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Chemistry and Mineralogy of Natural Bitumens and Heavy Oils and Their Reservoir Rocks from the United States, Canada, Trinidad and Tobago, and Venezuela

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Chemistry and Mineralogy of Natural Bitumens and Heavy Oils and Their Reservoir Rocks from the United States, Canada, Trinidad and Tobago, and Venezuela

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CURTIS A. PALMER, MICHAEL W. DOUGHTEN, and
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CONTENTS

TABLES

[Tables follow References Cited]

METRIC CONVERSION FACTORS

Conversion factors for the units used in this report are given below.

Multiply	By	To obtain
micrometer (μm)	0.000039	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	.6214	mile (mi)
hectare (ha)	2.471	acre
millipascal second (mPa·s)	1	centipoise (cP)
milligram (mg)	.000035	ounce (oz)
degree Celsius (°C)	1.8 and add 32	degree Fahrenheit (°F)

°API gravity.—The degree API gravity is the standard term devised by the American Petroleum Institute to specify the density of crude petroleum.

Chemistry and Mineralogy of Natural Bitumens and Heavy Oils and Their Reservoir Rocks from the United States, Canada, Trinidad and Tobago, and Venezuela

By John W. Hosterman, Richard F. Meyer, Curtis A. Palmer, Michael W. Doughten, *and* Donald E. Anders

Abstract

Twenty-one samples from natural bitumen and heavy oil deposits in seven States of the United States and six samples from outside the United States form the basis of this initial study. This Circular gives the mineral content of the reservoir rock, the trace-element distribution in the reservoir rock and hydrocarbons, and the composition of the heavy oil and natural bitumen.

The reservoir rock and sediment residues from California contain more trace-element maximum amounts than any of the other rock samples. These relatively high concentrations of trace elements may be due, in part, to the low quartz content of the rock and to the presence of heulandite, cristobalite, siderite, and pyrite. The reservoir rock and sediment residues from Oklahoma contain more minimum amounts of trace elements than any of the other rock samples. This pattern probably results from the large amount of quartz in four of the samples and a large amount of calcite in the other sample.

The maximum and minimum amounts of trace elements in the bitumen and heavy oil do not correlate with those in the reservoir rocks. The bitumen from Utah contains the greatest number of trace-element maxima, whereas there is no trend in the trace-element minima in the bitumen and heavy oil.

INTRODUCTION

Supplies of conventional crude oil are diminishing; therefore, it is important to understand the reservoir characteristics of unconventional oil deposits to enhance the recovery of the contained resource. Unconventional deposits contain oils heavier than 20 °API gravity and less viscous than 10,000 centipoises (cP) or natural bitumens (in tar sands and oil sands), which are more viscous than 10,000 cP. The resources of these hydrocarbons are very large, particularly for the heavy oil of the Orinoco oil belt of Venezuela as well as the natural bitumen of the Western Canada Sedimentary Basin of Alberta. In addition, many deposits of heavy oil and bitumen occur in the United States. Although the total resources of unconventional oil deposits are extensive, many environmental, economic, and technological factors inhibit their productivity. To facilitate their exploitation, we need to know the mineralogy of the host rock, the amount and type of clay minerals present, the physical and chemical composition of the hydrocarbons, and the trace-element distribution.

The U.S. Geological Survey (USGS) is undertaking a program to analyze the reservoir rock mineralogy and hydrocarbon chemistry of samples from natural bitumen and heavy oil deposits of the world. Results from the first phase are reported in this Circular. The samples analyzed are from Canada, Trinidad and Tobago, the United States, and Venezuela. Sample localities are provided in the appendix.

Twenty-one samples from natural bitumen and heavy oil deposits in seven States of the United States and six samples from outside the United States form the basis of this initial study. The hydrocarbons were extracted from each sample, leaving the ground rock as a sediment residue. X-ray diffraction analysis of the residue and its clay fraction identified the minerals present in the reservoir rock (table 1). The components of the available hydrocarbons were determined (table 2). Trace-element contents were determined in the reservoir rock sample, in the sediment residue remaining after the hydrocarbons were removed, and in the extracted hydrocarbons (tables 3–9).

The authors divided the work as follows. The program was conceived by Meyer, and he obtained the samples

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and prepared the appendix. Extraction of the bitumen and X-ray diffraction to determine sample mineralogy were done by Hosterman. The distribution of 29 trace elements in reservoir rock and sediment residue was determined by Palmer by instrumental neutron activation analysis (INAA). INAA determinations of the distribution of the same 29 trace elements in bitumen and heavy oil were made by the Nuclear Radiation Center, Washington State University, Pullman, Wash., under a contract from the USGS. Contents of nine other trace elements in all samples were determined by Doughten by atomic absorption spectrometry, atomic emission spectroscopy, and thermal combustion infrared spectroscopy. Hydrocarbon components were determined by Anders by chromatography.

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We are grateful to the following individuals for providing samples of bitumen and heavy oil for this study: Cynthia Brandt and M.D. Laine, Utah Geological and Mineralogical Survey; Antonius J. Budding, New Mexico Institute of Mining and Technology; Margaret R. Burchfield, Oklahoma Geological Survey; James W. Earley, consultant, Santa Maria, Calif.; Deborah Henry, Alberta Research Council; Caroline M. Issacs, USGS; Jeffrey D. Meyers, Conoco, Inc.; Martin C. Noger, Kentucky Geological Survey; and H. Rambarran, Trinidad and Tobago Oil Company, Ltd.

ANALYTICAL TECHNIQUES

Dividing Reservoir Rock Samples into Available Hydrocarbon and Sediment Residue

The weight of the available hydrocarbon (bitumen), or extractable organic matter (EOM), was derived by two methods. Both methods were used on all samples. In one method, a weighed sample of reservoir rock was crushed and elutriated with benzene. Subtracting the weight of the sediment residue from the weight of the original sample gave the weight of the EOM. The hydrocarbons extracted by this method were used to determine the trace-element content. In the other method, the EOM was separated from the crushed reservoir rock sample with chloroform in a Soxhlet apparatus. The extract was then used to determine the composition of the available hydrocarbon.

Determining the Composition of the Available Hydrocarbon

The EOM, heavy oil, or gilsonite was combined with iso-octane at room temperature; the precipitate was asphaltene. The remaining solution was decanted and evaporated in a nitrogen atmosphere until a constant weight was obtained. A sample of 4–5 mg was elutriated on an alumina-silica gel column to separate the major hydrocarbon components. The aromatic hydrocarbons, resins, and heterocompounds (nitrogen-sulfur-oxygen) were adsorbed on the alumina gel, and the saturated hydrocarbons, on the silica gel. For chromatographic analysis, the column was elutriated progressively with more polar solvents—cyclohexane or heptane for the saturated hydrocarbons, benzene for the aromatic hydrocarbons, and 50/50 benzene/methanol for the resins and in part for the aromatics. The saturated hydrocarbons are the paraffin series, that is, the alkanes; the aromatic hydrocarbons are the aromatic (benzene ring) series; and the resins are included with the N–S–O compounds as polar compounds.

Determining the Mineral Content of the Sediment Residue

Contents of major and clay minerals in the sediment residue were determined by X-ray diffraction (XRD) using copper (CuK_{α_1}) radiation. The minerals in the sediment residue are the same as those in the reservoir rock. Small portions of sediment residue were ground with a mortar and pestle to ensure a uniform 200-mesh size and were pressed into wafers in which the minerals were randomly oriented. Each wafer was mounted in the sample holder of the X-ray unit and rotated during exposure to X-ray radiation. An X-ray line trace was made for each sample as the goniometer traveled from 4° to 60° 2 θ in 0.02° 2 θ increments. Each increment was counted for 1 second for a total of 2,800 counts in the digital trace. The major minerals identified were quartz, feldspar, calcite, and dolomite (table 1). The semiquantitative mineral determinations were made from the digital trace by the method described by Hosterman and Dulong (in press). The central algorithm reads and operates on the digitized data of the XRD trace. The generalized calculations are (1) smoothing the digitized data, (2) determining and subtracting the background, (3) determining the peak positions, (4) identifying the peaks from a library of peaks for standard minerals, and (5) estimating the weight percentages for as many as 12 minerals.

A portion of the sediment residue from each sample was dispersed in deionized water, and the clay fraction of less than 2 µm was siphoned onto a porous ceramic tile by using the vacuum technique of Kinter and Diamond (1956). XRD traces were made of (1) the untreated clay fraction, (2) the clay fraction saturated with ethylene glycol, and (3) the clay fraction heated to 350 °C. Kaolinite, illite, mixed-layer clay, smectite, and chlorite were determined semiquantitatively from the XRD traces and computer program (table 1).

Determining the Trace-Element Distribution

The trace-element distribution in all samples was determined by INAA, atomic absorption spectrometric

(AAS) methods, and atomic emission spectroscopy (AES) methods. Twenty-nine elements were determined by INAA, four by AAS, and four by AES. Sulfur was determined by thermal combustion infrared spectroscopic analysis (Rait and Aruscavage, 1989).

The INAA method used for reservoir rock and sediment residue samples was similar to that used for determining trace-element distributions in coal (Palmer and Baedecker, 1989). It consisted of measuring the photon spectra (X-rays and Γ-rays) emitted from a neutron-activated sample; multielement coal, fly-ash, and gelatin standards were used as laboratory monitors. After irradiation of the sample, X-rays and Γ-rays were counted by a germanium detector. The peak areas were used to determine the amount of each element present according to an updated version of programs reported by Baedecker (1976).

