assay:</b>							
Oil.....gal/ton	66.2	22.2	45.6	46.9	13.9	71.4	24.5
Oil.....percent	24.8	8.2	17.6	17.6	5.7	26.1	9.3
Water.....do...	8.3	2.2	3.0	1.8	2.0	3.8	1.0
Spent shale.....do...	57.6	86.6	75.6	78.4	87.2	66.3	87.5
Gas and loss.....do...	9.3	3.0	3.8	2.2	5.1	3.8	1.6
Conversion of organic material to oil <sup>4</sup> .....do...	45	<sup>5</sup> 56	34	<sup>5</sup> 57	26	71	70
<b>Rock characteristics:</b>							
Specific gravity, at 60° F.....	1.46	2.22	1.58	1.80	2.09	1.61	2.23
Heating value.....Btu/lb	9,150	2,540	8,230	5,380	3,870	6,630	2,200
Ash.....percent	32.7	77.8	42.5	62.8	72.1	56.4	66.9
Organic carbon.....do...	45.7	12.3	43.8	26.0	18.8	30.8	11.3
<b>Assay oil:</b>							
Specific gravity, at 60° F.....	0.90	0.88	0.93	0.90	0.98	0.88	0.91
Carbon.....percent	83.4	-	84.8	-	85.0	84.4	84.6
Hydrogen.....do...	11.8	-	11.1	-	9.0	12.4	11.6
Nitrogen.....do...	0.6	-	-	0.9	0.7	1.1	1.8
Sulfur.....do...	0.6	-	0.6	0.3	1.7	0.4	0.5
<b>Ash analysis, percent:</b>							
SiO <sub>2</sub> .....	44.2	55.7	61.3	56.6	62.4	60.8	43.6
Al <sub>2</sub> O <sub>3</sub> .....	28.1	25.1	30.5	27.6	17.6	19.9	11.1
Fe <sub>2</sub> O <sub>3</sub> .....	20.5	9.9	2.9	9.1	10.7	4.8	4.6
CaO.....	4.6	2.6	1.6	2.6	1.2	3.3	22.7
MgO.....	1.4	3.1	1.7	2.2	1.7	3.8	10.0
Other oxides.....	1.2	3.6	2.1	1.9	6.4	7.4	8.0

<sup>1</sup>Data obtained largely from analyses of air-dried samples given in BuMines Rept. of Inv. 5504, Petrographic Examination and Chemical Analyses for Several Foreign Oil Shales, by H. N. Smith, J. W. Smith, and W. C. Kommes, 1959, 34 pp.

<sup>2</sup>Average sample.

<sup>3</sup>Selected sample.

<sup>4</sup>Based on recovery of carbon in oil from organic carbon in shale.

<sup>5</sup>Carbon content of oil estimated as 84 percent.

<sup>6</sup>Approximate.

TABLE 3. - Composition of oil-shale sections averaging 25 gallons of oil per ton in the Mahogany zone of Colorado and Utah

	<u>Weight-percent</u>
Organic matter:	
Content of raw shale.....	<u>13.8</u>
Ultimate composition:	
Carbon.....	80.5
Hydrogen.....	10.3
Nitrogen.....	2.4
Sulfur.....	1.0
Oxygen.....	<u>5.8</u>
Total.....	100.0
Mineral matter:	
Content of raw shale.....	<u>86.2</u>
Estimated mineral constituents:	
Carbonates, principally dolomite.....	48
Feldspars.....	21
Quartz.....	13
Clays, principally illite.....	13
Analcite.....	4
Pyrite.....	<u>1</u>
Total.....	100

Comparatively little is known about the constitution of the oil-shale organic material, commonly referred to as kerogen. It is a mixture of high-molecular-weight compounds of carbon, hydrogen, nitrogen, oxygen, and sulfur. According to Himus (23), the composition ranges within the following wide limits: Carbon, 66 to 88 percent; hydrogen, 7.2 to 12.8 percent; nitrogen, 0.1 to 3.1 percent; sulfur, 0.1 to 8.8 percent; and oxygen (plus errors), 0.8 to 24.7 percent. Kerogen is only slightly soluble in the usual organic solvents. In this respect it differs from the organic material in bitumen-impregnated rocks, such as Athabaska, Canada, tar sand, that is largely soluble in oil solvents. It is similar to coal in physical state, but differs from coal in that larger amounts of volatile material are produced from it by pyrolysis. Most kerogens produce 65 to 70 percent volatile material, which is much more than is obtained from high-volatile coals. Kerogen differs from petroleum in physical state, but the oil produced from it can be used as a source of products similar to those obtained from petroleum.

Kerogen is essentially insoluble in alkaline, acidic, or organic solvents. Aqueous solutions of chlorhydrate or chloroform cause it to swell slightly, but only about 10 percent dissolves. By using a series of solvents or long extraction times (several weeks), the amount of soluble material obtained at room temperature is increased only slightly. Higher extraction temperatures result in an increase in the amount of soluble material, but a large increase is not obtained until a temperature sufficiently high to cause rupture of chemical bonds is used. The inability either to dissolve or to swell kerogen appreciably, except by thermal degradation, suggests a rigid structure.



Information about the constitution of the organic portion of shale has been obtained by oxidation studies with alkaline potassium permanganate. In these studies investigators (10, 16, 32, 35, 36) have examined kerogens from different parts of the world by a carbon-balance technique in which the proportion of organic carbon appearing in different classes of oxidation products is determined. From the results of these investigations, (table 4) general ideas about the structure of the kerogens are obtained. Some of the kerogens resembled coal in that benzenoid acids were identified in their oxidation products. However, benzenoid structures were less pronounced in kerogen than in coal. The first three kerogens listed in the table were almost completely oxidized to carbon dioxide and oxalic acid, showing that they were neither highly aromatic nor contained large amounts of long chains in the form of waxes or fats. Most of the other kerogens examined contained substantial quantities of materials that were resistant to oxidation, probably because of the presence of fatty and waxy substances.

TABLE 4. - Distribution of organic carbon in oxidation products of oil-shale kerogens

Source of shale	Percent of total organic carbon as--			Reference <sup>1</sup>
	Acids, except oxalic	Carbon dioxide and oxalic acid	Unoxidized material	
Estonia, Gdov.....	3	102	0	(32)
United States, Colorado.	2	96	1	(36)
U.S.S.R., Volga.....	<sup>2</sup> 8	93	0	(32)
Burma, Amherst.....	7	68	25	(16)
England, Kimmeridge.....	<sup>2</sup> 19	80	1	(16)
France, St. Hilaire.....	<sup>2</sup> 10	42	48	(10)
India, Kohat.....	19	74	7	(16)
Scotland:				
Broxburn Main.....	<sup>2</sup> 14	42	44	(16)
Middle Dunnet.....	<sup>2</sup> 19	43	39	(16)
Pumpherston.....	<sup>2</sup> 18	32	51	(16)
Republic of South Africa	<sup>2</sup> 22	44	34	(16)

<sup>1</sup>Numbers in this column refer to items in the list of references at end of this report.

<sup>2</sup>Benzenoid acids were identified in these products.

The data in table 4 show that the kerogen in Colorado oil shale is low in aromatic structures. A study (34) of low-temperature thermal extracts obtained from this kerogen at 77° to 662° F (25° to 350° C) indicated that it contained approximately 5 to 10 percent straight and branched chain paraffin structures, containing 25 to 30 carbon atoms, 20 to 25 percent cycloparaffin structures with 3 to 5 rings per molecule, 10 to 15 percent aromatic structures with 3 to 5 rings per molecule, and 45 to 60 percent cyclic nonhydrocarbon material containing oxygen, nitrogen, and sulfur. These results generally agree with oxidation studies and suggest that the kerogen is predominantly a heterocyclic material connected to or associated with smaller amounts of hydrocarbon material consisting of straight and branched chain paraffins, cyclic paraffins, and aromatics.

X-ray diffraction studies show that the kerogen in Colorado oil shale is essentially noncrystalline with a very low degree of regularity of atomic positions. The crystalline property is much less than that of high-rank coal and may be somewhat related to low-rank coal or coal resins. These data confirm other information showing that the kerogen does not have an ordered arrangement of carbon atoms typical of a condensed aromatic structure. The presence of aliphatic structure or the high degree of saturation with hydrogen that occurs in this kerogen may account for the noncrystalline property.

Chemical and infrared analyses of the kerogen from the Colorado shale show the presence of oxygen in the form of acid and ester functional groups. However, these two groups do not account for most of the oxygen in the kerogen, so it is assumed that a large portion of the oxygen is present as ether linkages. This latter type of linkage is difficult to detect by either chemical or infrared analysis. The amount of oxygen in hydroxyl or phenolic groups appears to be small. The nitrogen apparently occurs in two types of structure in the kerogen, one of which is more easily soluble than the other. Little information is available as to the types of compounds in which the sulfur occurs in the kerogen.

#### CHARACTERISTICS OF SHALE OILS

Shale oil, as mentioned earlier, is obtained by the pyrolytic degradation of the organic matter in oil shale. It is composed of hydrocarbons plus sulfur, nitrogen, and oxygen derivatives of hydrocarbons and can be used as a source of the products now usually obtained from petroleum. However, utilization of shale oil presents special problems because its composition differs in some respects from that of petroleum, and because shale oils differ from each other. Shale oil contains large quantities of olefinic hydrocarbons; in this respect it resembles the products from thermal cracking of petroleum, as would be expected from its pyrolytic conversion. In general, shale oil contains larger quantities of nonhydrocarbons, particularly nitrogen and oxygen compounds, than does petroleum. Shale oil in some respects, particularly in regard to degree of unsaturation, may be considered as intermediate between petroleum and coal tar; that is, it has a carbon-hydrogen ratio of 7 to 9 as compared with 6 to 7 for petroleum and 10 to 16 for coal carbonization products.

The composition of a shale oil depends on the characteristics of the shale from which it was obtained and the variables of the retorting method used to produce it. Table 5 lists some properties of shale oils obtained from various locations throughout the world (1, 12, 44). The oils have a severalfold variation in nitrogen, sulfur, and hydrocarbon group composition. Although the factors governing these differences are interrelated, shale characteristics and retorting variables will be discussed separately.

The values for nitrogen in table 5 range from about 0.5 percent to about 2 percent. The nitrogen content of shale oil seems to be primarily a function of the character of the organic matter from which the oil was obtained. Table 6 gives the ratio of the nitrogen content of an average oil from each of several sources to the nitrogen content of the organic matter from which the

oil was produced (11). The value for U.S. shales is substantially higher than those of the others. This suggests that the nitrogen structures in the organic matter of the U.S. shale differ from the nitrogen structures in the other shales.

The sulfur contents of the oils given in table 5 also show substantial variation. This condition may be due to the characteristics of the organic matter. However, relating the sulfur content of the oil to that of the shale is more difficult than it is with nitrogen, because the sulfur exists in the shale in both inorganic and organic forms.

