Petroleum Systems and Geologic Assessment of Oil and Gas in the San Joaquin Basin Province, California

Chapter 24

U.S. Geological Survey Assessment Concepts for Conventional Petroleum Accumulations

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Contents

Abstract

Conventional petroleum accumulations are discrete fields or pools localized in structural or stratigraphic traps by the buoyancy of oil or gas in water; they float, bubble-like, in water. This report describes the fundamental concepts supporting the U.S. Geological Survey "Seventh Approximation" model for resource assessments of conventional accumulations.

The Seventh Approximation provides a strategy for estimating volumes of undiscovered petroleum (oil, gas, and coproducts) having the potential to be added to reserves in a 30-year forecast span. The assessment of an area requires (1) choice of a minimum accumulation size, (2) assignment of geologic and access risk, and (3) estimation of the number and sizes of undiscovered accumulations in the assessment area. The combination of these variables yields probability distributions for potential additions to reserves. Assessment results are controlled by geology-based input parameters supplied by knowledgeable geologists, as opposed to projections of historical trends.

Introduction

The U.S. Geological Survey (USGS) periodically conducts assessments of the recoverable oil and natural-gas resources of areas within the United States and also in other regions of the world. The purpose of these assessments is to develop geology-based, well-documented estimates of quantities of petroleum having the potential to be added to reserves within some future time frame. For the National Oil and Gas Assessment (NOGA) series begun by the USGS in 2000, the future time frame—the forecast span—is 30 years.

In recent years, the USGS has distinguished between conventional and continuous petroleum accumulations for purposes of resource assessment (Gautier and others, 1995; U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995; U.S. Geological Survey World Energy Assessment Team, 2000). Briefly stated, conventional accumulations are described in terms of discrete fields or pools localized in structural or stratigraphic traps by the buoyancy of oil or gas in water. In contrast, continuous accumulations are petroleum accumulations (oil or gas) that have large spatial dimensions and indistinctly defined boundaries, and which exist more or less independently of the water column (Schmoker, 1995). Conventional accumulations "float," bubble-like, in water; continuous accumulations do not. Because of their fundamental geologic dissimilarities, the USGS assesses conventional and con-

tinuous accumulations using different resource-assessment models and methods.

The primary purpose of this report is to describe the fundamental concepts behind USGS resource assessments of conventional accumulations. The basic USGS assessment model is called the "Seventh Approximation," which is a term that expresses both the evolution of the model and the idea that an exact analysis of undiscovered resources can never be achieved. The Seventh Approximation is the model used to assess potential additions to reserves in undiscovered conventional accumulations as part of the ongoing NOGA series of domestic petroleum assessments.

Computer programs are used in conjunction with the Seventh Approximation to calculate resource estimates. However, assessment results are controlled by geology-based input parameters supplied by knowledgeable assessment geologists, as opposed to computer-generated projections of historical statistical trends.

The Seventh Approximation has an antecedent in the assessment model for undiscovered conventional accumulations used by the USGS in the 1995 National Assessment of United States Oil and Gas Resources (Gautier and others, 1995; U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995). The Seventh Approximation was first described by us in 1999 (Schmoker and Klett, 1999), and it was the model used to assess undiscovered conventional resources in the USGS World Petroleum Assessment 2000. Documentation for the World Petroleum Assessment 2000 (U.S. Geological Survey World Energy Assessment Team, 2000) described the Seventh Approximation in considerable detail, as well as operational procedures and practical considerations associated with its implementation. The reader is referred to that reference for more detail than is provided here.

Geologic Nature of Conventional Accumulations

Conventional accumulations, as recognized by the USGS for purposes of resource assessment, are defined by two key geologic characteristics: (1) they occupy limited, discrete volumes of rock bounded by traps, seals, and down-dip water contacts, and (2) they depend upon the buoyancy of oil or gas in water for their existence. Because of these properties, conventional accumulations are commonly assessed in terms of the sizes and numbers of discrete accumulations (for example, individual oil and gas fields).

