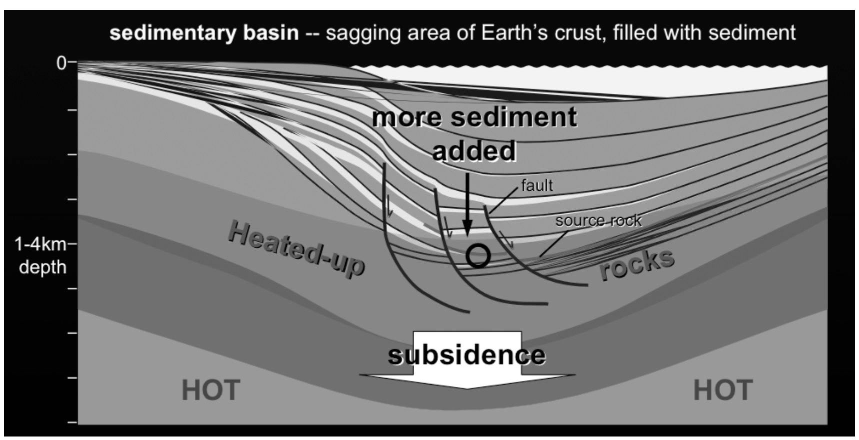
Oil and Gas: Fossil Fuels

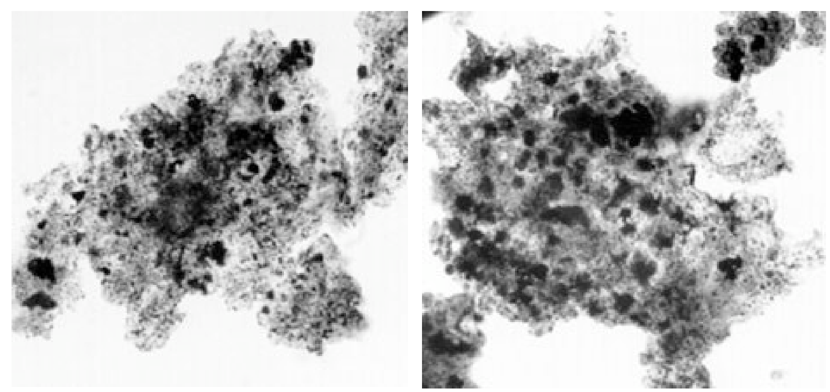
What do you need to find oil and gas?

- A source of carbon—buried organic matter in the form of dead organisms
- A *source rock* where conditions are right for oil and gas formation (high temperature and pressure)
- A *reservoir* into which the oil and gas can pass
- A *trap* in which the oil and gas can accumulate but not escape

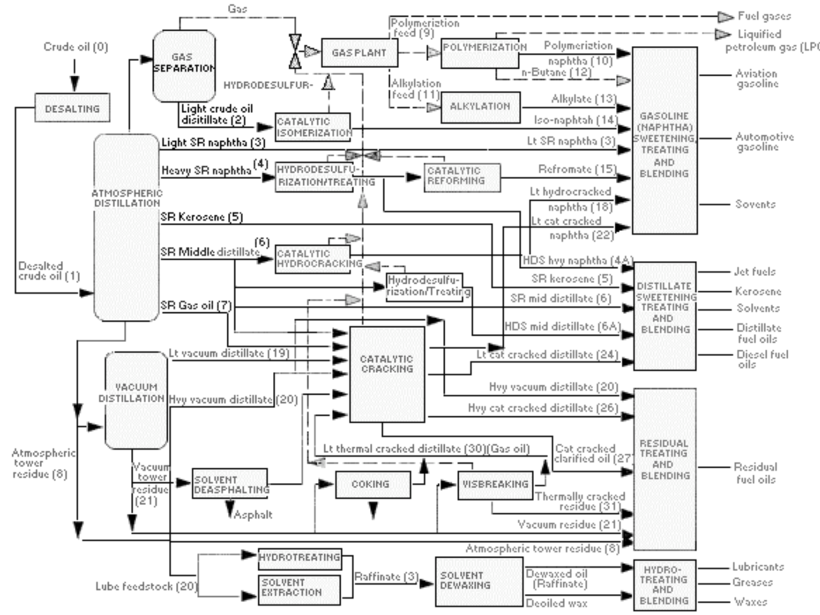
As the source rock is more and more heated and compressed, the organic matter in the source rock begins to "cook". . .



