

$^{87}\text{Sr}/^{86}\text{Sr}$ ratios of any seawater during the Phanerozoic. The lithologic character of the host reservoir rocks had little influence on the strontium isotopic composition of the oil waters. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of the waters, at least those from Ness, Hodgeman, and Ford Counties, correlate positively with Sr/Ca ratios (2×10^{-2} to 10×10^{-2}) and negatively with total dissolved solid (TDS) contents (32 to 48 g/L). The results of the strontium isotopic investigation have several implications for understanding migration and accumulation histories of the oils. The strontium isotopic data can be useful in providing information on the hydrologic relationship among oil pools in an oil field and in determining the genetic relationship among oils produced from stratigraphically separate reservoirs within an oil field. The strontium isotopic data of oil-field waters are useful potentially in differentiating an oil-bearing reservoir from an oil-barren reservoir within an oil field.

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Influence of Precambrian Shear Zones on Paleozoic Rocks in Southeastern Colorado

Recurrent movement along Precambrian-age shear zones throughout the Pennsylvanian and Mississippian has been a significant factor controlling depositional patterns during these periods. The displacement, although subtle and superposed on the epeirogenic movement, appears to have affected locally the bathymetry or paleotopography in the vicinity of the Las Animas arch. As a result, lithofacies distribution of either clastic or carbonate rock is related to proximity to the shear zones.

Surface lineations derived from Landsat analysis, coupled with lithofacies mapping based on subsurface data, identify the location of several shear zones in the region. The northeast and northwest orientations of these fault zones is subparallel to mapped faults in the Rocky Mountain region. Lithofacies mapping on a regional scale indicates the fault zones may have controlled the orientation and location of middle Morrowan sandstones. Similarly, the fault zones are thought to control Mississippian facies and subsequent dolomitization.

In addition, differential movement of fault blocks bounded by the shear zones is thought to have influenced formation of the Sierra Grande and Apishapa uplifts as well as the Las Animas arch. Isopach and lithofacies mapping show that precursors to the present Las Animas arch were present intermittently during the Mississippian and Pennsylvanian. Although these ancestral folds were not as positive as the present arch, they were oriented in the same general direction and as a result were influenced by the same set of shear zones.

The significance of the shear zones in controlling stratigraphy and structural development of the arch has been a factor largely overlooked during past petroleum exploration in the region. Further study of these shear zones is expected to lead to significant future petroleum discoveries.

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Computer-Assisted Exploration in Kansas

Some explorationists have regarded computers in the same category as dry holes, however, their capabilities for efficiency, assembling, and manipulating data cannot be disputed.

By inputting the following data—(1) geologists' correlated log tops on 33 horizons, (2) location and times of selected intervals of 1,400+ mi (2,250+ km) of CDP seismic data, and (3) completion and production information on 10,000+ wells in western Kansas—the efficiency, accuracy, and productivity of the exploration department at Voyager Petroleum, Inc., have increased by at least 500%. A county map printed by the computer with geologists' correlated tops and geophysical data can be hand contoured in one working day. A prospect can be in final drafted form in two working days. Submittals can be evaluated almost instantly. All data entries are verified previously so accuracy is insured.

The use of the computer has allowed the geologist to evaluate the region in a time-efficient and cost-efficient manner. The resulting prospects therefore are based upon a thorough understanding of the geologic constraints that control hydrocarbon distribution. Additionally, computer speed and versatility allow unconventional data manipulation resulting in prospects which would have been overlooked by using conventional exploration techniques.

All newly released information is being integrated weekly insuring a complete and accurate western Kansas data base.

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Control of Arbuckle (Cambrian-Ordovician) Production by Block Faulting

The Central Kansas uplift is a collapsed arch which was eroded to granite on both sides of a central graben during the post-Mississippian. Uplift and collapse produced a myriad of horst and graben blocks affecting the Arbuckle Group below the so-called pre-Pennsylvanian unconformity.

Arbuckle production comes from horst blocks, and about 75% of the Arbuckle production on the uplift comes from blocks within the central graben. Mapping Arbuckle structures as fault blocks rather than as erosional features allows a completely different use of subsurface data and can lead to many unsuspected field extensions and wildcat prospects.

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Naturally Occurring Hydrogen Gas from a Borehole on the Western Flank of Nemaha Anticline in Kansas

Since August 1982, the CFA 1 Scott well in Sec. 20, T14S, R6E, Morris County, Kansas, located about 14 mi (23 km) south of Junction City, has yielded a gas composed of $50 \pm 10\%$ free hydrogen, $50 \pm 10\%$ nitrogen, and only traces of hydrocarbons. This analysis has been ascertained by gas chromatography and mass spectrography of samples taken over a period of 6 months. The reservoir rock is a "Kinderhook" sand from 2,176 to 2,196 ft (663 to 669 m) depth. The gas samples analyzed are accumulating in the head space above a fluid level (salt water) of 1,805 ft (550 m) from a bottom-hole depth of 2,197 ft (670 m).

