CHAPTER

# 1

# Introduction

And God said unto Noah…Make thee an ark of gopher wood; rooms shalt thou make in the ark, and shalt coat it within and without with pitch. *Genesis 6:13-14*

## 1.1 HISTORICAL REVIEW OF PETROLEUM EXPLORATION

### 1.1.1 Petroleum from Noah to Organization of Petroleum Exporting Countries

Petroleum exploration is a very old pursuit, as the preceding quotation illustrates. The Bible contains many references to the use of pitch or asphalt collected from the natural seepages with which the Middle East abounds. Herodotus, writing in about 450 BC, described oil seeps in Carthage (Tunisia) and the Greek island Zachynthus (Herodotus, c. 450 BC). He gave details of oil extraction from wells near Ardericca in modern Iran, although the wells could not have been very deep because fluid was extracted in a wineskin on the end of a long pole mounted on a fulcrum. Oil, salt, and bitumen were produced simultaneously from these wells. Throughout the first millenium AD, oil and asphalt were gathered from natural seepages in many parts of the world. The early uses of oil were for medication, waterproofing, and warfare. Oil was applied externally for wounds and rheumatism and administered internally as a laxative. From the time of Noah, pitch has been used to make boats watertight. Pitch, asphalt, and oil have long been employed in warfare. When Alexander the Great invaded India in 326 BC, he scattered the Indian elephant corps by charging them with horsemen waving pots of burning pitch. Nadir Shah employed a similar device, impregnating the humps of camels with oil and sending them ablaze against the Indian elephant corps in 1739 (Pratt and Good, 1950). Greek fire was invented by Callinicus of Heliopolis in AD 668. Its precise recipe is unknown, but it is believed to have included quicklime, sulfur, and naphtha and it ignited when wet. It was a potent weapon in Byzantine naval warfare.

Up until the mid-nineteenth century, asphalt, oil, and their by-products were produced only from seepages, shallow pits, and hand-dug shafts. In 1694, the British Crown issued a patent to Masters Eele, Hancock, and Portlock to "make great quantities of pitch, tarr, and oyle out of a kind of stone" (Eele, 1697). The stone in question was of Carboniferous age and occurred at the eponymous Pitchford in Shropshire (Torrens, 1994). The first well in the Western World that specifically sunk to search for oil (as opposed to water or brine) appears to have been at Pechelbronn, France, in 1745. Outcrops of oil sand were noted in this region, and Louis XV granted a license to M. de la Sorbonniere, who sank several borings and built a refinery in the same year (Redwood, 1913). The birth of the oil shale industry is

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credited to James Young, who began retorting oil from the Carboniferous shales at Torban, Scotland, in 1847. The resultant products of these early refineries included ammonia, solid paraffin wax, and liquid paraffin (kerosene or coal oil). The wax was used for candles and the kerosene for lamps. Kerosene became cheaper than whale oil, and therefore the market for liquid hydrocarbons expanded rapidly in the mid-nineteenth century. Initially, the demand was satisfied by oil shales and from oil in natural seeps, pits, hand-dug shafts, and galleries. Before exploration for oil began, cable-tool drilling was an established technique in many parts of the world in the quest for water and brine (Fig. 1.1). The first well to produce oil intentionally in the Western World was drilled at Oil Creek, Pennsylvania, by Colonel Drake in 1859 (Owen, 1975). Previously, water wells in the Appalachians and elsewhere produced oil as a contaminant. The technology for drilling Drake's well was derived from Chinese artisans who had traveled to the United States to work on the railroads.