Some "unconventional" accumulations are so designated because, for example, they are overlain by deep water, are in a remote area, or require unusual engineering techniques. However, these circumstances do not necessarily make them unconventional from the standpoint of resource assessment. As long as accumulations are discrete and "float" in water, they are considered to be conventional in terms of USGS resource-assessment nomenclature and models, and the Seventh Approximation is applicable.

Petroleum Volumes Assessed

The Seventh Approximation assessment model provides a means to estimate quantities of undiscovered oil, gas, and natural gas liquids (petroleum) in conventional accumulations that have the potential to be added to reserves in some specified future time span. For purposes of this model, undiscovered petroleum is that which is postulated from geologic knowledge and theory to exist outside of known accumulations, and which resides in accumulations having sizes equal to or exceeding a stated minimum volume. Undiscovered petroleum volumes include initial accumulation sizes as they are perceived at the time of discovery, as well as any reserves anticipated to be added as these discoveries are developed and produced.

The Seventh Approximation does not attempt to predict volumes of petroleum that will actually be discovered in a given future time span. To do so would require full knowledge of future petroleum economics and exploration technologies, and the extent of exploration effort that will be conducted in the area being assessed. Rather, the Seventh Approximation is used to estimate volumes of petroleum having potential, from a geologic standpoint, to be discovered in a specified time frame.

In order for USGS resource assessments to be of near-term relevance to the society that funds them, the assessment scope needs to be constrained from that of crustal abundance to those petroleum resources that might be recoverable in the foreseeable future. Such constraint is supplied by limiting assessments of undiscovered resources in conventional accumulations to those quantities of oil and gas having the potential to be added to reserves within some specified forecast span.

Forecast span is the number of years that a resource assessment looks into the future. A forecast span of 30 years—approximately one generation—was used by the USGS in the World Petroleum Assessment 2000 (U.S. Geological Survey World Energy Assessment Team, 2000), and a 30-year forecast span has also been adopted for the current NOGA series begun in 2000. Given the numerous unforeseen developments of the past few decades that have significantly affected the petroleum industry and the possibility for surprises of similar magnitude in the future, 30 years appears to be approaching the limits of a realistic forecast span.

A particular forecast span should not be interpreted too literally. An algorithm does not exist for calculating potential additions to reserves in the next 30 years, as opposed to the next 29 or 31 years, for example. It is more appropriate to equate a forecast span to the idea of a societally relevant resource inventory.

The 30-year forecast span imposes limits upon the volume of potential additions to reserves assessed in conventional accumulations. Entire groups or classes of conventional accumulations are excluded from assessment consideration if they are not considered to be practicable in the timeframe of 30 years. An example to illustrate the point might be small,

isolated, stratigraphically trapped accumulations in very deep water.

Another way of thinking about constraints upon the scope of assessed undiscovered resources is to visualize the volume of petroleum residing in conventional accumulations as being ranked in the form of a pyramid, with a relatively small volume of high-quality resources near the top and increasing volumes of progressively lower quality and less practicable resources towards the base (fig. 24.1). A forecast span of 30 years can be regarded as a slice through the resource pyramid at some quality level. Accumulation categories below the slice are not assessed.

Probability Distributions

The uncertainties associated with the variables required for an assessment of undiscovered conventional resources are considerable, leading to a substantial range of possible input values. Many of the variables that make up the set of input data are therefore represented by probability distributions rather than by single (point) values. Resource forecasts derived from these input data are also represented by probability distributions.

The probability distributions for some input variables show the uncertainty of a fixed but unknown value, whereas other probability distributions represent input variables that have a naturally occurring range of values. F_{100} (minimum), F_{50} (median), and F_0 (maximum) fractiles are the input parameters estimated for all variables represented by probability distributions. These three fractiles are not specifically linked to a particular type of probability distribution (for example, lognormal). The choice of probability-distribution type is an operational decision that is not constrained by the basic Seventh Approximation assessment model. For the NOGA series, a truncated, shifted lognormal distribution is used for the sizes of undiscovered accumulations, and triangular distributions are used for all other input variables represented by probability distributions.