TABLE 5. - Properties of oils produced from shales from different countries

Country	Retort	Grav- ity, ° API	Nitrogen, weight- percent	Sulfur, weight- percent	Analysis of distil- late boiling to 600° F (315° C), weight-percent		
					Satu- rates	Olefins	Aro- matics
Australia, Glen Davis..	Pumpherton...	27.9	0.52	0.56	42	39	19
Brazil, Tremembé.....	Gas combustion	22.5	1.06	.68	23	41	36
France:							
Autun.....	Pumpherton...	20.5	.90	.51	33	36	31
Sévérac.....	Marecaux.....	21.5	.53	3.00	30	32	38
Do.....	Petit.....	16.0	.65	3.40	25	20	55
St. Hilaire.....	Lantz.....	24.3	.54	.61	31	44	25
Scotland.....	Pumpherton...	30.4	.77	.35	42	39	19
South, Africa, Ermelo..	Salerno.....	24.7	.85	.64	35	44	21
Spain, Puertollano.....	Pumpherton...	25.6	.68	.40	51	27	22
Sweden, Kvarntorp.....	Rockesholm....	13.3	.68	1.65	12	24	64
United States, Colorado	Gas combustion	18.6	2.13	.69	27	44	29
Do.....	Pumpherton...	25.7	1.57	.77	30	38	32

TABLE 6. - Relation of nitrogen content of oil to that of shale  
from which it was produced

Source of shale	Nitrogen content of oil divided by nitrogen content of organic material in shale
Australia, Glen Davis.....	0.36
Brazil, Tremembé.....	.44
France:	
Autun.....	.41
Sévérac.....	.50
St. Hilaire.....	.29
Scotland.....	.39
South Africa, Ermelo.....	.56
Spain, Puertollano.....	.43
Sweden, Kvarntorp.....	.52
United States, Colorado.....	.83

The differences in hydrocarbon composition shown in table 5 depend in part on the characteristics of the organic matter in the shale. In addition to the gas-combustion data given in table 5 for the Brazilian and U.S. shale oils, data from Fischer assay and high-temperature retorting of shales from both sources were

obtained. Hydrocarbon analysis of the distillate boiling below 600° F (315° C) from each of these oils was determined (11). The results for the six oils are presented in table 7. The content of saturates is higher in each of the U.S. oils than in the corresponding Brazilian oils, the aromatic content is always lower, and the olefin content is about the same. Apparently the shale characteristics affect the hydrocarbon composition. This conclusion is substantiated by the data in table 5 for oils obtained by the Pumpherton process. There are differences in the equipment and operation of this process in the various countries, but the substantial differences in composition shown in table 5 must be due, at least partly, to the characteristics of the shale from which the oils were produced.

TABLE 7. - Analyses of distillates boiling below 600° F (315° C) from shale oils of Brazil and the United States of America

Retort	Shale source	Hydrocarbon composition, volume-percent		
		Saturates	Olefins	Aromatics
Fischer assay.....	Brazil, Tremembé.....	18	54	28
Do.....	United States, Colorado...	27	51	22
High temperature...	Brazil, Tremembé.....	9	46	45
Do.....	United States, Colorado...	20	46	34
Gas combustion.....	Brazil, Tremembé.....	23	41	36
Do.....	United States, Colorado...	27	44	29

Table 8 gives the hydrocarbon compositions of distillates boiling up to 600° F (315° C) obtained from oils produced by high-temperature retorting (42) of the same shale at different temperatures. The values for the oil produced at 1,000° F (540° C) are only slightly different from those obtained on oils produced by ordinary retorting methods. However, as the retorting temperature is increased, the oil becomes more aromatic so that the oils produced at 1,400° F (760° C) and 1,600° F (870° C) are almost entirely composed of this class of compounds. Temperature is not the only retorting variable of importance, but data to evaluate others, such as residence time, are not available.

TABLE 8. - Analyses of distillates boiling below 600° F (315° C) from oils produced at different temperatures from Colorado, U.S.A., shale

Retorting temperature		Hydrocarbon composition, volume-percent		
° F	° C	Saturates	Olefins	Aromatics
1,000	540	18	58	24
1,200	650	8	40	52
1,400	760	0	3	97
1,600	870	0	0	100

The preceding discussion of the differences in shale oils has indicated that utilization of any given oil shale presents individual problems. An example is the oil produced by internally heated retorts from shale of the

Green River formation in Colorado. This oil is composed of about 40 percent hydrocarbons and 60 percent nonhydrocarbons. The oil is deficient in low-boiling constituents with the gasoline-boiling-range material amounting to only about 5 percent. Also, only about 55 percent can be distilled below 572° F (300° C) at a pressure of 40 mm of mercury. The composition of distillate fractions from the oil is important in the production of liquid fuels. The naphtha fraction contains 30 percent saturates, 42.5 percent olefins, 15.5 percent aromatics, and 12 percent nonhydrocarbons (15). The gas-oil fraction boiling from 600° F (315° C) to 932° F (600° C) contains 20 percent saturates, 15 percent olefins, 15 percent aromatics, and 50 percent nonhydrocarbons (13, 14).

#### UTILIZATION OF OIL SHALE

The first recorded reference to processing oil shale is a patent issued in England in 1694. Sellique devised the process that started the French shale-oil industry in 1838, and James Young and his associates commercialized a process for making oil from boghead coal in Bathgate, Scotland, in 1850. Robert Bell started production of oil from the oil shales west of Edinburgh, Scotland, in 1862. Both coal oil and shale oil were produced in the United States and Canada before Col. Drake drilled the first oil well near Titusville, Pa., in 1859. The first Australian shale was retorted in December 1865 at America Creek, Woolongong district, New South Wales. Later shale industries started in Brazil in 1881, New Zealand in 1900, Switzerland in 1915, Sweden and Estonia in 1921, Spain in 1922, Manchuria in 1929, and South Africa in 1935.

The French industry was the first to process oil shale commercially, but it operated only intermittently and has been shut down for several years. The Scottish industry, although varying somewhat in output and now being reduced, has operated continuously since its inception. Australian operations were intermittent; the latest venture at Glen Davis, New South Wales, started operations in 1940, but it was closed down in May 1952 and the plant was dismantled. Swedish operations, although now being reduced, have been continuous as have those in Estonia, except for periods of destruction and derangement caused by successive occupation by the Germans and Soviets during the Second World War. The South African Torbanite Mining and Refining Co. discontinued shale operations in 1960 when its torbanite reserves were exhausted. Small intermittent operations have been underway in Brazil for many years, and present plans envision a new and larger industry in the near future.

China is reported to have the largest shale-oil production in the world at Fushun, Manchuria, presently producing about 9 to 12 million barrels of shale oil per year. The capacity of the original eighty 50-ton-per-day Fushun retorts (25) at the West plant was doubled in 1934 by enlarging the conical throat between the upper retorting section and the lower gas producing section of each retort. In 1942 sixty 150-ton-per-day retorting units of a similar type were added. In 1944 a new plant, consisting of sixty 150-ton-per-day retorting units, was constructed at the East oil-shale mine, bringing the total crude oil capacity of the Fushun plants to between two and three million barrels a year. During World War II, according to Japanese sources, the

Fushun plant was the primary source of fuel for the Japanese Navy, crude oil production reaching a maximum of 1,317,000 barrels in 1943. Until 1959 all shale oil production in China (37) came from Fushun, but in 1960 and 1961 a few hundred thousand tons of oil from shale reportedly came from Mowming, Kwangtung (north of Canton). Another large and presumably undeveloped deposit is near Mutanchiang in Heilungkiang, Manchuria. Other substantial deposits exist in Kansu, Hunan, Hopei, Inner Mongolia, Kirin, Kweichow, Honan, and Yunnan.

Estonia (49) and the Gdov district in the USSR have extensive oil-shale operations. Soviet reserves are estimated to be 172 billion tons of oil shale (grade is not stated). Many small experimental plants have been operated for short periods in the United States, but no commercial production has been developed.

### Mining

Because of the diversity of types and characteristics of oil-shale deposits, mining methods vary rather widely. Open-pit techniques are used in some places where oil shale is recovered in conjunction with mining coal; however, many shale deposits are several hundred feet below the surface and are mined by underground methods. Room-and-pillar techniques are applied to some formations, but longwall and other techniques using artificial support are not uncommon.

A low-cost underground method was developed by the Bureau of Mines for mining Colorado oil shale (24, 26). Exemplified in this experimental mine is a room-and-pillar system requiring no artificial support and providing rooms that can accommodate large machines. Such large rooms would not be practical if the formation were not endowed naturally with favorable characteristics--thick beds lying almost horizontal, and strong, tough rock that makes serviceable pillars.

Entries to the rooms were driven into the base of a 500- to 800-foot near-vertical cliff, which is the oil-shale outcrop. The overburden is supported by 60-foot pillars spaced 60 feet apart in both directions and staggered in one direction. The upper 39 feet of the Mahogany zone was removed in a heading operation, and the remaining 34 feet was mined later by benching.

A major mining achievement at the mine was the design and development of equipment especially suited for working most efficiently in the space available. Using large machines and few men made it possible to demonstrate low mining costs. The demonstrated output of shale per man-shift of underground labor was 148 tons.

In Scotland the majority of the shale deposits are in underground seams 5 to 33 feet thick and broken by many faults and folds. For the few deposits that lie near the surface, opencut mining is used to a limited extent. However, most mines necessarily are underground and generally are characterized by rooms with timber supports (26) and by vertical and sloping access shafts,

although longwall methods have been used. Mechanization in the Scottish mines is advancing, and electric hand drills, conveyor belts, electric engines, cable cars, and electric hoists are used, although cars are loaded by hand.

Open-pit mining is practiced in Sweden, where the deposits are covered by 20 to 26 feet of loose soil and gravel overburden. After the overburden is removed by bulldozers and draglines, the comparatively loose shale bed is broken by blasting. Limestone constitutes about 15 percent of the shale deposit, and large pieces are separated by power shovels in the mine; smaller pieces are removed by hand picking during the crushing operation. The output of shale per man-shift of mine labor is 115 tons.

In the Glen Davis mines (31) in New South Wales, Australia, modern mechanical equipment was used for winning the thin but rich seams of oil shale. Access to the mine was by tunnels into the cliff face above the plant. A room-and-pillar method was used, leaving 60 percent of the shale as pillars, which eventually would have been extracted had not the plant been shut down. Electricity was used for drilling, loading, hauling, and lighting.

Coal was mined in the Fushun area in Manchuria at least 700 to 800 years ago. However, the West open-pit operation was started in about 1920 and reached a size of 12 miles long, 1-1/4 miles wide, and 525 feet deep in 1946. To reach the coal seam necessitated removing up to 400 feet of oil shale averaging 5 to 6 percent oil yield by assay. In 1929 the South Manchurian Railway Co. began utilizing commercially the oil shale in its West oil-shale plant, charging the entire mining cost to the coal operation. Another pit in the same formation was opened about 5 miles to the east to supply the East oil-shale plant, which began operation in 1944. The open pits are mined by the multiple bench system and are completely mechanized and electrified.

Table 9 shows the production of oil shale throughout the world for 1955-59. These data are not complete because statistics are not available from some countries.

#### Retorting

More than 2,000 oil-shale retorting systems have been patented throughout the world (28, 29); some are batch type and others are continuous. They may be divided into four major classes, based upon the following method of heat application:

1. Heat is transferred to the shale through a wall.
2. Heat is transferred to the shale from combustion of product gases and residual carbon within the retort.
3. Heat is transferred to the shale by passing heated gases or liquids through the shale.
4. Heat is transferred to the shale by mixing it with hot solids. Each of these classes can be subdivided on the basis of the direction of flow of heat, shale, or products.

TABLE 9. - Production of oil shale

	Tons <sup>1</sup>				
	1955	1956	1957	1958	1959
Austria <sup>2</sup> .....	942	792	777	358	251
China: (Fushun, Manchuria) <sup>3</sup>	-	-	-	17,500,000	29,000,000
France <sup>2</sup> .....	240,083	161,133	45,403	2,858	3,251
Germany <sup>4</sup> .....	459,247	461,439	475,769	-	-
Great Britain <sup>2</sup> .....	1,496,424	1,180,295	1,010,309	829,891	793,493
Spain <sup>2</sup> .....	545,069	658,937	815,619	852,217	930,768
Sweden <sup>2</sup> .....	2,048,558	2,042,000	2,065,520	1,987,154	-
U.S.S.R. <sup>5 6</sup> .....	11,897,000	12,734,000	13,639,000	14,537,000	15,102,000

<sup>1</sup> Expressed in U.S. short tons. Values are rounded to same number of significant figures as data in original quoted source.

<sup>2</sup> Her Majesty's Stationery Office. Statistical Summary of the Mineral Industry. London, 1961, p. 233.

<sup>3</sup> Unconfirmed estimate.

<sup>4</sup> Piepersche Buchdruckerei und Verlagsanstalt. Statistische Mitteilungen der Bergbehörden der Bundesrepublik Deutschland für die Jahre 1955-1961 (Statistical Information of the Mining Authority of the Federal Republic of Germany for the Years 1955-61). Clausthal-Zellerfeld.