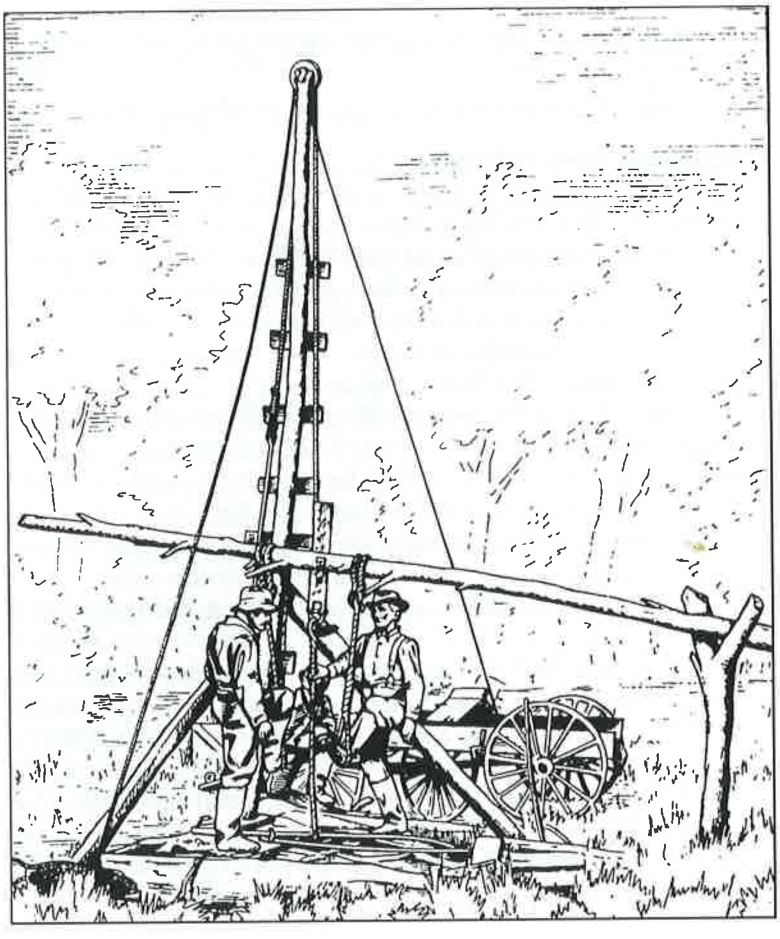

**FIGURE 1.1** Early cable-tool rig used in America the motive power was provided by one man and a spring pole. *Courtesy of British Petroleum.*

Cable-tool drilling had been used in China since at least the first century BC, the drilling tools being suspended from bamboo towers up to 60 m high. In China, however, this drilling technology had developed to produce artesian brines, not petroleum (Messadie, 1995). The first "oil mine" was opened in Bobrka, Poland, in early 1854 by Ignacy Lukasiewicz (Frank, 2005; Wikipedia, 2014 "History of the Petroleum Industry"). Lukasiewicz was interested in using seep oil as an alternative to the more expensive whale oil and was the first in the world to distill kerosene from seep oil.

A rapid growth in oil production from subsurface wells soon followed, both in North America and around the world. A major stimulus to oil production was the development of the internal combustion engine in the 1870s and 1880s. Gradually, the demand for lighter petroleum fractions overtook that for kerosene. Uses were found, however, for all the refined products, from the light gases, via petrol, paraffin, diesel oil, tar, and sulfur, to the heavy residue. Demand for oil products increased greatly because of the First World War (1914–1918). By the 1920s, the oil industry was dominated by seven major companies, termed the "seven sisters" by Enrico Mattei (Sampson, 1975). These companies included:

European:
- British Petroleum
- Shell

American:
- Exxon (formerly Esso)
- Gulf
- Texaco
- Mobil
- Socal (or Chevron)

