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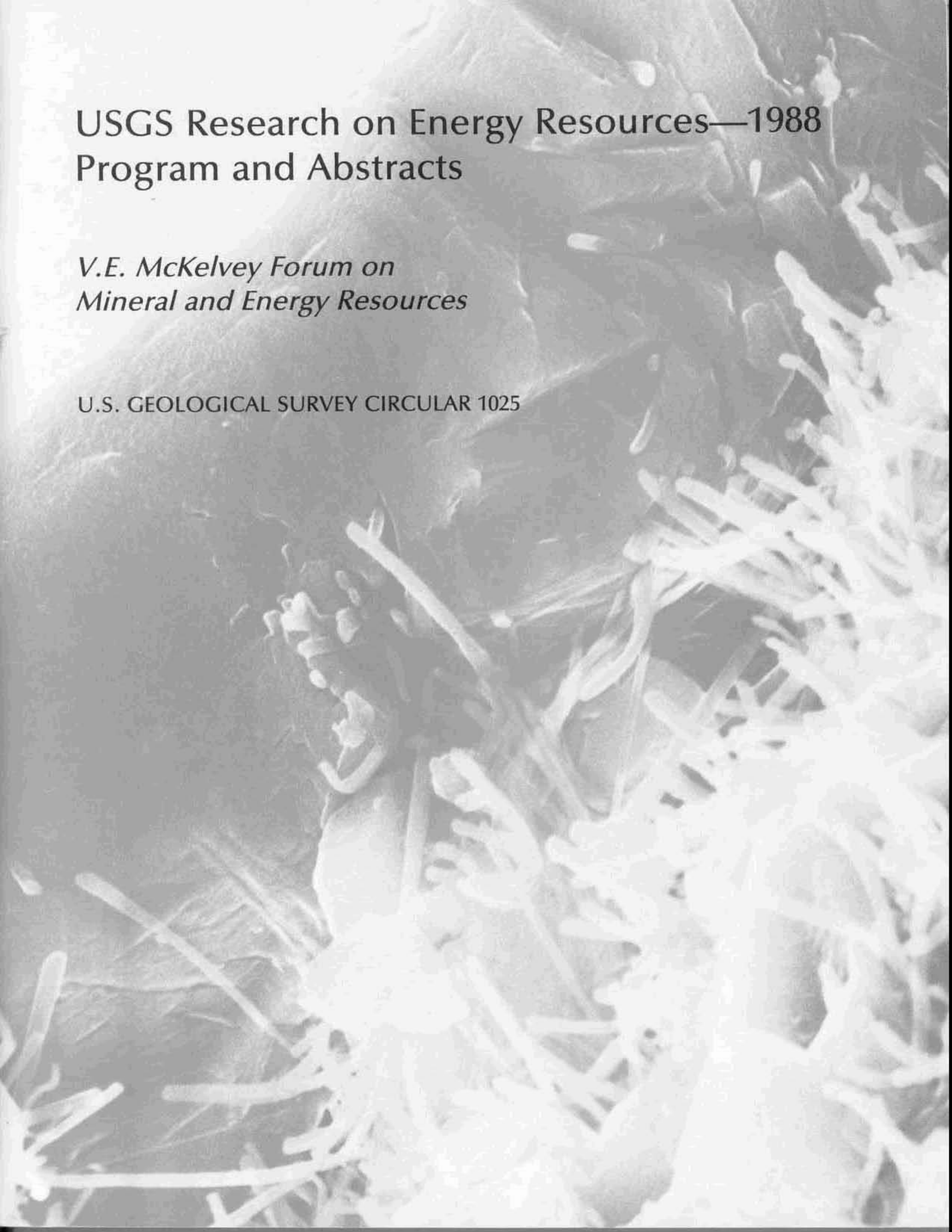

Petroleum Geology of the Northern Part of the Arctic National Wildlife Refuge, Northeastern Alaska

Kenneth J. Bird, Leslie B. Magoon, and C.M. Molenaar

The northern part of the Arctic National Wildlife Refuge and adjacent Native lands, an area between the Brooks Range and the Beaufort Sea encompassing about 2.4 million acres, is judged to have the geologic characteristics of a major petroleum province. Except for the undeformed northwest quarter, the area is involved in an east-west- and northeast-trending, north-verging imbricate fold and thrust-fault system related to Brooks Range deformation.

The most likely petroleum-reservoir rocks are sandstones of Cretaceous and Tertiary age and intra-basement carbonate rocks of pre-Mississippian age. Clastic and carbonate reservoir rocks of Mississippian to Triassic age, similar to the reservoir rocks at Prudhoe Bay, are truncated by Early Cretaceous erosion related to rifting; these rocks are expected to occur in the southern part of the area considered.

