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

plane parallel with bedding plane and the minimum reflectance axis is perpendicular to the bedding plane. If maximum reflectance is achieved prior to folding, the minimum reflectance is always perpendicular to the bedding regardless of the subsequent folding and the attitudes of the coal beds. Thus, the attitude of the minimum reflectance is a good parameter for evaluating whether maximum thermal maturation is achieved prior or after folding or other structural changes. Twenty-five samples were collected from coal-bearing strata from Monkman's Pass north to Sparwood, British Columbia, in the Canadian Rockies. Most of the coal beds sampled were highly disturbed by folding and faulting with dips ranging from a few degrees to overturned. Analysis results indicate distinctive groupings of the samples with the minimum reflectance deviating a few degrees to more than 30° from the normal of the bedding. This suggests a varied thermal history for the coal fields studied. The technique can be applied not only to the investigation of coal-bearing strata but also to the study of source rocks of petroleum as to whether thermal maturation occurs before or after a trap has been developed.

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Depositional History of Strawn Group (Pennsylvanian), Fort Worth Foreland Basin, Colorado River Valley, Central Texas

In the Colorado River Valley of central Texas about 1,200 ft (366 m) of Pennsylvanian (Desmoinesian) terrigenous clastic and carbonate facies were deposited in the Fort Worth basin. Paleocurrent and petrographic data indicate that the clastic provenance, to the west and northwest, was the rising Ouachita orogenic foldbelt.

Surface study suggests that the Strawn Group includes two main stratigraphic divisions: (1) a lower sequence representing basin and submarine fan sediments deposited as active tectonic subsidence substantially increased water depths in the Fort Worth basin; and, (2) an upper progradational sequence of fluvial-deltaic and carbonate plaform sediments deposited as passive isostatic subsidence or regional uplift to the east accompanied progressive shoaling of the sediment surface. The lower Strawn is characterized by sediment gravity flows suggestive of submarine fan deposition. It is subdivided into four facies (from proximal to distal): (1) massive channeled sandstone; (2) massive amalgamated sandstone; (3) turbidite; and (4) shale facies. The upper Strawn constitutes a delta-platform assemblage that includes: (1) delta facies including channel-mouth-bar sands, delta-front sands, delta-slope shales, and interdistributary fine clastics; and (2) carbonate platform facies that includes phylloid algal mounds and perideltaic bioclastic limestones.

The lower Strawn basinal shale and submarine fan sequence is gradational with the underlying basinal Smithwick Shale (Atokan) and records foreland basin subsidence synchronous with orogenesis in the Ouachita foldbelt. In contrast, the basal contact of the upper Strawn is variable. Generally, the upper Strawn is gradational with the lower Strawn but locally it rests disconformably on the Marble Falls Formation (Morrowan-Atokan). This stratigraphic relationship suggests that regional compressive forces from the Ouachitas were depositionally more important than previously supposed.

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Resource Appraisal and Environmental Problems Associated with Oil-Shale Deposits in Morocco

The best-known oil-shale deposit in Morocco occurs in the Middle Atlas region at an elevation of 5,000 ft (1,525 m), and contains total estimated reserves of 3.5 billion bbl. Approximately 1 billion bbl is amenable to open-pit mining techniques, having an overburden ratio of 0.8. Yields from this deposit reach maximum values of 45 gal/ton and average more than 20 gal/ton. Questionable infrastructure and extreme climatic conditions are important considerations, but do not represent major obstacles to development. Run-off of precipitation is very important in this region because the water is used for field irrigation. Major changes from the present hydrologic pattern could easily destroy the dominantly cedar vegetation and adversely affect the most important inland recreational area in the region.

Conditions are much more favorable for developing the 100 billion bbl deposit situated near Tarfaya. This oil shale averges 19 gal/ton and approximately 60% of the deposit has an overburden ratio of 0.8 and thus could be mined in an open pit. Suitable infrastructure conditions exist in this area, including a harbor, an airport, and asphalt roads. Proximity to the Atlantic Ocean, stable climate, and low precipitation conditions help resolve problems which exist for other oil-shale deposits worldwide. Under these conditions, this particular deposit could be exploited by above-ground retort technology.

Development of these two deposits would be in contrast to current United States operations which tend to favor in-situ processing because of environmental considerations.

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Utopia Algal-Bank Complex and Its Potential in Shallow Gas Exploration in South-Central Kansas

The Utopia Limestone (Upper Pennsylvanian) was deposited as a series of algal banks forming a narrow arcuate band approximately 25 mi (40 km) long on the shelf margin of Sedgwick basin in south-central Kansas. Utopia banks may attain a maximum thickness of 70 ft (21 m) and are encased in a dark gray shale, creating excellent reservoirs for hydrocarbon accumulation. Having porosities of up to 22%, the Utopia produces economic quantities of gas from depths of 2,000 to 2,500 ft (610 to 762 m).

The Utopia contains three distinct facies: (1) biomicrite, the "core" facies; (2) calcilutite, an *Osagia*-coated biosparite, the mound facies; and (3) an oolitic facies associated with the mound. The facies distribution was controlled by basin geometry and the variations in the subtidal and intertidal environments of the shelf. Sedimentation rate approximately equaled subsidence rate, maintaining the position of the bank tops within the shallow intertidal range. The banks are slightly asymmetrical and thicken basinward. The initial mound accumulation began with the deposition of a biomicritic mound "core," in a quiet-water environment. The major constituents of the calcilutite facies are green algae (*Osagia* and *Epimastopora*), along with a wide assortment of shallow-water biota. The oolite shoal facies formed contemporaneously beside the mound facies.

Subaerial exposure and subsequence leaching of the banks during successive marine transgressions created the intraparticle and oomoldic porosity. Locally, dolomitization of the algal fragments occurred.

Results of this study indicate that further exploration in this area and basinward should prove profitable.

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Hydrocarbon Migration and Accumulation as Influenced by Growth-Fault Building Mechanism