GEOLOGICAL SURVEY CIRCULAR 523

Organic-Rich Shale of the United States and World Land Areas

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By Donald C. Duncan and Vernon E. Swanson

Geological Survey Circular 523

Washington 1965

United States Department of the Interior
STEWART L. UDALL, *Secretary*

Geological Survey
William T. Pecora, *Director*

REPRINTED
1966

Free on application to the U.S. Geological Survey, Washington, D.C. 20242

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ABSTRACT

A review of organic-rich shale deposits in the United States and world land areas was conducted to estimate the energy and oil potential of these little-used resources.

Organic-rich shale is defined as fine-textured sedimentary rock containing 5–65 percent combustible organic matter. The total organic content and the total thermal energy obtainable by combustion of the shale are estimated in grade categories of units containing 10–65 percent organic matter and 5–10 percent organic matter. These shale deposits can be made to yield oil or combustible gas by unconventional experimental methods such as hydrogenolysis of the organic matter. The total resources of oil thus technically extractable from organic-rich shale are estimated in grade categories of units yielding more than 25 gallons per ton, 10–25 gallons per ton, and 5–10 gallons per ton. The estimates are for oil equivalent in the deposits. The combustible gas potential of some deposits is considered, but a full inventory is not attempted.

Oil shale is defined as organic-rich shale that yields oil in substantial amounts by conventional destructive distillation methods, such as those used by established industries. For purposes of the study the range of oil yield of deposits that are considered oil shale is from 10 to more than 100 gallons per ton of rock, corresponding to the range in grade of deposits used in oil shale industries. The shale oil resources of the known deposits and their possible extensions are estimated in grade categories of units that yield more than 25 gallons per ton and units that yield 10–25 gallons per ton. The oil equivalent in some lower grade shale units that yield 5–10 gallons per ton by conventional assay are also estimated, but such rock is considered too low grade to be classed as oil shale at present.

Oil-shale and other organic-rich shale deposits are widely distributed in unmetamorphosed sedimentary rocks ranging in age from Cambrian to Tertiary. The major world deposits were formed in large marine embayments or basins and in in large lake basins. Some of the individual deposits are many thousands of square miles in extent and are interpreted to contain trillions of barrels of oil equivalent. Many deposits formed in smaller bodies of water and associated with coal-bearing rocks contain individually from about 1 million to a few billion barrels of oil equivalent.

Oil-shale industries were developed in Europe in the 19th century and have since operated on a small scale in parts of Europe, Africa, Asia, and Australia where petroleum was in short or uncertain supply. Estimated world production from about 1850 to 1961 totaled about 400 million barrels from an assortment of deposits of varied size and grade. Shale from a few deposits is used as solid fuel or as the source from which combustible gas is produced.

Resources of organic-rich shale extending to maximum depths of 20,000 feet are estimated statistically in this report. By this method the deposits in the United States are estimated to contain an order of magnitude of 72 trillion tons of organic matter, which has an energy potential of 1,900 Q (10^{18} Btu), or an alternative potential yield of about 170 trillion barrels of oil. An inventory of known oil-shale resources of the United States includes 80 billion barrels of oil equivalent in parts of higher grade accessible deposits that are considered recoverable under present conditions. About 2.1 trillion barrels of oil equivalent in known lower grade or less accessible oil-shale deposits is considered marginal or submarginal resources. The possible extensions of the known oil-shale deposits contain an order of magnitude of 3.2 trillion barrels oil equivalent. Undiscovered and unappraised organic-rich shale deposits that can be made to yield more than 10 gallons of oil per ton by one method or another are believed to contain about 23 trillion barrels oil equivalent. Very low grade organic-rich shale, which yields 5–10 gallons of oil per ton, contains approximately 140 trillion barrels oil equivalent.

Organic-rich shale deposits of the world land areas (including the United States) contain an order of magnitude of 900 trillion tons of organic matter, which has an energy potential of about 24,000 Q (10^{18} Btu). These deposits have an alternative potential yield of more than 2 quadrillion barrels of oil. An inventory of the known world shale oil resources includes 190 billion barrels oil equivalent recoverable under approximately present conditions and more than 3.1 trillion barrels in place in marginal and submarginal oil-shale deposits. The possible extensions of known oil-shale deposits contain an order of magnitude of 10.6 trillion barrels oil equivalent; undiscovered and unappraised organic-rich shale deposits that can be made to yield oil, by one method or another in amounts greater than 10 gallons per ton, contain an order of magnitude of 325 trillion barrels oil equivalent. Approximately 1.7 quadrillion barrels oil equivalent is estimated in very low grade organic-rich shale which yields 5–10 gallons of oil per ton.

Details of these estimates are contained in discussions of the resources of the United States and six continental land areas.

INTRODUCTION

Fine-grained sedimentary rocks containing substantial amounts of combustible organic matter constitute an enormous low-grade source of potential energy. Thus far, such deposits have been used as sources of synthetic oil and combustible gas or as solid fuel only on a small scale, but their use is expected to increase in the future as methods of mining and processing are developed and improved. The deposits included in this inventory vary widely in composition of organic matter and in mineral content. The group of deposits as a whole is herein designated "organic-rich shale," and selected parts of these deposits that yield oil in substantial amounts by conventional destructive distillation methods are designated "oil shale."

ACKNOWLEDGMENTS

This review was prepared in large part from published data, although the authors have substantially modified some resource estimates to conform with different limitations and wider parameters selected for this report. Important assistance and advice are gratefully acknowledged from the following U.S. Geological Survey personnel: John R. Donnell, William B. Cashion, Jr., and William C. Culbertson, for advice on selected oil-shale deposits in Colorado, Utah, and Wyoming; George V. Cohee, George W. Colton, and Wallace deWitt for information on the extent and nature of the Devonian black shale deposits in the Appalachian Basin and in Michigan; Earl Brabb, Irving Tailleur, William Patton, William Brosge, Ernest Lathram, George Gryc, and George O. Gates for information on oil-shale deposits in Alaska; Kenneth Englund and John W. Huddle for information on the cannel shale deposits of the Appalachian region; Alfred J. Bodenlos for information on oil-shale resources of Brazil; James F. Pepper for data on land areas of sedimentary rocks; Z. S. Altschuler for data on organic carbon content of selected shale deposits; and Mary D. Carter for search of literature, assembling oil-shale production data, and other assistance in the preparation of the report. Special thanks are also due Kenneth E. Stanfield, U.S. Bureau of Mines, for discussion of several oil-shale deposits and the energy potential of organic matter.

PREVIOUS SUMMARIES

No published summary of the total energy potential of organic-rich shale is known to the authors. Previous summaries of world resources of oil shale include reports by the Great Britain Mineral Resource Bureau (1924), proceedings of two conferences on oil shale and cannel coal published by The Institute of Petroleum (1938, 1951), Cadman (1948), Guthrie and Thorne (1954), Jaffé (1962), and Thorne, Stanfield, Dinneen, and Murphy (1962). Summaries covering parts of oil shale and black shale resources of the United States include reports by Winchester (1923, 1928), U.S. Bureau of Mines (1960), U.S. Geological Survey (1951), Rubel (1955), Duncan (1958), Swanson (1960), and Shultz (1962).

These summaries reflect an increasing knowledge of shale oil resources and contribute to a general increase in estimates of resources in known deposits. The estimates of the better known shale oil resources in the United States have increased from about 140 billion barrels in the 1920's to more than 2 trillion barrels in 1963, and the world known resource estimates from a few hundred billion barrels to more than 3 trillion barrels during the same period. Weeks (1960) estimated that "possible potential resources" of the higher grade organic-rich shale in the United States were about 2 trillion barrels oil equivalent and in the world about 12 trillion barrels.

DEFINITIONS

The organic matter of shale deposits is variously described by many common and special terms that overlap in meaning and that are used differently by different authorities. Definitions and classifications of the organic matter of shales are discussed in reports by Jaffé (1962, p. 2–4), Prien (1951, p. 79), Swanson (1962, p. 69–70), Twenhofel (1950, p. 452–485), and Vine (1962, p. 117–120). The different classifications—based on physical or chemical properties, on origin, or on use of the deposits—are somewhat incompatible. The principal terms used in this report are discussed below. Other special or local terms relating to specific deposits are explained in the detailed descriptions.

ORGANIC-RICH SHALE

For purposes of this report organic-rich shale is defined as a fine-textured sedimentary rock containing 5 to about 65 percent indigenous organic matter, which consists of reduced carbon predominantly and smaller amounts of hydrogen, oxygen, nitrogen, and sulfur. The organic matter of the deposits is mostly finely divided solid matter sometimes called "kerogen." Minor amounts of bitumen and oil (Forsman and Hunt, 1958) and varied amounts of hydrocarbon gas also may be in the organic matter. The inorganic materials of different deposits may include predominantly siliceous minerals such as opal or chert, other silicate mineral mixtures such as clay minerals or feldspar and quartz detritus, or carbonate minerals such as calcite or dolomite. The mineral grains may range from clay (colloid) size to silt size. The term "shale," as used in this report, therefore includes for convenience a somewhat wider range of materials than are normally included as shale, particularly a few oil-yielding rocks that might be designated impure coal and impure limestone according to some classifications.

OIL SHALE

Oil shale is defined as organic-rich shale that yields substantial quantities of oil by conventional methods of destructive distillation of the contained organic matter, which employ low confining pressures in a closed retort system (Stanfield and Frost, 1949). For purposes of this report any part of an organic-rich shale deposit that yields at least 10 gallons (3.8 percent) of oil per short ton of shale by such extraction methods is considered oil shale. As thus defined, the term has economic implications that ignore mode of origin and detail of composition of the rock. The 10-gallon figure represents the approximate minimum oil yield of deposits that have been mined and processed on commercial scale by the world oil-shale industries, and which thus may be considered as possible sources of oil for future development by demonstrated recovery methods. Individual deposits yield oil in greatly varying amounts, some yielding little more than 10 gallons per ton of shale, others yielding more than 100 gallons per ton. Most of the oil-shale deposits do not contain much oil or bitumen as such; they contain predominantly solid organic matter, part of which is converted to oil and hydrocarbon gas, and part of which remains in the shale as coke or char when the shale is heated in a retort.

Deposits yielding less than 10 gallons of oil per ton by conventional extraction methods are not considered oil shale in this report. Shale yielding a few gallons to 10 gallons of oil per ton by conventional extraction methods has received some casual recognition as possible oil sources, however (McAuslan, 1959; Hunt and Jamieson, 1958; Gejrot, 1958). An inventory of shale yielding 5–10 gallons of oil per ton by conventional methods is included therefore with the assumption that such material may become usable.

OTHER TERMS

The term "black shale" is used to describe very dark (principally black) shale deposits, most of which are colored by organic matter. It is generally applied to shale deposited in marine environments. Parts of such deposits that contain substantial amounts of organic matter are classed in this report as organic-rich shale, and parts yielding substantial amounts of oil by conventional destructive distillation are classed as oil shale.

"Cannel shale" is an oil shale that burns with a bright flame. Such shale yields substantial amounts of illuminating gas and oil by thermal decomposition. Cannel shale is commonly associated with coal. The terms "torbanite," "tasmanite," "kerosene shale," and "maharahu" are synonyms that are applied locally to selected foreign cannel shale deposits.

The term "carbonaceous shale" is generally applied to organic-rich shale containing coaly material, graphitic material, or other carbonaceous matter that is presumed to be predominantly nonvolatile. The term is generally avoided in discussion of known oil-yielding kinds of shale because the observers wish to emphasize oil-yielding characteristics. Such terms as "coaly shale" or "lignitic shale" are sometimes used as synonyms of "carbonaceous shale," but they may also imply that a large percentage of organic matter (25–50 or 65 percent) may be present in the shale. (See Vine, 1962, p. 119; Schopf, 1956, p. 527). In practice, however, the term "carbonaceous shale" is used in many geologic reports to identify organic-rich shale associated with coal-bearing rocks without implication as to the amount of organic matter or to the potential oil yield. The term is also used to describe some carbon-rich marine shale that yields little oil by distillation.

The term "bituminous," as applied to shale and impure limestone, may imply that the rock yields bitumen or oil by thermal decomposition of the contained organic matter.

It is used in technical literature, however, with assorted other meanings. Because the term has varied undefined meanings, it is not used in this report except as quoted from selected literature sources.

TYPES OF DEPOSITS

Organic-rich shales were deposited in bodies of water that contained abundant aquatic plants (and animals), or debris from land plants, under conditions that prevented oxidation of much of the organic debris that accumulated on the bottom. The principal environments in which the known organic-rich shales were formed were (1) large lake basins, (2) large marine basins, and (3) smaller bodies of water such as lakes, stagnant streams, and lagoons near coal-forming swamps. Oil-shale deposits of various sizes and grade, and associated organic-rich shales, which have low or undetermined oil yields are widely distributed in deposits formed in each of these environments.

POTENTIAL ENERGY, OIL, OR GAS YIELD OF THE ORGANIC MATTER IN SHALE

The potential thermal energy of organic-rich shale deposits, which are considered in this report, is based mainly on correlation of the estimated energy content of organic matter with a few hundred actual calorimetric measurements of random shale samples reported in the literature.

The principal energy-producing materials of organic matter in shale are organic carbon, which by direct combustion yields about 14,500 Btu per lb, and chemically combined hydrogen, which yields 52,000–61,000 Btu per lb. Inorganic or oxidized carbon such as that contained in carbonate minerals and hydrogen combined with oxygen principally as water are excluded for purposes of estimating energy content. Ratios of organic carbon to combined hydrogen in the organic matter range from about 6:1 in some unmetamorphosed deposits (Smith, Smith, and Kommes, 1959) to about 50:1 in some metamorphosed deposits. A carbon-hydrogen ratio of 10:1 is assumed to be average for the moisture-free organic matter in the principal unmetamorphosed deposits that compose the resources considered in this report; thus, a pound of organic matter containing 67 percent carbon and 6.7 percent combined hydrogen yields on the average about 13,000 Btu, and a ton of moisture-free organic matter yields 26 million Btu. Most of the organic matter of different types of shale can be converted to light oil or to combustible gas products by one or more experimental extraction methods (Hubbard and Fester, 1959; Elliott and others, 1961; Shultz, 1962), as for example, the hydrogenolysis of shale under high confining pressures. For purposes of estimating potential resources it is assumed that about half the energy potential of any organic-rich shale can be converted by such methods to energy-producing light oil or gas products and that the remaining thermal energy of the organic matter can be used for the conversion process. Thus a ton of "average" organic-rich shale containing 10 percent organic matter is assumed to yield 2.6 million Btu by direct combustion, or 10 gallons of light-oil product, or 1,300 cubic feet of gas per ton by such methods.