<sup>5</sup> Gosstatizdat. Narodnoye Khozyaystvo SSSR: Statisticheskiiy Yeshegodnik (National Economy of the U.S.S.R.: Statistical Yearbook). Moscow, 1958, p. 213; 1961, p. 212.

<sup>6</sup> Pravda, Jan. 22, 1960.

Only a few of the patented processes have been used in industrial-scale operations, and no process appears to be best for use under all conditions. Some features or characteristics of a process may be advantageous in some countries but not in others because of differences in the shales or economic conditions. Shale properties that must be considered in designing or selecting a retorting process are mineral carbonate content, water content, coking or clinkering tendency, and the amount of carbonaceous residue left in the shale after it has been heated to the pyrolysis temperature. Economic factors that may have an influence are the market for oil-shale products and byproducts, availability and cost of power, and wage rates.

In the United States, research is being carried on by both Government and industry in an effort to develop the technology needed in producing liquid and gaseous fuels economically from oil shale of the Green River formation (26). The Bureau of Mines development of the gas-combustion retorting process progressed from a 6-ton-a-day pilot plant to a 150-ton-a-day demonstration plant but was not completed due to discontinuance of the Rifle experimental program (2,4-6).

In this process, an upward-flowing stream of gas contacts a descending bed of broken shale. The shale passes successively through preheating, retorting, combustion, and cooling stages. The gas entering the bottom of the retort absorbs heat from the spent shale. Just below the middle of the retort vessel, air is injected, providing the oxygen necessary to burn the gas and some of the



residual carbon in shale that has passed through the retorting zone. The resulting hot combustion gases, as they travel upward, heat the raw shale to retorting temperature. The oil and gaseous products evolved from the shale are swept along with the combustion gases. Finally, the oil-laden gas stream is cooled by the incoming cold shale, and the oil condenses as a mist, which is carried from the retort by the gas. An oil recovery system separates the shale oil from the gas stream. Part of the gas then is recycled through the retort, and the remainder leaves the system and is available for other uses, such as generation of power.

Attractive features of this process are high thermal efficiency, high oil yields, and high retorting rates. Another feature that makes the process attractive in the semiarid region where the Green River deposits are located is that it requires no water for condensing the oil product.

The Union Oil Co. of California has developed a countercurrent internal-combustion-type retorting process (22, 26) in which shale is forced upward through an inverted cone-shaped vessel. Air enters the top of the retort, and combustion takes place about 2 feet below the top of the shale bed. The resulting hot combustion gases, as they travel downward, retort the raw shale before it reaches the fire zone where the carbonaceous residue in the retorted shale is burned. The oil vapors in the gas stream leaving the retorting zone are condensed on the cold shale in the lower part of the retort. The entering air cools the shale ash to some extent before it reaches the top of the retort where it is removed by rotating plows. The Union retort requires no water for cooling, is thermally efficient, and is capable of high oil yields.

A retort known as the N-T-U is based on the same principle as the Union process but is designed for batch rather than continuous operation. It has been tested on a rather large pilot-plant scale by the Bureau of Mines (2). In the N-T-U process, air enters at the top of the retort, combustion begins at the top of the stationary shale bed, and the combustion zone gradually moves down to the bottom of the retort.

The Bureau also has made pilot-plant studies on the gas-flow process (3, 26), the Royster retort (2, 50), an entrained-solids retort (42), and thermal solution extraction (2, 48); a hot-solids-contact retort (26) has been designed but has not been tested.

The Oil Shale Corp. has studied a modification of the Aspeco Process for retorting Green River oil shale and has developed the process through the small pilot-plant stage (33). This process comprises heating and simultaneously grinding the shale by solid-to-solid milling contact with hot, solid, heat-carrying bodies to produce oil vapors and gases along with a carbonaceous residue that is used as fuel in reheating the heat-carrying bodies.

Fluidized retorting was investigated by the Standard Oil Development Co. at Baton Rouge, La., where an experimental two-vessel fluid catalytic cracking unit that had been built to process petroleum stocks was converted to a retorting system in which one vessel acted as a retort and the other as a spent-shale burner (26).

Retorts used in Scotland (20) during the past 90 years have been primarily of the Pumpherstons type. Heat from the combustion of gases is circulated through a system of flues up and around an elliptical or cylindrical retort vessel, heating the downward flowing bed of shale inside. The oil-laden retort gas is withdrawn from the top of the vessel, the oil is condensed, and the gas is burned to produce the heat for retorting. Steam usually is injected into the bottom of the shale bed to "sweep" the oil from the retort. Modifications of this process include the Rockesholm or HG retort (Hultman and Gustafason) used in Sweden (20), the Henderson retorts used in Brazil and Spain (30, 46), and the Fell retorts formerly used in Australia (31). A more recent modification, the Westwood retort, is now used in Scotland and employs not only external heating but also internal combustion of retort gas, some of the gas being recycled and injected into the bottom of the shale bed with the steam and air.

In France (20) Pumpherstons retorts were used at Autun, and the plants at St. Hilaire and Sévérac-la-Château used modified Grand Paroisse (or Lantz), modified Cantieny, and Marecaux retorts. The modified Grand Paroisse process is characterized by a crossflow of hot gas through a shale bed that is retained on two sides by louvers. The shale flows by gravity down through preheating, retorting, and spent-shale cooling sections.

The Bergh retort, originally the preferred process in Sweden, was modified to permit increased throughput and is now called the Kvarntorp retort after the location of the Swedish shale-oil plant. Residual carbon and sulfur, remaining in the retorted shale after kerogen conversion, are burned to supply heat to the retort vessel proper. The hot gas resulting from combustion of the spent shale as it emerges from the bottom of the 8- to 10-inch-diameter retorting tubes passes up around the tubes, heating the downcoming shale to retorting temperatures. Another method used in Sweden is the novel Ljungstrom system which utilizes electrical resistance heating to retort the oil shale without removing it from the ground.

The Fushun retort in Manchuria (25), sometimes referred to as the modified Pintsch or Estonian type, consists essentially of two cylindrical sheet iron receptacles lined with refractories. These are superimposed and connected by a section in the form of a truncated cone. Crushed shale, from 3/4 to 4 inches in size, is fed continuously to the top of the retort and discharged from the bottom by a revolving grate. The fixed carbon is burned in the lower section by injecting steam and air, and the resulting hot producer gases pass through the upper section which functions as a distillation retort. Due to the low fixed carbon content (about 4 percent) of the retorted shale, the gas produced in the lower section is insufficient to carry out complete retorting of the raw shale; hence part of the recovered gases (retort and producer) is recycled to the base of the top section, after being freed of condensable vapors and ammonia and reheated in a brickwork heat exchanger outside the retort. The maximum temperature is about 930° F (500° C) in the retorting zone and about 1,650° F (900° C) in the gas-producer zone.

Other retorting processes have been used in various other countries, including Germany, the U.S.S.R., and South Africa (20, 47).

In many retorts steam is introduced to act as a carrier gas or sweep gas to remove the retort products, to react with the nitrogen in the shale to form ammonia, to enrich the gas by a water-gas reaction, or for any combination of these. Fines usually are screened from the feed for retorts that heat the shale by direct contact with hot gas.

Dust is a problem in processes that use finely ground feed material and in those that entail attrition of the shale to a marked degree. If carryover of the dust with product oil and gas cannot be prevented, the dust must be separated from the oil. Usually continuous internal-combustion retorts must be provided with close temperature control. Too high a temperature may cause coking or clinkering with some shales, especially those with a pronounced coking tendency, such as the richer beds of the Green River deposit.

### Refining

Shale-oil refining research and process development by the Bureau of Mines and industrial laboratories in the United States have been devoted to adapting modern petroleum-refining techniques and to developing new processes more suitable to shale oil (2-6, 8, 9, 26). The characteristics of shale oil previously discussed indicate differences between shale oil and petroleum that affect the refining method that may be applied. In some instances petroleum-refining methods are not applicable; in others, considerable changes in the methods are required. For example, catalytic cracking, a common process practiced by the petroleum industry, is not directly applicable to shale oil, as the activity of the common cracking catalysts is inhibited by the nitrogen compounds. Also, some catalytic desulfurization and reforming processes are not as successful on shale oil as on petroleum. On the other hand, hydrogenation, even at low pressures, reduces the sulfur and nitrogen content of shale-oil fractions and stabilizes the more reactive unsaturated components to reduce their gum and color-forming tendencies. The nitrogen and sulfur are removed as ammonia and hydrogen sulfide, both of which may be valuable byproducts. Nitrogen and sulfur also may be reduced by treatment with sulfuric acid and caustic soda, but product losses are greater than with hydrogenation, because the oxygen- and nitrogen-containing compounds are extracted during the process. However, these also may have byproduct value.

The various types of thermal processing common to the petroleum industry have been applied experimentally to Colorado shale oil under a wide variety of conditions on an engineering scale at the Bureau's refinery at Rifle, Colo., and on a laboratory scale (26) at Laramie, Wyo. Viscosity breaking has produced a crude oil suitable for pipeline transportation. Recycle cracking of the crude oil has produced over 50 percent gasoline-boiling-range material. Distilling the crude oil to yield coke and a distillate boiling lower than the original crude may be advantageous to subsequent refining. Catalytic or thermal reforming of the gasoline fraction improves its octane rating. High-temperature or vapor-phase cracking of the crude oil or its high-boiling fractions produces highly aromatic products. This aromatic oil may be hydrogenated readily to premium-grade gasoline or aromatic chemicals.

Overall shale-oil refining procedures made up of various combinations of the mentioned unit operations described have been evaluated. The National Petroleum Council in 1951 proposed a procedure whereby crude shale oil would be coked. The resulting gasoline would be reformed catalytically, and the higher boiling distillate would be hydrogenated to remove sulfur and nitrogen. Then a portion of the hydrogenated oil would be cat-cracked to gasoline, and the remainder would be used as diesel fuel (5). By this procedure about equal quantities of regular- and premium-grade gasoline could be made. The Bureau proposed a process that consisted of viscosity breaking, recycle cracking, catalytic reforming, and acid treating (5, 26). Gasoline and heavy fuel oil are the main products of this processing sequence.

Through about 100 years of experience, the Scottish industry (20, 25) has developed a refining procedure well suited to its crude oil and market demand for products. The crude oil is distilled into naphtha or spirit, a wax-free cut, a heavy oil and paraffin, and a residue. The spirit and the naphtha obtained by scrubbing the retort gases are treated with caustic soda and sulfuric acid to produce motor fuel and solvent naphthas. The wax-free oil also is treated with soda and acid and is distilled to produce diesel fuel and residue. The heavy oil and paraffin are chilled and filtered to separate the paraffin, which is further refined into several grades of waxes. The dewaxed oil is added to the wax-free cut for further refining as described. The residue from the distillation of the wax-free and dewaxed oils is thermally cracked to produce additional crude spirit, which is treated for motor fuel, additional diesel fuel, and coke. Byproduct detergents are made from the  $C_{10}$  to  $C_{20}$  olefins.

Swedish refining operations at Kvarntorp (20) consist of atmospheric distillation to produce gas, light oil, and fuel oil. Only the light oil is given additional treatment. It is washed with caustic soda and is treated in three stages with cold sulfuric acid, then with methyl alcohol and soda, and finally with sodium plumbite solution. The treated oil is then distilled into light naphtha to 212° F (100° C), heavy naphtha to 392° F (200° C), and kerosene to 518° F (270° C). A motor fuel of 70 to 72 octane number is made by blending the light and heavy naphthas, and a premium motor fuel of 75 to 78 octane number is produced by the addition of tetraethyllead.

The Empresa Nacional Calvo Sotelo plant in Puertollano, Spain, was designed to produce largely lubricants and paraffin waxes. Some gasoline, solvents, and ammonia-based fertilizers are manufactured. The crude shale oil is hydrogenated at about 752° F (400° C) and 325 atmospheres pressure and is distilled; the higher boiling fractions are dewaxed. These dewaxed oils are blended to produce a wide range of lubricating oils to supply most of the demand from such products in Spain.

