ERE 120

Fundamentals of Petroleum Engineering

COURSE NOTES
LECTURE 1

Fall Quarter 2014

https://piazza.com/stanford/fall2014/ere120/home
http://coursework.stanford.edu

A. Welcome

The following sources were used in compiling these notes:
The Properties of Petroleum Fluids, William D. McCain, 2nd edition
Petroleum Reservoir Engineering, Amyx, Bass and Whiting
Applied Petroleum Reservoir Engineering, B.C. Craft, M. Hawkins and R.E. Terry, 2nd edition

Many of the pictures were found on the web. Some references to interesting websites are given at the relevant places in the notes. Some pictures will be drawn in class and space is provided in the notes for this purpose. Please check you have all necessary figures if you miss a lecture.

B. Important Information

All material in these notes is examinable. Some material is added for illustrative purposes mainly and will not be covered in class.

The notes are interspersed with questions/tasks.

Most, but not all, of these questions will be answered in class. Use them to help digest the material.

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1. Introduction

Petroleum is a mixture of hydrocarbons that occur in their natural states as gas, liquid or solid. The state of petroleum is determined by its composition, pressure and temperature.

Virtually all petroleum is produced from the earth in either the gas or liquid state. Commonly, these materials are referred to as natural gas (gas state) or crude oil (liquid state). Examples of solid materials are wax, asphalt and coal.

In the early days of the petroleum industry, natural gas was considered undesirable and people were only interested in crude oil. Currently, natural gas is an important product in itself.

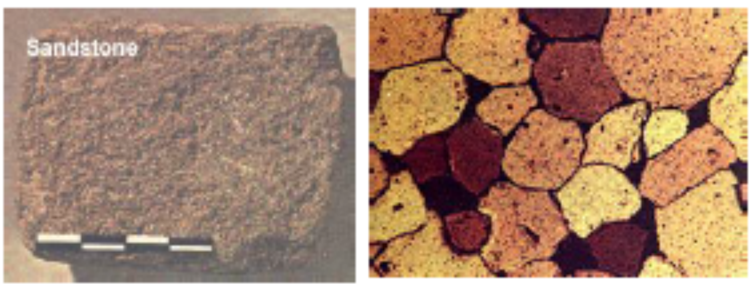


Figure 1-1 a: sandstone (scale shown in inches); b: sandstone cut (1 grain approx. 1 millimeter)

Petroleum is a mineral substance. The liquid or gas is contained in the pore space or interstices of rock materials, which are referred to as reservoir rocks. The rocks in which petroleum is found are sedimentary materials, generally sandstones, shales or limestones. Sandstone grains sizes are 1/16 to 2 mm in size.

1.1 How petroleum reservoirs are formed

Petroleum is formed in sedimentary rocks known as source rocks, which contain large quantities of organic material. This material may have been isolated in a stagnant area of the seabed with little oxygen, where it became covered with successive layers of deposits.

