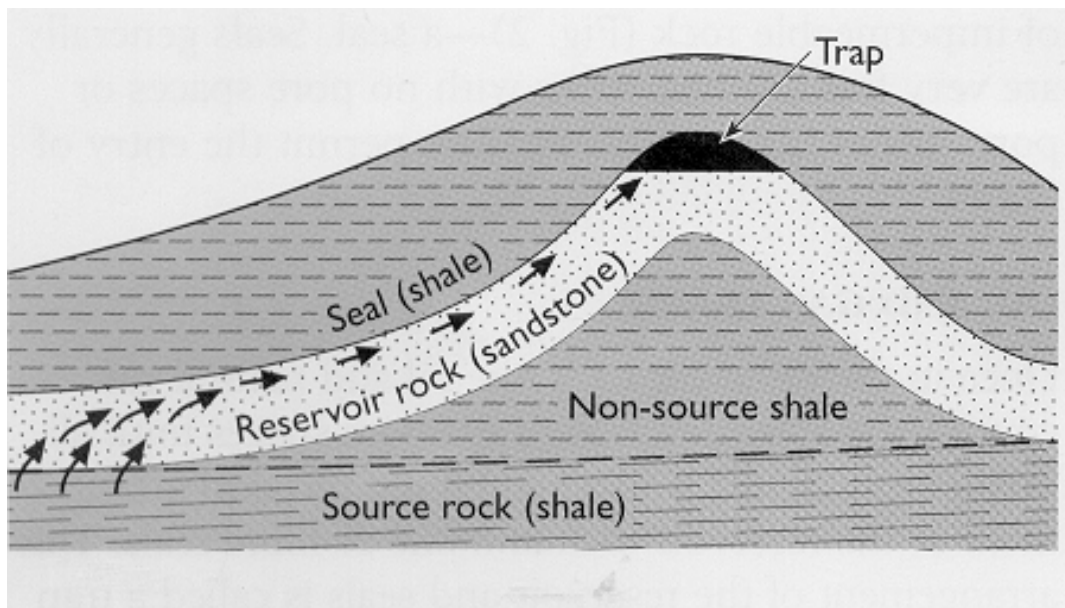


# PETROLEUM GEOLOGY: AN INTRODUCTION

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## INTRODUCTION

The oil and natural gas that are produced from oil and gas 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 (Figure 1): (1) oil and gas source rocks, (2) reservoir rocks, (3) seals, and (4) traps. Each of these features is discussed and illustrated below and the role of each type of feature in our natural oil and gas system is emphasized.



