INTRODUCTION

Oil shale is a fine-grained sedimentary rock that contains significant amounts of organic material that is insoluble in organic solvents and that yields oil when heated. The organic material is known as kerogen, and it converts to oil at temperatures of about 500°C (930°F) in a closed retort, a process of destructive distillation. The oil yields reported here were determined by Fischer assay (Stanfield and Frost, 1949). Only formations that are reported to yield at least 4 gal/ton (17 L/t) of oil are considered, but it is recognized that this oil yield is probably too low to be of commercial interest in the near future. Some stratigraphic units, most notably petroleum source rocks, probably have oil-shale potential but are excluded from this study for one or more of the following reasons: (1) no Fischer assays are reported, (2) formations are too deeply buried to be of economic interest by present mining methods (i.e. Bakken Formation of North Dakota and Woodford Shale of west Texas), or (3) maps showing precise location of the units are unavailable. An excellent collection of papers on petroleum source rocks is found in Woodward and others (1984), where the organic-carbon content of the Bakken Formation is reported to average about 11 weight percent (p. 57), which is very high. If the Bakken were at or close to the surface, it would most likely be a potentially economic oil shale.

Some oil shales contain potentially economic mineral resources in addition to oil and make the oil shale more attractive economically; these co-product resources include sodium, aluminum, and phosphate minerals. Other oil shales contain certain metals in anomalously large concentrations that could have economic potential when combined with the oil resource. For many oil shales there is no information available on mineral resources or metal anomalies.

The following are brief descriptions of the oil-shale-bearing stratigraphic units and individual localities shown on the map, including oil yields and estimates of total oil resources, where available.

DESCRIPTION OF OIL-SHALE-BEARING STRATIGRAPHIC UNITS

Tm **Monterey Formation (Miocene)**—The marine Monterey Formation is located in southwestern California and contains bitumen and kerogen. Oil yields of 30 or 40 gal/ton (125 or 167 L/t) have been reported by Gore (1924). The Monterey Formation is considered a source of petroleum for oil fields in the vicinity of Santa Barbara

Te **Elko Formation (Oligocene? and Eocene)**—The lacustrine Elko Formation, located near Elko in northeastern Nevada, is stratigraphically and structurally complex. Remnants of the Elko Formation are scattered over an area about 100 mi (161 km) from north to south and about 30 mi (48 km) from east to west (Moore and others, 1983), indicating that the distribution of the Elko was considerably more extensive originally. The Elko oil shales yield from about 20 to 86 gal/ton (83 to 358 L/t) (Solomon, 1979) and contain at least 228 x 10^6 barrels (36 x 10^6 m^3) of oil (Moore and others, 1983). The Catlin Shale Products Co. produced about 12,000 barrels (1,896 m^3) of shale oil at Elko during the period 1917-1930 and outperformed all other U.S. oil shale operations in existence at the time (Russell, 1980). It is evident that the Elko Formation has oil-shale potential, but it is greatly overshadowed by the Green River Formation

Tt **Tatman Formation (Eocene)**—The Tatman Formation of lacustrine and paludal origin is located in the Bighorn basin of northern Wyoming. Oil yields as high as 14 gal/ton (58 L/t) have been reported (Love, 1964). Not all of the Tatman contains oil shale, and where it does it is usually low grade

Twb **Wagon Bed Formation (Upper and Middle Eocene)**—Much of the lacustrine Wagon Bed Formation contains little or no oil shale, but at Lysite Mountain in north-central Wyoming it includes oil shale, coal, and tuffaceous lacustrine beds. The oil content of the oil shale is as much as 38 gal/ton (159 L/t) (Love, 1964). The Wagon Bed Formation at Lysite Mountain was mapped as the Aycross(?) Formation equivalent prior to the publication of the Wyoming state geologic map in 1985

Tg **Green River Formation (Eocene)**—The oil shales of the Green River Formation, of lacustrine origin, are extensive in the Piceance Creek basin of northwestern Colorado, the Uinta basin of northeastern Utah (locally of Paleocene age), and the Green River basin of southwestern Wyoming. The Green River Formation contains one of the largest oil shale resources in the world. The oil shales yield from about 10 to 90 gal/ton (42 to 375 L/t) (Winchester, 1923) and contain approximately 1.8 x 10^{12} barrels (0.3 x 10^{12} m^3) of oil in rocks yielding an average of at least 15 gal/ton (63 L/t) (Culbertson and Pitman, 1973). For the most part, the Green River Formation is structurally simple. The Mahogany ledge of the Green River Formation contains some of the richest oil shale and has received considerable attention in mapping and resource evaluation.

