19.4 wt. % total salts for calcite-hosted inclusions and 20.0 wt. % for dolomite-hosted inclusions. Eutectic and intermediate melting data indicate that NaCl and $CaCl_2$ are the principal brine components. The significantly higher mean homogenization temperature for dolomite-hosted inclusions suggests that the dolomitizing fluids were warmer than the fluids from which calcite cement precipitated. Petrographic relationships shown dolomitization preceded calcite cementation. The presence of high-temperature, high-salinity fluids conflicts with previously proposed low-temperature, freshwater diagenetic conditions. The shallow (< 1,500 ft, 450 m) burial history of the Burlington sediments is incompatible with the generation of elevated temperature and salinity fluids intraformationally, and suggests a more deeply buried source, such as the Illinois basin. Cathodoluminescent cement stratigraphy and fluid temperatures indicate that the diagenetic history of the Burlington Limestone was complex, with several generations of hydrothermal brine migration into the porous Burlington carbonates along the northwestern edge of the basin. Two basinal brine expulsion models can account for the temperature variations seen during diagenesis, either an episodic, compaction-driven flow system or a gravity-driven ground-water flow system.

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Mechanical Compaction and Porosity Reduction of Miocene Sandstones, South Louisiana

Porosity reduction of 3 compositionally mature Miocene sandstones from Louisiana was determined petrographically. These sandstones were the S Sand at Weeks Island field, R_Z Sand at East Bayou Postillion field, and Planulina 6 Sand at Jeanerette field. The S Sand attained a maximum burial depth of 15,800 ft (4,800 m), the R_Z Sand 15,700 ft (4,800 m), and the Planulina 6 Sand 14,710 ft (4,485 m), all prior to structural uplift.

Porosity reduction caused by mechanical compaction ($\Delta\phi$) was determined by: $\Delta\phi = 40 - (C + \phi)$, where 40 is porosity prior to mechanical compaction, C is cement (petrographically determined), and ϕ is porosity (petrographically determined), all in volume percent. The term $(C + \phi)$ is the porosity remaining after reduction caused solely by mechanical compaction. The S Sand (with the greatest maximum burial depth) has an average $\Delta\phi$ of 11.5%, the R_Z Sand 16.0%, and the Planulina 6 Sand 17.5%. The difference in $\Delta\phi$ between these sandstones is due to differences in the depths at which calcite cementation began to hinder compaction.

By comparing the term $(C + \phi)$ of each sandstone to the porosity expected from the Atwater and Miller porosity reduction rate, it appears compaction-arresting cementation occurred at approximately 9,000 ft (2,750 m) in the S Sand, 12,500 ft (3,800 m) in the R_Z Sand, and 14,000 ft (4,270 m) in the Planulina 6 Sand. At greater depths, this calcite cement dissolved, resulting in secondary porosities up to 35 vol. %. Therefore, many deep hydrocarbon reservoirs may exist in the Gulf Coast with porosities greater than expected.

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Porosity Development and Dedolomitization in Bass Islands Dolomite of Kentucky

A 33-m (108-ft) core of the Upper Silurian Bass Islands formation from a well in Johnson County, Kentucky, consists mainly of finely crystalline dolomite and intraclastic dolomite. These rocks reflect low-energy, hypersaline coastal environments which bordered the Cincinnati arch. Environments included the supratidal mud flat (evaporite minerals and desiccation features), intertidal flat (algal stromatolites), tidal channels (intraclasts), and beach ridges (peloids and intraclasts). The original lime sediments are believed to have been totally dolomitized penecontemporaneously with deposition.

Several shows of natural gas were reported from the formation in this well. The entire "Corniferous" group, including the Bass Islands carbonates, was treated and had an initial production of 464 MCFGD. Porosity is generally poor throughout the formation, but it is as high as 9% in some zones. Porosity occurs as micropores (50μ) associated with dedolomitization, and mesopores (up to 5mm) interpreted to be solution-enlarged molds of carbonate grains and evaporite minerals, horizontal fractures along bedding planes, and incompletely filled vertical fractures.

Dedolomitization probably occurred with the development of an Early Devonian paraconformity, when the Bass Islands was buried to a depth less than 40 m (130 ft). Evaporitic sulfate minerals were attacked by anaerobic bacteria and replaced by silica in this near-surface diagenetic setting. Both reactions released calcium to the pore water. As the calcium/magnesium ratio increased, calcite began to replace dolomite. The dedolomitized calcite generally has a poikilotopic texture but also has a porphyrotopic texture. At some later time, outside pore water entering through fractures in the carbonate formation partially leached some of the dedolomitized calcite, thus creating most of the porosity preserved in the Bass Islands.

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Validity of Spontaneous-Potential Curve Shape for Interpretation of Sandstone Depositional Environments

Many explorationists employ the spontaneous-potential (SP) curve shape as an aid in interpretation of sandstone depositional environments and prediction of subsurface sand-body occurrence. The bell, cylinder, and funnel-shaped SP profiles are among the most widely used. The basic assumption of users of these curve shapes is that decreasing deflection of the SP curve from the baseline is due to decreasing quartz grain size and/or increasing clay content in a reservoir sandstone. However, theoretical, experimental, and actual field data indicate that quartz grain size bears no relation to the amount of SP deflection. Clay content does show a relation, but is often overshadowed by a number of variables which affect SP.

