Geology of Tight Gas Reservoirs

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INTRODUCTION

Tight gas reservoirs occur in low-permeability, gas-bearing formations that are present to some extent in all gas-producing basins worldwide. This is the first volume to bring together data on tight reservoirs for a variety of basins and different geologic settings. The papers in this volume discuss characteristics of some of the most significant tight gas areas in the United States; however, these data are equally applicable to many other recognized and unrecognized tight gas provinces in other nations. In general, tight reservoirs in the United States are grouped into tight gas sandstones and eastern Devonian shales. The Devonian shale sequences are dominantly marine shale but include some siltstone and sandstone. Tight gas sandstone formations of other than Devonian age are present throughout the United States and consist primarily of fluvial and marine sandstones and siltstones. In addition, gas also occurs in low-permeability marine carbonate reservoirs. Spencer (1985) summarizes the geologic and engineering characteristics of tight formations in the Rocky Mountain region.

It is generally agreed that the magnitude of gas resources in tight reservoirs in the United States is quite large, but much uncertainty remains as to the ultimately recoverable resource. In 1985 the U.S. Congress' Office of Technology Assessment (OTA) reviewed estimates of gas in tight reservoirs in the U.S. It concluded that tight sandstone formations are likely to have recoverable resources of 100 to more than 400 trillion cubic feet (tcf) and that the Devonian shale has an estimated recoverable resource of at least 20 to more than 100 tcf (Office of Technology Assessment, 1985, p.9). We believe these estimates are conservative and the ultimately recoverable resource will prove much greater. Regardless of the amount of gas that may be recovered, available data make it clear that tight reservoirs are a significant source of gas and will be an increasingly important domestic source in the future.

Devonian shale gas reservoirs have been exploited to varying degrees for more than 100 years. Western tight gas sandstone and chalk have only been seriously explored for since the development and application of hydraulic fracturing. In recent years the U.S. Department of Energy (DOE) implemented research to characterize tight gas reservoirs and develop advanced gas recovery technologies applicable to both Devonian shale and western tight lenticular sandstone reservoirs. The Gas Research Institute (GRI) has been supporting parallel and complementary research activities in blanket sandstones, coal beds, and Devonian shale.

Two areas in North America with significant gas resources occurring in tight formations are not discussed in this volume. These areas are the northern Great Plains in the United States and the Alberta Deep basin in Canada. The geology, origin of gases, and gas resources of the northern Great Plains have previously been thoroughly described by Rice and Claypool (1981) and Rice and Shurr (1980). When this volume was initially compiled, we were aware of the large gas potential of the Alberta Deep basin. At that time J. A. Masters was completing an AAPG memoir on the Deep basin tight gas formations. We intended to include a summary of the Alberta data in the present volume; however, there is so much valuable information in Masters' (1984) volume that we recommend the reader study it *in toto*. The geologic characteristics and distribution of gas in the Alberta Deep basin are applicable to some deep basins in the United States and *vice versa*. The papers in this volume are generally broad in scope and describe a wide variety of major occurrences of gas in tight reservoirs. A paper on "Devonian Gas-Bearing Shales in the Appalachian Basin" by de Witt traces the history of development, describes characteristics of the gas shales, and provides a qualitative assessment of the production potential of 19 plays within the Appalachian basin. The gas shales underlie about (440,300 km^2) and have produced about 3 tcf. The resource is presently only sparsely developed.

Laughrey and Harper compare the characteristics of Devonian and Silurian tight reservoirs in Pennsylvania. Their well-illustrated paper on "Comparisons of Upper Devonian and Lower Silurian Tight Formations in Pennsylvania—Geological and Engineering Characteristics" notes many similarities among tight reservoirs of significantly different ages. The reservoirs occur in sandstones that have been diagenetically altered with both negative and positive results. Most of the porosity is secondary. They note, as do other authors in this volume, that natural fracturing is an important aspect of ultimate gas recovery from wells and fields.