The State Oil-Shale Industry plant in Estonia (20) thermally cracks crude shale oil into cracked gasoline, diesel oil, impregnating oil, and a residue. The gasoline and diesel oil are treated with caustic soda and sulfuric acid and are distilled. The cracked gasoline yields a motor fuel of 65 to 70 octane number, and the diesel oil is satisfactory for farm machinery. The impregnating oils contain phenols and are used for treating railroad ties.

The residue is blown with air to give asphaltic products suitable for roofing and similar uses. Other Estonian plants use simple distillation without cracking, followed by acid and caustic soda treating to produce finished products.

The shale-oil refineries at Glen Davis, Australia (31), Boksburg North, Transvaal, Republic of South Africa (47), and Fushun, Manchuria (25), had, as their principal refining units, combination crude-distillation and thermal-cracking units in which the crude oil and cracked products were fractionated in a main fractionating tower. Light and heavy oil streams were cracked separately. In Australia, only gasoline was marketed; the gas, coke, or residual fuel was used in the plant. The South African operations differed from those in Australia in that a portion of the intermediate distillate was refined to kerosene and the residual oil was vacuum distilled to produce asphalt and lighter oils for use as cracking stock and asphalt cutback stocks. At Fushun, light and heavy diesel fuels, waxes, and lubricants catalytically polymerized from olefins were additional products produced particularly during World War II.

Along with these primary products, numerous secondary products are obtained. Byproducts of the retorting step depend upon the composition and properties of the shale, as well as on the characteristics of the retorting process. Ammonium sulfate often is manufactured from the ammonia produced in retorts that use steam injection; hydrogen from the steam reacts with the nitrogen in the shale to form ammonia, which is later collected by scrubbing (26). Recovery of sulfur from retort gas is sometimes an important adjunct to oil extraction plants when the shale has a high sulfur content. In Sweden and Scotland (26) shale ash is mixed with lime to make building blocks or bricks. Other byproducts of some shale-retorting plants are cement, calcium nitrate, steam, and electricity. In Sweden, limestone is found in some of the shale beds and is used to manufacture lime.

Byproducts of shale-oil refineries are asphalt, coke, pitch, waxes, and detergents (26). In the United States the important byproducts will probably be raw materials for manufacturing organic chemicals (45). Tar acids and tar bases are present in shale-oil distillates and may be recovered by chemical treatment. The tar acids are principally of the phenol series and constitute 2 to 5 percent of the light shale-oil distillates, that is, naphtha and light gas oil; tar bases consist principally of the higher homologs of pyridine and quinoline and are present in about twice the concentration of the tar acids. If hydrogenation is used as an alternate treating step, byproducts will be hydrogen sulfide and ammonia.

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<sup>4</sup>Titles enclosed in parentheses are translations from the language in which the item was originally published.

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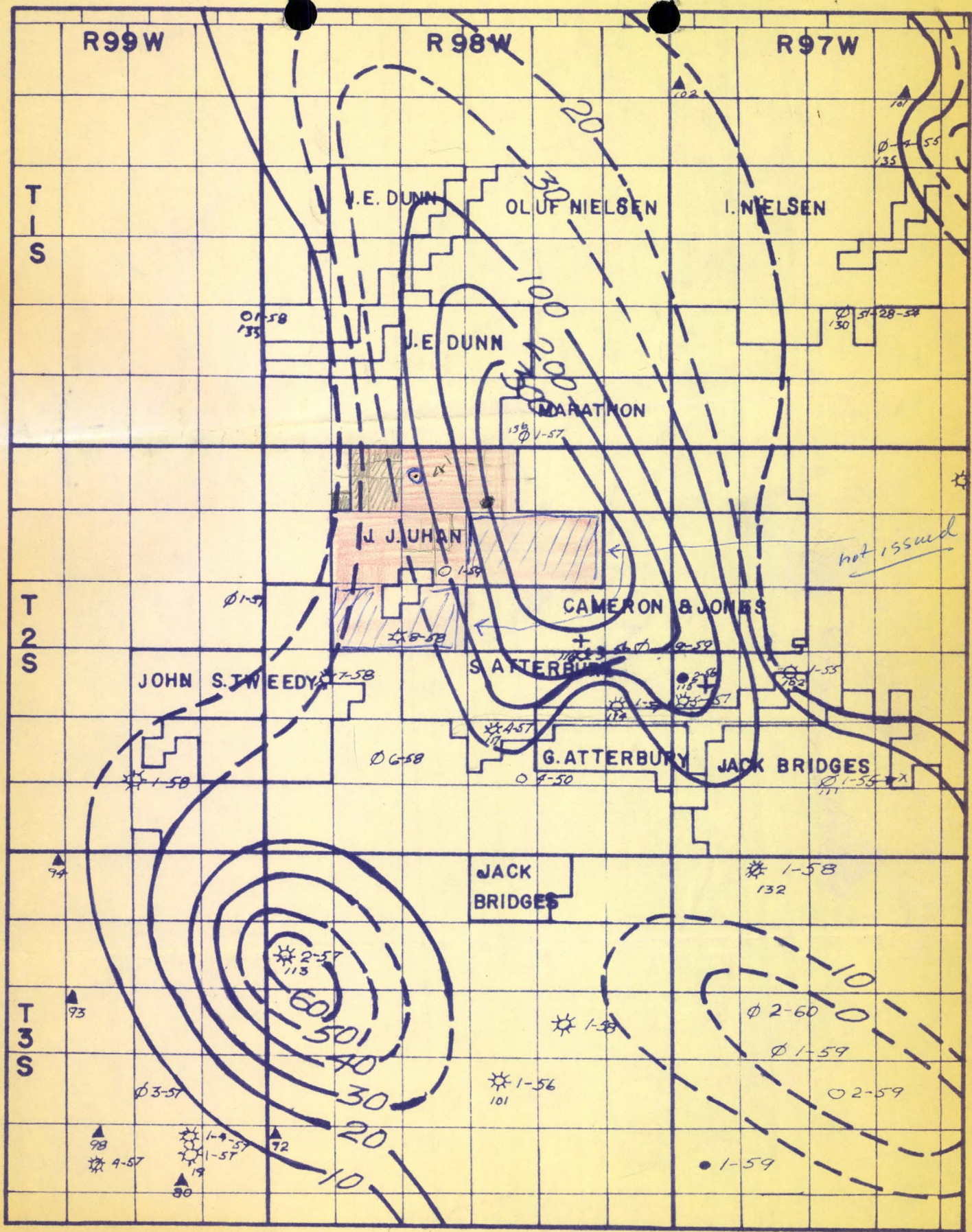


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# There's Aluminum in That There Oil!

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ONLY deer roam there now, but Colorado's desolate Piceance Basin, some 200 miles due west of Denver, is the greatest oil field in the world. It contains an estimated 4 trillion barrels, worth at today's prices close to \$10 trillion. About 80% is owned by the U.S. Government.

Last month, the Interior Department opened the government-owned land in the Piceance Basin to commercial leasing. To almost nobody's surprise, the oil companies merely shrugged and turned away. To almost everybody's surprise, the only major company that did express interest was a company that has absolutely no connection with the oil business, Kaiser Aluminum.

Kaiser has an idea. It could, of course, prove thoroughly worthless. On the other hand, it could revolutionize the nation's aluminum industry, if—a big if—it works out.

**Expensive Oil.** The oil companies were disinterested in Piceance Basin because the oil there is shale oil, locked in the land in a form called kerogen. Shale oil is not difficult to extract—you simply mine the shale and heat it—but the process is expensive. And, since there is more than enough oil in the world that can be pumped from the ground at far less cost to meet the world's needs, extracting shale oil makes no economic sense, at least at the present time. It's actually far cheaper to find oil in the far corners of the world and ship it here than to extract oil from shale right in this country.

Quite aside from that, the Interior Department hedged its offer to lease the Piceance Basin with all kinds of conditions. Among other things, Interior demanded the right to determine what particular technology each company should use in extracting the shale oil.

Spokesmen for Standard Oil of California and Shell immediately said the conditions would effectively prevent most oil companies from taking advantage of the opportunity to lease Piceance Basin land, and this attitude was echoed by Chairman A. L. Nickerson of Mobil Oil and Chairman Herbert Doan of Dow Chemical.

The reason for Kaiser Aluminum's interest lies in a discovery that until now has been known to only a handful of people. Last year, according to

Russell G. Wayland, chief of the U.S. Geological Survey's Conservation Division, "While conducting routine tests on a core sample of oil shale, Charles Milton, a research metallurgist for the U.S. Geological Survey, discovered that there was an unusually high percentage of dawsonite in the core sample. Dawsonite is a chemical compound that contains alumina or aluminum oxide. . . .

"Shortly thereafter, two Denver researchers discovered that dawsonite-rich oil shale dominated the entire Piceance area—in some spots as deep as 600 feet. The dawsonite and oil shale were deposited together. . . ."

Further research showed that when the oil shale is heated to about 500 degrees, it not only throws off the oil, it also throws off the dawsonite in the form of white powder, which can be leached—or separated—into soluble compounds to produce aluminum carbonate. This, in turn, can be converted by a simple and inexpensive process into aluminum itself, which, of course, indicates that the process yields not only oil but eventually aluminum.

J.R. Dyni, a Geological Survey metallurgical researcher, says: "The yield of alumina from dawsonite-rich oil shale is lower than from bauxite, but if dawsonite alumina can be recovered by a water leach . . . it may be competitive with bauxite alumina."

Says Wayland: "In addition, we think that a good deal of the production costs can be charged off to shale oil mining and recovery. . . . There's a possibility . . . this could make the United States independent of imported bauxite."

**Shoe Clerks Beware.** Kaiser Aluminum is extremely cautious in discussing its plans in the Piceance Basin. Queried about them by FORBES, Kaiser officials spent hours in preparing a statement because, as one explained: "We practically have to clear this statement with the Securities & Exchange Commission. You know, sometimes the shoe clerks read quickly, then rush out and buy shares."

The statement, when it finally did appear, said little more than this: "We have an interest in two lease applications in the Piceance Basin. Some preliminary exploratory work has been done there; results inconclusive. Clarification of Interior's position will enable us to determine how much



**Shades of Gold.** Colorado School of Mines is conducting research here at Rifle Colo., to find a commercial process for extracting oil from shale. But there may also be "white gold" in the rock.

further work should be done.

"A long-range research program is necessary to determine if alumina can be economically extracted from shale."

Reynolds Aluminum and the Aluminum Co. of America have not yet followed Kaiser's lead in seeking leases in Piceance, but at Harvey Aluminum, Chairman Leo M. Harvey told FORBES: "You can bet we're watching what Kaiser is doing out there in Colorado."

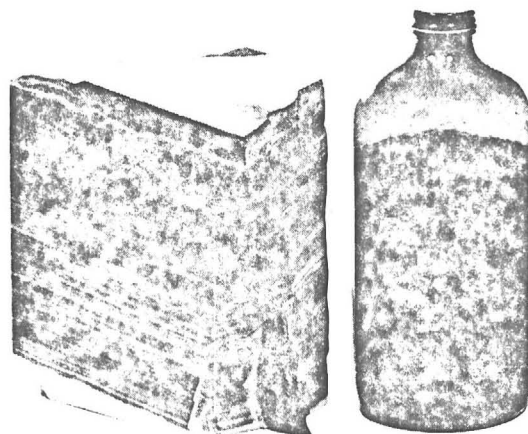
Harvey pointed out a barrier to exploiting Piceance dawsonite quickly: the worldwide investment the aluminum industry has in traditional bauxite mining. "You can't just drop all that and go somewhere else," he said. "There is close to \$1 billion invested in plants that take aluminum from bauxite by the Bayer process." Nevertheless, he conceded that if aluminum could be produced from Piceance's oil shale, "it would be a terrific development. Today, the U.S. has almost no bauxite. During World War II, 90% of the bauxite shipped to this country was sunk before it reached the U.S."

