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Fold-Nappes and Polyphase Thrusting in North-Central Brooks Range, Alaska

Ongoing study involving inch-to-the-mile mapping of a geologic transect along the Itkillik-Koyukuk Rivers is providing new information on the structural style and kinematic development of the central Brooks Range. The principal structures controlling north-directed structural telescoping are three detachments. These detachments are stratigraphically controlled and occur in: (1) Devonian Hunt Fork Shale, (2) Mississippian Kayak Shale, and (3) Permian and Triassic shale. The detachments and the subsidiary thrusts that branch from them form a thrust complex that developed in two stages. During the first stage, duplexes consisting of horses of Mississippian Lisburne Group platform carbonates formed where the Kayak Shale detachment ramped up to Permian and Triassic beds, imbricating the intervening Lisburne Group. In the second stage, alpine-style fold nappes involving Devonian Kanayut Conglomerate and elements of the underlying Hunt Fork Shale were emplaced sequentially from south to north on thrust faults solely in the Hunt Fork Shale. Thrust faults that emplace the fold nappes merge with the previously formed detachment in the Kayak Shale. Complex deformation associated with both stages include: (1) ramping of duplexes in Lisburne Group rocks over previously imbricated Lisburne Group rocks; (2) regional folding of imbricated Lisburne Group rocks; (3) folded individual subsidiary faults within the duplexes of Lisburne Group rocks; (4) warping, folding, and thrusting of the Kayak Shale detachment associated with generation and emplacement of the underlying fold nappes; and (5) faults that cut through the hinge area of fold nappes and thrust the trailing limbs of the fold nappes over the overturned leading limbs of the fold nappes.

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Detachment Tectonics in Sadlerochit and Shublik Mountains and Applications for Exploration Beneath Coastal Plain, Arctic National Wildlife Range, Alaska

Preliminary field investigations suggest three detachments in the Sadlerochit and Shublik Mountains: (1) the Kingak Shale, (2) along the pre-Mississippian unconformity, and (3) within the pre-Mississippian basement. The Kingak Shale décollement is the sole thrust for divergently branching subsidiary thrusts that repeat the Cretaceous Kemik Sandstone Member and overlying section. Well-exposed footwall and hanging-wall cutoffs together with multiple repetitions of Jurassic and Cretaceous over short distances demonstrate the detachment and provide permissive evidence of large-scale shortening. The detachment along the pre-Mississippian unconformity is not a sole thrust for subsidiary thrust faults. It is marked by cleavage development and folding of the overlying Mississippian and younger rocks in marked disharmony with the underlying homoclinal pre-Mississippian strata. Detachment within the pre-Mississippian basement is not exposed but is interpreted from cumulative shortening across thrust faults observed and inferred in the Sadlerochit and Shublik Mountains. As envisioned, it would be a shallow south-dipping floor thrust for subsidiary faults largely controlled by the basement infrastructure.

Thrust faults that cut the overlying Mississippian and younger section have horizontal displacements of 5-8 km and emplace pre-Mississippian rocks on Cretaceous strata. A large number of smaller thrust faults, responsible for deformation of the pre-Mississippian surface contribute to shortening. Structures involving the pre-Mississippian section trend east-west whereas earlier formed structures related to the Kingak Shale décollement trend east-northeast to west-southwest. Possible exploration leads beneath the coastal plain include: (1) large, broad, basement-involved structural culminations that may have subtle seismic expressions and (2) pre-Mississippian potential reservoirs thrust over Cretaceous source beds. Possible applications for regional seismic interpretation include: (1) a means of discriminating basement-involved structures from preexisting basement-detached structures and (2) suggestion that two broadly different structural patterns exist under the coastal plain.

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Interior Provinces in Alaska

The U.S. Geological Survey is using a multidisciplinary approach to assess the petroleum potential of the interior provinces of Alaska. Geophysical parameters, petroleum geochemistry, thermal maturation, paleontology, and petrography are some of the disciplines being used to evaluate the basins as well as to compare them geologically with other explored basins.

Three types of interior provinces have been tested by exploratory drilling for their petroleum potential: three Tertiary nonmarine basins, two Jurassic and Cretaceous flysch and fold belts, and a Paleozoic thrust belt. Although the presence of hydrocarbons has not yet been demonstrated, the present data base is too limited to make a definitive assessment of hydrocarbon potential.

During the 1983-84 field seasons, we acquired new gravity data and collected rock samples in and adjacent to the Yukon flats and the Nenana basins. These basins contain upper Tertiary, primarily nonmarine, sedimentary rock in extensional graben and half-graben complexes that are superimposed across preexisting terrane boundaries. The location and development of the basins result from strike-slip motion along the Tintina and Denali fault systems. Adjacent to the basins and within the fault systems are thick sections of nonmarine lower Tertiary coal-bearing rocks in deformed basin remnants. If these lower Tertiary rocks are present beneath the upper Tertiary fill, their greater depth and advanced maturation could enhance the hydrocarbon generative potential. Gravity modeling suggests the Tertiary fill is at least 3 km thick in the deeper parts of the basins and may be significantly thicker.

