The Origin of Oil

By John Bluemle and Lorraine Manz

Oil and natural gas are two major sources of hydrocarbons – organic compounds composed only of carbon and hydrogen. Hydrocarbons may be gaseous, liquid or solid. Naturally occurring petroleum is known as "crude oil" (it is not "refined"). Crude oil consists of a complex mixture containing between 50 and 95% hydrocarbon by weight. The remainder comprises organic and inorganic chemical compounds of nitrogen, oxygen, sulfur, and metals such as iron and sodium (as salt, or NaCl).

Even though disagreement exists about the origin of oil, years of research by geologists has resulted in a reasonably clear understanding of how crude oil forms in the earth's crust, its composition, and how it occurs. Ideas about the origin of oil follow two different lines of thinking: organic theories and inorganic theories.

One of the earliest inorganic theories originated with Arab philosophers who, in about 850 A.D., suggested that water and air combined with fire to produce sulfur and mercury. The sulfur and mercury then combined with "earth" and, at great subterranean temperatures, yielded "naft" (naphtha) and "qir" (asphalt).

Two nineteenth-century scientists, Louis Joseph Gay-Lussac (1778-1850) and Alexander von Humboldt (1769-1859) proposed that oil formed as a result of impregnation of marine sediments by subaqueous hot springs. Another nineteenth-century idea was that oil formed when hot alkalis combined with carbon dioxide deep in the earth's interior. A Russian chemist, Dimitri Mendeleev (Fig. 1) (Mendeleev was also the "inventor" of the Periodic Table), believed that percolating water encountered iron carbide deep in the earth, generating hydrocarbons. Other scientists, noting that methane occurs in trace amounts in volcanic gases and in fluid inclusions in igneous rocks, assumed that it was "sweated" out of the earth's interior throughout geologic time, rose in the crust, changed into heavier hydrocarbons, and finally accumulated into the petroleum deposits we use today.

Figure 1. Russian chemist Dimitri Ivanovitch Mendeleev (1834-1907) is best known for his work on the Periodic Table. He also believed that crude oil was the product of a chemical reaction between water and iron carbide deep inside the earth.

Hypotheses suggesting an organic origin for oil are also old. Oil and coal were linked by some naturalists as early as the sixteenth century. Abundant imprints of leaves, stems, and other evidence of vegetation left little doubt as to the origin of coal. Chemists discovered that small amounts of oil could be distilled from coal in the laboratory and postulated that this occurred in nature as well. Geologists had problems with this idea though, because the primary oil-producing strata lacked associated coals, and naturally-occurring oils were chemically different from the oils derived from the distillation of coal.

Other nineteenth-century workers believed that oil was derived from terrestrial vegetation, which was washed into the sea and deposited with the sediments containing the petroleum. Problems with this idea include the fact that some oil is produced from rocks containing only marine fossils, and also the high temperatures needed to convert wood into liquid organic matter are not geologically reasonable. By the late 1800's and early 1900's, the prevailing view was that crude oil represents an accumulation of hydrocarbons that were originally produced by living organisms, both plants and animals and coal came from the accumulations of dead plants. (*When I was growing up in the 1940's and 1950's, I recall being taught that oil was a product of decaying animals: the pressure of overlying sediments squeezed the oil right out of them! – JPB*)

Other scientists tried to explain the origin of oil in other ways. The occurrence of hydrocarbons in meteorites has been well known to scientists since the mid-1800's. In the early 1930's, astronomers learned that methane is a major component of the large outer planets – Jupiter, Saturn, Uranus, and Neptune. Because it was believed that all the planets in our solar system were closely related in origin, some researchers concluded that the raw materials for hydrocarbons must have been present in the substances from which the primordial earth accreted 4.6 billion years ago. By the 1950's, such reasoning led astronomer Fred Hoyle to argue that the deep earth must contain vast untapped reserves of oil just awaiting our technological ability to find and exploit them. This idea is still favored by a small group of scientists.

Most geologists today believe that oil was formed millions of years ago from a combination of hydrocarbons synthesized by living organisms and hydrocarbons formed by thermal alteration of organic matter in sedimentary rocks. Ten to twenty percent of the oil in the earth's crust is thought to form from living organisms, whereas 80 to 90 percent is formed by thermal alteration. Marine plankton are the major components in both methods of natural crude oil formation.

