METHODS OF EXPLORATION AND PRODUCTION OF PETROLEUM RESOURCES

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Summary

Methods of petroleum exploration and production (E&P) typically involve expensive, technologically driven approaches. During the prospecting phase, petroleum E&P includes the use of subsurface geologic evaluation, seismic data and large computing power to process the geophysical data. Drilling exploratory wells is also an expensive and risky undertaking. All decisions about investments made in exploratory drilling, development, and production are weighted against the potential economic return anticipated from the investment.

1. Introduction - Background of the Petroleum Industry

Demand for petroleum products has grown continuously since the first discovery of large crude oil accumulations in the United States by Edwin Blake in 1859 near Titusville, Pennsylvania (see Petroleum (Oil and Gas) Geology and Resources, this volume; and Coal, Oil and Gas for the Twenty-first Century, this volume). As a result, the petroleum industry is now a major component of the global economy. Most petroleum products derived from refining crude oil are combusted to provide energy as in diesel fuel, jet fuel, kerosene, fuel oil and gasoline. The burning of fossil fuels (coal, natural gas and oil) provides the vast majority of energy today and the dependence on petroleum products is anticipated to continue into the foreseeable future (see Petroleum (Oil and Gas) Geology and Resources, Figure 1, this volume). However, there are a number of environmental concerns associated with the burning of petroleum products. Concerns about air pollution, smog and greenhouse gas effects on global warming is causing a shift in the demand for liquid fuel towards greater use of natural gas (methane) for non-transportation needs. Natural gas, or methane, has many uses including home heating and cooking, electrical power generation plants, and as a feedstock for certain chemical processes. In addition to producing refined fuels, crude oil can also provide petrochemicals for wide range of uses, both as products themselves and as chemical feedstocks used to make other products. These petrochemical products include pharmaceuticals, plastics, synthetic rubbers, insecticides, fungicides, fertilizers, and lubricants.

The value of the crude oil that provides heating fuel and fuel for internal combustion engines creates the incentive for investors, including national governments, to spend large amounts of money to search for it underground. However, there is a great deal of risk associated with investing money in oil and gas exploration because petroleum deposits are generated by natural processes that commonly occur at great depth and are poorly understood and predicted by earth scientists. Financially there is a lot at stake and commercial failures can be very costly to the investor because exploration wells often cost millions to hundreds of millions of dollars in deepwater and harsh environments; exploration programs (property leasing, data collection and analysis, etc.) commonly cost in excess of one hundred million dollars,

Oil industry investors and company managers commonly refer to “the size of the prize” when considering the investment risk in hydrocarbon exploration. They ask themselves, “Does the amount of petroleum our geologists think is down there, justify the high cost of exploratory drilling and subsequent development program?” The goal of the investor/shareholder or company is to make money at a desired return of investment, not just to find oil or gas. In order to make money, the company must find, produce, and sell petroleum at a profit that meets their financial goals? Many beginning oil company exploration geologists or geophysicists get caught up in the technical aspects of subsurface analysis, but find out quickly that the business aspects of making money drive the technical work, not the other way around. This is a critical point to remember from this chapter on methods of oil and gas exploration. The methods described in this chapter, which can be very “high tech”, cutting edge and expensive, are developed and used by oil companies and investors for one purpose only: to reduce the uncertainty of predicting the subsurface location, volume and nature of economic occurrences of petroleum deposits. The use of these methods depends on whether the value of the information that they provide is expected to exceed the cost to employ them. Alternatively stated, the methods employed in oil exploration are driven by the business need to evaluate the investment risk relative to the monetary return expected.

There are seven major conceptual steps involved in the complete commercial “Petroleum Product Life Cycle” (Figure 1). These steps are (1) Prospecting, (2) Leasing or acquiring access, (3) Drilling operations, (4) Developing and producing, (5) Transporting, (6) Processing and refining, (7) Marketing and sales. Of the seven steps listed above, the first three steps are called the “exploration phase” and the forth step is the “production/extraction phase”. The majority of wildcat wells drilled to date have been dry holes that contained no commercial hydrocarbons. Wildcat drilling success rates in the industry have climbed from about a 10% success rate 20 years ago, to approximately 56% of wells discovering hydrocarbons currently. Thus steps 1 through 3 in Figure 1 may need to be repeated many times before a successful venture that moves forward to steps 4 through 7 is achieved.

