

**Chapter 3**  
**Natural Gas Basics**

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This chapter briefly describes basic theories and terminology used within the report-i. e., it briefly **describes what natural gas is, how it is formed, how it is found and subsequently produced, and**

how discoveries are reported. Words in boldface are defined in *Appendix D: Glossary*. **Readers familiar with basic terminology and concepts of natural gas supply may wish to skip this section.**

## WHAT IS NATURAL GAS?

As its name implies, natural gas is a naturally occurring mixture of hydrocarbon and nonhydrocarbon gases found in subsurface reservoirs within the Earth's crust. Methane (CH<sub>4</sub>, a light hydrocarbon, is the primary constituent of natural gas and of principal interest to the energy in-

dustry. Associated heavier hydrocarbons such as ethane, propane, and butane and impurities such as water, hydrogen sulfide, and nitrogen occur with the methane. If the concentrations of these other constituents render the gas unmarketable, they must be removed prior to use.

## HOW DOES NATURAL GAS FORM?

There is no universally accepted explanation of how natural gas formed. Most hydrocarbon deposits of significant size have been discovered in **sedimentary basins**, however, and generally are thought to have originated from the decay and alteration of organic matter. Hundreds of millions of years ago, seas that covered a large portion of the land exposed today were inhabited by tiny plants and animals that, upon dying, sank to the bottom and were buried under layers of sediment. In areas of rapid **sedimentation**, organic decay was accompanied by high pressures and temperatures which, over millions of years, effectively "cooked" the organic material into **petroleum (oil and natural gas)**. **Hydrocarbons may** also have been formed by other processes: by the **anaerobic** (without oxygen) digestion of organic materials by bacteria at relatively low temperatures, and inorganically by the chemical transformation of carbon compounds at high pressures and temperatures deep within the Earth. The fraction of natural gas that is bacteria-generated gas, usually called biogenic gas, is at issue, but estimates range to as high as 20 per-

cent or more.<sup>1</sup> As for the "deep earth gas," a major controversy exists as to whether or not this gas even exists. According to arguments by Thomas Gold and Steven Soter of Cornell University, **most** naturally occurring methane is of inorganic origin and vast reserves remain to be discovered at depths below 15,000 ft.<sup>2</sup>

Temperature and pressure conditions play a critical role in determining the physical state of the hydrocarbons that result. Natural gas may be found at all depths, but it originated mostly in rocks subjected to particularly high temperatures and pressures over long periods of time. It generally is the only hydrocarbon present at depths beyond 16,000 ft. Liquid hydrocarbons occur at shallower depths, from about 2,500 to 16,000 ft,

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<sup>1</sup> D. D. Rice and G. E. Claypool, "Generation, Accumulation, and Resource Potential of Biogenic Gas," *AAPG Bulletin*, vol. 65, No. 1, January 1981.

<sup>2</sup> T. Gold and S. Soter, "Abiogenic Methane and the Origin of Petroleum," *Energy Exploration and Exploitation* (city, st: Graham & Trotman, Ltd., 1982).

where lower temperatures are characteristic.<sup>3</sup> Most crude oil is found between 6,500 and 9,000 ft, with light hydrocarbon liquids occurring at depths greater than 9,500 ft.<sup>4</sup> Biogenic gas is usu-

<sup>3</sup>H. Douglas Klemme, *Geothermal Gradients, Heat Flow, and Hydrocarbon Recovery. Petroleum and Global Tectonics* (Princeton and London: Princeton University Press, 1975), p. 260. Cited in Jensen Associates, Inc., *Understanding Natural Gas Supply in the U. S.*, contractor report to OTA, April 1983.

<sup>4</sup>B. P. Tissot and D. H. Welte, *Petroleum Formation and Occur-*

ally found at depths of a few hundred to a few thousand feet, because it is formed at the low temperatures that accompany shallow burial and rarely is generated at depths greater than 3,000 ft.<sup>5</sup>

*rence* (New York: Springer-Verlag, 1978), p. 202. Cited in Jensen Associates, Inc., op. cit.

<sup>5</sup>Rice and Claypool, op. cit.