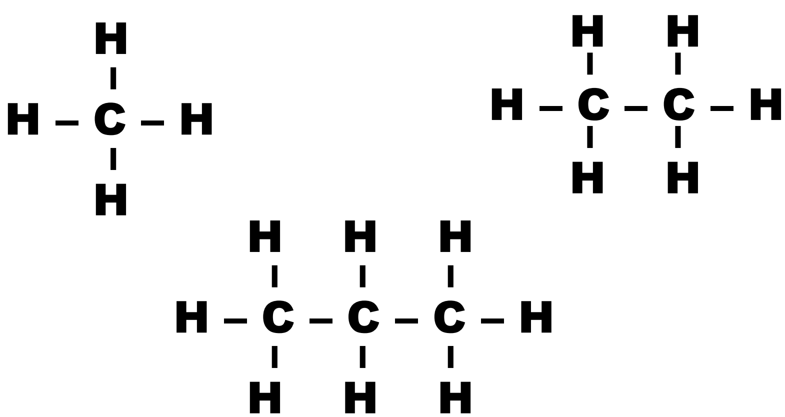
If the temperature is right (130-150°C), the organic matter breaks down, first into a waxy material called *kerogen* (shown here in microscopic view), and then into simple hydrocarbons. . .



Refineries take the crude oil and heat it, sometimes under vacuum. As the crude oil heats, different substances boil off: first the lighter molecules, and then the heavier ones. . .



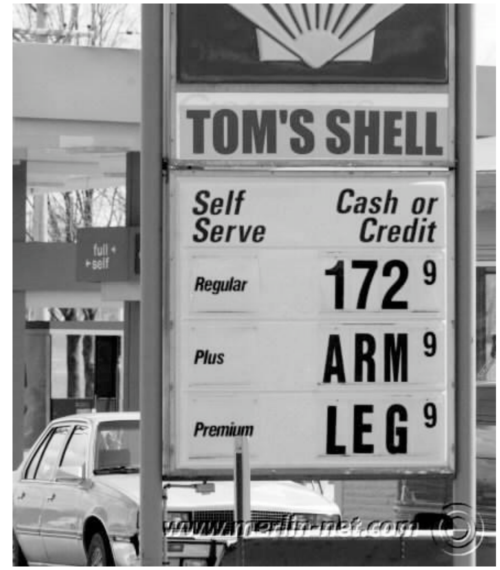
The lightest hydrocarbons are gaseous at surface temperatures and pressures: *methane*, *ethane, propane,* and *butane*, with 1 to 4 carbon atoms each respectively.



Hydrocarbons with five to seven carbons are light, volatile liquids (e.g. industrial solvents, ingredients in various products, and, usually with some chemical modification, dry cleaning fluids)

Smaller hydrocarbons are also used, with some chemical modifications, as feedstock for many other products, in particular for most plastics, and for artificial fertilizers. (1% of the world's energy supply—mostly as natural gas—goes into making fertilizer, through a chemical process called the Haber-Bosch Process)

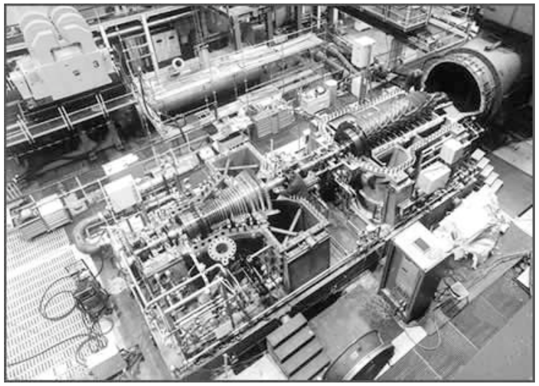
Gasoline is mostly C_7-C_8 hydrocarbons; *kerosene* and *jet fuels* are C_{10}-C_{15} mixtures, and *diesel fuel* and *home heating oil* are mixtures of C_{10}-C_{20}.