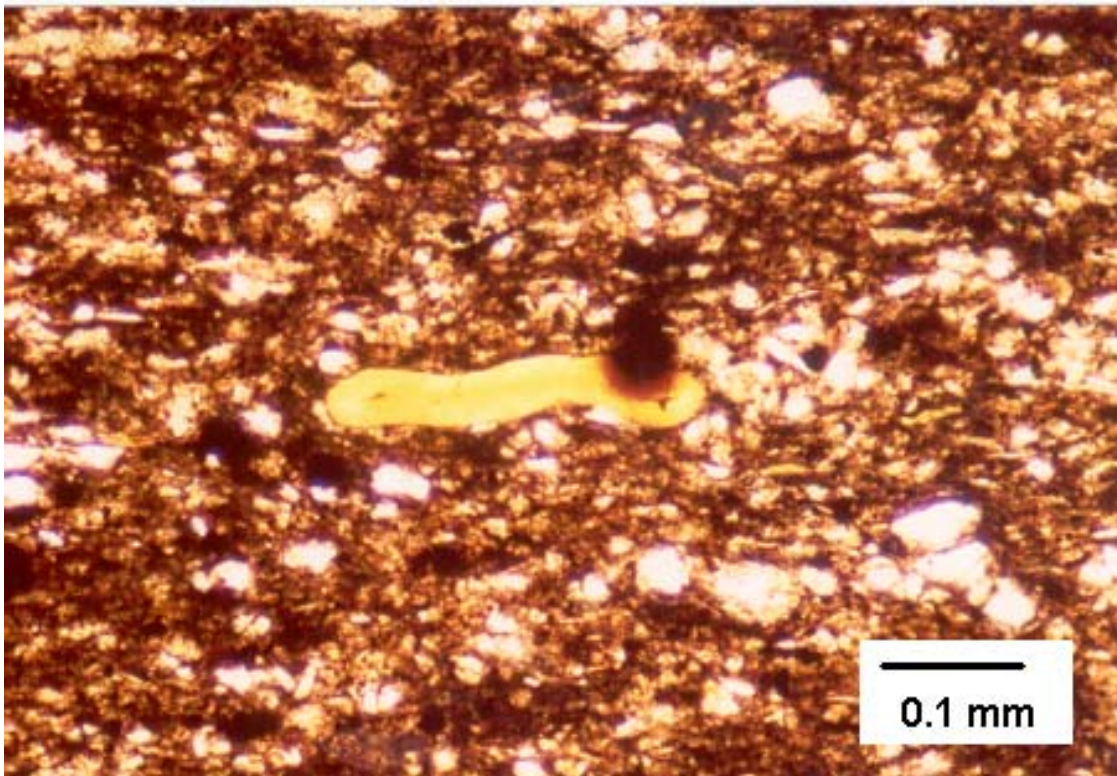
**Figure 1. Arrangement of oil and gas source rocks, a reservoir, a seal, and a trap in a way that has allowed the natural accumulation of oil and gas. From Broadhead<sup>1</sup>.**

## OIL AND GAS SOURCE ROCKS

Oil and natural gas originate in *petroleum source rocks*<sup>2</sup>. Source rocks are sedimentary rocks that were deposited in very quiet water, usually in still swamps on land, shallow quiet marine bays, or in deep submarine settings. Source rocks are comprised 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 (Figure 2). When these fine-grained sediments are buried by deposition of later, overlying sediments, the increasing heat and pressure resulting from burial turns the soft sediments into hard rock strata. If further burial ensues, then temperatures continue to increase. When temperatures of the 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 formed from the organic remains and expelled from the source rock. It takes millions of years for these source rocks to be buried deeply enough to attain these *maturation temperatures* and additional millions of years to cook (or generate) sufficient volumes of oil and natural gas to form commercial accumulations as the oil and gas are expelled from the source rock into adjacent *reservoir rocks*. Oil and gas formed in this manner are referred to as *thermogenic* oil and gas.

If the organic materials within the source rock are mostly wood fragments, then the primary hydrocarbons generated upon maturation are 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 deeply enough so that temperatures are above 150° C (300° F), the organic remains have produced most of the oil they are able

to. Above these temperatures, any oil remaining in the source rock or any oil that has been trapped in adjacent reservoirs will be broken down into natural gas. So, gas can be generated in two ways in the natural systems; 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.



**Figure 2. Greatly magnified microscopic image of a source rock with mineral grains (lighter colored material) and pieces of organic matter that are mostly the remains of algae (dark material). This source rock will also act as a seal. From Broadhead<sup>1</sup>.**

