

Unconventional Gas and Tight Oil Exploitation

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Society of Petroleum Engineers

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Editor-In-Chief

Roberto Aguilera, University of Calgary

Society of Petroleum Engineers

Richardson, Texas, USA

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Preface

Being an expert in all topics related to tight oil and unconventional gas (TOUG) is nearly impossible. As a result, this book has been prepared by 14 subject-matter experts with specialization in different TOUG areas.

Chapter 1 provides background on TOUG and why there is general interest in fully exploiting reservoirs.

Chapter 2 addresses geologic aspects and parameters that can be considered to apply to all unconventional resources. The chapter focuses on unconventional-resource-play geology and introduces the geological differences between conventional and unconventional plays. Determination of source-rock composition and maturity, hydrodynamics of unconventional plays, and their rock mechanics and geomechanics are also included.

Chapter 3 discusses real-time well construction and performance drilling. This requires accurate subsurface information in real time, and complete understanding of reservoir behavior and its characteristics. Precise geological, reservoir, and geomechanical-coupled models play a significant role in well design. Accurate subsurface information is critical for effective drilling and completions designs to maximize the production with the least reservoir damage. Real-time well construction is based on precise dynamic modeling of the subsurface reservoir and understanding its characteristics and behavior.

Chapter 4 discusses completion for gas and liquid-rich shales. Technology advances, including multistage fracturing of horizontal wells, slickwater fluids with minimum viscosity, sequential rate increases, and simultaneous fracturing, have evolved to increase formation-face contact of the fracture system into the range of 10 million to 100 million ft² in shales, where local stresses and the presence of natural fractures permit development of complex or network-type fracturing. These innovations have led to significant improvement in gas and oil recoveries from unconventional reservoirs.

Chapter 5 discusses environment and regulatory processes. Development and implementation of appropriate best practices is a professional responsibility. Communication of scientific facts, supported with field data, is integral to alleviating fear and building trust with the public and all stakeholders. Proactive communication with the public to increase energy literacy is vital to creating and maintaining a social license to operate. This is particularly important given the intensity of hydraulic-fracturing activity involving large volumes of water, which has gained public and media attention. Some of the issues discussed in this chapter include environmental effects of oil and gas activity and transportation, potential groundwater impacts, water consumption, chemical composition of hydraulic-fracturing fluids (and their storage and disposal methods), seismic activity, and changes in air quality—greenhouse-gas (GHG) emissions associated with fossil fuels.

Chapter 6 discusses tight gas and tight oil development. Tight petroleum reservoirs, including sandstones, carbonates, and shales, are characterized by very low permeabilities (fraction of a millidarcy to nanodarcies). Because these reservoirs are found in continuous accumulations that can extend over thousands of square kilometers, they are usually referred to as “resource plays.” The successful development of many tight petroleum reservoirs primarily in the United States and Canada is the result of significant advances in drilling and completion techniques associated primarily with horizontal wells and multistage hydraulic fracturing; but, understanding the rocks—a key component of this chapter—is fundamental for proper evaluation and exploitation of tight petroleum reservoirs. The presence of natural-fracture swarms in tight petroleum reservoirs adds to the probability of success in these types of reservoirs.

Chapter 7 discusses coalbed methane (CBM), an unconventional gas resource with global significance. Coal, by definition, is a “readily combustible rock containing more than 50% by weight and more than 70% by volume of carbonaceous material formed from compaction and induration of variously altered plant remains similar to those in peaty deposits” (Schopf 1956). What makes CBM an “unconventional” resource is the combination of gas storage and transport mechanisms exhibited by coal reservoirs. Further, in some cases, advanced well-stimulation and completion processes are required to produce CBM commercially. The primary gas-storage mechanisms in CBM reservoirs include adsorption within organic matter, conventional storage in natural fractures, conventional storage in matrix porosity (organic and inorganic matter), solution in formation water, and absorption (solution) in organic matter. The chapter includes methods for estimating volumes of gas in place and gas recoveries.

Chapter 8 discusses shale gas and liquid-rich shales. A common misconception is that production of natural gas from shales started only a few years ago. This is not the case. Actually, we have known about shale gas for decades, and by 1980, thousands of hydraulically fractured vertical wells had been producing in the Appalachian basin of the United States for several years. This chapter explains how to characterize and how to estimate recovery from shale reservoirs. In general, percent recovery from shales is very low. Thus, the chapter also develops some ideas on how to improve oil recovery from shales.