Lubricating oils and greases (including Vaseline) are C_{16}-C_{20}. Finally, *paraffin wax* and *asphalt* are made of molecules with more than twenty carbon atoms each.

Incidentally, crude oil is classified as *heavy* or *light* depending on relative amounts of large vs. small hydrocarbons. Oil that's low in sulfur (which needs less refining) is said to be *sweet*.

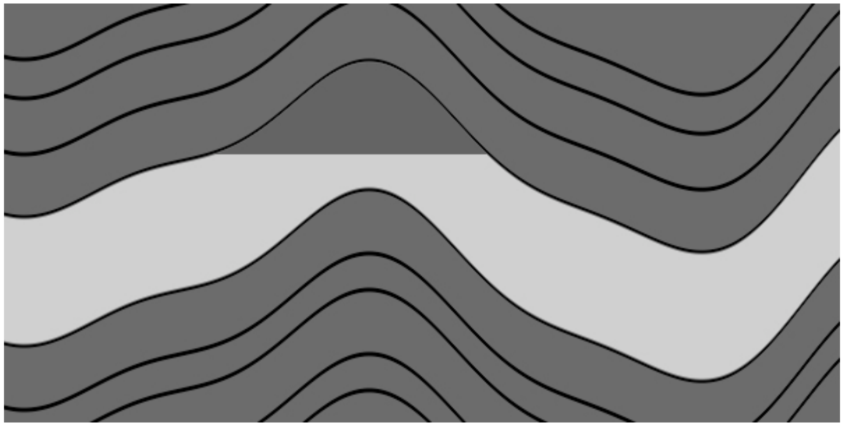
Heavy hydrocarbons (such as those in paraffin, asphalt, or diesel) can be chemically converted by intense heat and pressure to lighter hydrocarbons (such as those in gasoline), a process known as *catalytic cracking*.



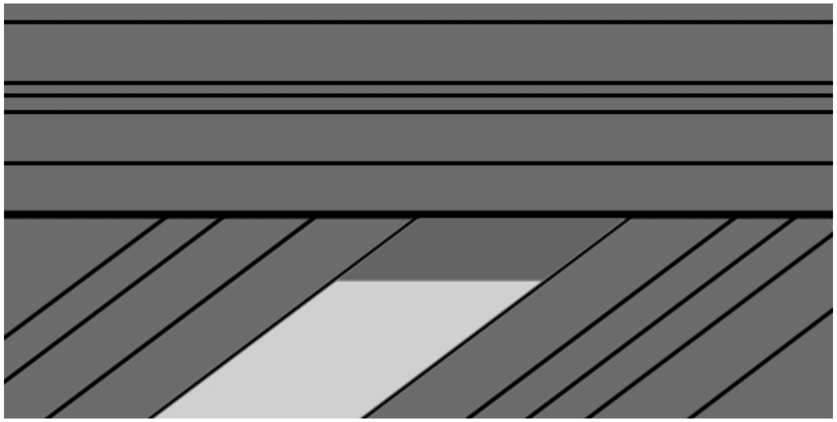
Traps

- Oil and gas migrate from their source rock because they're under pressure.
  - Oil and gas will travel through *permeable* rock (rock that's porous enough to let them pass through), such as sandstone and some kinds of limestone
  - Oil and gas are blocked by *impermeable* (non-porous) rock, such as shale
- Petroleum geologists look for *traps*—places where oil and gas have accumulated in a *reservoir* because they're blocked from going farther by impermeable rock layers (the *seal*)