Many geoscientists employed by the petroleum industry refer to themselves as working in the "upstream" part of the business, or in "E&P". This means the exploration and production aspects of the business. "Midstream" business consists of transportation and refining (steps five and six). The "downstream" business deals with marketing and sales (step seven), which is represented by the gasoline stations that are familiar to many consumers. This chapter addresses only the methods employed by those engaged in the exploration and production phases of the petroleum industry. In addition, this chapter focuses on the role of the geoscientist in E&P, and does not provide detail on the role of other disciplines such as economics and engineering.

National Oil Companies (NOC's) that are owned and directed by national governments are subject to rules and regulations outside of the commercial marketplace. Their motives and objectives may involve energy supply and security for their citizens rather than strictly financial investment return. Thus they may not need to conduct steps two and seven above, or these and other steps may be greatly modified from those undertaken by industrial enterprises.

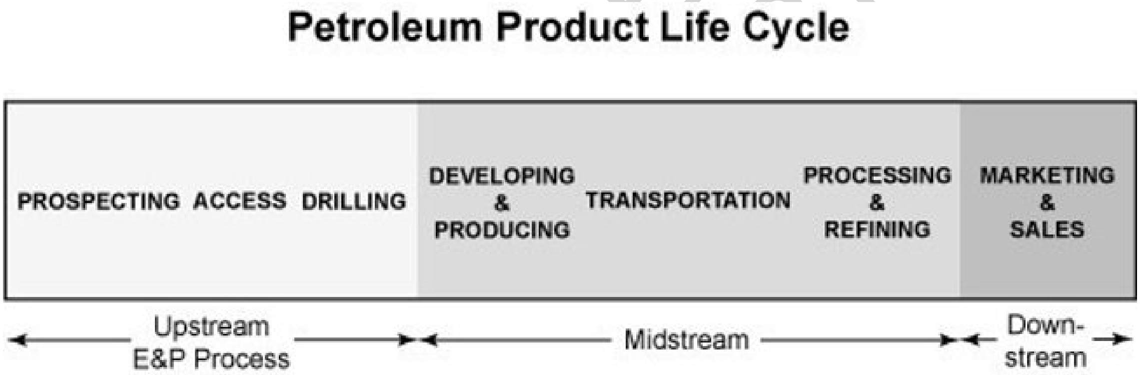

Figure 1. The Petroleum Product Life Cycle

2. The Role of Geoscientists

The majority of geoscientists employed in the search for oil and gas fall into one of three sub-specialties. Although there can be much overlap, these three sub-specialties are as follows: geologists (understanding the rocks), geophysicists (interpreting the subsurface structure or configuration through seismic, gravity, etc.) and geochemists (understanding the subsurface fluids, like petroleum). Geoscientists are employed by oil exploration and production companies because of their expertise in applying earth science to predict subsurface conditions and processes at work in sedimentary basins that form the "hydrocarbon habitat" for oil and gas deposits. In their role of assessing uncertainty, geoscientists must have the ability to work in multidisciplinary teams that collectively bring together a variety of expertise, including geophysics, petrophysics, drilling, reservoir engineering, production engineering, facilities operations, environmental analysis, economics, accounting, legal, commercial, and negotiations. It is critical that the multidisciplinary team decides the value of information that they either have or need, and members of the team must learn quickly from each other and from past experience. As stated earlier, mistakes in the exploration business can be costly in terms of money, environmental impact, and human safety. Typically, every well that is drilled undergoes an extensive study afterwards, called a “post-well appraisal”, to learn as much as possible about successes and failures. The information learned from the appraisal is often applied to future projects.