Many oil-shale deposits have been examined and sampled systematically. The principal analytical data obtained, however, are analyses of oil that is extractable from the deposits by destructive distillation of the organic matter in a conventional retort. Data relating to gross energy content of the organic matter, the energy content of produced gas, or the residual char or coke after extraction of the oil are generally incompletely known except for the mined parts of some deposits. The energy extractable as heavier oil by normal destructive distillation from selected deposits ranges from about 1/4 to 3/4 of the gross potential energy of the shale. In addition some unspecified amounts of hydrocarbon gas and heat from residual char or coke not included in the estimates would be produced and would be available for use in processing the shale or for marketed energy.

Extraction methods other than the conventional retort process applied either to oil shale or other organic-rich shale perhaps yield substantially different amounts and quality of oil and gas products. For example, hydrogenolysis of numerous shales under high confining pressure allows almost complete conversion of the organic matter to oil or gas, but the process consumes substantial energy herein assumed to be half the contained energy of the organic matter. In situ processing by partial combustion underground or by extraction with catalysts or special solvents at high temperatures and pressures would doubtlessly yield products in different amounts. Many schemes to extract energy or products are patented, but few have been developed commercially.

STATUS OF THE SHALE INDUSTRY

WORLD PRODUCTION

Although organic-rich shale has been used as a solid fuel and as a source of oil and combustible gas in fuel-short areas of the world during the past 125 years, the world production has been small, totaling by the close of 1961 an estimated 770 million tons of shale, which has an estimated energy content of about 4–4.5 quadrillion Btu. The energy recovered from the shale deposits was marketed mostly in the form of oil which probably contained about 2.3 quadrillion Btu.

Oil-shale deposits in Scotland, France, Russia, Estonia, Sweden, Germany, Spain, South Africa, Australia, and Manchuria have been mined at modest sustained commercial scale to produce a total of about 400 million barrels of oil to the end of 1961. The principal production had been from deposits in Scotland (about 100 million bbl), Estonia (possibly 100 million bbl), and Manchuria (probably more than 100 million bbl). Industries each producing about 500–750 thousand barrels of shale oil per year closed down in Scotland and Sweden in 1962, but a similar small industry at that time was in operation in Spain. Expanding oil-shale industries in Estonia and Manchuria were reported during the same period; the larger Manchurian industry was probably producing 40,000 barrels of oil per day or more.

Illuminating gas produced from cannel shale and other oil-shale deposits was used in small amounts during the 19th century in Europe, Eastern United States, and Australia. Shale gas, produced as a byproduct with shale oil, has been used locally for heating or power generation in connection with several European oil-shale industries. The only substantial modern commercial shale gas production, however, is reported in Estonia and in the Leningrad region of Russia where large quantities of low-heat-value gas have been produced since about 1950 for domestic and industrial purposes.

Shale has been used as solid fuel in a small way for domestic heat and for industrial purposes in parts of Europe. In addition, the residual carbonaceous matter left in some oil shale after distillation of oil and gas is used to produce process heat or steam for power generation.

BYPRODUCTS

Nitrogen compounds and sulfur, which normally occur in the organic matter of shale, but which are undesirable in fuels, are extracted as useful byproducts in some of the European oil-shale industries. Other materials such as vanadium, uranium, copper, trona, and phosphatic material are also present in some deposits of oil shale in sufficient amounts to be of commercial interest as coproducts. Other oil-shale industries produce lime, brick, or lightweight aggregate from the ash of the shale. Some oil-shale deposits associated with coal are mined as a byproduct with the coal.

ACTIVITIES IN THE UNITED STATES

In the Eastern United States minor high-grade cannel shale and lower grade black shale were mined to produce small amounts of oil and illuminating gas prior to the discovery of abundant petroleum in 1859. Several commercial experiments to produce shale oil in the United States have been conducted during the present century although no sustained production has been attained. Recent pilot-scale mining and extraction of one of the higher grade oil-shale deposits in western Colorado by the U.S. Bureau of Mines and by oil companies suggest that shale oil can be produced from the higher grade deposits with demonstrated mining and retorting methods at prices somewhat comparable to or a little above the present prices of similar petroleum or coal-tar products (about 5 cents per gallon). Some experiments to extract oil from shale in place also have been conducted by commercial concerns, but results have not been published.

CLASSIFICATION OF RESOURCES

As there is only minor use of oil shale or other organic-rich shale, under present conditions the deposits are generally considered uneconomic energy sources. In special situations, however, where other fuels are in short or uncertain supply and where shale industries are developed or contemplated, selected deposits are provisionally considered economically recoverable energy sources.

KNOWN RESOURCES

The known resources reported used in tables 2 and 3 include parts of deposits for which knowledge of organic content and oil or gas yield is based on assays and for which knowledge of size is based on measurements and mapping. The known resources as recognized in this report include such categories used in literature as proven, measured, indicated, minimum, and some inferred, possible, and maximum "reserves" used in technical reports. The so-called "inferred reserves" and similar categories included here in the known resources generally are partly sampled and mapped, but the estimator has considered his estimate to be subject to large error.

POSSIBLE EXTENSIONS OF KNOWN RESOURCES

Parts of deposits in areas remote from sampled and mapped parts are classed in a separate category as possible extensions of known resources. The estimates of these possible resources are mostly conjectural. They include some "inferred" resources of some reports.

UNDISCOVERED AND UNAPPRAISED RESOURCES

Deposits that are inadequately sampled or mapped for detailed appraisal along with deposits that are inferred to exist but are truly undiscovered are classed as undiscovered and unappraised resources.

TOTAL RESOURCES

Total resources include all potential energy, oil, or gas resources of organic-rich shale including oil shale. Estimates of the order of magnitude of the total energy resources of shale containing more than 5 percent organic matter are shown separately in table 1; their alternative potential oil yields are shown in tables 2 and 3.

RECOVERABLE RESOURCES

Oil-shale deposits that are mined or that are in advanced stages of planned development and in areas where petroleum is in short or uncertain supply are considered usable at present for purposes of this report. The more accessible, higher grade parts of such deposits are classed as "recoverable resources." In the United States these resources are assumed to include parts of oil-shale deposits yielding more than 25 gallons of oil per ton of shale in deposits 25 feet or more thick that extend to limiting depths of 1,000 feet below surface. These limits are based mainly on recent pilot-scale mining and processing experiments of the U.S. Bureau of Mines and of commercial concerns in western Colorado. Both the thickness-grade-depth limits and amounts of recoverable oil might be changed greatly, however, by use of different recovery or extraction methods, or by different market conditions. In those foreign areas where oil shale industries are established or have recently operated on a sustained basis, deposits that have the grades and thicknesses of those already mined are considered recoverable. These can be roughly grouped as: (1) deposits yielding 25–100 gallons of oil per ton, in beds a few feet thick or more, extending to depths of 1,000 feet below surface and (2) some lower grade deposits yielding 10–25 gallons of oil per ton, in units 25 feet thick or more, which are minable by open-pit methods. About 50 percent of the oil shale in place is assumed to be minable under present conditions, although larger percentages could be recovered from parts of deposits minable by open-pit methods.

MARGINAL AND SUBMARGINAL RESOURCES

Except for the recoverable resources previously defined, oil-shale and other organic-rich shale deposits are considered uneconomic sources of oil or energy at present. They are classed as marginal and submarginal resources. The deposits are classified according to their organic content or oil yield. No attempt is made here to classify the deposits according to thickness, depth, or other factors that might affect commercial use.

Deposits that have not been assayed for oil yield are grouped into two categories according to organic content: deposits which contain 10 percent or more organic matter and deposits which contain 5–10 percent organic matter. The organic and energy content of these deposits are inventoried in table 1, and their estimated oil potential is shown in tables 2 and 3.

Deposits that have been assayed for oil yield are subdivided into units that yield 25–100, 10–25, and 5–10 gallons per ton. These are inventoried in tables 2 and 3 as known resources and their possible extensions.

Minimum thicknesses of shale resources included in the inventory vary with the deposit and opinions of different estimators, from about 20 inches (or 50 cm) to 25 feet. The principal known deposits generally lie at depths less than a few thousand feet, but in a few areas deposits as much as 10,000 feet below surface are included. A limiting depth of 20,000 feet, roughly the present limit of commercial drilling, is used in the inventory of undiscovered and incompletely appraised deposits.

TOTAL RESOURCES OF ORGANIC-RICH SHALE

According to data taken principally from Trask and Patnode (1942), somewhat more than 5 percent of the sedimentary rocks in the United States is shale, which contains 5 percent organic matter or more, and somewhat more than 0.5 percent of the sedimentary rocks is shale containing 10 percent organic matter or more. The orders of magnitude of these organic-rich shale resources, their contained organic matter and estimated energy potential in the United States, and—by extrapolation according to area—other major lands of the world are shown in table 1. They were estimated with the following assumptions. The land areas including terrains underlain by both marine and nonmarine sedimentary rocks were modified from summary data prepared by J. F. Pepper (written commun., 1962). The average thickness of sedimentary rocks extending to a maximum depth of 20,000 feet was assumed to be $1\frac{1}{2}$ miles. About one-half the sedimentary rock is shale. A cubic mile of organic-rich shale constitutes about 10 billion tons. The average combustion energy of 1 ton of organic matter in shale is assumed to be 26 million Btu.

The estimates of tonnage and organic content are believed to be minimum amounts for the grades of shale considered. More nearly correct figures may be double the amounts shown, if Rubey's (1951) speculation of 25 quadrillion metric tons of reduced organic carbon, equivalent to about 35 quadrillion tons of organic matter, in sedimentary rocks of the earth is valid.

Table 1.—*Order of magnitude of total stored energy in organic-rich shale of the United States and principal land areas of the world*

[Estimates and totals rounded]

Continent or country	Approximate area underlain by sedimentary rocks (millions of square miles)	Shale containing 10–65 percent organic matter			Shale containing 5–10 percent organic matter		
		Shale in deposits (trillions of short tons)	Minimum organic content (trillions of short tons)	Combustion energy content Q (10^{18} Btu)	Shale in deposits (trillions of short tons)	Minimum organic content (trillions of short tons)	Combustion energy content Q (10^{18} Btu)
United States	1.6	120	12	310	1,200	60	1,600
Africa	5.0	370	37	960	3,700	190	4,900
Asia	7.0	500	50	1,300	5,000	250	6,500
Australia	1.2	90	9	230	900	45	1,200
Europe	1.6	120	12	310	1,200	60	1,600
North America (including United States)	3.0	220	22	570	2,200	110	2,900
South America	2.4	180	18	470	1,800	90	2,300
World total	20	1,500	150	4,000±	15,000	750	20,000±

SHALE OIL RESOURCES

Although many organic-rich shale deposits are reported in the land areas of the world, information on quality, thickness, and extent of most deposits is inadequate for detailed appraisal of their energy, oil, or gas potentials. The reported appraised deposits shown in figure 1 are demonstrated to contain oil shale, and the principal available inventory of their resources is that of their oil potential which is summarized in tables 2 and 3 and in the following pages. Alternative resource potentials of combustion heat, or combustible gas obtainable from some of these deposits, is discussed but not inventoried in detail.

The orders of magnitude of the total oil potentials of organic-rich shale deposits of major land areas are derived from table 1. The possible yield of oil shown as total resources in tables 2 and 3 or gas (not tabulated) by processes known from laboratory experiments (Hubbard and Fester, 1959; Shultz, 1962) but not applied commercially is estimated to represent about half the contained energy, equivalent to about 2.38 barrels of light-oil product, or 13,000 cubic feet of 1,000 Btu gas per ton of organic matter. Energy of the remaining organic matter in the shale would presumably be sufficient for the conversion process. Shale that contains 5–10 percent organic matter is assumed to have a potential yield of 5–10 gallons of oil per ton and is included in total resources in tables 2 and 3. Shale containing 10–65 percent organic matter is assumed to have a potential oil yield equivalent to the combined 10–25 and 25–100 gallon yields of shale shown in tables 2 and 3. The estimate of the undiscovered and unappraised higher grade

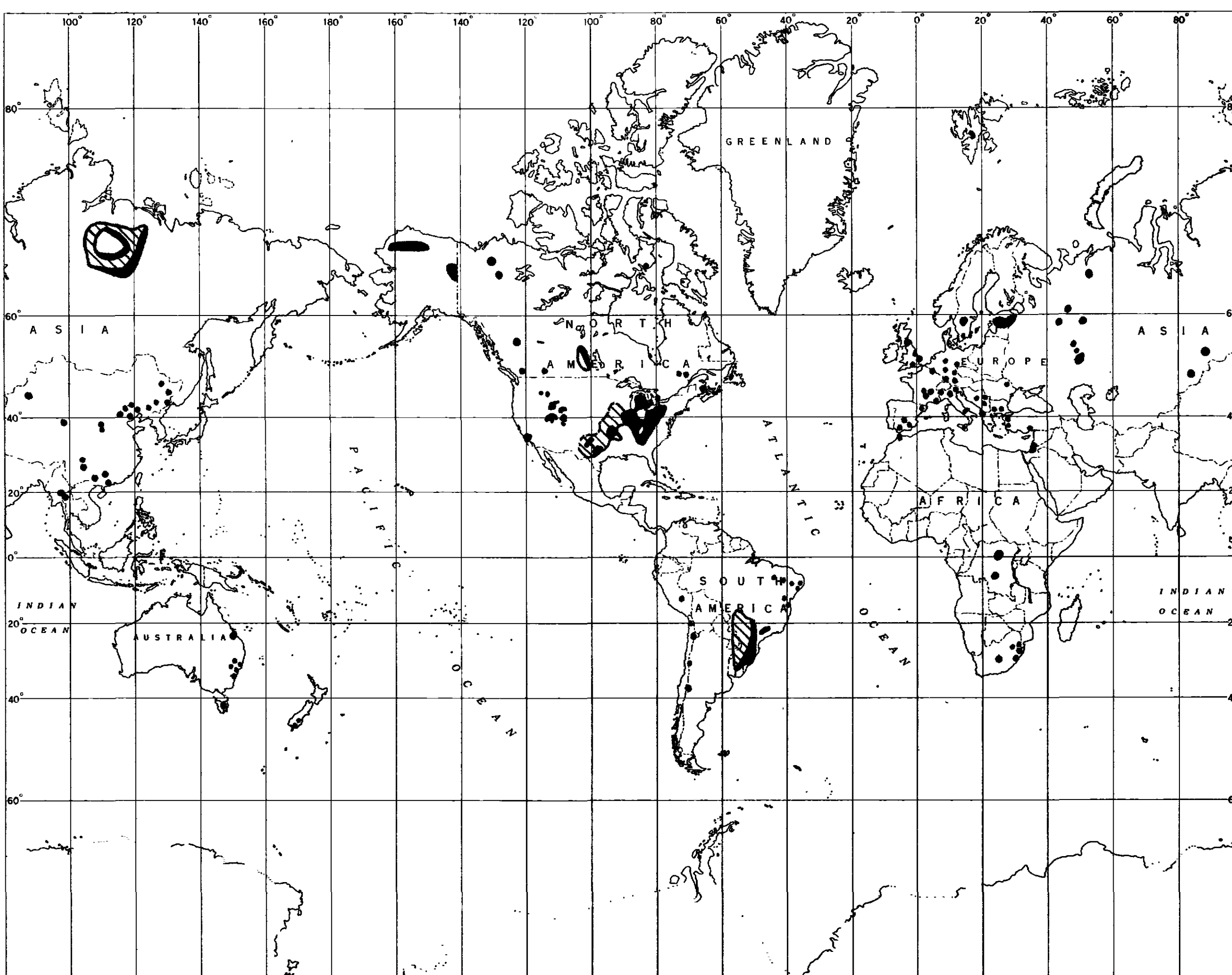

Figure 1.—Principal reported oil-shale deposits of the world. Diagonally lined areas include possible extensions of some major deposits.