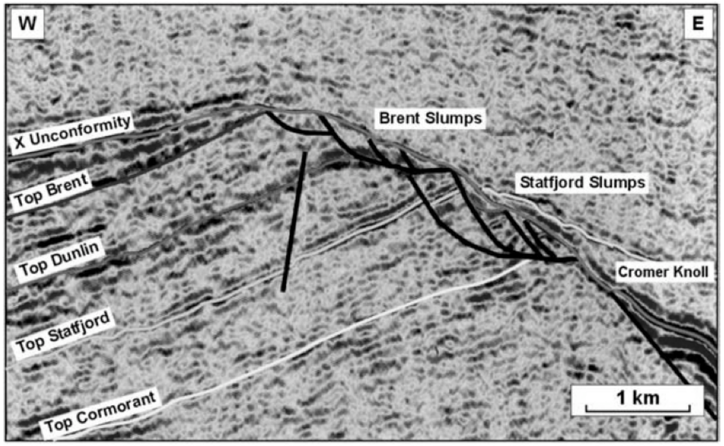
Anticlines with alternating layers of porous or nonporous rock may form *anticline traps* (such as the Ghawar field in Saudi Arabia). . .



If lower layers of reservoir rock form an angular unconformity with upper layers of impermeable rock—as is the case in east Texas—you get an *unconformity trap*.

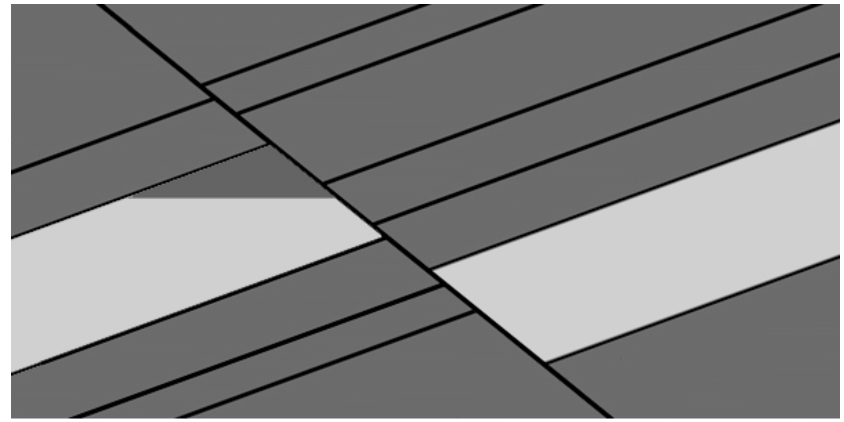


This *seismic image* (made by passing shock waves through the earth and recording how they reflect off rock layers), from the North Sea off the coast of Scotland, shows an unconformity trap