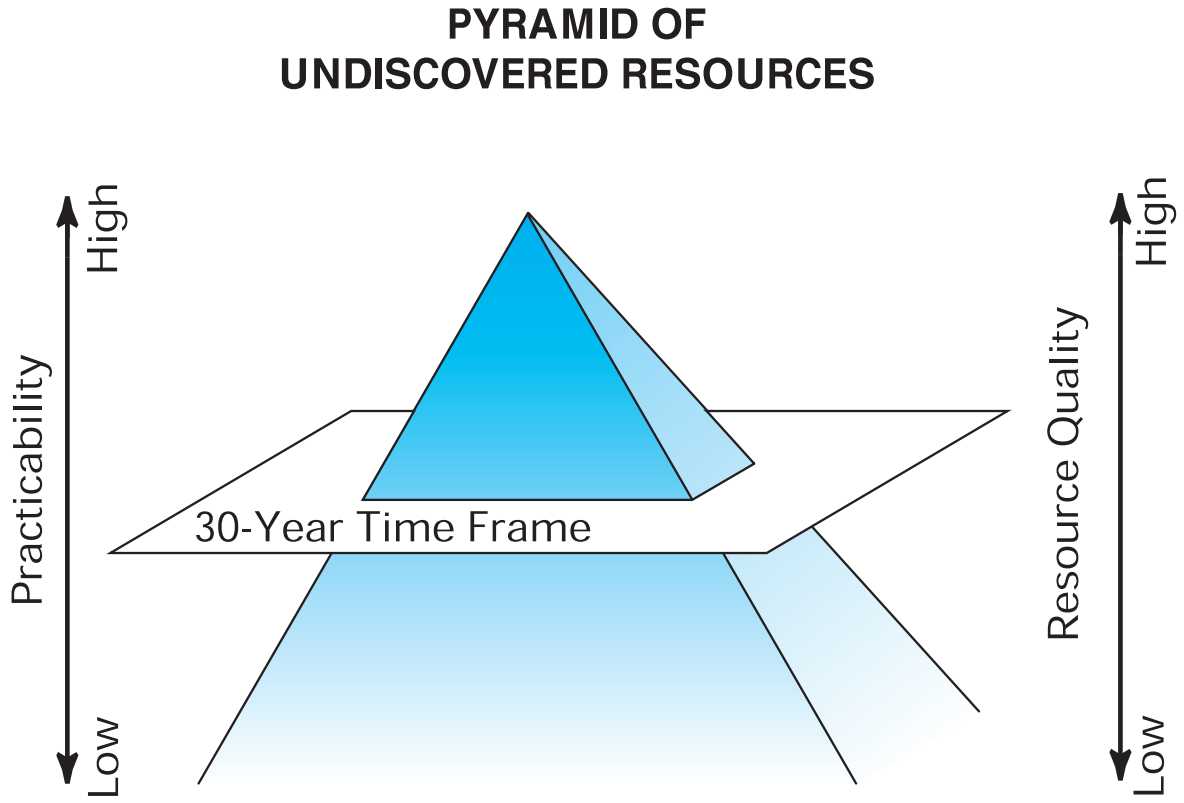

Figure 24.1. Sketch depicting a 30-year resource-assessment forecast span as a slice through the conventional-accumulation resource pyramid at some quality level. Accumulation categories below the selected slice level are excluded from assessment consideration. (Modied from McCabe, 1998.)

Fundamental Assessment Procedure

To begin an assessment of undiscovered conventional resources using the Seventh Approximation, the volume of rocks to be assessed is apportioned into reasonably homogeneous sub-units. For the NOGA series, these sub-units are divisions of total petroleum systems, termed assessment units. Assessment units are considered and assessed individually, as outlined by the flow diagram in figure 24.2.

The essence of the assessment procedure is as follows:

- A minimum accumulation size (field size or pool size), expressed as barrels of oil for oil accumulations and barrels of oil equivalent for gas accumulations, is chosen for the assessment unit. Petroleum in accumulations expected to be smaller than the minimum size is not considered to be a significant resource within the 30-year forecast span and is excluded from the assessment.
- Probabilities for the occurrence of adequate charge, adequate rocks, and adequate timing for at least one undiscovered accumulation of minimum size or greater are assigned to the assessment unit; this defines the geologic risk. The probability that essential petroleum-related activities will be possible in the next 30 years, at least somewhere in the assessment unit, is also assigned; this defines the access risk.
- The number of undiscovered oil accumulations and the number of undiscovered gas accumulations in the assessment unit that are greater than or equal to the minimum size are estimated
- Sizes of these undiscovered oil accumulations and undiscovered gas accumulations are estimated. Size estimates include both the reserves estimated at the time of discovery and anticipated reserve