The challenge for geoscientists is to interpret the subsurface and for exploration the most important thing is the idea or concept of where hydrocarbons might be found in the subsurface and why. The geologist must develop creative and innovative ideas about where oil and gas might be found. This is particularly true because the majority of the large fields and “easy finds” have already been discovered, generally decades ago. Petroleum geoscientists look for new exploration areas by studying the regional geology. This regional overview provides an understanding of which areas are, or may be, productive, why they are productive, and what other areas should be examined. Geologists and geophysicists try to predict where oil and gas occur by “remote sensing”, using gravity and magnetics, rock distribution and properties, and geophysical imaging tools to gather data on subsurface characteristics. The data that are generated are typically subjected to computer processing, advanced modeling with three-dimensional (3-D) visualization in order to better understand and image the subsurface. Drilling for oil and gas may take place when all geological, economic, political and environmental conditions are deemed to be favorable. Geologists also use concepts, like the anticlinal theory (popularized in the 1880s) and the total petroleum system (popularized in the 1980s), to develop geologic models that support business and engineering decisions (see Petroleum (Oil and Gas) Geology and Resources, this volume). Geochemists study the chemistry of petroleum and its sources to characterize the petroleum type, history and origin. Geochemists also develop input into basin modeling which provides quantitative integrated petroleum system models, including source, reservoir, seal, trapping mechanism and hydrocarbon charge.

Two additional geologic specialty areas, structural geology and stratigraphy, are widely used in the oil industry. Structural geology provides an understanding of subsurface deformation processes that can create hydrocarbon traps. Stratigraphy is the study of the origin, composition, distribution, and succession of rock layers. Stratigraphers try to recognize and follow rock beds or layers from one well or outcrop to another. The act of going from a well or rock formation whose beds and rock layers are known to an area that is unknown, but assumed to be similar is called “stratigraphic correlation”. The correlation process is an attempt to match fossil type and age, rock mineralogy, grain size and rock texture from one area to another. Correlation is important for understanding the geometry, size and lateral continuity of potential oil and gas traps, reservoirs, and seals.

The methods and tools that a geologist may use include conducting rock studies, constructing maps and cross-sections, making chemical and physical measurements, developing conceptual and numerical subsurface models, developing databases and making calculations. Geologists also provide input into business and economic models, drilling operations, and planning of facilities like oil and gas production platforms.

3. The Exploration and Production (E&P) Process

3.1 Steps of the E&P Process

The commercial E&P process is a multiphase process (as shown in Figure 2) that typically proceeds in a variety of forms from Step 1 through Step 16, depending on investor interests. Step 1 business strategy; is outside the scope of this chapter. Steps 2 through 9 comprise the Prospecting Phase of Exploration (sections 3.2, 3.3, and 4 of this chapter). Steps 10 through 13 comprise the Conventional Exploration Phase (section 5 of this chapter). Steps 14 through 16 comprise the Field Development Phase (section 6 of this chapter). Steps 2 through 5 make up the geological and geophysical assessment of undiscovered potential (see Petroleum (Oil and Gas) Geology and Resources, this volume). During the prospecting phase (prior to drilling), work can stop at any point after step 2, 3, 4, 5, 6, or 7 and not advance to the leasing and drilling stage, if the business decision is made not to proceed. Work is particularly likely to stop during Step 6, when many of the scientific and technical results are risked and weighted against other, non-technical factors. For unsuccessful wells (called "dry holes"), step 9 is reached and the well is "plugged and abandoned" because hydrocarbon was not present in sufficient quantities to be worth the cost to produce it.

National Oil Companies and government entities that conduct oil and gas exploration either within their own borders or in foreign countries often take a different approach toward the non-technical aspects of exploration occurring in Steps 1, 6 and 7 of Figure 2. However, the geoscience evaluation and prediction of petroleum systems by the geologist, geochemist, and geophysicist remain very similar to that described in this chapter.

