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Petroleum Geochemistry of Alaskan North Slope—An Update

When the U.S. Geological Survey took over the drilling program in the National Petroleum Reserve in Alaska (NPRA), many explorationists expected that a major oil accumulation would be found on or adjacent to the Barrow arch. This expectation was based on the presumption that the oil source rocks are buried to great depths in the Colville trough and that the oil generated would have migrated north to be trapped in sandstone or carbonate reservoir rocks near the Barrow arch. Subsequent drilling failed to confirm this model for oil occurrence in NPRA. To date, commercial oil generated in the Colville trough appears to be limited to the Prudhoe Bay area. Understanding the geological reasons for localization of major oil occurrence has important implications for oil exploration in northern Alaska, both onshore and offshore.

Consideration of the basic requirements for oil occurrence (source, migration pathway, reservoir, trap, and seal) suggests that source rock adequacy may be a limiting factor in NPRA. Two geochemically distinct types of North Slope oil have been recognized: the Simpson-Umiat type (associated with a "pebble-shale" unit/Torok Formation source) and the Barrow-Prudhoe type (associated with a Shublik Formation/Kingak Shale source). Except for the oil from the Fish Creek 1 well and the reservoirs of Cretaceous age in the Prudhoe area, the Barrow-Prudhoe oil reservoirs are in Ellesmerian sequence rocks on the Barrow arch. The source-reservoir thermal-maturity patterns, the inferred timing of oil generation, and the structural configuration of the Ellesmerian rocks all suggest that the oil should have migrated to the Barrow area as well as to the Prudhoe area. The presence of subcommercial Barrow-Prudhoe-type oil in NPRA also suggests that deficiencies in the "oil plumbing system" do not explain the lack of oil accumulations along the Barrow arch.

The large volumes of oil in the Prudhoe area, as compared to only "oil shows" in the Barrow area, are best explained by the greater amount and better quality of organic matter in the Shublik Formation and the Kingak Shale to the east of NPRA.

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Facies Correlation and Basin Analysis of Ivishak Formation, Arctic National Wildlife Refuge (ANWR), Alaska

The Ivishak Formation forms a regressive-transgressive deposit. The stratigraphic divisions are (1) a lower prograding deltaic unit of massive sandstone; (2) a middle fluvial unit of sandstone, shale, and minor conglomerate; and (3) an upper destructive deltaic unit of thin-bedded to massive sandstone. These Ivishak units defined in ANWR are recognized in the subsurface and traced over much of the North Slope.

Basin analysis consisted of isopach and percent-sandstone mapping and paleocurrent measurement of 15 outcrops. Formation thickness averages 400 ft (120 m) with a northeast-trending depocenter axis through the Romanzof Mountains. Paleocurrent data define two main provenances of quartz-chert sands: northwest and east. Paleocurrents are oriented normal to, and dip toward, the basin axis. Outcrops located within the axis record bidirectional transport.

A Lower Cretaceous unconformity (LCU) truncates the Ivishak in the Sadlerochit Mountains. Here, Neocomian "pebble shale" rests atop the Ivishak, with Shublik through Kingak formations missing. The LCU truncation is part of a regional unconformity that occurs along the north side of the North Slope.

Ivishak units thin near the unconformity, suggesting an older high, which we term the Nularvik high. This high is part of a regional trend extending through ANWR from the Point Thomson area to Bathtub syncline.

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Sedimentological Evolution of Mississippian Kekiktuk Formation, Sagavanirktok Delta Area, North Slope, Alaska

The reservoir interval in the Endicott field, located under the delta of the Sagavanirktok River east of Prudhoe Bay, is the Mississippian Kekiktuk formation. The rocks are quartzose, and lithofacies and sequence analysis of core material shows that the Kekiktuk in that area can be subdivided into three sedimentologically distinct intervals, each of which reflects a different fluviatile depositional environment. The lowermost interval (zone 1) rests directly on metamorphic basement and comprises interbedded coal, mudstones, siltstones, and fine-grained sandstones. These rocks were deposited in a very low-lying swamp plain containing local lakes and sluggish, highly sinuous streams. Zone 1 is overlain sharply by zone 2, which comprises medium to coarse-grained, multistory sandstone that was deposited within an unconstrained braided river system. The braid plain contained both ephemeral and permanent lakes, and periodic gravity flows deposited coarser sediment into the latter. That sequence passes gradationally upward into zone 3, which is composed of coarse-, medium-, and fine-grained sandstones, as well as siltstones, mudstones, and coals. The lower part of zone 3 is dominated by upward-fining sandstone sequences, interpreted as channel bars deposited within a moderately sinuous fluvial system. They pass gradationally upward into other, distinct upward-fining sequences, which differ in having higher proportions of siltstone, mudstone, and coal. Those rocks were deposited in a more highly sinuous (meandering) fluvial environment. The rocks grade upward into shallow marine sediments of the Kayak/Itkilyariak formations. The vertical sequence within the Kekiktuk in this area permits an interpretation of the structural history of the basin during Kekiktuk time.