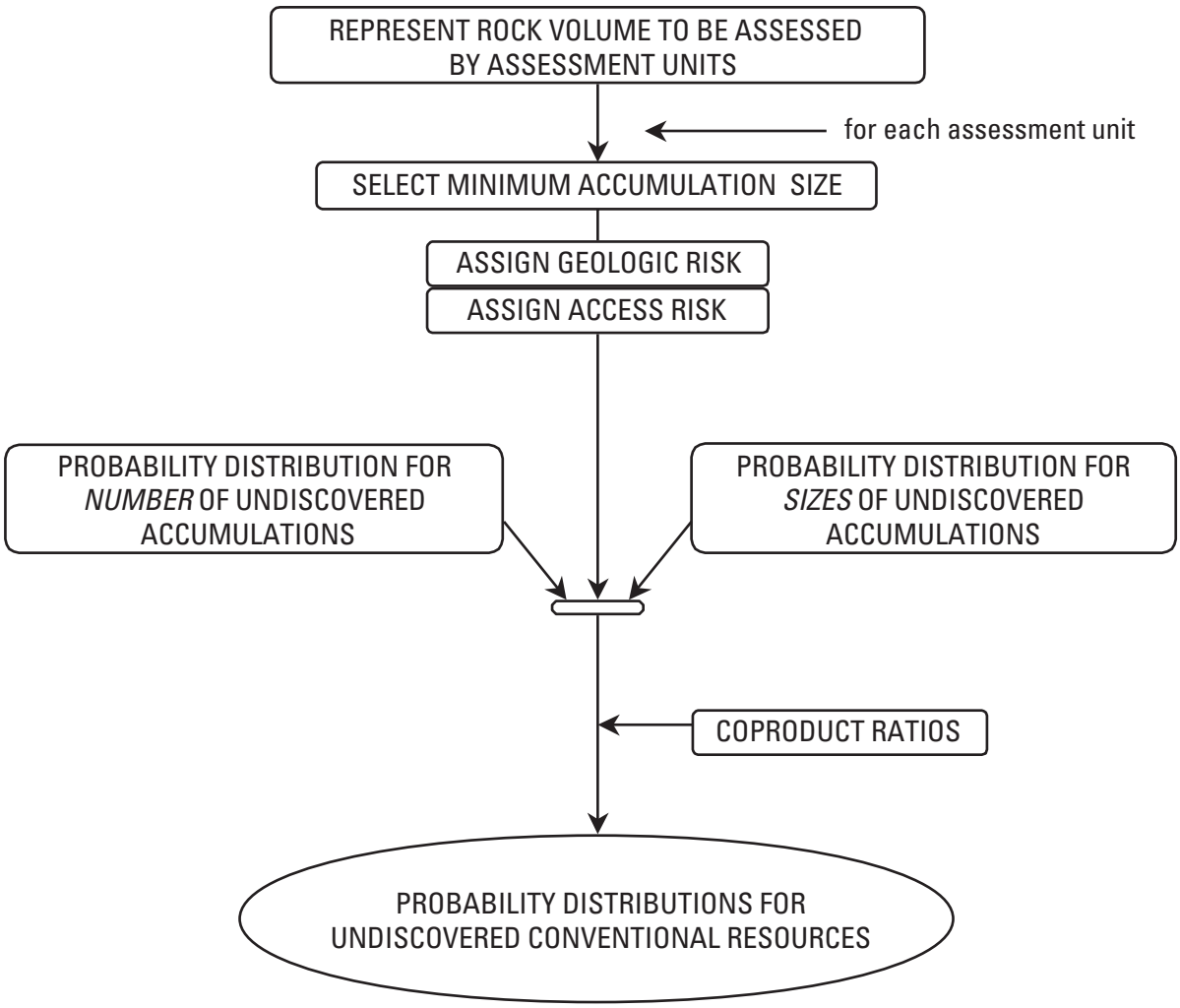

Figure 24.2. Flow diagram emphasizing key steps of Seventh Approximation assessment model for undiscovered conventional accumulations. (Modified from Schmoker and Klett, 1999.)

additions as accumulations are exploited after discovery (reserve growth).
- For undiscovered oil accumulations, ratios of gas/oil and natural-gas liquids/gas are estimated. For undiscovered gas accumulations, the ratio of total liquids/gas is estimated. These ratios are used to assess the coproducts associated with oil in oil accumulations and with gas in gas accumulations.