The Anadarko basin of Oklahoma, Kansas, and Texas covers 35,000 mi^2 (90,650 km^2). Conventional and tight sandstones in the Pennsylvanian produce significant amounts of gas in the basin. Al-Shaieb and Walker describe the reservoir characteristics, petrology, and reservoir evolution of Morrowan sandstones based on extensive studies of many cores. Their paper on "Evolution of Secondary Porosity in Pennsylvanian Morrow Sandstones, Anadarko Basin, Oklahoma" shows that most of the porosity is of secondary origin and ranges from 2 to 25%. Al-Shaieb and Walker emphasize the roles of carbon dioxide, carbonic acid, and hydrogen sulfide in controlling the hydrogen ion concentration in formation waters. The amount of porosity development is directly related to hydrogen ion concentration produced during various stages of diagenesis. These data should be useful to model and predict porosity in tight gas reservoirs in the similar basins.

Finley's paper, "An Overview of Selected Blanket-Geometry Low-Permeability Gas Sandstones in Texas," represents an excellent synthesis of available geologic and engineering data on the more significant blanket-type tight reservoirs in Texas. These reservoirs range in age from Jurassic to Cretaceous and were dominantly deposited in fluvial-deltaic to marine-shelf environments. Finley notes the similarities of these reservoirs to comparable reservoirs in other areas of the United States.

Any exploration program directed at the gas in tight sandstones in coaly sequences should consider the economic potential of recovering the gas in the associated coal beds. Too often in the past, operators have focused on gas-well completions in only the sandstones. Rightmire and Choate provide an in-depth analysis of coal-bed methane and associated tight gas sandstones. Their paper, entitled "Coal-Bed Methane and Tight Gas Sands Interrelationships," describes coals as combined source beds, reservoirs, and sources of gas for interbedded tight sandstones. The authors note the occurrence of these interrelationships in 13 basins in the United States, and they describe them in detail in the Piceance basin in Colorado and the San Juan basin in New Mexico and Colorado and demonstrate the importance of the coal-bed methane resource.

Rose et al. discuss the gas potential of a sequence of interbedded sandstones, coals, and shales in the Raton basin, Colorado. Their paper, "Potential Basin-Centered Gas Accumulation in Cretaceous Trinidad Sandstone, Raton Basin, Colorado," shows the correlation among thermally mature source rocks, basin-centered gas-bearing reservoirs, and basin-margin water-bearing sandstones. Though the Raton basin is in an early stage of exploration, they note the direct correlation of this basin with major gas-producing basins in the Rocky Mountain region.

Pollastro and Scholle describe a unique but important reservoir type present in the eastern part of the Rocky Mountains and Plains region. These reservoirs are in chalks deposited in the shallow Western Interior seaway during Late Cretaceous time. Their paper, "Exploration and Development of Hydrocarbons from Low-Permeability Chalk—An Example from the Upper Cretaceous Niobrara Formation, Rocky Mountain Region," describes gas occurrence in high-porosity, low-permeability reservoirs in chalk beds. The gas is of biogenic origin and occurs at shallow depth in accumulations in low-relief domes or anticlinal noses. Porosity in these rocks exhibits a relatively predictable decrease with increasing depth. Foam fracturing is discussed as the most effective stimulation method.

The Wattenberg field is the major gas-producing area in the Denver basin, Colorado. Weimer et al. describe the reservoirs, gas occurrence, stimulation methods, and development of tight gas and gas and condensate reservoirs in their paper entitled "Wattenberg Field, Denver Basin, Colorado." The accumulations are all in stratigraphic traps in dominantly marine and marginal marine rocks of Early and Late Cretaceous age. However, unconformities and paleostructure are also noted as playing a subtle but mappable role in the accumulation of gas.

A paper by Johnson and Nuccio, entitled "Structural and Thermal History of the Piceance Creek Basin, Western Colorado, in Relation to Hydrocarbon Occurrence in the Mesaverde Group," discusses the conditions that determine the occurrence and distribution of gas in low-permeability sandstone reservoirs in a major Rocky Mountain gas-producing basin. The Mesaverde Group is a thick sequence of nonmarine lenticular sandstones, carbonaceous shales, and siltstones grading downward into a coaly sequence and then to marginal marine sandstones. The authors analyze the tectonic, sedimentologic, and thermal history of the Piceance basin, incorporating data from the U.S. DOE Multiwell Experiment (MWX) site in the southern Piceance basin. Their thermal history data provide a valuable aid for predicting the distribution of hydrocarbons in the basin.