Chapter 9 discusses gas hydrate reservoirs, concentrating particularly on the geological and engineering understanding gained over the past two decades. The chapter demonstrates how this understanding has moved industry closer to commercial

production from gas hydrates. Because of the current state of the gas hydrate industry—that is, the precommercial stage—the discussions are primarily based on theoretical developments and small-scale field trials. This is of paramount importance given the extremely large volumes of methane estimated at present. Although the estimates vary considerably as a result of different assumptions that are not well controlled by geological data and a lack of understanding of the associated petroleum system, the gigantic estimated volumes warrant further investigations of gas hydrate reservoirs.

Chapter 10 discusses economic aspects of unconventional petroleum reservoirs. The well-production profiles and associated cash flow of unconventional gas and tight oil projects are markedly different from those of conventional ones. Estimates of ultimate recoveries and production forecasts from shale gas wells and tight oil formations have significant uncertainties because of reservoir heterogeneity, emerging completion practices, and relatively short production histories. Great strides have been made in reducing the finding and development costs and the operating expenses of unconventional plays. However, there are still controversies about the full-cycle economics of some plays, especially in areas outside of the sweet spots.

In summary, changes to global energy markets, shifts in international oil-supply projections, advancements in horizontal drilling and multistage hydraulic-fracturing technologies—these realities coalesce to potentially extend natural gas and oil supplies by several decades by current levels of consumption. In *Unconventional Gas and Tight Oil Exploitation*, the authors lend their expertise to offer an in-depth look at unconventional low-permeability resource accumulations, the required technologies for specialized development, and the assessments currently being applied.

While percent recoveries from unconventional gas and tight oil accumulations have been very low compared with conventional reservoirs, these unconventional resources have been enough to dramatically change the slope of production decline in the United States from negative to positive in a very short period of time. This change of slope is “magic” and reflects the creativity of the oil and gas industry. The authors of this book seek to ascertain and explore the challenges and opportunities associated with the current commercial development techniques in an effort to fully understand the reservoirs, the mode of petroleum storage and transport within the reservoirs, the design of drilling and completion programs, and the physics behind formation analyses. Through this understanding, unconventional gas and tight oil exploitation techniques can be developed further, resulting in low production costs, improved economics, increase in technically recoverable resources while respecting the environment, and significant positive impact of gas and tight oil developments globally.

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12 September 2017

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Introduction

John Etherington, *PRA International Ltd.*
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The rapid development of unconventional resources has dramatically changed the global energy market. Future development of shale gas, coalbed methane, and tight gas projects around the world may extend natural gas supply to over 250 years of current consumption if the full estimates of technically recoverable gas are confirmed. Accelerated exploitation of tight oil reservoirs in North America has significantly shifted international oil supply projections. Unconventional resources are being unlocked by a combination of horizontal drilling and multistage hydraulic fracturing technologies. This monograph examines the unique aspects of these unconventional, low permeability resource accumulations, the specialized development technologies required, and the assessment processes being applied.

The SPE Petroleum Resources Management System (PRMS) (SPE 2007) defines unconventional resources as hydrocarbon accumulations that are pervasive throughout a large area and that are generally not significantly affected by hydrodynamic influences (also called “continuous-type deposits”). Such accumulations require specialized extraction technology, and in the case of heavy oil and bitumen, raw production may require significant processing before sale.

The relationship of conventional to unconventional resources is illustrated by a resource triangle (Fig. 1.1). Heavy oil, tight oil, and tight gas resources straddle the boundary; nonetheless, they present challenges in applying the assessment methods typically used for conventional accumulations. This monograph is focused on assessment of resources in the highlighted low permeability reservoirs ranging from dry gas to liquid rich accumulations and, in some cases, light oil in tight reservoirs.

While very large volumes of petroleum exist in unconventional reservoirs, their commercial recovery often requires a combination of improved technology and higher product prices. Technically recoverable resources (TRR) as used by the Energy Information Administration (Kuuskraa et al. 2013) “represents the volumes of oil and natural gas that could be produced with current technology, regardless of oil and natural gas prices and production costs.” TRR includes both discovered and undiscovered resource estimates. The undiscovered resources have been risked for chance of discovery. While most authors assume that the recovery technologies are confined to those currently being applied within the industry, others may assume future improvements. TRR includes, but is not limited to, development projects that are commercial under current conditions of regulatory, environmental, and economic constraints.