British Petroleum and Shell found their oil reserves abroad from their parent countries, principally in the Middle and Far East, respectively. They were thus involved early in long-distance transport by sea, measuring their oil by the seagoing tonne. The American companies, by contrast, with shorter transportation distances, used the barrel as their unit of measurement. The American companies began overseas ventures, mainly in Central and South America, in the 1920s. In the 1930s, the Arabian–American Oil Company (Aramco, now Saudi Aramco) evolved from a consortium of Socal, Texaco, Mobil, and Exxon. Following the Second World War and the postwar economic boom, the idea of oil consortia became established over much of the free world. Oil companies risked the profits from one productive area to explore for oil in new areas. To take on all the risks in a new venture is unwise, so companies would invest in several joint ventures, or consortia. Table 1.1 shows some of the major consortia, demonstrating the stately dance of the seven sisters as they changed their partners around the world. In this process the major consortia shared a mutual love–hate relationship. The object of any business is to maximize profit. Thus, it was to their mutual benefit to export oil from the producing countries as cheaply as possible and to sell it in the world market for the highest price possible. The advantage of a cartel is offset by the desire of every company to enhance its sales at the expense of its competitors by selling its products cheaper.

In 1960, the Organization of Petroleum Exporting Countries (OPEC) was founded in Baghdad and consisted initially of Iraq, Iran, Kuwait, Saudi Arabia, and Venezuela (Martinez, 1969). It later expanded to include Algeria, Dubai, Ecuador, Gabon, Indonesia,

**TABLE 1.1** Partners of Some of the Major Overseas Oil Consortia[a]

| Companies | The Consortium, Iran | I.P.C., Iraq | Aramco, Saudi Arabia | Kuwait Oil Co., Kuwait | Admar, Abu Dhabi | A.D. P.C., Abu Dhabi | Oasis, Libya |
|---|---|---|---|---|---|---|---|
| B.P. | X | X | | X | X | X | |
| Shell | X | X | | | | X | X |
| Exxon | X | X | X | | | X | |
| Mobil | X | X | X | | | X | |
| Gulf | X | | | X | | | |
| Texaco | X | | X | | | | |
| Socal | X | | X | | | | |
| C.F.P. | X | | | | | X | |
| Conoco | | | | | | | X |
| Amerada | | | | | | | X |
| Marathon | | | | | | | X |

[a]*Note that partners and their percentage interest varied over the lifetime of the various consortia.*

Libya, Nigeria, Qatar, and the United Arab Emirates. To qualify for membership, a country's economy must be predominantly based on oil exports; therefore, the United States and the United Kingdom do not qualify. By the mid-1970s, OPEC was producing two-thirds of the free world's oil. The object of OPEC is to control the power of the independent oil companies by a combination of price control and appropriation of company assets. For many OPEC countries, oil is their only natural resource. Once it is depleted, they will have no assets unless they can maximize their oil revenues and spend them in the development of other industries. The OPEC objective has been notably successful, although its large price increases in the early 1970s contributed to a global recession, which affected both the developed and the poorer Third World countries alike.

The idea of the producing state controlling the oil company's activities has now been exported from OPEC. Not only have state oil companies been formed in countries that formerly lacked indigenous oil expertise (e.g., Statoil in Norway and Petronas in Malaysia), but they have also been formed in those that had the expertise (Petrocan in Canada and the former Britoil in the United Kingdom). Formerly, the profit that the oil companies made in one country was the risk capital to be invested in the next country. With state oil companies the taxpayer shares the risk and the profit.

The most influential state oil and gas companies based in countries outside the Organization of Economic Co-operation and Development according to the Financial Times (2007) are:

- China National Petroleum Corporation (China)
- Gazprom (Russia)
- National Iranian Oil Company (Iran)
- Petrobras (Brazil)

- Petroleos de Venezuela S.A. (Venezuela)
- Petronas (Malaysia)
- Saudia Aramco (Saudi Arabia)

This group of state oil and gas companies has been labeled the "New Seven Sisters (Hoyos, 2007)." These largely state-owned companies are the new rule makers and control almost one-third of the world's oil and gas production and more than one-third of the world's total oil and gas reserves.

