trolled by the total thicknesses of sediment deposited within the Mississippian lows, the varying types of lithologies deposited within the lows, the lithologic variations in the overlying sediments, the angle at which the seismic is shot across the Mississippian "channels," and the geometry of the Mississippian channel cut.

Accumulations of the Norcan-Fager type are subtle traps that are difficult to discover using only wireline logs. The key to successful exploration for Norcan-Fager-type reservoirs is geologic interpretation of seismic data.

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Wrenching and Oil Migration, Mervine Field Area, Kay County, Oklahoma

Since 1913, the Mervine field (T27N, R3E) has produced oil from 11 Mississippian and Pennsylvanian zones, and gas from two Permian zones. The field exhibits an asymmetric surface anticline, with the steeper flank dipping 30° east, maximum. A nearly vertical, basement-controlled fault occurs immediately beneath the steep flank of the surface anticline. Three periods of left-lateral wrench faulting account for 93% of all structural growth: 24% in the post-Mississippian to the pre-Desmoinesian; 21% in the Virgilian; and 48% in the post-Wolfcampian.

The Devonian Woodford Shale—and possibly the Desmoinesian Cherokee and Ordovician Simpson shales—locally generated oil in the Mesozoic through the early Cenozoic, which should have been structurally trapped in the Ordovician Bromide sandstone. This oil may have joined oil previously trapped in the Bromide, which had migrated to the Mervine area during the Early Pennsylvanian from a distant source. Intense post-Wolfcampian movement(s) fractured the competent pre-Pennsylvanian rocks, allowing Bromide brine and entrained oil to migrate vertically up the master fault and accumulate in younger reservoirs.

Pressure, temperatures, and salinity anomalies indicate that vertical fluid migration presently continues at Mervine field. Consequently, pressure, temperature, and salinity mapping should be considered as a valuable supplement to structural and lithologic mapping when prospecting for structural hydrocarbon accumulations in intracratonic provinces.

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Comparative Precambrian Stratigraphy Along Mid-Continent Rift Trend

In 1983, leasing agents representing several major exploration corporations appeared in the Lake Superior district of northern Wisconsin, an area best known for its exposures of Duluth gabbro and Mellen "black granite," and not for its hydrocarbon potential. The geologic column of interest is the 7,620+ m (25,000+ ft) thick clastic sequence termed the Keweenawan Supergroup (Precambrian), a basal shale that has been Rb-Sr-age dated at 1,075 ± 50 billion years. Within the past decade, this sequence has been recognized as having been deposited in response to tensional processes resulting in the development of a rift system. This Mid-Continent rift is best outlined by gravity and can be traced from the Keweenawan Peninsula of Michigan across northern Wisconsin, Minnesota, Iowa, and Nebraska into northeastern Kansas, a distance of 1,290 km (800 mi).

An organic-rich shale source unit is known in the Lake Superior area, where it creates intermittent subsurface oil seeps in the White Pine copper mine of Michigan. To the southwest along the trend of the rift, the extent of Keweenawan-equivalent sediments are masked by Paleozoic and younger sediments, increasing from a feather edge in central Minnesota to a reported 1,524 m (5,000 ft) in southwestern Iowa. In the mid-1960s, a natural-gas-storage drilling program centered on Dakota County, Minnesota, cored extensive thicknesses of Precambrian clastics, subsequently named the Solor Church Formation. This subsurface unit, together with surface exposures of the younger Hinckley Sandstone and Fond du Lac Formation, constitutes the Keweenawan section of Minnesota. Less is known of the Keweenawan-equivalent lithology of Iowa, where the Minnesota terminology is being used in geophysical studies of the Mid-Continent gravity high. Here, a late Precambrian "red clastic" sequence is known, apparently similar to that termed the Rice Formation in Kansas—a carbonate subordinate sequence of sandy shales and feldspathic sandstones.

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Petrology and Diagenesis of Pennsylvanian Collier Limestone, Hitchland Field, Hansford County, Texas

The Pennsylvanian Collier limestone in Hansford County, Texas, is found at depths of 4,500 to 4,700 ft at Hitchland field, along the shelf edge in the western portion of the Anadarko basin. Lithology and geometry of the limestone can be compared with Bahamian oolite shoals.

The four major carbonate rock types or facies present within the Pennsylvanian Collier limestone are: (1) oolite grainstone, (2) fusulinid pelletal mudstone, (3) bioclastic wackestone, and (4) bioclastic grainstone. Discontinuous, thin lime mudstones and shales are found above and below the Collier limestone.

A Collier isopach map indicates a northeast-southwest depositional strike. The Collier shoal complex extends approximately 20 mi in length and 5 mi in width with a maximum thickness of 45 ft. Paleogeographic slice maps reveal that three isolated shoals, adjacent and parallel to the shelf-slope margin, prograded shelfward, coalescing to form one large oolite shoal complex. The Amarillo-Wichita uplift and basin subsidence caused a rapid rise in sea level and a northward influx of clastic sediment toward the shelf. These events finally drowned and destroyed the carbonate environment that formed the Collier limestone.