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Rua Cove: Anatomy of Volcanogenic Fe-Cu Sulfide Deposit in Ophiolite on Knight Island, Alaska

Tabular deposits of massive Fe-Cu sulfide and subjacent fracture- and void-controlled sulfide in volcanic breccia represents a sea-floor and subsea-floor hydrothermal system in the Tertiary ophiolitic terrane on Knight Island. The massive sulfide bodies at Rua Cove occur within a sequence of mafic volcanic rocks that include pillow lava, pillow-fragment breccia, mixed volcanic-chert breccia, and hyaloclastite. The principal massive sulfide horizon, composed of pyrrhotite and chalcopyrite with thin partings of talc + chlorite + quartz, is concordant with fine-grained volcaniclastic units altered to an assemblage of chlorite + quartz + sphene + ilmenite.

Discordant, diffuse feeder-zone mineralization below the massive sulfide body includes fracture- and void-filling aggregates of pyrrhotite + chalcopyrite + talc + quartz and late-stage veins of quartz + epidote + chlorite + pyrrhotite + chalcopyrite. The formation of talc appears to postdate pervasive chloritization of mafic breccia and hyaloclastite.

The thick section of mixed volcanic breccia and hyaloclastite suggests a depositional environment near the base of a steep volcanic edifice. Sulfide deposition was contemporaneous with formation of breccia and hyaloclastite. Rapid burial by fine-grained volcaniclastic material and succeeding lava flows inhibited sea-floor weathering of the Fe-rich massive sulfide. The occurrence of additional "nested" massive sulfide bodies, isolated fragments of massive sulfide in the volcanic breccia, and sulfide-rich matrix supporting fragments cut by quartz-sulfide veins suggests recurrent hydrothermal activity and sulfide deposition near an active volcanic center. The spatial association with sheeted dikes at depth and intercalated and overlying flysch-type strata of the Orca Group indicate that mineralization occurred in a rift setting near a continental margin.

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Temperature and Depth of Permafrost on North Slope, Alaska

Analysis of recently measured near-equilibrium temperatures from 24 oil-exploration wells on and near the National Petroleum Reserve in

Alaska (NPRA) provides the first information on permafrost depth and recent climatic trends over large parts of the Arctic coastal plain, foothills province, and northern Brooks Range. These new data extend earlier results from wells along the Arctic Coast that indicated a climatic warming of 1°-3°C since the middle of the 19th century. With important regional variations, this warming was evidently widespread at inland sites as well. The deepest permafrost extends to about 600 m and occurs along the eastern part of the Beaufort Sea coast. However, over most of the Arctic Slope, including the NPRA, permafrost depth ranges from 200 to 400 m, with large local variations and few conspicuous regional trends. Of the three factors that determine permafrost depth—surface temperature, heat flow, and thermal conductivity—thermal conductivity is most important. Generally, where conductivity is high, the geothermal gradient is low and the permafrost is deep. A systematic southward increase in mean surface temperature is revealed by the data, but it has only a secondary influence on permafrost depth north of the Brooks Range. We do not have enough thermal-conductivity data to determine whether certain regions with anomalously thin permafrost might have anomalously high heat flow; if they do, they might indicate upwelling of interstitial fluids in the underlying basin sediment. The absence of a thermal disturbance in coastal wells along the Beaufort Sea implies the shoreline there has been transgressing rapidly, a conclusion consistent with other evidence that hundreds of meters of warming permafrost has been covered by the advancing sea on the Beaufort Shelf.

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Mississippian Conodonts, Lisburne Group, St. Lawrence Island, Alaska

Late Mississippian conodonts recovered from two sections of the Lisburne Group exposed along the Ongoveyuk River, western St. Lawrence Island, are few, poorly preserved, yet relatively diverse. At the West Fork and East Fork Ongoveyuk sections, the lower, dark-colored, cherty beds yield conodonts that belong in the upper part of Lane Faunal Unit 8. They are correlatives of the upper St. Louis Formation in the Mississippi River Valley and, in northwest Alaska, are equivalent to the upper Nasorak and Kogruk Formations (Lisburne Group) along Nasorak Creek near Point Hope, and the Kogruk Formation at Trail Creek, De Long Mountains, Misheguk Mountain quadrangle. The upper, light-colored, thicker-bedded interval at the West Fork exposure yields conodonts assignable to Lane Faunal unit 9 of latest Meramecian and earliest Chesterian age. This fauna occurs widely over North America in beds that correlate with the Ste. Genevieve Limestone in the Mississippi River Valley. On the Lisburne Peninsula, this interval correlates with at least a portion of the Kogruk Formation exposed at Niak Creek and Cape Lewis north of Point Hope. Conodont alteration indices (CAI) are very high and variable, ranging from 5.5 to 8.0, suggesting they resulted from contact rather than regional metamorphism.