Table 2.—*Shale oil resources of the United States, in billions of barrels*

[ne, no estimate. Estimates and totals rounded]

Deposits	Known resources				Order of magnitude of possible extensions of known resources			Order of magnitude of undiscovered and unappraised resources			Order of magnitude of total resources		
	Recoverable under present conditions	Marginal and submarginal (oil equivalent in deposits)									Oil equivalent in deposits		
Range in grade (oil yield, in gallons per ton of shale)	10–100	25–100	10–25	5–10	25–100	10–25	5–10	25–100	10–25	5–10	25–100	10–25	5–10
Green River Formation, Colorado, Utah, and Wyoming	80	520	1,400	2,000	600	1,400	2,000	------	------	------	1,200	2,800	4,000
Devonian and Mississippian shale, Central and Eastern United States	None	None	200	200	None	800	1,800	------	------	------	------	1,000	2,000
Marine shale, Alaska	Small	Small	Small	Small	250	200	Large	------	------	------	250	200	Large
Shale associated with coal	do	do	ne	ne	Small	Large	do	60	250	210	60	250	210
Other shale deposits	do	do	Small	ne	ne	ne	ne	500	22,000	134,000	500	22,000	134,000
Total	80	520	1,600	2,200	850	2,400	3,800	550	22,000	134,000	2,000	26,000	140,000

shale is speculative. It is based on the assumption that the shale oil resources in undiscovered deposits yielding more than 25 gallons per ton should be about one-twentieth of the resources in shale yielding 10–25 gallons per ton.

NORTH AMERICA

UNITED STATES

Known oil shale deposits in the United States are distributed in rocks ranging from Ordovician to late Tertiary in age. Resource estimates of the principal better known deposits are shown in table 2 and their locations are shown on figure 2.

GREEN RIVER FORMATION, COLORADO, UTAH, AND WYOMING

The Green River Formation of Eocene age underlies about 16,000 square miles of several basin areas in Colorado, Utah, and Wyoming (fig. 3) and contains the largest known higher grade oil-shale deposits in the United States. The regional extent and oil potential of these lake basin deposits are summarized by Winchester (1923), Bradley (1931), and Duncan (1958). The oil-shale resources of the more completely explored of these deposits in the Piceance Basin, Colo., are reported in more detail by Donnell (1961) and Stanfield, Smith, Smith, and Robb (1960). Oil-shale resources of parts of the Uinta Basin, Utah, are described by Cashion and Brown (1956), Cashion (1957, 1959, 1962, 1964), Stanfield, Rose, McAuley, and Tesch (1954), and Stanfield, Smith, and Trudell (1964). Resources of parts of the Green River basin, Wyoming, are described by Culbertson (1964) and Stanfield, Rose, McAuley, and Tesch (1954).

The moisture and the ash-free organic matter of the richer oil shale of the Green River Formation yields about 16,000 Btu per pound. Between 75 and 80 percent of the potential energy is converted to energy in heavy shale oil, about 6 percent to energy in combustible gas, and the residue remains as coke or char in the shale when processed by the standard Fischer retort assay (Stanfield and others, 1951). The resource estimates that follow, however, include only the shale oil producible by the conventional retort assay. By different extraction methods other proportions of oil, combustible gas, and char can be produced. For example, by hydrogenolysis, about 65 percent of the gross energy potential of the rich shale can be converted to net energy in high-heat-value gas (Elliott and others, 1961; Shultz, 1962). About 100 cubic feet of fuel gas yielding 1,000 Btu per cubic foot reportedly could be produced by this alternative method for each gallon of oil producible by conventional retort methods. Light-oil products in substantial amounts are producible by hydrogenolysis under somewhat different conditions (Hubbard and Fester, 1959). For lack of systematic information these alternative energy or product potentials of the shale deposits of the Green River Formation are not treated in detail in this report.

Shale units that yield a few gallons to about 65 gallons of oil per ton are distributed throughout much of the Green River Formation, which ranges in thickness from a few hundred feet to about 7,000 feet. In general the central parts of the Piceance Basin and the Uinta Basin contain thick rich oil-shale sequences that grade to thinner and leaner oil shale at the basin margins. Somewhat thinner and generally lower grade oil shale in the Green River basin and Washakie Basin, Wyoming, also show decrease in grade toward the basin margins.

Combined estimates of the shale oil resources of the Green River Formation are shown in table 2. Although parts of the deposits have been explored in detail by core drilling, the oil potentials of most of the deposits are known mainly from assays of rotary drill cuttings. These cuttings supply a general indication of the grade and thickness of the deposits but probably also supply analytical data on the resource potential of higher grade shale that are conservative because of contamination of higher grade material by interbedded leaner shale or barren rock (Stanfield and others, 1964, p. 17). The estimates show the shale oil potential of units 10 feet thick or more yielding 25–65, 10–25, and 5–10 gallons per ton of shale. The estimates are somewhat different from some previous estimates by the U.S. Geological Survey, as resources within each grade range used in this report exclude resources of other grade categories. In the previous estimates the higher grade shale was included in each successively lower grade category, and cutoff values were not used. The major resources of current interest are

EXPLANATION

Tertiary deposits
Green River Formation in Colorado, Utah, and Wyoming; Monterey Formation, California; middle Tertiary deposits in Montana. Black areas are known high-grade deposits

Mesozoic deposits
Marine shale in Alaska

Permian deposits
Phosphoria Formation, Montana

Devonian and Mississippian deposits (resource estimates included for hachured areas only). Boundary dashed where concealed or where location is uncertain

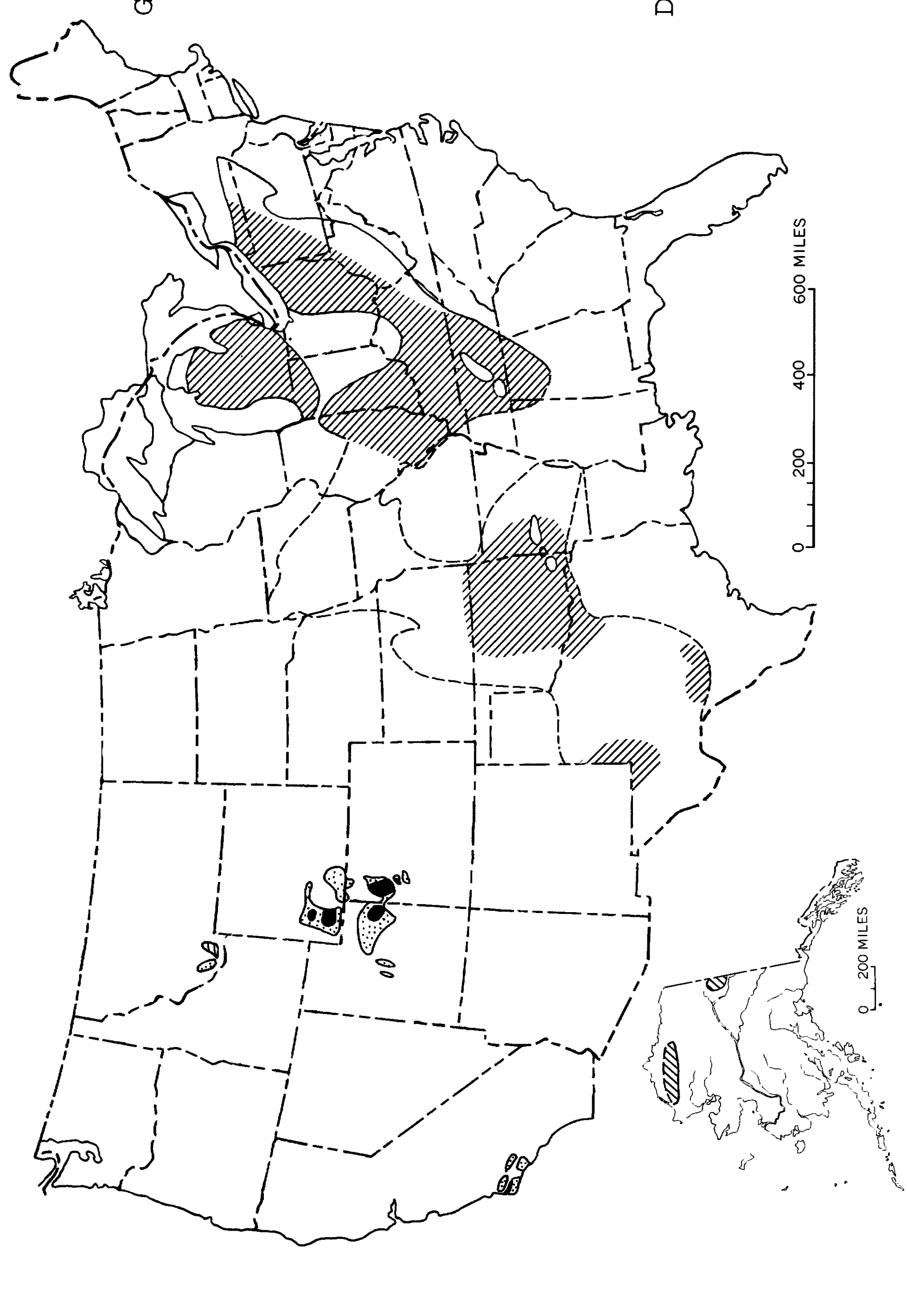

Figure 2. —Principal reported oil-shale deposits of the United States.

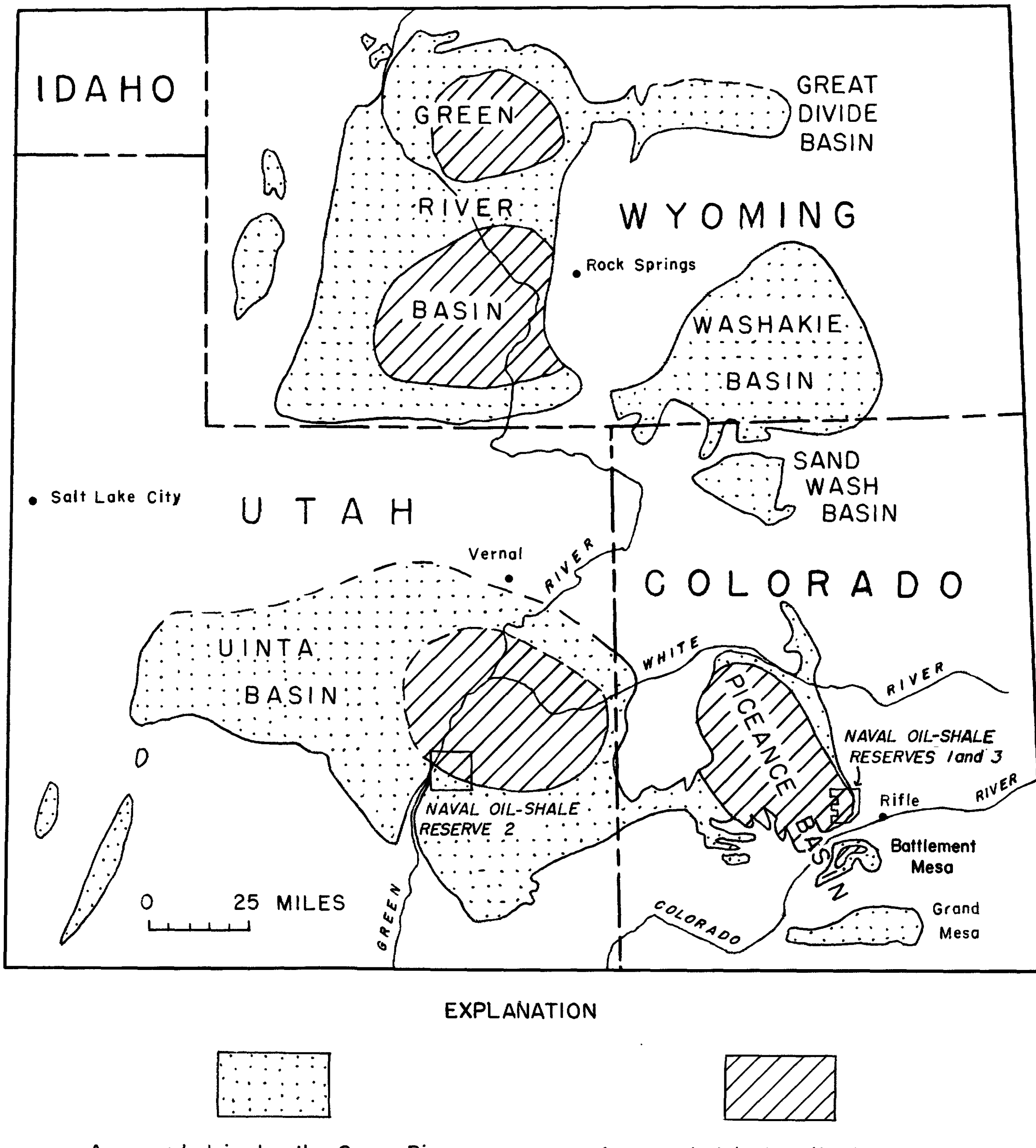

Figure 3.—Distribution of oil shale in the Green River Formation, Colorado, Utah, and Wyoming.

parts of the deposits in which combined low-grade and high-grade oil shale, excluding very lean or barren rock units, range in thickness from a few hundred to 2,000 feet and average in oil yield from 15–30 gallons per ton.