Diagenetic alteration occurred in eogenetic and mesogenetic stages. During eogenetic diagenesis, five events occurred: (1) cementation of allochems by bladed isopachous calcite and coarse, equant, spar calcite in the freshwater phreatic zone; (2) dissolution of allochems in the freshwater, phreatic zone; (3) development of micrite envelopes in the marine phreatic zone; (4) fracturing of the oolite grainstone facies; and (5) Dorag dolomitization. Mesogenetic diagenesis included: (1) partial infilling by saddle dolomite in vuggy and moldic porosity; (2) fracturing of the oolite grainstone facies; and (3) stylolitization of the fusulinid pelletal mudstone facies.

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Dolomites Formed Under Deep Burial Conditions: Hunton Group Carbonate Rocks (Upper Ordovician to Lower Devonian) in Deep Anadarko Basin of Oklahoma and Texas

Petrographic and geochemical study of cores and cuttings from 25 boreholes ranging in depth from near surface to 30,000 ft (9.1 km) of the Hunton Group (Upper Ordovician to Lower Devonian), in the deep Anadarko basin of Oklahoma and the Texas panhandle, shows progressive burial diagenesis with increased depth. Limestone conformably overlying shale has been diagenetically altered to dolomite, commonly ferroan, chiefly below current depths of 10,000 ft (3.0 km).

The dolomite occurs as finely disseminated, 10 μm and larger rhombic crystals, and is most abundant near the base of the Hunton Group, particularly where an oolite unit overlies the thick marine Sylvan Shale inferred to be the chief source of Fe^{2+} and Mg^{2+} ions. Dolomite crystals are euhedral above about 10,000 ft (3 km). Below 10,000 ft, more complete dolomitization of the oolite produced hypidiotopic and xenotopic textures. Fluids associated with hydrocarbon migration (following dolomitization) dissolved the nonreplaced calcite, thereby creating intercrystalline and moldic porosity.

X-ray diffraction verifies a trend of higher dolomite concentrations in the same oolite horizon with increasing depth. Oolite samples from outcrop lack dolomite (100% $CaCO_3$); cores from 9,200 ft (2.8 km) are about 25% dolomite; and cores and cuttings from 15,000 ft (4.6 km) and below are +85% dolomite. Radioisotope-induced x-ray fluorescence shows that dolomites below 10,000 ft (3 km) are iron enriched relative to both nondolomitized oolite and dolomites of surface origin. We therefore conclude that dolomite has formed under deep burial conditions.

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Stratigraphy and Depositional Environments—Krebs Formation in Southeastern Kansas

The Krebs Formation (Middle Pennsylvanian-Desmoinesian) forms the lower portion of the Cherokee Group in the Cherokee basin of southeastern Kansas. The Krebs Formation near its outcrop in Cherokee and Crawford Counties consists of 78% shale and mudstone, 18% sandstone and siltstone, 3% coal, and 1% limestone, comprising a total thickness of 120 to 220 ft (37 to 67 m). Integration of data from continuous cores, outcrops, and geophysical logs provides a detailed stratigraphic framework and facilitates interpretation of depositional environments. Coal beds and associated seat-rock units, some having an areal extent of several thousand square miles, provide excellent stratigraphic marker beds for correlation of discontinuous reservoir sandstones. Radioactive dark-gray shale units and argillaceous limestone units often overlie coal beds and may be equally widespread.

Net-sandstone isolith maps reveal the presence of a lobate deltaic complex in southwestern Missouri, characterized by both stacking and offset of major sandstone bodies. Coal beds commonly cap upward-coarsening, mud-dominated sequences consisting of dark-gray shale with occasional argillaceous limestones overlain by lenticular-bedded shale or wavy-bedded siltstones. This vertical transition of lithofacies is interpreted to result from the progradational infilling of large interdistributary bays. Coarsening-upward sandstone sequences—consisting of lenticular-bedded shale grading upward into wavy-bedded siltstone, flaser-bedded sandstone, and rippled or cross-bedded sandstone—represent distributary mouth-bar or crevasse-splay deposits. Fining-upward sequences—composed of a basal scour surface overlain by mud-clast conglomerates, large-scale cross-bedded sandstone, and rippled or flaser-bedded sandstone—are interpreted to be channel-fill or point-bar deposits.

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Seismic Exploration for Pennsylvanian Granite Wash Reservoirs, Palo Duro Basin

A seismic reflection common-depth-point technique was designed specifically for the Palo Duro basin. The goal was to locate hydrocarbon traps in the Pennsylvanian granite wash. Success ratios using the designed techniques were approximately as follows: (1) to locate hydrocarbon-bearing features, approximately 25%; (2) to locate structures, approximately 50%; (3) to pinpoint development locations, approximately 75%.

The specific technique design is presented as it relates to: (a) density and layout of seismic lines; (b) spread lengths and configuration; (c) field parameters, e.g., geophone array and shot-hole depths; (d) data correction techniques, including weathering correction, choice of datum plane, and choice of datum velocity; (e) data processing requirements and quality control; and (f) interpretation of data, including depth conversion and well ties.

