

especially useful in studying dolomites and magnesian calcites. The capability for simultaneous electron diffraction from regions less than 1 μm allows for identification of phases and evaluation of short-range ordering.

In addition, many modern TEMs have scanning devices allowing scanning-transmission images (STEM) as well as the more conventional secondary-electron images to be formed. The use of energy-dispersive X-ray spectrometers is optimized with such STEM instruments as spatial resolution of roughly 150 Å is possible.

Recent studies of carbonate minerals using these techniques have revealed a wide variety of defect microstructures characteristic of different growth and diagenetic conditions. In many places, the microstructures are present in such high densities as to significantly influence the stability and reactivity of the mineral.

Notable examples include the calcium-rich dolomites, both from ancient rocks and Holocene sediments. The ancient calcian dolomites exhibit a complex modulated structure with growth and possibly transformation-induced defects. Holocene dolomites are structurally distinct, characterized by a high-density domain structure associated with growth faults. Pervasive, complex microstructures have also been found in saddle dolomites, magnesian calcites, and low-Mg calcites. In the latter, the defect structure is thought to be associated with local CO_3 group disorder.

Since the microstructures are characteristic of different diagenetic growth conditions, their proper characterization and interpretation represents a potential tool for hydrocarbon exploration in carbonate terrains.

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Depositional History and Petroleum Potential of Permian Tannehill Sand, King and Knox Counties, Texas

Channel deposits of the lower Wolfcampian Tannehill sand are a major oil-producing interval in west-central Texas. These sand bodies represent a fluvial meander belt that was part of an extensive depositional system which shifted laterally along paleoslope toward the slowly subsiding Midland basin.

Within the producing zone, stratigraphic traps commonly are formed by structural closure caused by differential compaction and updip pinch-outs against clay plugs of former channel thalwegs. Porosities range from 20 to 30%, with permeabilities of 300 to 700 md. Oil columns of approximately 5 to 30 ft (1.5 to 9 m) are reported. The abrupt erosional contacts of the channel deposits with the regionally persistent Stockwether Limestone clearly delineate the lower boundaries of the Tannehill sand. The typical Tannehill E-log signature shows a sharp basal contact, a decrease in SP amplitude upward, and a more serrate curve upward—all characteristic of point-bar sequences. However, an abnormally low resistivity value (2 ohms) is observed in the oil-saturated portions of the sand. Core analysis shows that this abnormal value does not result from high water-saturation levels. Instead, this anomalous feature is probably due to the retention of water in clay lenses found within the sand bodies.

Ultimate recoverable oil in the Tannehill is estimated to average 400 bbl per acre-foot. The relatively shallow depth, 2,600 to 2,700 ft (792 to 823 m), of the Tannehill and the low cost of drilling to reach it create favorable exploration prospects. Recognition and understanding of the resistivity anomaly in the Tannehill sand could be of major economic importance.

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Hydrocarbon Assessment of the Chattanooga (Devonian) Shale in North Alabama, Northwest Georgia, and South Tennessee

Devonian oil-bearing shale (Chattanooga Shale) occurs over a wide area of north-central Alabama and south-central Tennessee. Four counties, Limestone and Madison Counties, Alabama, and Giles and Lincoln Counties, Tennessee, appear to have the best potential for future development in the region. In this area, the shale ranges from 0 to 15 ft (4.5 m) thick and has less than 100 ft (30 m) of overburden. The shale is typically dark gray to black with pyrite laminae and nodules. Very small lenses and interbeds of sandstone and siltstone, calcite streaks, phosphate nodules, and cherty layers occur locally. The unit is correlative with the Gassaway Member of the Chattanooga Shale as recognized in Tennessee. Shale samples of high oil content are typically very dark gray to black, slightly pyritic, and some have a petroliferous odor. Sandy and silty shale samples show a sharp decrease in oil yield values. In this region, the shale appears to have accumulated in a shallow (less than 100 ft, 30 m) marine reducing environment with a highly irregular shoreline and some scattered islands. If this depositional hypothesis is correct, it may account for the sporadic occurrence, variable thicknesses of the formation, and vertical variations of chemical data for the shale unit.