The AAS method, described briefly by Aruscavage and Crock (1987), consists of using a heat source to dissociate molecules into gaseous atoms that are capable of absorbing specific light energy of known wavelength from the light source of that same wavelength. A photomultiplier-amplifier system converts the light energy to an electrical signal and records the data. The intensity of the light absorption is used to determine the amount of each element present. Cu, Pb, and V concentrations were determined on a graphite furnace atomic absorption spectrometer, where the heat source used was a graphite atomizer.

Hg content was determined by cold-vapor AAS, where Hg was evolved from the sample solution by the addition of $SnCl_2$. The Hg was amalgamated onto gold beads centered in the coil of an induction furnace. When the furnace was activated, the Hg was driven into a quartz cell, where its atomic absorption signal was measured (Wilson and others, 1987; Aruscavage and Moore, 1989).

The AES method, described briefly by Lichte and others (1987), is inductively coupled plasma-atomic emission spectroscopy (ICP–AES). It consists of using a high-energy heat source (a plasma) to excite the atoms into a higher energy state. As atoms relax back to their ground state, they emit light at a characteristic wavelength. This light emission is detected by a photomultiplier tube array. The intensity is used to determine the amount of each element present. Li, Mo, Nb, and Y concentrations were determined by ICP–AES.

BITUMEN AND HEAVY OIL DEPOSITS

The deposits sampled are described below. They are in California, Kentucky, New Mexico, Oklahoma, Texas, Utah, Wyoming, Canada, Trinidad and Tobago, and Venezuela. Sample localities are listed in the appendix. The samples are from well-known deposits that have been sources of natural asphalt, that are presently sources of petroleum or synthetic oil, or that are potential sources of petroleum.

California

The tar seeps and asphalt accumulations just east of the cities of Goleta and Carpinteria in Santa Barbara County have been known for many years as the largest bitumen deposits in southern California (Priestaf, 1979). According to Dibblee (1966), the bitumen and asphalt are indigenous to the Monterey Shale and leak from fractured zones in it.

Three of the four samples used for this study were also from the Monterey Shale. The three samples were from Santa Barbara County—two (CA–2 and CA–3) from Gaviota Beach approximately 45 km west-northwest of Santa Barbara and one (CA–1) from near Santa Maria. A fourth sample (CA–4) was medium-brown siltstone from the Pismo Formation in San Luis Obispo County, near Edna. The two samples of diatomaceous shale (CA–1 and CA–2) contained cristobalite and were light to medium brown. One sample (CA–3) was a carbonaceous marl containing the zeolite heulandite. All samples except the marl contained abundant quartz, some feldspar, and a little clay. The available hydrocarbon in these four samples ranged from 2.80 to 14.37 weight percent. Data for these four samples are in tables 1–3.

Kentucky

Two samples from Kentucky were analyzed. Sample KY–1, from the Homer quarry in Logan County, was fine-grained sandstone from the Big Clifty Sandstone Member of the Mississippian Golconda Formation. This unit ranges in thickness from 0 to 23 m (Williams and others, 1982). The sample consisted of quartz, feldspar, and kaolinite. A trace of illite was present in the clay fraction, but no smectite was detected.

Sample KY–2, from the Indian Creek quarry in Edmonson County, was taken from part of the Kyrock Sandstone Member of McGrain (1976) of the Lower Pennsylvanian Caseyville Formation. The brown asphaltic sandstone part of the Kyrock ranges in thickness from 3 to 27 m (McGrain, 1976). The sample contained quartz, feldspar, and kaolinite. A trace of illite, but no smectite, was indicated by X-ray diffraction. The available hydrocarbon averaged 7.6 weight percent in these samples. Data for the two samples from Kentucky are in tables 1, 2, and 4.

New Mexico

One sample (NM–1) of tar sand was obtained from the Triassic Santa Rosa Sandstone in Guadalupe County, N. Mex. The sandstone is asphaltic in an area of about 3,600 ha north of Santa Rosa (Foster, 1965); its saturated zones range in thickness from 3 to 18 m. The brown sandstone was composed of quartz, kaolinite, and traces of feldspar, dolomite, and illite. This one sample contained almost 7 weight percent available hydrocarbon. Data on this sample are in tables 1, 2, and 4.

Oklahoma

Two samples (OK–1 and OK–3) of asphaltic sandstone were obtained from Murray County, Okla., and three samples (OK–2, OK–4, and OK–5) came from Carter County. Sample OK–1 was from a sandstone bed in the Upper Cambrian Arbuckle Limestone. It consisted predominantly of quartz and contained traces of feldspar and several clay minerals. The other sample (OK–3) from Murray County was from the Ordovician Viola Limestone and was composed of calcite, some quartz, and traces of feldspar and illite.

Two of the Carter County samples (OK–2 and OK–5) were from rocks of the Pennsylvanian Morrowan Series. Both of these sandstone samples and a third sandstone sample (OK–4 from the Pontotoc Group) contained quartz, a minor amount of kaolinite, and a trace of illite. No smectite was detected in any of these samples. The available hydrocarbon of the Oklahoma samples ranged from 4.52 to 26.62 weight percent. Data on the five Oklahoma samples are in tables 1, 2, and 5.

Texas

A sample (TX–1) containing very heavy oil was obtained from the Upper Cretaceous San Miguel Formation in the Eagle Pass area, Maverick County, Tex. It was a medium-gray, fine-grained sandstone containing quartz, some feldspar, some kaolinite, and a trace of mixed-layer clay.

A second sample (TX–2) contained natural bitumen and was from the Upper Cretaceous Anacacho Limestone in the Uvalde area, Uvalde County. The Anacacho is 122–152 m thick, and its asphalt-bearing zone ranges from 3 to 23 m in thickness (Evans, 1975). This sample was almost all calcite and contained traces of quartz, dolomite, kaolinite, and illite. The available hydrocarbon contents in samples TX–1 and TX–2 were 11.42 and 6.63 weight percent, respectively. Data for these samples are in tables 1, 2, and 6.

Utah

Four samples containing bitumen were obtained from two deposits in Utah. Samples UT–2 and UT–3 were from light-brown sandy marls of the Eocene Green River Formation in the Sunnyside deposit, near Sunnyside, Carbon County (Cashion, 1964). They were composed of quartz, feldspar, carbonate minerals, and traces of illite, kaolinite, and pyrite. There is no indication of smectite. The available hydrocarbon in these two samples averaged 12.8 weight percent.

Samples UT–4 and UT–5 were from the Asphalt Ridge NW deposit near Vernal in Uintah County. The bitumen occurs at the contact between the Upper Cretaceous Rim Rock Sandstone of Walton (1944) of the Mesaverde Group and the overlying lower Tertiary Duchesne River Formation (Kayser, 1966). The bitumen deposit is a little more than 30 m thick. Both samples were light-gray to buff, very fine grained to fine-grained sandstone. UT–4 consisted predominantly of quartz and contained some feldspar and traces of kaolinite and illite. UT–5 had nearly equal amounts of quartz and feldspar and contained dolomite, pyrite, and illite and a trace of kaolinite. The available hydrocarbon in these two samples also averaged 12.8 weight percent.

Sample UT–1 was heavy oil from the Rozel Point oil field, Box Elder County, and UT–6 was gilsonite from the Bonanza mine in Uintah County. Data on all six Utah samples are in tables 1, 2, and 7.

Wyoming

Bitumen-bearing sandstone has been mined and processed intermittently since 1962 at the Trapper Canyon deposits in Big Horn County, Wyo. The earliest reference to these deposits was by Darton (1906). The bitumen-bearing sandstone is part of the Pennsylvanian Tensleep Sandstone, which was named by Darton (1904) for outcrops of sandstone east of Ten Sleep, Wyo. The Tensleep Sandstone ranges in thickness from about 30 m at a point 16 km northwest of the Trapper Canyon bitumen deposits to about 61 m at a point 16 km southeast of them. The lower part of the Tensleep consists of minor amounts of light-gray, fine- to medium-grained crystalline dolomite interbedded with red and green mudstone beds in a white to gray sandstone. The upper part of the formation is composed of very fine grained to fine-grained, well-sorted quartz sandstone. This part is thickly bedded and finely laminated eolian sandstone, which exhibits large-scale crossbedding. The bitumen occurs within the crossbedded eolian sandstone, which is 3–12 m thick.

The bitumen-bearing sandstone underlies a total area of about 27 ha (Hosterman and others, 1989). Drilling by Bronco Oil and Gas Company through the bitumen-bearing sandstone showed it to be as thick as 10 m and to underlie 2.7–23.5 m of overburden (Ver Ploeg and De Bruin, 1985). Where it is exposed in the pit from which sample WY–1 came, the bitumen-bearing sandstone is as thick as 7 m. Drill cores taken by Ver Ploeg and De Bruin (1985) indicated that the deposits have a bitumen saturation ranging from 7.9 to 15.1 weight percent.

The sample of Tensleep Sandstone reservoir rock (WY–1) consisted mostly of quartz; small amounts of feldspar and calcite and a trace of dolomite were present. Clay minerals were not present. The available hydrocarbon content of the sample was 15.35 weight percent. Data for this sample are in tables 1, 2, and 6.

Canada

Sample AB–8 was from the Lower Cretaceous McMurray Formation from Alberta, Canada. The sample was a medium-brown, fine-grained sandstone containing quartz, feldspar, pyrite, kaolinite, and illite. Smectite was not indicated by the XRD trace. The available hydrocarbon content for the sample was 14.73 weight percent (table 2). The hydrocarbon components have not been determined. The mineralogy of the reservoir rock and trace-element contents are in tables 1 and 8.