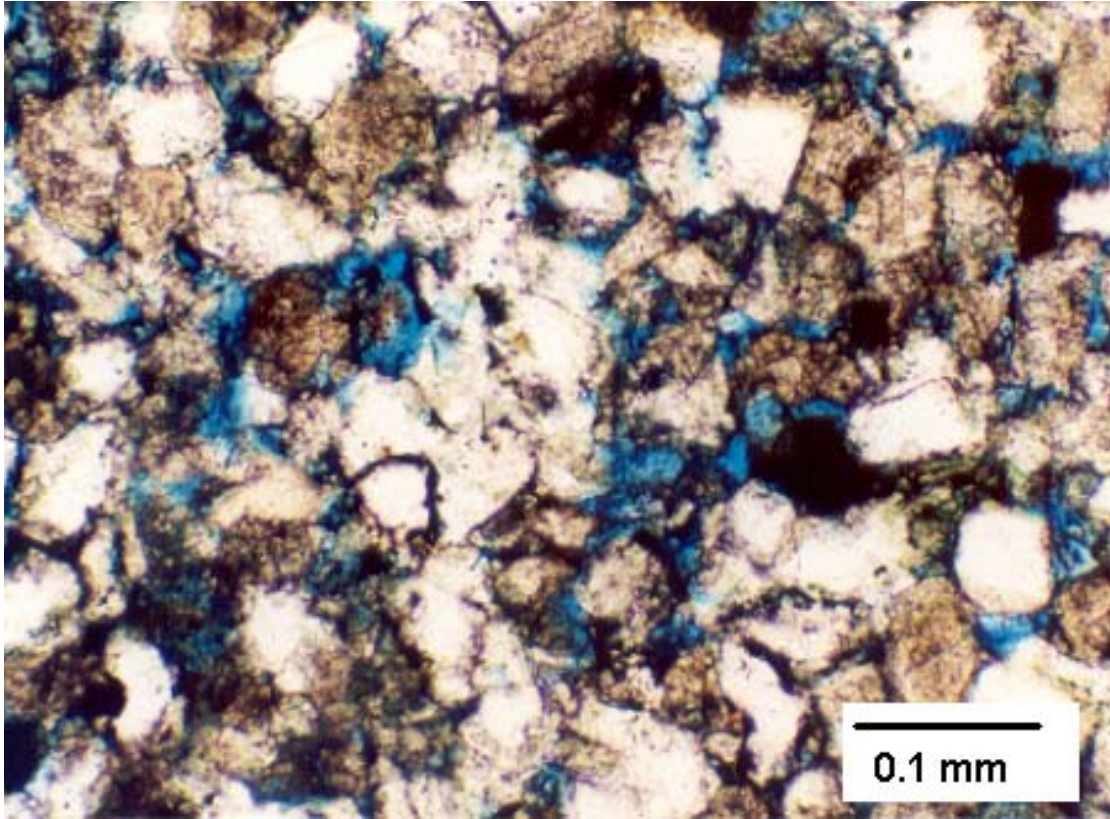
Some organic-rich sedimentary rocks can generate gas through bacterial processes at shallow burial depth before thermal maturation temperatures are attained. In this

process, referred to as *biogenic gas generation*, the organic-rich source rocks are never buried very deeply and do not attain temperatures necessary for the thermogenic production of gas<sup>2,3</sup>. Instead, anaerobic bacteria generate gas in shallow source rocks that are generally located around the basin margin. Biogenic processes produce less gas per unit volume of sediment than thermogenic processes. Gas wells associated with biogenic gas are usually low volume. Most accumulations of biogenic gas occur at depths of less than 2000 ft<sup>3</sup>.