The Scott well is located on the western flank of the complexly faulted Nemaha anticline, updip from the central North American rift system and 30 mi (48 km) south of Riley County where serpentinized kimberlites occur. The geothermal gradient is $30^\circ\text{C}/\text{km}$ ($87^\circ\text{F}/\text{mi}$). Basement rock beneath the well is granite, probably overlying deeply buried magnetic rocks.

Bulk composition of gas from the Scott well is similar to H_2 -rich gases issuing from hydrothermal vents at the 21°N site on the East Pacific Rise, and to certain gases occurring within the Zechstein strata of Poland.

Mechanisms proposed by others to explain the origin of naturally occurring free hydrogen include: bacterial or inorganic decomposition of organic matter; bombardment of organic matter by radioactive decay products; high-temperature magmatic and volcanic processes; dissociation of H_2O by low-temperature or metamorphic reactions involving sulfur species of the $\text{Fe}^{+2} - \text{Fe}^{+3}$ redox half reaction (e.g., during serpentinization of ultramafic rocks), and mantle out-gassing of primordial reduced gases. For some wells, artificial production of H_2 (e.g., oxidation of iron tools or pipe), also has been proposed to occur. Light, stable, isotope ratios (e.g., D/H, $^{18}\text{O}/^{16}\text{O}$, and $^{15}\text{N}/^{14}\text{N}$) may be distinctive sufficiently to rule out certain of the proposed H_2 -generating mechanisms.

No single mechanism is responsible solely for generating this H_2 -rich gas from the Scott well; rather, a combination of fortuitous geologic and possibly biologic processes are contributing in various proportions to the production of the H_2 and N_2 . Conceivably, the local geologic setting merely is circumstantial and unrelated to the genesis of the gases. However, in view of its spatial association with the central North American rift zone, a major geologic feature with similarity to the East Pacific Rise, the Kansas gas occurrence warrants additional study.

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Basement Rift Control on Oil Production in Eastern Kansas

Improved understanding of the central North American rift system (CNARS) offers a new interpretation of the basement structure in certain parts of the Mid-Continent. In eastern Kansas, basement structure can be shown to control oil production from some producing fields. Structural

control includes rotated blocks along faults created by horst and graben tectonics typically associated with rift zones.

A distinctive gravity signature, the Mid-Continent geophysical anomaly (MGA) is related directly to the CNARS and provides good data for interpretation of the basement structure. Some oil fields can be correlated directly with gravity-interpreted basement structure. Aeromagnetic and Landsat information, combined with the gravity data, further define exploration targets along the general trend of basement features.

Migration of thermally matured hydrocarbons into pre-Pennsylvanian, rift generated traps in the ancestral north Kansas basin is postulated. The Nemaha ridge subsequently divided that basin into two smaller basins, the present Salina and Forest City basins. Several exploration targets could exist in this area, with the Arbuckle, Simpson, and Viola units being primary targets. The source of hydrocarbons also may lie in the deep but distant Anadarko basin.

An additional totally untested hydrocarbon potential exists in the deep Precambrian/Cambrian sedimentary subbasins created along the flanks of the CNARS. Recent data points to sedimentary columns with depths of approximately 15,000 ft (4,500 m) which might be hosts to gas reserves similar to the Rome trough potential of the Appalachian region.

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Outlook for United States Natural Gas Industry: Pricing, Supply, and Demand

Major changes which are occurring in natural gas pricing and gas markets in the United States present new opportunities and challenges for the gas industry. This paper assesses the current importance of natural gas to the United States; future outlook for United States natural gas pricing, supply, and demand; potential for oil displacement by gas; and the benefits which would accrue to consumers and the nation from increased gas use. Particular attention is given to emergence of new, premium markets which will take advantage of the inherent cleanliness, efficiency, and operating advantages of natural gas.

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Ravia Nappe, Bryan County, Oklahoma: A Gravity Slide Block off the Tishomingo Uplift

The Ravia nappe in Bryan County, Oklahoma, is located along the southwestern flank of the Tishomingo uplift, between the Cumberland and East Durant oil fields. This mass of Cambrian-Ordovician through Mississippian sediments tectonically overlies younger Springer shales (Pennsylvanian) of the Ardmore basin. Previously, this feature has been interpreted to have been thrust southward along the Cumberland fault, a fault parallel to the Ravia thrust. Reinterpretation of this area, with additional well data, indicates the Ravia nappe is a gravity slide block off the uplifted Tishomingo mountains.