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Depositional Environments of Permo-Triassic Ivishak Formation, Prudhoe Bay, Alaska: Sequence and Geometry within Fluvial-Deltaic Reservoir

The Ivishak Formation, the main reservoir in the Prudhoe Bay field, averages 600 ft (180 m) within the field and consists of a lower progradational sequence (400 ft or 120 m) and an upper retrogradational sequence (200 ft or 60 m). Depositional environments interpreted from core examination and log correlation include delta-front, delta-plain, and coarse-grained coastal-plain facies within the lower sequence and a fine-grained coastal-plain facies in the upper sequence.

Coarsening-upward deposits of the delta-front facies overlie and interfinger with the marine to prodelta Kavik shale. Fluvially dominated deposition within a sand-rich delta resulted in overlapping and coalescing channel-mouth bars occasionally truncated by fining-upward distributary channel sequences averaging 7 ft (2 m) thick. Thicker fining-upward cycles (averaging 10.5 ft or 3.2 m) mark a shift from distributary to fluvial deposition on the delta plain. Some fluvial cycles grade vertically into flood-plain deposits of interbedded shale and siltstone that form the most extensive permeability barriers in the reservoir. A coastal-plain facies consisting of crossbedded pebbly sandstone and conglomerate deposited by braided rivers overlies the delta-plain deposits. Shale is uncommon and discontinuous within this facies. The upper retrogradational sequence rests with sharp contact upon the lower sequence and is interpreted as a coastal-plain facies composed predominantly of sandy braided-fluvial deposits.

Throughout the fluvial part of the reservoir, individual, complete, braided channel-fill deposits average 10 ft (3 m) thick. Less common meandering-stream deposits average 14 ft (4.2 m) thick. Channel dimension and depositional environment determine the geometry of silty and sandy shales that form the dominant permeability barriers in the reservoir. Continuous shales within the fluvial sequence were deposited as flood-plains. Discontinuous shale beds include abandoned channel-fill, bar-drape, and slough-fill deposits.

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Style and Age of Tectonism of Sadlerochit Mountains to Franklin Mountains, Arctic National Wildlife Refuge (ANWR), Alaska

The pre-Tertiary rocks north of the Franklin Mountains and south of the coastal plain in ANWR can be subdivided into two major structural units: (1) basement—Neruokpuk Formation, Nanook Limestone, and Katakturuk Dolomite—and (2) Lower Mississippian to Upper Cretaceous sedimentary rocks. Basement rocks underwent intense deformation prior to deposition of Lower Mississippian rocks; locally the contact is structural.

Crustal shortening at the structural level exposed was accommodated primarily by concentric folding. Axial planes of major folds generally strike N70°-90°E and dip 50°-80°S, indicating north vergence, and can be subdivided into two groups: east-northeast trending and east trending. Major folds plunge subhorizontally and continue laterally for up to 10 mi (15 km). Exposed reverse faults show relatively small amounts of throw (< 7,500 ft or 2.5 km).

Relative shortening decreases from greater than 41% at the northern margin of the Franklin Mountains to less than 16% in the Sadlerochit Mountains, amounting to approximately 14 mi (22 km) over 39 mi (64 km) of a north-south transect.

Reverse/thrust faults are interpreted to sole out along a basal décollement. This detachment probably lies between the Neruokpuk Formation and overlying basement carbonate rocks between the Franklin and Sadlerochit Mountains, and ramps upward under the coastal plain.

Field structural data of the study area, and well and seismic data of the area west of ANWR, constrain the principal post-Mississippian deformation, a phase of north-south compression, to have occurred between the mid-Eocene and the present. East-trending folds suggest two deformational events. Relative timing of these events, based on field data, is equivocal.

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Tulare Lake Field, Kings County, California—A Significant Onshore Development

The Tulare Lake field is located in Kings County, California, on the west side of the San Joaquin Valley and 10 mi east of the Kettleman Hills (North Dome) field and 30 mi southeast of the city of Coalinga. The field was discovered by Husky Oil Co. (Marathon) in October 1981 with the completion of the Boswell 22-16, Sec. 16, T22S, R20E from sands in the Burbank formation of Oligocene geologic age.

Chevron U.S.A. offset the Husky discovery well with the completion of the Salyer 678X, Sec. 8, T22S, R20E, in May 1983. Both Chevron and Husky have continued an orderly development of the field, and to date Chevron has 9 producing wells and Husky 10 producing wells.

Production is found in the Burbank formation at a vertical depth below 12,800 ft. The entrapment of hydrocarbons is caused by a low amplitude, seismically subtle, anticlinal fold trending northwest/southeast. Isochore maps of the Burbank formation show that stratigraphy is important in the distribution of the four producing sand intervals. Oil gravities from the sands vary 39° API to 51° API and the GOR ranges from 1,050 to over 5,500. As of January 1, 1984, the field has a cumulative production of 1.7 million bbl of oil and 3.5 billion ft^3 of gas.