

Ellenburger dolomite with up to 310 ft (94 m) of gross and net pay. The Midland Farms (Ellenburger) field is part of a larger structure which incorporates not only Midland Farms field, but Midland Farms, West (Devonian), Inez (Ellenburger), and parts of the Fasken (Penn) and Block 41 (Wolfcamp) fields. The structure is a complex, uplifted block composed of two doubly plunging, asymmetric anticlines bisected by at least one wrench-type fault and several normal faults. This block has undergone at least three periods of structural compression and uplift. Middle Ordovician folding and faulting of Ellenburger dolomite created initial fracture porosity and permeability. Fractures and vugs were enlarged by meteoric water circulating through the emergent Ellenburger carbonates prior to the deposition of the overlying Simpson rocks. A post-Fusselman period of exposure developed vuggy and cavernous porosity in the Fusselman limestones, and beveled existing fault scarps. Late Mississippian to Early Pennsylvanian compression, related to the uplift of the Central Basin platform, folded the Paleozoic rocks and reactivated conjugate shears trending N10° to 30°E. Ellenburger fracture porosity was enhanced during this period of structural movement. No significant fracture-controlled reservoirs developed in any of the younger rocks, probably due to ductile deformation of the interbedded limestones and shales. Oolite limestone banks developed on a shallow platform over the Midland Farms area during the early Wolfcampian. Penecontemporaneous leaching produced oomoldic porosity in the limestones.

Ellenburger oil production was established in the Midland Farms area in September 1952, and has amounted to 61.6 million bbl oil and 28.5 bcf of gas from 91 wells to January 1983. Major Fusselman and Wolfcamp oil accumulations were discovered during development of the Ellenburger field. Fusselman oil was first produced in June 1953, and has totaled 10.1 million bbl of oil and 5 bcf of gas from 33 wells to January 1983. Wolfcamp production was established in January 1954 and totals 10.7 million bbl of oil and 1 bcf of gas from 39 wells. Less significant deep production has been established in several other pre-Leonard reservoirs in the Midland Farms area, including the Thirtyone Formation (Devonian) (751,624 bbl of oil and 1.8 mmcf gas from 31 wells); Atoka (368,000 bbl of oil and 0.2 mmcf gas from 8 wells); and Strawn (420,000 bbl of oil and 1.1 mmcf of gas from 9 wells). Total production from all zones including post-Leonard beds in the Midland Farms field area to date has been 210 million bbl of oil and 84 bcf of gas.

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#### Advanced Mud-Logging Analysis Techniques in Delaware Mountain Group of Delaware Basin

Ineffective electric-log interpretations and complex completion problems have discouraged much of the possible development of the Delaware Mountain Group of the Delaware basin of west Texas and New Mexico for over 40 years. During the early days of exploration and development, many producible horizons in the Bell Canyon, Cherry Canyon, and Brushy Canyon Formations were eliminated from future consideration because of faulty oil/water ratio and permeability estimates based primarily on resistivity logs, and the subsequent difficulties in completing wells using this information. Along with inefficient water shut-offs, and complicated cementing techniques, wells drilled during this period were further handicapped by a \$2 per bbl or less market price.

In the 1980s, with the price of oil at or near the \$30 per bbl level, many DMG prospects that originally were marginal, or even submarginal, are now being considered for prime exploitation

programs because of the tremendous amount of acreage in the Delaware basin that has been either passed over as "non-producible" or has not been investigated or drilled at all. New electric-log presentations, although markedly improved by computer-enhanced parameters, are still less than decisive in too many situations, leading to continued completion problems.

This paper describes a possible solution to many of the problems presently restraining more economical development within the Delaware basin and other areas with similar complex formations. An example of a typical oil/water inversion commonly found in the DMG is given along with references explaining the creative mechanism. This reservoir type is matched with a "text-book" type reservoir of the same formation and the methods used to analyze and identify each. The instruments and techniques required to accomplish an accurate determination of reservoir oil/water ratios are given along with documentation.