Known parts of the deposits that yield 25–65 gallons of oil per ton contain about 450–500 billion barrels oil equivalent in the Piceance Basin, Colo., about 90 billion barrels in the Uinta Basin, Utah, and about 30 billion barrels in the Green River basin, Wyo., totaling about 600 billion barrels for the three basins. Approximately 160 billion barrels oil equivalent is in part of this higher grade shale averaging 30–35 gallons of oil per ton in units more than 25 feet thick and lying less than 1,000 feet below surface. Assuming that approximately half of this higher grade more accessible shale could be mined under present conditions, about 80 billion barrels of shale oil is herein considered recoverable by demonstrated mining and retorting methods.

Known oil-shale deposits that yield 10–25 gallons of oil per ton contain about 800 billion barrels oil equivalent in the Piceance Basin, Colo.; about 230 billion barrels in the Uinta Basin, Utah; and about 400 billion barrels in the combined Green River basin and Washakie Basin, Wyoming.

Known shale deposits that yield 5–10 gallons of oil per ton contain about 200 billion barrels oil equivalent in Colorado, 1,500 billion barrels in Utah, and approximately 300 billion barrels in Wyoming.

The possible extensions and possible upward revisions of the oil-shale resources of the Green River Formation are estimated to be about equal to the known resources. The larger undiscovered better grade resources are perhaps in the deeply buried parts of the formation in the Uinta Basin.

DEVONIAN AND MISSISSIPPIAN SHALE, CENTRAL AND EASTERN UNITED STATES

Black shale deposits of marine origin are widely distributed in Upper Devonian and lowest Mississippian formations between the Appalachian and Rocky Mountains (Conant and Swanson, 1961, pl. 14). Parts of these deposits included in this inventory underlie about 250,000 square miles of the region (diagonal-patterned area, fig. 3), are distributed in units ranging in thickness from a few feet to about 800 feet, contain organic matter ranging from 5–25 percent of the shale, and yield as much as 7 million Btu per ton of shale by direct combustion. The yields of oil by conventional retort assay are small, generally representing from 25–40 percent of the full energy potential of the shale. The possible net yield of combustible gas (mostly methane) by laboratory-scale hydrogasification process is larger, representing perhaps 50–60 percent of the full energy content (Shultz, 1962). The thicker sequences of the deposits generally average less than 10 gallons of oil per ton of shale at the few places where they have been completely sampled. In some large areas, however, units 5–20 feet thick yield 10–20 gallons of oil per ton.

Previous estimates of the oil or gas potential of the Devonian and Mississippian black shale vary widely. Ashley (1917) estimated 100 billion barrels oil potential in shale yielding at least 10 gallons per ton in Indiana. Winchester (1928) estimated 18.6 billion barrels was contained in near-surface strippable deposits in Indiana and Kentucky. Crouse (1925) estimated about 60 billion barrels oil potential in near-surface deposits of five States extending from Indiana and Ohio to Alabama. Rubel (1955) estimated a total of about 1,500 billion barrels oil equivalent in the Devonian and Mississippian shale, which yields a few gallons to 20 gallons per ton in several midcontinent and Eastern States. Shultz (1962) estimated that the near-surface deposits in Kentucky and Indiana would yield 130 trillion cubic feet of methane by an alternative gasification process; this estimate would correspond to Winchester's estimate of 18.6 billion barrel resources for the same area.

The resource estimates of this report revised in part on modern analytical data (Swanson, 1960; Hoover, 1960; Lucas, 1953; Breger and Brown, 1962; Smith and Stanfield, 1964) include deposits in Michigan and Texas not included in previous estimates and include deposits projected to depths as much as several thousand feet in some areas.

The principal known resources in zones 5 feet or more thick include parts of the deposits where they are sampled and correlated in

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Arkansas, Illinois, Indiana, Kentucky, Michigan, Ohio, Oklahoma, Tennessee, and Texas, and total about 200 billion barrels oil equivalent in units that yield more than 10 gallons per ton and 200 billion barrels in units that yield 5–10 gallons per ton. The possible extensions in unexplored or little-sampled parts of the deposits are estimated to contain an order of magnitude of 800 billion barrels oil equivalent in units that yield more than 10 gallons per ton and 1,800 billion barrels in units that yield 5–10 gallons per ton. (See table 2.) The major resources here inferred are in the thicker shale sequences of Ohio, of the Illinois basin, of the Michigan basin, and in the midcontinent region of southern Oklahoma and adjacent parts of Texas.

An alternative estimate of the potential methane yield of the total deposits, assuming a somewhat more complete conversion of organic matter to methane (Shultz, 1962), is about 8 quadrillion cubic feet from the better grade deposits and about 16 quadrillion cubic feet from the lower grade deposits. For lack of data the estimates exclude correlative Devonian black shale in other large areas of Western United States.

MARINE SHALE, ALASKA

Incompletely appraised or little-studied marine oil-shale deposits, which are mostly of Triassic and Jurassic age, are reported in several areas in Alaska (Smith and Mertie, 1930; Miller and others, 1959).

Upper Triassic oil-shale deposits, which are locally 200 feet thick, are exposed along 10 miles of outcrop adjacent to the Nation River, eastern Alaska. Known parts of the near-surface deposits, which yield about 30 gallons of oil per ton of shale, are estimated to contain about 2 million barrels of oil equivalent (Earl Brabb, written commun., 1962). The order of magnitude of unexplored possible extensions of similar-grade shale oil resources of the region is herein estimated to be about 200 billion barrels.

Several marine black-shale units are widespread in the northern foothills of the Brooks Range in northern Alaska. Black papery shale in the Shublik Formation of Triassic age is intermittently exposed along a 300-mile belt in the northern foothills. Few analyses of their organic-matter content are reported, although selected samples have yielded 25 gallons of oil per ton (Irving Tailleur, written commun., 1962). The Shale Wall Member of the Seabee Formation of Late Cretaceous age contains fissile black shale, in zones as much as 400 feet thick, which extend 80–100 miles along the northern foothills belt. These deposits probably contain some oil shale. High-grade oil shale in the Tiglukpuk Formation of Late Jurassic age is known from widely distributed float along the northwestern foothills belt of the Brooks Range. Samples, representing a few inches to a few feet of shale, yield 30–140 gallons of oil per ton (Tailleur, 1964). The deposit is herein inferred to contain an order of magnitude of 50 billion barrels oil equivalent in high-grade shale. Black marine shale of Mississippian age exposed in the Brooks Range yields about 7 gallons of oil per ton.

Although the known oil-shale resources in Alaska are small, possible extensions are estimated to contain an order of magnitude of 250 billion barrels oil equivalent in deposits that yield more than 25 gallons per ton and perhaps more than 200 billion barrels in deposits that yield 10–25 gallons per ton. (See table 2.) Deposits that yield 5–10 gallons per ton are presumed to be large.

SHALE ASSOCIATED WITH COAL

Organic-rich shale is widely distributed in the coal fields of the United States in rocks ranging in age from Mississippian to Tertiary. The general distribution of the coal fields containing associated shale is shown on maps by Trumbull (1960) and Barnes (1961).

Some cannel-shale deposits in the United States were used in a small way to produce illuminating gas and oil in the middle 1800's, but they have not been used since. The small number of deposits that have been appraised in detail seem to be comparable in size and oil potential to many of the foreign cannel-shale deposits that have been mined in oil-short areas. Some of the United States deposits could be of commercial interest as sources for byproducts in modern or future coal utilization.

The shale beds of Pennsylvanian age in the Interior and Appalachian coal provinces generally range in thickness from 1 foot to a few tens of feet. Some of the individual shale beds in the Interior coal provinces are persistent marine-shale units that underlie thousands of square miles, but in the Appalachian coal province most of the individual organic-rich shale bodies are less extensive nonmarine deposits. The reported individual high-grade deposits that yield 25–100 gallons per ton are generally small and contain an oil equivalent of a half million to tens of million barrels in shale in place (Ashley, 1918; Fettke, 1923). Winchester (1928) estimated selected appraised higher grade cannel-shale deposits in Pennsylvania and West Virginia that yield about 1 barrel of oil per ton of shale to contain about 27.6 million barrels of oil equivalent. The estimate did not include many deposits that were known at the time but had not been appraised in detail.

Reeves (1922, p. 1099–1105) reported that shale zones above 5 of 16 coal beds in western Indiana yielded oil, which ranged in amount from 7–54 gallons per ton and which averaged about 20 gallons per ton. Lamar, Armon, and Simon (1956) reported that 31 shale beds in the coal-bearing rocks of Illinois yielded a few gallons to 40 gallons per ton. About 3 percent of the sampled shale beds yielded more than 25 gallons per ton, 26 percent yielded 10–25 gallons, and 25 percent yielded 5–10 gallons. Runnels, Kulstad, McDuffee, and Schleicher (1952) and Swanson (1960) reported that several shale units in Kansas, which were from 2–10 feet thick, yielded 5–12 gallons of oil per ton. These units were estimated by Runnels to contain an oil equivalent of about 3 billion barrels in rocks less than 100 feet below surface.

Reinemund (1955) reported that organic-rich shale associated with Triassic coal beds of the Deep River field in North Carolina yielded a few gallons to 15 gallons of oil per ton.

The shale associated with coal in the Cretaceous and Tertiary rocks of the Western United States and the Gulf Coast is mostly untested for oil potential, because these coal-bearing areas were examined after interest in the oil potential of the associated shale had subsided. Substantial oil yields are reported, however, in shale from a few coal-bearing areas such as the Santa Tomas field in southwestern Texas, the Cannel King area in Utah (Ashley, 1918), and a few other localities.

Although the oil potential of carefully appraised deposits in the United States is small, the total potential in unappraised or inadequately appraised deposits is believed to be large. The amount of organic-rich shale probably exceeds the total statistically estimated coal in place. Somewhat more than 4 billion tons of such shale is provisionally estimated in the coal-bearing areas.

Assuming that the shale in the northern Interior coal province is fairly representative, about 2 percent of the shale associated with coal in the United States yields 25–100 gallons of oil per ton and contains about 60 billion barrels oil equivalent; about 20 percent yields 10–25 gallons per ton and contains 250 billion barrels; and about 30 percent yields 5–10 gallons per ton and contains 210 billion barrels. Estimates of these unappraised and undiscovered resources are shown separately in table 2.

OTHER SHALE DEPOSITS

Organic-rich marine shale deposits of Ordovician age are extensive in the northern part of the Appalachian Basin, in the Great Basin, and in the northern midcontinent region. Most are unappraised. The Upper Ordovician Utica Shale in New York and the Maquoketa Shale and other Ordovician shales in Illinois and Iowa, and the Middle and Lower Ordovician Vinini Formation in western Nevada are extensive marine black shales each of which locally contains units that yield 10–25 gallons of oil per ton. Although the oil potentials of these deposits are not reported in detail, they are presumably large.

Thick sequences of marine organic-rich shale of Carboniferous age are widely distributed in the Great Basin, the southern Rocky Mountains, and the southern midcontinent region.

Black shale of marine origin in the Phosphoria Formation and in correlative units of Permian age are widely distributed in Idaho, Montana, Utah, and Wyoming. At some places the deposits contain 10–20 percent organic matter but samples from Utah, Idaho, and Wyoming yield little oil (1–6 gal per ton) by conventional retort assay methods. Some sampled sections of the deposits in a 600-square-mile area in southwestern Montana (fig. 2) yield 10–15 gallons of oil per ton

(Bentley, 1963, p. 45; Swanson, 1960) and indicate that part of the deposits contain an order of magnitude of 5–10 billion barrels oil equivalent. The shale oil potentials of these deposits are not shown separately but are included with other unappraised deposits in table 2.

Organic-rich shale beds of Cretaceous age are widespread in the Great Plains and Rocky Mountains. Random samples of some of these deposits yield from 5 to about 15 gallons of oil per ton (Winchester, 1923). Oil potentials of the deposits are not reported in detail but are believed to be large.

Diatomaceous shale of the Monterey Shale and other shale formations of Miocene age in southern California contains substantial amounts of organic matter (Trask and Patnode, 1942, fig. 24). Rubel (1955) estimated that this shale in a 3,000-square-mile area contains about 70 billion barrels oil equivalent in beds that yield 3–30 gallons of oil per ton. (See fig. 2.) Although the deposits have not been reported in detail, possibly 1 billion barrels of oil can be considered recoverable from shallow higher grade parts that yield about 25 gallons of oil per ton. The more deeply buried deposits perhaps contain about 50 billion barrels oil equivalent in shale that yields 10–25 gallons per ton and 20 billion barrels in shale that yields 5–10 gallons per ton. The resources of the Monterey Shale are not tabulated separately but are included with other unappraised resources in table 2.

Middle Tertiary lake-basin deposits underlie about 280 square miles in Beaverhead County, southwestern Montana (fig. 2), and contain many oil-shale beds in a sedimentary sequence that is about 1,000 feet thick (Bentley, 1963; Winchester, 1923). These deposits are not appraised in detail, but they may contain an order of magnitude of tens of billion barrels oil potential. Data on them are included with those of other unappraised deposits in table 2. Several other lacustrine shale deposits that are reported in Montana, Nevada, and Wyoming contain oil shale, but few have been adequately explored to determine their oil potential. Near-surface parts of thin high-grade deposits in the Humboldt Formation of Miocene and Pliocene(?) age, which are exposed near Elko, Nev., were estimated by Winchester (1928, p. 13) to contain about 6 million barrels oil potential. The shale sequence of the Humboldt Formation is reportedly thicker at depth but has not been assayed. The location of Tertiary lake-basin deposits in the Western United States is shown by Feth (1963); some of these deposits are reported to contain oil shale.

TOTAL SHALE OIL RESOURCES

The estimates of total shale oil resources of the United States shown in table 2 are derived from data in table 1. The difference between the total resources and the known shale oil resources plus extensions of known resources is shown as undiscovered and unappraised resources. A somewhat larger proportion of high-grade shale is estimated for the United States than for other world areas, for the reason that the deposits in the Green River Formation may be uniquely large.