Kaiser Aluminum's experiment with Piceance oil shale may come to nothing. Or it may work out—some day. But it's one more example of the tremendous technological ferment going on as industry pushes deeper into the earth for new sources of energy and raw material for an exploding world population. (For another example, see the report on Union Pacific's ambitious development of its vast trona holdings, page 34.) ■

# Shale Oil:

## From Potential To Production

By: C. E. Reistle, Jr., Former Chairman of the Board  
Humble Oil & Refining Company



Look at the block of oil shale at the left, and it is hard to understand how the liquid in the bottle at the right could have come from such a solid mass.

The piece of oil shale looks exactly like what it is—a chunk of ordinary brownish rock. Commercial-grade shale will yield 25 or more gallons of oil per ton. But producing and processing shale oil requires a series of complicated and expensive steps.

First, the shale must be mined and crushed into small pieces. Then the pieces are fed into a retort, where high temperatures convert kerogen, or organic material, into oil vapors. These vapors are then condensed and recovered as liquid shale oil.

Shale oil cannot be economically converted into useful products by ordinary means available in today's petroleum refineries. But expensive research and pilot studies are now underway to develop ways of converting shale oil into products which can be sold at prices that will be competitive with energy from other sources.

The security and welfare of the United States demand that adequate supplies of domestic energy be available at all times. The most abundant energy resources in the U.S. are hydrocarbon fossil fuels—oil, gas, coal, and oil shale.

Essentially all private and most public transportation is powered by energy derived from fossil fuels—mainly from crude oil. At some point in future time the increasing demand for liquid fuels will probably require that conventional sources of liquid energy be supplemented with those from oil shale and other sources. It's difficult at this time, however, to predict how soon these supplemental fuels can be produced at a price that will make it possible for them to com-

pete effectively for a share of the national energy markets.

Nevertheless, it is reasonable to assume that when oil from shale enters the national energy markets it will do so gradually and as a supplement to production of domestic crude oil. The obvious problems of developing this new industry are such that any fear that it will swamp the present petroleum industry or "take over" a disproportionate share of the markets is unfounded. Certainly it could not do so in the light of today's economics and technology. Two things will bring shale oil into the picture: (1) increased costs of finding and developing new reserves of crude oil, and (2) advancements in shale technology.

## Use of Energy in the United States

As all of us know, our national economy is marked by an insatiable thirst for energy. The use of energy contributes directly to the high standard of living we enjoy. Use, I might add, is the key word. Some countries, such as those in the Middle East, are richer in specific energy resources than we are, but their people use less energy for productive purposes.

By contrast, use of petroleum and natural gas as sources of energy in the U.S. has increased steadily. During the past year, the U.S. consumed petroleum products at a rate of about 11 million barrels a day. That was enough to provide 874 gallons a year for every man, woman, and child in this country. By contrast, per capita consumption in the rest of the Free World was only 109 gallons in 1965.

Taking a look at the future, I believe a reasonable estimate of U.S. consumption in 1985 is 18 million barrels per day. To meet that much demand, and maintain present reserves to production ratios, the oil industry must develop an additional 89 billion barrels of reserves in the next 20 years. That is more liquid energy than the U.S. consumed during the past 100 years and presents a tremendous challenge to our industry. This also explains why it is probable that supplies of energy from conventional sources will have to be supplemented by liquid fuels from shale oil, coal, and tar sands at some point during the next two decades.

### Interfuel Competition

As the petroleum industry goes about its important task of meeting energy needs in the future, we are going to see some keener rivalry as each type of energy strives for a greater share of the market. This is nothing new; interfuel competition has been getting hotter for a long time, with shifts occurring from time to time among competing fuels. The percentage of energy supplied by oil and gas has grown tremendously. By the late 1920's, oil and gas accounted for one third of all energy consumed in this country; this had grown to one half by the late 1940's; today it is about three fourths.

A good example of inter fuel competition is the changing picture in use of fuels for home heating between 1940 and 1965. During that period, coal's percent of the home heating market declined from 55 to an estimated 7.7. In the same 25 years, oil increased from 10.5 to an estimated 29.2, and gas increased from 11.4 to 50.1. But coal in recent years has made great progress in becoming a strong competitor of petroleum in other energy fields—particularly in the public utilities generation of electricity.

Each of us could name reasons for intense inter fuel competition. One is the increasing costs of finding and developing new crude oil reserves. Another reason, and a fortunate one for the public, is that the consumer has greater variety of energy sources at competitive prices from which to choose, as well as a greater number of suppliers. As an example, electricity for home heating is making great strides, and the oil industry will have a real fight on its hands to maintain its present position in the space heating field.

With this as a background, let's turn our attention

back to our main subject—shale oil. The fact is there has been interest in shale oil in this country—to a greater or lesser degree—for the past 40 or more years. But just about the time shale oil would begin to look like a paying project, something would happen to shove it into the background again—something, for example, such as new discoveries of large reserves of crude oil, both domestic and foreign, or the changing concern over our energy supplies during and after major wars.

Shale oil recovery has a much longer history in other parts of the world, beginning in England about 500 years ago. Over the years, moderate amounts of oil have been recovered from shale in Australia, Brazil, Manchuria, Estonia, France, Germany, Scotland, Spain, and Sweden. By far the most extensive oil shale deposits in the world are those in Brazil and the United States.

### Important Shale Deposits in U. S.

The most important oil shale deposits in the U. S. (and possibly in the world) occur in the Green River Formation which underlies about 16,500 square miles in the Piceance Basin of northwestern Colorado, the Uinta Basin of northeastern Utah, and the Green River Basin of southwestern Wyoming. These shales have been estimated to contain more than two trillion barrels of shale oil.

Of the three areas just mentioned, by far the most significant is the Piceance Basin covering about 1,380 square miles (roughly 880,000 acres) in northwestern Colorado. This area is bordered on the south by the main stem of the Colorado River, on the east by the White River Uplift, on the north by the White River, and on the west by the Douglas Creek Arch.

While the total shale oil deposits in Colorado have been estimated as high as 1.5 trillion barrels, the richer portion averaging 25 gallons of oil per ton of shale, and varying from 50 to 2,000 feet thick, is estimated to contain about 480 billion barrels. The recoverable portion based on present technology is estimated roughly at 280 billion barrels of oil from this rich section. By contrast, domestic reserves of crude oil are about 31 billion barrels.

These are tremendous numbers. They are big enough to cause speculative fever among men who have no idea of what must be done to get the oil out of the shale at a price low enough to compete with fuels from conventional crude. No practical oil man will be misled by what may seem to be a mammoth supply of oil in the shale, just ready for the taking. There is a big difference between this "on the books" oil from shale and oil in a pipeline. It is the same difference that exists between gold in the sea and gold in Fort Knox. It has been estimated that the oceans of the world contain more than six million tons of gold. That is enough to make a pile which would weigh almost as much as the Great Pyramid of Egypt. Figured at today's market value, that pile of gold would be worth *seven trillion dollars*. By contrast, the present monetary gold supply of the entire world is worth only *forty billion dollars*. But you don't see anyone rushing to mine the sea for gold. And no wonder! A ton of sea-water contains only 2 to 60 milligrams of gold—not worth the effort with

our present knowledge.

The plain facts are, it will be necessary to spend large sums on research and development before a profitable shale oil industry can become a reality. Substantial progress is being made in oil shale research. Technology has now progressed to the stage where we may hope to produce and process oil from shale at a cost closely competitive with crude oil. But we still have a lot to do if we are going to get those costs closer together. A differential of just half a cent a gallon for gasoline makes a terrific difference in this highly competitive business. That amounts to 21 cents a barrel, and every producer fights hard for much smaller cost reductions than that in his regular operations.

### **Shale Oil Will Enter Energy Markets**

Let me emphasize that I do not mean to imply that oil and gasoline from shale will not eventually enter the market. Today, few question that. My company would not be spending money on research unless we were reasonably inclined to believe that shale oil can one day supplement other energy sources. Nor would our competitors! But the old question of economics remains a deciding factor. The point I want to make is that even a fractional difference in price of gasolines derived from shale and crude oil will defer or hasten the day when fuels from shale oil can begin to compete with fuels from conventional crude.

How soon that day will come depends basically on two factors which are still unknowns in the shale oil equation. The first of these factors is the technology that industry can provide to make shale oil competitive with crude oil and other energy sources. The second factor is government and the kind of environment it is willing to provide to encourage development of shale oil by private industry. Let's look first at the industry side of the equation.

There are two major methods that are being studied for getting oil out of the shale: (1) mining and retorting and (2) *in situ* retorting. Work is going forward on both methods; one or both may ultimately prove to be economically feasible. Using the mining and retorting method, a minimum shale oil plant is believed to be one which will produce at least 50,000 barrels of oil per day. Such an operation involves mining, crushing, and retorting 80,000 tons of shale per day. Capital investment in such a plant, including upgrading facilities, would be in the order of \$100 million. An operation like the one just described would be comparable to finding, developing, and producing a 365 million barrel oil field—and we don't find many fields of that size. In fact, there have been only 23 fields which have produced that much oil in the history of the domestic petroleum industry.

### **Research and Development Needed**

Using the *in situ* method involves creating some type of permeability in the shale formation, so that heat can be brought in contact with the shale in place and hydrocarbon vapors generated from the heated kerogen can be recovered at the surface. Considerable effort has been carried on with the use of conventional hydraulic fracturing, followed by super-

heated steam or other heated gases. There has been considerable discussion between the government and industry concerning the use of a nuclear device to create a "rubble zone," or chimney, in the shale which would be followed by some means of heat. A contract has also been let by the government to experiment with high voltage electricity to create permeability between adjacent wells.

As recovered by any method, shale oil is a viscous, waxy liquid of low gravity and high pour point. It contains a moderate amount of sulfur and a relatively high amount of nitrogen. In its raw state it is too thick to be moved easily by pipeline. It cannot be used as a normal feedstock in present-day refineries because of its nitrogen content. Removal of nitrogen is unusually difficult because it occurs in shale oil throughout the boiling range, in contrast to conventional crudes, where nitrogen is substantially restricted to the residual cut. Once the nitrogen is removed, however, shale oil can be converted into quality fuels.

I would say that lead-time of from 8 to 10 years will be needed by an aggressive industry in order to carry out research and development necessary to design and build commercial equipment. Recognizing this lead-time requirement, Humble is now involved in research programs in laboratories of its research affiliates and also in the consortium operating the Bureau of Mines experimental facilities at Anvil Points. These facilities have been leased from the Department of the Interior by the Colorado School of Mines Research Foundation. This program is sponsored and the experimental work is manned by several companies with the research effort primarily directed to future development in retorting technology.

### **Government and the Leasing Situation**

Having briefly discussed the industry side of the shale oil equation, let us turn now to the role of government.

The ownership and leasing situation with regard to oil shale lands is unusual. The bulk of the high quality deposits are in Colorado in an area which is owned about 10 per cent by private interests and 90 per cent by the federal government. The privately controlled lands are generally of a poorer quality or else are so distributed that they could not support a competitive industry. Their ultimate disposition and value will depend almost entirely on the programs adopted for the development of the federal lands.

To those familiar with the problems associated with trying to develop a commercial oil shale industry, it is obvious that a satisfactory basis for leasing the federal lands must be devised at an early date. At the present these lands are an idle and frozen asset and there is no indication of how their leasing and development will be administered. I have previously emphasized that substantial amounts of time and money will be required to make shale oil commercial. Industry cannot be expected to make the necessary commitments of either effort or funds without knowledge of the framework within which

this industry will have to function, or without the opportunity for commensurate reward for the risk capital necessary to carry on the development efforts.

### **Private Industry Will Do the Job**

I believe private industry should be given the opportunity to do the necessary research and spend the funds to develop the shale oil deposits under a program in keeping with those applied so successfully under similar circumstances. In my opinion, the public interests would best be served by making these federal lands available in an orderly and intelligent manner under a competitive bid, fixed royalty lease basis, similar to that employed so successfully in federal offshore oil and gas lease sales. Not all of the shale lands need be leased at once, but reasonable amounts should be made available at reasonable frequencies. The system adopted should be designed to attract numerous operators, thereby fostering the diversity of approach to both research and development which has stimulated industrial progress in this country. The type of government-industry relations utilized in leasing the offshore continental shelf areas has benefited both industry and the public. And after all, it is the public who really owns these lands and whose interests should be served.