Trinidad and Tobago

One sample (TT–1) of Trinidad's reservoir rock containing heavy oil was analyzed for comparison with the samples from the United States. This sample was taken from an outcrop in the lower part of the Tertiary Morne L'Enfer Formation in the Parrylands area, St. Patrick County. The gray, fine-grained sandstone was composed of quartz, feldspar, and clay minerals. The clay minerals were kaolinite, illite, chlorite, and mixed-layer clay. The available hydrocarbon content was 11.96 weight percent. Data for this sample are in tables 1, 2, and 8.

Venezuela

One sample (VE–4) of Venezuela's reservoir rock containing heavy oil was also analyzed for comparison. This sample was taken from the Oficina Formation in the Orinoco oil belt. The gray, medium-grained sandstone contained quartz and trace amounts of feldspar and clay minerals (kaolinite, illite, and smectite). Kaolinite was the dominant clay mineral. The available hydrocarbon content was 17.29 weight percent. In addition to the one sample of reservoir rock, three samples of heavy oil (VE–1, 2, and 3) were analyzed for their hydrocarbon and trace-element contents. These data and the reservoir rock mineralogy are in tables 1, 2, and 8.

DISCUSSION

The reservoir rock and sediment residue samples richest in trace elements were the four samples from California (table 9). The trace-element distribution in the reservoir rock samples shows that 35 of the 38 trace elements detected were most abundant in the four California samples. In the sediment residue samples, 33 trace elements were most abundant in the four California samples. This concentration of trace elements was probably due to the low quartz content of the California samples and to the presence of heulandite, cristobalite, siderite, and pyrite.

In the reservoir rock and sediment residue samples, trace elements were scarcest in the five Oklahoma samples. In the reservoir rock samples, 27 of 38 trace elements were least abundant in the five Oklahoma samples. In the sediment residue samples, 25 trace elements were least abundant in the five Oklahoma samples. This scarcity of trace elements was probably due to the high quartz content of four of the Oklahoma samples and to the high calcite content of the fifth sample.

The trace-element distribution in the available hydrocarbon differs from that in the reservoir rock and sediment residue. The maximum and minimum contents of trace elements in bitumen or heavy oil listed in table 9 do not include the values for the heavy oil and gilsonite from Utah or the heavy oil samples VE–1, 2, and 3 from Venezuela because we lack the chemical and mineralogical data for the reservoir rock of these hydrocarbons. The bitumen in the four Utah samples for which we have reservoir rock and sediment residue data contains the highest concentrations of trace elements among all hydrocarbon samples compared. Nineteen of the 38 trace elements detected were most abundant in the available hydrocarbon of these four Utah samples. No pattern in trace-element scarcity is obvious for the hydrocarbon samples.

REFERENCES CITED

Aruscavage, P.J., and Crock, J.G., 1987, Atomic absorption methods: U.S. Geological Survey Bulletin 1770–C, 6 p.

Aruscavage, P.J., and Moore, Roosevelt, 1989, The determination of mercury in whole coal by cold-vapor atomic absorption spectrometry, *in* Golightly, D.W., and Simon, F.O., eds., Methods for sampling and inorganic analysis of coal: U.S. Geological Survey Bulletin 1823, p. 55–57.

Baedecker, P.A., 1976, SPECTRA; Computer reduction of gamma-ray spectroscopic data, *in* Taylor, R.E., ed., Advances in obsidian glass studies: Park Ridge, N.J., Noyes Press, p. 334–349.

Cashion, W.B., 1964, Other bituminous substances, *in* Mineral and water resources of Utah: U.S. Congress, 88th, 2d session, Senate Committee on Interior and Insular Affairs, Committee Print, p. 63–68.

Darton, N.H., 1904, Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range: Geological Society of America Bulletin, v. 15, p. 379–448.

———1906, Geology of the Bighorn Mountains: U.S. Geological Survey Professional Paper 51, 129 p.

Dibblee, T.W., Jr., 1966, Geology of the central Santa Ynez Mountains, Santa Barbara County, California: California Division of Mines and Geology Bulletin 186, 99 p.

Evans, T.J., 1975, Native bituminous materials in Texas: Texas University, Bureau of Economic Geology, Mineral Resource Circular 57, 18 p.

Foster, R.W., 1965, Asphalt and other bitumens, *in* Mineral and water resources of New Mexico: U.S. Congress, 89th, 1st session, Senate Committee on Interior and Insular Affairs, Committee Print, p. 116–118, 126–130.

Hosterman, J.W., and Dulong, F.T., in press, A computerized system for semiquantitative mineral analysis by X-ray diffraction: Clays and Clay Minerals, Special Report.

Hosterman, J.W., Hill, R.H., Kulik, D.M., and Gese, D.D., 1989, Mineral resources of the Medicine Lodge, Alkali Creek, and Trapper Creek Wilderness Study Areas, Big Horn County, Wyoming: U.S. Geological Survey Bulletin 1756–A, 18 p.

Kayser, R.B., 1966, Bituminous sandstone deposits, Asphalt Ridge, Uintah County, Utah: Utah Geological and Mineralogical Survey Special Studies 19, 62 p.

Kinter, E.B., and Diamond, Sidney, 1956, A new method for preparation and treatment of oriented-aggregate specimens of soil clays for X-ray diffraction analysis: Soil Science, v. 81, no. 2, p. 111–120.

Lichte, F.E., Golightly, D.W., and Lamothe, P.J., 1987, Inductively coupled plasma-atomic emission spectrometry: U.S. Geological Survey Bulletin 1770–B, 10 p.

McGrain, Preston, 1976, Tar sands (rock asphalt) of Kentucky—A review: Kentucky Geological Survey, ser. 10, Report of Investigations 19, 16 p.

Palmer, C.A., and Baedecker, P.A., 1989, The determination of 41 elements in whole coal by instrumental neutron activation analysis, *in* Golightly, D.W., and Simon, F.O., eds., Methods for sampling and inorganic analysis of coal: U.S. Geological Survey Bulletin 1823, p. 27–34.

Priestaf, Iris, 1979, Natural tar seeps and asphalt deposits of Santa Barbara County: California Geology, v. 32, no. 8, p. 163–169.

Rait, Norma, and Aruscavage, P.J., 1989, The determination of forms of sulfur in coal, *in* Golightly, D.W., and Simon, F.O., eds., Methods for sampling and inorganic analysis of coal: U.S. Geological Survey Bulletin 1823, p. 63–68.

U.S. Defense Intelligence Agency, 1972, Geopolitical data elements and related features, 29 September 1972: U.S. Defense Intelligence Agency Manual DIAM 65–18, variously paged.

U.S. National Bureau of Standards, 1979, Counties and county equivalents of the States of the United States and the District of Columbia: U.S. National Bureau of Standards Federal Information Processing Standards (FIPS) Publication 6–3, 44 p.

Ver Ploeg, A.J., and De Bruin, R.H., 1985, Trapper Canyon tar sand deposit, Big Horn County, Wyoming; An exhumed stratigraphic oil trap: Wyoming Geological Survey Report of Investigations 30, 34 p.

Walton, P.T., 1944, Geology of the Cretaceous of the Uinta Basin, Utah: Geological Society of America Bulletin, v. 55, no. 1, p. 91–130.

Williams, D.A., Noger, M.C., and Gooding, P.J., 1982, Investigation of subsurface tar-sand deposits in western Kentucky: Kentucky Geological Survey, ser. 11, Information Circular 7, 25 p.

Wilson, S.A., Kane, J.S., Crock, J.G., and Hatfield, D.B., 1987, Chemical methods of separation for optical emission, atomic absorption spectrometry, and colorimetry: U.S. Geological Survey Bulletin 1770–D, 14 p.

TABLES 1–9

Table 1. Mineral content of the reservoir rock samples as determined semiquantitatively by X-ray diffraction

[All values in weight percent. Mixed, mixed-layer clay; dashes (--), not present; tr, trace. No reservoir rock samples were available for heavy oils UT–1 (US49003–1), VE–1 (VE02–1), VE–2 (VE16–1), and VE–3 (VE16–2) or for gilsonite UT–6 (US49047–3)]

Sample nos.		Quartz	Cristobalite	Feldspar	Calcite	Dolomite	Siderite	Pyrite	Heulandite	Kaolinite	Illite	Mixed	Chlorite	Smectite
CA-1	US06083-1	61.6	10.0	11.6	--	2.9	--	5.9	--	2.0	2.2	--	--	3.8
CA-2	US06083-2	63.3	11.0	15.2	--	--	--	6.5	--	--	1.6	--	--	2.4
CA-3	US06083-3	20.8	--	10.8	27.7	1.9	10.5	8.0	17.5	--	.9	--	--	1.9
CA-4	US06079-1	76.4	--	22.1	--	--	--	--	--	.3	.6	--	--	.6
KY-1	US21141-1	89.0	--	4.0	--	--	--	--	--	6.9	.1	--	--	--
KY-2	US21061-1	80.4	--	7.4	--	--	--	--	--	11.6	.6	--	--	--
NM-1	US35019-1	89.1	--	2.5	--	1.6	--	--	--	6.7	.1	--	--	--
OK-1	US40099-1	94.9	--	1.5	--	--	--	--	--	1.2	1.5	0.9	--	--
OK-2	US40019-1	95.5	--	--	--	--	--	--	--	4.4	.1	--	--	--
OK-3	US40099-2	4.2	--	1.5	93.8	--	--	--	--	--	.5	--	--	--
OK-4	US40019-2	96.5	--	--	--	--	--	--	--	3.3	.2	--	--	--
OK-5	US40019-3	96.0	--	--	--	--	--	--	--	4.0	tr	--	--	--
TX-1	US48323-1	81.6	--	8.3	--	--	--	--	--	9.9	--	.2	--	--
TX-2	US48463-1	1.5	--	--	96.5	.5	--	--	--	.8	.7	--	--	--
UT-2	US49007-1	48.3	--	32.7	3.0	15.5	--	--	--	--	.5	--	--	--
UT-3	US49007-2	65.8	--	24.0	--	4.0	--	1.3	--	.9	4.0	--	--	--
UT-4	US49047-1	91.3	--	8.2	--	--	--	--	--	.4	.1	--	--	--
UT-5	US49047-2	40.4	--	35.5	--	10.4	--	4.7	--	1.9	7.1	--	--	--
WY-1	US56003-1	83.4	--	5.9	8.9	1.8	--	--	--	--	--	--	--	--
AB-8	CA01-8	82.2	--	7.1	--	--	--	2.2	--	7.5	1.0	--	--	--
TT-1	TD09-1	68.5	--	18.5	--	--	--	--	--	5.8	3.3	1.9	2.0	--
VE-4	VE00-1	94.5	--	1.5	--	--	--	--	--	3.0	.3	--	--	.7