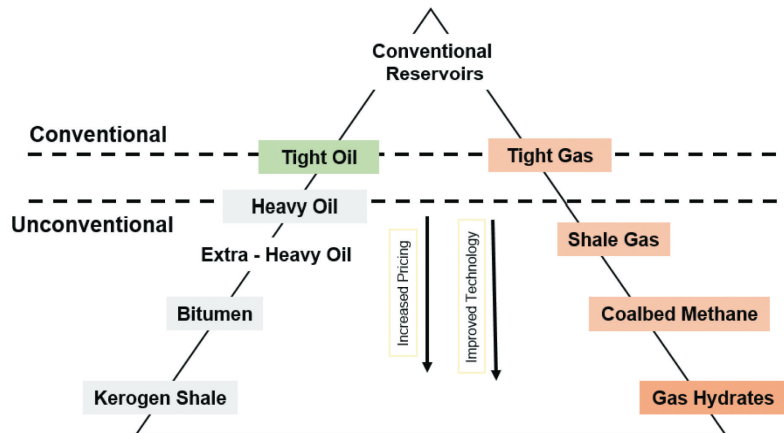


Fig. 1.1—Resource triangle (after Holditch and Al-Madani 2010).

	Estimated Gas Initially-In-Place	Estimated Technically Recoverable	Reference
Tight formations		15,000 Tscf	Aguilera et al. (2008)
Coalbed methane		9,000 Tscf	Jenkins and Boyer (2008)
Shale gas		7,795 Tscf*	Kuuskræa et al. (2013)
Gas hydrates	60,000 Tscf		Collett and Kuuskræa (1998)

*These estimates do not include significant potential in Russia and the Middle East.

Table 1.1—Estimated unconventional gas resource potential.

The global estimated TRR for unconventional gas accumulations ranges over 30,000 Tscf (excluding gas hydrates) compared to less than 3,000 Tscf produced to date. The estimates given in **Table 1.1** are preliminary, and estimates in the literatures have significant variation; however, they indicate the order of magnitude of these resources. The quoted TRR volumes are assumed to be “best estimates.” While extremely large gas hydrate accumulations have been identified, no feasible commercial development techniques have yet been defined, and estimates are confined to in-place volumes.

Regarding unconventional tight oil resources, the Energy Information Administration (Kuuskræa et al. 2011) estimates worldwide TRR of 335 billion bbl. With the recent focus on developing liquids-rich reservoirs, the estimate of recoverable liquid volumes may be conservative.

Fig. 1.2 compares TRR to the more rigorous PRMS classification system. “The PRMS resources definitions, together with the classification system, are intended to be appropriate for all types of petroleum accumulations regardless of their in-place characteristics, the extraction method applied, or the degree of processing required. However, specialized techniques often are employed in assessing in-place quantities and evaluating development and production programs of unconventional resources” (SPE/AAPG/WPC/SPEE/SEG 2011).

The whole process of project development and resource assessment is undergoing significant changes. Whereas shale or coal beds were previously considered source rock or seals, they now have become the target reservoirs. What has not changed is our process of considering chance of discovery and chance of development in classifying resources.

Estimations of recoverable unconventional resource quantities must include an indication of the associated uncertainty expressed by allocation to PRMS categories using the same low/best/high methodology as for conventional resources. Typically, the assessment process begins with estimates of original in-place volumes considering free, adsorbed and diffused gas in the case of gas accumulations. Thereafter, portions of the in-place quantities that may be potentially recovered by identified development programs are defined. In some cases, there are no current technically viable methods of recovery and the in-place volumes are classified as “unrecoverable.”

As in conventional accumulations, undiscovered recoverable volumes of unconventional resources are classed as “prospective resources,” which are recoverable estimates, assuming their discovery and commercial development. PRMS recognizes that the hydrocarbon type and/or the reservoir quality may not support a flowing well test but the accumulation may be classed as “discovered” on the basis of other evidence (e.g., sampling and/or logging).

While large in-place volumes in unconventional resource plays may be defined as “discovered,” they remain classified as unrecoverable until a pilot project consisting of several penetrations has demonstrated the technical feasibility of producing significant volumes. Where technically feasible recovery techniques are identified, but economic and/or other commercial criteria are not satisfied, estimates of recoverable quantities are classified as “contingent resources.”