### **No Windfall Profits**

Let me say at this point that all industry, not just petroleum, has an obligation to expose the fallacy of the hue and cry that some have raised about windfall profits and stealing of the public treasures if these lands are leased to private industry for development. Nothing could be farther from the truth. To my mind, the worst thing that could be done to the public interest would be to depend upon the federal government to develop and actually operate an oil shale business. To do so would strike at the very heart of the basic institutions on which this country has grown and prospered. Furthermore, there is no evidence that government can match the efficiency and economy which are the natural outgrowths of industrial competition.

In the specific case of shale oil there is no basis to suggest that there is a potential windfall to anyone, but rather there is only the opportunity to invest large sums and to devote much time and effort in the hopes of realizing a reasonable profit. My company, and I am sure many others, will be willing to take these risks. And I would urge those who talk of windfalls to have a little more faith in the ability of our present competitive system to continue to serve the public good by providing both reasonable prices and reasonable profits.

For the public good, the rate and extent of shale oil development should be determined by economic forces which control the interfuel competition in this country without artificial stimulus or delay. Interfuel competition will assure continued and adequate supplies of energy at the lowest possible costs. Economic development of oil shale deposits, even in competition with other fuels, will, however, require reasonable government policies which will encourage private industry to do its own research, develop its own processes, and make its own investments.

While the leasing problem is of the utmost importance, it must also be recognized that the government can discourage or encourage private development through use of its power to tax. Another government matter is the oil import policy; any drastic shifts in present imports policy would either discourage or encourage development of shale oil by private industry.

Things that happen in Washington, of course, are not the only factors which affect the shale oil question. Those willing to risk capital in this new industry must also recognize that any unforeseen changes in the domestic oil picture could affect the economic rewards and speed up or delay shale oil development. For example, new discoveries of crude reserves, if large enough, could decrease the interest in shale oil — just as such discoveries have in the past. On the other hand, a continued slowing down of oil finding success could encourage the development of shale oil. Breakthroughs in technology that would lower the costs of producing liquid fuels from shale would also speed up the development of the shale reserves. By similar reasoning, any such breakthroughs in producing gasoline from coal or tar sands would have an obvious effect on the development of a shale oil industry.

### **Timely Action by Government Necessary**

In summary, I believe that shale oil can become a viable segment of the petroleum industry during the 1970's. If this is to happen, however, several conditions must be met. A firm program, including reasonable leasing rules, must be adopted for the federally controlled public lands which dominate this country's oil shale deposits. There needs to evolve in the minds of the people and of government officials an understanding that while the uncertainties of exploration have been removed, unknowns of equal or greater magnitude exist in the mining, retorting, and refining processes which must be developed for this industry. These uncertainties foreclose without question any possibility of windfall profits to oil shale developers at the expense of the public. These same uncertainties are, however, the first half of the risk-reward formula which has so successfully motivated private industry in the past and has been the hallmark of the industrial leadership of this country.

Gasoline from oil shale will require significant commitments of technical talent and large capital expenditures for research and development, all of which will take time. Private industry is more than willing to take these steps. Timely action by government in establishing a framework within which a shale oil industry can function is essential to provide sufficient lead time for the research and development necessary to commercialization. Given these opportunities, private industry can bring oil shale from potential to production.

(Editor's Note: Mr. Reistle presented the above article before the 95th Annual Meeting, AIME, in New York, and we sincerely appreciate being given the opportunity of reprinting his interesting and informative comments on shale oil.)





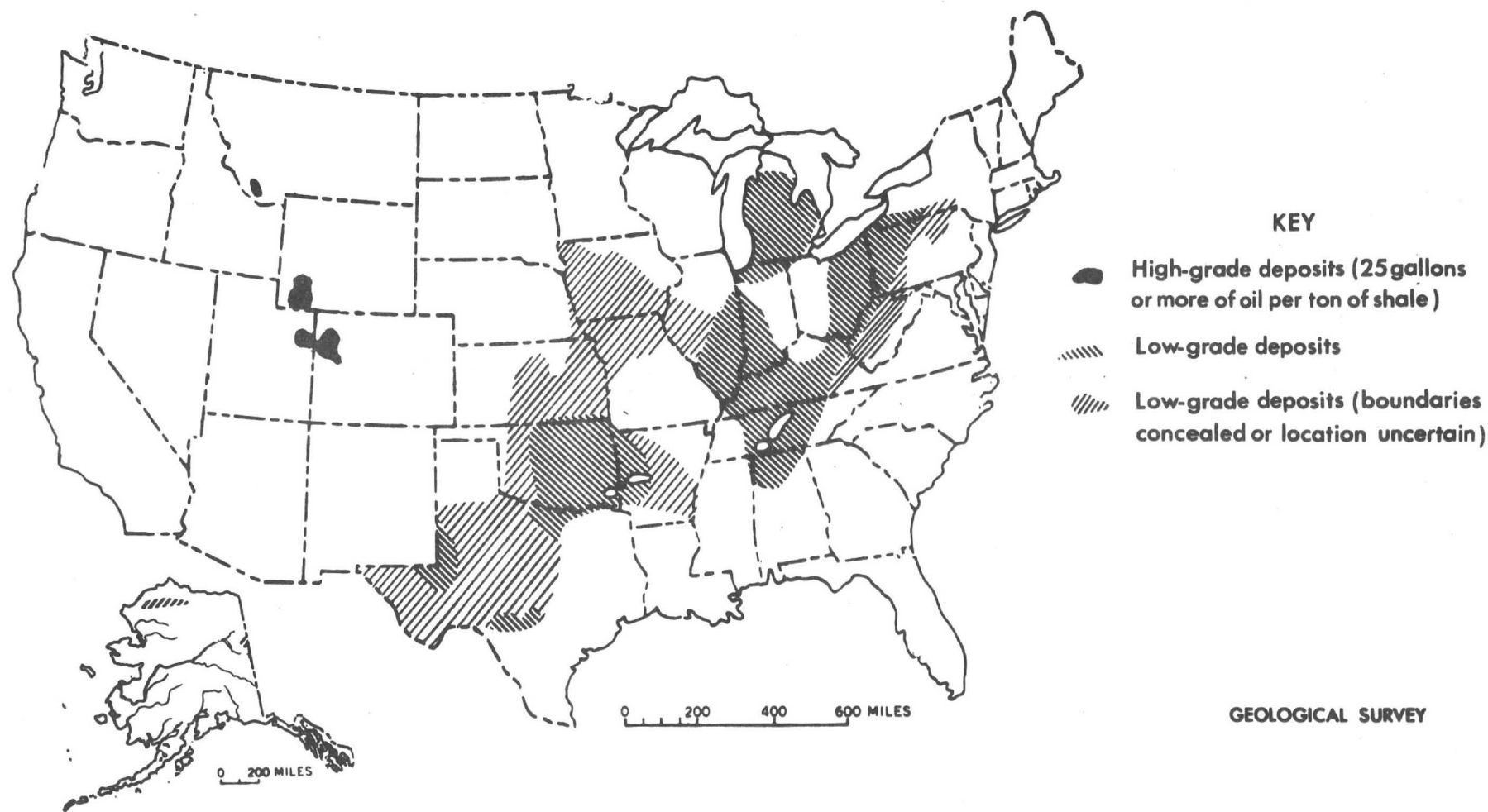
- There may be as much as 28 trillion barrels of oil equivalent in less accessible or lower-grade oil shale deposits in the United States.
- Oil shale in the United States contains about 80 billion barrels of oil equivalent considered recoverable under approximately present conditions. South America has about 50 billion, Europe 30 billion, Asia 20 billion, and Africa 10 billion barrels.
- Assuming that one-half the amount of reported oil shale is economically available, the recoverable shale oil reserves of Communist China are estimated at 14 billion barrels.
- Oil shale deposits were mined in many European countries during the 19th century and much of the present century under conditions of local oil shortage.
- A rough estimate of the oil produced from shale in Europe from about 1875 to 1961 is about 250 million barrels, most of which were produced in Scotland and Soviet-dominated Estonia.
- In Europe oil shale deposits have been used largely as sources of oil and gas, or as solid fuel on a small scale. Their use throughout the world is expected to increase in the future as methods of mining and processing are developed and improved.
- Materials such as vanadium, uranium, copper, iron, aluminum, and phosphorous are present in some deposits of oil shale in sufficient amounts to be of possible commercial interest as byproducts.

X X X X

(Note to Editors: Simplified map showing principal oil-shale deposits of the United States is attached.)

94372-67

# PRINCIPAL OIL-SHALE DEPOSITS OF THE UNITED STATES



HEINRICH  
GEOEXPLORATION CO.



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Phone: (602) 623-0578

Cable: GEOEX

GEOPHYSICAL ENGINEERS

Report

Juban Oil Shale  
Properties

Rio Blanco County Colo.

for

ALASKAMET

by

HEINRICHS Geoporation Co.

## Introduction

At the request of Mr. Bud Tinkle, President of Alaskamet, Henricus GeosExploration Co. reviewed the file and technical data supplied by Mr. Joe T. Suhann on some oil shale properties located in T. R. Rio Blanco County, Colorado.

The objective of the data review was to summarize the information available and submit conclusions & recommendations on the possible economics of the properties involved.

## Table of Contents

1. General Location Map
2. Introduction
3. Conclusions & Recommendations
4. Data review
5. Map showing barrels of oil per ton of shale rock.
6. Schematic diagram of known drill holes showing a generalized log.
7. Signature page
8. Bibliography

# Introduction

At the request of Buddy <sup>Mines Inc</sup> Tinkle, President of Alaska Metal <sup>Co.</sup> ~~Heinrich Geoporation~~ <sup>has initiated</sup> a study <sup>& summary</sup> review of ~~oil shale~~ oil shale technology and the <sup>potential</sup> economic possibilities related to <sup>certain</sup> oil shale properties ~~certain properties~~ ~~owned or~~ owned or controlled by J. T. Juhon located in T. 1 N. R. 98 W., Rio Blanco County, Colorado.

The most extensive oil shale deposits in the world are located in the Green River formation of Eocene age in Northwestern Colorado and a certain area known as the Piceance Basin contain rich sections averaging 25 gallons of oil per ton of rock material that represent 400 billion barrels of oil in place.



(1)

Report

Juban - Dawsonite  
Oil Shale Project

~~Report~~

Rio Blanca County, Colorado

by

Heinrichs Geoporation Co.

Tucson

ARIZONA

②

# Index MAP

# Table of Contents

100 (1)

## Suhad Oil Shale Proj.

Summary <sup>on economic</sup> Feasibility of development of the oil shale reserves in T. 1 N., R. 98 W., Sec. 9, 10, 11, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, and portions of 12, 13, 24.

The foregoing described lands are held under 160 acre placer claims for dawsonite.

### Assumptions

Conventional Mining Methods (underground room & pillar)  
Minimum 50,000 bbl/day capacity      Avg. 20 gpt.

" 15,000 T/day crushed shale

Est. net profit before taxes \$40 to \$70/bbl  
(conservative/low est.)

Credits computed for other possible contained products such as alumina & soda ash could increase the ultimate yield or profits 2 to 3 times, or perhaps

### Confirming Drill Hole information

#### Drill Logs

General Petroleum has drilled two holes in the immediate area as described below & identified as (2) & (3) on the <sup>enclosed</sup> sketch.

(2) G.P. 64-8-G; (3) GP 46-27-G

These drill holes confirm the existence of an average of +20 GPT oil shale with saline facies containing nahcolite (Soda Ash) bearing zones that likely also contain dawsonite (Alumina) See attached sketch.

(2)

## Economics

### Recommendations

Because of the tremendous <sup>fuel</sup> reserves per square mile <sup>in the Prance Creek basin.</sup>, ~~having a certain~~ It is ~~not~~ economically wise <sup>if easily acquired</sup> for Alaskamet to have some ~~to hold~~ <sup>on participating</sup> in the potential development of these reserves.