OTHER AREAS IN NORTH AMERICA

Many organic-rich shale deposits, which range in age from Ordovician to Tertiary, are reported in Canada, although most have not been sampled or appraised in detail.

Restrictive estimates of near-surface parts of the Albert Shale in New Brunswick include 30 million barrels oil equivalent in zones that yield about 13 gallons per ton (Canada Department of Mines and Resources, 1948). These lacustrine deposits are of Mississippian age and, as interpreted from mapping and deeper subsurface exploration (Gussow, 1953), may underlie an area of about 3,000 square miles in the Moncton Basin. The principal oil-shale-bearing unit of the Albert Shale averages about 500 feet in thickness in the subsurface throughout much of the Moncton Basin (Greiner, 1962, p. 230). The oil shale is a few feet to a few hundred feet thick and yields from a few gallons to about 40 gallons of oil per ton. The size and grade of the deposit may be substantially more than previously estimated (King, 1963, fig. 3). About 50 billion barrels oil equivalent is inferred in shale that yields more than 25 gallons per ton, and 100 billion barrels in shale that yields 10–25 gallons per ton.

Laboratory experiments show that an alternative net yield of about 110 cubic feet of 1,000 Btu gas may be obtained from the Albert Shale by hydrogasification for each gallon of oil recoverable by conventional retort (Shultz, 1962, p. 15, 18).

Other reported deposits in Canada include small amounts of high-grade cannel shale in Pennsylvanian coal-bearing rocks of Nova Scotia and large bodies of lower grade black shale in the Utica Shale of Ordovician age in Ontario and Quebec, in the Ohio Shale of Devonian age in Ontario, in shale of Cretaceous age in Saskatchewan and Manitoba, and in shale of Mesozoic and Paleozoic age in the Yukon and Northwest Territories (Great Britain Mineral Resource Bureau, 1924; Swinnerton, 1938). Random analyses of some of the marine black shale deposits indicate generally low oil yields that range from about 7–15 gallons of oil per ton; however, no specific estimates of size of individual deposits are available.

In the Deer Lake region of Newfoundland, oil-shale deposits of early Carboniferous age yield 16–50 gallons per ton and underlie an area estimated at 150–750 square miles (Great Britain Mineral Resource Bureau, 1924, p. 68). The known resources of the Deer Lake deposits are small, but possible extensions are herein estimated to be an order of magnitude of 10 billion barrels oil equivalent, of which 2 billion barrels are allocated to deposits that yield 25 gallons per ton or more and 8 billion barrels to deposits yielding 10–25 gallons per ton.

The oil yields of a few shale deposits in Mexico are reported, but not in sufficient detail to permit estimate of resources of individual deposits.

Although the known shale oil resources of the other areas in North America are small, the possible extensions are interpreted to contain an order of magnitude of 50 billion barrels oil equivalent in shale that yields 25 gallons per ton and 100 billion barrels in shale that yields 10–25 gallons per ton. The unappraised and undiscovered deposits are interpreted, however, to be large, possibly about equal in total size to the deposits in the United States even though the higher grade deposits in the United States are interpreted to be uniquely large. Estimates of amounts of oil potential in the combined total North American deposits are shown in table 3.

AFRICA

Oil-shale deposits have been of interest in central and southern Africa since the 1920's, and a small oil-shale industry in South Africa was operated from 1935–1960. Most of the reported oil-shale deposits are in the coal-bearing Karroo Series and its marine equivalents of late Paleozoic and early Mesozoic age.

In South Africa several high-grade cannel shale and other lower grade oil-shale deposits associated with the coal-bearing rocks of the Karroo Series have been partly explored in small areas along a 250-mile belt (Cadman, 1948; Petrick, 1937, p. 5–10). A small oil-shale industry (Thorne and Kraemer, 1954), operated from 1935 through 1960, produced about 3.5 million barrels of shale oil. Reported "reserves" in selected tracts of deposits that yield more than 25 gallons per ton contain about 80 million barrels oil equivalent, and reported deposits that yield about 20 gallons per ton contain about 50 million barrels (Petrick, 1937). These deposits represent only a small fraction of the shale resources of the region.

In the Stanleyville Basin of the Congo, extensive deposits of oil shale of Triassic age in several beds that aggregate about 30 feet in thickness yield more than 25 gallons of oil per ton. The estimated oil equivalent of the known deposits is about 100 billion barrels (Gejrot, 1958), of which approximately 10 billion barrels is tentatively considered recoverable under present conditions. Other large deposits of undefined quality are reported in the Mayumbe region of the Congo.

Oil shale that yields about 20 gallons of oil per ton is reported in the vicinity of Tangier, Morocco (Great Britain Mineral Resource Bureau, 1924, p. 186).

TOTAL SHALE OIL RESOURCES OF AFRICA

Other organic-rich shale deposits in Africa are known in rocks of the Karroo Series, in the Tertiary rocks of the coastal plain areas, and in the marine sediments of northern Africa, but they are not reported in literature adequately enough so that appraisal of individual deposits may be made. Some of the large Cenozoic lake basins of the African Rift Valley region (Hutchinson, 1957, p. 10–11) also might contain major undiscovered oil-shale deposits. The total shale oil resources of organic-rich shale of Africa are shown in table 3. The estimates are derived from table 1.

Table 3.—*Shale oil resources of the world land areas, in billions of barrels*

[ne, no estimate. Estimates and totals rounded]

Continents	Known resources				Order of magnitude of possible extensions of known resources			Order of magnitude of undiscovered and unappraised resources			Order of magnitude of total resources		
	Recoverable under present conditions	Marginal and submarginal (oil equivalent in deposits)									Oil equivalent in deposits		
Range in grade (oil yield, in gallons per ton of shale)	10–100	25–100	10–25	5–10	25–100	10–25	5–10	25–100	10–25	5–10	25–100	10–25	5–10
Africa	10	90	Small	Small	ne	ne	ne	4,000	80,000	450,000	4,000	80,000	450,000
Asia	20	70	14	ne	2	3,700	ne	5,400	106,000	586,000	5,500	110,000	590,000
Australia and New Zealand	Small	Small	1	ne	ne	ne	ne	1,000	20,000	100,000	1,000	20,000	100,000
Europe	30	40	6	ne	100	200	ne	1,200	26,000	150,000	1,400	26,000	140,000
North America	80	520	1,600	2,200	900	2,500	4,000	1,500	45,000	254,000	3,000	50,000	260,000
South America	50	Small	750	ne	ne	3,200	4,000	2,000	36,000	206,000	2,000	40,000	210,000
Total	190	720	2,400	2,200	1,000	9,600	8,000	15,000	313,000	1,740,000	17,000	325,000	1,750,000

ASIA

The described oil-shale deposits in Asia range in age from Cambrian to Tertiary.

CHINA

Extensive exploration and development of oil-shale deposits in China have been conducted since the 1920's. Several deposits were discovered and explored in Manchuria during the Japanese occupation; these discoveries led to the development of a substantial shale oil industry. More recent search for deposits throughout China is reported to have resulted in discovery of about 180 "commercial" oil-shale deposits distributed in 21 provinces.

At Fushun, Manchuria, an oil-shale deposit of Oligocene age occupies a small monoclinal graben, ranges from 300–650 feet in thickness, yields 2–15 percent oil, and overlies a bituminous coal bed that ranges from 20–450 feet in thickness. Oil shale in this area is mined in open pits to expose the underlying coal. Shale that yields 11–30 gallons of oil per ton and that perhaps averages 15 gallons per ton is processed. In 1961 reported shale oil production was 40,000 barrels per day. The deposit, which extends to depths of as much as 2,500 feet, contains about 6 billion short tons of shale which has an oil equivalent of 2.1 billion barrels (Quackenbush and Singwald, 1947; Sakamoto and Yabe, 1958). About 600 million tons of shale was considered available in 1938 by open-pit mining the shale as a byproduct of coal (O'Hashi and Fukuzawa, 1938). Possibly half the deposit representing 1 billion barrels of shale oil can be considered recoverable under present conditions; the remaining half containing about 1 billion barrels should be considered marginal or submarginal.

Other near-surface oil-shale deposits mostly associated with coal-bearing rocks which range in age from Triassic to Tertiary been been reported in many areas in Manchuria (Kobayashi and others, 1958; Ohki, 1959, 1960; Okada, 1956; Yube, 1955a, b, 1956). Some of these deposits, more recently designated the Heilungkiang province oil shale, are reported to contain 180 million tons of "proven" oil shale and 120 billion tons of "probable" oil shale (Rosu, 1959). Other large deposits are reported near Mowming, Kwantung province; near Urumchi, Sinkiang province; and in Kansu Corridor (Rosu, 1959).

Data derived from the Communist China 5-year plans indicate that "proven reserves" of 60 billion metric tons of shale and "probable reserves" of 360 billion metric tons were reported in 1959 (Rosu, 1959, p. 99). Assuming that one-half the "proven" oil shale is economically available, known recoverable shale oil reserves of China are about 14 billion barrels. Additional known resources herein assigned to the marginal and submarginal category contain 14 billion barrels oil equivalent; and "probable reserves" reported by Rosu and herein assigned to possible extensions of known deposits, 140 billion barrels oil equivalent. All these shale deposits are assigned average yields of 15 gallons of oil per ton, although some higher grade shale is reported.

ISRAEL, JORDAN, AND SYRIA

Extensive deposits of oil shale which are mostly organic-rich marine marlstone are reported in rocks of Senonian and Danian (Cretaceous) age in Israel and Jordon (Blake, 1930; Gil-Av and others, 1954; McKelvey, 1959; Nir, 1960). The deposits contain about 5–20 percent organic matter and yield from 2.4 to about 12 percent oil (6–30 gal per ton) on distillation.

Explored parts of the Um-Barek deposit in Israel were estimated to contain about 20 million barrels of oil equivalent from shale that yields about 12.5 gallons of oil per ton. Near-surface parts of the deposit that yield 17 gallons per ton and that contain 2.2 million barrels oil equivalent were in preliminary phases of development in 1960 (Nir, 1960).

In the Yarmuk Valley, Wadi Arab region, and in the Nebi Musa area of Jordan similar shale deposits of Cretaceous age that yield 5–8 percent oil are believed to contain many billions of barrels of oil equivalent. Most of the deposits are too deeply buried for open-pit mining, but near-surface parts contain about 45 million barrels oil equivalent (McKelvey, 1959). Blake (1930, p. 18) indicated that the oil-shale sequence also extends unmapped into Syria.

The explored parts of deposits yielding 10–25 gallons of oil per ton in Israel, Jordan, and Syria are interpreted to contain about 70 million barrels oil equivalent. Possible extensions of the same deposits are interpreted to contain an order of magnitude of 50 billion barrels oil equivalent in shale of about the same quality.

SIBERIA

Although many deposits of oil shale and combustible shale are reported in Siberia (Dobryansky, 1947; Shabarov and Tyzhnova, 1958), most of them are not appraised in detail. Large deposits in three areas have received attention: the Kenderlick and other deposits in Kazakhstan, the Barzasski deposit in the Kuznetsk Basin, and deposits in the northeastern Siberian platform (Hodgkins, 1961, p. 90). The shale resources that are classed as "minable" by Russian standards include deposits, more than 0.5 meter (20 in.) thick, that yield more than 2,700 Btu per pound, or by destructive distillation more than 10 percent oil. The deposits are categorized by depths approximating 1,000, 2,000, and 6,000 feet, and the shallower deposits are the ones considered "minable."

Several oil-shale deposits in Kazakhstan are described. The largest of these are the Upper Carboniferous and Permian Kenderlick deposits. Several oil-shale zones interspersed with coal-bearing zones yield 10–70 gallons of oil per ton. These zones are reported to contain about 4 billion metric tons of shale, herein assigned 2.6 billion barrels oil equivalent. About 700 million tons of shale, herein assigned 450 million barrels oil equivalent, are near surface and "minable."

In the Kuznetsk Basin, oil-shale beds in the Barzasski deposit of Late Devonian age are reported to contain about 1.5 billion metric tons of shale, herein assigned 1 billion barrels oil equivalent. About 500 million tons, herein assigned 330 million barrels oil equivalent, are considered "minable."

In the northeastern Siberian platform large marine oil-shale deposits of Early and Middle Cambrian age are reported to underlie more than 58,000 square miles in the Anabar, Olenek, and Lena Rivers regions. The deposits range in thickness from 60–280 feet. Known resources have been estimated to contain about 112 billion metric tons of shale, herein assigned 78 billion barrels oil equivalent. About 22 billion tons, herein assigned 14 billion barrels of oil, are considered "minable" (Hodgkins, 1961). Unexplored extensions which would yield 10–25 gallons of oil per ton might well contain an order of magnitude of 3.5 trillion barrels of oil equivalent.

Assuming that half of the "minable shale" is recoverable, the Siberian deposits are tentatively estimated to contain about 7 billion barrels oil equivalent in recoverable parts of known higher grade deposits. About 67 billion barrels oil equivalent is estimated to be in known but less accessible deposits of similar grade; and possibly 3.5 trillion barrels, in lower grade extensions.

THAILAND AND BURMA

Rich oil shale is known in several small Tertiary coal basins in the region near Mae Sot, western Thailand, and in the nearby Amherst district of eastern Burma (Great Britain Mineral Resource Bureau, 1924, p. 82–83). The oil-shale deposits are of lacustrine origin, in a coal-bearing sequence of Pliocene age; they range in thickness from a few feet to about 20 feet and yield 25–70 gallons of oil per ton. The known deposits in Burma have been estimated to contain about 2 billion tons of shale with an oil equivalent of about 2 billion barrels. The explored parts of the deposits in Thailand reportedly contain about 500 million tons of shale and yield about 67 gallons of oil per ton, or a total of 800 million barrels. Possible extensions may contain an order of magnitude of 1.5 billion tons of similar grade shale or about 2 billion barrels oil equivalent (Oil and Gas Journal, 1958).

For purposes of this report about half the known resources in the combined Burma-Thailand deposits, or 1.4 billion barrels oil equivalent, is considered recoverable. An additional 1.4 billion barrels is considered marginal or submarginal, and possible extensions are assigned 2.0 billion barrels oil equivalent.

TURKEY

Oil-shale deposits are reported near Ankara, in northwest Turkey in the Eregli coal field, and near Manisa. Known resources in the Eregli coal field and near Manisa contain about 25 million tons of shale, with possibly 18 million barrels oil equivalent. Oil-shale deposits associated with lignite are also known at Mersina in the Gulf of Iskanderun

(Cadman, 1948, p. 120; Great Britain Mineral Resources Bureau, 1924, p. 270).