The combination of geologic and access probabilities, number of undiscovered accumulations, sizes of undiscovered accumulations, and coproduct ratios yields probability distributions for potential additions to reserves of oil, gas, and coproducts in the assessment unit.

An important aspect of this assessment procedure is that historical exploration and discovery patterns serve only as a starting point for the assessment forecast, and they are not necessarily projected as characteristic of future exploration and development trends. With historical data as a point of reference, input parameters can be chosen to reflect perceived impacts of future change, such as improved technologies and newly developed geologic concepts, as well as the recognition that the larger fields in an assessment unit tend to be found first.

Additional Assessment Data

Four input-data elements in addition to those discussed in the previous section are recorded at the assessment-unit level.

Identification Information

Identification information includes the assessor's name, the date of the assessment meeting at which input data were discussed and reviewed, and the names and numerical codes of the region, province, total petroleum system, and assessment unit. Brief notes relevant to the assessment can also be recorded.

Characteristics of Assessment Unit

These input data, although not essential elements of the assessment model, provide information that is useful for the resource-assessment process.
- Classification of the assessment unit as oil prone or gas prone, based on the criteria that the overall gas/oil ratio of an oil-prone assessment unit is less than 20,000 cubic feet of gas/barrel of oil, and that of a gas-prone assessment unit is greater than or equal to 20,000 cubic feet of gas/barrel of oil.
- Number of discovered oil accumulations and gas accumulations of minimum size or larger, and the median sizes of three sub-groups of these accumulations—the first-third discovered, the second-third discovered, and the third-third discovered (or first-half and second-half discovered if the number of fields is small).

A classification of the exploration maturity of the assessment unit—as established, frontier, or hypothetical—is also made, based on the number of discoveries equal to or exceeding minimum size. Established (more than 13 accumulations discovered) and frontier (1 to 13 accumulations discovered) assessment units are known to have all the geologic elements necessary for at least one petroleum accumulation of minimum size. Additionally, established assessment units have a sufficient number of discovered accumulations for historical field- or pool-level data to be of help in postulating properties of undiscovered accumulations. Hypothetical assessment units have no discovered accumulations, and their assessment is therefore more speculative than for established and frontier assessment units.

Selected Ancillary Data for Undiscovered Accumulations

These data establish a modest set of information useful for economic and environmental analyses of assessment results. They do not contribute directly to assessment calculations. Ancillary data for undiscovered conventional oil accumulations are estimates of API gravity of oil, sulfur content of oil, drilling depth, and water depth (if applicable). Ancillary data for undiscovered conventional gas accumulations are estimates of inert-gas content, carbon dioxide content, hydrogen sulfide content, drilling depth, and water depth.

Allocations of Assessed Undiscovered Resources

These input data consist of percentages necessary to allocate assessed undiscovered conventional resources to various land entities of interest within the assessment unit, as well as to the offshore portion of each entity, if applicable. Such land entities could include, for example, surface and mineral ownerships, special use categories of State and Federal lands, or ecological zones.

Comparison to USGS 1995 National Assessment

Through the years, the methods and procedures used in USGS petroleum assessments have not remained static but have evolved as databases, computers, and geologic knowledge have advanced, and as the need for resource forecasts of more short term relevance has increased. The assessment

concepts for conventional accumulations described in this report are essentially the same as those of the USGS World Petroleum Assessment 2000 (U.S. Geological Survey World Energy Assessment Team, 2000) but are changed somewhat from those of the USGS 1995 National Assessment of United States Oil and Gas Resources (Gautier and others, 1995). This section describes three of the more important conceptual differences between the 1995 and the present (Seventh Approximation) assessment models.