The attached sketch map is indicative of a similar feeling by many of the major domestic oil producers.

Problems

The economics looks very bright if the Dept. of Interior would evolve an equitable operational solution to granting leases <sup>for</sup> oil shale & sodium (soda ash) and permitting the conventional means of protecting the title to the lands containing significant amounts of dawsonite (alumina) as a locatable mineral

To date the Dept. of Interior has chosen to differ any decision but pressure is building up for a move one way or another.

# Washington Impact

## Government proposals for test leasing of oil shale a flop

Legislators from the three major oil shale states are expected to push legislation this year to encourage immediate private development of the resources following failure last month of the Interior Dept. to generate much industry interest in bidding on three test leasing tracts. The move will come from Senators and Congressmen in Colorado, Utah and Wyoming. They want more favorable lease terms, minimum government intervention, plus royalties and other conditions more in line with existing federal leases on conventional oil and gas lands as well as lease acreages large enough to encourage private interest.

Last year's Interior Dept. invitation to industry to bid on three parcels of land in Colorado's Piceance Basin was made as a test of commercial interest in government-supported private development of oil shale desposits. But the results turned out to be a bitter disappointment to Interior Secretary Stewart Udall. When Interior announced terms for the bids in November 1967, Udall was talking of bonus offers of more than \$20-million for each of three tracts offered. Only three bids were made at the proposed lease sale last Dec. 20. Of these, two were by Oil Shale Corp. (Tosco), which bid \$249,000 for Tract 1, representing a bonus of \$199 per acre, and \$250,000 for Tract 2, representing \$48 an acre. The only other bid came from one Fred C. Crafts of Eugene, Ore., who bid \$625 on Tract 1, an amount equivalent to 50¢ an acre. No one bid on Tract 3.

Interior howled that bids were ridiculously low, but said it wasn't surprised. After all, officials said, the three parcels were offered to "test the market," to weigh industry interest. Discussions with companies just before bid opening convinced Interior officials of industry's lack of interest. At the time it made the offer, Interior said it thought it would be acceptable to industry. However, recent Alaskan oil finds, implied Interior, apparently put a damper on prospects for oil shale development. With \$-billions slated for outer continental shelf oil and gas production and heavy investment in Alaskan oil development and transportation, industry obviously wasn't willing to get into shale oil production, still involving questionable technology, Interior said. *Industry sources, however, blamed the lack of interest on unfavorable lease terms.*

Test lease 1 (1,250 acres) contains an estimated 900-million bbl of recoverable crude from shale; tract 2 (5,120 acres) has an estimate 500-million bbl; and tract 3 (5,083 acres) 900-million bbl (estimated).

Under Udall's lease terms, the winning bidder would have to undertake carefully programmed development work, observe stringent conservation practices and pay the government 14¢ a ton on shale rock extracted. The terms would have permitted deduction from future royalties of the amount bid, with ceilings of \$30-million on Tract 1 and \$20-million on Tract 2.

One reason for the lack of interest by industry is the hope that the Nixon administration may offer them better lease terms. However, some suspect that the new Interior Secretary, Walter Hickel, may not be keen on pushing oil shale development at this time, much less on asking funds for any ambitious federal program to restart government research and development.

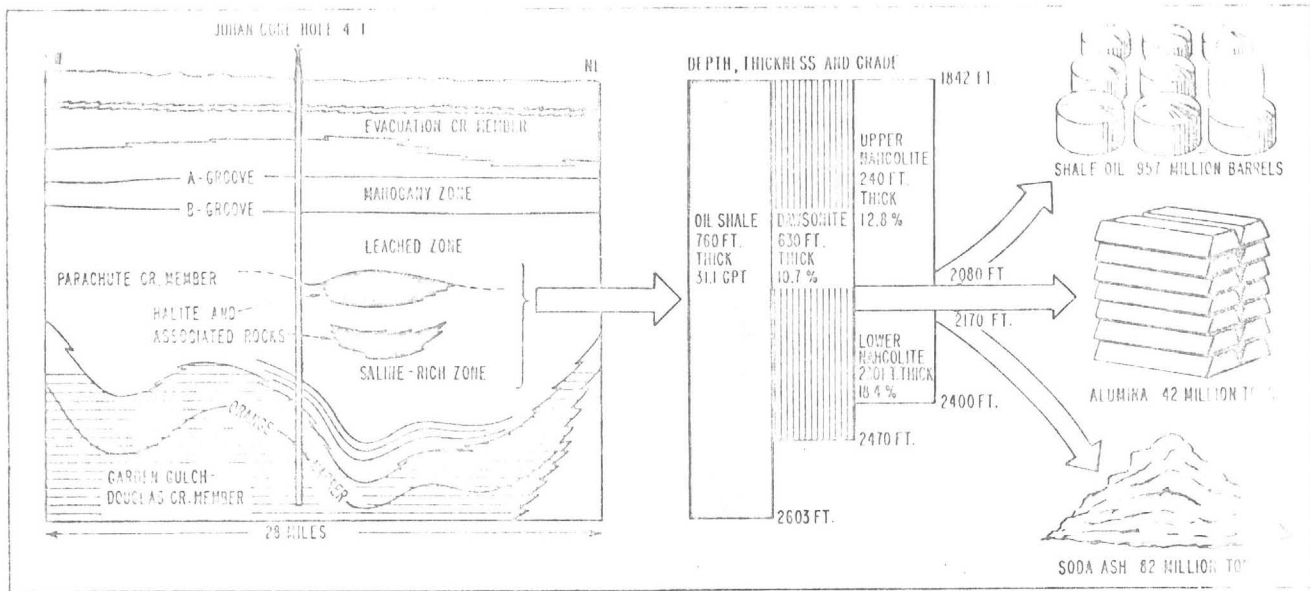
Explaining the low bid Tosco had offered, President Hein Koolsbergen said uncertain geological conditions, and "impractical" lease terms discouraged the company from making a bonus bid in excess of the \$250,000. Tosco is particularly interested in Tract 2 where it cited three adverse conditions: Presence of water, in substantial quantities from unascertained sources, in the formation above and below the mineable horizon; and the presence of fluid hydrocarbons in unascertained quantities near mineable horizons on and near the tract.

Tosco also objected to unfavorable lease terms, including a termination provision requiring that the entire delayed bonus bid be paid even if the leasehold is abandoned for good cause, after all bonafide efforts to develop it.

In a letter to Udall, Koolsbergen advanced two alternate proposals. Under one proposal the company would undertake an extensive supplementary program of geological evaluation, the results of which would be made available to the Interior Dept. At the end of 30 months, Tosco would either surrender the lease or increase the amount of its bonus bid. If the final evaluation showed the leasehold to be favorable and if present termination provisions remain in force, Tosco would increase its bid up to \$10-million. If an "equitable adjustment" is made in the termination clause, Tosco would increase its bid up to \$20-million.

Under the second proposal, Tosco would carry out a supplementary program of evaluation, as offered in the first proposal. Depending on the outcome of this evaluation, the company would either commit itself to the construction of a commercial shale oil plant within 5 years of the award of the lease or else it would surrender the lease.

# The amazing Piceance mineral suite...



Theoretical resources of a square mile of the Piceance Basin are shown at right and based on thickness and grades of the center chart. Large amounts of oil shale overlie the

saline-rich zone as shown by diagram on left. The top of the salines is marked by a dissolution surface and almost all soluble salts in the oil shale have been leached by water.

## ...and its industrial potential for ENERGY-OIL-METALS-CHEMICALS

Irvin Nielsen  
Consulting geologist

LONG NOTED FOR ITS OIL SHALE RESERVES, the discovery of sodium-rich salines within Colorado's Piceance Basin now suggests the possibility of developing one of the world's most unique and highly diversified industrial complexes.

The recent identification of dawsonite [NaAlCO<sub>3</sub>(OH)<sub>2</sub>] and nahcolite (NaHCO<sub>3</sub>) in central basin areas of the Green River formation a few years ago not only sparked a lease scramble and a great deal of legal maneuvering, it also broadened considerably the natural resource base of areas formerly looked upon solely as potential sources of shale oil.

Dawsonite was first viewed as a source of alumina. Then nahcolite stole the limelight as a relatively ideal and cheap reactant for removal of sulphur from stack gases. There was even a proposal to leave dawsonite in shale retorted to extract shale oil and to use the ash as a low-cost source of "alkalized alumina", another sulphur-removing chemical which is getting attention from the U.S. Bureau of Mines.

The same sodium-rich and kerogen-rich beds of the Green River Formation also hold large reserves of halite, anhydrite (a sulfate sodium aluminum silicate) and limestone. It seems almost inconceivable that such a useful suite of minerals could be stacked up in sedimentary strata in one area. The existence, however, opens the potential for a mine in the central portion of the Piceance Basin from which oil, alumina, lime and soda ash could be produced as a start (see the conceptual flowsheet on the following page).

Moving a step further, it is possible to tap the energy

of a hydrogenated shale oil base for support of a primary aluminum smelter. The unique mineral assembly also presents interesting opportunities for production of other primary products such as: Caustic soda; quicklime; sodium bicarbonate; cement; sulphur; sulphuric acid; ammonia; chlorine; hydrochloric acid; sodium sulphate; sodium chloride; calcium chloride and others. The secondary chemicals that could be made from these basic building blocks are too numerous to mention.

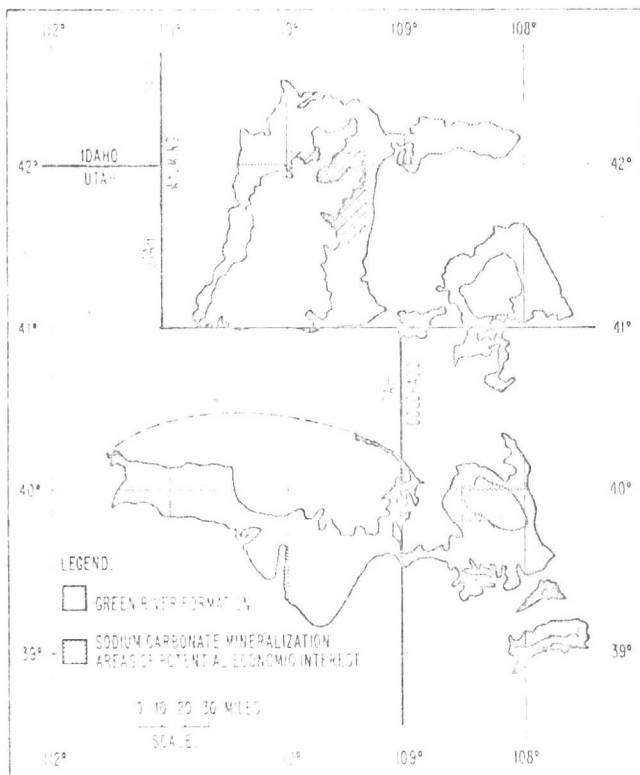
While many technical problems stand in the path of a multi-product industrial complex, it takes a little imagination to think of what might evolve from specialized research on utilization of these deposits. There is an open-end opportunity to provide a new domestic source of aluminum, perfect an economic oil recovery process and produce reactants useful in correcting air pollution problems.

### The oil shale and saline environment

The Piceance Basin of northwest Colorado has long been known for its Mahogany Ledge oil shale deposits that outcrop around the rim of the basin. A 60-ft thick interval in the area of Parachute Creek can be mined to produce a 33-gal per ton upper lift and a 35-gal per ton lower lift. It is the upper section that has been mined in demonstration plants. Oil field drilling and diligent survey work by the U.S. Bureau of Mines was responsible for the finding of a thick "oil shale" sequence near the center of the basin. Later, core drilling and assay work demonstrated that the rocks that gave such high "shale oil" yields were not really so rich but had a high concentration of sodium minerals that dissolved in oil well drilling fluids and in effect, the cuttings were upgraded by removal of the soluble minerals.