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Jurassic-Neocomian Biostratigraphy, North Slope, Alaska

The foraminiferal and palynological biostratigraphy of subsurface Jurassic and Neocomian (Early Cretaceous) age strata from the North Slope were investigated to better define biostratigraphic zone boundaries and to help clarify the correlation of the stratigraphic units in the National Petroleum Reserve in Alaska (NPRA). Through use of micropaleontologic data, eight principal biostratigraphic units have been identified. The Neocomian and Jurassic strata have each been subdivided into four main units.

The gamma-ray zone (GRZ), or "hot zone," sediments include both northern and southern source starved-basin deposits. These deposits range from Barremian to possibly middle Albian age in NPRA. East of NPRA, these Early Cretaceous starved-basin deposits coalesce with Late Cretaceous starved-basin deposits and form a GRZ at least as young as Senonian.

Early Cretaceous starved-basin deposits of northern source are recognized by the presence of dispersed, rounded, frosted quartz sand grains. These sand grains, floating in a mudstone matrix, are essentially absent from the starved-basin deposits of southern source.

The Lower Cretaceous unconformity occurs within the Hauterivian to Barremian biostratigraphic interval in the Tunalik, Peard, and Inigok wells on the NPRA; it cannot be recognized through microfossil evidence in those particular areas. In most other areas of the North Slope, the unconformity occurs at the base of the Hauterivian to Barremian biostratigraphic interval. This unconformity truncates progressively older strata eastward along the present coastal region and onto the Barrow arch.

A mid-Jurassic sandstone unit appears to be of Early to Middle Jurassic rather than Late Jurassic (Oxfordian) age.

Lower to Middle Jurassic strata are characterized by southward depositional thinning and distal (starved-basin) deposition in certain areas.

The Sag River Sandstone is a time transgressive unit that ranges from Late Triassic in the north and northwestern NPRA to Early Jurassic on the Fish Creek platform to the east.

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Ophiolitic Rocks of Iditarod Quadrangle, West-Central Alaska

Reconnaissance geologic mapping during 1984 revealed previously unreported ultramafic rocks of probable ophiolitic origin in the northern part of the Iditarod quadrangle. The ultramafic rocks are poorly exposed on rounded tops of the low rolling hills in the area, and they form a northeast-southwest belt at least 8 mi long and as much as 3 mi wide. Although these rocks are associated with Mississippian to Jurassic(?) chert, tuff, argillite, and basalt of the Innoko terrane, the contact relations are uncertain.

The ultramafic rocks consist of harzburgite, lherzolite, pyroxenite, and pods of altered dunite; disseminated chrome spinel is a common but minor constituent. Serpentinization is ubiquitous, all samples showing at least some effects and many being entirely serpentinized. Discontinuous pods of former serpentinized dunite(?) within lherzolite are entirely altered to a magnesite + talc + chrome spinel assemblage, indicative of low-grade metamorphism in the presence of water and carbon dioxide.

The ultramafic rocks of Iditarod quadrangle are similar to and on trend with those of the Mount Hurst area, 25 mi to the northeast in the Ophir quadrangle. The Mount Hurst rocks represent part of a dismembered ophiolite, probably related to the Yukon-Koyukuk ophiolite belt. Although several of the classic ophiolite components are missing from the ultramafic sequence in Iditarod quadrangle, an ophiolite origin is strongly suggested by correlation with the Mount Hurst rocks and is supported by the presence of a structural slice of hypersthene gabbro in close proximity to the ultramafic sequence.

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Late Cretaceous Coccolith Biostratigraphy of San Miguel Island, California

Coccoliths recovered at 69 localities from the northwest coast of San Miguel Island provide definitive biostratigraphic criteria for subdivision of more than 1,425 m of submarine fan strata of the Mirounga formation of Late Cretaceous age. The seven coccolith zones recognized from the stratigraphic distribution of 38 species suggest that San Miguel Island has one of the most complete sequences of Upper Cretaceous strata in southern California. The zones are, from oldest to youngest: *Quadrum gartneri, Eiffellithus eximius, Marthasterites furcatus, Micula staurophora, Broinsonia parca, Quadrum trifidum,* and *Arkhangelskiella cymbiformis* zones. These coccolith zones are known elsewhere in the world. They appear to represent a time interval from the early Turonian to the middle Maestrichtian, although coccolith criteria for the Santonian stage interval were not observed, possibly because of ecological restrictions.

