CHAPTER TWO

OIL AND NATURAL GAS ENERGY

DECISION-MAKERS
FIELD CONFERENCE 2002
San Juan Basin

The Origin of Oil and Gas

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We will pass through a number of oil and natural gas fields during this field conference. The oil and gas that are produced from these fields reside in porous and permeable rocks (reservoirs) in which these liquids have collected and accumulated throughout the vast expanse of geologic time. Oil and gas fields are geological features that result from the coincident occurrence of four types of geologic features (1) oil and gas source rocks, (2) reservoir beds, (3) sealing beds, and (4) traps. Each of these features, and the role it plays in the origin and accumulation of oil and gas, is illustrated below (Fig. 1).

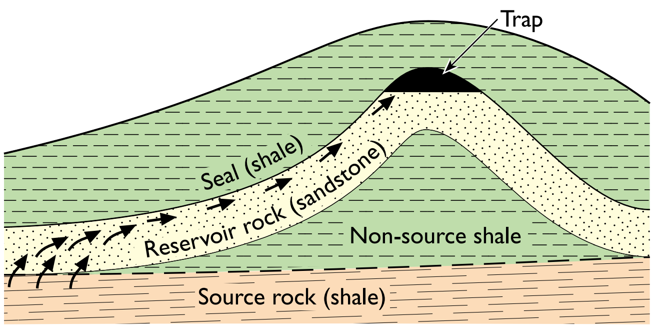

FIGURE 1 Natural accumulation of oil and gas.

OIL AND GAS SOURCE ROCKS

Oil and natural gas originate in petroleum source rocks. Source rocks are sedimentary rocks that formed from sediments deposited in very quiet water, usually in swamps on land or in deep marine settings. These rocks are composed of very small mineral fragments. In between the mineral fragments are the remains of organic material (usually algae), small wood fragments, or pieces of the soft parts of land plants (Fig. 2). When these fine grained sediments are buried by younger, overlying sediments, the increasing heat and pressure resulting from burial turns the soft sediments into hard layers of rock. If further burial ensues, then temperatures continue to increase. When temperatures of organic-rich sedimentary rocks exceed 120° C (250° F), the organic remains within the rocks begin to be "cooked," and oil and natural gas are expelled. It takes millions of years for these source rocks to be buried deep enough to attain these maturation temperatures. It takes many more millions of years to generate commercial accumulations of oil and natural gas, and for these accumulations to migrate into adjacent reservoir rocks.

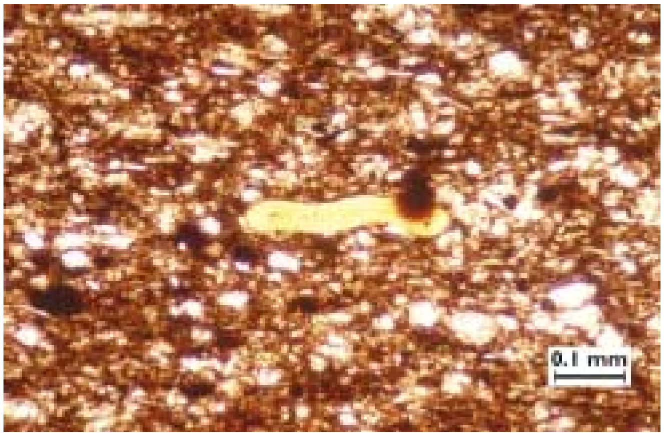

FIGURE 2 Microscopic image of a source rock with mineral grains (lighter colored material) and organic matter which is mostly algae remains (brown to black and yellow colored material). The source rock will usually act as a seal.

If the organic materials within the source rock are mostly wood fragments, then the primary hydrocarbon generated upon maturation is natural gas. If the organic materials are mostly algae or the soft parts of land plants, then both oil and natural gas are formed. By the time the source rock is buried deep enough to reach temperatures above 150° C (300° F), the organic remains have produced most of the oil they are able to produce. Above these temperatures, any oil remaining in the source rock or trapped in adjacent reservoirs will be broken down into natural gas. So, gas can be generated in two ways: it can be generated directly from woody organic matter in the source rocks, or it can be derived by thermal breakdown of previously generated oils at high temperatures.