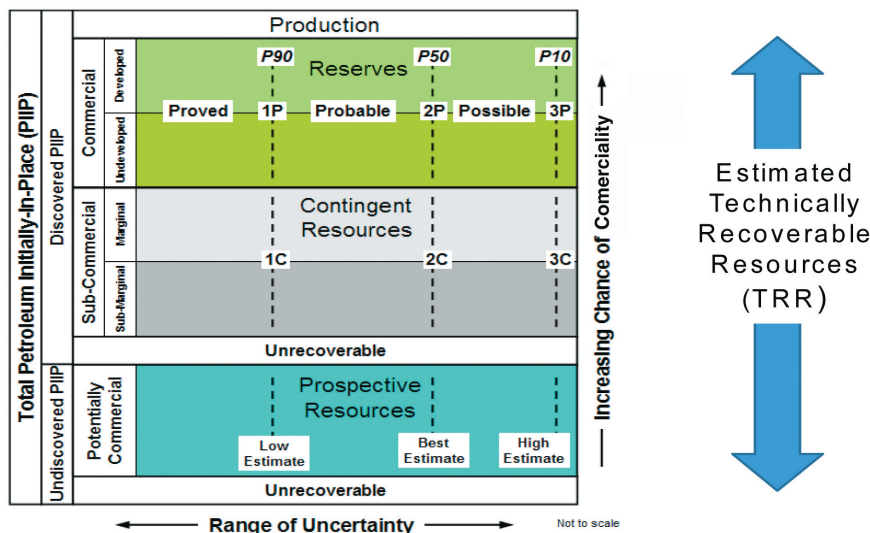


Fig. 1.2—PRMS classification matrix and estimated technically recoverable resources (TRR).

It is not uncommon to recognize very large areas where prior penetrations beyond the current well/pilot area have identified the presence of petroleum in-place. This is not sufficient to designate the total area as contingent resources. Typically the success of unconventional resource plays requires a large scale of development involving hundreds of wells. Only after completion of several pilot projects that broadly sample the total accumulation can one define the limits of the “productive area.” In addition, the productivity across unconventional resource accumulations is often directly related to reservoir heterogeneity of local natural fracturing and other variations in geology not well understood in early phases of exploration and appraisal.

As the play and completion technologies mature and development projects are better defined, portions of estimated volumes may be assigned to the contingent resources subclasses that recognize their progressive technical and commercial maturity. Reserves are only attributed to those areas demonstrating economic producibility and after capital is committed for development. Again, because of the heterogeneity, while the overall project is commercial, individual wells may not be full-cycle economic.

Because these accumulations are often pervasive throughout a very large area and are developed with high-density drilling, statistical assessment techniques may be more applicable than in conventional plays. While unconventional resources are typically very heterogeneous locally in terms of productivity, they may be “regionally homogeneous” as indicated by the similar distributions of estimated ultimate recoverable (EUR) volumes associated with groups of wells. The classical demonstration is an overlay of cumulative EUR distributions of wells completed in successive years showing similar range and curve shape.

The *Guidelines for the Practical Evaluation of Undeveloped Reserves in Resource Plays* (SPEE 2010) builds on this finding to develop a process that estimates proved undeveloped reserves. As will be discussed in Chapter 10, the EUR estimates are typically developed using decline curve analysis techniques applied to existing producing wells to define the proved developed producing reserves. Specifically for shale gas and tight oil projects, there remains significant controversy regarding the detailed interpretation and reliability of the resulting estimates. Because these plays are developed with hundreds of wells within a single project, the aggregation of well EUR distributions has a very significant portfolio effect such that the aggregate proved reserves approaches the aggregate proved plus probable reserves. The industry is still evaluating the detailed components of this process.

The investment and production profiles of unconventional resources show marked divergence from those in conventional resource projects as reflected in economic analyses (see Chapter 10). Simply stated, as the natural permeability of the host unconventional resources reservoir decreases, the number of wells required increases. In the case of shale gas and tight formation wells, the hydraulic fracturing completion dramatically increases the well costs.

While the end result of assessments is an estimate of future production and associated cash flow schedules, such evaluations require an in-depth understanding of the reservoirs, the mode of petroleum storage and transport within the reservoirs, the design of drilling and completion programs, the physics behind formation analyses, and any factors that impact the commercial development. The following sections by different authors provide current information on these issues:

- Chapter 2 discusses the geologic aspects of unconventional gas resources.
- Chapter 3 reviews the drilling of horizontal wells targeting unconventional resources.
- Chapter 4 provides a detailed review of hydraulic fracture stimulation techniques applied to shale gas and tight oil.
- Chapter 5 addresses environmental and regulatory issues associated with unconventional resource projects.
- Chapter 6 focuses on tight gas and tight oil resource assessment and development.
- Chapter 7 reviews the characteristics of coalbed methane resources and assessment methods and includes field development examples.
- Chapter 8 includes a history of shale gas and shale oil development, the underlying physics, and assessment techniques, including reservoir simulation.
- Chapter 9 explains the origin of natural gas hydrate resources, their modes of occurrence, and the current status of experimental recovery projects.
- Chapter 10 provides background on the global impact of gas and tight oil developments and their economic evaluation.