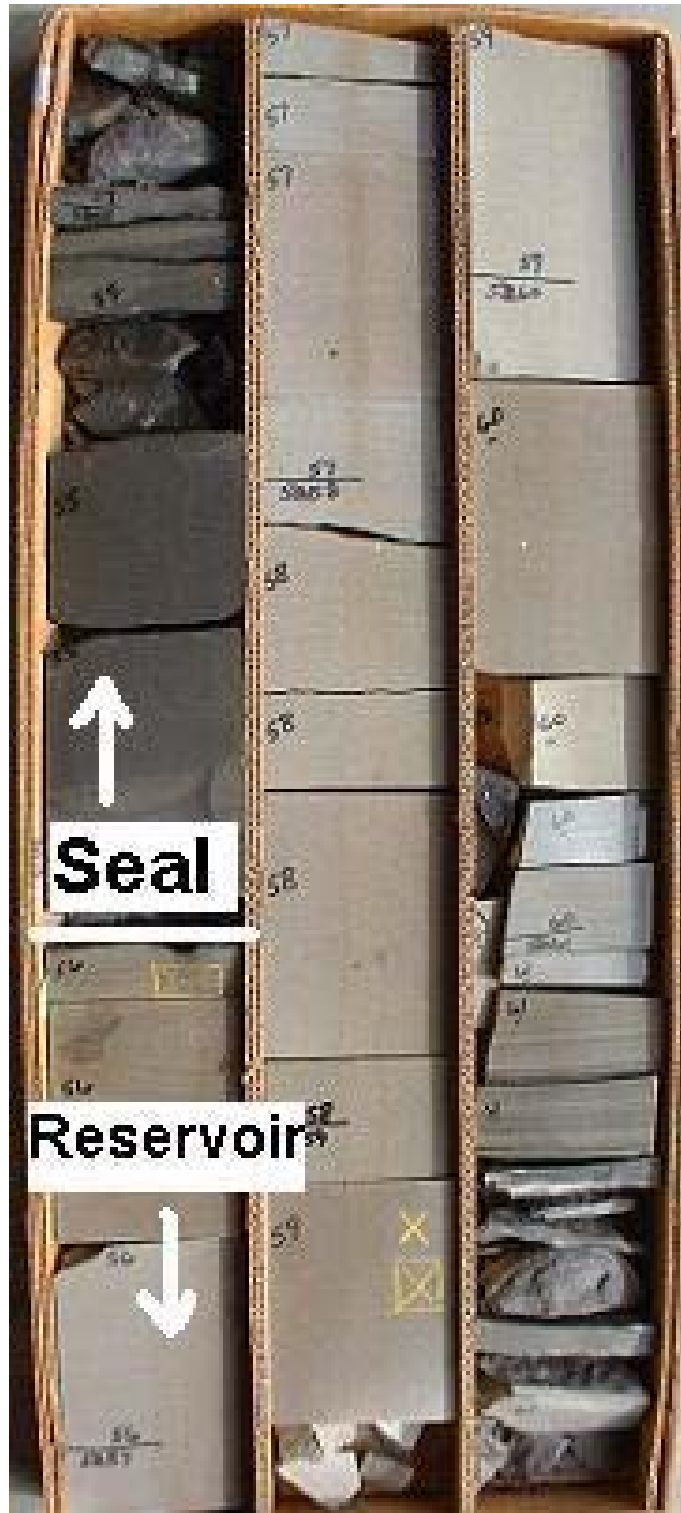
## **OIL AND GAS RESERVOIR ROCKS**

Oil and gas *reservoir rocks*<sup>4,5</sup> are porous and permeable. They contain interconnected passageways of microscopic pores or holes that occupy the areas between the mineral grains of the rock (Figure 3). When oil and gas have been naturally expelled from source rocks, they enter or *migrate* into adjacent reservoir rocks<sup>6</sup>. Most oil and gas reservoir rocks are sandstones, limestones, or dolomites.

Once oil and gas enter the reservoir rock, they are relatively free to move. Most reservoir rocks are initially saturated with saline groundwater. Saline ground water has a density of slightly more than 1.0 g/cm<sup>3</sup>. Because oil and gas are less dense than the ground water (density oil = 0.82-0.93 g/cm<sup>3</sup> and density gas = 0.12 g/cm<sup>3</sup>), they rise upward through the water-saturated pore spaces until they meet a barrier of impermeable rock (Figures 2, 4; 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<sup>7</sup>.



**Figure 3. Greatly magnified microscopic image of a sandstone reservoir rock. The pore spaces may be occupied by oil, gas, or water. This is from the gas-productive sandstone of Figure 4. From Broadhead<sup>1</sup>.**

