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Crude oil or petroleum is a liquid that occurs in the rock strata which forms the earth's crust or skin. This liquid is a complex mixture of chemical compounds and elements. The compounds are mainly organic; that is, they contain carbon. Gases are sometimes associated with these crude oil liquids and these gases are usually composed primarily of organic chemical compounds. Non-associated gases (gases occuring separately and distinctly from crude oil accumulations) are also present in rock strata. Crude oils vary tremendously in their composition and in their physical characteristics. There are three general types of crude oil: asphalt base, paraffin base, and mixed base.

Origin

Crude oil and natural gas (excluding gases of volcanic origin) are formed by the deposition of plant and animal tissues and tissue products inter-mixed with rock-forming particles such as muds, silts, dusts, sand grains, and animal skeletons. These plant and animal tissues are modified by chemical reactions within the tissue cell structure and by later chemical reactions between the products of the original reactions. These chemical reactions within the original source material and subsequent products are influenced, initiated, or stopped by four factors: time, pressure, temperature, and reaction with, or catalysis by, the surrounding rock or liquid material. If combinations of the above reactions go on long enough (but not long enough to convert all of the original tissues and subsequent products into engery and solids) you have a crude oil, natural gas, or both.

Accumulation

Rock-forming materials and the included petroleum-forming matter are generally deposited under water which may be salty, brackish, or fresh. A great deal of this water is trapped within the rock-forming materials as they are laid down. During the subsequent process of consolidating this material into rock some of the water is squeezed out and the remainder lies trapped in the interstices of the rock. This original depositional water which remains in the rock is called connate water.

Any pause in deposition of rock-making particles or any change in type of material being deposited gives rise to what is termed a distinct layer, stratum, or bed. For example, limy muds are deposited, followed by clay muds, followed by sand. These three types of material upon consolidation will be called respectively a bed of limestone, shale, and sandstone. During and after the consolidation of these beds, the earth's crust is more or less continuously being tilted, folded, broken, squeezed, and shook.

Picture now a few liquid petroleum particles being formed in the presence of a great deal of connate water in rock beds that are being distorted from their original plane of deposition. These petroleum particles being lighter than water move upward as long as there are connecting pore spaces

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to allow movement. If enough of these particles are stopped in the same vicinity, that constitutes a pool. Every subsequent tilting or folding disturbs the equilibrium reached previously and the oil, gas, and water readjust until they can no longer move any further. Another factor affecting oil and gas accumulations is introduced by the intake of meteoric (rain and snow) water which mixes with the original connate water and sometimes almost completely replaces it. Some of the connate water is immovable because of capillary forces and is forever trapped.

Accumulation has gone on since the appearance on the earth of living organic matter and is going on at the present time. Our present-day oil and gas fields may be pictured as drops of oil and gas resting on an ocean of water. The ordinary petroleum province in the United States has an average area underlain by the "ocean of water" of 96%, an average area underlain by the "drop of oil or gas" of 4%. The problem then is to locate these segregated drops in this ocean and it would be very simple indeed if these "segregated drops" did not occur in solid rock at depths ranging from 300 to 20-30,000 feet below the surface of the ground.

The Finding of Oil and Gas

Oil or gas pools, as they are called, are not in reality a pool in the ordinary sense of the word, since the oil and gas occur in minute pore spaces in solid rock. As noted above, the oil or gas particles are nearly always lighter than the water and they move until there is no direction for them to move in. It is this barrier to movement which forms a trap and it is the search for these traps that is involved in the finding of oil and gas. Barriers are of many types and, as a rule, no particular pool is controlled completely by one type of barrier. Two or more kinds of barriers usually contribute to the formation of any specific pool. Barriers are of two main types: structural and stratigraphic. The most common structural traps are upfolds in the reservoir rocks.