## WHERE IS NATURAL GAS FOUND?

Petroleum accumulations occur as **reservoirs** or **pools**—not in caverns or large holes in a rock mass but in the minute pore spaces between the particles that compose the rock. The greater the amount of pore space in the rock (**porosity**), the larger the quantity of gas or oil that may be contained within it. Pools often occur together in a **field**, and multiple fields in similar geologic environments constitute a **province**.

Gas occurs separate from (**nonassociated gas**) and together with oil. When together, it occurs in solution with the oil (**dissolved gas**) or, when no more gas can be held in solution under the pressure and temperature conditions of the reservoir, as free gas (**associated gas**) in a gas cap.

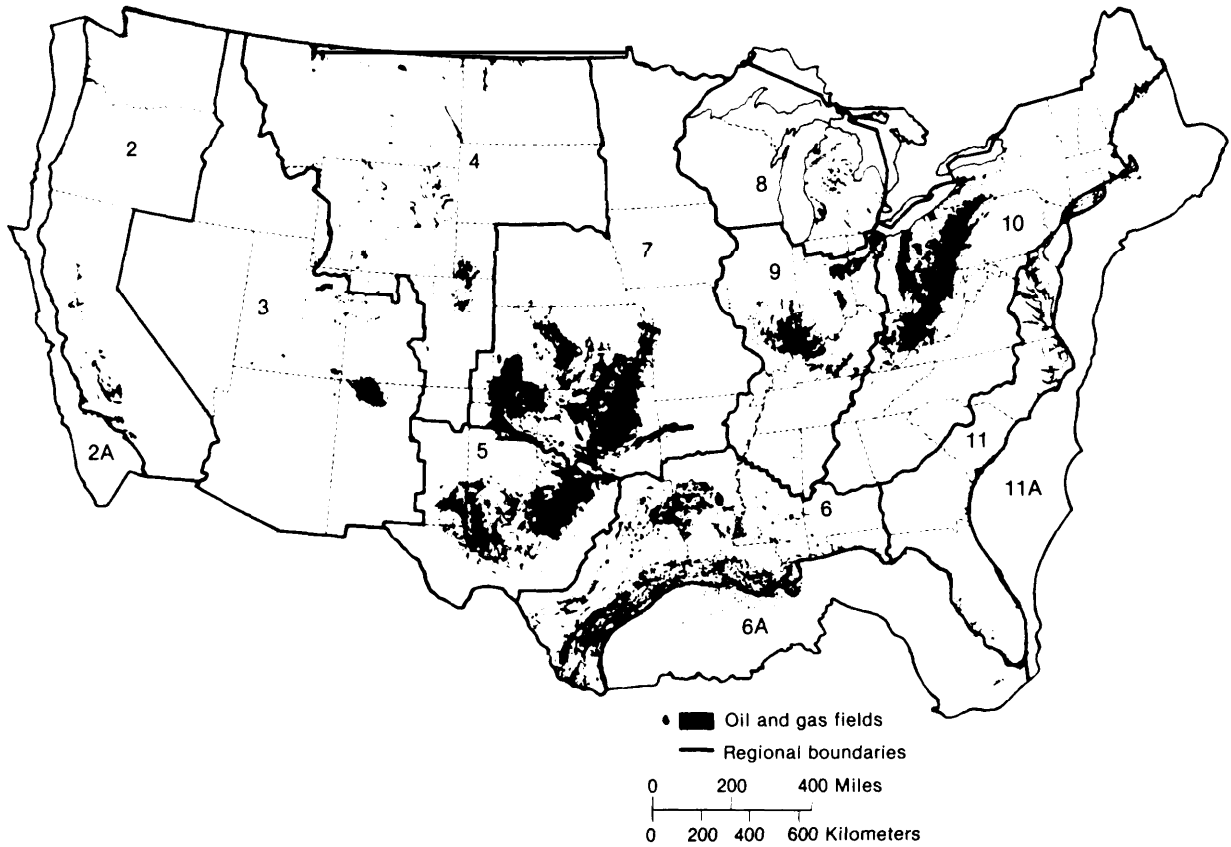
The search for hydrocarbon accumulations is narrowed by the requirement for the presence of organic material in the sediment at the time of burial. Sedimentary basins are the areas most likely to have contained the organic-rich rocks—**source** rocks—required for petroleum formation. Sedimentary rocks compose about 75 percent of the exposed rocks at the surface, but only percent of the Earth's crust (outer 10 miles). The known oil- and gas-bearing areas in the United States are identified in figure 3.

