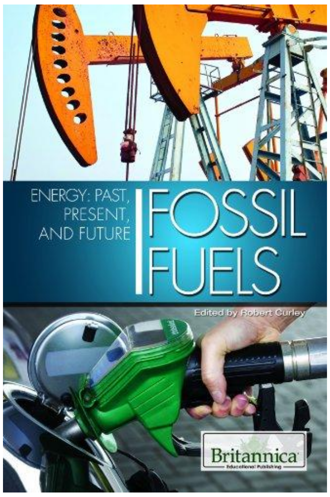

Curley, R. (Ed.) (2012). *Fossil fuels*. New York: Britannica Publishing.

From Planktonic Remains to Kerogen

The organic material that is the source of most oil has probably been derived from single-celled planktonic (free-floating) plants, such as diatoms and blue-green algae, and single-celled planktonic animals, such as foraminifera, which live in aquatic environments of marine, brackish, or fresh water. Such simple organisms are known to have been abundant long before the Paleozoic Era, which began some 542 million years ago.

Rapid burial of the remains of the single-celled planktonic plants and animals within fine-grained sediments effectively preserved them. This provided the organic materials, the so-called protopetroleum, for later diagenesis (i.e., the series of processes involving biological, chemical, and physical changes) into true petroleum.

The first, or immature, stage of petroleum formation is dominated by biological activity and chemical rearrangement, which convert organic matter to kerogen. This dark-coloured, insoluble product of bacterially altered plant and animal detritus is the source of most hydrocarbons generated in the later stages. During the first stage, biogenic methane is the only hydrocarbon generated in commercial quantities. The production of biogenic methane gas is part of the process of decomposition of organic matter carried out by anaerobic microorganisms (those capable of living in the absence of free oxygen).

From Kerogen to Petroleum

Deeper burial by continuing sedimentation, increasing temperatures, and advancing geologic age result in the mature stage of petroleum formation, during which the full range of petroleum compounds is produced from kerogen and other precursors by thermal degradation and

cracking (the process by which heavy hydrocarbon molecules are broken up into lighter molecules). Depending on the amount and type of organic matter, oil generation occurs during the mature stage at depths of about 750 to 4,800 metres (2,500 to 16,000 feet) at temperatures between 65 and 150 °C (150 and 300 °F). This special environment is called the "oil window." In areas of higher than normal geothermal gradient (increase in temperature with depth), the oil window exists at shallower depths in younger sediments but is narrower. Maximum oil generation occurs from depths of 2,000 to 2,900 metres (6,600 to 9,500 feet). Below 2,900 metres primarily wet gas, a type of gas containing liquid hydrocarbons known as natural gas liquids, is formed.

Approximately 90 percent of the organic material in sedimentary source rocks is dispersed kerogen. Its composition varies, consisting as it does of a range of residual materials whose basic molecular structure takes the form of stacked sheets of aromatic hydrocarbon rings in which atoms of sulfur, oxygen, and nitrogen also occur. Attached to the ends of the rings are various hydrocarbon compounds, including normal paraffin chains. The mild heating of the kerogen in the oil window of a source rock over long periods of time results in the cracking of the kerogen molecules and the release of the attached paraffin chains. Further heating, perhaps assisted by the catalytic effect of clay minerals in the source rock matrix, may then produce soluble bitumen compounds, followed by the various saturated and unsaturated hydrocarbons, asphaltenes, and others of the thousands of hydrocarbon compounds that make up crude oil mixtures.

At the end of the mature stage, below about 4,800 metres (16,000 feet), depending on the geothermal gradient, kerogen becomes condensed in structure and chemically stable. In this environment, crude oil is no longer stable and the main hydrocarbon product is dry thermal methane gas.

