Structural, stratigraphic, and geomorphic analyses have been performed to locate geologic anomalies. Image analysis provides a better understanding of the regional stress-strain relations for tectonic correlation.

Digital Landsat (satellite) data were processed to produce a variety of images (i.e., edge-enhanced, high pass filter, false color, and ratio). Some of the images were geometrically corrected with map controls and nonlinear deconvolution resampling techniques (coverage 13,000 mi^2; 33,670 km^2). This helped facilitate more detailed mapping, interpretation, and data integration. These specially processed images have been used to map surface geology, lineament systems, and tectonic anomalies in relation to subsurface geologic and geophysical data.

Project areas are defined in terms of tectonic genesis, structural trends, and hydrocarbon potential. Numerous exploration targets and several modes of hydrocarbon entrapment were identified by geologists at the TCU Center for Remote Sensing and Energy Research. This information is being used by various companies for planning their seismic programs in these frontier drilling areas.

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Manetoe Facies—Gas-Bearing Late Diagenetic Dolomite of Northwest Territories, Canada

The white coarsely crystalline space-filling and replacement, late-diagenetic Mississippi Valley–type dolomite of the Manetoe facies occurs across a broad area of at least 15,000 sq km in the southern Mackenzie Mountains of the Northwest Territories. Through most of this area it is stratiform and confined to a thin (<100 m thick) stratigraphic interval under a shale unit within a lower Paleozoic carbonate sequence. Some large vertical developments of the Manetoe facies, such as at the Kotaneelee and Pointed Mountain gas fields, occur in the eastern part of this region where the overlying shale of the Headless Formation is thin. These large dolomite masses have a core of dolomite-cemented breccia and are surrounded by a halo of replacement dolomite. Solution-collapse breccias and large solution cavities are common throughout. Quartz and bitumen are the final vug infillings. The pronounced curvature of Manetoe dolomite crystal faces is similar to that displayed by many Mississippi Valley–type dolomites.

These dolomites are nearly stoichiometric with a mean of 51 mole % $CaCO_3$, and they exhibit a high degree of cation order. The range of carbon isotope values ($+1.33$ to -2.99 δC^{13}PDB) and a sodium concentration of ~100 to 350 ppm are typical for this type of dolomite. But the range of oxygen isotope values (-8.03 to -17.33 δO^{18} PDB), the extremely high strontium content of ~200 to 1,000 ppm, and an iron content less than 120 ppm is atypical and must reflect precipitation from a medium of unusual composition, enriched in strontium but depleted in iron and in the O^{18} isotope.

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Rb-Sr Dating of Illite Diagenesis

In the Woodford Shale (Upper Devonian), apparent Rb-Sr ages decrease as clay grain size decreases, which in turn correlates with increasing abundance of diagenetic illite. Analyses of the fine-clay size fraction ($<0.2\mu$) from widely spaced wells in the Delaware basin of west Texas, plot on a single isochron indicating an age of 300 ± 4 m.y. (Middle Pennsylvanian). At this time the Woodford was buried only 200 to 600 m; consequently diagenesis must have been triggered by a circumstance other than deep burial. Possibly diagenesis was accomplished by hydrothermal fluids moving toward the craton out of the Ouachita geosyncline, which at that time was experiencing horizontal compression. These fluids may have been responsible for petroleum migration and lead-zinc mineralization.

In the Frio Formation (Oligocene) of the Texas Gulf Coast, samples of fine clay-size material ($<0.06\mu$) from the 3 to 5 km depth interval in a single well also provide a well-defined isochron corresponding to 21.6 ± 2.2 m.y. Burial here was possibly so rapid that transformation of smectite to illite approximated an episodic event over the entire depth interval. Alternatively, because the sediment is geopressured, the age might record the time of geopressure development which was accompanied by a rapid rise in temperature.