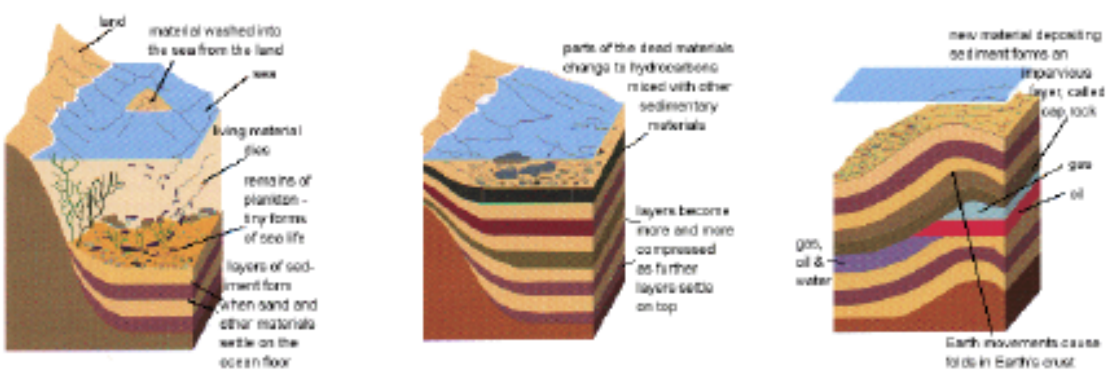


Figure 1-2 Formation of oil reservoirs illustrated

Due to the absence of oxygen, algae and other organic materials were only partially broken down and became preserved in the layers of sediment. The organic material is compressed as further layers settle on top and gradually forms a material known as kerogen. At a high enough pressure, the kerogen begins to convert into oil. This process takes millions of years. North Sea oil, for example, come from clay shale, estimated to be 150 million years old (Jurassic period). North sea gas is thought to originate primarily in the Carboniferous period, approximately 300 million years ago.

Oil and gas have a lower density than water and will therefore migrate up through the most permeable porous strata (such as sandstone) and through small fractures (like those present in shale). These migration layers are collectively referred to as the carrier bed. The migration is due to buoyancy, capillarity and wettability effects. Their path is finally blocked by an impermeable type of rock, called a cap rock, which forms a trap, preventing the petroleum from migrating further upwards, thus forming deposits large enough to allow for economically viable exploration.

There are several classifications of traps, which were developed by Wilhelm in 1945, Bull. Am. Assoc. Petro. Geologists, Vol. 29.

A simple trap is the so-called convex trap (or dome or anticline), illustrated in Figure 1-3a. This trap is formed by folding of the deposition layers. Fault trap reservoirs (Figure 1-3b) are sealed by fault boundaries. Both traps are illustrated below, as is a 3rd type of trap, the so-called salt dome.

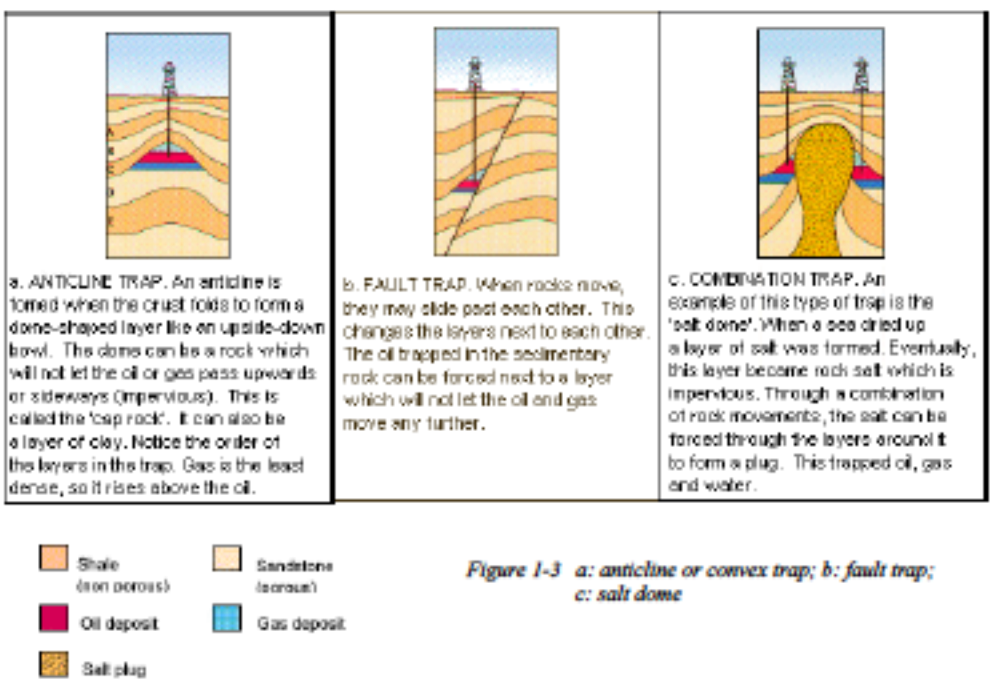
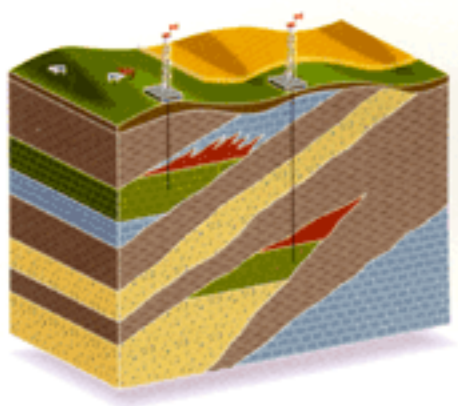