### 1.1.2 Evolution of Petroleum Exploration Concepts and Techniques

From the days of Noah to OPEC the role of the petroleum geologist has become more and more skilled and demanding. In the early days, oil was found by wandering about the countryside with a naked flame, optimism, and a sense of adventure. One major U.S. company, which will remain nameless, once employed a chief geologist whose exploration philosophy was to drill on old Indian graves. Another oil finder used to put on an old hat, gallop about the prairie until his hat dropped off, and start drilling where it landed. History records that he was very successful (Cunningham-Craig, 1912). One of the earliest exploration tools was "creekology." It gradually dawned on the early drillers that oil was more often found by wells located on river bottoms than by those on the hills (Fig. 1.2). The anticlinal theory of oil entrapment, which explained this phenomenon, was expounded by Hunt (1861). Up to the present day, the quest for anticlines has been one of the most successful exploration concepts.

Experience soon proved, however, that oil could also occur off structure. Carll (1880) noted that the oil-bearing marine Venango sands of Pennsylvania occurred in trends that reflected not structure, but paleoshorelines. Thus was borne the concept that oil could be trapped stratigraphically as well as structurally. Stratigraphic traps are caused by variations in deposition, erosion, or diagenesis within the reservoir.

Through the latter part of the nineteenth and the early part of the twentieth century, oil exploration was based on the surface mapping of anticlines. Stratigraphic traps were found accidentally by serendipity or by subsurface mapping and extrapolation of data gathered

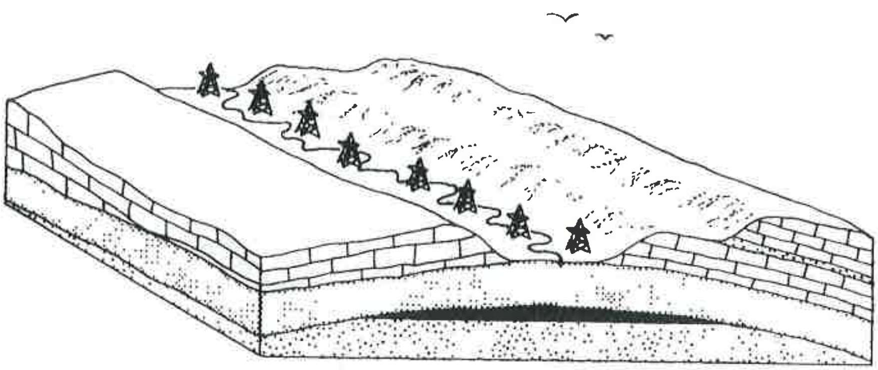

FIGURE 1.2 Creekology—the ease of finding oil in the old days.

from wells drilled to test structural anomalies. Unconformities and disharmonic folding limited the depth to which surface mapping could be used to predict subsurface structure. The solution to this problem began to emerge in the mid-1920s, when seismic (refraction), gravity, and magnetic methods were all applied to petroleum exploration. Magnetic surveys seldom proved to be effective oil finders, whereas gravity and seismic methods proved to be effective in finding salt dome traps in the Gulf of Mexico coastal province of the United States. In the same period geophysical methods were also applied to borehole logging, with the first electric log run at Pechelbronn, France, in 1927. Further electric, sonic, and radioactive logging techniques followed. Aerial surveying began in the 1920s, but photogeology, which employs stereophotos, only became widely used after the Second World War. At this time aerial surveys were cheap enough to allow the rapid reconnaissance of large concessions, and photogeology was notably effective in the deserts of North Africa and the Middle East, where vegetation does not cover surface geology.

Pure geological exploration methods advanced slowly but steadily during the first half of the twentieth century. One of the main applications to oil exploration was the development of micropaleontology. The classic biostratigraphic zones, which are based on macrofossils such as ammonites, could not be identified in the subsurface because of the destructive effect of drilling. New zones had to be defined by microfossils, which were calibrated at the surface with macrofossil zones. The study of modern sedimentary environments in the late 1950s and early 1960s, notably on Galveston Island (Texas), the Mississippi delta, the Bahama Bank, the Dutch Wadden Sea, and the Arabian Gulf, gave new insights into ancient sedimentary facies and their interpretation. This insight provided improved prediction of the geometry and internal porosity and permeability variation of reservoirs.