In addition to its oil-shale resources, the Green River Formation contains nahcolite (sodium bicarbonate) and other saline minerals in the Piceance Creek basin and the northwestern part of the Uinta basin. In the Piceance Creek basin it is estimated that there are about 30 x 10^9 short tons (27 x 10^9 metric tons) of nahcolite; the average grade is about 20 percent by weight in the oil shales of the lower part of the Parachute Creek Member of the Green River Formation (Beard and others, 1974; Dyni, 1974b). Authigenic sodium minerals occur in the subsurface underlying an area of about 86 mi^2 (223 km^2) in the upper part of the Green River Formation near Duchesne, Utah (Dyni and others, 1985).

The world's largest trona deposits are confined to the saline facies of the Wilkins Peak Member of the Green River Formation in the Green River basin. The trona is often mixed with halite and occurs in nearly flat-lying beds. Some 25 beds are estimated to contain 81.7 x 10^9 short tons (74.1 x 10^9 metric tons) of trona and 52.7 x 10^9 short tons (47.8 x 10^9 metric tons) of mixed trona and halite (Burnside and Culbertson, 1979). Trona in the Green River basin is being actively exploited and used for its soda ash (Na_2CO_3), an industrial chemical.

Another co-product resource of the oil shales in the Piceance Creek basin is dawsonite, an aluminum mineral of significant resource potential. It has been estimated that there are about 19 x 10^9 short tons (17 x 10^9 metric tons) of dawsonite (whose grade ranges from a few percent to at least 20 percent) containing 6.5 x 10^9 short tons (5.9 x 10^9 metric tons) of alumina (Al_2O_3) (Beard and others, 1974). If this aluminum resource were exploited, most likely in conjunction with oil shale and nahcolite, it would greatly overshadow all conventional domestic aluminum resources. Dawsonitic oil shale is partly coextensive with nahcolitic oil shale but also extends beyond the limits of nahcolite deposition

TKsp **Sheep Pass Formation (Oligocene to Upper Cretaceous?)**—The largely lacustrine Sheep Pass Formation occurs in eastern Nevada and has long been known to contain oil shale. The Sheep Pass strata are also considered to be source beds of petroleum. The oil-shale potential of this formation is largely unknown

TKnc **Newark Canyon Formation (Paleocene and Cretaceous)**—The lacustrine Newark Canyon Formation crops out in east-central Nevada. Oil yields greater than 10 gal/ton (42 L/t) have been reported (Fouch and others, 1979), but there is insufficient geologic information available to evaluate the oil-shale potential

JTR **Undifferentiated Jurassic and Triassic sedimentary rocks**—Jurassic and Triassic marine formations of northern and eastern Alaska contain oil shale, but not much is known about its occurrence. Samples taken from the northern part of the Brooks Range yielded 26-146 gal/ton (108-609 L/t) of oil (Tailleur, 1964), and some samples contain unusually high concentrations of barium, boron, chromium, cobalt, copper, gold, lead, mercury, molybdenum, nickel, silver, strontium, vanadium, and zinc (Donnell and others, 1967). Approximately 250 x 10^9 barrels (39.5 x 10^9 m^3) of oil in deposits that contain more than 25 gal/ton (104 L/t) have been estimated for Alaska (Duncan and Swanson, 1965)

Pp **Phosphoria Formation (Lower Permian)**—The Phosphoria Formation, of marine origin, includes the Meade Peak Phosphatic Shale Member and the Retort Phosphatic Shale Member. Both members locally contain oil shale in southwestern Montana, southeastern Idaho, and parts of Wyoming. The phosphatic shale members contain anomalously large amounts of barium, chromium, copper, lanthanum, lead, molybdenum, neodymium, nickel, silver, strontium, titanium, vanadium, yttrium, ytterbium, and zinc (Maughan, 1976); uranium is also found in high concentrations in these rocks (McKelvey and Carswell, 1956). Parts of the Phosphoria are source beds for petroleum in Idaho, Montana, Utah, and Wyoming. In southwestern Montana, oil shale in the Phosphoria is reported to yield 25-30 gal/ton (104-125 L/t) of oil (Condit, 1920).

The Meade Peak and Retort Phosphatic Shale Members of the Phosphoria Formation also contain phosphorite. The Phosphoria Formation in the western U.S. has been estimated to contain 6.0 x 10^9 metric tons (6.6 x 10^9 short tons) of rock containing more than 24 percent P_2O_5 (Cathcart and Gulbrandsen, 1973). Additional hypothetical phosphate resources are also large. The combined resources of the rocks may be of economic value whereas the individual resources may not be

Mb **Barnett Formation (Upper Mississippian)**—The marine Barnett Formation is exposed in central Texas. The formation averages 20-40 ft (6-12 m) thick in outcrop and consists of black and brownish-black, extremely thin-bedded, soft, petroliferous, fossiliferous oil shale with a few thin layers of limestone (Plummer, 1940). The shale yields as much as 42.2 gal/ton (176.1 L/t) of oil (Plummer, 1940) and averages about 13.6 gal/ton (56.7 L/t) for 63 samples tested (Plummer and Grant, 1944). Estimates of total oil-shale resources in the Barnett Formation range from large to insignificant, and more information is needed