Figure 1-3 a: anticline or convex trap; b: fault trap; c: salt dome

Another trap is the permeability trap, which has a barrier resulting from the loss of permeability in the reservoir layer itself. In pinch out trap reservoirs, the trap is formed due to the pinchout of the reservoir bed.

PICTURE



Which of these traps do you think could be spotted from geophysical and regional geographic information, and which could be disclosed by drilling?

Of course, the trap must be overlain by impermeable beds so that oil and gas cannot seep from the trap and migrate to higher beds in sequence. Additionally, the existence of a trap is not sufficient to guarantee an oil reservoir.

Fluid distributions

Gravitational forces will cause the less dense fluids to seek the higher positions in the trap. Capillary forces tend to cause a wetting fluid to rise into pore space containing a non-wetting fluid.

Is water a wetting fluid with respect to oil, or vice versa? What about water and gas, and gas and oil?

Capillarity tends to counteract the force of gravity in segregating fluids. Prior to the disturbance of the accumulation, equilibrium exists between the capillary and gravitational forces.

A possible fluid distribution is an oil zone in the top of the trap, underlain by water. Between the two zones, and oil-water transitional zone exists. The rock pores in the oil zone contain a small amount of water (commonly called connate water). The fraction of the pore space occupied by water increases with depth in the transitional zone, so that the base of this zone is delineated by completely water-saturated pore space. Natural gas initially occurs in such a reservoir only as solution gas (dissolved in the crude oil).

PICTURE

Another possibility is that both crude oil and natural gas (free gas) occur in the trap. The natural gas occupies the highest position of the trap and forms a gas cap. The oil is again underlain by water. Connate water exists in the gas cap as well as in the oil zone. The natural gas in such a reservoir exists as associated free gas in the gas cap and solution gas dissolved in the crude oil.

PICTURE

It is also possible to have only natural gas (non-associated free gas) underlain by water. The gas zone contains connate water, which increases with depth in a transitional gas-water zone to complete water saturation in the water zone.

PICTURE

1.2 A short history of petroleum exploration

1850	"Paraffin" Young takes out his patent for shale oil distillation (Scotland)
1851	Young opens the world's first commercial scale oil refinery at Inchcross in central Scotland
1859	Edwin Drake drills the first producing oil well, in Titusville, PA
1862	Young's distillation plants begin production and for over half a century 3 million tons of shale and coal each year are mined and treated.
1870	John D. Rockefeller enters the oil refining business and forms Standard Oil to produce kerosene for lighting purposes
1882	Edison invents the electric light bulb, endangering future petroleum markets
1896	Invention of the automobile (Daimler and Benz) resurrect the market for petroleum

1901	Petroleum discovered in Persia. Petroleum boom in Texas (Sun, Texaco, Gulf)
1903	Petroleum boom in California (Unocal)
1905	Petroleum in Oklahoma
1907	Merger of Shell and Royal Dutch
1908	Petroleum boom in Persia (BP)
1911	Dissolution of Rockefeller's Standard Oil cartel to form smaller companies which eventually became Exxon, Mobil, Amoco, Chevron, etc.
1927	Petroleum boom in Iraq
1938	Boom in Kuwait and Saudi Arabia
1960	Formation of OPEC
1962	Shale oil industry in Scotland final closure
1968	Petroleum discovered in Alaska (not exploited until 1977)
1969	Petroleum discovered in the North Sea (not exploited until 1975)
1973	First energy crisis: Arab oil embargo against the US in retaliation for US support of Israel in the Yom Kippur war.
1979	Second energy crisis: Iranian revolution causes major disruptions in oil supplies from the Persian Gulf.
1980	Iran/Iraq war
1982	OPEC establishes production quotas
1990	Third energy crisis: Gulf war
1998	Baku (Caspian) sea region becomes focus of interest of oil companies
2000 – Current	Shale gas and tight oil boom