Analyses of hydrocarbons from oil seeps and oil-stained rocks in outcrop suggest that three types of oil are present, all dissimilar to oils from the Prudhoe Bay area. The most important source rock for oil is postulated to be the Tertiary(?) and Cretaceous Hue Shale. With a present-day geothermal gradient of about 30 °C/km (1.6 °F/100 ft), oil generation is expected to occur between depths of 3.7 and 6.9 km (12,000–22,500 ft), mostly within the thick Cretaceous and Tertiary (Brookian) sequence. Oil generation, accompanied by clay-mineral transformation and abnormal-fluid-pressure development, probably began about 50 Ma at the southern edge of the coastal plain and progressed northward, reaching the coastline about 10 Ma.

Seismic data indicate that many more structures are present than have been previously suspected. Short-wavelength folds, perhaps numbering in the hundreds, are complexly faulted and involve mostly Brookian rocks. These folds overlie one or more regionally extensive low-angle faults that structurally detach them from a relatively small number of long-wavelength, moderately faulted structures composed mostly of pre-Brookian rocks. Structural traps are believed to have formed before, during, and after oil generation and migration.

Mean value estimates of in-place oil and gas resources for a 1.5-million acre part of this area are 13.8 billion bbl of oil (bbo) and 31.3 trillion ft^3 of gas. The amount of economically recoverable oil in 26 seismically mapped structures in estimated at 3.2 bbo (mean value). Evaluation showed that natural-gas resources are not economically recoverable.

Hydrocarbon Distribution in the Cretaceous-Tertiary Sagavanirktok Formation, North Slope, Alaska

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New insights on the Sagavanirktok Formation as an important North Slope hydrocarbon reservoir rock unit are provided by C.M. Molenaar and others' 1986 subsurface correlation sections and ongoing USGS studies of gas hydrates and basin evolution. Detailed correlation sections in the Prudhoe-Kuparuk region and analyses of gas samples show that more heavy oil resides in Sagavanirktok sandstone reservoirs than previously reported, that several areally extensive gas hydrate deposits are present, and that the gas in the hydrate deposits likely originated through a combination of biogenic and thermogenic processes.

Throughout Cretaceous and Tertiary time on the North Slope, clastic debris shed northward from the rising ancestral Brooks Range filled the adjacent foredeep and prograded northeasterly across the subsiding Barrow arch to form a passive margin sequence, collectively known as the Brookian sequence. The nonmarine to shallow-marine Sagavanirktok Formation and its finer grained marine partial equivalent, the Canning Formation, form one of the thickest (0–2,700 m) clastic wedges in this sequence. The Sagavanirktok Formation consists of Late Cretaceous through Tertiary shallow-marine shelf and delta plain deposits composed of sandstone, shale, conglomerate, and coal. The areal distribution of the Sagavanirktok is limited to the coastal plain of the eastern half of the North Slope and the adjacent continental shelf.

Hydrocarbon occurrences within the Sagavanirktok Formation have been known since early exploratory drilling in the Prudhoe Bay area, and from earlier studies of outcrops to the south. Two oil-bearing sandstone intervals in wells from the Kuparuk area, informally named the West Sak and Ugnu sands, are estimated by ARCO Alaska to contain an in-place oil volume of 21 to 36 billion barrels. The oil in the West Sak sands ranges from 16 to 22 degrees API gravity and contains methane through pentane gases in solution. Oil in the lower Ugnu sands ranges from 8 to 12 degrees API gravity, and methane is the only gas in solution. Our analysis of well logs shows that the West Sak and Ugnu sands are not the only oil-bearing horizons within the Sagavanirktok of the Kuparuk River area: in some wells, rock units stratigraphically above the Ugnu sands contain oil columns more than 20 m thick. Outside the Kuparuk River area, the Sagavanirktok Formation is also oil bearing at Milne Point, Point Thomson, and east of the Kuparuk River oil field in the Prudhoe Bay oil field area.

Gas hydrates, crystalline compounds of water and gas, occur within the Sagavanirktok Formation. Direct evidence comes from a core recovered by Exxon Corporation in the Northwest Eileen-2 well, located 25 km west of Prudhoe Bay, and indirect evidence has been obtained from our analysis of open-hole geophysical logs—the most useful of these being the resistivity, acoustic transit-time, and the gas chromatograph on the mud log. We have mapped six laterally extensive gas hydrate accumulations in the Prudhoe-Kuparuk area. One rock unit in the southern part of the Kuparuk area contains gas hydrate, coal, and oil.

Previous investigators have suggested that the oil, and presumably the associated gas, within the Cretaceous and Tertiary sandstones of the Prudhoe-Kuparuk area were "spilled" from the underlying Prudhoe Bay Sadlerochit structure as a consequence of regional tilting during mid to late Tertiary time. Our analyses of canned drill-cutting samples provided by ARCO Alaska from several development wells in the Kuparuk River oil field suggest that the gas hydrates contain a mixture of biogenic and thermogenic gases. The gas in the Sadlerochit is thermogenic; therefore, not all of the gas in the Sagavanirktok Formation is from the underlying Prudhoe Bay Sadlerochit structure.