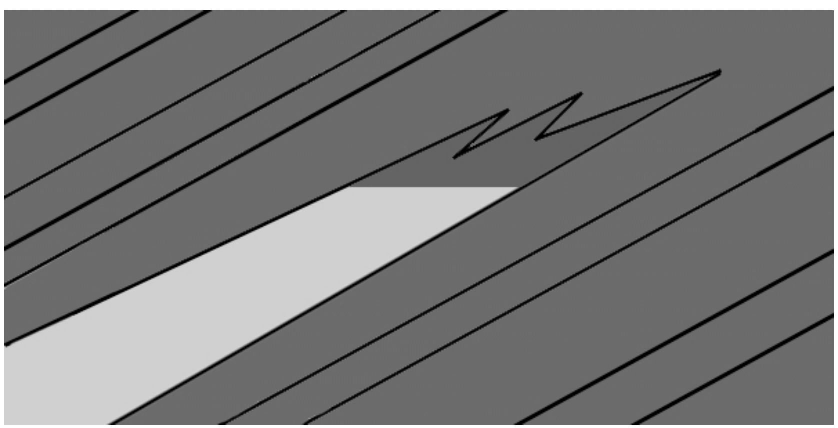


Brent Field, block 211/29, East Shetland Basin

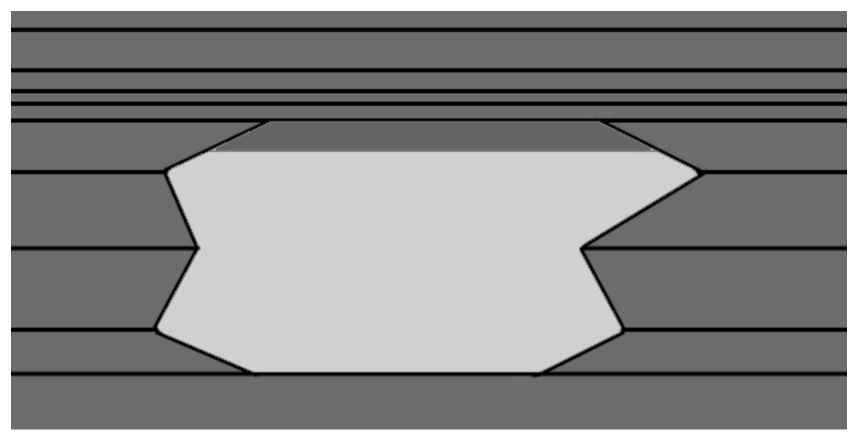
Fault traps form when faulting cuts off a portion of reservoir rock. . .



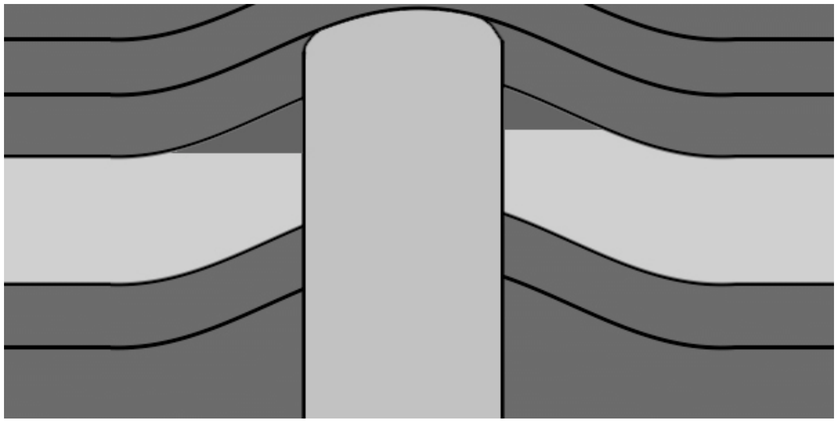
A reservoir layer that narrows and finally disappears may form a *pinchout trap* (as is the case in parts of Alberta, Canada). . .



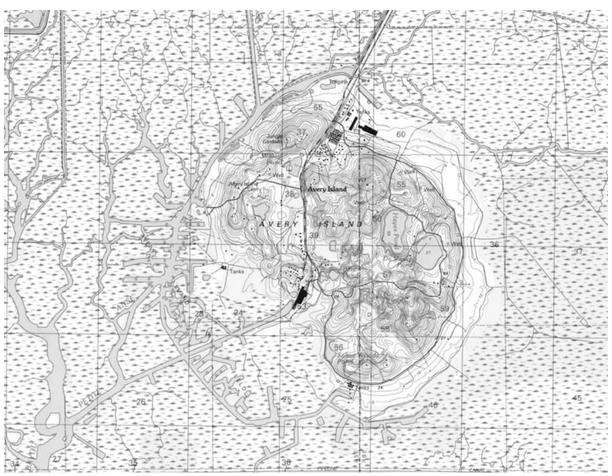
Reef traps form when a reef, made of permeable limestone, is buried by impermeable sediments



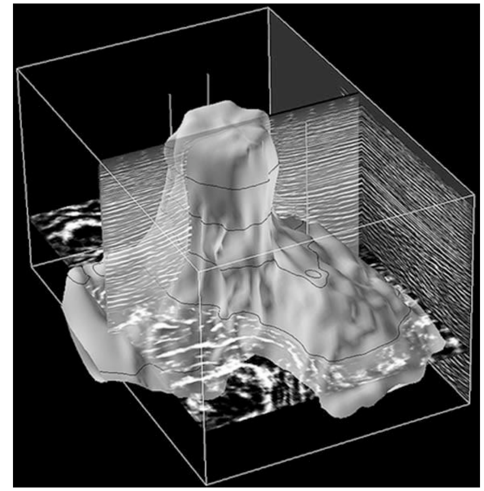
Salt flank traps, common in south Louisiana, are found on the flanks of massive intrusions of salt, known as *salt domes*.