TOTAL SHALE OIL RESOURCES OF ASIA

The shale oil resources of Asia include more than 20 billion barrels oil equivalent in recoverable resources and, in addition, 70 billion barrels in marginal and submarginal resources that yield more than 25 gallons per ton and 14 billion barrels in resources that yield 10–25 gallons per ton. Possible extensions of selected deposits include 2 billion barrels oil equivalent in shale yielding more than 25 gallons per ton and 3.7 trillion barrels in shale yielding 10–25 gallons per ton. (See table 3.) Estimates of the total shale oil resources and of undiscovered and unappraised resources of Asia are derived from data in table 1.

AUSTRALIA AND NEW ZEALAND

Many small high-grade oil-shale deposits associated with Permo-Carboniferous coal measures are widely distributed in New South Wales (Kraemer and Thorne, 1951, fig. 1). At Glen Davis the principal oil-shale (torbanite) seam is restrictively estimated to contain about 50 million barrels oil equivalent (Institute of Petroleum, 1951, p. 190). About 200 million barrels oil equivalent is inferred in less thoroughly explored cannel-shale deposits of the region.

Lacustrine oil-shale deposits of Tertiary age are reported in the region near Port Curtis, Queensland (Ball, 1915). The deposits are as much as 80 feet thick, yield about 15 gallons of oil per ton, and may contain more than 200 million barrels oil equivalent (Jaffé, 1962).

Small oil-shale deposits locally known as tasmanite are distributed in Permo-Carboniferous marine shale in the Latrobe district of north-central Tasmania. "Proved reserves" of oil shale, which yield 25–35 gallons of oil per ton in beds 3–6 feet thick, were reported to be about 10 million tons of shale; mapped but unsampled possible extensions of the Tasmanian deposits may contain about 25 million tons of shale. These deposits perhaps contain about 20 million barrels oil equivalent (Tasmania Geological Survey, 1933).

Several small deposits of oil shale of Tertiary age, some of them associated with lignite, are partly explored in southern New Zealand. At Orepuki, shale underlying a small coastal terrace yields about 45 gallons of oil per ton and contains about 2 million barrels (proven) and 7.5 million barrels (inferred) oil equivalent (Willett and Wellman, 1940). At Nevis, partly explored Tertiary shale associated with coal yields 11–15 gallons of oil per ton and contains about 250 million barrels oil equivalent. Inferred extensions contain a possible 300 million barrels oil equivalent (Willett, 1943, p. 250B).

TOTAL SHALE OIL RESOURCES

The known higher grade oil-shale deposits and possible extensions in Australia and New Zealand contain about 280 million barrels oil equivalent, and the lower grade shale that yields 10–25 gallons per ton contains about 760 million barrels. These deposits are shown as combined 10–25 gallons shale resources in table 3, along with estimated resources of the total and undiscovered shale oil of these regions which are derived from data in table 1.

EUROPE

Oil-shale deposits were developed in many European countries during the 19th and much of the present century under conditions of local oil shortage. The amount of oil produced from individual deposits has not commonly been reported, although tonnage of shale is reported. A rough estimate of the oil produced from shale in Europe from about 1875 to 1961 is about 250 million barrels, most of which was produced in Scotland and Estonia. Other deposits in France, Spain, Sweden, and the Volga region of Russia have produced oil on a sustained basis, and experimental or minor production has been obtained from deposits in Austria, Bulgaria, Germany, Italy, Yugoslavia, and Czechoslovakia.

European oil-shale deposits are distributed in rocks ranging from Cambrian to late Tertiary in age. Marine shale deposits of Cambrian and Ordovician age are widespread in Sweden and the Baltic region of Russia. Deposits of Devonian age are reported in the southern Urals of Russia. Lower Carboniferous deposits are known principally in

Scotland. Numerous cannel-shale deposits in the Upper Carboniferous and Permian coal-bearing rocks are distributed throughout Europe, the principal mined deposits being in England, Spain, and France. Triassic marine oil-shale units, mostly thin, are reported at numerous localities in central Europe. Probably the most widespread oil deposits in Europe are in marine shale of Early Jurassic age. They include both thin high-grade and thicker low-grade deposits reported in Portugal, England, France, Germany, Luxembourg, the Russian Platform and Bulgaria. Oil-shale deposits of Cretaceous age, associated with coal-bearing rocks, are reported in Bulgaria, Yugoslavia, Czechoslovakia, and France. Lacustrine oil-shale beds of Tertiary age are reported in Yugoslavia, Czechoslovakia, and Caspian region of Russia, and Spain. Marine Tertiary oil-shale deposits are reported in Sicily.

BALKAN PENINSULA AND ADJACENT AREAS

In western Bulgaria near Bresnik the near-surface parts of large oil-shale deposits of Jurassic age are as much as 160 feet thick and contain shale zones as much as 20 feet thick yielding more than 30 gallons of oil per ton. Known reserves are estimated to be about 125 million barrels oil equivalent in near-surface deposits (Jaffé, 1962). Numerous other exposures of the deposits in the region including Bresnik, Sofia, Kustindil, Radomir, and Vratca are known, but their oil content is unreported (Great Britain Mineral Resource Bureau, 1924, p. 124). The possible extensions of the deposits are presumably large.

Other deposits are reported in central Bulgaria near Stora Zagora and Kazanlik. High-grade Tertiary cannel-shale deposits associated with lignite are reported in southwestern Bulgaria, north of Gorna Djoumaya.

The Cypris Shale of Miocene age in the western Bohemian region of Czechoslovakia is reported to underlie an area of 25 square miles, to contain about 20 percent organic matter, and to yield about 10 gallons of oil per ton. In the Kladno Basin thin rich cannel shale which is associated with Permian coal and which has been used for gas making (Schulz, 1938, p. 284) is reported to contain about 6 million barrels oil equivalent.

Along the Morava Valley in eastern Yugoslavia large and rich lacustrine oil-shale deposits of Oligocene age are known. They have been explored at Alexinac where they are 250–400 feet thick, yield 25–40 gallons of oil per ton, and contain about 210 million barrels oil equivalent in the more accessible, explored shale (Organization for European Economic Cooperation, 1952, p. 13; Great Britain Mineral Resources Bureau, 1924, p. 154; Jaffé, 1962, p. 6). Near Valjevo in the Kolubara Valley near-surface lacustrine oil shale of Miocene age underlies an area of at least 20 square miles, averages about 175 feet in thickness, and in part yields substantial amounts of oil. The possible extensions of the Tertiary deposits of Yugoslavia may be large. Upper Cretaceous marine oil-shale beds, about 60 feet thick and associated with coal, are reported near Zajecar on the eastern Yugoslavia border. The deposits are not appraised in detail. Organic-rich shale of Cretaceous age is associated with asphaltic limestone in the Dalmatian coastal region of Yugoslavia and in parts of Albania and Greece. The deposits locally yield about 7 percent bitumen.

Oil shale in the Balkan Peninsula and adjacent areas includes some large high-grade deposits that perhaps could be commercially developed. Known recoverable reserves in Jurassic and Tertiary shale are herein considered to be about 170 million barrels of oil, or about one-half the reported 340 million barrels reported in explored deposits. The possible extensions are large, perhaps containing tens to hundreds of billions of barrels oil equivalent.

FRANCE

Of about 50 known oil-shale or organic-rich shale deposits in France, only 4 have been operated in recent decades. An oil-shale industry flourished in France from about 1838 to 1900 but had almost ceased by 1905. A few deposits continued to be productive under government subsidy until the industry closed in 1957. During the period 1914–57 reported production ranged from 50,000 to nearly 500,000 tons of shale per year and totaled about 8 million tons of shale, which possibly yielded 3 million barrels of oil.

The principal reported oil-shale deposits in France include those in coal-bearing rocks of Permian age near Autun and St. Hilaire, marine deposits of Jurassic age at Ceverac-le-Chateau and Creveney, and deposits of Cretaceous age near Vagnas. Other deposits ranging from Carboniferous to Tertiary in age are reported (Guthrie and Klosky, 1951, p. 18 and fig. 12; Cadman, 1948, p. 115).

At Autun three or more oil-shale beds are 3–11 feet thick and yield 10–18 gallons of oil per ton. Restrictive estimates of resources of these deposits are about 9 million barrels proved and 80 million barrels inferred oil equivalent (Guthrie and Klosky, 1951, p. 38). In the 80 square mile basin (Cadman, 1948, p. 115), possible extensions of the deposits may be large. Proven "reserves" of oil shale at St. Hilaire are estimated at about 3.3 million barrels oil equivalent. Inferred "reserves" in the same deposits are about 80 million barrels (Guthrie and Klosky, 1951, p. 18).

At Severac-le-Chateau and at Creveney oil-shale deposits of Jurassic age ranging from 30–50 feet in thickness and yielding about 10 gallons of oil per ton have been of some interest as sources of oil by in-place processing. The deposits at Severac-le-Chateau contain about 8 million barrels oil equivalent in "proven reserves" and about 250 million barrels in inferred deposits (Guthrie and Klosky, 1951, p. 18). Deposits at Creveney may contain about 800 million barrels oil equivalent in shale yielding about 11 gallons per ton (Cadman, 1948, p. 115).

Oil-shale zones are associated with lignite in Cretaceous rocks near Vagnas. The thin shale beds yield 20–30 gallons of oil per ton and contain estimated reserves of 3–6 million barrels oil equivalent.

The known oil-shale deposits in France yield 10–25 gallons of oil per ton and are estimated to contain about 425 million barrels oil equivalent, and possible extension perhaps greatly exceed the 1.1 billion barrels in reported "inferred reserves."

GERMANY

Oil-shale deposits of Early Jurassic age are widely distributed in Germany. The principal deposits are in Württemberg near Balingen and in the Hanover Basin near Braunschweig. The deposits have been operated during periods of oil shortage. Restricted estimates of resources in Wurttemberg include a shale zone that averages 16 feet in thickness and that yields about 12 gallons of oil per ton. This zone extends along approximately 105 miles of outcrop in a belt about 1.8 miles wide and contains a total of about 1.7 billion barrels oil equivalent. Near Braunschweig, shale of about the same quality is estimated to contain about 170 million barrels oil equivalent (Guthrie and Klosky, 1951, p. 50). Gejrot (1958, p. 9) estimated the known German deposits to contain about 2 billion barrels oil equivalent. The possible extensions of the deposits are perhaps much larger.

GREAT BRITAIN

Oil shale of the Lothians of central Scotland have been mined and processed to produce oil since about 1850 (Guthrie and Klosky, 1951; Institute of Petroleum, 1938, 1951). The deposits are of early Carboniferous age and were laid down in shallow lacustrine or marine estuarine environments. About half of the dozen or more oil-shale beds, ranging from 4–12 feet in thickness, yield 16–40 gallons of oil per ton and have been mined extensively, mostly by underground methods. The average yields of oil from earlier mining operations were at least 30 gallons per ton, but the yields gradually decreased in recent decades to about 25 U.S. gallons of oil per ton. The industry was closed in 1963. The deposits were mined to depths in excess of 1,000 feet in parts of a 75-square mile area, but oil shale that is little explored extends to depths as much as 5,000 feet west of the principal oil-shale mining area. "Reserves" of Lothian oil shale were estimated in 1948 to be 480–880 million long tons (Cadman, 1948, p. 114). These probably contain oil equivalent or 300–500 million barrels.

Recoverable resources under present conditions assuming 50-percent recovery in mining are herein considered to be about 150 million barrels oil equivalent; additional known marginal and submarginal resources include 330 million barrels oil equivalent. Possible remote extensions of the deposits are perhaps several times larger than known resources.

Oil-shale deposits of Jurassic age are extensive in Dorset and Norfolk, England. The deposits are thin (2–7 ft) and yield 10–45 gallons of oil per ton; the higher grade has been used locally as solid fuel. The deposits are inferred to contain more than 1 billion barrels oil equivalent (Jaffé, 1962, p. 6) and are herein assigned to known resources of shale that average 10–25 gallons per ton.

Many small cannel-shale deposits associated with Upper Carboniferous coal have been mined in Great Britain and used for production of oil and illuminating gas. The cannel-shale production started about 1850 and was virtually closed down by 1900. From incomplete records (Institute of Petroleum, 1938, p. 86, 87, 93, 424–430) production of cannel shale in Great Britain may have totaled a few million tons yielding about a barrel per ton. Impure "cannel reserves" in Scotland, which include coal and shale, are estimated at about 80 million tons of material containing oil equivalent of 80 million barrels (Institute of Petroleum, 1938, p. 429), but no separate estimate of cannel-shale resources is available.

ITALY, AUSTRIA, AND SWITZERLAND

Thin oil-shale deposits of Triassic age have been mined for centuries at several localities in Austria, northern Italy, and Switzerland to produce ichthyol. Known shale resources at individual localities are small (Jaffé, 1962, p. 6, 7; Great Britain Mineral Resource Bureau, 1924, p. 122–123, 144–146, 181–182), but the possible extensions of the deposits may be large.

In Sicily a deposit of diatomaceous shale of Tertiary age averages 16 feet in thickness, yields about 25 gallons of oil per ton, and is estimated to contain about 35 billion barrels oil equivalent (Biagio, 1951; Gejrot, 1958), of which about 7 billion barrels is herein considered recoverable. Possible extensions in more deeply buried and lower grade parts of the deposit may be large.

LUXEMBOURG

Deposits of Jurassic oil shale have been explored in an area of about 55 square miles in Luxembourg, where the deposits, averaging 30 feet in thickness and yielding 10 gallons of oil per ton, contain about 700 million barrels of oil (Organization for European Economic Cooperation, 1952, p. 13).

RUSSIA

Many of the higher grade oil-shale and combustible shale deposits in European Russia have been described in some detail by Dobryansky (1947). The deposits of most interest are those that are more than 30 inches thick, have an organic content in excess of 20 percent, and have an oil yield of 10 percent or more, or heat value of more than 2,700 Btu per pound. The described deposits, however, include many units having less organic content, heat yield as little as 900 Btu per pound of shale, and small oil yield. Resources estimates have been prepared for some of the more promising deposits (Shabarova and Tyzhnova, 1958; Hodgkins, 1961). High-grade oil shale deposits in the Baltic region and in the Kuibyshev-Saratov area along the Volga River have produced substantial amounts of shale since the 1920's. About 15 million tons, of which about 10 million tons was from Estonia, was reported mined in Russia in 1959. This shale was used as a solid fuel and for production of oil and gas.