Table 2. Composition of natural bitumen, heavy oil, and gilsonite

[Available hydrocarbon is given as a weight percentage of the whole sample; the other four materials are given as weight percentages of the available hydrocarbon. Dashes (--), not determined]

Sample nos.		Available hydrocarbon	Asphaltene	Saturated hydrocarbon	Aromatic hydrocarbon	Polar compounds
CA-1	US06083-1	14.37	18.9	16.9	38.4	25.8
CA-2	US06083-2	2.80	24.7	30.9	16.0	28.4
CA-3	US06083-3	3.87	22.2	9.7	13.2	54.9
CA-4	US06079-1	12.34	25.6	21.4	30.3	22.6
KY-1	US21141-1	8.24	24.6	20.4	35.1	19.9
KY-2	US21061-1	7.02	40.3	13.0	24.5	22.2
NM-1	US35019-1	6.95	46.9	20.2	22.3	10.6
OK-1	US40099-1	4.52	25.7	8.6	30.6	35.2
OK-2	US40019-1	17.56	80.9	5.8	5.2	8.1
OK-3	US40099-2	5.69	31.6	15.2	26.2	27.0
OK-4	US40019-2	10.88	81.7	4.4	4.3	9.6
OK-5	US40019-3	26.62	68.8	7.9	8.0	15.4
TX-1	US48323-1	11.42	40.1	5.3	37.7	17.0
TX-2	US48463-1	6.63	--	--	--	--
UT-1	US49003-1	100.00	29.9	2.7	52.5	15.0
UT-2	US49007-1	10.56	80.2	2.9	5.7	11.2
UT-3	US49007-2	15.12	30.2	21.8	31.5	16.5
UT-4	US49047-1	11.38	33.4	17.3	17.2	32.1
UT-5	US49047-2	14.27	--	--	--	--
UT-6	US49047-3	100.00	49.5	4.9	19.1	26.5
WY-1	US56003-1	15.35	15.5	7.5	41.5	35.5
AB-8	CA01-8	14.73	--	--	--	--
TT-1	TD09-1	11.96	19.7	11.9	41.2	27.2
VE-1	VE02-1	100.00	22.0	19.6	44.5	13.9
VE-2	VE16-1	100.00	22.8	20.0	46.4	10.8
VE-3	VE16-2	100.00	20.0	22.0	46.3	11.6
VE-4	VE00-1	17.29	--	--	--	--

Table 3. Trace-element content of reservoir rock, sediment residue, and bitumen samples from California (CA)

[All values in parts per million. Dashes (--), not determined. The first 29 elements were determined by instrumental neutron activation analysis; the next 4 elements (Cu, Hg, Pb, V) were determined by atomic absorption spectrometry; the next 4 elements (Mo, Nb, Y, Li) were determined by atomic emission spectroscopy; and the last element (S) was determined by thermal combustion infrared spectroscopy. Underlined values have an error less than ±10 percent; normal type indicates errors of ±10–30 percent; and **bold** type indicates errors greater than ±30 percent. There was not enough CA–2 bitumen to be analyzed]

	CA-1 (US06083-1)			CA-2 (US06083-2)		CA-3 (US06083-3)			CA-4 (US06C79-1)		
	Reservoir rock	Sediment residue	Bitumen	Reservoir rock	Sediment residue	Reservoir rock	Sediment residue	Bitumen	Reservoir rock	Sediment residue	Bitumen
Na	7,000	8,700	14	20,300	19,200	13,800	11,500	1,210	19,400	19,300	73
K	13,900	12,300	55	19,700	19,400	11,100	11,400	1,000	28,100	28,000	134
Sc	13.7	10.72	.083	14.13	12.5	7.69	7.51	1.39	1.75	1.69	.143
Cr	107	81.9	1.23	170	151	343	327	44.3	78.5	43.3	7.86
Fe	3,100	23,700	114	31,200	28,000	16,700	14,600	2,370	4,150	23,700	2,860
Co	8.3	8.11	.155	7.8	6.81	5.61	7.86	3.67	1.20	3.2[illegible]	1.45
Ni	75	< 31	55	86	57	192	148	228	20.1	< 20	132
Zn	92	72	1.33	200	166	258	244	64.6	14.7	18.6	7.5
As	1.51	6.18	.039	16.1	15.1	14.4	13.1	3.96	2.34	2.3[illegible]	3.15
Se	1.9	< 0.3	.47	5.7	5.5	42.1	21.6	40.0	< 1	< .8	1.84
Br	24.0	1.68	1.92	40.9	31.3	93	70.1	40.7	.84	5.5	2.38
Rb	76	66	< 9	85	73	48	46	< 70	74	84	< 9
Sr	57	200	< 24	268	250	1,240	1,240	290	269	300	7.9
Sb	.49	.43	< .01	2.79	2.86	8.9	8.3	1.40	.46	.5[illegible]	.105
Cs	4.16	3.4	.036	4.1	3.52	2.48	2.00	.256	1.34	1.27	.043
Ba	296	400	< 30	680	590	570	560	58	950	960	4.7
La	7.7	19.2	.123	37.5	35.0	15.0	15.7	3.04	13.0	13.5	.124
Ce	12.3	33.1	.26	58.1	56.0	16.7	17.1	3.94	20.8	21.1	.45
Nd	< 8	8.7	< 4	< 15	20	< 15	< 15	< 22	< 7	5.6	< 7
Sm	1.65	3.66	.019	6.08	5.53	3.42	2.84	.615	2.10	2.10	.036
Eu	.376	.78	.019	1.20	1.09	.73	.80	.188	.568	.52[illegible]	.013
Tb	.239	.41	< .008	.772	.63	.525	.46	.127	.235	.197	.005
Yb	1.75	1.65	< .06	3.27	3.07	2.34	2.53	.55	.98	.93	< .03
Lu	.243	.285	< .009	.55	.55	.39	.47	< .04	.121	.17[illegible]	< .02
Hf	2.69	2.40	.015	4.84	4.22	1.58	1.64	.176	2.42	2.50	.024
Ta	.555	.49	< .02	.88	.74	.352	.35	.036	.399	.30	.024
W	1.02	1.15	< .02	2.1	1.16	< .8	.72	< .2	< .9	< 2	< .02
Th	6.26	6.08	.045	10.04	8.68	3.42	3.04	.745	3.27	3.53	.122
U	3.17	2.5	.086	13.1	9.8	24.4	25.5	7.1	2.33	2.06	1.72
Cu	19	20	9.3	47	45	80	93	--	2.2	< 2	7.3
Hg	< .005	< .005	< .005	<.005	< .005	.050	.010	--	< .005	.03[illegible]	< .005
Pb	3.2	13	3.3	8.4	11	5.4	7.5	--	5.9	14	6.6
V	170	150	160	160	100	450	570	--	16	17	63
Mo	3.7	1.9	2.0	18	23	37	54	--	2.3	1.2	10
Nb	7.6	6.2	2.9	9.6	9.1	4.3	2.9	--	3.3	3.1	4.6
Y	11	14	7.9	35	30	29	35	--	8.0	8.9	7.2
Li	34	37	18	22	24	8.1	11	--	6.9	8.0	9.9
S	3,400	15,000	9,900	20,000	20,000	26,000	18,000	--	4,200	1,900	22,000

Table 4. Trace-element content of reservoir rock, sediment residue, and bitumen samples from Kentucky (KY) and New Mexico (NM)

[All values in parts per million. The first 29 elements were determined by instrumental neutron activation analysis; the next 4 elements (Cu, Hg, Pb, V) were determined by atomic absorption spectrometry; the next 4 elements (Mo, Nb, Y, Li) were determined by atomic emission spectroscopy; and the last element (S) was determined by thermal combustion infrared spectroscopy. Underlined values have an error less than ±10 percent; normal type indicates errors of ±10–30 percent; and **bold** type indicates errors greater than ±30 percent]