Mh **Heath Formation (Upper Mississippian)**—The marine Heath Formation underlies more than 2,700 mi^2 (6,990 km^2) in central Montana. The Heath contains oil shale that yields approximately 10 gal/ton (42 L/t) of oil or less (Cox and Cole, 1981). An estimate of oil-shale resources in the Heath is reported by Desborough and others (1981) to exceed 180 x 10^9 barrels (28 x 10^9 m^3) of oil based on a minimum thickness of 160 ft (48 m) of shale with an oil yield of 10 gal/ton (42 L/t). However, Derkey and others (1985) have estimated that there are only about 0.32 x 10^9 barrels (0.05 x 10^9 m^3) of oil in oil shale in an area of 120 mi^2 (310 km^2) that has an average thickness of 6.2 ft (1.9 m) and a weighted average oil yield of 10.4 gal/ton (43.4 L/t). The large discrepancy between these two resource estimates is caused by selecting different areas in which oil shale is believed to occur and using different thicknesses of oil shale. The oil shale also contains anomalously large amounts of molybdenum, nickel, selenium, vanadium, and zinc; the amounts are larger in samples that have higher oil yields (Desborough and others, 1981)

Dwf **Woodruff Formation (Devonian)**—The marine Woodruff Formation of central Nevada is considered a petroleum source rock and also a low-grade oil shale. Oil yields from fresh black rock are as much as 12 gal/ton (50 L/t). The rock also contains anomalously large amounts of molybdenum, selenium, vanadium, and zinc (Desborough and others, 1979). In unoxidized samples of the rock, molybdenum ranges from 70 to 960 ppm (parts per million), selenium ranges from 30 to 200 ppm, vanadium oxide (V_2O_5) ranges from 3,000 to 7,000 ppm, and zinc ranges from 4,000 to 18,000 ppm (Desborough and others, 1979)

Ov **Vinini Formation (Ordovician)**—The Vinini Formation, of marine origin, occurs over a broad area in central, north-central, and northeastern Nevada, and locally contains oil shale and anomalously large amounts of chromium, selenium, silver, molybdenum, vanadium, and zinc (Poole and Desborough, 1980). Oil yields for the Vinini range from less than 10 to 30 gal/ton (42 to 125 L/t) (Poole and Desborough, 1980). Systematic sampling and analysis of the Vinini has not been carried out

DESCRIPTION OF OIL-SHALE-BEARING LOCALITIES

Oil shale of lacustrine origin is interbedded with tuff of the Little Butte Volcanics, Tl, of Miocene and Oligocene age, located in southwestern Oregon (Newton and Lawson, 1974). Oil yields of from 35 to 37 gal/ton (146 to 154 L/t) have been reported, but the thickest layer of oil shale is only 4 ft (1 m) thick (Newton and Lawson, 1974). The deposits are probably small.

Tertiary coal and associated carbonaceous shale, Tc, of fluvial and paludal origin, in the Medicine Lodge Creek Valley in extreme southwestern Montana, have some oil-shale potential. Oil yields for the coal and carbonaceous shale are as much as 14.9 gal/ton (62.2 L/t), but most samples reportedly yielded a trace to about 5 gal/ton (21 L/t) (Dyni and Schell, 1982). It is unlikely that these low-grade oil shales will be exploited in the near future.

The lacustrine Kishenehn Formation, Tk, of Oligocene age, contains oil shale in northwestern Montana. The oil shale and sapropelic coals yielded from 8 to 37 gal/ton (34 to 155 L/t) of oil, using the modified Fischer assay method (Constenius and Dyni, 1983). It is unlikely that these deposits will be mined in the near future because of geologic and environmental considerations.

The Paleocene and Upper Cretaceous Raton Formation, TKr, of paludal and flood-plain origin, is exposed in northeastern New Mexico. Of a total of 23 samples of the Raton, four samples of carbonaceous shale were reported to yield from 4.2 to 8.6 gal/ton (17.5 to 35.9 L/t) of oil (Foster and others, 1966). Insufficient information is available to assess the oil-shale potential of this formation, but it appears to be low.

The Upper Cretaceous Crevasse Canyon Formation, Kccg (probably the Gibson Coal Member, of paludal-deltaic origin), contains carbonaceous, coaly shales in outcrops located about 35 mi east of Gallup, New Mexico. As much as 10 gal/ton (42 L/t) of oil has been reported from these shales, but most oil yields are lower (Foster and others, 1966). More information is needed to make an oil-shale assessment of the Crevasse Canyon Formation.