Hydrocarbons can also influence SP, often yielding a false bell profile. In addition, borehole or formation-pressure differentials, variations in mud-filtrate resistivity, and regional differences in formation-water salinity can greatly alter the SP curve shape. Bed thickness, especially when less than 3 ft (1 m), also exerts some control over the SP response.

Field examples in which these factors influence SP in Gulf Coast sandstones demonstrate that the SP curve shape is often misleading. Paleoenvironmental reconstructions and predictions of subsurface sand-body occurrence based on such shapes would therefore be in error.

Curve shapes derived from the micro-resistivity tool (expanded dipmeter curve) are suggested as alternatives to SP curve shapes. Unlike the SP, the micro-resistivity tool is immune to the effects of hydrocarbons, variations in mud-filtrate resistivity and formation-water salinity, pressure differentials, and bed thickness.

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Relationship of Benthic Foraminiferal Biofacies to Lithofacies in Phosphatic Miocene Sediments, Mid-Atlantic Continental Shelf

Changes in benthic foraminiferal assemblages accompany changes in total sediment texture and mineralogy (primarily percent phosphatic grains) throughout the Pungo River Formation in Onslow Bay, North Carolina. Only Burdigalian (late-early Miocene) deposits have been cored in southern Onslow Bay. Basal phosphorite sands (30% phosphate) are overlain by phosphatic (8%) muds and slightly phosphatic (4%) quartz sands. Elongate buliminaceans (*Bolivina, Bulimina, Buliminella, Uvigerina*) comprise over 50% of the benthic assemblage in phosphorites. They also predominate (43%) in phosphatic muds where *Siphogenerina* and *Florilus* become conspicuous faunal elements. Diverse trochospirally coiled forms (mainly *Hanzawaia*, also *Valvulineria* and *Cibicides*) become predominant in quartz sands; buliminaceans decline to 30% of the fauna. Pungo River deposits in northern Onslow Bay are Burdigalian, Langhian (early-middle Miocene), and Serravallian (middle Miocene) in age. Burdigalian deposits are nonphosphatic, muddy quartz sands in which *Hanzawaia* predominates and buliminaceans comprise only 22% of the fauna; *Florilus* accounts for 5%. *Hanzawaia* remains the dominant genus in the slightly phosphatic (4%) quartz sands of the Langhian and the phosphatic (10%) sands of the Serravallian; buliminaceans increase to 29% of the fauna, but *Florilus* nearly disappears. Both vertically and laterally through the Miocene of Onslow Bay, nutrient-loving buliminaceans thrive where phosphate content increases. *Florilus* and *Siphogenerina* are associated with the influx of fine-grained terrigenous sediments. The *Hanzawaia*-dominated assemblage thrives in clean, coarser-grained substrates. Regional trends in the distributional patterns of these taxa may aid in locating additional phosphate deposits.

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Reservoir Properties and Pore Structure of Tight Gas Sands

Thin section and SEM observations indicate that tight gas sands may be grouped into four broad categories based on pore geometry. These consist of (1) primary interparticle porosity; (2) primary interparticle porosity filled with authigenic minerals; (3) primary porosity reduced to narrow cracks with secondary honeycombed grains; and (4) intercrystalline porosity within a fine grained, elongate matrix. Type 1 porosity is common in conventional sands, types 2 and 3 are prevalent in tight sands, and type 4 is a rare class found in extremely tight rocks.

Reservoir property data on 51 sandstone core samples from the Mesaverde, Spirit River, and Frontier Formations led to an attempt to correlate reservoir parameters with pore geometry. The reservoir properties measured on these rocks under net confining stress include dry permeability, relative permeability, porosity to gas, and pore volume compressibility.

Results of the core analysis were combined with petrographic information to provide the following observations.

(1) Pore volume compressibility correlates well with pore geometry. Rocks containing types 1 and 2 pore structures are relatively incompressible owing to a rigid support framework of quartz sand grains in intimate contact. Clay linings on quartz overgrowths and weakly structured solution pores in the type 3 geometry cause moderate compressibility. Type 4 geometry, which occurs in matrix-supported rocks with rare quartz-grain contacts, is generally the most compressible of the 4 classes.

(2) Permeability correlates in general with the pore classes. Type 1 geometry is the most permeable and type 4 is generally the tightest.

(3) Porosity to gas did not correlate very well with pore geometry except on a sample-by-sample basis.

Development of a specific type of pore geometry in a tight sand is controlled by the original grain size and composition, depositional environment, and diagenetic history. It is usually difficult to isolate the effects of one factor from the others. The Mesaverde samples, however, were deposited from a single source into a variety of depositional environments, and underwent approximately uniform diagenesis. In this case, with the composition and diagenesis held constant, notable differences were seen in the pore geometry and reservoir properties that correlated quite well with depositional environment.