	KY-1 (US21141-1)			KY-2 (US21061-1)			NM-1 (US35019-1)		
	Reservoir rock	Sediment residue	Bitumen	Reservoir rock	Sediment residue	Bitumen	Reservoir rock	Sediment residue	Bitumen
Na	590	400	7.8	56.6	73.4	6.6	67.6	105	11
K	4,420	2,600	128	950	350	50	390	390	97
Sc	1.09	.728	.062	.82	.383	.049	.679	.680	.053
Cr	47.0	45.0	1.61	12.2	6.6	4.16	9.9	10.7	1.02
Fe	3,270	2,170	365	750	520	340	2,020	1,630	200
Co	1.19	.64	.452	.38	.519	.688	1.05	.89	.850
Ni	9.4	< 12	70	9.8	< 10	72	< 3	< 11	12.2
Zn	7.5	7.3	1.21	6.5	6.3	1.87	3.1	5.0	1.86
As	.43	.21	.053	.52	.45	1.95	.91	.78	.84
Se	< .3	< .6	.17	< .1	< .5	.18	< .6	< .7	.124
Br	.48	.38	.540	.37	.30	.70	.21	.251	.439
Rb	11.9	7.3	< 5	3.8	< 6	< 4	< 2	< 8	< 3
Sr	31	< 80	< 2	< 15	< 50	< 3	34	< 80	< 6
Sb	.151	.116	.019	.134	.100	.102	.152	.140	.036
Cs	.302	.171	.022	.137	.113	< .05	.087	.119	.030
Ba	79	90	< 1	36	47	< 2	27	37	< 10
La	8.87	6.47	.770	5.77	3.93	.436	8.83	7.66	.533
Ce	14.8	11.8	1.94	8.1	8.2	1.07	16.3	14.9	1.15
Nd	< 4	3.4	< 2	< 4	2.6	< 2	< 4	4.2	< 1
Sm	1.54	1.365	.140	1.010	.673	.075	1.69	1.433	.114
Eu	.289	.245	.040	.171	.122	.020	.325	.256	.034
Tb	.169	.124	.017	.083	.075	.009	.293	.139	.025
Yb	.93	.69	.047	.452	.298	.028	1.41	.71	.055
Lu	.133	.125	.010	.067	.050	< .004	.189	.123	< .01
Hf	7.3	6.23	.031	2.02	1.09	.040	9.1	3.54	.031
Ta	.253	.222	.037	.122	< .1	< .02	.365	.261	.033
W	.23	.184	.023	.151	.13	< .01	.410	.21	.021
Th	1.97	1.54	.226	1.54	1.13	.210	2.71	1.87	.342
U	.70	.50	.153	.49	.29	.193	1.99	1.33	1.55
Cu	3.0	< 2	4.40	3.0	3.2	3.70	3.6	5.3	4.50
Hg	< .005	.010	< .005	< .005	< .005	< .005	< .005	< .005	< .005
Pb	< 3	5.4	5.10	< 3	7.5	9.10	5.6	11	13
V	20	4.1	150	16	3.3	210	7.7	5.2	42
Mo	1.3	< 1	< 1	1.9	< 1	< 1	< 1	< 1	< 1
Nb	2.6	1.9	5.80	1.7	< 1	< 1	3.7	2.6	5.20
Y	6.6	< 5	6.10	< 5	< 5	< 5	5.2	< 5	15
Li	6.8	5.3	24.0	< 5	< 5	< 5	< 5	< 5	18
S	2,400	110	16,000	2,300	1,470	22,000	3,600	980	17,000

Table 5. Trace-element content of reservoir rock, sediment residue, and bitumen samples from Oklahoma (OK)

[All values in parts per million. Dashes (--), not determined. The first 29 elements were determined by instrumental neutron activation analysis; the next 4 elements (Cu, Hg, Pb, V) were determined by atomic absorption spectrometry; the next 4 elements (Mo, Nb, Y, Li) were determined by atomic emission spectroscopy; and the last element (S) was determined by thermal combustion infrared spectroscopy. Underlined values have an error less than ±10 percent; normal type indicates errors of ±10–30 percent; and **bold** type indicates errors greater than ±30 percent]

	OK-1 (US40099-1)			OK-2 (US40019-1)			OK-3 (US40099-2)			OK-4 (US40019-2)			OK-5 (US40019-3)		
	Reservoir rock	Sediment residue	Bitumen	Reservoir rock	Sediment residue	Bitumen	Reservoir rock	Sediment residue	Bitumen	Reservoir rock	Sediment residue	Bitumen	Reservoir rock	Sediment residue	Bitumen
Na	49	85	39	87	112	16	147	124	19	138	112	118	50.4	93	11.8
K	1,010	900	190	750	450	66	330	1,460	300	2,090	1,500	210	320	< 900	80
Sc	.093	.090	.422	2.1	1.513	.140	.284	.639	.090	.953	.537	.361	1.27	.962	.174
Cr	1.45	1.37	2.92	64	60.4	5.57	2.02	5.4	1.84	8.8	3.9	4.26	51.2	30.6	5.05
Fe	320	230	460	3,200	1,340	460	1,330	8,200	500	760	600	1,220	1,310	1,180	640
Co	.430	.268	2.97	1.21	.91	1.56	.746	1.04	.702	.62	.418	.976	1.06	.82	2.18
Ni	3.3	< 8	63	14.4	< 16	111	< 4	< 15	108	14.8	< 15	116	21.1	< 14	101
Zn	< 2	< 2	2.46	8.2	6.0	2.75	2.3	5.5	2.73	34.2	17.3	68.6	5.2	7.7	4.90
As	.128	.058	1.62	7.9	6.79	2.47	2.28	17.1	.98	1.78	1.07	2.08	4.52	4.17	2.19
Se	.46	< .6	4.65	< .8	< .1	.83	< .3	< .5	.41	< .4	< .3	1.23	< .3	< .3	.47
Br	.79	.71	.78	.53	.260	.88	1.15	.515	1.07	1.05	.52	1.85	.44	.54	.85
Rb	3.6	3.6	< 6	5.0	< 9	< 15	< 2	6.8	< 7	8.1	5.9	< 17	2.3	< 7	< 5
Sr	< 8	< 60	9.3	< 25	< 70	< 6	333	560	< 26	20	< 70	9.8	< 20	< 70	< 3
Sb	.051	.048	.219	.22	.263	.073	.105	.153	.022	.183	.142	.087	.412	.20	.062
Cs	.07	.074	.050	.55	.30	.076	.062	.34	.102	.273	.167	.067	.185	.23	.046
Ba	27	36	15.5	37	61	< 3	17	30	< 27	80	51	9.3	< 24	< 40	2.7
La	1.13	1.18	4.04	16.7	10.44	1.32	1.99	4.40	.416	10.8	6.40	2.05	8.79	6.21	2.26
Ce	1.51	1.91	7.70	25.8	18.2	2.50	2.24	6.6	.70	19.2	11.8	4.71	14.2	10.9	3.92
Nd	< 2	< 3	< 16	< 12	6.8	< 6	< 2	< 8	< 3	< 6	4.9	< 6	< 3	5.6	< 3
Sm	.136	.143	.423	2.7	1.75	.165	.350	.814	.069	1.73	1.14	.351	1.51	1.15	.305
Eu	.025	.045	.102	.44	.292	.042	.072	.167	.022	.277	.172	.099	.222	.189	.063
Tb	.014	< .04	.061	.30	.172	.023	.054	.093	.012	.137	.116	.049	.212	.146	.039
Yb	.080	.084	.176	2.02	1.35	.050	.228	.393	.055	.536	.58	.110	1.44	1.08	.090
Lu	.013	.012	< .04	.26	.24	< .02	.030	.060	< .009	.072	.074	< .01	.213	.135	.017
Hf	.296	.354	.074	17.4	11.8	.117	.048	.34	.031	2.49	3.27	.121	14.2	7.4	.148
Ta	.085	< .1	.059	.47	.45	< .04	.023	< .1	< .01	.179	.19	.026	.399	.35	< .01
W	< .07	< .2	.071	.53	.46	.032	< .1	.25	< .03	.17	< .5	.031	.36	< .6	.020
Th	.238	.243	1.07	4.11	2.52	.535	.235	.83	.110	1.87	1.42	.687	2.59	1.96	.74
U	.50	.145	4.87	2.15	1.10	1.00	.84	.99	.27	.62	.43	.70	1.37	.77	.69
Cu	9.2	< 2	14	2.0	2.2	4.6	3.6	4.7	9.9	2.9	2.9	--	2.0	1.5	5.4
Hg	< .005	< .005	.040	< .005	< .005	< .005	< .005	< .005	< .005	< .005	< .005	--	< .005	< .005	< .005
Pb	< 3	< 3	5.9	< 3	5.4	< 2	< 3	3.3	2.5	11	11	--	5.6	3.9	3.60
V	10	2.7	210	67	28	60	5.1	13	170	44	6.6	--	53	14	380
Mo	< 1	< 1	1.9	1.1	< 1	< 1	2.9	< 1	< 1	1.5	< 1	--	< 1	< 1	< 1
Nb	< 1	< 1	< 1	5.6	5.3	< 1	< 1	< 1	< 1	1.6	1.1	--	3.7	3.3	1.8
Y	< 5	< 5	< 5	8.3	6.5	< 5	< 5	6.1	< 5	< 5	< 5	--	9.8	6.0	< 5
Li	< 5	< 5	< 5	5.9	6.2	< 5	< 5	< 5	5.5	5.9	5.2	--	< 5	< 5	6.1
S	1,200	420	14,000	3,400	920	10,000	940	9,000	14,000	3,600	400	--	3,300	450	23,000

Table 6. Trace-element content of reservoir rock, sediment residue, and bitumen samples from Texas (TX) and Wyoming (WY)