Commercial petroleum accumulations are not usually found in the source rock. Source rocks are generally of too low a permeability, meaning the texture of the source rock does not allow petroleum to flow easily through the pores of a producing well. Typically, after the petroleum has formed, the gases and fluids (oil and **formation**

**water**) migrate from the source bed to a more **permeable** rock, called the "**reservoir rock**" (this process is called "primary migration"). The fluids move in the path of least resistance (or highest permeability) and continue migrating within the reservoir rock (secondary migration) until an impermeable barrier is encountered, which prohibits further migration into adjacent or overlying rock units or **formations**. The petroleum then migrates further along the barrier to a place of accumulation, called a trap—usually located at the highest point where the reservoir rock contacts the more impermeable, barrier rock. The four requirements for a hydrocarbon accumulation—a source rock, reservoir rock, impermeable barrier rock, and trap—are illustrated pictorially in figure 4.

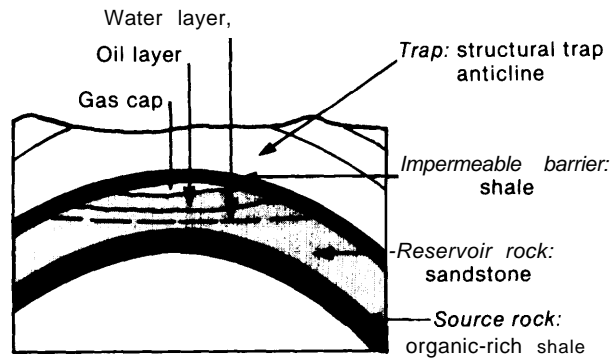
There are three basic types of petroleum traps: **structural**, **stratigraphic**, and **combination** (see fig. 5). Structural traps are formed by earth movements that deform or rupture rock strata, thereby creating favorable locations for hydrocarbons to accumulate. Such structural features as faults and **anticlines** create enclosures that serve as loci for migrating petroleum. Stratigraphic traps are created by permeability and porosity changes characteristic of the alternating rock layers that result from the sedimentation process. In stratigraphic traps, pinched-out beds, sandbars, or reefs serve as reservoirs for migrating petroleum. Combination traps result from both structural and stratigraphic conditions. An example of a combination trap is one that results from a salt dome intrusion during deposition that alters the thickness of the strata deposited.

Figure 3.—Known Oil- and Gas. Bearing Areas in the Lower 48 States



SOURCE: *Estimates of Undiscovered Recoverable Conventional Resources of Oil and Gas in the United States*, U.S. Geological Survey Circular 860, 1981

Figure 4.—Four Requirements for Petroleum Accumulation



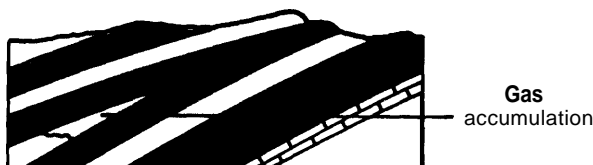
SOURCE: Office of Technology Assessment

**Figure 5.-Trapping Mechanisms**

**Structural trap—fault**



**Stratigraphic trap—pinched-out bed**



**Combination trap—salt intrusion**



SOURCE: Office of Technology Assessment.

## HOW IS NATURAL GAS DISCOVERED?

Before an understanding of subsurface geology was acquired or rules of petroleum occurrence were established, petroleum discoveries were based on surface seeps, knowledge gained from water well drilling, and luck. Today there are a variety of concepts, exploration methods, and instruments available to help geologists locate subsurface hydrocarbon accumulations.