The 1970s saw major advances on two fronts: geophysics and geochemistry. The advent of the computer resulted in a major quantum jump in seismic processing. Instead of seismologists poring painfully over a few bunched galvanometer traces, vast amounts of data could be displayed on continuous seismic sections. Reflecting horizons could be picked out in bright colors, first by geophysicists and later even by geologists. As techniques improved, seismic lines became more and more like geological cross sections, until stratigraphic and environmental concepts were directly applicable.

In the 1980s, increasing computing power led to the development of 3D seismic surveys that enabled seismic sections of the earth's crust to be displayed in any orientation, including horizontal. Thus, it is now possible to image directly the geometry of many petroleum reservoirs. Similarly enhanced processing methods made it possible to detect directly the presence of oil and gas. These improvements went hand in hand with enhanced borehole logging. It is now possible to produce logs of the mineralogy, porosity, and pore fluids of boreholes, together with images of the geological strata that they penetrate. These techniques are discussed and illustrated in detail in Chapter 3.

As the millenium approaches, one can only speculate on what new advances in petroleum exploration technology will be discovered. All techniques may be expected to improve. Remote sensing from satellites may be one major new tool, as might direct sensing from surface geochemical or geophysical methods. These latter methods generally involve the identification of gas microseeps and fluctuations in electrical conductivity of rocks above petroleum accumulations. Such methods have been around for half a century, but have yet to be widely accepted.

From the earliest days of scientific investigation the formation of petroleum had been attributed to two origins: inorganic and organic. Chemists, such as Mendeleyev in the nineteenth century, and astronomers, such as Gold and Hoyle in the twentieth, argued for an inorganic origin—sometimes igneous, sometimes extraterrestrial, or a mixture of both. Most petroleum geologists believe that petroleum forms from the diagenesis of buried organic matter and note that it is indigenous to sedimentary rocks rather than igneous ones. The advent of cheap and accurate chemical analytical techniques allowed petroleum source rocks to be studied. It is now possible to match petroleum with its parent shale and to identify potential source rocks, their tendency to generate oil or gas, and their level of thermal maturation. For a commercial oil accumulation to occur, five conditions must be fulfilled:

1. There must be an organic-rich source rock to generate the oil and/or gas.
2. The source rock must have been heated sufficiently to yield its petroleum.
3. There must be a reservoir to contain the expelled hydrocarbons. This reservoir must have *porosity*, to contain the oil and/or gas, and *permeability*, to permit fluid flow.
4. The reservoir must be sealed by an impermeable cap rock to prevent the upward escape of petroleum to the earth's surface.
5. Source, reservoir, and seal must be arranged in such a way as to trap the petroleum.
6. The timing of trap formation, petroleum generation, and accumulation must be in a favorable sequence.
7. The accumulation must be preserved or protected from breaching, flushing, aerobic bacteria, thermal degradation, etc. until exploitation.

Chapter 5 deals with the generation and migration of petroleum from source rocks. Chapter 6 discusses the nature of reservoirs, and Chapter 7 deals with the different types of traps.

## 1.2 THE CONTEXT OF PETROLEUM GEOLOGY

### 1.2.1 Relationship of Petroleum Geology to Science

Petroleum geology is the application of geology (the study of rocks) to the exploration for and production of oil and gas. Geology itself is firmly based on chemistry, physics, and biology, involving the application of essentially abstract concepts to observed data. In the past, these data were basically observational and subjective, but they are now increasingly physical and chemical, and therefore more objective. Geology, in general, and petroleum geology, in particular, still rely on value judgments based on experience and an assessment of validity among the data presented. The preceding section showed how petroleum exploration had advanced over the years with the development of various geological techniques. It is now appropriate to consider in more detail the roles of chemistry, physics, and biology in petroleum exploration (Fig. 1.3).