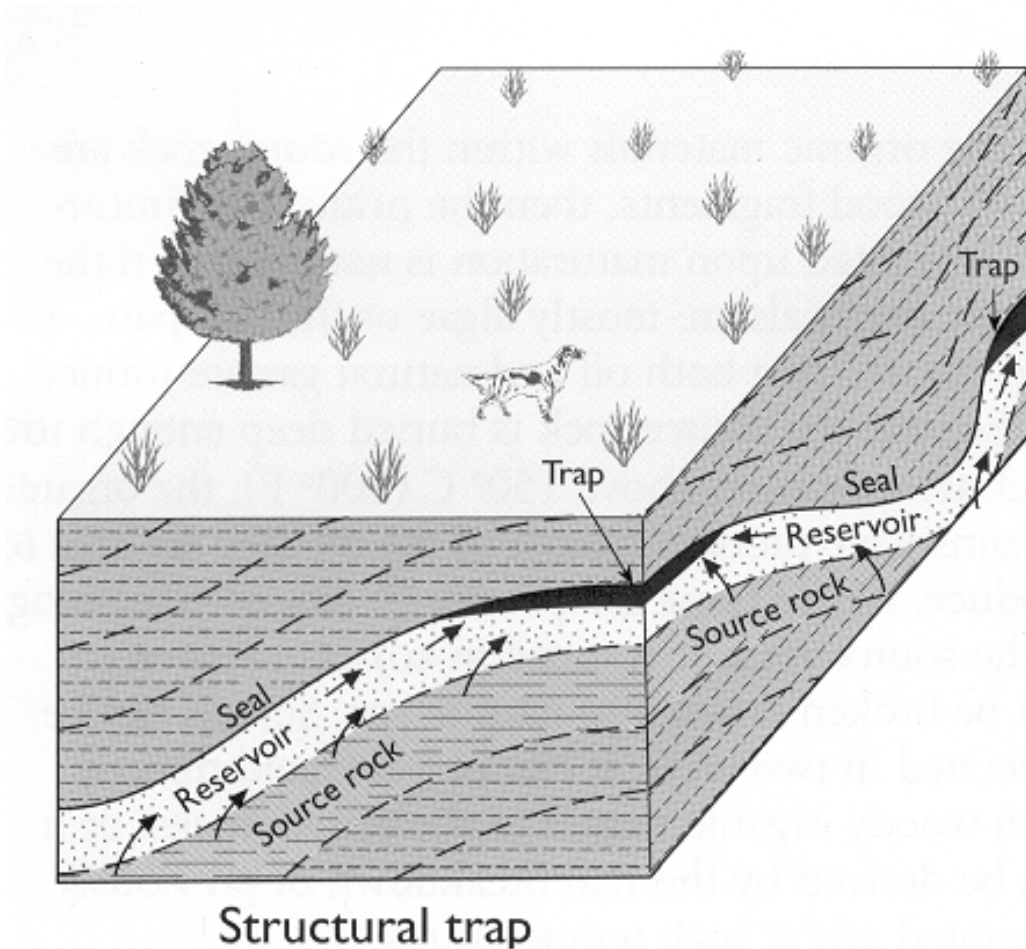


**Figure 4. Core of a gas producing sandstone reservoir with the reservoir interval and the overlying shale seal indicated. See Figure 3 for microscopic view of the sandstone reservoir.**

## OIL AND GAS TRAPS

Once in the reservoir rock, the oil and natural gas continue to migrate through the pore spaces of the reservoir rock until all further movement of the oil and gas are blocked by physical arrangement of the reservoir rock and one or more seals. This arrangement of the reservoir and seals is called a *trap*<sup>4,5</sup> (Figure 1).