The type of exploration techniques used varies between sites and depends on how much is known about the area being explored. In areas where little is known about the subsurface, reconnaissance techniques—which provide limited information over a large area—are used to identify favorable areas that warrant more detailed investigation. Satellite and high-altitude imagery

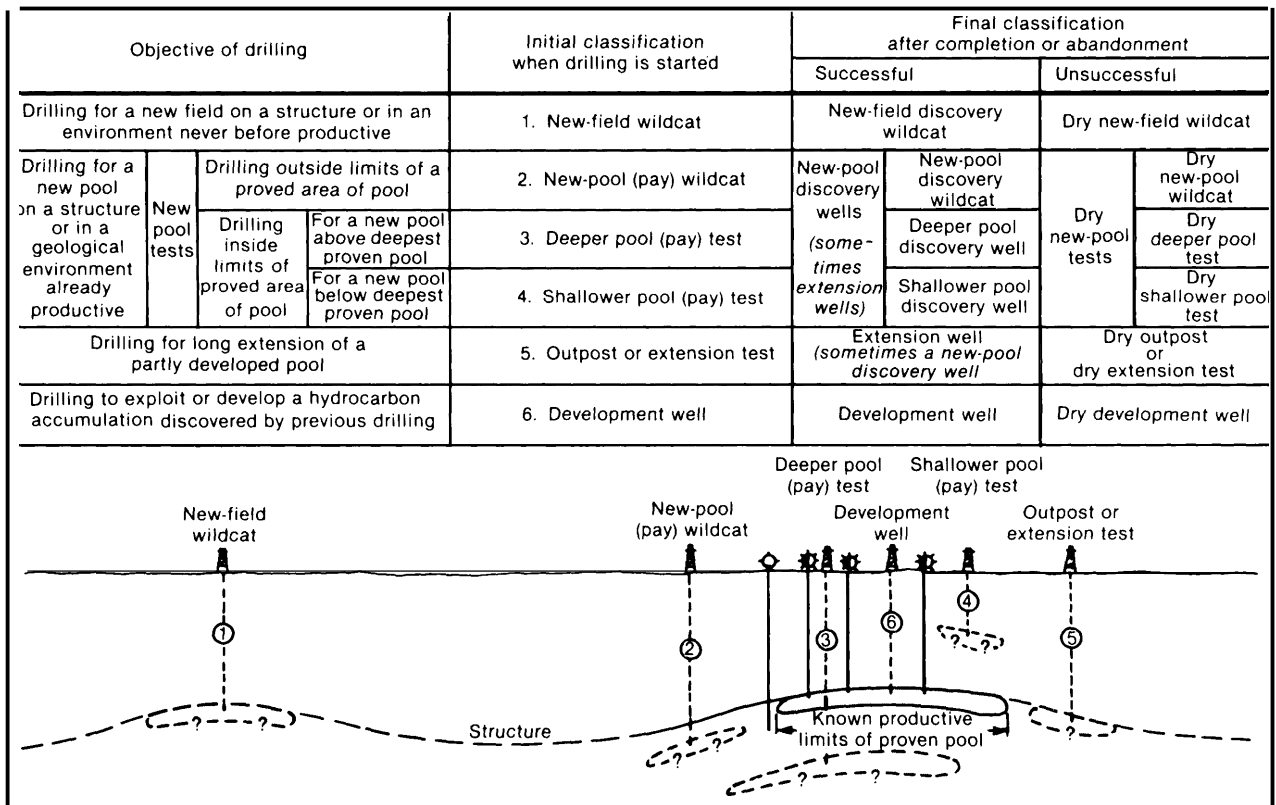
sometimes reveals large geologic features or trends that are surface expressions of subsurface geologic structure. Magnetic and gravity surveys detect changes in the magnetic or density properties of the Earth's crust and are also used to infer subsurface structure.

Once a promising area has been identified, more detailed, higher resolution exploratory techniques are used to locate individual prospects for the drill and to project conceptually related groups of prospects, or **plays**. The seismic reflection method, which measures and interprets the reflections of sound waves off of geologic discontinuities, is particularly effective for providing detailed subsurface information. Drilling is the final stage of the exploratory effort and the only sure way to determine if hydrocarbon-filled reservoirs exist in the subsurface.

In some basins, drilling may be performed so cheaply that predrilling exploration expenditures for seismic surveys and other analyses are not justified. These shallow areas are becoming increasingly scarce, and the role of predrilling exploration analysis is increasing in importance, particularly in frontier areas. If these high-cost areas are to be drilled, operators must be relatively sure that the drilling expense is justified.