This paper covers the aforementioned topics with a minimum of advanced mathematics, and it poses questions for the advanced mathematician.

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Atokan (Pennsylvanian) Berlin Field: Anatomy of a Recycled Detrital Dolomite Reservoir, Deep Anadarko Basin, Oklahoma

Berlin gas field in Beckham County, Oklahoma, was discovered in 1977, and is the largest Atoka (Pennsylvanian) hydrocarbon accumulation in the Anadarko basin. It is an overpressured reservoir at a depth of 15,000 ft (4,572 m) and occupies a surface area of 41 mi^2 (106 km^2). The reservoir rock consists of recycled, detrital Arbuckle dolomite (Cambrian-Ordovician), and contains ultimate recoverable reserves of 242 to 362 bcf.

Arbuckle dolomite and limited exposures of Precambrian granite rocks were eroded from the Amarillo-Wichita Mountains in the Atokan and were deposited as a terrigenous, sandy dolomite clastic wedge adjacent to the uplift. In the late Atokan, the Elk City structure was uplifted and subaerially exposed in the vicinity of the northern limit of the dolomite clastic wedge. The detrital dolomite on the structure was concurrently eroded and recycled northward as a shallow marine fan delta. Subsequent recrystallization destroyed the detrital depositional texture and created the present intercrystalline porosity.

The deep Elk City structure consists of an upthrust block bound by the late Atokan unconformity that is genetically associated with the Berlin fan delta. Present relief on the upthrust block and overlying anticlinal folds formed during post-Atokan growth of the structure.

Berlin field provides a model of a large, localized clastic deposit derived from uplift and erosion of a prominent structure, and it is an example of the potential for large detrital stratigraphic traps around the perimeters of prominent structures that contain crestal unconformities.

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Upper Pennsylvanian Marine Algal Banks of Kansas: Comparison and Implications

Marine algal banks (mounds or buildups) present in the Shawnee Group (Upper Pennsylvanian) crop out in eastern Kansas. The youngest of about 20 banks known to occur in the section differ in shape and size but, in general, cause a local increase in thickness that is compensated by a decrease in thickness of the overlying shale. The phylloid algae, *Eugonophyllum* and *Epimastopora,* trapped and bound the carbonate mud in a role similar to the modern sea grass, *Thalassia,* in Florida Bay. The soft mudbanks created barriers to water circulation and fauna distribution. The Shawnee banks decrease in size, contain less algae and more micrite, and are more difficult to define with decreasing age. The Plattsmouth bank formed instantaneously by building on the "normal" lithology over a large area; the Ervine Creek bank started locally and spread laterally so it is funnel shaped; the Hartford bank is diffuse with the algae occurring in small curls instead of larger, flat blades. All three banks are capped with a layer of osagite/pellets/fusulinids. The Plattsmouth bank is topped with a crust of algal(?) material, and the Ervine Creek bank shows evidence of solution features, indicating possible subaerial exposure. Interpretation of the sequence is that the elongated banks were formed in shallow, warm water parallel to shore in a regressive environment until smothered by an influx of fine clastic material. Differences in size, shape, algae type and quantity, and postdepositional alterations result from subtle differences in setting and timing of development.

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Reservoir Characterization Study of Mississippian "Chat" Reservoirs, South-Central Kansas

Mississippian "Chat" intervals in south-central Kansas have produced more than 20 million bbl of oil as of December 1983, but only 8-12% of estimated oil in place was produced. Generally, poor "Chat" production has been attributed to low API gravity and low-viscosity oils, producing from high-porosity, low-permeability in-situ chert intervals. Production is from Mississippian "Chat" residual, tripolitic, in-situ chert intervals and overlying Pennsylvanian Cherokee sands.

One reservoir initially classified as having low API gravity and low-viscosity oil is the Hardtner field in southern Barber County, Kansas, near the axis of Pratt anticline. Previous studies using structure, isopach, net-pay, and combinations of porosity and water saturation maps have had limited success in defining hydrocarbon migration paths or increasing reserves through drilling. Recent studies indicate that, by mapping the reservoir parameters of relative oil-water permeability, water- and oil-wet rock conditions, and phase-drive mechanism, producibility may be better estimated.

Reservoir core analysis and geophysical well logs indicate both water-wet and oil-wet rock conditions are present within 80-ac spacings. Further core analysis indicates pore-throat geometries are related to the dissolution of sponge spicules present in the cherts.

The present study uses variables of relative permeability, paleotopography, pore-throat tortuosity, and coordination numbers as input for multivariant vector-analytical algorithms (CABFAC-QMODE family of algorithms). Results of this and other "Chat" reservoir studies suggest a practical evaluation criteria for more effective exploitation drilling and increased efficiency in enhanced recovery programs.

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Gravity-Slide Thrusting and Folded Faults in Western Arbuckle Mountains, Oklahoma