Below are a few historic shots. For more photos see historic American pictures at http://little-mountain.com/oilwell/pages/photoalbum.html, a historic Saudi-Arabian photo archive at http://www.saudiaramco.com/aboutus/photo_archieve.htm, and a Scottish heritage site at http://www.almondvalley.co.uk.

Figure 1-4 from left to right: "bings" in the Scottish landscape, early oilwagons in Pennsylvania, signing of concession agreement between Saudi-Arab Government and the Standard Oil Company of California in 1933 (Lloyd Hamilton and HE Sheikh Abd Allah Sulayman Al-Hamdan)

1.3 Oil discovery and production

Several methods are used to locate oil reservoirs. Promising geological features are located using aircraft or satellite pictures. Small samples of rock are dug out and studied by geologists. The properties of the rocks can further be studied using magnetometers, gravitometers and seismic waves. Magnetometers measure very small changes in the strength of the Earth's magnetic field. Sedimentary rocks are nearly non-magnetic whilst igneous rocks have as stronger magnetic effect. Gravitometers measure the strength of the Earth's gravitational field, which varies as a result of different rock densities. Igneous rocks like granite are denser than sedimentary rocks. Also, the gravitational pull depends on the depth of the rock layers. In seismic surveys (Figure 1-5), a shock wave is created by various means. On land, a thumper trick can be used or explosives can be drilled into the ground. Over water, a compressed-air gun can be used to shoot pulses of air into the water, or explosives cab be thrown overboard. The shock waves are reflected back by the various rock layers. The reflected waves travel back at different speeds depending upon the type or density of the rock layers, and are detected by sensitive microphones or vibration detectors – hydrophones over water, seismometers over land. The success rate for finding new oil fields is still no more than 10%

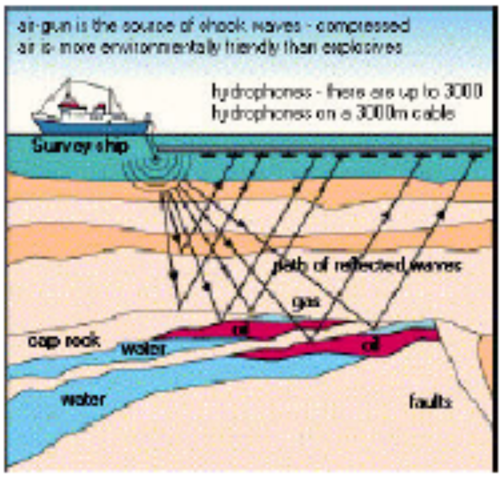


Figure 1-5 Seismic survey illustrated

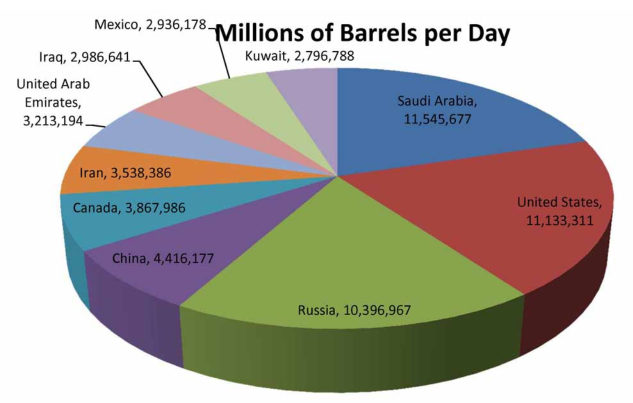


Figure 1-6a: World Oil Production

As can be seen from Figure 1-6a, in 2013, Saudi Arabia, Russia and the USA each produced approximately 11 million barrels per day of oil. In the USA, the five main oil-producing states are Oklahoma, California, Alaska and Texas, with an major increase in North Dakota due to tight oil production (Figure 1-6b). The consumption of oil still exceeds the production.