The degree of risk involved in drilling depends on how much is known about the subsurface at the drill site. As illustrated in figure 6, a classification scheme has been established to categorize the exploratory wells based on their relationship to known petroleum discoveries. There are three basic kinds of exploratory well. A **new field wildcat** is a well drilled in search of a new field, that is, in a geologic structural feature or environment

Figure 6.—AAPG and API Classification of Wells



SOURCE: Lahee classification of wells, as applied by the Committee on Statistics of Drilling of the American Association of Petroleum Geologists, and the American Petroleum Institute Developed by Frederic H Lahee in 1944.

that has never been proven productive. New field wildcats generally have the greatest associated risk because they are drilled based on the least preexisting knowledge. New **pool wildcats-in search** of pools above (shallower), below (deeper), or outside the areal limits of already known pools—are generally less risky because the field in which they are drilled has been proven productive. **Outpost and extension tests are drilled to determine the bounds** of known pools. Development wells are the least risky because their primary function is to extract the petroleum from the already proven pools; they are not exploratory wells.

When an exploratory well encounters petroleum, the quantity of proved reserves is estimated, and the commercial viability of the reservoir evaluated. Proved reserves are determined by analyzing actual production data or the results of conclusive formation tests. The proved area is the area that has been delineated by drilling and the adjoining area not yet drilled but judged as economically producible based upon available geologic and engineering data. Because of its conservative nature, the initial estimate of proved reserves based on a field's discovery well is generally significantly smaller than the quantity of gas ultimately recovered from the field. Wells drilled in subsequent years may increase the proved area of the reservoir or lead to the discovery of additional reservoirs within the field.

Each year, the sum of reserve additions attributed to the three types of exploratory wells are reported by the Energy Information Administration (EIA) as "new field discoveries" (these are the **initial**, first year estimates of a new field's proved reserves), "extensions," and "new reservoir (pool) discoveries in old fields." (In this memorandum, this last category of reserve additions is called new **pool discoveries**, for brevity.) Another reporting category, "revisions," includes those reserves that are added or subtracted because of new information about old fields, for example, an indication that the fields will be drawn down to lower pressures because of a gas price increase, pressure histories during production that deviate from the expected values, or the use of measures to increase recovery. Another category, "Net of Corrections and Adjustments," reports reserve changes from corrections of previous arithmetic or clerical errors, adjustments to previously reported gas production volumes, late reporting of reserve additions, and so forth. \* Table 4 shows the changes in U.S. gas reserves from 1977 to 1981 as reported by the EIA, *U.S. Crude Oil, Natural Gas and Natural Gas Liquids Reserves—Annual Report*.

\*EIA began its data series in 1977. The American Gas Association and American Petroleum Institute also published reserve statistics in basically the same format (without a "corrections and adjustments" category) from 1966 to 1979, and in a somewhat different format from 1947 to 1965,

Table 4.—Estimated Total U.S. Proved Reserves of Natural Gas—1977-83

Year	Net of corrections & adjustments (1)	Revision increases (2)	Revision decreases (3)	Extensions old reservoirs (4)	New reservoir to discoveries in old fields (5)	New field discoveries (6)	Total discoveries (7)	Production (8)	Proved reserves <sup>b</sup> 12/31 (9)	Net change from prior year (10)
<b>Natural gas<sup>c</sup></b>										
1976 . . .	—	—	—	—	—	—	—	—	213,278 <sup>d</sup>	—
1977 . . .	-20d	13,691	15,296	8,129	3,301	3,173	14,603	18,843	207,413	-5,865
1978 . . .	2,429	14,969	15,994	9,582	4,579	3,860	18,021	18,805	208,033	620
1979 . . .	-2,264	16,410	16,629	8,950	2,566	3,188	14,704	19,257	200,997	-7,036
1980 . . .	1,201	16,972	15,923	9,357	2,577	2,539	14,473	18,699	199,021	-1,976
1981 . . .	1,627	16,412	13,813	10,491	2,998	3,731	17,220	18,737	201,730	2,709
1982 . . .	2,378	19,795	19,340	8,349	2,687	3,419	14,455	17,506	201,512	-218
1983 . . .	3,090	17,602	17,617	6,909	1,574	2,965	11,448	15,788	200,247	.1,265

NOTE: "Old" means discovered in a prior year. "New" means discovered during the report year.

aColumn 4 + Column 5 + Column 6.

bPrior year Column 9 + Column 1 + Column 2 - Column 3 + Column 7 - Column 8

cBillion cubic feet, 14,73 psia, 60° F.

dConsists only of reported corrections.

eBased on following year data only.