The Eploration and Production (E&P) Process

1. Company/Investor Business Plan Strategy
2. Global or Regional Basin Analysis
3. Play Concept Development
4. Exploration Fairway or Trend Delineation
5. "Leads" to Drillable Prospect Identifacation and Evaluation
6. Preliminary/Screening of Environmental, Economic, Commercial, and in the Case of Foreign Exploration, Political Risk Against Business Plan and Strategy. This is repeated throughout the process as the amount and accuracy of information improves.
7. Leasing
8. Engineering Plan
9. Wildcat Drilling - Fronteir Exploration
10. Appraisal Wells
11. Production Feasibility Analysis
12. Field Facilities
13. Exploitation Drilling
14. Developmental Drilling
15. Field Production
16. Abandonment

Figure 2. The Exploration and Production (E&P) Process for a Commercial Enterprise

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Bibliography

Baker, Ron, 1979 (various editions), A Primer of Oilwell Drilling, University of Texas at Austin Press, Austin, TX, 94 pp.
[The best overall text that gives a non-technical person an overview of drilling oil wells, including the types of people and expertise involved, their roles in the process, and the terminology that is a jargon and language unto itself.]

Campbell, J.M., Jr, J.M. Campbell, Sr., and R.A. Campbell, 1987, Analysis and Management of Petroleum Investments: Risk, Taxes and Time: CPS Publishing, Norman, OK, 494pp.
[A mid-level to high-level text on business aspects of petroleum investment and economic risk analysis.]

Deffeyes, K.S., 2001, Hubbert's Peak, The Impending World Oil Shortage, Princeton University Press, Princeton, NJ, 208pp.
[A recent book from the popular press that describes the oil business and oil exploration in layman's terms and raises controversial issues of current debate regarding resource appraisal.]

Fundamentals of Petroleum, 1981 (various editions), The University of Texas at Austin Press, Austin, TX, 280 pp.
[The standard issue introductory manual provided to beginning oil company geologists that provides a broad overview of the petroleum industry, ranging from drilling operations, to pipelines and refining, all the way to marketing.]

Orban, John, 1997. Money in the Ground. Meridan Press, Oklahoma City, 408pp.
[Overview of all aspects of oil and gas commercial development.]

Society of Professional Well Log Analysts (SPWLA), 1984, Glossary of Terms and Expressions Used in Well Logging, Second Edition. Published by the SPWLA.
[A publication that contains a thorough dictionary of oil-field terminology.]

Steinmetz, R., 1992, The Business of Petroleum Exploration, American Association of Petroleum Geologists (AAPG) Treatise of Petroleum Geology, Handbook of Petroleum Geology, AAPG, Tulsa, OK, 382pp.
[A basic textbook that covers the business, financial, risking, and economics aspects of the oil industry from the perspective of what a geologist needs to know.]

Yergin, Daniel, 1993, The Prize: The Epic Quest for Oil, Money and Power, Touchstone Books.
[A book from the popular press, also made into a video documentary series, that details the birth and history of the oil industry, highlighting the interplay of emotion, finance, economics, technology and geography.]

Biographical Sketch

Ione L. Taylor received her Bachelor's of Science degree in Chemistry from Guilford College and Master's of Science and Doctorate of Philosophy in Geology from the University of North Carolina at

Chapel Hill, USA in 1985. The topic of the dissertation research was use of geochemistry and petrology to study an ancient geothermal system operating in Cenozoic volcanic and volcaniclastic rocks of the southern Rio Grande Rift system, southwestern Basin and Range province, USA. This research was in collaboration with and financially supported by the New Mexico Bureau of Mines and Mineral Resources, Socorro, NM, USA. The author then began a 14 year career with the petroleum industry starting with a major multinational oil company as an Operations Geologist developing and overseeing drilling wells in the offshore Gulf of Mexico, USA. The goal of the work was to provide the geoscience analysis needed for discovering oil and gas on the outer continental shelf. Subsequent assignments involved petrologic and geochemical consulting for oil and gas exploration and production ventures in the domestic US, as well as overseas. The author then moved from technical positions into management with assignments as a Research Supervisor, Technical Director, and Exploration Manager. Areas of expertise include petroleum reservoir quality prediction, inorganic geochemistry, and petroleum system and reservoir risk assessment. In 1999, the author joined the US Geological Survey as Chief Scientist for the Eastern Energy Resources Team within the Geologic Division. This team includes scientific experts conducting research projects addressing fossil fuel (coal, oil, gas) assessment, as well as the environmental and health impacts of fossil fuel use.