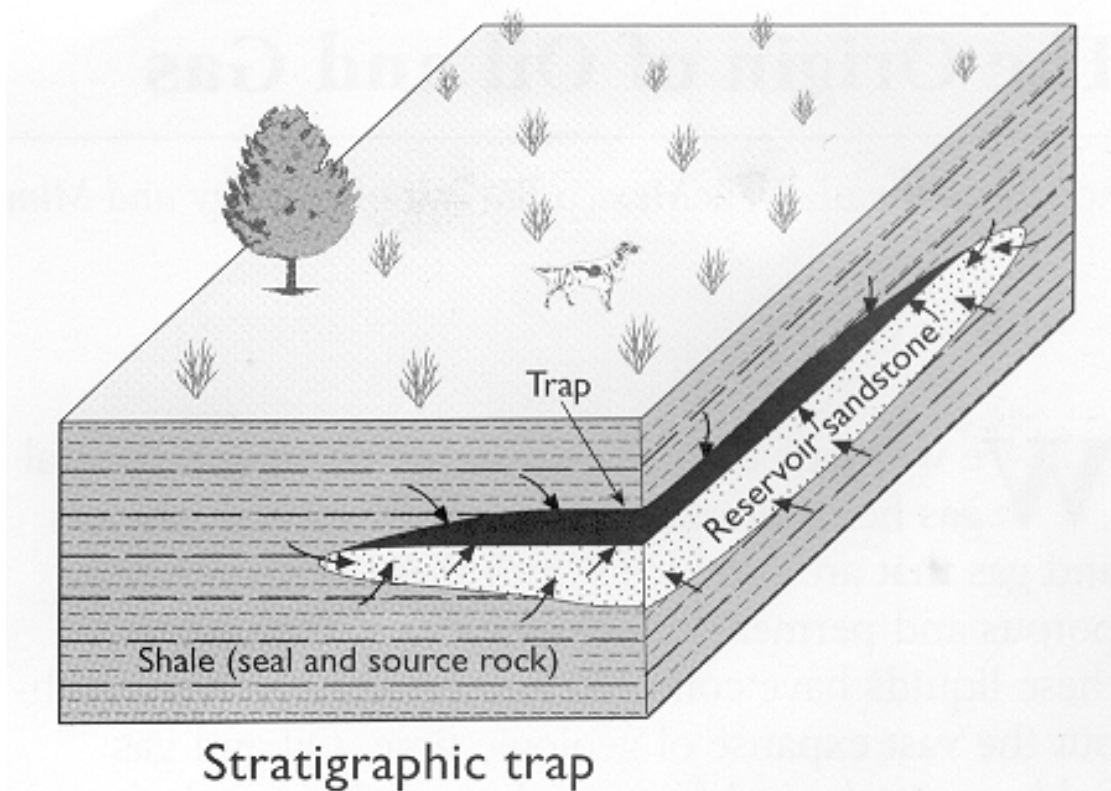
There are two main types of traps, structural and stratigraphic<sup>4,5</sup>. Structural traps are formed when the reservoir rock and overlying seal have been deformed by folding or faulting. Usually this deformation takes place tens of millions or hundreds of millions of years after deposition of the sediments that get turned into seals and reservoir rocks. The oil and gas migrate upward through the reservoir and accumulate in the highest part of the structure (Figure 5). 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 the natural gas is less dense than the oil. The layer of oil will, in turn, rest upon the water-saturated portions of the reservoir.



**Figure 5. Folded strata that form a structural trap. From Broadhead<sup>1</sup>.**

Stratigraphic traps (Figure 6) 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 is a coastal barrier island. Impermeable shale seals are deposited both landward and seaward of the barrier island, which forms an elongate lens of sandstone. The result is a porous sandstone reservoir surrounded by shale seals that may also be source rocks.