Clay diagenesis at the surface is illustrated by a paleosoil developed on Pennsylvanian shale in the Llano uplift of central Texas. The paleosoil was buried by Cretaceous basal conglomerate and records the time of marine transgression 119 ± 3 m.y. ago. Constituents of the shale were degraded by soil-forming processes which erased previous isotopic memory, then reconstituted by coming in contact with marine water. This field relation offers a new way to date directly a time of sedimentary deposition.

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Was the Mannville Group the Source for Alberta's Heavy Oils?

The Western Canadian basin hosts about 12 billion bbl of conventional oil in Devonian to Cretaceous reservoirs. Lower Cretaceous heavy-oil sands contain 1,300 to 2,600 billion bbl in place. They represent the biodegraded remnants of supergiant conventional deposits, the source for which has been thought to be mature rocks of the equivalent-age Mannville Group. This work shows, however, that the Mannville rocks alone are incapable of generating the required volume of hydrocarbons.

Volume of hydrocarbons generated in the Mannville under central Alberta was calculated by combining measured geochemical and geologic data with a model (modified from Lopatin's method) for thermal maturation. Original hydrocarbon generative capacity of the Mannville rocks was calculated from geochemical analyses of immature samples. Using average values for TOC (1.3%) and Rock-Eval Hydrogen Index (100 mg HC/g TOC), maximum hydrocarbon generation per unit volume of source rock was calculated. The maturation model was then employed to estimate the extent to which maximum yield has been achieved.

Total volume of source rock in the basin was obtained from isopachs of Mannville shale. Multiplication of actual oil generation per unit volume by source rock volume gave a generated volume of 450 billion bbl. Inclusion of oil generated in the Foothills belt would less than double this number. These calculated values are exceedingly optimistic, however, because they ignore inefficiencies in expulsion and migration. It is therefore clear that the Mannville Group cannot be the major source of the heavy oils. Dominant contributions probably come from Paleozoic and other Mesozoic rocks.

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Petroleum Geology of Central Beaufort Sea, Northwest Territories, Canada

Drilling on the continental shelf of the Central Beaufort Sea has led to significant oil and gas discoveries. There is considerable optimism that the region may encompass a new oil basin. Hydrocarbons are present in Eocene and Oligocene strata. The environment of deposition, established by paleontology and seismic facies analysis, is deep marine. Reservoirs are considered to be sand, transported by turbidity currents and deposited as deep-sea fans. The resulting accumulations are constructional in that they form large mounds and are readily identified on seismic sections taken parallel with the sedimentary strike of the deposits. Traps are stratigraphic where closure is the result of deposition, and structural where shale swells have arched the sand layers. Timing of the latter may play a significant role in the migration and final concentration of hydrocarbons. Marine shales form an effective seal.

The first conventional cores of the reservoirs were cut during the 1981 drilling season. At Koakoak O-22, several oil-bearing sands were recovered. Porosities averaged 29% and permeabilities ranged from 61 to 2,500 md with an average of 1,000 md. The fine to medium-grained sands are friable with very little clay matrix.

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Evidence of Cross-Formational Flow Above Healdton Oil Field, Carter County, Oklahoma

An anticlinal trap is the locus of deep-water discharge with hydrocarbons being retained while the water is transmitted vertically through the sediments. The change in the sense of water movement from lateral to vertical at the apex of the anticline is accompanied by temperature- and salinity-gradient changes. Because of this, it might be possible to outline an oil field by an analysis of these gradients over an anticline.

To test this hypothesis, Healdton anticline, Carter County, Oklahoma, a textbook example of an anticline, was selected for study. This paper examines by an analysis of the salinity and geothermal gradients in the shallow beds the probability of cross-formational flow through the anticline. A large amount of data is available from electric logs of wells drilled in Carter County. Using the spontaneous potential curve and a modified computer program, formation-water resistivities were calculated and these resistivities were converted into total dissolved solids (salinity) based on empirical data from the study area. It is anticipated that contour maps of salinity and geothermal gradients will show the outline of the Healdton oil field.