OIL AND GAS RESERVOIR ROCKS

Oil and gas reservoir rocks are porous and permeable. They contain interconnected passageways of microscopic pores or holes between the mineral grains of the rock (Fig. 3). When oil and gas are naturally expelled from source rocks, they migrate into adjacent reservoir rocks.

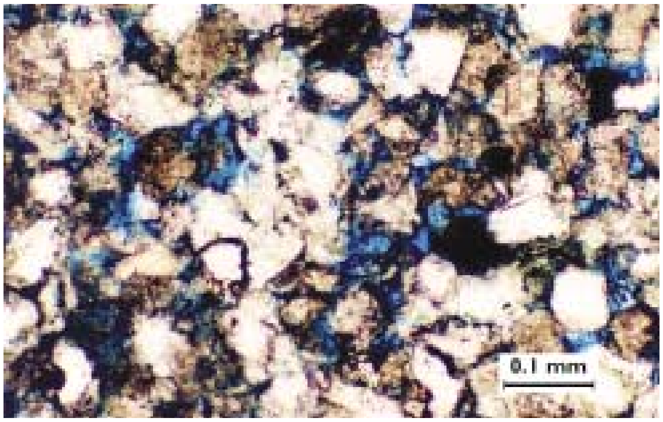

FIGURE 3 Microscopic image of a sandstone reservoir rock. The pore spaces (blue) may be occupied by oil, gas, or water.

Once oil and gas enter the reservoir rock, they are relatively free to move. Most reservoir rocks are initially saturated with saline ground water. Saline ground water has a density of more than 1.0 g/cm^3. Because oil and gas are less dense than the ground water (the density of oil is 0.82–0.93 g/cm^3; the density of natural gas is 0.12 g/cm^3), they rise upward through the water-saturated pore spaces until they meet a barrier of impermeable rock (Fig. 2)—a seal. Seals generally are very fine grained rocks with no pore spaces or pore spaces that are too small to permit the entry of fluids.

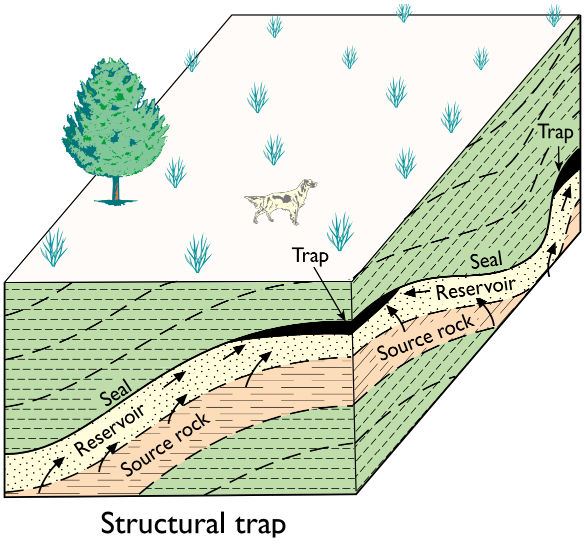

FIGURE 4 Folded strata that form a structural trap.

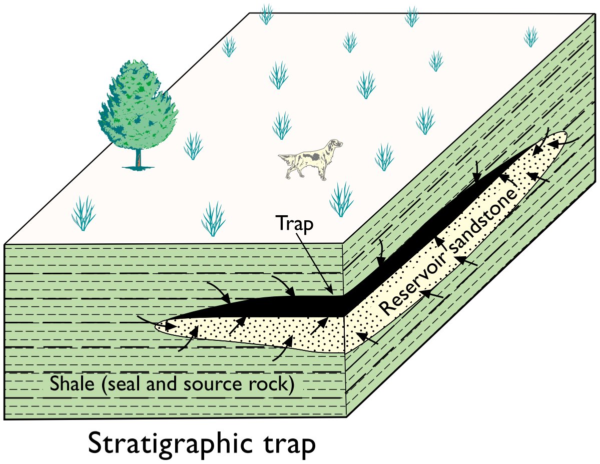

FIGURE 5 A discontinuous layer of sandstone that forms a stratigraphic trap.