To form a petroleum province, four things must be present: source beds, reservoir beds, cap rocks, and barriers. Source beds are beds in which oil or gas may have been formed because of the original organic content of the beds. Reservoir beds are beds that have sufficient pore spaces and interconnections between pores so that fluids or gases can flow or be pumped from them if a hole is drilled into them. A cap rock is an impervious rock above a reservoir bed and it prevents the upward escape of any oil gas in the reservoir bed. A barrier may be either structural or stratigraphic and it prevents the lateral movement of oil or gas. Before an area is considered an oil province, it must fulfill the above requirements.

Since all of the four requirements must be buried at depth to hold an accumulation of hydrocarbons, it is necessary to map and describe outcrop belts on the periphery of a suspected oil province (the periphery is commonly a foothill or mountain belt) and draw conclusions from the peripheral outcrops to postulate what may occur in the middle part of the suspected oil province (commonly called a basin). Once the area has been shown to contain the four fundamental requirements, the next step is to map structural and stratigraphic barriers so that drillsites may be located in specific localities. In a new area, this is most commonly done by surface geologic mapping. This consists of preparing maps showing the distribution of various outcropping formations and their inclination from a horizontal surface. After this has been done, structure contour maps can be prepared. The definition of a structure contour is "a line connecting points of equal elevation along a rock bedding plane." Structure contours should not be confused with topographic contours. The definition of a topographic contour is "a line connecting points of equal elevation on the surface of the earth."

The mapping of stratigraphic barriers from outcrop data alone is usually difficult due to the presence of unconformities in the series of rock strata that are present in any basin area. An unconformity is a hiatus zone in a sequence of rock layers. For example, red limy muds are deposited on top of black muds at the bottom of a shallow ocean shelf similar to that now present on the west coast of Florida. If some of this ocean bottom is uplifted, the uplifted portion of the former depositional shelf will be stripped of the red limy muds that were previously deposited. Later subsidence of the uplifted area, combined with the influx of ocean currents carrying sand grains, will deposit sand on the area that was once high. It will be seen that in one portion of the area under discussion, a complete section sand (future sandstone) resting on red limy mud (future red limestone) resting on black mud (future black shale) will be present, and in another portion of the area, sand will be resting on black mud. Thus, in part of this area in this example, there is a missing interval of deposition (the red limestones). The contact between the sandstone and the black shale constitutes an unconformity since there is a missing sequence of beds at that point and this missing sequence covered a considerable period of geologic time. Since the earth's surface from a geologic time perspective is never stable but is always moving up, down, or sideways, a little reflection will show that all rock units terminate somewhere. Where rock units are present they will thicken and thin, and in some cases they will have been removed completely by erosion and thus not be preserved where they can be seen in an out-crop or in a well bore.

Rock units of the same type that were deposited more or less continuously are known as formations and maps which show the thickness of a formation (or group of formations) in different areas are called isopach maps.

Because of the variations in thickness and composition of rock layers, it is most important that complete data concerning rock character are assembled in order to explore for new oil and gas fields. For this reason surface outcrops are measured and described in great detail, maps are prepared on different rock units both from surface and subsurface data, wells are carefully watched, and cuttings and cores from wells are preserved and examined microscopically. Without all of this data, accurate maps could not be made and bona fide conclusions cannot be drawn with regard to the four critical necessities that make an oil province or an old field. Compilation of accurate geological data from outcrops, well cuttings, well logs, and well cores is one of the most important functions of a petroleum geologist and a function that should be emphasized since this aspect of petroleum exploration is frequently neglected in the drawing of contracts, operating agreements, farmout agreements, etc.

Where surface outcrops and subsurface information (that is data obtained from wells drilled in an area) are not sufficient to determine the presence or absence of structural barriers, it is necessary to use geophysical methods to delineate structure. Geophysical prospecting is generally concerned only with the structural aspect, and not with the stratigraphic aspect.