Plays Versus Assessment Units

The 1995 National Assessment used the play as the basic level of assessment. Plays are established primarily according to similarities of the rocks in which petroleum accumulations occur. In contrast, the National Oil and Gas Assessment (NOGA) series begun by the USGS in 2000 uses subdivisions of the total petroleum system—termed assessment units—as the basic level of assessment. A total petroleum system consists of all genetically related petroleum generated by a pod or closely related pods of mature source rocks. Particular emphasis is placed on similarities of the fluids of petroleum accumulations. Assessment units are therefore more closely associated with the generation and migration of petroleum than are plays.

The choice of play versus assessment unit probably does not result in significant systematic differences in assessed undiscovered resources. However, the total petroleum system and its assessment units provide a more comprehensive and unifying framework for studying oil and gas accumulations.

Technically Recoverable Resources Versus Potential Additions to Reserves

In the 1995 National Assessment, the fundamental petroleum quantity assessed was technically recoverable resources. These were defined as resources producible using current recovery technology but without reference to economic profitability (U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995).

However, given the sophistication of current petroleum-related technology, essentially all of the moveable oil or gas in almost any accumulation that can be envisioned has become recoverable from a purely technical standpoint. In the Seventh Approximation, more restrictive conditions are imposed, to the extent that assessed petroleum volumes must not only be technically recoverable but must also have the potential to be added to reserves.

Unlimited Versus 30-Year Timeframe

In the 1995 National Assessment, volumes of undiscovered resources were estimated without regard for the time span that might be required to realize them. Because the forecast span was unlimited, the question of "when?" was not addressed. In contrast, a finite forecast span is a central tenet of the Seventh Approximation assessment model. This forecast span equals 30 years for the NOGA series, which is a more restrictive condition than an unlimited time span.

Because of the unlimited time span of the 1995 National Assessment, all plays were considered accessible for petroleum-related activities; no political or technological barrier should be expected to last forever. In a 30-year timeframe, however, access to a particular area for petroleum-related activities (for example, Yellowstone National Park) might not be certain. The Seventh Approximation therefore includes a probability for adequate access, at least somewhere in the assessment unit, during the forecast span.

Summary

This report focuses on concepts used by the USGS for assessing petroleum resources in undiscovered conventional oil and gas accumulations. Conventional accumulations are discrete fields or pools localized in structural and stratigraphic traps by the buoyancy of petroleum in water. As such, conventional accumulations can be represented and assessed in terms of the sizes and numbers of individual, countable fields or pools that are delineated by down-dip water contacts.

The USGS model described here for assessing undiscovered conventional resources is called the Seventh Approximation. The Seventh Approximation provides a strategy for estimating volumes of undiscovered petroleum having the potential to be added to reserves in a 30-year forecast span, and is being used by the USGS in the National Oil and Gas Assessment (NOGA) series begun in 2000.

To begin an assessment using the Seventh Approximation, the volume of rocks to be assessed is apportioned into reasonably homogeneous subunits, termed assessment units, which are then assessed individually. A minimum accumulation size is chosen for the assessment unit, and geologic risk and access risk are assigned. Estimates in the form of three fractiles (F_{100}, F_{50}, and F_0) are developed for the number and sizes of undiscovered oil accumulations and undiscovered gas accumulations in the assessment unit. Coproduct ratios are also estimated. The combination of these variables yields probability distributions for potential additions to reserves of oil, gas, and coproducts in the assessment unit. These assessed petroleum volumes can be allocated to various land entities of interest within the assessment unit, according to percentages specified by the assessor.

The concepts described herein have evolved somewhat from those used to assess conventional accumulations in the USGS 1995 National Assessment of United States Oil and Gas Resources (Gautier and others, 1995), although estimation of the number and sizes of undiscovered accu-

mulations is at the core of both. Three of the more important conceptual changes embedded in the Seventh Approximation assessment model are (1) use of the total petroleum system (of which assessment units are a subdivision) instead of plays, (2) estimation of potential additions to reserves instead of technically recoverable resources, and (3) use of a 30-year forecast span instead of an unlimited assessment time frame.

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