Several lines of evidence support this contemporary view of the origin of petroleum:

1. Oil is rarely found in rocks that formed before life developed on the earth;
2. Oil contains compounds derived from the pigments of living organisms;
3. The ratio of carbon isotopes in oil is similar to that in organic matter;
4. Hydrocarbon compounds found in oil affect polarized light in the same way that hydrocarbons and other compounds synthesized by living organisms affect polarized light;
5. The structures of many oil compounds are similar to those of fats and waxes found in living organisms and, therefore, could be formed from them.

So, how do we get from living organisms to oil in the Red River or Bakken Formation in western North Dakota? When organisms die, bacteria attack their remains. These bacteria require oxygen, and if oxygen is plentiful, destruction of the organic remains is complete. Abundant remains of marine plankton, however, sometimes accumulate along with mud in stagnant underwater environments (Fig 2a). The aerobic bacteria use up any dissolved oxygen quickly. Anaerobic bacteria, which obtain their oxygen from dissolved sulfur compounds and hydroxides in the pore waters of the mud, then take over. These bacteria consume most of the easily decomposable compounds in the organic matter, such as carbohydrates and proteins. As the muds are buried by an increasingly thicker cover of sediment, physical and low-temperature chemical reactions continue to alter the chemical structure and composition of much of the organic matter (Fig. 2b). At even deeper burial depths, rising temperatures and pressures cause the organic debris to decompose further to form crude oil. The muds compact and become shale (Fig. 2c). Petroleum migrates from the shale (it is "squeezed" out) and travels through more porous and permeable strata until it encounters a trap like the Nesson Anticline in northwestern North Dakota, or the Lodgepole Waulsortian mounds near Dickinson (Fig. 2d) (a discussion of how oil is trapped is a topic for another article).

Recent ideas about the origin of oil are based on a long history of scientific investigation. Some perceptive geologists intuitively reached the same conclusions over 100 years ago. For example, Henry Rogers (Fig. 3), the first State Geologist of Pennsylvania (where oil was first discovered, in 1859), thought that Devonian black shales were the source of the oil found in