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Tectonics and Sedimentation Along Continental Margin of Western India, Pakistan, and Adjacent Arabian Sea

The Chagos-Laccadive Ridge and its northern extension, the Lakshmi Ridge (CLLR), trending parallel with the coastline in the deep eastern Arabian Sea, is a continental fragment (with crustal thickness >20 km). Sea-floor spreading-type magnetic anomalies are absent and crustal thickness is about 16 km in the region east of CLLR. West of the ridge, magnetic anomalies, from 5 to 28 on the magnetic time scale, are present and the crustal thickness is 11.5 km. The magnetic anomalies, crustal thickness, and considerations of land geology suggest that most of the sedimentary basins in the region east of the ridge were initiated during the rifting stage in the Late Cretaceous, whereas those in the western region evolved during sea-floor spreading since 64 m.y. ago. The NNW-SSE and to some extent northeast-southwest and ENE-WSW basement trends, as well as associated horsts, grabens, and growth faults in the eastern region, formed as a result of reactivation of the ancient Precambrian trends observed on the Indian shield during and after rifting, and have determined the shapes, extents, and tectonic styles of the sedimentary basins there. The acoustic structure of sediments suggests that a basal sedimentary layer with a velocity of 4.0 to 4.3 km/sec is present in the region east of CLLR, but is absent west of it. This sediment layer, believed to be composed of clastics, volcaniclastics, and limestone, was probably deposited during the rifting stage. The seismic layers and the velocity structure (1.9 to 3.5 km/sec) of the overlying sediments are similar both east and west of the CLLR and suggest similar influences on sedimentary evolution in both the eastern and western regions during sea-floor spreading. However, sea-level changes during the Cenozoic in conjunction with tectonics resulted in several unconformities in the shelf sedimentary sequences. By about Oligocene and Miocene times, with the closure of Tethys Sea and the uplift of Himalayas, terrigenous sediments from the Himalayas became important for the northern margin and initiated the Indus deep-sea fan.

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Estimation of Paleo-Pore Pressure and Time of Hydrocarbon Expulsion—Computerized Simulation Model

A geological simulation model of generation and expulsion of hydrocarbon can be a useful tool in hydrocarbon exploration. The advantage of the model is to realize different environments in which hydrocarbon accumulations form under various geologic conditions.

A geologic cross section of an area is divided into a series of vertical columns, which are sectioned into rectangular cells. The model simulates the various geologic processes during basin development: (1) burial compaction of sediments, (2) history of temperature estimated from thermal conductivity and heat flow, (3) R_O (vitrinite reflectance) value calculated by Lopatin's method, and (4) the amount of generated hydrocarbon as a function of generation potential and of transformation ratio represented by R_O. Increase of pore pressure is assumed to be caused by (1) increase of overburden, (2) increase of volume of free water resulted by clay dehydration, (3) aquathermal expansion of water, and (4) expansion of fluid phase by hydrocarbon generation. Residual pore pressure in each step of geologic time in the model is calculated by Rubey-Hubbert's equation:

$$P_A = kT + (P_O - kT) \cdot e^{-t/T}$$

where P_A = residual abnormal pressure, P_O = initial abnormal pressure, k = ratio of pressure increase, t = duration, and T = relaxation constant. T is a function of permeability that is derived from porosity and grain size. The amount of hydrocarbon expelled is calculated from residual abnormal pore pressure as a function of relative permeability and viscosity of fluids. Direction and time of hydrocarbon migration can be interpreted from spatial distributions of paleo-pore pressure and of hydrocarbon expelled from source rocks for each geologic time.

The model is applied to the Niigata sedimentary basin of the coastal region of the Sea of Japan. Regional differentiation of time of hydrocarbon accumulation in the basin is observed. Upward hydrocarbon migration across the strata is also implied at culminations of the trapping structures.

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