Reconnaissance sampling throughout the four-county area, augmented by widely spaced core holes in Alabama, indicate that the shale has an average oil yield potential of 13 gal/ton by modified Fischer Assay. Maximum oil yield obtained was 23 gal/ton from a sample in Lincoln County, Tennessee. For samples having more than 7 gal/ton oil, whole rock and trace metals (Co, Cr, Mo, Ni, V, Ti, Zn, and U) analyses were made. Uranium values range from 0.0 to 70 parts per million (ppm) (av. 20 ppm). Values for other trace metals are as follows: Co 4 to 300 ppm (av. 91 ppm); Cr 5 to 200 ppm (av. 81 ppm); Mo 0 to 845 ppm (av. 230 ppm); Ni 10 to 600 ppm (av. 234 ppm); V 12 to 540 ppm (av. 257 ppm); Ti 3,000 to 11,500 ppm (av. 7,439 ppm); Zn 30 to 910 ppm (av. 228 ppm). Fixed carbon ranges from 0.60 to 12.97%, with an average of 9.58%. Total organic carbon averages 16.93 wt. % with a hydrocarbon index of 305 mg/g. The predominant clay mineral is illite, but mixed layered clays are common. The kerogen and organic content appears to coat and be interstitial to the quartz grains and clay particles. Coaly fragments were noted in some samples, but amorphous material suggestive of algal origin was noted in many samples. The components of the kerogen fraction are 29% aromatics, 65% resin and asphaltenes, and 6% saturates. Analyses of the extracted oil indicate 11% paraffin-naphthenes, 45.7% aromatics, 4.2% sulfur, 25.9% eluted NSOs, 1.5% non-eluted NSOs, and 11.7% precipitated asphaltine. Solid-state ^{13}C NMR spectra suggest a poor conversion of organic carbon to oil.

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Distinction Between In-Situ Biogenic Gas and Migrated Thermogenic Gas in Ground Water, Denver Basin, Colorado

Methane-rich gas commonly occurs in ground water in the Denver basin, southern Weld County, Colorado. The gas generally is in solution in the ground water of the aquifer. However, exsolution resulting from reduction to hydrostatic pressure during water production may create free gas, which can accumulate in wells and buildings and pose an explosion and fire hazard.

The ground water is found in siltstones and sandstones that make up the Upper Cretaceous Laramie-Fox Hills aquifer at

depths of 500 ft (152 m) or less. The gas-bearing aquifer is underlain by gas-bearing, low-permeability sandstones of Early Cretaceous age that form the Wattenberg field. It contains reserves of natural gas at depths of 7,500 to 8,500 ft (2,285 to 2,590 m) but requires massive hydraulic stimulation to provide economic flow rates.

Gases from the water wells are generally dry ($C_1/C_{1-5} > 0.99$) and enriched in the light isotope ^{13}C ($\delta^{13}C_1$ values range from -73 to -70 ppt). These gases are interpreted to be of biogenic origin that are being or have been generated in an anoxic, sulfate-free environment within the aquifer system. The probable source of carbon is the organic matter originally deposited with the Upper Cretaceous sediments.

In an area north of Milton Lake, coinciding with a region containing higher amounts of dissolved sulfate in ground water, methane is generally not detected in ground water. Water from wells in this region has a putrid odor and probably contains hydrogen sulfide resulting from microbial sulfate reduction. The absence of methane is probably explained by the fact that methanogenesis generally is not concurrent with the process of sulfate reduction and usually begins after dissolved sulfate is removed from ground water.

Gases from the Wattenberg field, coming from considerably greater depths than those from the water wells, are distinctly different from most of the water-well gas in both chemical and isotopic composition. They contain significant amounts of heavier hydrocarbons (C_1/C_{1-5} values range from 0.83 to 0.87) and are isotopically heavier ($\delta^{13}C_1$ values range from -49 to -43 ppt). The chemical and isotopic composition of the gases indicate that they are thermogenic in origin and were generated by thermal cracking processes during intermediate stages of thermal maturity in the deeper part of the Denver basin. This interpretation is consistent with the level of maturation determined by source rock studies.

Occasionally, gases from water wells are almost identical in both chemical and isotopic composition to gases produced from the underlying Wattenberg field in the immediate area. These gases are also interpreted to be of thermogenic origin and probably migrated from deeper reservoirs.