Coccolith localities along the northwest coast of San Miguel Island indicate Upper Cretaceous strata where the Paleogene Pozo-Canada Formations and South Point sandstone had been mapped previously. These new data may add more than 500 m of rock to the previously recognized Late Cretaceous stratigraphic column. On the basis of coccolith criteria, various parts of the Mirounga formation correlate with Upper Cretaceous rocks of the southern California mainland such as: the Jalama Formation (western Santa Ynez Mountains), the Chatsworth Formation (Simi Hills), the Holz Shale Member of the Ladd Formation (Santa Ana Mountains), and the Point Loma Formation of the Rosario Group (San Diego area). Correlations are possible also with the Valle Formation of Mexico (Vizcaino Peninsula).

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Depositional History and Seismic Stratigraphy of Lower Cretaceous Rocks, National Petroleum Reserve, Alaska and Adjacent Areas

Knowledge of depositional history of Lower Cretaceous rocks in the National Petroleum Reserve in Alaska is necessary for predicting the occurrence of potential sandstone reservoirs. These rocks range in thickness from 7,000+ m along the Colville basin axis to about 1,200 m on the Barrow arch. Lower Neocomian strata on the north flank of the basin consist of southward-prograding marine shelf and slope deposits of shale and minor sandstone units. Uplift, erosion, and subsequent transgression on the northernmost flank of the basin resulted in deposition of the pebble shale unit in late Neocomian time and termination of the northern provenance. Following this, the basin was downwarped, and little deposition occurred on the north flank until distal, deep-water deposits of the Torok Formation onlapped and downlapped the south-dipping flank of the basin in middle or late Albian time.

On the south flank of the basin, southern-source turbidites of the Okpikruak Formation (early Neocomian) accumulated in a subsiding foredeep and were subsequently thrust northward in late Neocomian or Aptian time. The Fortress Mountain Formation (early Albian), which consists of as much as 3,000 m of mainly deep-water deposits, unconformably overlies the Okpikruak and older rocks on the southernmost flank of the basin. Filling of the Colville basin occurred in middle to late Albian time as thick prodeltaic and deltaic deposits of the Torok Formation and Nanushuk Group, respectively, prograded across the basin from the south on the south side of the basin, but prograded principally from the west-southwest over most of the basin.

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Significant Outcrops of Cretaceous and Tertiary Rocks in Northeastern Alaska

Cretaceous and Tertiary rocks in northeastern Alaska comprise the Neocomian part of the northerly derived Ellesmerian depositional sequence and the overlying Brookian sequence, which was derived from the ancestral Brooks Range to the south and southwest. The Ellesmerian part is less than a few hundred meters thick and consists of the upper part of the Kingak Shale and the overlying transgressive part of the pebble-shale unit and associated Kemik Sandstone Member of the Kongakut Formation. The Brookian sequence is more than 4,000 m thick and consists of, in ascending order: (1) a deep-water condensed section of organic-rich shale and bentonite with a discrete 30 to 60-m thick radioactive zone at the base; (2) a slope-and-shelf shale section with turbidites at the base; (3) a fluvial-dominated deltaic sequence that, except for one major and several minor transgressions, prograded from southwest to northeast during Albian to Eocene time; and (4) a shallow marine and nonmarine post-Eocene section.

Rocks of the four facies, which represent a wide range of depositional environments, are discontinuously exposed along the coastal plain and foothills of the Brooks Range in northeastern Alaska. Certain outcrops are significant because they show critical facies relationships. Recognition of vertical and lateral facies sequences and key lithologic units, in conjunction with available paleontologic data, facilitates correlation of the Cretaceous and Tertiary rocks both across the outcrop belt and into the subsurface to the north.

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Pre-Mississippian Accreted Terranes of Northeastern Brooks Range, Alaska

Low-grade metamorphic rocks (Neruokpuk Formation, sensu lato) underlying a regional angular unconformity in the northeastern Brooks Range have been interpreted as a conformable Precambrian to Devonian stratigraphic succession. The pre-Mississippian rocks include not only "miogeoclinal" quartzites and carbonates but also a variety of "eugeoclinal" lithologies such as radiolarian cherts, argillites, and graptolitic shales; mafic to intermediate volcanic rocks; and volcanogenic graywackes. Fossils of Cambrian, Ordovician, and Silurian age have been identified in these lithologies. Many of these units are fault-bounded and may be interpreted as pre-Mississippian tectono-stratigraphic terranes. Several of the terranes are depositionally overlapped by Middle(?) Devonian clastic rocks and intruded by plutonic rocks depositionally overlain by Mississippian and younger rocks, but which yield equivocal middle Paleozoic age dates. Similar relationships are exposed in the Doonersk anticlinorium in the central Brooks Range. These features are interpreted to indicate that the lower Paleozoic rocks of the eastern Brooks Range were tectonically assembled by accretionary processes along an active continental margin prior to Middle Devonian time. Subsequent uplift and erosion occurred prior to deposition of the Mississippian to Neocomian (Ellesmerian) passive margin sequence.

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Stratigraphy and Sedimentology of Kuskokwim Group in Vicinity of Cairn Mountain, Southwestern Alaska