[All values in parts per million. Dashes (--), not determined. The first 29 elements were determined by instrumental neutron activation analysis; the next 4 elements (Cu, Hg, Pb, V) were determined by atomic absorption spectrometry; the next 4 elements (Mo, Nb, Y, Li) were determined by atomic emission spectroscopy; and the last element (S) was determined by thermal combustion infrared spectroscopy. Underlined values have an error less than ±10 percent; normal type indicates errors of ±10–30 percent; and **bold** type indicates errors greater than ±30 percent. There was not enough TX–2 reservoir rock left to be analyzed]

	TX-1 (US48323-1)			TX-2 (US48463-1)		WY-1 (US56003-1)		
	Reservoir rock	Sediment residue	Bitumen	Sediment residue	Bitumen	Reservoir rock	Sediment residue	Bitumen
Na	8,600	9,000	100	253	15.6	165	189	6.4
K	9,700	13,500	139	< 2,000	17.4	4,070	3,900	116
Sc	2.18	2.21	.103	.744	.016	.189	.165	.077
Cr	14.4	14.2	.640	11.4	1.20	2.34	1.7	1.94
Fe	5,290	5,150	408	4,440	142	660	838	217
Co	1.90	1.60	.284	.87	1.01	.46	.19	.714
Ni	< 12	< 16	29	< 14	56	4.6	< 14	45
Zn	13.7	11.8	14.0	3.4	2.95	1.75	5.4	1.62
As	3.23	2.74	.166	2.57	.86	2.45	2.10	1.22
Se	< .3	< .8	.170	< .7	.44	< .3	< .5	1.17
Br	4.29	2.10	13.8	.69	1.37	.41	.33	.75
Rb	38.6	34.3	< 4	< 11	< 4	8.3	8.2	< 6
Sr	58	120	5.7	370	< 11	48	55	4.3
Sb	.53	.61	.028	< .09	.033	.106	.133	.080
Cs	1.04	1.12	.034	< .08	< .03	.167	.20	.042
Ba	353	370	2.8	< 60	< 1	119	93	14.3
La	25.0	25.0	.585	4.88	.264	1.30	1.89	--
Ce	41.8	47.3	1.21	7.0	.62	2.4	3.27	--
Nd	< 10	< 21	< 2	< 5	< 2	< .6	< 5	< 120
Sm	4.05	4.43	.091	1.07	.081	.301	.264	.078
Eu	.75	.92	.028	.300	.033	.057	.056	.042
Tb	.365	.46	.016	.120	.017	.035	< .03	.016
Yb	1.45	1.58	.042	.389	.028	.231	.156	< .04
Lu	.190	.203	.008	.041	.008	.038	.017	< .2
Hf	6.49	7.7	.029	< .1	.019	1.07	.73	.066
Ta	.554	.67	.026	< .1	.015	.033	< .1	.027
W	< 1	< 2	.037	< .7	.035	.20	< .5	.031
Th	5.21	5.38	.167	.150	.039	.447	.51	.320
U	1.43	1.39	.256	< .4	.075	7.9	2.39	24.6
Cu	3.1	3.9	6.2	< 2	--	2.9	< 2	3.7
Hg	< .005	< .050	.050	< .005	--	< .005	< .005	< .005
Pb	9.2	12	5.6	< 3	--	< 3	3.3	2.0
V	24	20	97	9.0	--	19	< 2	130
Mo	3.1	< 1	16	< 1	--	9.4	3.7	35
Nb	6.8	6.3	7.3	< 1	--	< 1	< 1	< 1
Y	12	11	8.20	6.1	--	< 5	< 5	< 5
Li	18	18	29	< 5	--	< 5	< 5	< 5
S	9,200	2,800	69,000	1,300	--	8,200	1,100	52,000

Table 7. Trace-element content of reservoir rock, sediment residue, bitumen, heavy oil, and gilsonite samples from Utah (UT)

[All values in parts per million. Dashes (--), not determined. The first 29 elements were determined by instrumental neutron activation analysis; the next 4 elements (Cu, Hg, Pb, V) were determined by atomic absorption spectrometry; the next 4 elements (Mo, Nb, Y, Li) were determined by atomic emission spectroscopy; and the last element (S) was determined by thermal combustion infrared spectroscopy. Underlined values have an error less than ±10 percent; normal type indicates errors of ±10–30 percent; and **bold** type indicates errors greater than ±30 percent. There were not enough UT–4 and UT–5 reservoir rocks left to be analyzed]

	UT-1 (US49003-1)	UT-2 (US49007-1)			UT-3 (US49007-2)			UT-4 (US49047-1)		UT-5 (US49047-2)		UT-6 (US49047-3)
	Heavy oil	Reservoir rock	Sediment residue	Bitumen	Reservoir rock	Sediment residue	Bitumen	Sediment residue	Bitumen	Sediment residue	Bitumen	Gilsonite
Na	301	23,200	23,600	1,270	20,900	24,000	45	259	46	27,400	106	46.7
K	< 30	18,800	14,600	1,390	17,800	24,000	215	2,600	77	23,000	377	< 130
Sc	.005	4.00	4.15	3.06	2.70	2.94	.88	.470	.098	3.13	.772	.031
Cr	.56	9.3	7.9	9.2	11.4	11.10	5.71	8.5	1.46	10.5	6.27	.77
Fe	41.1	7,810	8,040	7,120	5,500	6,600	840	1,800	1,360	7,790	1,050	200
Co	1.76	3.34	3.35	3.98	3.75	2.23	6.4	1.99	2.7	3.48	11.6	37.9
Ni	20.7	< 5	< 21	44	< 11	< 21	58	< 13	67	< 21	61	195
Zn	1.86	23.4	21.7	49.9	10.1	10.4	3.76	7.4	6.9	29.0	6.3	3.4
As	1.73	< .6	< 2	.95	4.34	3.01	2.87	10.3	8.66	11.7	22.0	14.3
Se	.28	< .6	< .9	.38	< .3	< 1	1.45	< .3	3.91	< .4	< .2	< .4
Br	5.34	1.40	1.36	4.57	.83	2.6	.530	.51	.82	.91	.99	.42
Rb	< 19	53	50	< 10	70	71	< 5	8.4	< 5	68	< 14	< 5
Sr	< 3	290	270	103	175	170	6.0	< 50	< 15	200	8.1	< 70
Sb	< .03	.196	.221	.173	.381	.310	.20	.283	.140	.72	.48	.51
Cs	< .009	.79	.89	.225	1.13	1.16	.078	.308	.037	1.05	.112	< .05
Ba	< 2	522	520	71	590	690	18.3	125	6.1	590	14.7	< 21
La	< .03	19.1	20.7	14.8	20.6	17.1	7.16	6.67	.144	16.9	13.5	.138
Ce	< .1	36.4	39.8	28.8	34.5	29.7	16.1	9.5	.85	27.7	22.8	< .3
Nd	< 6	< 8	16	< 10	< 11	9.1	< 8	5.2	< 5	11.9	< 9	< 2
Sm	.007	3.55	4.09	1.91	2.87	2.67	.699	1.06	.084	2.46	< .5	.018
Eu	.006	.733	.75	.529	.552	.520	.219	.196	.039	.502	.332	< .01
Tb	< .004	.382	.45	.346	.267	.31	.109	.105	.030	.232	.157	< .02
Yb	< .05	1.76	1.99	1.32	1.03	1.21	.309	.489	.134	1.25	.45	< .04
Lu	< .009	.239	.239	.172	.142	.148	.048	.066	< .008	.151	.083	< .007
Hf	< .007	5.25	4.42	.409	4.31	3.83	.114	1.24	.029	4.65	.215	< .04
Ta	< .008	.352	.27	.402	.624	.38	.121	< .1	< .01	.49	.219	< .04
W	.336	< .9	< 2	.51	< .9	< 2	.109	< .6	< .01	< 2	.256	< .09
Th	< .009	5.30	6.17	3.38	4.52	4.06	2.13	1.05	.092	3.86	3.57	< .06
U	< .1	1.13	.95	2.88	1.92	1.26	2.53	1.10	2.11	1.5	1.90	< .09
Cu	48	3.3	< 2	--	5.0	3.6	18	5.0	8.3	6.5	8.1	< 2
Hg	< .005	< .005	< .005	--	< .005	< .005	< .005	< .005	< .005	< .005	< .005	< .005
Pb	< 2	10	11.0	--	11	13	8.8	6.6	3.8	17	7.3	< 3
V	< 10	23	16	--	23	17	95	4.1	25	20	48	4.2
Mo	85	< 1	< 1	--	< 1	< 1	1.9	3.8	27	< 1	2.3	5.6
Nb	< 1	3.4	3.6	--	6.6	5.3	23	< 1	1.1	5.0	6.2	< 1
Y	< 5	16	16	--	8.4	7.4	22	6.2	9.9	8.4	13	< 5
Li	15	< 5	< 5	--	< 5	< 5	7.1	5.6	8.0	< 5	< 5	< 5
S	10,000	590	420	--	2,000	2,600	18,000	5,900	6,700	4,500	11,000	5,400

Table 8. Trace-element content of reservoir rock, sediment residue, bitumen, and heavy oil samples from Canada (AB), Trinidad and Tobago (TT), and Venezuela (VE)

[All values in parts per million. Dashes (--), not determined. The first 29 elements were determined by instrumental neutron activation analysis; the next 4 elements (Cu, Hg, Pb, V) were determined by atomic absorption spectrometry; the next 4 elements (Mo, Nb, Y, Li) were determined by atomic emission spectroscopy; and the last element (S) was determined by thermal combustion infrared spectroscopy. Underlined values have an error less than ±10 percent; normal type indicates errors of ±10–30 percent; and **bold** type indicates errors greater than ±30 percent. There was not enough VE–4 reservoir rock left to be analyzed]