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Porosity Types in Limestones

A suite of selected oolitic limestones ranging in age from Devonian to Pleistocene was studied petrographically with light microscopy and SEM observation of resin pore casts, and petrophysically with measurements of porosity, gas and liquid permeability, and with mercury injection capillary pressure curves. A new genetic classification of porosity types and related processes in oolitic limestones is presented which is based on the chronological order of their occurrence in the natural history of the rock, following the terminology and concepts of Choquette and Pray.

The 11 subdivisions of the proposed classification are: *Primary Porosity*: pre-deposition, deposition; *Secondary Porosity*: eogenetic dissolution, eogenetic drusy cementation, eogenetic compaction, mesogenetic cementation, mesogenetic dissolution, mesogenetic compaction, late mesogenetic cementation, telogenetic recrystallization and telogenetic dissolution. Furthermore, it is possible to subdivide the investigated samples into five evolutionary stages showing the gradual reduction of primary porosity mainly through cementation, and into six stages showing the modification of secondary porosity mainly through dissolution.

Concurrently, 11 laboratory experiments were performed in which samples of a tightly cemented Mississippian oolitic calcarenite were submitted to simulated burial conditions, and under-saturated carbonic acid solution was forced to pass through them. The result was selective dissolution of the ooid cortical layers, with the sparite cement preserved undissolved. It is concluded that oomoldic porosity can result from textural variation between components and does not necessarily imply that the ooids had an unstable mineralogy.

The understanding of the complex time and space relationships between the different types of porosity in oolitic limestones is critical for reconstructing their depositional-diagenetic history and for evaluating their economic importance as potential hydrocarbon reservoirs.

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Lithologic Comparison of Two Linear Sand Ridges from Nearshore and Middle Portions of New Jersey Continental Shelf, U.S.A.

Two linear sand ridges from the nearshore and middle portions of the New Jersey continental shelf were sampled using a vibro-core system and box corer. Lithologic descriptions were made of the cores based on epoxy peels, X-ray radiographs, and impregnated core slabs. The cores were sampled for grain-size analysis. Box cores sampled lithologies and relative abundance of physical and biogenic structures found in the upper 25 to 46 cm (9.8 to 18.1 in.) of the sediment. Bottom topographies were established using 3.5 kHz data.

The nearshore sand ridge sampled ($74^{\circ}22'W$, $39^{\circ}19'N$) exceeded 5 km (3 mi) in length and ranged up to 2 km (1.2 mi) in width and had a relief of 6 to 10 m (20 to 33 ft). A mid-shelf ridge ($74^{\circ}08'W$, $39^{\circ}09'N$), nearly 4 km (2.5 mi) long and up to 1 km (0.6 mi) wide, with a relief of 10 to 11 m (33 to 36 ft) was also studied.

The vibracores averaged 6 m (20 ft) of penetration and in excess of 95% recovery, and although partially deformed as a result of the coring procedure, revealed three general lithologic units which may be common to both ridges.

At the base of many of the cores, nonskeletal mud and poorly sorted sand are present; some of the interlayered sands and muds contain laminations and abundant pebbles. Overlying this unit in the nearshore ridge is a shell-rich mud and sand interval that is for the most part massive (bioturbated). This lithology was also recovered in one core from the middle shelf ridge. C-14 dates taken from the shell-rich units indicate that the middle and nearshore ridges are of different ages.

The top unit in all the cores is a fine to medium-grained sand, here termed the upper ridge sand. This unit, similar in both ridges, consists of stacked beds ranging from 3 to 71 cm (1.2 to 28 in.) in thickness, and generally coarsens upward. This unit in the nearshore ridge system has a slightly coarser mean grain-size range (150 to 400 μ) than the mid-shelf ridge (130 to 350 μ). Both ridges contain some alternating laminated and nonlaminated bed sequences. C-14 dates from the upper ridge sand units are indecisive in establishing whether the upper units in the nearshore and middle shelf are time equivalent. Nearshore box cores which only penetrate the upper ridge sand from 25 to 46 cm (9.8 to 18.1 in.) contain well-developed ripples and cross-bedding; physical structures dominate. The middle shelf box cores are dominantly burrowed sand and are muddier than nearshore box cores.