### 1.2.2 Chemistry and Petroleum Geology

The application of chemistry to the study of rocks (geochemistry) has many uses in petroleum geology. Detailed knowledge of the mineralogical composition of rocks is

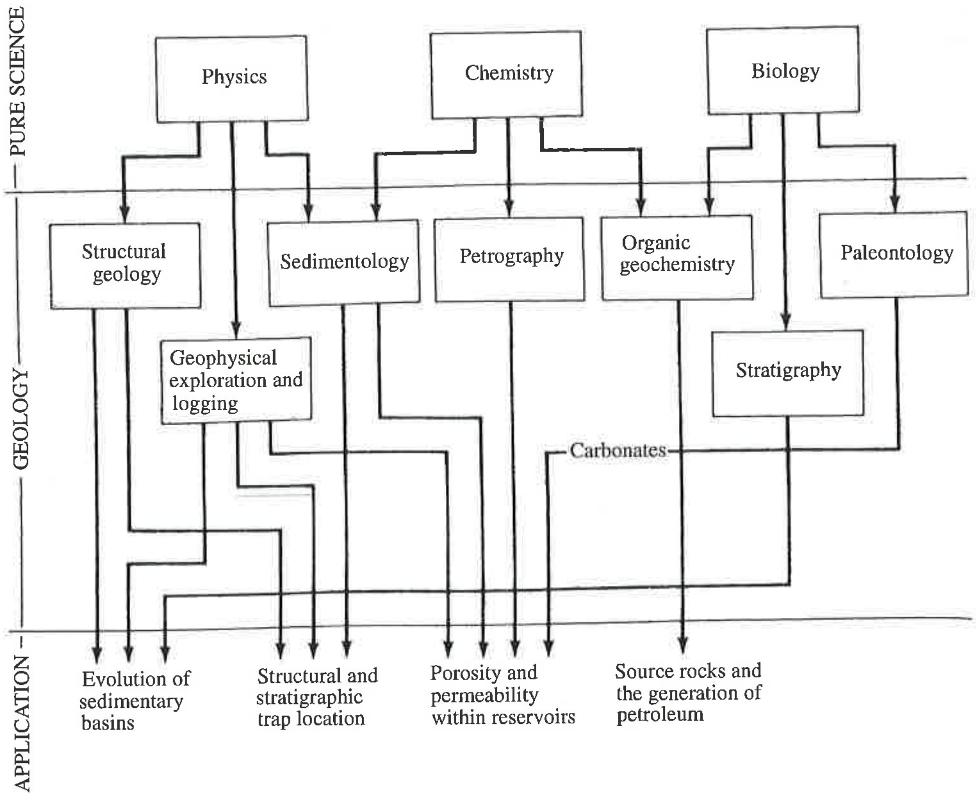


**FIGURE 1.3** The relationship of petroleum geology to the pure sciences.

important at many levels. In the early stages of exploration, certain general conclusions as to the distribution and quality of potential reservoirs could be made from their gross lithology. For example, the porosity of sandstones tends to be facies related, whereas in carbonate rocks this is generally not so. Detailed knowledge of the mineralogy of reservoirs enables estimates to be made of the rate at which they may lose porosity during burial, and this detailed mineralogical information is essential for the accurate interpretation of geophysical well logs through reservoirs. Knowledge of the chemistry of pore fluids and their effect on the stability of minerals can be used to predict the places where porosity may be destroyed by cementation, preserved in its original form, or enhanced by the solution of minerals by formation waters. Organic chemistry is involved both in the analysis of oil and gas and in the study of the diagenesis of plant and animal tissues in sediments and the way in which the resultant organic compound, kerogen, generates petroleum.