Oil shale known as kukersite, which is a marine deposit of Late Ordovician age underlying, at shallow depths, broad areas in Estonia and the adjacent Leningrad region, contains an estimated 22 billion tons of shale of which 15 billion tons is considered, by Russian standards, rich and thick enough to mine. The thickest and richest part of the kukersite deposit in Estonia yields about 50 gallons of oil per ton in beds aggregating about 10 feet in thickness (Lutz, 1938, p. 127; Baukov, 1958, p. 51). Estimated recoverable resources reportedly contain about 10 billion barrels of oil equivalent.

In the eastern and northeastern part of the Russian Platform, oil-shale deposits of Jurassic age have been prospected at many localities. Estimated minable reserves of these deposits in the Izhem, Sysolsk, Tartar-Ulyanovsk, and Kuibyshev-Saratov areas include about 18.7 billion tons of "minable" shale, and 1.5 billion tons of substandard shale. The oil yield of these deposits is presumed to be about 25 gallons per ton and to total about 13 billion barrels. Of this amount, about 5 billion barrels is in the Middle Volga region from Tartar to Saratov provinces where oil-shale industries are established, and is herein considered to be recoverable reserves. The remaining 8 billion barrels oil equivalent in the deposits is considered marginal or submarginal in this report. As the Jurassic shale deposits underly larger areas of the Russian platform, their oil potential in possible extensions is probably much larger than the reported "reserves."

SPAIN AND PORTUGAL

Oil-shale deposits are known in several provinces of Spain and Portugal. A small oil-shale industry near Puertollano, Ciudad Real, has operated since 1918, and total production to 1962 was about 8 million short tons of shale which yielded about 5.5 million barrels of oil. The shale, which is in several beds associated with coal in a sequence of Carboniferous age, is as much as 15 feet thick and yields about 30 gallons of oil per ton. Estimated oil-shale "reserves" of about 115 million tons (Thorne and Kraemer, 1950, p. 4) containing about 80 million barrels of oil equivalent are in explored parts of a small structural basin at Puertollano.

Several oil-shale deposits of Tertiary age are partly explored in southern and eastern Spain. These include some high-grade lacustrine deposits of unreported size. Small high-grade oil-shale deposits of Early Jurassic age are reported at three areas in Portugal (Cadman, 1948, p. 118; Great Britain Mineral Resource Bureau, 1924, p. 174).

Known oil-shale deposits in Spain were estimated by Gejrot (1958, p. 9) to contain about 280 million barrels oil equivalent in deposits that yield more than 25 gallons per ton; of this 280 million barrels about 40 million barrels, or the equivalent of half the explored Puertollano deposit, is considered recoverable; the remaining 240 million barrels is considered marginal or submarginal.

SWEDEN

The Alum Shale, a marine black shale of Cambrian and Ordovician age, is widely distributed in Sweden. The deposits have been described in great detail by Westergard, Eklund, and others of the Swedish Geological Survey. Three areas in the provinces of Närke, Öland, and Gotland contain shale ranging from 30–50 feet in thickness and yielding 10 gallons oil per ton or more. About 10 million barrels of shale oil were produced during the period 1942–62, after which the industry was shut down. The shale industry at Kvarntorp, Närke province, was developed as a byproduct industry and yielded substantial amounts of oil, combustible gas, heat for electric-power generation, sulfur, ammonia, lime, and brick (Gejrot, 1958). Some zones of the oil shale also contain substantial amounts of vanadium, uranium, and potassium.

The richest Alum Shale deposit, in the vicinity of Kvarntorp, contains about 25 percent organic matter, yields about 3,600 Btu per pound of shale, 4–7 percent oil, and about 6 percent sulfur, and contains an estimated 600 million barrels oil equivalent. The deposits in Öestergotland and in Öland, each yielding about 3.8 percent oil, contain about 1.9 billion barrels oil equivalent; those in Västergotland yielding about 1.7 percent oil contain about 350 million barrels oil equivalent (Gejrot, 1958, p. 7). In Skane Province a correlative deposit containing more than 10 billion tons of carbonaceous shale yields almost no oil, but has been considered of interest as a source of solid fuel (Brynielsson, 1956, p. 231).

For purposes of this report the deposits at Närke, Öestergotland, and Öland, containing a total of about 2.5 billion barrels oil equivalent, are considered to be known marginal and submarginal resources yielding more than 10 gallons per ton, as is the deposit in Västergotland, which yields about 5 gallons of oil per ton and which contains about 350 million barrels oil equivalent.

TOTAL SHALE OIL RESOURCES OF EUROPE

The recoverable shale oil resources in Europe contain a total of more than 30 billion barrels oil equivalent mostly in shale that yields more than 25 gallons per ton. Additional known resources, herein considered marginal and submarginal, include about 40 billion barrels oil equivalent in shale yielding 25 gallons or more per ton and about 6 billion barrels in shale yielding from 10–25 gallons per ton.

Possible extensions of selected major European deposits perhaps contain, in the aggregate, orders of magnitude in excess of 100 billion barrels oil equivalent in higher grade shale (25+ gallons) and 200 billion barrels in lower grade shale (10–25 gal). Major extensions are interpreted for the widespread marine Jurassic deposits throughout Europe and the more restricted Tertiary lake basin and marine shale deposits of southern Europe. The possible extensions of many of the other reported deposits also are presumably orders of magnitude larger than the reported "reserves." The unappraised, undiscovered, and total shale oil resources shown on table 3 are derived from table 1.

SOUTH AMERICA

Oil-shale deposits have been explored in several areas in South America. Deposits in Argentina, Brazil, Chile, and Uruguay have received some consideration for development, but many other organic-rich shales ranging in age from Cambrian to Tertiary have not been reported for their potential energy or oil content.

The Iraty Shale of Late Permain age underlies the Paraná basin in southern Brazil, Uruguay, and eastern Paraguay. The deposit is exposed principally along the eastern outcrop of a broad area which extends for about 1,000 miles in a north-south direction and which is as much as 380 miles wide in an east-west direction. Explored parts of the deposit in the States of Sao Paulo, Paraná, Santa Catarina, and Rio Grande do Sul, in Brazil, indicate that the Iraty Shale ranges from 100–328 feet in thickness and that the higher grade parts, which are as much as 30 feet thick (Araujo and Mariti, 1938; Bastos, 1951; Kraemer, 1950), yield about 5–8 percent oil (13–20 gal per ton). The deposits has also been studied in the State of Cerro Largo, northeastern Uruguay, where it is reported to yield about 3.6–5 percent oil (Schroeder, 1935, p. 208).

Several restrictive estimates of the oil potential of explored, more accessible parts of the Iraty Shale have been made. For example, a 35-square mile area near Sao Mateus do Sul in southern Paraná State has been closely sampled by drilling and contains a proven oil equivalent of about 600 million barrels (Ertl, 1961). Part of the deposit along the 220 miles of outcrop in the State of Paraná in a belt 12 miles wide has been estimated to contain about 200 billion metric tons of shale having an oil content of 16 billion metric tons, or approximately 110 billion barrels (Bastos, 1951). Nearly one-half this amount or 50 billion barrels, available in near-surface deposits and minable by open-pit methods, is herein considered recoverable under present conditions. Other estimates of the "exploitable" oil of the Iraty Shale range from 300 billion barrels (United Nations Economic Commission for Latin America, 1957, p. 231) to 800 billion barrels (Kraemer, 1950, p. 16) and are restrictive in that they include a relatively narrow belt of shale along approximately 1,000 miles of outcrop length. Assuming that the deposit underlies almost all the 250,000 square miles underlain by Upper Permian rocks of the Paraná basin and that it yields about 5 percent oil (13 gal per ton) through a 30-foot-thick sequence, the deposit would contain about 4 trillion barrels of oil equivalent. Thicker zones of lower grade shale in the deposit that yields 5–10 gallons per ton would contain an additional 4 trillion barrels.

For purposes of this report the Iraty Shale is interpreted to contain 800 billion barrels oil equivalent, of which 50 billion barrels is recoverable, in known resources of shale that yield 10–25 gallons of oil per ton and 3.2 trillion barrels in possible extensions. Resources that yield 5–10 gallons of oil per ton are assigned 4 trillion barrels oil equivalent in possible extensions.

Tertiary (Pliocene) lacustrine oil shale lies near the surface in the Paraiba River Valley, Sao Paulo State, Brazil. The deposits are known along a 90-mile length of the valley, are as much as 60 feet thick, and yield oil in amounts that range from 12–50 gallons per ton (Kraemer, 1950, p. 23; Smith and others, 1959, p. 5, 25), and perhaps average 15–18 gallons per ton. Their estimated oil content is about 2 billion barrels (Jaffé, 1962, p. 6).

Algal or lignitic shale yielding oil is reported in the Tertiary sediments in several areas in Brazil. Deposits at Marahu are perhaps the most notable. Individual deposits so far reported generally yield a barrel or more oil per ton. Reported "reserves" herein considered marginal and submarginal contain about 1 million barrels of oil equivalent.

Oil-shale deposits are reported in several localities in Argentina (Schroeder, 1935, p. 167–169). Estimated "reserves" of shale oil in Argentina are about 400 million barrels (Parker, 1962).

At Lonquimay in Cautin Province of Chile a shale of Eocene age exposed along the Bio-Bio River has been studied in some detail. Thin higher grade explored parts of the deposit, which yield about 20 gallons of oil per ton, contain about 21 million barrels oil equivalent; parts that yield about 6 gallons of oil per ton contain about 140 million barrels (Chile Departmento de Minas y Petróleo, 1936, p. 85–86).

Some other organic-rich shale deposits in South America are discussed by Schroeder (1935), Kraemer (1950), and others but the tonnage, organic content or oil potential are not reported in detail. Some of the marine Devonian, Cretaceous, and Tertiary deposits are large, however.

TOTAL SHALE OIL RESOURCES OF SOUTH AMERICA

The known oil-shale resources of South America (table 3) are interpreted to contain 50 billion barrels of recoverable shale oil, plus 750 billion barrels oil equivalent in marginal and submarginal deposits that yield 10–25 gallons per ton. There are possible extensions in selected deposits of about 3.2 trillion barrels in shale that yields 10–25 gallons per ton and 4 trillion barrels in shale that yields 5–10 gallons per ton. Estimates of the total shale oil resources of South America are derived from table 1.

REFERENCES CITED

Araujo, C. E. N., and Mariti, L., 1938, Shale oil industry in Brazil, *in* Oil shale and cannel coal: London, Inst. Petroleum, p. 272–282.

Ashley, G. H., 1917, Oil resources of black shales of the Eastern United States: U.S. Geol. Survey Bull. 641–L, p. 311–324.

_____1918, Cannel coal in the United States: U.S. Geol. Survey Bull. 659, 127 p.

Ball, Lionel C., 1915, Oil shales in the Port Curtis district: Queensland Geol. Survey Dept. Mines Pub. 249, 35 p.

Barnes, F. F., 1961, Coal fields of the United States, Sheet 2, Alaska: U.S. Geol. Survey Map.

Bastos, A. A., 1951, Oil shale in Brazil, *in* Fuel and energy resources: United Nations Sci. Conf. Conservation and Utilization of Resources Proc., v. 3, p. 62–64.

Baukov, S. S., 1958, Zakonomernosti veshchestvennogo sostava goryuchego slantsa Pribaltiiskogo slantsevogo basseina: Esti NSV Teaduste Akad., Geol. Inst., v. 2, p. 49-72.

Bentley, C. B., 1963, Oil shale, *in* U.S. Geological Survey, Mineral and water resources of Montana: U.S. 88th Cong., 1st sess., Senate Comm. on Interior and Insular Affairs, Comm. print, p. 45–46.

Biagio, Giunta, 1951, Bituminous rocks of Sicily, *in* Oil shale and cannel coal: London, Inst. Petroleum v. 2, p. 178–179.

Blake, G. S., 1930, The mineral resources of Palestine and Transjordan: Geol. Advisor Palestine Govt., Jerusalem, no. 2, 41 p.

Bradley, W. H., 1931, Origin and microfossils of the oil shale of the Green River Formation of Colorado and Utah: U.S. Geol. Survey Prof. Paper 168, 58 p.

Breger, I. A., and Brown, Andrew, 1962, Kerogen in shale: Sci., v. 137, p. 221–224.

Brynielsson, Harry, 1956, Sweden's energy outlook, *in* Peaceful uses of atomic energy: United Nations Proc., v. 1, p. 229–232.

Cadman, W. H., 1948, The oil shale deposits of the world and recent developments in their exploitation and utilization, reviewed to May 1947: Inst. Petroleum Jour., v. 34, no. 290, p. 109–132.

Canada Department of Mines and Resources, 1948, Summary of investigations on New Brunswick oil shales: Rept. 825, 24 p.

Cashion, W. B., Jr., 1957, Stratigraphic relations and oil shale of the Green River Formation in the eastern Uinta Basin [Utah], *in* Intermountain Assoc. Petroleum Geologists Guidebook, Eighth Ann. Field Conf., Geology of the Uinta Basin: p. 131–135.

———1959, Geology and oil-shale resources of Naval Oil-Shale Reserve No. 2, Uintah and Carbon Counties, Utah: U.S. Geol. Survey Bull. 1072–0, p. 753–793 [1960].

_____1962, Potential oil-shale reserves of the Green River Formation in the southeastern Uinta Basin, Utah and Colorado, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–C, p. C22–C24.

_____1964, Oil shale, *in* U.S. Geol. Survey, Mineral and water resources of Utah: U.S. 88th Cong., 2d sess., Senate Comm. on Interior and Insular Affairs, Comm. print, p. 61–63.

Cashion, W. B., and Brown, J. H., Jr., 1956, Geology of the Bonanza-Dragon oil-shale area, Uintah County, Utah, and Rio Blanco County, Colorado: U.S. Geol. Survey Oil and Gas Inv. Map OM–153 [with text].

Chile Departmento de Minas y Petróleo, 1936, Esquistos Bituminosos de Lonquimay y Pular: 175 p.

Conant, L. C., and Swanson, V. E., 1961, Chattanooga shale and related rocks of central Tennessee and nearby areas: U.S. Geol. Survey Prof. Paper 357, 91 p.

Crouse, C. S., 1925, An economic study of the black Devonian shales of Kentucky: Kentucky Geol. Survey, ser. 6, v. 21, p. 59–97.

Culbertson, W. B., 1964, Oil shale resources and stratigraphy of the Green River Formation in Wyoming: The Mountain Geologist, v. 1, no. 3, p. 18.