The benefits of this system of reservoir analysis during the drilling process are (1) elimination of testing and/or completing salt water or other non-producible zones; (2) augmentation or elimination of coring programs; (3) as an aid to a selective frac and/or acidizing program; and (4) a maximum production potential indicator when used with only neutron or sonic porosity logs.

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#### Permian (Guadalupe) Shelf Deposition and Diagenesis: Tansill Formation of Cheyenne Field, Winkler County, Texas

Cheyenne field, Winkler County, Texas, produces oil from shelf-margin lithofacies of the Tansill Formation of late Guadalupe age. The Tansill Formation encountered in the Cheyenne field compares favorably with basin-margin outcrops found in the Guadalupe Mountains of New Mexico and Texas. The Delaware basin margin consisted of (1) outer shelf ooid shoals and back-shoal green-algal flats, (2) a shelf-crest pisoid-tepee complex, and (3) inner shelf evaporitic, stromatolitic, and peloidal sediments during the late Guadalupean.

The Cheyenne field reservoir exhibits varied lithologies and porosities in the Tansill Formation. Fresh-water phreatic diagenesis created moldic porosity in the outer shelf, green-algal lithofacies. Fresh-water vadose conditions existed during low sea level stands preserving intergranular porosity in the pisolitic lithofacies of the shelf-crest tepee complex. Fresh-water vadose diagenesis also helped form burrow-moldic porosity and fenestral porosity in the inner shelf peloidal lithofacies. Periodic hypersaline vadose conditions occluded some porosity with evaporites and aragonitic cements. Dolomitization of the Tansill Formation occurred in the mixing zone between a seasonal fresh-water lens in the shelf-crest sediments and the saline waters of the Permian sea and inner shelf lagoon. As sea level fluctuated the mixing zone migrated laterally. In this way, much of the Tansill Formation was dolomitized, forming finely crystalline dolomite that preserved textural details well but did little to enhance porosity.

Porosity is best developed in the thin beds of the outer shelf, green-algal lithofacies. More importantly, the 194 ft (59 m) of pay in the Cheyenne field results from favorable diagenesis of lithofacies on the shelf margin that were interbedded with the shelf-crest lithofacies by fluctuations of sea level. The arid climate at the time of deposition was essential in maintaining porosity created by early diagenesis and for the absence of abundant vadose cements in the Tansill Formation. The trap in Cheyenne field is depositionally controlled by updip, nonporous, and impermeable sediments of the inner shelf lagoon. Anhydrites of the overlying Salado Formation provide an excellent seal. Interbedded

lithologies of the Cheyenne field average 8% porosity and 1 md permeability. The field has recovered 499,950 bbls of oil as of May 1983, with estimated total recoverable reserves of 1,744,987 bbls of oil.

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Geology of Abo Gas-Producing Areas of Pecos Slope, Chaves County, New Mexico

The discovery of Abo gas production from continental Permian red beds in north-central Chaves County, New Mexico, resulted in a flurry of drilling activity. Yates Petroleum Corp. reentered the Honolulu 1 McConkey, an Ellenburger dry hole, and completed it from Abo perforations for an initial potential of 2,551 mcf of gas per day and 1 bbl of condensate per day. Although this discovery was completed in September 1977, drilling continued at a slow pace until federal regulations designated the Abo formation as "tight gas sands," in 1980. This stimulated drilling activity to the extent that, as of August 1983, almost 850 wells had been drilled, with a high success ratio.

Lee named the Abo formation for sandstone exposures in Abo Canyon, at the south end of the Manzano Mountains, southeast of Albuquerque. Needham and Bates re-described the Abo and named a type section for exposures in Socorro and Torrance Counties and considered it to be of continental origin because of cross-bedding, plant remains, and other characteristics.

The Abo is generally believed to be Wolfcampian in age; however, in a few areas the upper portion of the Abo is Leonardian. This is based partly on fossils and also on the fact that the Abo in places grades into the overlying Yeso.