	AB-8 (CA01-8)			TT-1 (TD09-1)			VE-1 (VE02-1)	VE-2 (VE16-1)	VE-3 (VE16-2)	VE-4 (VE00-1)	
	Reservoir rock	Sediment residue	Bitumen	Reservoir rock	Sediment residue	Bitumen	Heavy oil	Heavy oil	Heavy oil	Sediment residue	Heavy oil
Na	273	522	39.3	13,900	10,800	21.4	33.4	471	130	420	71.6
K	3,970	5,800	104	17,000	12,100	49.6	< 6	31	8.6	3,500	44.5
Sc	.548	1.79	.207	3.94	2.92	.279	.003	.002	.0004	1.388	.071
Cr	3.46	11.1	2.96	15.8	14	1.24	.44	3.59	.127	5.9	.94
Fe	1,970	8,780	530	9,100	4,550	624	10	33.2	2.6	3,540	226
Co	1.88	3.86	5.36	5.19	3.75	7.06	.610	.307	.091	1.18	.544
Ni	16.7	< 16	74	23	< 22	118	85	107	27	< 16	89
Zn	3.5	11.8	2.38	39.5	23.3	4.69	.88	1.02	.15	15.0	8.3
As	1.27	2.50	.68	4.4	2.7	.271	.159	.140	.038	.93	.324
Se	< .4	< .7	.59	< .3	< .4	.69	.51	.51	.156	< .7	.46
Br	.36	.42	.45	.66	.76	.295	.403	10.0	1.98	< .6	.98
Rb	11.2	20.0	< 12	58	37	< 4	< 15	< 40	< 9	12.2	< 14
Sr	25	< 80	3.2	157	136	13.9	< 10	9.5	< 18	< 110	< 30
Sb	.076	.100	.093	.44	.435	.032	< .05	.025	.012	.106	.037
Cs	.171	.41	.048	1.52	.95	.026	.014	< .01	.006	.33	.023
Ba	169	280	4.4	455	369	4.3	< 6	< 5	< 40	114	< 50
La	5.51	10.4	1.35	22.3	21.3	.823	< .02	< .05	< .02	4.61	.635
Ce	10.32	19.4	2.68	39	39.5	1.79	< .1	< .1	< .04	8.4	1.16
Nd	< 3	< 13	< 7	< 11	13.9	< 1	< 3	< 10	< 2	7.6	< 4
Sm	.888	1.70	.178	4.81	4.22	.138	< .002	< .005	< .002	.894	.103
Eu	.169	.301	.050	.96	.79	.037	.015	.007	.005	.152	.034
Tb	.092	.136	.032	.47	.47	.027	< .008	< .006	< .003	.100	.010
Yb	.311	.82	< .08	1.60	1.83	.064	< .06	< .1	< .04	.60	< .06
Lu	.035	.129	< .03	.199	.229	.010	< .01	< .03	< .007	.081	< .02
Hf	.87	2.54	.088	2.66	7.8	.035	< .009	< .008	< .003	3.89	.091
Ta	.144	.28	.042	.47	.59	.041	< .02	< .02	< .008	.72	.025
W	.25	< 14	11.4	< .8	< 2	.021	.037	< .07	< .03	1.33	.476
Th	1.07	2.48	.373	4.88	5.39	.235	.014	< .009	< .003	1.68	.201
U	.39	.58	< .1	1.43	1.32	.258	< .08	< .2	< .1	.74	.34
Cu	< 2	4.4	< 3	5.4	3.5	15.0	8.6	--	5.0	10.0	24
Hg	< .005	< .005	< .005	< .005	< .005	< .005	< .005	--	< .005	< .005	< .005
Pb	< 3	11	3.2	11	12	6.4	< 2	--	3.0	11	4.3
V	38	11	260	56	25	230	530	--	510	13	470
Mo	2.1	< 1	11	< 1	< 1	< 1	1.9	--	1.8	< 1	1.4
Nb	1.3	3.1	1.2	5.1	6.0	19	< 1	--	< 1	8.5	1.9
Y	< 5	< 5	< 5	15	9.6	20	< 5	--	< 5	< 5	< 5
Li	6.2	14	8.5	13	11	23	< 5	--	< 5	5.2	6.4
S	7,200	8,900	51,000	3,400	670	20,000	83,000	--	41,000	1,100	34,000

Table 9. Maximum and minimum trace-element contents of reservoir rock, sediment residue, and bitumen or heavy oil samples from all deposits

[All values in parts per million. Underlined values have an error less than ±10 percent; normal type indicates errors of ±10–30 percent; and **bold** type indicates errors greater than ±30 percent. The error level is included in determining the minimum values]

	Reservoir rock				Sediment residue				Bitumen or heavy oil[1]			
	Maximum		Minimum		Maximum		Minimum		Maximum		Minimum	
Na	23,200	UT-2	49	OK-1	27,400	UT-5	73.4	KY-2	1,270	UT-2	6.4	WY-1
K	28,100	CA-4	320	OK-5	28,000	CA-4	350	KY-2	1,390	UT-2	17.4	TX-2
Sc	14.13	CA-2	.093	OK-1	12.5	CA-2	.090	OK-1	3.06	UT-2	.016	TX-2
Cr	343	CA-3	1.45	OK-1	327	CA-3	1.37	OK-1	44.3	CA-3	.640	TX-1
Fe	31,200	CA-2	320	OK-1	28,000	CA-2	230	OK-1	7,120	UT-2	114	CA-1
Co	8.3	CA-1	.38	KY-2	8.11	CA-2	.19	WY-1	11.6	UT-5	.155	CA-1
Ni	192	CA-3	3.3	OK-1	148	CA-3	< 8	OK-1	228	CA-3	12.2	NM-1
Zn	258	CA-3	1.75	WY-1	244	CA-3	3.4	TX-2	68.6	OK-4	1.21	KY-1
As	16.1	CA-2	.128	OK-1	17.1	OK-3	.058	OK-1	22.0	UT-5	.039	CA-1
Se	42.1	CA-3	.46	OK-1	21.6	CA-3	< .1	OK-2	40.0	CA-3	.17	KY-1, TX-1
Br	93	CA-3	.21	NM-1	70.1	CA-3	.251	NM-1	40.7	CA-3	.295	TT-1
Rb	85	CA-2	2.3	OK-5	84	CA-4	3.6	OK-1	< 70	CA-3	< 3	NM-1
Sr	1,240	CA-3	20	OK-4	1,240	CA-3	55	WY-1	290	CA-3	3.2	AB-8
Sb	8.9	CA-3	.051	OK-1	8.3	CA-3	.048	OK-1	1.40	CA-3	.019	KY-1
Cs	4.16	CA-1	.062	OK-3	3.52	CA-2	.074	OK-1	.256	CA-3	.022	KY-1
Ba	950	CA-4	17	OK-3	960	CA-4	30	OK-3	71	UT-2	2.7	OK-5
La	37.5	CA-2	1.13	OK-1	35.0	CA-2	1.18	OK-1	14.8	UT-2	.123	CA-1
Ce	58.1	CA-2	1.51	OK-1	56.0	CA-2	1.91	OK-1	28.8	UT-2	.26	CA-1
Nd	< 15	CA-2, CA-3	< .6	WY-1	20	CA-2	2.6	KY-2	< 120	WY-1	< 1	NM-1, TT-1
Sm	6.08	CA-2	.136	OK-1	5.53	CA-2	.143	OK-1	1.91	UT-2	.019	CA-1
Eu	1.20	CA-2	.025	OK-1	1.09	CA-2	.045	OK-1	.529	UT-2	.013	CA-4
Tb	.772	CA-2	.014	OK-1	.63	CA-2	.075	KY-2	.346	UT-2	.005	CA-4
Yb	3.27	CA-2	.080	OK-1	3.07	CA-2	.084	OK-1	1.32	UT-2	.028	KY-2, TX-2
Lu	.55	CA-2	.013	OK-1	.55	CA-2	.012	OK-1	.172	UT-2	.008	TX-1, TX-2
Hf	17.4	CA-2	.048	OK-3	11.8	OK-2	.34	OK-3	.409	UT-2	.015	CA-1
Ta	.88	CA-2	.023	OK-3	.74	CA-2	.19	OK-4	.402	UT-2	.024	CA-4
W	2.1	CA-2	.151	KY-2	< 14	AB-8	.13	KY-2	11.4	AB-8	.020	OK-5
Th	10.04	CA-2	.235	OK-3	8.68	CA-2	.150	TX-2	3.57	UT-5	.039	TX-2
U	24.4	CA-3	.39	AB-8	25.5	CA-3	.145	OK-1	24.6	WY-1	.075	TX-2
Cu	80	CA-3	2.0	OK-2, OK-5	93	CA-3	1.5	OK-5	24	VE-4	3.7	WY-1, KY-2
Hg	.050	CA-3	**< .005**	(2)	.030	CA-4	**< .005**	(3)	.05	TX-1	**< .005**	(4)
Pb	11	OK-4, UT-3, TT-1	3.2	CA-1	17	UT-5	3.3	OK-3, WY-1	13	NM-1	2.0	WY-1
V	450	CA-3	5.1	OK-3	570	CA-3	2.7	OK-1	470	VE-4	25	UT-4
Mo	37	CA-3	1.1	OK-2	54	CA-3	1.2	CA-4	35	WY-1	1.4	VE-4
Nb	9.6	CA-2	1.3	AB-8	9.1	CA-2	1.1	OK-4	23	UT-3	1.1	UT-4
Y	35	CA-2	5.2	NM-1	35	CA-3	6.0	OK-5	22	UT-3	6.10	KY-1
Li	34	CA-1	5.9	OK-2, OK-4	37	CA-1	5.2	OK-4, VE-4	29	TX-1	5.5	OK-3
S	26,000	CA-3	590	UT-2	20,000	CA-2	110	KY-1	69,000	TX-1	6,700	UT-4

[1] Maxima and minima for bitumen or heavy oil do not include contents of trace elements in the heavy oil and gilsonite from Utah (UT–1 and UT–6) or the heavy oil samples VE–1, 2, and 3 from Venezuela because we do not have data for their reservoir rocks.

