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Tectonics, Sedimentation, and Petroleum Potential, Northern Denver Basin, Colorado, Wyoming, and Nebraska

A stratigraphic analysis of Paleozoic and Mesozoic strata in the northern Denver basin shows that recurrent movement on basement faults influenced sedimentation, especially during major sea-level changes. The research integrates surface and subsurface data for an area of approximately 30,000 mi^2 (77,700 km^2).

Twenty stratigraphic intervals in the Paleozoic and Mesozoic were identified from well data. Areas of thickness variations on isopach maps within these stratigraphic intervals are caused by onlap, offlap, convergence, and subtle unconformities which may be directly related to the development of paleostructure. In general, thin areas on isopach maps correspond to paleohighs and thick areas correspond to paleolows. In the northern Denver basin, four major northeast-trending paleostructures had recurrent movement during the Permian and Cretaceous, and three major northwest-trending paleostructures had recurrent movement during the Pennsylvanian, Permian, Triassic, and Cretaceous. Wedge-outs of Cambrian, Ordovician, Mississippian, and Triassic strata were also controlled by the northeast- and northwest-trending fault systems. In addition, the late Paleozoic stratigraphic sequence is thicker in the subsurface than in surface measured sections which is evidence for major paleostructure movement.

The tectonics and sedimentation model of recurrent fault-block movement will aid in the exploration for hydrocarbons in the Denver basin by predicting the distribution of both source and reservoir rocks and by identifying early traps associated with paleostructures. Moreover, the large number of wells which penetrate only the Cretaceous section may be used in some areas to predict the Paleozoic paleostructure.

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Influence of the Pre-Cretaceous Unconformity on Deposition of Lower Mannville Clastic Sequence, Drumheller, Alberta

The paleotopography of the Pre-Cretaceous unconformity and distribution of the overlying sediments has been examined in a 576 mi^2 (1,491 km^2) area of south-central Alberta using all available cores, geophysical logs, selected well cuttings, micropaleontology, and seismic sections. Control averages one well per square mile.

The Cretaceous strata in this area lie unconformably on Mississippian carbonates and shales. The relief is controlled, in part, by the lithology of the subcropping Paleozoic formations.

The basal sandstones of the lower Mannville are valley-fill deposits ranging in thickness from 0 to more than 100 ft (30 m). They are separated from the underlying Paleozoic carbonate rocks by a detrital assemblage consisting of variegated, poorly sorted, cherty rocks. This thick basal quartz sandstone assemblage can be subdivided into a number of distinct lithic units which are recognizable on the basis of core studies, but are not readily identifiable on geophysical logs.

Three different lithic units have been mapped integrating all available data. A depositional model has been constructed which clarifies the relation between the unconformity and the occurrence of basal quartz hydrocarbon reservoirs.

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Model of Ocean's Coupled Carbon, Oxygen, and Phosphorous System

A simple steady-state one-dimensional advective-diffusive model of the coupled carbon, oxygen, and phosphorous system is developed. The model can be viewed as an extension of Wyrtki's model of the oxygen distribution. The occurrence of anoxia requires two conditions: (1) sufficiently high productivity, and (2) sufficiently low oxygen concentration in the bottom water. It is shown that anoxia is likely to occur fairly high in the water column (as the present-day oxygen minimum does).

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Prudhoe Bay Field—Geophysical Case History

In June 1968, ARCO-Exxon completed the Prudhoe Bay State I well, discovering the largest oil accumulation in the United States. This discovery was the result of a 4-year seismic program which began in 1963. Prior to this time, and beginning in 1943, the U.S. Navy carried out a 10-year exploration program within Naval Petroleum Reserve 4. Small accumulations of oil and gas were discovered on NPR 4 during this period. Industry exploration started on the North Slope in 1958 with geologic field work. The first industry seismic work began in 1962. Initial emphasis was between the Colville and Canning Rivers on federal acreage within the foothills belt north of the Brooks Range. By 1963, each of the three predecessor companies of Atlantic Richfield (Atlantic Refining Co., Richfield Oil Corp., and Sinclair Oil Corp.) were involved in separate geophysical exploration programs. North-south regional seismic lines and State of Alaska land availability resulted in shifting, in 1964, the exploration effort north to the Arctic coastal area. By this time both the Prudhoe Bay and Colville structures had been delineated. In December 1964, during the first state sale on the North Slope, Sinclair in partnership with British Petroleum (now Sohio-BP) leased the entire Colville structure. By mid-1965 additional seismic control had further defined the Prudhoe Bay structure. The critical state lease sale of July 1965 determined the eventual ownership of Prudhoe Bay field. It resulted in Richfield-Humble (now Exxon) buying the top tracts, with BP acquiring flank acreage. In January 1967, ARCO-Humble acquired additional offshore tracts. Prior to the Prudhoe discovery well in January 1968, 10 wells had been drilled on the North Slope by industry without commercial success.

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Pyrolitic Properties of Maceral Types

The gas and oil generation potential of organic matter of a source rock depends on the nature of the organic matter and its thermal history. The maceral composition is a direct measure of the original organic matter in immature rocks. The optical properties of specific maceral groups are used for the determination of their degree of maturation. Pyrolysis is a means for the evaluation of the generation potential. A combination of these methods enables a comparison of generation properties of different sources.

Kerogen concentrates were separated by heavy liquids into fractions enriched in a single maceral group (algae, altered algae, particulate liptinites, amorphous liptinites, amorphous humic matter, vitrinite, and inertinite). Their composition and maturation level were defined by transmitted light, fluorescence, and vitrinite reflectance. These measurements were repeated after pyrolysis.