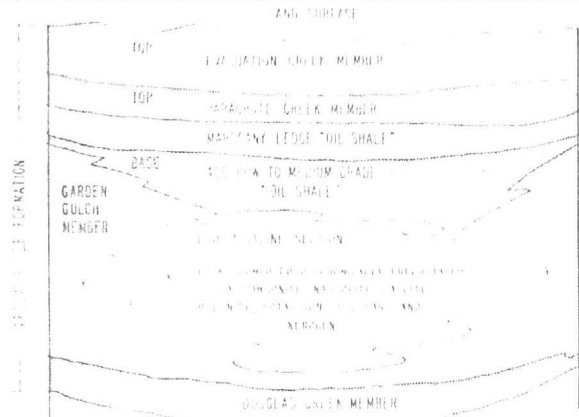


Major basins of the Green River formation occur in three states. Cross-hatching indicates sodium mineralized areas.

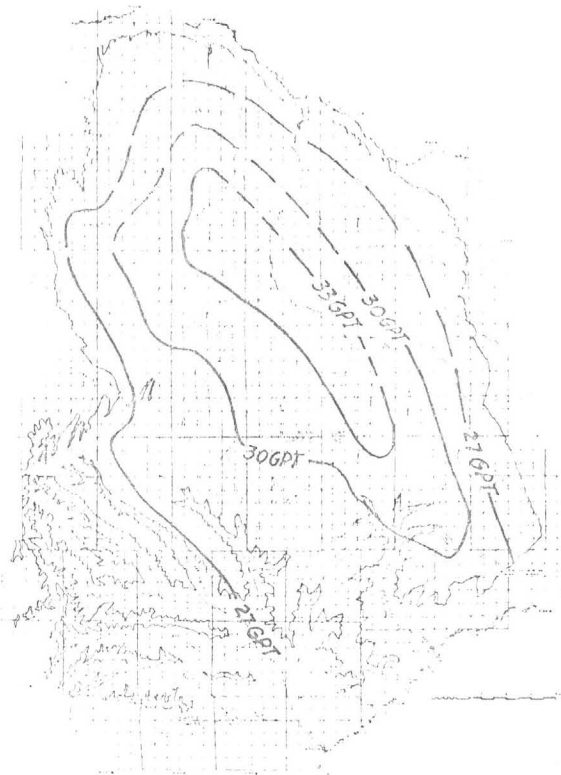
operated oil shale demonstration plants. To date no shale oil is being produced commercially. It must be concluded that all these efforts failed to prove conclusively that an oil company could invest its risk capital to produce shale oil and make more profit than it could by investing its risk capital to find oil at home or in foreign countries under today's lease and depletion conditions.

The indicated economics for a 30,000 bbl per day shale oil operation reveal a potential profit of \$0.16 per bbl as shown in Table I. This situation would prevail for a room and pillar mine with a shale oil assay of 38 gal per ton and where overall mine and plant recovery amounted to 80%. If the shale oil was hydrogenated and pipelined to metropolitan areas it might command the \$3.00 (plus or minus) price ordinarily paid for oil, but this would necessitate a large quantity of product.

The fundamental concept of a multi-products plant in the accompanying flowsheet assumes an idealized underground mine working strata containing 21% nahcolite,



Stratigraphy of saline section of Piceance Basin. Sodium minerals are at depth in central portion of basin.



Average grade of oil shale in Mahogany Ledge member of the Piceance Basin in Western Colorado is indicated on the map.

12% dawsonite, and 16% organics.

From the flowsheet materials consumed are: (1) Carbon dioxide, 1,028 tpd; (2) water, 1,010 tpd; (3) lime, 803 tpd; and (4) mined rock 30,100 tpd. The products recovered include: (1) Nahcolite, 6,310 tpd; (2) oil, 24,700 bbl per day (3,900 tpd); (3) alumina, 1,000 tpd; and (4) soda ash from dawsonite, 947 tpd.

If the 1,000 tpd alumina is refined to aluminium on site, then the 24,700 bbl per day oil would supply the fuel to produce 14-million kwh electric energy. Since each pound of aluminum requires 10 kwh for electrolytic reduction from alumina, a total of 10-million kwh will be used in the electrolytic plant. Therefore, 70% of the oil would be consumed if the oil were used as fuel. As a result, the material input-output balance would become:

**Consumed:** (In addition to lime, water, CO<sub>2</sub>, and ore)

Oil	17,290 bbl per day
Alumina	1,000 tpd

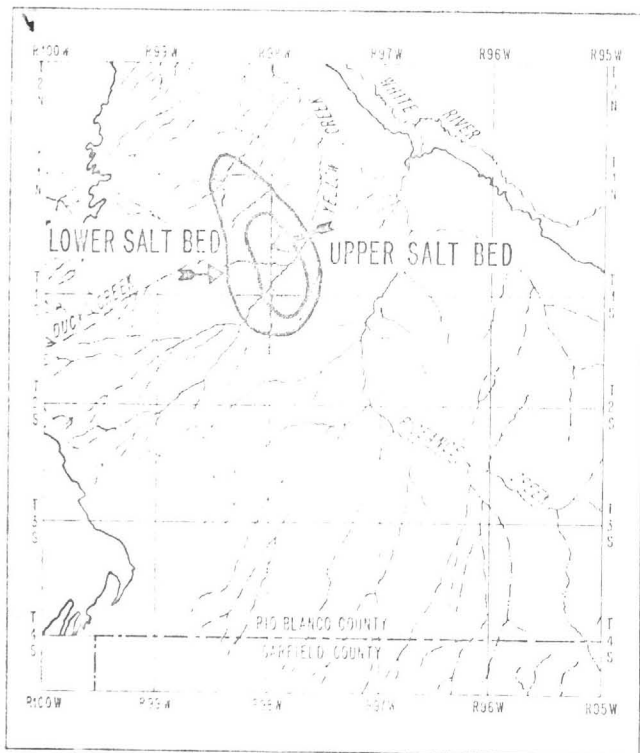
**Products:**

Nahcolite	6,310 tpd
Soda Ash	947 tpd
Aluminium	800 tpd
Oil	2,410 bbl per day

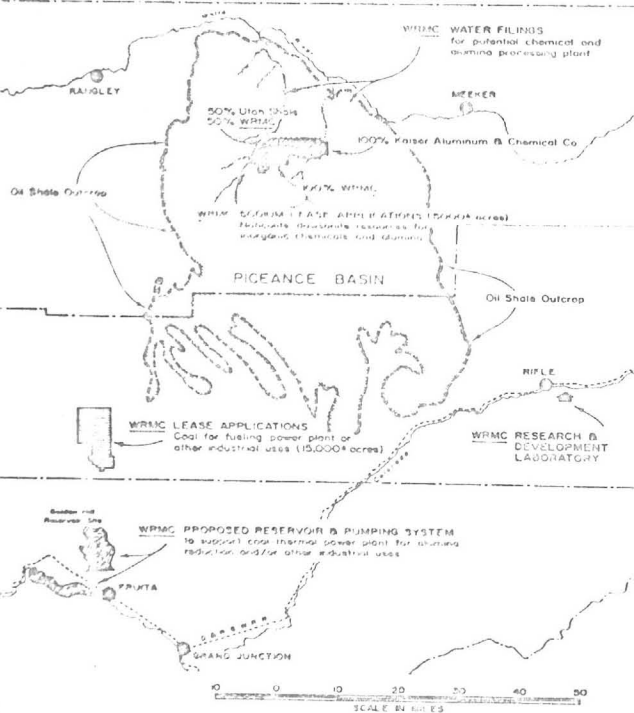
The operator may option to produce oil and burn locally available coal or produce soda ash instead of nahcolite. He may also produce any of the basic inorganics previously mentioned and/or a host of organic chemicals.

The mine could be designed to increase product flexibility by selecting minable horizon having varying ratios of dawsonite, nahcolite, and shale oil. Dawsonite can be varied from 0 to 13%, nahcolite from 0 to 90% and shale from 20 to 46 gal per ton.

What about economics? One would find little argument from oil shale-experienced companies that shale oil can be produced at a cost less than its value at many sites in Colorado, though perhaps not at a profit sufficient to attract risk capital to build a plant. The questions preventing development are largely political and legal, in-



Aerial extent of two salt beds which delineate the area of maximum saline mineral deposition within Piceance Basin.



Piceance Basin map shows various projects related to sodium development. It was prepared by Wolf Ridge Minerals Corp.

involving depletion allowance, land titles, tax treatment, royalties, public domain land availability, etc.

### The cost advantage of a multi-product plant

As an idealized illustration, a comparison is made of two kerogen-bearing properties—one without and the other with nahcolite. The economics of the first case are as indicated in Table I—a pre-tax profit of 16¢ a bbl.

For the second case, the same production rate is as-

sumed; however, the mining occurs in the deep saline section which will require shaft hoisting. Both shale oil and nahcolite can be recovered. For the production of shale oil, the costs based on a pro-rata per ton are as follows: \$0.65 for mining and crushing, \$0.25 for retorting, and \$0.40 for general expense, ash disposal, depreciation, and amortization. However, the feed to the retort is 45 gal per-ton after removing the nahcolite. At an 80% recovery, 1.17 tons are required to produce a barrel of oil. On a per-barrel basis and before taxes, royalty, and interest, the total cost amounts to \$1.52. On the same aforementioned basis, the profit is \$0.23 per barrel or \$0.21 per ton.

For the production of nahcolite, the mining and crushing cost remains at \$0.65 per ton, but the mechanical recovery, stockpiling and loading amounts to \$0.75 per ton, and general expense, depreciation, and amortization, are \$0.25 per ton. Nahcolite may be sold for as little as \$6.00 per ton, f.o.b. mine site, for use as an air pollution control reactant or for other uses. Total costs are \$1.65 per ton nahcolite produced. Value is \$6.00 and profit per ton nahcolite is \$4.35 before taxes, royalties, and interest. Profit on each ton of rock mined due to sale of the contained 420 pounds of nahcolite would be \$0.91, which exceeds any logical profit expectations from sale of crude shale oil from the same rock.

### Current investigations of the salines

Wolf Ridge Minerals Corp., one of the companies that claim preference right leases to sodium deposits in the Piceance by virtue of discovery of sodium minerals on issued U.S. sodium prospecting permits, has done considerable research on the salines. This has ranged from making alumina from dawsonite, to soda ash from nahcolite, and glass from the inorganic constituents of the mineral zone.

Investigation of nahcolite from Wolf Ridge's sodium discovery cores shows that it is fully as reactive as synthetic sodium bicarbonate in removing sulphur compounds from stack gas, and sodium bicarbonate is considered ideal for treatment at low temperatures (300°F.) of stack gas discharge. The company has been in touch with the U.S. Dept. of Health, Education, and Welfare with regard to the use of nahcolite in air pollution control.

The Health Dept. process envisions injecting powdered nahcolite into stack gas streams where it reacts with sulphur oxides in the hot gas to form granular sodium sulphate or sodium bisulphate. The latter is the most desirable since only one atom of sodium combines with one of sulphur. The solid sulphates are then removed by means of a baghouse filter. Wolf Ridge is now mining several tons of nahcolite to use in a pilot plant scale test designed by the Health Dept's research group.

The company has also studied the approximate costs of transcontinental and transoceanic freight rates. These rates and review of nahcolite production costs show that a crude powdered form of the mineral may be delivered by unitized trains to all major cities of the eastern U.S. for \$16 per ton or less. Delivery to the Gulf and West Coast seaports may be as low as \$11 a ton, and therefore nahcolite can be shipped to Europe or Japan for about \$15 a ton. No chemical known is as suited for low temperature stack gas reaction as nahcolite, and there is no other major deposit of this mineral known in the world.

Wolf Ridge has also devised and tested a method to make glass from the saline section of the Green River formation. In making oil, gas and glass the only additives required for glass are additional silica, additional sodium carbonate and sodium sulphate.

Credit for work on the use of Colorado's vast nahcolite reserves should be given to Richard Herrington, James F. Durham, and especially, Robert Borgwardt.