

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.

Analogues 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

strata and environments can be mapped with seismic data if used properly. Different targets demand different forms of the seismic reflection method. Examples of the types of reflection data, equipment, and practical uses will be shown, from analog systems of the past 30 years to state-of-the-art digital systems developed in the past year. Problems associated with these systems will be discussed.

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Morrowan Stratigraphy, Depositional Systems, and Hydrocarbon Accumulation, Sorrento Field, Cheyenne County, Colorado

The Sorrento field, located on the western flank of the present-day Las Animas arch in western Cheyenne County, Colorado, has approximately 29 million bbl of oil and 12 bcf of gas in place in sandstones of the Lower Pennsylvanian Morrow units. The sandstones were deposited in a fluviolally dominated deltaic system, and the trap for the hydrocarbon accumulation is formed by pinch-out of this deltaic system onto regional dip. The primary reservoirs are point-bar deposits.

At the Sorrento field, the basal Keyes limestone member of the Morrow formation rests unconformably on the Mississippian St. Louis Formation. Above the Keyes limestone, the Morrow shale is 180 to 214 ft (55 to 65 m) thick, and locally contains reservoir sands. The Morrow shale consists, in ascending order, of: (1) a lower marine shale averaging 40 ft (12 m) thick with minor limestone, siltstone, and sandstone; (2) a deltaic regressive sequence 10 to 65 ft (3 to 20 m) thick consisting of shoreline siltstone that grades laterally into channel-mouth siltstone and sandstone, flood-plain mudstone and coal, fluvial sandstone and conglomerate, levee deposits, and abandoned-channel mudstone; and (3) an upper marine shale averaging 105 ft (32 m) thick with minor limestone and siltstone.

The deltaic system prograded from northwest to southeast into a shallow, low-energy sea. The delta was inundated subsequently by regional transgression. The fluvial system of the delta was confined by levees to a meander belt; within this belt, the streams maintained a meandering character to the channel mouth. The major reservoir facies consists of fining-upward grain-size sequences of conglomerate and sandstone up to 55 ft (17 m) thick which are interpreted as point-bar deposits. Individual point bars within the field are characterized by sharp bases, lobate geometry formed by thinning toward the margins due to loss of section from the top, and diameters of 5,200 to 6,500 ft (1,600 to 2,000 m). The bases of the bars consist of very coarse sandstone and granular conglomerate with rip-up clasts of shale and coal. Where complete sequences are developed, the bars fine upward to fine-grained sandstone interbedded with shale at the tops. The point bars are overlain by marine shale with little reworking of the upper parts of the bars by marine energy. Channel-mouth bar deposits are developed only locally and are generally silty and tight. One well has encountered reservoir-quality channel-mouth bar sandstone which is distinguished from point-bar sandstone by better sorting, stratigraphic position, and finer grain size lacking the basal, very coarse sandstone and conglomerate.

Gas/oil and oil/water contacts are not uniform through the field owing to discontinuities between separate point bars. One such discontinuity is formed by an apparent mud plug of an abandoned channel separating two point bars on the southeastern end of the field.

In a well 7,000 ft (2,100 m) from the edge of the meander belt, the regressive sequence is represented by a shoreline siltstone unit 8 ft (2 m) thick with flaser bedding, graded bedding, load structures, and rare wave-ripple cross-bedding overlain by 3 ft (1 m) of flood-plain mudstone and coal with no indication of proximity to a nearby sand system.

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Control on Reservoir Distribution and Quality in Regressive Member of an Upper Pennsylvanian Cyclothem

Isopach maps and diagenetic features may be used to predict the distribution of reservoir-quality rock in the D-zone cyclothem of the Lansing-Kansas City Groups in southwestern Nebraska. The D-zone cyclothem was deposited during one major oscillation of the epeiric sea in Late Pennsylvanian (Missourian). This cyclothem records a transgression of

sea level followed by a major regression. During the regressive phase there was a brief sea level transgression.

The D-zone cyclothem consists of the four basic lithofacies common to most cyclic deposits of this age in northwestern Kansas and southwestern Nebraska: (1) a thin lower carbonate unit deposited in a shallow-marine environment; (2) a laterally extensive lower shale unit of marine origin resulting from a terrigenous influx from the north; (3) a complex upper carbonate unit deposited in shoaling water during waning terrigenous influx; and (4) an upper shale unit deposited in tidal flat to nonmarine environments.

Core data and an isopach map of the upper shale unit suggest that several shoal areas existed in Hitchcock County during part of the Missourian. Pellet, ooid grainstone deposition was localized on these bathymetric highs. The bathymetric highs may have been formed by (1) differential compaction of the upper shale unit of the underlying E-zone over erosional topography, or (2) movement on the ancestral Las Animas arch.

The presence of equant-calcite fringing cements in pores of the grain-supported rock indicate early diagenesis in a freshwater phreatic zone formed during initial subaerial exposure. Limpid dolomite rhombs intergrown with the early calcite cements and replacing the edges of some framework grains suggest cementation in a mixing zone. The highest stratigraphic occurrence of dolomite, if plotted on a cross section, forms a line which transects facies boundaries and may represent either the position of the mixing zone or an early paleowater table. The majority of the leached porosity in the grain-supported rock occurs above this line. Dolomitization of underlying carbonate facies probably occurred contemporaneously as the mixing zone migrated through the porous mud-supported sediments. Further enhancement of porosity may have occurred in a vadose zone above a later paleowater table. The position of this paleowater table is indicated by the distribution of skeletal fragments replaced by red silica, dissolution cracks infiltrated with nonmarine clay, and authigenic gypsum. These features formed during a later stage of diagenesis which took place contemporaneously with soil formation and calchification in the upper shale in a semiarid or arid environment.

Conclusions: (1) paleobathymetry is reflected in an isopach map of the upper shale unit; (2) distribution of grain-supported rock is controlled in part by formation of bathymetric highs while underlying shales compacted around preexisting topographic highs; (3) enhancement of porosity by dissolution in the grain-supported rocks occurred in the freshwater phreatic and vadose zones; (4) recognition of diagenetic features associated with formation of paleowater tables may be used to predict the distribution of porosity in these grainstones.

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Aeromagnetism in Exploration

Uses for aeromagnetic surveys include the evaluation of prospect leads and prospects that are controlled by basement fault movements. The identification of basement faults is based on the interpretation of the significance of magnetic edges. Magnetic edges are of two general types: (1) contacts between rock types within the basement, and (2) faults on top of the basement.

Traditionally, aeromagnetic surveys have undersampled so that magnetic-edge interpretations were not practicable. High resolution aeromagnetic surveys are designed so that basement faulting can be identified and interpreted. Interpretations must be made from magnetic records that have been processed adequately.

Many of the magnetic edges which are contacts between different basement lithologies are related to the paleostress fields and are caused by shearing. The identification of the components of the shear models help to explain the orientations of magnetic edges and help to identify the types of basement faults that can be expected. The interpretations are used as working hypotheses for establishing prospects and prospect leads in the overlying sediments.

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Computer Exploration in Graham County, Kansas

Oil production in Graham County, Kansas, is from the sands and carbonates of the Lansing-Kansas City Groups (Upper Pennsylvanian).