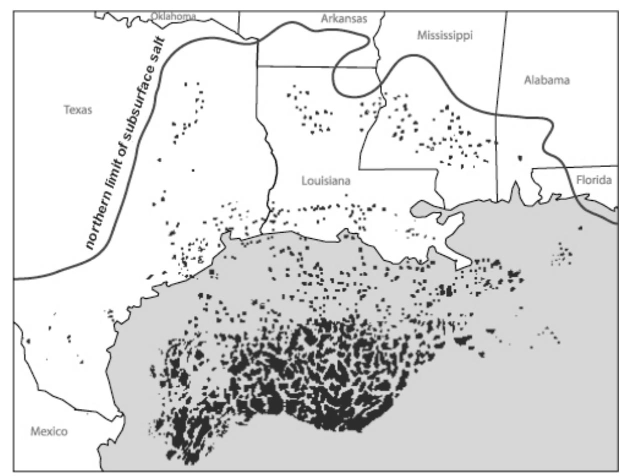


Uplifted layers on top of a salt dome may form substantial surface hills. In south Louisiana swamps, these—like Avery Island, shown here on a topo map—may be the only high ground (el. 160 ft).



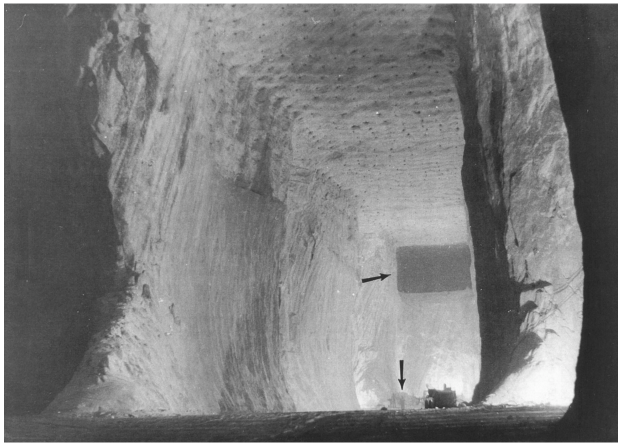
Salt domes, by the way, result when high pressure on deeply buried layers of rock salt causes the salt to flow, and to push upwards.