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Application of Solids MAS Nuclear Magnetic Resonance to Study of Diagenetic Processes

Magic angle spinning–nuclear magnetic resonance spectroscopy (MAS-NMR) provides the opportunity to probe composition of and ordering in minerals involved in the formation and alteration of sediments. MAS-NMR has the capability to detect a large number of elements, including aluminum, silicon, boron, oxygen, and magnesium. The chemical state, structural location, and with cross polarization, hydration character and surface proximity can also be determined using this method. Although MAS-NMR is relatively new and quantitative methodology is still being developed, a variety of geologic processes have been clarified through its application. Use of ^{27}Al NMR allows detailed determination of the smectite-illite transformation by monitoring the movements of aluminum into tetrahedral positions and resultant cation ordering. Because ^{27}Al is detectable to low ppm levels, clay mineral components can be determined well below XRD detection levels. The ^{29}Si and ^{27}Al MAS-NMR have sufficient resolution to discriminate between minerals in a natural assemblage but not with the resolution of XRD. Quadrupolar nuclei such as ^{27}Al have relatively poor spectral resolution as compared to nonquadrupolar nuclei such as ^{29}Si. However, modern high field instrumentation can discriminate between most aluminum-containing minerals including aluminum oxides, hydroxides, oxyhydroxides, clays, and feldspars, as well as trace aluminum levels in quartz, cristobalite, and tridymite. The combination of ^{27}Al and ^{29}Si NMR (and availability of other nuclei) provide a powerful aid to the resolution of exploration and production problems including determination of minor to trace amorphous components, hydration state of elements in cherts and clays, and formation damage.

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Sorrento Field—Morrow Discovery in Southeast Colorado

Pennsylvanian Morrow sandstones are oil and gas productive throughout a large area in southeast Colorado. The Sorrento field is a recent Morrow discovery with recoverable reserves estimated at more than 10 million bbl of oil in an area of 3,200 acres (1,280 ha.) at depths of 5,400 to 5,600 ft (1,646 to 1,707 m). Minor production also occurs from the Mississippian Spergen, Mississippian Saint Louis, and Pennsylvanian Marmaton.

Productive Morrow sandstones are interpreted on the basis of subsurface mapping as fluvial valley-fill deposits, mainly channel sandstone. These deposits are encased in marine shale and range in thickness from 5 to 55 ft (1.5 to 16.7 m). Net pay ranges from 5 to 30 ft (1.5 to 9.1 m). Porosities average 19% and permeabilities range from 1 to 4,000 md.

Analyses of Morrow stratigraphic intervals indicates that paleostructure influenced Morrow depositional patterns. Morrow channel sandstones accumulated in paleostructural low areas created by movement on basement fault blocks. Structural nosing is present in the same location and trend as the Morrow channels, indicating structural inversion. The field is regarded as a combination structural-stratigraphic trap.

Knowledge of paleostructural control on reservoir facies provides a new idea for exploration for Morrow reservoirs in southeast Colorado.

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Recent Resource Assessments of Tight Gas Reservoirs

Two fairly recent estimates of natural gas recoverable from tight gas reservoirs in the U.S. have been made. One was prepared in 1978, by Lewin and Associates for DOE (U.S. Department of Energy) and the second was made by the NPC (National Petroleum Council) in 1980. Lewin estimated about 200 tcf is recoverable from the 14 most favorable regions in the U.S. The NPC estimated that about 500 tcf is recoverable from the entire onshore U.S.

These studies involved a careful analysis of available data; however, both studies excluded large areas and great thicknesses of rock strata from their resource data base. The reasons for these exclusions were mostly lack of good well control and not absence of gas potential. Therefore, both assessments were conservative and the potential recoverable resource is probably much larger than even the 500 tcf estimated by the NPC.

Unfortunately present-day technology is not able to consistently identify, stimulate, and produce large volumes of gas from lenticular and (or) deep tight reservoirs. The NPC recognized these problems and listed many research topics and programs, in their report, that should be undertaken to increase the amount of recoverable gas.

A few of the more important informational needs are: (1) better methods to predict geometry of reservoirs, (2) improvement of log interpretation, (3) better prediction of natural fracture systems, (4) control of, and prediction of, hydraulic fracture height, length, and orientation, (5) elimination of formation damage, and (6) development of innovative reservoir stimulation methods. DOE has supported a number of research efforts directed toward solving many of these problems.

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Microcomputers and the Geoscientist

The microcomputer represents a technology that heretofore has not been afforded the professional. To the user, this technology renders a powerful advantage with respect to ease of data access and manipulation; increased security and user control; increased efficiency in processing and conveying information to management and clients; and most important, better informed and more accurate decision-making processes.

At this time, the primary oil and gas applications for the micro fall into 4 basic categories: (1) data base management such as well and reservoir data, client files, lease management, financial records, taxes, and accounting; (2) word processing for letter correspondence, contracts,