SOURCE' Energy Information Administration, US. *Crude Oil, Natural Gas, and Natural Gas Liquids Reserves-1983 Annual Report*, DOE/EIA-0216 (83), October 1984.



## HOW IS NATURAL GAS PRODUCED?

The way in which gas is produced depends on the properties of the reservoir rock and whether the gas occurs by itself or in association with oil. As illustrated in figure 7, hydrocarbons in the reservoir rock migrate to the producing well because of the pressure differential between the reservoir and the well. How readily this migration occurs is a function of the pressure of the reservoir and the permeability of the reservoir rock. When the reservoir rock is of low permeability, the rock may be artificially fractured to form pathways to the well bore. This is accomplished either with explosives or by hydraulic means, pumping a fluid under pressure into the well.

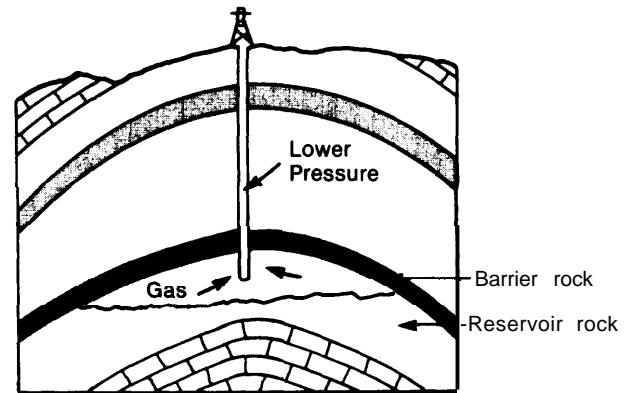
Production can continue as long as there is adequate pressure in the reservoir to propel the hydrocarbons toward the producing well. \* If gas is the only propellant, the reservoir pressure decreases as the gas is extracted and is eventually no longer sufficient to force the hydrocarbons toward the well. In a water-drive reservoir, water displaces the hydrocarbons from the pores of the reservoir rock, maintaining reservoir pressure during production and improving the recoverability of the hydrocarbons. In most reservoirs, gas recovery is high, generally greater than oil recovery. A "typical" recovery value of 80 percent is often cited, but the basis for this value is not firm, and **recovery is certainly** less in many reservoirs under current conditions. When gas occurs in association with oil, it can be reinfected into the reservoir to maintain pressure for maximum oil recovery. Gas is also reinfected when there are no pipeline facilities available to transport it to market.

Once the raw gas is produced from the well, it is gathered with production from other nearby wells and processed to remove natural gas liquids and impurities that could cause problems

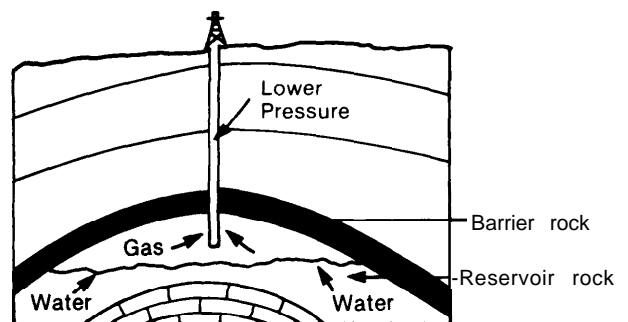
\*However, the requirement that the revenues generated by gas sales at least match the expense of operating the well generally will force an end to production before the flow of gas actually ceases.

Figure 7.— Production Mechanics

### Gas drive mechanism



### Gas and water drive mechanism



SOURCE Off Ice of Technology Assessment

in the pipeline. The gas is then sent by pipeline to local gas utilities who sell it to the end-user. In some instances, such as those involving large industrial users, the pipeline will sell directly to the end-user and bypass the local gas utility.