Coal Quality and Distribution in Upper Cretaceous and Tertiary Rocks, East-Central North Slope, Alaska

Stephen B. Roberts

Extensive coal deposits underlie a region of greater than 4,000 square miles on the east-central North Slope of Alaska. The coal-bearing strata, which include rocks of both the Upper Cretaceous Prince Creek Formation and the Tertiary Sagavanirktok Formation, have been interpreted as part of a time-transgressive deltaic sequence which prograded generally northeastward. Previous workers have estimated the coal resources of this region to be 50 to 60 billion tons. Current investigations focus on the characterization of the coals in terms of stratigraphic occurrence, quality, and areal distribution. Coal-bearing outcrops were sampled and described, and selected geophysical logs from oil and gas wells in the region have been analyzed.

Surface exposures of the coal beds occur in a belt extending more than 50 miles from the White Hills eastward to the Kavik River. Sections were measured along the Sagavanirktok River near Sagwon, at two locations on the Shaviovik River, and at Juniper Creek. The coal-bearing outcrops consist primarily of interbedded sandstone, siltstone, shale (mudstone), carbonaceous shale and coal. Sandstones are dominantly fine to medium grained and ripple laminated to trough crossbedded; pebble lag occurs at the base of troughs. Shales are commonly interbedded with both siltstone and very fine grained, ripple-laminated sandstone, and locally the shales are bentonitic. Both shales and siltstones contain abundant coalified plant fragments. Siderite concretions occur throughout the coal-bearing section.

The coal beds in outcrops range in thickness from 2 to 12 feet, and many contain layers of coaly carbonaceous shale and bone (high-ash) coal interbedded with bright coal. Clay partings are abundant. Analyses of 16 coal samples from 11 coal beds indicate that the apparent rank of the coal ranges from lignite A to subbituminous B, and is most commonly subbituminous C. Average values for the ash and total sulfur are 7.5 percent and 0.3 percent respectively.

Subsurface data on the coal-bearing sequence are from oil and gas test wells within the Prudhoe Bay region. Interpretation of 10 geophysical logs from wells located along a 50-mile line between the Kuparuk and Kadleroshilik Rivers near the Arctic coast indicates that the coal-bearing sequence, defined here as the interval between the stratigraphically highest and lowest coal beds, ranges in thickness from 720 to 1,340 feet. Depth to the top of the sequence increases west to east from 2,800 feet to 5,400 feet. Coal bed thickness ranges from 2 to 25 feet, with cumulative coal thickness generally constituting 6–8 percent of the total thickness of the coal-bearing interval.

Results of these investigations will further delineate the extent of coal bed occurrence in Upper Cretaceous and Tertiary rocks, and better define the coal resource potential within this large area of Alaska's North Slope.

Eocene Lava and Epigene Mineralization Alter Alaska's Thickest Known Coal Deposit

Gary D. Stricker and Ronald H. Affolter

Alaska's thickest known coal accumulated in the 4 square mile tectonic Boulder Creek basin in Death Valley, southeastern Seward Peninsula, Alaska. Bedrock in the area consists of Precambrian(?) and Paleozoic metamorphic rocks that were intruded in the Late Cretaceous by acid magmas resulting in the formation of alkalic monzonitic plutons. Post-intrusive faulting formed the Boulder Creek graben, which filled with sediments and organic debris. An 80-foot-thick Eocene basaltic lava flowed into a thick peat swamp, catastrophically ending organic accumulation. Subsequent epigenetic mineralization began after deposition of the host sediments and has continued to the present. The geochemical effects of lava and epigenetic mineralization in Death Valley make this coal deposit unique.

Exploratory core holes in the graben, drilled for uranium, contained three coal beds, with one bed exceeding 165 ft thick. Chemical analyses were determined on six vertical increments of the thick coal from two core holes, and vitrinite reflectance was determined on 20 random samples taken throughout this coal.

Mean random vitrinite reflectance values are 0.4 *Ro* percent at the base and 2.6 *Ro* percent at the top. Total sulfur content ranges from 0.38 to 1.5 percent with the highest value near the base of the bed. Ash content is variable from 2.3 to 6.8 percent. Significant enrichment in the contents of Cu, F, Hg, K, Li, Mg, Na, Ni, Pb, and Sr occurs within the top 35 ft of the coal bed. These elements were mobilized in the basalt by steam produced by the violent reaction of lava entering the wet peat swamp.

Uranium content of 37 ppm (whole coal) in the basal 30 ft of the coal represents an enrichment of 30 times the average for other United States coals. Uranium was derived from the nearby plutons and concentrated in the base of the coal during and after peat accumulation by epigenetic mineralization. The basalt may have acted as a barrier to these mineralizing fluids, thereby minimizing the enrichment of uranium at the top of the bed. Death Valley coal has the highest reported content of tungsten (360 ppm whole coal) for any United States coal. A linear correlation of 0.95 between uranium and tungsten suggests that the epigenetic mineralization phase which concentrated uranium also concentrated tungsten.

Apparent rank increases from subbituminous C near the coal's base to semianthracite at the top. This, coupled with high tungsten and uranium content, makes the Death Valley deposit different from other Alaskan and United States coals. Intense heat over a relatively short time interval and epigenetic mineralization are the major factors affecting rank and element distribution in this coal and warrant further investigation.