Brown et al. analyze the geologic and engineering characteristics of marginal marine, tight gas sandstones of Late Cretaceous age in the southern Piceance basin, Colorado. Their paper, "Southern Piceance Basin Model–Cozzette, Corcoran, and Rollins Sandstones," describes a basin-centered gas trap with dynamic gas flow updip out of the basin. In their model the primary gas migration occurs along the better-quality shoreline-trend sandstones. They conclude that most undiscovered gas resources in marginal marine sandstones lie downdip of the present areas of active exploration and development.

Pitman and Sprunt provide a unique insight into the formation of natural fractures in their paper on "Origin and Distribution of Fractures in Lower Tertiary and Upper Cretaceous Rocks, Piceance Basin, Colorado, and Their Relation to the Occurrence of Hydrocarbons." Many other authors in this volume note the importance of natural fractures, but Pitman and Sprunt focus on the details of fracture-filling cements in an effort to detail the conditions under which fractures formed within a specific basin. Their studies of reservoir rock fractures in cores show that the fractures cut detrital grains, intergranular authigenic mineral cements, and secondary pores. Their data indicate that these fractures formed relatively late in the diagenesis of the reservoirs. On the basis of isotopic studies and other data, they believe the cements formed either at different times under very similar conditions or at about the same time throughout thick sections of rock that were hydrologically connected through an extensive vertical fracture system.

Pitman et al. discuss Uinta basin stratigraphy, reservoir quality, organic richness, thermal maturation, and hydrocarbon entrapment in "Depositional Environments, Diagenesis, and Hydrocarbon Potential of Nonmarine Upper Cretaceous and Lower Tertiary Rocks, Eastern Uinta Basin, Utah." The study emphasizes the importance of stratigraphy and diagenesis as related to oil and gas generation and entrapment in tight reservoirs. The authors describe a complex diagenetic history for the Upper Cretaceous and lower Tertiary reservoir rocks, which are lithic arkose and feldspathic litharenite. The porosity consists of mostly isolated secondary pores formed by dissolution of detrital grains and cement. This paper provides the first published geochemical and thermal maturation data on Cretaceous source beds in the Uinta basin.

Law et al. have made an extensive study of the geology of tight gas reservoirs in the Greater Green River basin. This basin is generally believed to have the greatest volume of gas in tight sandstones of any individual basin in the United States. Their paper is entitled "Geologic Characterization of Low-Permeability Gas Reservoirs in Selected Wells, Greater Green River Basin, Wyoming, Colorado, and Utah." Most of the gas-bearing reservoirs are in fluvial sandstones of Late Cretaceous age and are overpressured. The authors have been able to relate overpressuring to the active generation of gas in thermally mature rock sequences. The dominant trapping mechanisms are caused by stratigraphic and diagenetic changes.

The Upper Cretaceous Frontier Formation in the Green River basin, Wyoming, is one of the major gas-producing formations in the Rocky Mountain region. There are local areas where the sandstones are conventional reservoirs; however, most of the Frontier reservoirs have in situ permeabilities to gas of less than 0.1 millidarcy (md). Moslow and Tillman describe this reservoir sequence in their paper, "Sedimentary Facies and Reservoir Characteristics of Frontier Formation Sandstones, Southwestern Wyoming." Sandstones in the Frontier Formation of southwest Wyoming are marginal marine sequences that prograded eastward. The best reservoirs are found in distributary channels. They believe the best new exploratory area is east of the Moxa arch.

The rate at which tight gas resources will be developed in the future will be controlled by many factors. Some of these factors are (1) the development of geologic models and concepts that identify areas with the best-quality reservoirs, (2) improvement in predicting the distribution of natural fracture systems, and (3) the development of nondamaging well stimulation techniques. Geologic models are also needed to support technological work, especially for the effective application of hydraulic fracturing and other stimulation techniques to improve productivity and allow economic development. Finally, the demand for gas from tight reservoirs will depend largely on the availability of gas, from both conventional and unconventional sources, and the value of gas in world, national, and local markets.

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