tions 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 and source rocks may appear conducive to hydrocarbon accumulation but where there are no hydrocarbons.

A more effective strategy can be developed by first understanding the factors which control the path hydrocarbons take during migration. By determining the timing of hydrocarbon migration, the stratigraphy of carrier beds, and the paleostructural configuration of a basin at and since the time of migration, the pattern of hydrocarbon migration can be modeled. From this it is possible to make a reasonable prediction of the present distribution of hydrocarbons in a basin on a regional scale and to form an effective exploration program for prospect generation.

This model is successfully applied in a test case to the middle Cretaceous D and J sands of the Dakota Group in the Denver basin. Most production in the basin is from these sands and is located in a 75-mi (121 km) wide fairway stretching from Denver east and north into western Nebraska. Hydrocarbon migration appears to have begun some time between the Late Cretaceous and middle Tertiary; hydrocarbons migrated a distance of up to 100 mi (161 km). Combination of paleostructural and stratigraphic maps indicates hydrocarbons were focused into the fairway mainly by the stratigraphy of the sands.

This strategy works well in an already productive basin and can be particularly useful in frontier areas to make exploration programs more effective.

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Fluctuations in Marine Productivity Through Time: Inverse Relation with Terrestrial Floras

The earth's primary productivity was essentially aquatic before the mid-Devonian expansion of a vascular plant biomass. As organic carbon, nitrogen, and phosphorus were retained on land, the abundant phytoplankton was adversely affected. When nutrients that were utilized, buried, and not recycled exceeded the amount newly added, the early Paleozoic phytoplankton that were adapted to a high nutrient level either disappeared or greatly declined in importance.

The late Paleozoic fern-lycopsid-arthrophyte flora produced a second major land biomass increase. Organic carbon and nutrients were locked in the black shales and coals, and marine productivity remained low. After the Permo-Triassic regression, coastal swamps no longer bordered the Pangean supercontinent, so less organic carbon was buried and more was released into the surrounding seas. Coccolithophores and dinoflagellates diversified and marine productivity expanded in the Jurassic and Cretaceous, reinforced by the new siliceous phytoplankton (diatoms, silicoflagellates, chrysomonads). As mid-Cretaceous expansion of the deciduous angiosperms raised the carbon and nutrient content of the soils, their seaward transport decreased and marine productivity dropped catastrophically in latest Cretaceous time. After a renewed Paleogene expansion, the warm-water plankton again declined, and diatoms inhabiting the colder nutrient-rich upwelling waters became the dominant Neogene producers.

High productivity, reflected in carbon isotope ratios and petroleum deposits, was attained by those microfloras best utilizing contemporaneous nutrient levels. When successive land floras rapidly sequestered increased amounts of organic carbon and nutrients in biomass, soil, and sediments, the accumulations of land-derived organic detritus coincided with nutrient shortages in the seas and phytoplankton and marine productivity declined.

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Petroleum Resource Evaluation Procedure—an Example

The Middle Devonian barrier carbonate complex of northeast British Columbia is the locus of significant gas reserves (2.2 tcf). Future expected potential of this play is estimated to be 3.3 tcf. To make this estimate, the following procedure was used. First, an analysis of the paleogeography and stratigraphic relations of Middle Devonian units permitted us to formulize the facies model from which the opportunities for petroleum accumulation can be postulated. Second, reservoir parameters of the play were retrieved from the existing pool data file provided by the government of British Columbia. These reservoir parameters, including recovery factor, water saturation, reservoir pressure and temperature, gas deviation factor, area, net pay, and porosity, can be used in characterizing the undiscovered resource. The outputs of the statistical procedure used in the evaluation include the mean of play potential, number of pools which comprise the play potential, pool size, and reservoir parameters for each pool computed. These outputs, together with additional reservoir data, were used for economic analysis and simulation of future exploration history.

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Sedimentology and Mineralogy of Suffield Heavy Oil Sands (Lower Cretaceous), Southeastern Alberta

The Suffield heavy oil sands are found in the glauconitic sandstone of the Mannville Group in two major north-south-trending sand belts ranging in thickness from 15 to 20 m. The study area is centered around a heavy oil pilot site which is a joint venture operated by Alberta Energy Co., Alberta Oil Sands Technology and Research Authority, Dome Petroleum, and Westcoast Petroleum. At this location, the glauconitic sandstone is a 46-m thick, uninterrupted sandstone partly saturated with 13°API oil. The sandstone geometry, and the sequence of lithologies and sedimentary structures, indicate deposition in a prograding shoreline beach environment. An upward transition of facies from lower and middle shoreface sands, through foreshore, to backshore, marsh, and continental deposits, is represented. The sandstone is composed of quartz, chert, sedimentary rock fragments, trace amounts of feldspar, and 2 to 30 wt. % clay. Kaolinite, the dominant clay mineral, occurs as (1) small platelets forming grain linings and pore bridges, (2) vermicular growths, and (3) silt-sized rock fragments. Lesser amounts of illite, smectite, and mixed-layer clays occur as ridges on grain surfaces and as pore bridges. Illite can also occur as needlelike projections. The most argillaceous sands, located at the top of the sandstone unit, contain only very fine-grained kaolinite. Quartz overgrowths contribute to porosity reduction in the cleaner sands. Minor amounts of secondary porosity can be identified by the presence of partly leached feldspar grains.

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Paragenetic Relation of Thermal Maturation (Coalification) and Tectonic Framework of Some Canadian Rocky Mountain Coal

The attitude of the reflectance indicatrix of coal is a function of thermal history (coalification) and stresses (tectonics) at the time of maximum coalification. In normally coalified, horizontal-bedded coal seams, the maximum reflectance lies in a horizontal