Magnetic prospecting for structure consists of determining variations in the earth's vertical magnetic field in an area. No magnetic rocks of consequence are present in the sedimentary rocks in which oil and gas are present. However, the basement rocks (igneous and metamorphic rocks) that underly the sedimentary rocks are frequently magnetic and it is variations in basement rocks that are mapped with a magnetometer. If the sedimentary rock structure corresponds to basement rock structure or topography, then the magnetometer does provide an indirect approach to finding structures in the sedimentary rocks. This is a very big "if" since basement structures and/or buried hills, ridges, or mountains frequently do not coincide with structures in the sedimentary rocks.

Gravity geophysical prospecting for structure consists of measuring the pull of gravity at mapped points in an area where it is hoped to find structure. Normally the deeper and older sedimentary rocks are heavier and more dense than most surface sedimentary rocks. Therefore, if some of these heavier, older rocks are closer to the surface of the earth in one area (that is, an upfolded structure is present in the sediments) then the apparent weight of the earth and the pull of the earth's gravitation field will be greater in the area where older rocks are closer to the surface and lesser where older rocks are further from the surface of the ground. Gravity prospecting is usually more definitive than magnetic prospecting but due to variations in density of the near surface rocks and variations of density in basement rocks below the sedimentary cover, very erroneous conclusions may be drawn from a gravity map.

Seismic geophysical prospecting is the most direct geophysical approach in determining rock structure. Seismic prospecting is accomplished by means of generating sound waves near or at the earth's surface and measuring the travel time of these sound waves from the earth's surface down to a specific rock layer and back to the surface. If the identification of any particular sound wave is correct and corrections for surface and subsurface variations in sound wave velocity can be adequately computed, an extremely accurate structural map can be made using the seismic method.

All of the geophysical approaches are directed toward the finding of structural barriers. As previously noted, stratigraphic barriers may be as important or more important in localizing an oil or gas field. The mapping of stratigraphic barriers can be approached from surface outcrops or from subsurface data or from a combination of the two. For example, a prospective reservoir rock, sandstone, may come and go along an outcrop trace. Therefore, it may be inferred that the sandstone comes and goes in the subsurface. Logs of two nearby wells may show specifically that a reservoir rock is present in one and absent or changed in character in another.

From the foregoing discussion you may have gathered the impression that oil and gas fields can be found without too much trouble if the proper data and tools are used. Such is not the case. There are two big reasons why in this country only one out of every eight or nine wildcat wells drilled is a producer. These reasons are: #1, error in the mapping approach so that one or more of the barriers (that were thought to be present from the mapping procedure and were necessary to form a pool) were not present as mapped; #2, all of the mapping procedures and results were correct, all of the barriers, source reservoir, and cap rocks were present, but the structure or stratigraphic trap was barren when drilled. The reasons why item #1 above is frequently in error are summarized below. Surface outcrops may have been incorrectly mapped or there may not have been enough outcrops to draw correct conclusions. Subsurface information may not be complete, proper logs may not have been run in wildcat wells, well sample interpretation may have been poor or incorrect. Geophysical information may have been wrong. Most of the geophysical approaches give their answers in terms of measurements which are related to rocks but do not directly measure the rocks themselves. For this reason the various geophysical approaches are often inconclusive or the results are erroneously interpreted.

The reasons why the #2 item listed above results in a dry hole are much more puzzling and hard to evaluate. In other words, the structure or barrier is present as mapped; the other factors, source, reservoir, and cap rock beds are present as postulated, yet when a hole is drilled, this structure is barren. This phenomenon is due to factors relating to the migration and accumulation of oil or gas. These factors are summarized below. Because of stratigraphic changes on the flanks of this barren structure, there may not have been sufficient avenues of migration for the oil to ever get into the structure. Another explanation might be that oil was present in this now barren structure but that due to subsequent tilting of the earth's crust in that vicinity, the oil moved out again to some other location and has never returned. Another reason may be that oil was present at one time in this now barren structure and was moved out by the action of moving water under pressure in the reservoir rock.

After all of the many approaches to finding oil and gas have been used and evaluated, the final and *sine qua non* is to drill a hole.