The proportion of volatilized material ranges between 84 and 5% for algae and inertinite, respectively. The hydrocarbon yield ranges between 660 and 13 mg hydrocarbons/g organic matter for amorphous liptinites and inertinites, respectively. The residue after pyrolysis resembles inertinite ranging from micrinite to inertodetrinite except for vitrinites (and inertinites) which retain their textural characteristics. These types of inertinites occur in overmature sequences. The yields obtained by pyrolysis may be used to estimate the relative potential of the different maceral types. They possibly represent maximal values.

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Diagenesis of Frontier Formation, Moxa Arch, Wyoming—Function of Sandstone Geometry, Texture, and Composition of Fluid Flux

The lower Frontier Formation, Moxa arch, Wyoming, consists of sandstones and mudstones deposited in a wave-dominated delta and strand-plain system which prograded into the western margin of the interior Cretaceous seaway. Depositional environments in this system were offshore marine, marine sand ridges, marine shoreline, distributary channel, fluvial, and flood basin. Sediment from the Sevier orogene was sorted into different compositional and textural assemblages in depositional environments with different energies. Because of original differences in physical and compositional characteristics, diagenesis proceeded along different paths in different facies. The most important facets of original detrital composition affecting diagenesis are original clay content and the monocrystalline quartz/chert ratio.

Diagenesis was also very sensitive to fluid flux. Sedimentary textures and sand-body geometries were important controls of fluid flow during dewatering. In the southern part of the study area, erosion eliminated the shoreline interval leaving only thin fluvial sandstones overlying offshore marine rocks. To the north, the shoreline facies was not eroded and the sandstone interval is thicker. On the assumption that sandstones received the discharge from equal volumes of shale, the thinner fluvial sandstones to the south experienced a far greater throughput per unit volume of sand and a higher rate of flow than did the thicker combined fluvial and shoreline sequence to the north. As a result, the southern sandstones are extremely porous and permeable and show signs of extensive leaching, whereas in the north there is more evidence of in-situ reactions resulting in the development of abundant authigenic and neomorphosed clays. Here, porosity and permeability are poorer.

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Depositional Environments of Tyler Formation in Fryburg and Rocky Ridge Area, North Dakota

The Tyler Formation in southwestern North Dakota is a regressive barrier-island system dominated by two environments: (1) lagoon and (2) barrier-beach complex. The barrier islands formed along an east-west line in Golden Valley, Billings, and Stark Counties. Thickening eastward (5 to 20 ft), a gradational, coarsening-upward sequence of very fine to medium-grained, well-sorted quartzose sandstone is developed in the Medora, Fryburg, and Green River fields. Where there is good development of a shoreline, massive fine-grained, well-sorted sandstones with discontinuous, wavy carbonaceous laminae (foreshore environment) overlie fine-grained, well-sorted, cross-laminated, and bioturbated sandstones (shoreface environment).

Northward, several offshore sand bars developed in a predominantly shallow restricted sea, typified by medium-gray to grayish-black ripple cross-laminated argillaceous limestones and shales. On the south, in a landward direction, barrier-island sands interfinger with grayish-black carbonaceous lagoonal shales, coal, and mudstone marsh deposits and varicolored mudstone tidal-flat deposits. The sandstones present in the Rocky Ridge vicinity are characteristically medium grained and silty, and exhibit unidirectional cross-stratification. They are interpreted as channel deposits disecting a landward facies of the lagoonal environment.

The upper Tyler Formation is a regressive sequence characterized by anhydritic mudstones, desiccation features, and local chickenwire anhydrites overlying dark-gray fossiliferous, argillaceous limestones and shales.

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Role of Organic and Inorganic Reactions in Development of Secondary Porosity in Sandstones

The development of secondary porosity in many sandstones is the result of aluminosilicate and/or carbonate dissolution. The dissolution of aluminosilicates and creation of secondary porosity is a problem of aluminum mobility. Our experimental data demonstrate that it is possible to increase significantly the mobility of aluminum and to transport it as an organic complex in aliphatic acid solutions. The same aliphatic acid solutions have the capability of destroying carbonate cements and debris.

Carothers and Kaharka have shown that concentrations of aliphatic acid anions range up to 5,000 ppm over the temperature range 80 to 200°C in some oil field formation waters. Our experiments show that acetic acid solutions at the same concentrations and over the same temperature range can increase the solubility of aluminum by a half an order of magnitude, whereas oxalic acid solutions increase the solubility of aluminum by an order of magnitude. The textural relations observed in the experiments are identical to those observed in sandstones containing secondary porosity as a result of aluminosilicate dissolution.

A natural consequence of the burial of sedimentary prisms is the maturation of organic material. These maturation reactions result in the evolution of significant amounts of organic acids and carbon dioxide. The experiments suggest that the development of secondary porosity in a sandstone as a result of aluminosilicate or carbonate dissolution is the natural consequence of the interaction of organic and inorganic reactions during progressive diagenesis. The degree to which secondary porosity develops depends on the ratio of organic to inorganic matter, the sequence, rates and magnitude of diagenetic reactions, fluid flux, and sand/shale geometry.

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Effective Exploration Strategy—Stratigraphic and Paleostructural Controls on Hydrocarbon Migration in Denver Basin

Current exploration strategies generally focus on trap identification and the organic richness and maturity of source rocks. Yet, examination of producing basins worldwide commonly indicates a non-uniform distribution of production in basins, which is not related just to trap and source location. Clearly, exploration based on such a strategy may focus efforts on an area where traps