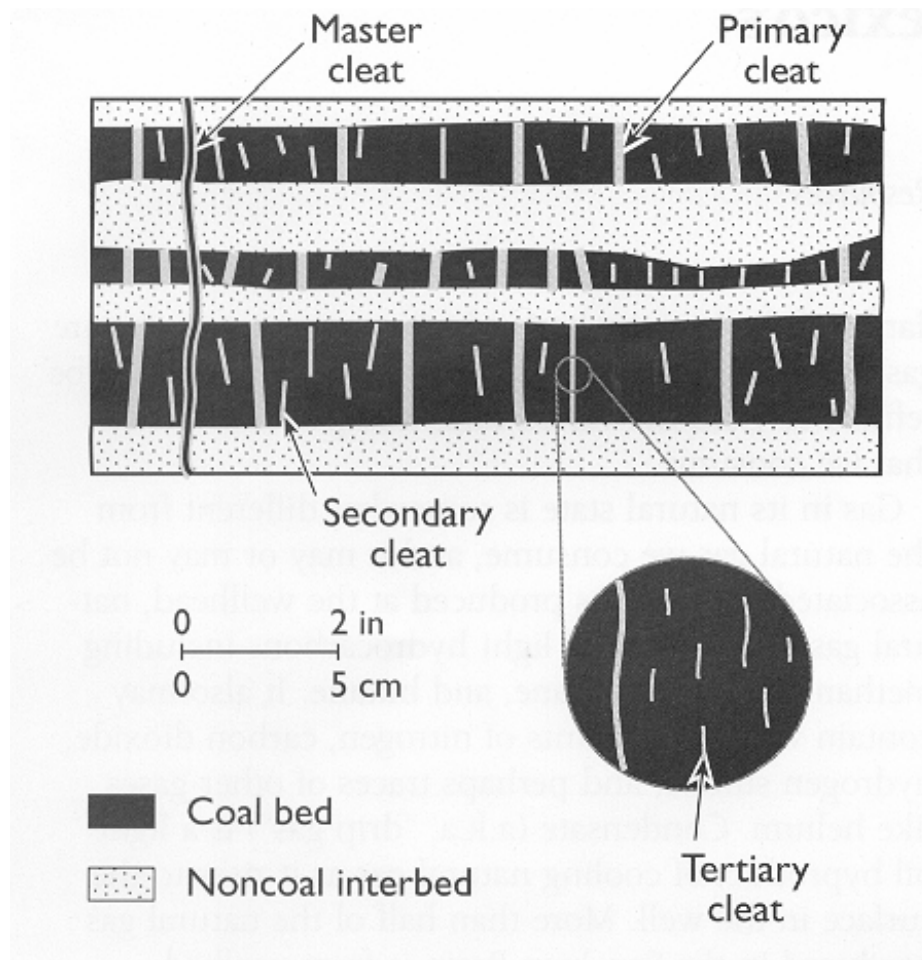
**Figure 6. A discontinuous layer of sandstone that forms a stratigraphic trap. From Broadhead<sup>1</sup>.**

## **COALBED METHANE**

Coals can act as both a source rock of natural gas and as a reservoir rock. When this is the case, coalbed methane "coal gas" can be produced<sup>8</sup>. 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 (like in

conventional source rocks described above). Greater volumes of gas are generally formed by the thermal processes than by the bacterial processes, but coal gas has been produced from both types of sources.

Most coals are characterized by pervasive systems of natural fractures (Figure 7). In the deep subsurface, these fractures are filled with water. The pressure exerted by this water on the coal holds the gas within the coals. In order to obtain gas production from the coals, the water must be first pumped out of the fractures. Once this is done, the gas may desorb off of the coals and move into the fractures, where it may be produced<sup>8</sup>.



**Figure 7. Diagram of vertical slice through coal reservoirs, showing vertical distribution of cleats (fractures) in the coals. Modified from Tremain and others<sup>9</sup>.**

## **SHALE GAS**

Shale forms important reservoirs for low-volume natural gas in some places. Gas in shales may be generated thermogenically or biogenically<sup>3,10</sup>. The gas may occur as free gas in fractures, as gas sorbed onto kerogen and clay-particle surfaces, or as gas dissolved in organic remains or hydrocarbons within the shales<sup>10</sup>. The shales are organic rich and act as the source rock as well as the reservoir. Because of their low natural permeability, most shale gas reservoirs need to be artificially fractured in order to obtain economic rates of production. Production rates from shale gas reservoirs are usually significantly less than production rates from conventional gas reservoirs, even after artificial fracturing.

## **CONCLUSIONS**

Oil and natural gas are generated from the remains of organisms that were deposited in fine-grained sedimentary rocks along with the mineral grains of 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 several thousands of 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 move 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.

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