Dobryansky, A. F., 1947, Combustible shales of the U.S.S.R.: Moscow, All-Union Sci. Inv. Inst. for Treatment of Shales.

Donnell, J. R., 1961, Tertiary geology and oil-shale resources of the Piceance Creek basin between the Colorado and White Rivers, northwestern Colorado: U.S. Geol. Survey Bull. 1082–L, p. 835–891.

Duncan, D. C., 1958, Oil shale deposits in the United States: Indep. Petroleum Assoc. America Monthly, v. 29, no. 4, p. 22, 49–51.

Elliott, M. A., Linden, H. R., and Shultz, E. B., Jr., 1961, Production of low molecular weight hydrocarbons from solid fossil fuels: U.S. Patent Office, Patent 2,991,164, 4 p. and 4 figs.

Ertl, Tell, 1961, Shale oil—a competitive fuel in the 1960's: Jour. Petroleum Technology, v. 13, no. 10, p. 983–986.

Feth, J. H., 1963, Tertiary lake deposits in western conterminous United States: Sci., v. 139, no. 3550, p. 107–110.

Fettke, C. R., 1923, Oil resources in coal and carbonaceous shales of Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. M2, 119 p.

Forsman, J. P., and Hunt, J. M., 1958, Insoluble organic matter (kerogen) in sedimentary rocks of marine origin, *in* Weeks, L. G., ed., Habitat of oil—a symposium: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 747–778.

Gejrot, Claes, 1958, Svenska Skifferolje A B: Orebro, Sweden, 35 p.

Gil-Av, E., Heller, S., and Steckel, F., 1954, The Um Barek oil shales: Resources Council Israel Bull., v. 4, no. 2, p. 136–143.

Great Britain Mineral Resources Bureau, 1924, The mineral industries of the British Empire and foreign countries, petroleum and allied products (1913–1919): London, H M Stationery Office, 296 p.

Greiner, H. R., 1962, Facies and sedimentary environments of Albert shale, New Brunswick: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 2, p. 219–234.

Gussow, W. C., 1953, Carboniferous stratigraphy and structural geology of New Brunswick, Canada: Am. Assoc. Petroleum Geologists Bull., v. 37, no. 7, p. 1713–1816.

Guthrie, Boyd, and Klosky, Simon, 1951, The oil-shale industries of Europe: U.S. Bur. Mines Rept. Inv. 4776, 73 p.

Guthrie, B., and Thorne, H. M., 1954, Shale oil, *in* Encyclopedia of chemical technology: New York, The Intersci Encyclopedia, Inc., v. 12, p. 207–220.

Hodgkins, J. A., 1961, Soviet Power—energy resources, production and potentials: Prentice-Hall, Inc., 190 p.

Hoover, K. V., 1960, Devonian-Mississippian shale sequence in Ohio: Ohio Div. Geol. Survey Inf. Circ. 27, 154 p.

Hubbard, A. B., and Fester, J. I., 1959, A hydrogenolysis study of the kerogen in Colorado oil shale: U.S. Bur. Mines Rept. Inv. 5458, 26 p.

Hunt, J. M., and Jamieson, G. W., 1958, Oil and organic matter in source rocks of petroleum [repr.], *in* Weeks, L. G., ed., Habitat of oil—a symposium: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 735–746.

Hutchinson, George E., 1957, Geography, physics, and chemistry, *in* A treatise on limnology: New York, John Wiley and Sons, Inc., v. 1, 1015 p.

Institute of Petroleum, 1938, Oil shale and cannel coal: London, 476 p.

———1951, Oil shale and cannel coal, v. 2: London, 832 p.

Jaffé, F. C., 1962, Oil shale, nomenclature, uses, reserves and production: Colorado School of Mines, Mineral Industries Bull., v. 5, no. 2, 11 p.

King, L. H., 1963, Origin of the Albert mines oil shale (New Brunswick) and its associated albertite: Canada Dept. Mines and Tech. Services, Mines Br. Research Rept. R–115.

Kobayashi, T., Ichikawa, T., and Yabe, S., 1958, Geologic map of Chin-Hsien, Manchuria: Tokyo [Japan] Geog. Soc.

Kraemer, A. J., 1950, Oil shale in Brazil: U.S. Bur. Mines Rept. Inv. 4655, 36 p.

Kraemer, A. J., and Thorne, H. M., 1951, Oil Shale in New South Wales, Australia: U.S. Bur. Mines Rept. Inv. 4796, 48 p.

Lamar, J. E., Armon, W. J., and Simon, J. A., 1956, Illinois oil shales: Illinois Geol. Survey Circ. 208, 21 p.

Lucas, E. L., 1953, Oil shale distillation techniques on Oklahoma shales: Oklahoma Acad. Sci. Proc., v. 34, p. 143–146.

Lutz, K., 1938, The occurrence and application of Kukersite in Estonia, *in* Oil shale and cannel coal: London, Inst. Petroleum, p. 124–142.

McAuslan, E. A., 1959, In the Niobrara—oil may yield to special methods: Oil and Gas Jour., v. 57, no. 38, p. 158–166.

McKelvey, V. E., 1959, Investigations needed to stimulate the development of Jordan's mineral resources: U.S. Geol. Survey rept. for the Internat. Coop. Adm., p. 65–68.

Miller, Don J., Payne, Thomas G., and Gryc, George, 1959, Geology of possible petroleum provinces in Alaska: U.S. Geol. Survey Bull. 1094, 131 p.

Nir, Yaacov, 1960, The oil shale deposits at Ein Boqeq [abs.]: Research Council Israel Bull., Geo-Sciences, v. 9G, nos. 2–3, p. 169–170.

O'Hashi, T., and Fukuzawa, T., 1938, The development of the shale oil industry in Manchuria, *in* Oil shale and cannel coal: London, Inst. Petroleum, p. 267–271.

Ohki, Kenichi, 1959, Geologic map of T'ieh-li: Tokyo [Japan] Geog. Soc.

______1960, Geologic map of Lung-Hua, Manchuria: Tokyo [Japan] Geog. Soc.

Oil and Gas Journal, 1958, Thailand plans shale project: v. 56, no. 25, p. 88.

Okada, Shigem itsu, 1956, Geologic map of Fu-Sung, Manchuria: Tokyo [Japan] Geog. Soc.

Organization for European Economic Cooperation, 1952, Swedish shale oil: Organization for European Econ. Coop., Tech. Assistance Mission 93, 65 p.

Parker, Albert, 1962, Survey of energy resources: London, World Power Conf., 68 p.

Petrick, A. J., 1937, A contribution to the study of South African oil shales: Fuel Research Inst. South Africa Bull. 7, 80 p.

Prien, C. H., 1951, Oil shale and shale oil, *in* Oil shale and cannel coal: London, Inst. Petroleum, v. 2, p. 76–111.

[Quackenbush, W. M., and Singewald, Q. E., compilers], 1947, Fushun coal field, Manchuria: Allied Powers, Supreme Command, Nat. Resources Sec. Rept. 68, 24 p.

Reeves, J. R., 1922, Preliminary report on the oil shales of Indiana, *in* Handbook of Indiana geology: Indiana Dept. Conservation Pub. 21, pt. 6, p. 1059–1105.

Reinemund, J. A., 1955, Geology of the Deep River coal field, North Carolina: U.S. Geol. Survey Prof. Paper 246, 159 p.

Rosu, George, 1959, Ten years of Red China oil: World Petroleum, v. 30, no. 12, p. 94–99.

Rubel, A. C., 1955, Shale oil—as a future energy resource: Mines Mag., Oct. 1955, p. 72–76.

Rubey, W. W., 1951, Geologic history of sea water: Geol. Soc. America Bull., v. 62, no. 9, p. 1111–1148.

Runnels, R. T., Kulstad, R. O., McDuffee, Clinton, and Schleicher, J. A., 1952, Oil shale in Kansas: Kansas State Geol. Survey Bull. 96, pt. 3, p. 157–184.

Sakamoto, T., and Yabe, S., 1958, Geologic map of Shen-Yang, Manchuria: Tokyo [Japan] Geog. Soc.

Schopf, J. M., 1956, A definition of coal: Econ. Geology, v. 51, no. 6, p. 521–527.

Schroeder, Juan, 1935, Esquistos bituminosos y su exploración química: Instituto de Geología y Perforaciones, Bull. 22, p. 1–256.

Schulz, Ferdinand, 1938, Shale and cannel deposits in Czechoslovakia, *in* Oil shale and cannel coal: London, Inst. Petroleum, p. 283–286.

Shultz, E. B., Jr., 1962, Methane, ethane and propane from American oil shales by hydrogasification. I. Green River Formation shale. II. Shales of the eastern United States and New Brunswick, *in* Part II *of* Am. Inst. Chem. Engineers, Symposium on hydrocarbons from oil shale, oil sand, and coal: Am. Inst. Chem. Engineers, 48th Ann. Meeting, Denver, Colo., 1962, Preprint 9, p. 44–57.

Shabarov, N. V., and Tyzhnova, A. V., 1958, Zapasy uglei i goryuchikh slantsev kratkaya svodka resultatov podsheta, 1956, SSSR [Reserves of coal and combustible shales of U.S.S.R., short summary of results of tabulations for 1956]: Moskva, Ministerstvo Geologii i Okhrany, 1958, 179 p.

Smith, H. N., Smith, J. W., and Kommes, W. C., 1959, Petrographic examination and chemical analyses for several foreign oil shales: U.S. Bur. Mines Rept. Inv. 5504, 34 p.

Smith, J. W., and Stanfield, K. E., 1964, Oil yields of Devonian New Albany shales, Kentucky: Am. Assoc. Petroleum Geologists Bull., v. 48, no. 5, p. 712–714.

Smith, P. S., and Mertie, J. B., Jr., 1930, Geology and mineral resources of northwestern Alaska: U.S. Geol. Survey Bull. 815, 351 p.

Stanfield, K. E., and Frost, I. C., 1949, Method of assaying oil shale by a modified Fischer retort: U.S. Bur. Mines Rept. Inv. 4477, 13 p.

Stanfield, K. E., Frost, I. C., McAuley, W. S., and Smith, H. N., 1951, Properties of Colorado oil shale: U.S. Bur. Mines Rept. Inv. 4825, 27 p.

Stanfield, K. E., Rose, C. K., McAuley, W. S., and Tesch, W. J., Jr., 1954, Oil yields of sections of Green River oil shale in Colorado, Utah, and Wyoming, 1945–52: U.S. Bur. Mines Rept. Inv. 5081, 153 p.

Stanfield, K. E., Smith, J. W., Smith, H. N., and Robb, W. A., 1960, Oil yields of sections of Green River oil shale in Colorado, 1954–57: U.S. Bur. Mines Rept. Inv. 5614, 186 p.

Stanfield, K. E., Smith, J. W., and Trudell, L. G., 1964, Oil yields of sections of Green River oil shale in Utah, 1952–62: U.S. Bur. Mines Rept. Inv. 6420, 217 p.

Swanson, V. E., 1960, Oil yield and uranium content of black shales: U.S. Geol. Survey Prof. Paper 356–A, 44 p.

_____1962, Geology and geochemistry of uranium in marine black shales, a review: U.S. Geol. Survey Prof. Paper 356–C, p. 67–112.

Swinnerton, A. A., 1938, Oil shale in Canada, *in* Oil shale and cannel coal: London, Inst. Petroleum, p. 210–226.

Tailleur, I. L., 1964, Rich oil shale from northern Alaska, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–D, p. D131–D133.

Tasmania Geological Survey, 1933, Report of Tasmanian Shale Oil Investigation Committee: Mineral Resources, no. 8, v. 2, 214 p.

Thorne, H. M., and Kraemer, A. J., 1950, Oil shale in Spain: U.S. Bur. Mines Rept. Inv. 4736, 21 p.

_____1954, Oil-shale operations in the Union of South Africa, October 1947: U.S. Bur. Mines Rept. Inv. 5018, 31 p.

Thorne, H. M., Stanfield, K. E., Dinneen, G. U., and Murphy, W. I., 1962, Oil-shale technology in second symposium on the development of the petroleum resources of Asia and the far east: U.S. Dept. Interior, p. 211–236.

Trask, P. D., and Patnode, H. W., 1942, Source beds of petroleum: Tulsa, Okla., Am. Assoc. Petroleum Geologists, 566 p.

Trumbull, J. F. A., 1960, Coal fields of the United States, Sheet 1: U.S. Geol. Survey Map.

Twenhofel, W. H., 1950, Principles of sedimentation: New York, McGraw-Hill Book Co., 673 p.

United Nations Economic Commission for Latin America, 1957, Energy in Latin America: Geneva, United Nations Dept. Econ. and Social Affairs, 268 p.

U.S. Bureau of Mines, 1960, Oil shale, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 573–580.

U.S. Geological Survey, 1951, Fuel reserves of the United States: U.S. 82d Cong., 1st sess., Senate Comm. on Interior and Insular Affairs, Comm. print, 49 p.

Vine, J. D., 1962, Geology of coaly carbonaceous rocks: U.S. Geol. Survey Prof. Paper 365–D, p. 113–170.

Weeks, L. G., 1960, The next hundred years energy demand and sources of supply: Geotimes, v. 5, no. 1, p. 18–21, 51–55.

Willett, R. W., 1943, The Nevis oil shale deposit, Nevis Survey district, Otago Central: New Zealand Jour. Sci. and Technology, v. 24, no. 6B, p. 239B–254B.

Willett, R. W., and Wellman, H. W., 1940, The oil-shale deposit of Orepuki, Southland: New Zealand Jour. Sci. and Technology, v. 22, no. 2B, p. 84B–99B.

Winchester, D. E., 1918, Results of dry distillation of miscellaneous shale samples: U.S. Geol. Survey Bull. 691–B, p. 51–55.

_____1923, Oil shale of the Rocky Mountain region: U.S. Geol. Survey Bull. 729, 204 p.

_____1928, The oil possibilities of the oil shales of the United States: Federal Oil Conservation Board of the President of the United States, Rept. 2, Jan. 1928, app. 1, p. 13–14.

Yabe, Shigeru, 1955a, Geologic map of Lin-Yu, Manchuria: Map NK50–12, Tokyo [Japan] Geog. Soc.

_____1955b, Geologic map of Ch'ih-Feng, China: Map NK50–6, Tokyo [Japan] Geog. Soc.

_____1956, Geologic map of Tung-Hsing-Chen, Manchuria: Map NK52–3, Tokyo [Japan] Geog. Soc.

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