The Ravia nappe subcrops below the Cretaceous unconformity as a 16 mi² (41 km²) triangular-shaped mass with a maximum thickness of 4,800 ft (1,450 m). The fault surface along its base has a bowl-like shape. This surface is neither the Cumberland fault nor the Ravia fault, but appears to be a separate fault surface. The nappe consists of overturned Caney through Simpson rocks (Mississippian-Ordovician) along its southwestern edge (toe), whereas right-side-up Arbuckle carbonates (Cambrian-Ordovician) occur on the northeastern side (heel) of the nappe. Arbuckle carbonates of the nappe overlie an overturned-to-the-south syncline of Arbuckle through Springer rocks. This overturned syncline, on the footwall side of the Ravia fault, is present north of the Cumberland oil field and trends southeastward into Sec. 9, T6S, R8E. At this location the structural style of the Tishomingo footwall rocks changes from an overturned syncline south of the Ravia thrust to another thrust with a footwall fold. The Ravia thrust possibly terminates near this change in structural style with the other northeast-dipping thrust continuing southeastward to the East Durant oil field.

The Ravia nappe is interpreted to have been originally the southwest overturned limb of the Tishomingo uplift. Prior to the major thrusting on the Ravia thrust, but after compressional folding and uplift of the Tishomingo mountains, a breakaway fault formed across the most intensely folded beds. This breakaway fault undercut the overturned southwestern limb of the Tishomingo uplift in a concave-upward fault

surface. Gravitational forces caused the Ravia nappe Mississippian Caney rocks to Cambrian-Ordovician Arbuckle rocks to slide rotationally southwestward 2.5 mi (4 km). Topographic relief prior to the slide may have been as much as 9,000 ft (2,700 m). The slide occurred sometime during late Morrowan to early Desmoinesian.

Analogous of this type of deformation are present in the Owl Creek Mountains, central Wyoming; Front Range, northern Colorado; Qal'eh Raisi, southwestern Iran; and Belton anticline and Sulphur syncline, Oklahoma. These analogous structures and the Ravia nappe, show three common elements: (1) they are competent, erosion-resistant units which slide off the flanks of folded anticlines across softer shaly units; (2) the heel portion of the slide surface is a bedding plane fault, whereas the toe of the slide surface cuts across bedding planes; and (3) the driving mechanism is the gravitational force associated with tectonic uplift.

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Mid-Continent Rift System—A Frontier Hydrocarbon Province

Geophysical evidence in the Mid-Continent has led to delineation of a rift system active during the Proterozoic Y Era. The Mid-Continent rift system can be traced by the Mid-Continent gravity high and corresponding aeromagnetic anomaly signature from the surface exposure of the Keweenaw Supergroup in the Lake Superior basin southwest in the subsurface through Wisconsin, Minnesota, Iowa, Nebraska, and Kansas.

The Mid-Continent gravity high, which includes the highest gravity values within the continental United States, has been interpreted historically as a reflection of mafic extrusives, structurally high to the surrounding basement complexes. However, studies of analogous continental rifts and current rift theory call for existence of an anomalous mantle-derived body within the crust. The presence of this anomalous dense body is expressed by the narrow gravity high. The gravity high is imposed upon a broader gravity low which reflects the crust-mantle boundary's isostatic response to injection of mafic mantle material into the crust. Seismic refraction studies support this with findings of an unusually thick crust in the Lake Superior region. The surface response to the crustal attenuation and subsidence due to mafic loading during the late Proterozoic was the development of a deep rift valley and sedimentary basin.

The aeromagnetic anomaly signature of the rift trend discloses where these sediments have been preserved. Thick accumulations of upper Proterozoic sediments are indicated by both upward continuation of the aeromagnetic profiles across the rift trend and gravity models which incorporate: (1) a deep mafic body to create the narrow gravity high, (2) anomalously thick crust to account for the more regional gravity low, and (3) sedimentary accumulations on the Precambrian surface to explain the small-scale "notches" which occur within the narrow gravity high. Reflection seismic data are virtually unknown in the rift area; however, data recently acquired by COCORP across the southern end of the feature in Kansas provide evidence of thick stratified sequences in the rift valley.

Studies of the East African rift have revealed that the tropical rift valley is an exceptionally fertile environment for deposition and preservation of kerogenous material. Although penetrations of the Keweenaw rift sediments are extremely scarce, the occurrence of indigenous mobile crude oil in the White Pine mine on the Keweenaw Peninsula, Michigan, and bituminous partings in a core at the periphery of the Twin Cities basin, Minnesota, strongly support the extrapolation of a rich algal-fungal community throughout the sediment-filled valley of the Mid-Continent rift. Rift valley basins areally represent only 5% of the world's basins, but they have been determined to contain 10% of the world's present reserves. The Sirte, Suez, Viking, Dnieper-Donetz, and Tsaidam basins are just a few of the rift basins currently classed as "giant" producers. The existence of a rift basin trend with thick accumulations of preserved sediments, demonstrably organic rich, introduces the northern Mid-Continent United States as a new frontier for hydrocarbon exploration.

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Geophysics in Kansas and Its Role in the Petroleum Exploration Industry

The geophysics industry has played an active part in development of the petroleum industry in the state of Kansas. The diversity of productive