The Pedernal landmass, situated to the north and west of the Pecos slope area, provided most of the sediments as siltstones, sandstones, mudstones, and shales. The sandstones are characteristically arkosic in most areas. These Abo sediments were deposited under fluvial-deltaic conditions.

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McDonald (Devonian) Field, Lea County, New Mexico

McDonald (Devonian) field, north-central Lea County, New Mexico, is an excellent example of the type of deep structure generally found in the Tatum basin, that is, small size, difficult to isolate with seismic, but lucrative when found, producing up to 1.0 million bbl of oil per well. Production is from Devonian rocks, with secondary Pennsylvanian (Atokan) gas potential. Variations in thickness from well to well of Pennsylvanian and Mississippian stratigraphic equivalents provide insight into the complex structural history of the field. McDonald-sized features are most likely to be discovered only by employing a closely integrated exploration program that includes all geophysical and geological parameters.

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Oil Production from Volcanic Rocks of Balcones Fault Region

Igneous rocks associated with the Balcones fault zone, extending from Kinney County in southwest Texas through Travis County in central Texas, have produced oil from more than 40 different fields dating from 1915. These rocks, referred to as serpentine by petroleum geologists, have been the subject of contin-

ued debate regarding their origin. Abundant evidence exists to support the conclusion that these igneous bodies are of volcanic origin related to crustal tension. Production is shallow and in many places economic. Most discoveries were made by surface geology or random drilling. Geophysical data have been used in exploration and have proved to be accurate.

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Ferroan Carbonates Formed at Depth Require Porosity Well-Log Corrections: Hunton Group (Upper Ordovician to Lower Devonian), Deep Anadarko Basin, Oklahoma and Texas

Iron in the minerals calcite and dolomite of limestones and dolostones increases bulk densities and probably also decreases resistivities recorded by logging tools. Whereas dolostones alone retain porosity (intercrystalline and moldic) in the deep Anadarko basin of southwestern Oklahoma and Texas, it is particularly important to distinguish variations in the chemical compositions of dolomite (especially of iron). Bulk densities determined by measuring proportions of major minerals (X-ray diffraction) and iron content (X-ray fluorescence) permit improved estimates of true porosities and water saturations. Dolomite densities range from 2.82 g/cm<sup>3</sup> up to 3.02 g/cm<sup>3</sup> for strongly ferroan dolomite.

In the Hunton Group (Upper Ordovician to Lower Devonian) of the Anadarko basin, we have calculated more porosity and hydrocarbons than expected for select zones. Intervals with less than 4% apparent porosity before correction for iron actually have 4 to 10% porosity. Potentially productive intervals have been missed.

At depths exceeding 10,000 ft (3 km), ferroan dolomite and calcite in the Hunton Group carbonates are predictably associated with interbedded argillaceous zones and with the underlying marine Sylvan Shale. In the deepest of the 50 wells studied, well logs show high densities in the lowermost Hunton (above the Sylvan Shale) which can only be interpreted as the presence of iron-rich dolomite. Detailed fossil correlations by Amsden have established the relatively constant age of a single lithostratigraphic horizon locally present at the base of the Hunton Group conformably overlying the Sylvan Shale, leading us to conclude that increased temperature with depth is the predominant factor for dolomitization. The smectite-to-illite transition in the Sylvan Shale is suggested as a possible source of magnesium and iron. Preliminary shale analysis and stable-isotope-ratio analysis support the above conclusions.

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Dolomitization, Sulfate Solution, and Porosity Development, San Andres Formation, Howard-Glasscock Field, Howard County, Texas

Facies of the Permian San Andres Formation, Howard-Glasscock field, Howard County, Texas, consist mainly of thick shelf carbonates topped by a carbonate-evaporite sabkha unit. Clastics are present as thin shale beds occurring sporadically throughout the sequence. Carbonate facies reflect a broad progradation across a promontory of the Eastern shelf bordering the Midland basin, punctuated by minor transgressions and onlap due to differential subsidence.

Core examination demonstrates that the carbonates have been pervasively dolomitized and plugged by sulfates, principally anhydrite. Dolomite crystal size shows a broad increase down-