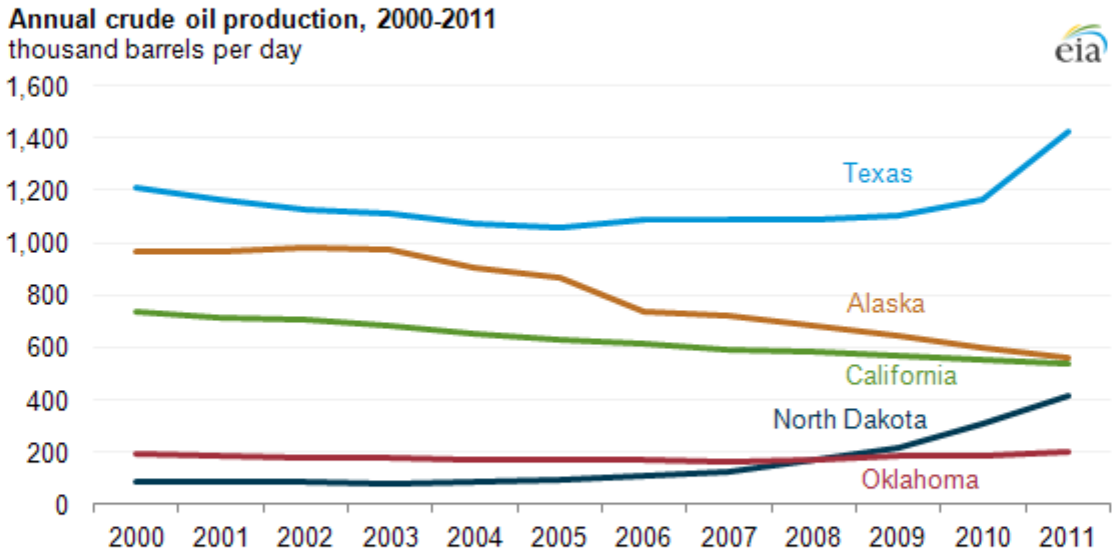


Figure 1-6b: US Oil Production by State

California's crude oil production totaled is about 550 thousand barrels a day, which only accounts for about 35% of the states oil consumption. Natural gas production is approximately on 550 million cubic feet per day. California has an estimated reserve of 2.9 billion barrels of recoverable crude oil. A map of the oil, gas and geothermal fields in California can be found here: http://energyalmanac.ca.gov/petroleum/documents/MAP_OIL_GAS_GEOTHERMAL.PDF

What are the current estimates of the world's oil supplies?

Drilling and Producing

Figure 1-7a shows the anatomy of an oilrig. A schematic of the vertical oil well is shown in 1-7b.