OIL AND GAS TRAPS

Once in the reservoir rock, the oil and natural gas continue to migrate through the pore spaces until all further movement is blocked by the physical arrangement of the reservoir rock and one or more seals. This arrangement of the reservoir and seals is called a trap (Fig. 1).

There are two main types of traps: structural and stratigraphic (Figs. 4–5). Structural traps are formed when the reservoir rock and overlying seal are deformed by folding or faulting. Usually this deformation takes place tens of millions of years after deposition of the sediments that serve as seals and reservoir rocks. The oil and gas migrate upward through the reservoir and accumulate in the highest part of the structure (Fig. 4). If both oil and gas are present, the gas will form a layer (within the pore spaces) that rests above a layer of oil, because natural gas is less dense than the oil. The layer of oil will, in turn, rest upon the water-saturated part of the reservoir.

Stratigraphic traps (Fig. 5) are formed when the reservoir rock is deposited as a discontinuous layer. Seals are deposited beside and on top of the reservoir. A common example of this type of trap, of which there are many examples in the San Juan Basin, is a coastal barrier island, formed of an elongate lens of

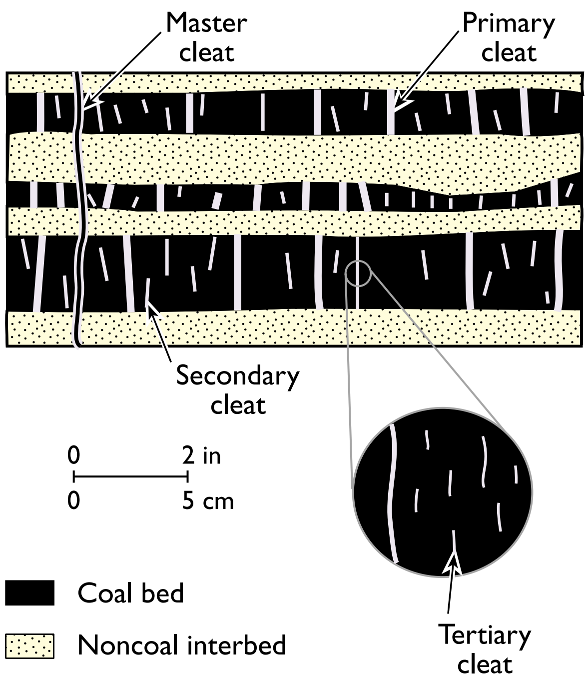

FIGURE 6 Diagram of vertical slice through coal reservoirs, showing vertical distribution of cleats (fractures) in the coal. From New Mexico Bureau of Geology and Mineral Resources, Bulletin 146.

sandstone. Impermeable shales that later serve as seals are deposited both landward and seaward of the barrier island. The result is a porous sandstone reservoir surrounded by shale seals. These same shales may also be source rocks.

COALBED METHANE

Coal can act as both a source rock of natural gas and a reservoir rock. When this is the case, coalbed methane ("coal gas") can be produced. The gas is generated from the woody organic matter that forms the coals. At shallow burial depths, relatively low volumes of gas may be generated by bacterial processes within the coals. At greater burial depths, where temperatures are higher, gas is generated thermally (as in conventional source rocks described above). Greater volumes of gas are generally formed by the thermal processes than by the bacterial processes. In the San Juan Basin gas has been formed through both processes.

Most coals are characterized by pervasive networks of natural fractures (Fig. 6). In the deep subsurface, these fractures are filled with water. The pressure exerted by this water holds the gas within the coal. In order to produce gas from the coal, first the water must be pumped out of the fractures. Once this is done, then the gas moves into the fractures, from where it may then be retrieved. The water that is first produced must be disposed of in a way that complies with existing regulations (see paper by Olson, this volume).

SUMMARY

Oil and natural gas are generated from the remains of organisms deposited in fine-grained sedimentary rocks along with the mineral grains that make up those rocks. As these source rocks are buried by overlying sediments, the organic matter is converted to oil and natural gas, first through bacterial processes and later by high temperatures associated with burial to a depth of several thousand feet. The oil and gas are then expelled from the source rocks into adjacent porous reservoir rocks. Because the oil and gas are less dense than the water that saturates the pores of the reservoir rocks, they rise upward through the pore system until they encounter impermeable rocks. At this point, the oil and gas accumulate, and an oil or gas field is formed.