The lower part of the Upper Cretaceous Mancos Shale, Kml, of marine origin, has some oil-shale potential in New Mexico. As much as 5 gal/ton (21 L/t) of oil has been reported from the lower part of the Mancos, in extreme northwestern New Mexico (Foster and others, 1966). Although the grade of the oil shale is very low, it would probably be worthwhile to test the Mancos more extensively because it occurs over a very broad area.

The marine Niobrara Formation, Kn, of Late Cretaceous age, may contain source rocks for petroleum and low-grade oil shale in parts of Colorado and Wyoming. Oil yields of from 10 to 12 gal/ton (42 to 50 L/t) have been reported (McAuslan, 1959), but sample locations are unknown. In northern Colorado, the Niobrara has yielded 4 gal/ton (17 L/t) of oil (Dyni, unpub. data). Probably the Niobrara is too low grade to be considered a good oil shale, but further sampling and analysis are probably warranted.

The marine Sharon Springs Member of the Upper Cretaceous Pierre Shale, Kpss, contains significant amounts of organic carbon in parts of Colorado, Kansas, and South Dakota. In south-central Colorado, the Sharon Springs yields 5 gal/ton (21 L/t) of oil, and in drill core of the Sharon Springs in eastern Colorado oil yields of 6 gal/ton (25 L/t) have been obtained (Dyni, unpub. data). Samples taken from the Sharon Springs in western Kansas are reported to yield 6-7 gal/ton (25-29 L/t) (Runnels and others, 1952). Samples that were taken from three localities in the southern part of South Dakota have oil yields of 4-8 gal/ton (17-33 L/t) (Swanson, 1960). The fact that the oil yields from widely scattered localities are uniformly low suggests that the oil-shale potential is low for much of the Sharon Springs.

The Lower and Middle Pennsylvanian Sandia Formation, IPs, of marine origin, in north-central New Mexico, contains highly carbonaceous shales with thin coal seams. As much as 5 gal/ton (21 L/t) of oil were distilled from samples of these rocks (Foster and others, 1966). There is insufficient information to determine the oil-shale potential of the Sandia.

A black shale of the Doublehorn Shale Member of the marine(?) Houy Formation, MDhd, of Early Mississippian and Late Devonian age, is exposed in central Texas. A Fischer assay of 21.8 gal/ton (90.9 L/t) of oil has been reported for this shale (Swanson, 1960). This assay is encouraging, but more information is needed.

The marine Cottonwood Canyon Member of the Madison Limestone, MDmc, of Mississippian and Devonian age, has some oil-shale potential in northwestern Wyoming. Carbonaceous shale of the Cottonwood Canyon is reported to yield 10.3 gal/ton (43.0 L/t) of oil, using the Ruska Still method (Sandberg, 1967).

The marine Woodford Shale, MDw, of Early Mississippian and Late Devonian age, is the approximate correlative of the Chattanooga Shale. The Woodford in southern Oklahoma is reported to contain as much as 15.3 gal/ton (63.8 L/t) of oil; the average of seven samples was 11.5 gal/ton (48.0 L/t) (Swanson, 1960). These data suggest that there is some oil-shale potential for the Woodford.

Contact of stratigraphic units that contain oil shale— Solid line is approximate outcrop limit of unit

Locality with reported oil shale that yields at least 4 gal/ton (17 l/t) of oil—Symbol shows host stratigraphic unit
- Tl, oil shale interbedded with tuff of Little Butte Volcanics (Miocene and Oligocene)
- Tc, coal and carbonaceous shale in Medicine Lodge Creek Valley (Tertiary)
- Tk, Kishenehn Formation (Oligocene)
- TKr, Raton Formation (Paleocene and Upper Cretaceous)
- Kccg, Crevasse Canyon Formation (Upper Cretaceous)
- Kml, Mancos Shale (Upper Cretaceous)
- Kn, Niobrara Formation (Upper Cretaceous)
- Kpss, Sharon Springs Member of the Pierre Shale (Upper Cretaceous)
- IPs, Sandia Formation (Middle and Lower Pennsylvanian)
- MDhd, Doublehorn Shale Member of the Houy Formation (Lower Mississippian and Upper Devonian)
- MDmc, Cottonwood Canyon Member of the Madison Limestone (Mississippian and Devonian)
- MDw, Woodford Shale (Lower Mississippian and Upper Devonian)

Area underlain by significant amounts of nahcolite ($NaHCO_3$) or trona ($NA_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) in the Eocene Green River Formation

Area underlain by significant amounts of dawsonite [$NaAl(OH)_2CO_3$] in the Eocene Green River Formation

Approximate area of outcrops of Phosphoria Formation that may contain phosphorite (sedimentary phosphate rock)

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MAP SHOWING THE AREAL DISTRIBUTION OF OIL SHALES WITH ASSOCIATED MINERAL RESOURCES AND METAL ANOMALIES IN THE WESTERN UNITED STATES AND ALASKA

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