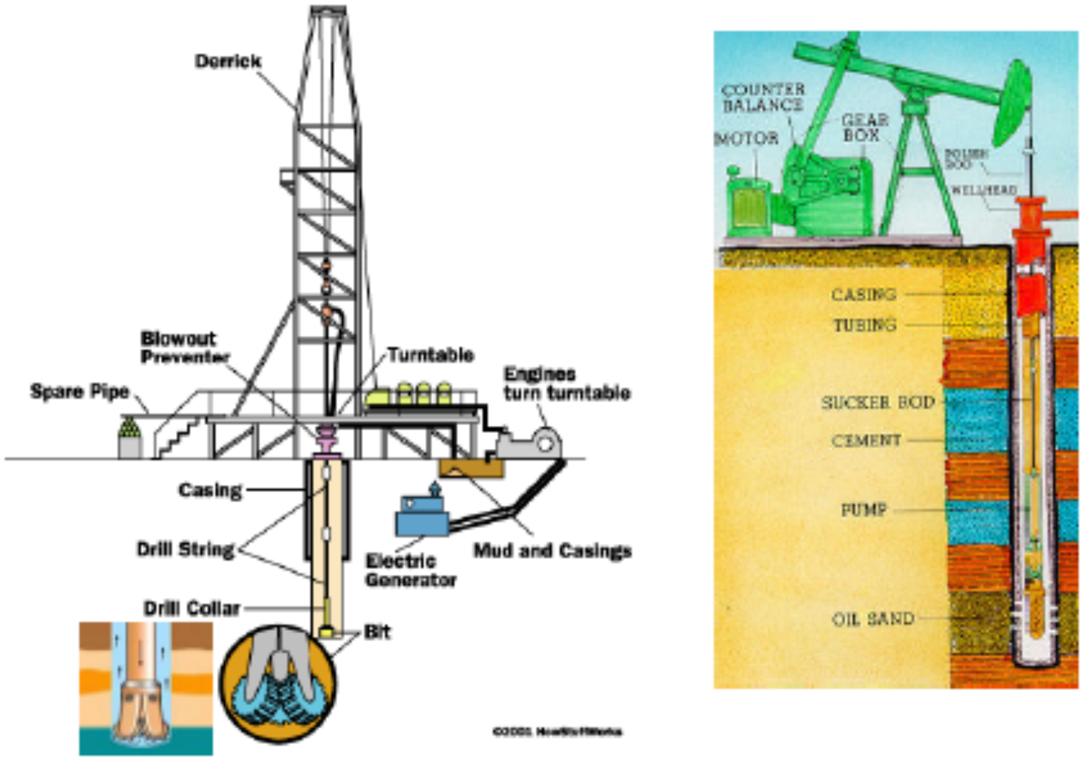


Figure 1-7 a: oil rig and drilling bit; b: oil well

Drill bits come in many shapes and materials (tungsten carbide steel, diamond) that are specialized for various drilling tasks and rock formations. The casing is a large-diameter concrete pipe that lines the drill hole, prevents the hole from collapsing and allows drilling mud to circulate. Drilling mud is a mixture of water, clay, weighting materials and chemical used to lift rock cuttings from the drill bit to the surface. A new drilling technology is horizontal drilling used to reach oil under ecologically sensitive areas.

Once the final depth is reached, a perforating gun is used to create holes in the casing to allow the oil and gas to flow in. To start the flow of oil into the well in a limestone reservoir, acid is pumped down into the well. In sandstone reservoirs, a specially blended fluid containing proppants (sand, shells, pellets) is pumped out into the perforations. The pressure from this fluid makes small fractures in the sandstone that allow oil to flow into the well. Once the oil is flowing, the oilrig is replaced by production equipment.

In some cases, the oil may be too heavy to flow and needs a little push. A second hole is the drilled into the reservoir and steam is injected under pressure. This process is referred to as enhanced oil recovery (Figure 1-8).

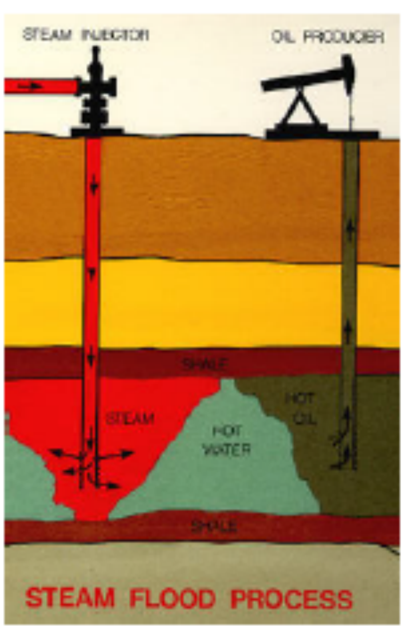


Figure 1-8 Enhanced oil recovery