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,