[2] The minimum content of Hg is the same (<**0.005** ppm) in reservoir rock samples CA–1, CA–2, CA–4, KY–1, KY–2, NM–1, OK–1, OK–2, OK–3, OK–4, OK–5, TX–1, WY–1, UT–2, UT–3, AB–8, and TT–1.

[3] The minimum content of Hg is the same (<**0.005** ppm) in sediment residue samples CA–1, CA–2, KY–2, NM–1, OK–1, OK–2, OK–3, OK–4, OK–5, TX–2, WY–1, UT–2, UT–3, UT–4, UT–5, AB–8, TT–1, and VE–4.

[4] The minimum content of Hg is the same (<**0.005** ppm) in bitumen and heavy oil samples CA–1, CA–4, KY–1, KY–2, NM–1, OK–2, OK–3, OK–5, WY–1, UT–3, UT–4, UT–5, AB–8, TT–1, and VE–4.

APPENDIX, DESCRIPTION OF SAMPLE LOCALITIES

This list of sample localities is arranged in a standard format of six lines for each sample. The type of information in each line is as follows: (1) Line 1 shows the laboratory sample number followed by the standard code for the locality. (2) Line 2 provides the country, State or Province, and county names. (3) Line 3 describes the sample locality. (4) Line 4 gives the sample description and the geologic name and age of the reservoir rock. (5) Line 5 gives the latitude and longitude of the sample locality. For localities in Trinidad and Tobago and Venezuela, the latitude and longitude given are for the nearest landmark, which is named in parentheses in the same line. (6) Line 6 has the name of the person supplying the sample.

The standard codes for localities in the United States are from the U.S. National Bureau of Standards Federal Information Processing Standards Publication 6–3 (1979). Each U.S. code begins with US, has a two-digit code for the State, has a three-digit code for the county, and ends with a dash and a unique number to distinguish the samples from the same county. The codes for localities in other countries are from the U.S. Defense Intelligence Agency Manual 65–18 (1972). Each code for a locality in another country begins with a two-letter designation for the country, has a two-digit code for the State, Province, or county, and ends with a dash and a unique number to distinguish the samples from the same political subdivision.

CA–1, US06083–1
USA, California, Santa Barbara County
Mine cut (Airox property) 1,000 ft (304.8 m) east of Casmalia oil field, west of Santa Maria
Diatomaceous shale of the Monterey Shale (Miocene)
34°56′ N., 120°30′ W.
J.W. Earley

CA–2, US06083–2
USA, California, Santa Barbara County
Outcrop on Gaviota Beach
Diatomaceous shale of the Monterey Shale (Miocene)
34°28.2′ N., 120°12′–13′ W.
C.M. Isaacs

CA–3, US06083–3
USA, California, Santa Barbara County
Outcrop on Gaviota Beach
Carbonaceous marl of the Monterey Shale (Miocene)
34°28.2′ N., 120°12′–13′ W.
C.M. Isaacs

CA–4, US06079–1
USA, California, San Luis Obispo County
Edna tar sand deposit and oil field
Siltstone of the Pismo Formation (late Miocene and early Pliocene)
35°12′ N., 120°36′ W.
R.F. Meyer

KY–1, US21141–1
USA, Kentucky, Logan County
Tar sand deposit in Homer quarry in Homer quadrangle
Sandstone of the Big Clifty Sandstone Member of the Golconda Formation (Mississippian, Chesterian)
37°00′ N., 86°45′ W.
M.C. Noger

KY–2, US21061–1
USA, Kentucky, Edmonson County
Indian Creek quarry, Brownsville quadrangle
Sandstone of the Kyrock Sandstone Member of the Caseyville Formation (Early Pennsylvanian)
37°15′ N., 86°15′ W.
M.C. Noger

NM–1, US35019–1
USA, New Mexico, Guadalupe County
Santa Rosa quarry
Sandstone of the lowermost sandstone unit of the Santa Rosa Sandstone (Late Triassic)
35°01′ N., 104°40′ W.
A.J. Budding

OK–1, US40099–1
USA, Oklahoma, Murray County
Sulphur deposit, SW1/4SE1/4 sec. 15, T. 1 S., R. 3 E.
Sandstone of the Arbuckle Limestone (Late Cambrian)
34°28′ N., 96°58′ W.
M.R. Burchfield

OK–2, US40019–1
USA, Oklahoma, Carter County
Woodford deposit, W1/2E1/2 sec. 2, T. 3 S., R. 1 W.
Sandstone of the Morrowan Series (Early Pennsylvanian)
34°19′ N., 97°17′ W.
M.R. Burchfield

OK–3, US40099–2
USA, Oklahoma, Murray County
Quarry, Dougherty area
Limestone of the Viola Limestone (Late Ordovician)
34°25′ N., 97°03′ W.
R.F. Meyer

OK–4, US40019–2
USA, Oklahoma, Carter County
Quarry
Sandstone in the Pontotoc Group (Late Pennsylvanian)
34°13′N., 97°13′ W.
R.F. Meyer

OK–5, US40019–3
USA, Oklahoma, Carter County
Woodford deposit, W1/2E1/2 sec. 2, T. 3 S., R. 1 W.
Sandstone of the Morrowan Series (Early Pennsylvanian)
34°19′ N., 97°17′ W.
R.F. Meyer

TX–1, US48323–1
USA, Texas, Maverick County
Conoco 2 Mary R. Saner, depth 1,413.5–1,414.5 ft (430.8–431.1 m)
Sandstone of the San Miguel Formation (Late Cretaceous)
28°58′ N., 100°11′ W.
J.D. Meyers

TX–2, US48463–1
USA, Texas, Uvalde County
Quarry
Limestone of the Anacacho Limestone (Late Cretaceous)
29°10′ N., 100°03′ W.
R.F. Meyer

UT–1, US49003–1
USA, Utah, Box Elder County
Rozel Point oil field, Amoco 2 West Rozel Point, NW1/4SW1/4 sec. 15, T. 8 N., R. 8 W.
Heavy oil (Pliocene)
41°24′ N., 112°44′ W.
M.D. Laine

UT–2, US49007–1
USA, Utah, Carbon County
Sunnyside deposit
Sandy marl of the Green River Formation (Eocene)
39°34′ N., 110°24′ W.
Cynthia Brandt

UT–3, US49007–2
USA, Utah, Carbon County
Sunnyside deposit
Sandy marl of the Green River Formation (Eocene)
39°34′ N., 110°24′ W.
Cynthia Brandt

UT–4, US49047–1
USA, Utah, Uintah County
Asphalt Ridge NW deposit
Sandstone at the contact between the Upper Cretaceous Rim Rock Sandstone of Walton (1944) of the Mesaverde Group and the overlying lower Tertiary Duchesne River Formation
40°26′ N., 109°36′ W.
Cynthia Brandt

UT–5, US49047–2
USA, Utah, Uintah County
Asphalt Ridge NW deposit
Sandstone at the contact between the Upper Cretaceous Rim Rock Sandstone of Walton (1944) of the Mesaverde Group and the overlying lower Tertiary Duchesne River Formation
40°26′ N., 109°36′ W.
R.F. Meyer

UT–6, US49047–3
USA, Utah, Uintah County
Bonanza mine southeast of Vernal
Gilsonite (formation unknown)
40°21′ N., 109°08′ W.
R.F. Meyer

WY–1, US56003–1
USA, Wyoming, Big Horn County
A pit in the Trapper Canyon deposits in the Bighorn Basin
Sandstone of the Tensleep Sandstone (Middle and Late Pennsylvanian)
44°27′ N., 107°34′ W.
J.W. Hosterman

AB–8, CA01–8
Canada, Alberta Province
Oil sand core in the Athabasca deposit
Sandstone in the McMurray Formation (Early Cretaceous)
57°00′ N., 111°30′ W.
Deborah Henry

TT–1, TD09–1
Trinidad, St. Patrick County
Outcrop at well D–74, Parrylands area
Sandstone in the lower part of the Morne L'Enfer Formation (Tertiary)
10°11′ N., 61°37′ W. (Parrylands)
H. Rambarran

VE–1, VE02–1
Venezuela, Anzoategui State
Well not known
Extra heavy crude oil from the Oficina Formation (early Miocene and late Oligocene)
8°24′ N., 65°13′ W. (Zuata)
R.F. Meyer

VE–2, VE16–1
Venezuela, Monagas State
Morichal well CH–32
Unsteamed extra heavy crude oil from the Oficina Formation (early Miocene and late Oligocene)
9°04′ N., 62°40′ W. (Temblador)
R.F. Meyer

VE–3, VE16–2
Venezuela, Monagas State
Morichal well CH–32
Steamed extra heavy crude oil from the Oficina Formation (early Miocene and late Oligocene)
9°04′ N., 62°40′ W. (Temblador)
R.F. Meyer

VE–4, VE00–1
Venezuela
Core from Orinoco oil belt
Sandstone from Oficina Formation (early Miocene and late Oligocene)
Location unknown
R.F. Meyer

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