## 1.2.3 Physics and Petroleum Geology

The application of physics to the study of rocks (geophysics) is very important in petroleum geology. In its broadest application geophysics makes a major contribution to understanding the earth's crust and, especially through the application of modern plate tectonic theory, to the genesis and petroleum potential of sedimentary basins. More specifically, physical concepts are required to understand folds, faults, and diapirs, and hence their roles in petroleum entrapment. Modern petroleum exploration is unthinkable without the aid of magnetic, gravity, and seismic surveys in finding potential petroleum traps. Nor could any finds be evaluated effectively without geophysical wireline well logs to measure the lithology, porosity, and petroleum content of a reservoir.

### 1.2.4 Biology and Petroleum Geology

Biology is applied to geology in several ways, notably through the study of fossils (paleontology), and is especially significant in establishing biostratigraphic zones for regional stratigraphical correlation. The way in which oil exploration shifted the emphasis from the use of macrofossils to microfossils for zonation has already been noted. Ecology, the study of the relationship between living organisms and their environment, is also important in petroleum geology. Carbonate sediments, in general, and reefs, in particular, can only be studied profitably with the aid of detailed knowledge of the ecology of modern marine fauna and flora. Biology, and especially biochemistry, is important in studying the transformation of plant and animal tissues into kerogen during burial and the generation of oil or gas that may be caused by this transformation.

### 1.2.5 Relationship of Petroleum Geology to Petroleum Exploration and Production

Geologists, in contrast to some nongeologists, believe that knowledge of the concepts of geology can help to find petroleum and, furthermore, often think that petroleum geology and petroleum exploration are synonymous, but they are not. Theories that petroleum is not formed by the transformation of organic matter in sediments have already been noted and are examined in more detail in Chapter 5. If the petroleum geologists' view of oil generation and migration is not accepted, then present exploration methods would need extensive modification.

Some petroleum explorationists still do not admit to a need for geologists to aid them in their search. In 1982, a successful oil finder from Midland, Texas, admitted to not using geologists because when his competitors hired them, all it did was increase their costs per barrel of oil found. The South African state oil company was under a statutory obligation imposed by its government to test every claim to an oil-finding method, be it dowsing or some sophisticated scientific technique. These examples are not isolated cases, and it has been argued that oil may better be found by random drilling than by the application of scientific principles.

Petroleum geology is only one aspect of petroleum exploration and production. Leaving aside atypical enterprises, petroleum exploration now involves integrated teams of people possessing a wide range of professional skills (Fig. 1.4). These skills include political and social expertise, which is involved in the acquisition of prospective acreage. Geophysical surveying is involved in preparing the initial data on which leasing and, later, drilling recommendations are based. Geological concepts are applied to the interpretation of the geophysical data once they have been acquired and processed. As soon as an oil well has been drilled,