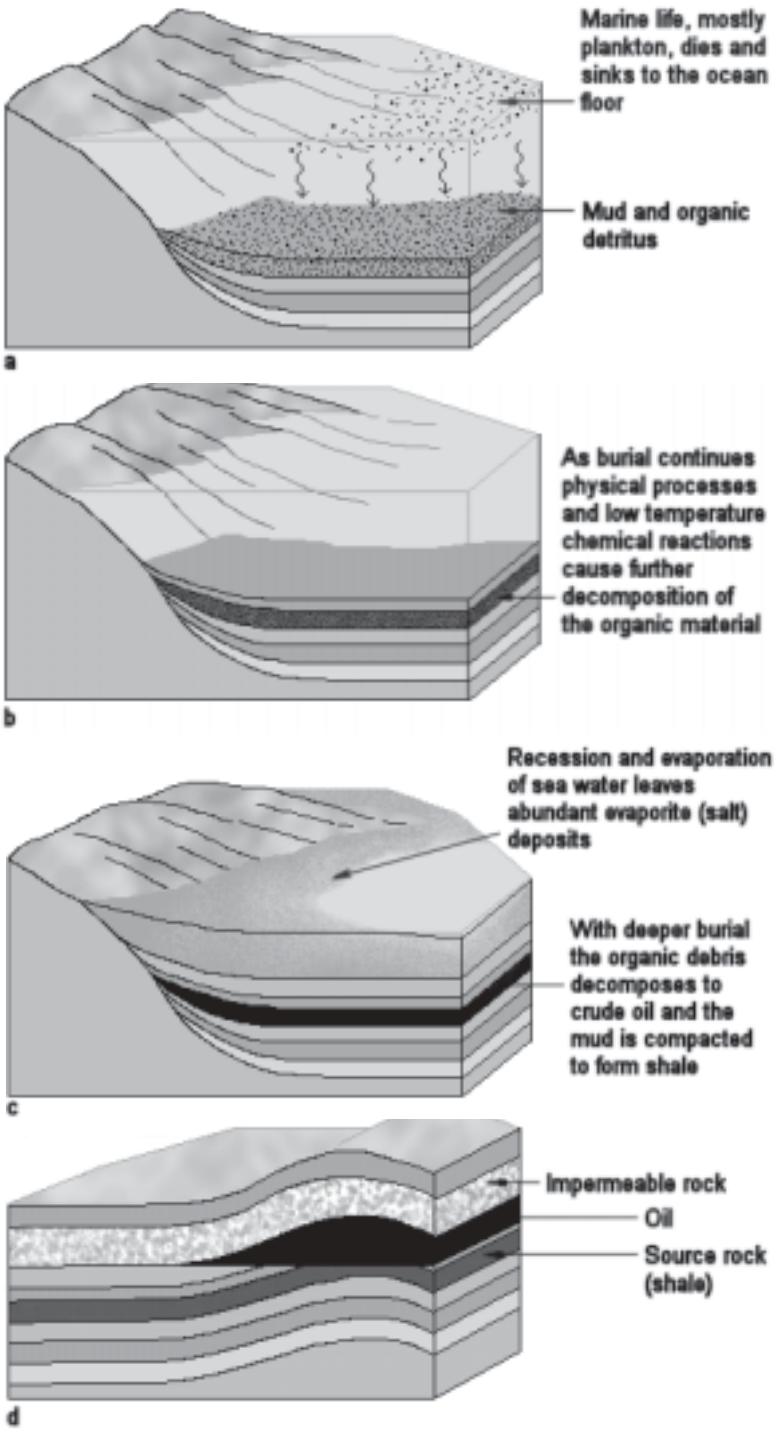

Figure 2. Most geologists today believe that oil was formed millions of years ago from a combination of hydrocarbons synthesized by living organisms and hydrocarbons formed by thermal alteration of organic matter in sedimentary rocks. Abundant remains of plankton and other marine life accumulate along with mud in stagnant underwater environments to be consumed by aerobic and anaerobic bacteria (a). As the muds are buried by an increasingly thicker cover of sediment, physical and low-temperature chemical reactions continue to alter the chemical structure and composition of much of the organic matter (b). At even deeper burial depths, rising temperatures and pressures cause the organic debris to decompose further to form crude oil. The muds compact and become shale (c). Petroleum migrates from the shale (it is "squeezed" out) and travels through more porous and permeable strata until it encounters a trap, in this case a salt dome consisting of evaporite minerals such as sodium chloride (NaCl) (d).

Figure 3. Henry Rogers, first State Geologist of Pennsylvania

the sandstones of Pennsylvania. He suggested that "...the greater portion of the oil and gas is derived from the marine [fossil organic matter in the] carbonaceous shales."

Given that so much was known correctly so long ago, why the appeal for so many other, sometimes fantastic, hypotheses about the origin of crude oil? The reason may be that the inorganic hypotheses were based on laboratory experiments by chemists and, therefore, seemed to offer both scientific validity and the reassurance of an inexhaustible supply of oil. An inexhaustible supply was also implied by the cosmic hypotheses. The organic theory, on the other hand, infers that a limited quantity of oil is available to us. We tend to believe what we wish was true.

Many petroleum geologists have made predictions about how much oil remains to be found – worldwide and in North Dakota. We won't comment on how accurate any of these predictions may be, but we need to recognize that the amount of oil available to us is finite. It took about 500 million years for North Dakota's oil and gas resources to accumulate. We have consumed, perhaps, 40 percent of the total usable oil and gas in the world that will ever be available to us.

Production of oil in the United States peaked in 1970 and, since then, we have had to import increasing amounts of oil. Some experts predict worldwide production of oil and gas to peak around 2010. From then on, we will face shortages. In fact (according to some experts), we have the unique good fortune to be living on Earth during a 60-year period, between 1965 and 2025, during which three generations of humankind will consume 80 percent of the entire supply of earth's oil and gas. Our children and grandchildren can expect to face shortages and much higher real prices for hydrocarbon energy if current practices and trends continue (terrorism and other political factors aside).

We will likely never completely run out of oil and gas, but it is going to be increasingly difficult, or at least more expensive, for geologists to find future reserves. We need to be wise in our use of what remains of this valuable resource.

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Civilization exists by geological consent, subject to change without notice.

Will Durant (1885-1981) American philosopher, historian and Pulitzer Prize winner