Origin in Source Beds

Knowing the maximum temperature reached by a potential source rock during its geologic history helps in estimating the maturity of the organic material contained within it. Also, this information may indicate whether a region is gas-prone, oil-prone, both, or neither. The techniques employed to assess the maturity of potential source rocks in core samples include measuring the degree of darkening of fossil pollen grains and the colour changes in conodont fossils. In addition, geochemical evaluations can be made of mineralogical changes that were also induced by fluctuating paleotemperatures. In general, there appears to be a progressive evolution of crude oil characteristics from geologically younger, heavier, darker, more aromatic crudes to older, lighter, paler, more paraffinic types. There are, however, many exceptions to this rule, especially in regions with high geothermal gradients.

Accumulations of petroleum are usually found in relatively coarse-grained, permeable, and porous sedimentary reservoir rocks that contain little, if any, insoluble organic matter. It is unlikely that the vast quantities of oil now present in some reservoir rocks could have been generated from material of which no trace remains. Therefore, the site where commercial amounts of oil originated apparently is not always identical to the location at which they are ultimately discovered.

Oil is believed to have been generated in significant volumes only in fine-grained sedimentary rocks (usually clays, shales, or clastic carbonates) by geothermal action on kerogen, leaving an insoluble organic residue in the

Blocks of oil shale from a large deposit known as the Green River Formation, in the United States. U.S.Department of Energy/Photo Researchers, Inc.

source rock. The release of oil from the solid particles of kerogen and its movement in the narrow pores and capillaries of the source rock is termed primary migration.

Accumulating sediments can provide energy to the migration system. Primary migration may be initiated during compaction as a result of the pressure of overlying sediments. Continued burial causes clay to become dehydrated by the removal of water molecules that were loosely combined with the clay minerals. With increasing temperature, the newly generated hydrocarbons may become sufficiently mobile to leave the source beds in solution, suspension, or emulsion with the water being expelled from the compacting molecular lattices of the clay minerals. The hydrocarbon molecules would compose only a very small part of the migrating fluids, a few hundred parts per million.

Migration Through Carrier Beds

The hydrocarbons expelled from a source bed next move through the wider pores of carrier beds (e.g., sandstones or carbonates) that are coarser-grained and more permeable. This movement is termed secondary migration. The distinction between primary and secondary migration is based on pore size and rock type. In some cases, oil may migrate through such permeable carrier beds until it is trapped by a permeability barrier and forms an oil accumulation. In others, the oil may continue its migration until it becomes a seep on the surface of the Earth, where it will be broken down chemically by oxidation and bacterial action.

Since nearly all pores in subsurface sedimentary formations are water-saturated, the migration of oil takes place in an aqueous environment. Secondary migration may

result from active water movement or can occur independently, either by displacement or by diffusion. Because the specific gravity of the water in the sedimentary formation is considerably higher than that of oil, the oil will float to the surface of the water in the course of geologic time and accumulate in the highest portion of a trap.

Accumulation in Reservoir Beds

The porosity (volume of pore spaces) and permeability (capacity for transmitting fluids) of carrier and reservoir beds are important factors in the migration and accumulation of oil. Most petroleum accumulations have been found in clastic reservoirs (sandstones and siltstones). Next in number are the carbonate reservoirs (limestones and dolomites). Accumulations of petroleum also occur in shales and igneous and metamorphic rocks because of porosity resulting from fracturing, but such reservoirs are relatively rare. Porosities in reservoir rocks usually range from about 5 to 30 percent, but all available pore space is not occupied by petroleum. A certain amount of residual formation water cannot be displaced and is always present.

Reservoir rocks may be divided into two main types: (1) those in which the porosity and permeability is primary, or inherent, and (2) those in which they are secondary, or induced. Primary porosity and permeability are dependent on the size, shape, and grading and packing of the sediment grains and also on the manner of their initial consolidation. Secondary porosity and permeability result from post-depositional factors, such as solution, recrystallization, fracturing, weathering during temporary exposure at the Earth's surface, and further cementation. These secondary factors may either enhance or diminish the inherent conditions.