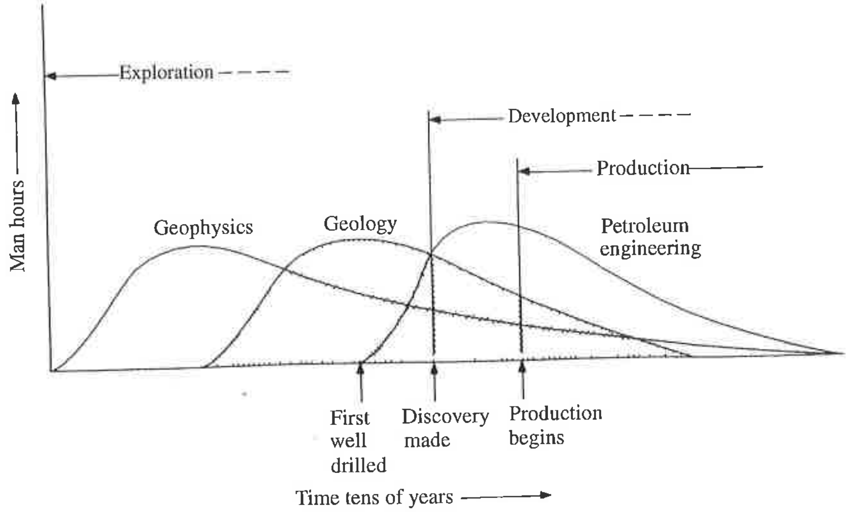


**FIGURE 1.4** Graph showing how petroleum geology is part of a continuum of disciplines employed in the exploration and production of oil and gas. Note that geophysics now extends beyond the beginning of production. Repeated seismic surveys can monitor the migration of fluid interfaces within fields during their productive lifetime (4D seismic).

the engineering aspects of the discovery need appraisal. Petroleum engineering is concerned with establishing the reserves of a field, the distribution of petroleum within the reservoir, and the most effective way of producing it. Thus petroleum geology lies within a continuum of disciplines, beginning with geophysics and ending with petroleum engineering, but overlapping both in time and subject matter (Fig. 1.5).

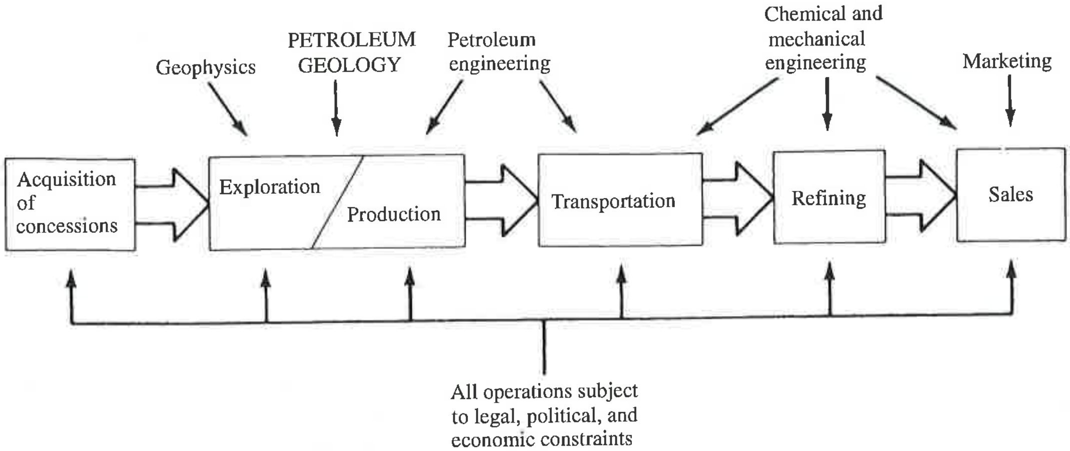


**FIGURE 1.5** Flowchart showing how petroleum geology is only one aspect of petroleum exploration and production, and how these enterprises themselves are part of a continuum of events subjected to various constraints and expedited by many disciplines.

Underlying this sequence of events is the fundamental control of economics. Oil companies exist not only to find oil and gas but, like any business enterprise, to make money. Thus, every step of the journey, from leasing to drilling, to production, and finally to enhanced recovery, is monitored by accountants and economists. Activity in petroleum exploration and production accelerates when the world price of petroleum products increases, and it decreases or even terminates when the price drops. Petroleum geologists are in the unusual position of being subject to firing for either technical incompetence or excellence, but not for mediocrity. If they find no oil, they may be fired; similarly, if they find too much oil, then their presence on the company payroll is unnecessary. This has been demonstrated repeatedly since the oil industry began. Competent geologists are more important to small companies, for whom a string of dry holes spells catastrophe. Major companies can tolerate a fair degree of incompetence because they have the financial resources to withstand a string of disasters. Nowhere is this more true than in state oil companies. With an endless supply of taxpayers' money to sustain them, the political expediency of searching for indigenous petroleum reserves may outweigh any economic consideration.

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