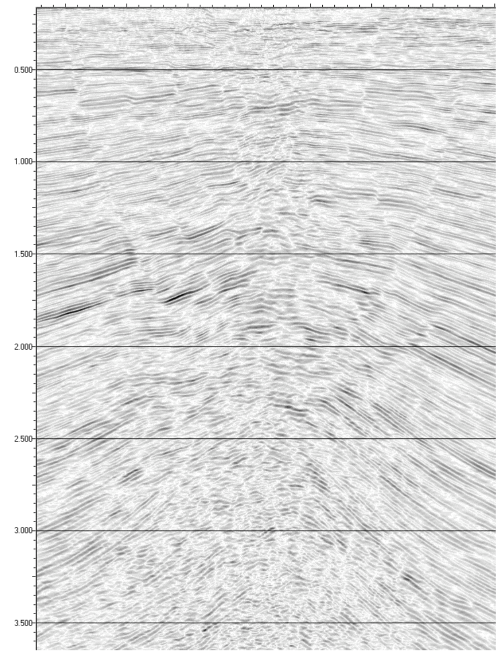




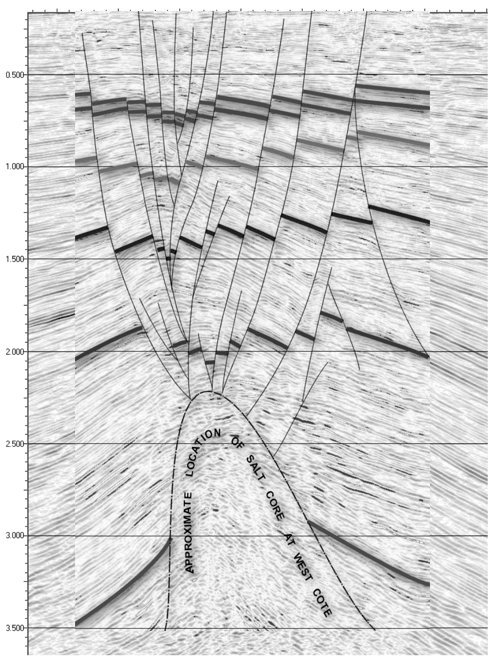
Salt domes forming from a huge buried salt layer called the Louann Salt are found throughout the Gulf of Mexico area (shown as green spots) and are closely associated with oil and gas deposits.

Since Louisiana's salt mines are huge caverns inside salt domes, oil drilling close to domes can lead to problems, as in the famous disaster at Lake Peigneur on November 21, 1980.





It's common to find several types of trap in one field. For example, the West Cote Blanche Bay oil field in Vermillion Bay, Louisiana has a number of fault traps above a salt trap. Here's the raw seismic image. . .



. . . and a colorized version showing the faults associated with the underground salt dome. There are both flank traps and fault traps (colored lines) that produce oil and gas here.

If there is no trap, oil and gas will eventually rise onto the Earth's surface. The heavier compounds in the oil will stay behind in *tar pits*, like this one on the island of Trinidad. . .

. . . and this one in Los Angeles, one of the famous La Brea Tar Pits (famous for having trapped and preserved the bones of countless animals between 40,000 and 10,000 years ago).

Are We Running Out of Oil?

- Well. . . if you mean "are we ever going to consume the very last drop of oil in the planet", the answer is definitely "NO!"
- What we *are* potentially running low on is oil that can be cheaply extracted and refined.

In the best-case scenario, an oil deposit is under enough pressure that it flows by itself through the drillhole. Too *much* pressure, and you get "gushers", like this one in 1914—but these are rare today.

If there is enough pressure, all you have to do is cap your well with a complex valve assembly (a "Christmas tree") and the petroleum or gas can be fed right into a pipeline.

Under Pressure. . .

- Usually, you can get about 20% of the oil in a typical reservoir by *primary extraction* (letting natural pressure do the work)
- *Secondary oil recovery* involves pumping oil out, or pumping fluid into a reservoir to force oil out—you get another 5-15% of the oil
- *Tertiary recovery* uses heat (such as injected steam, or burning part of the oil) to get oil out by decreasing its viscosity, giving you yet another 5-15% of the oil.
- Each step involves progressively more expense and may not be economically profitable. And note that you only get 30-50% of the oil in the reservoir, even using all of these methods. Getting out more that that wouldn't be economical at all.

Other processes?

- *Fischer-Tropsch Process*—converts coal to synthetic petroleum: 1 ton of coal produces about 45 gallons of crude oil equivalent.
  - Used by Germans in WWII, but not profitable under normal conditions.
- *Oil shales*—certain shales very rich in kerogen.
  - USA has massive reserves (equiv. 1200 billion barrels)
  - Problems:
    - Not economical unless crude prices go *permanently* over $40/barrel
    - Uses energy equivalent to 40% of the energy of the oil produced, and also requires large amounts of water, lots of infrastructure
    - Produces vast amounts of toxic waste (although new technologies show promise in reducing or eliminating this problem) and vast amounts of greenhouse gases

Other processes?

- *Tar sands*—deposits of sand rich in *bitumen* (petroleum tar)
  - 13% of Canada's oil needs are produced from massive tar sand deposits
  - Requires massive mounts of energy and hot water to operate
- *Biodiesel*—use of vegetable oils in diesel engines, either "as is" or mixed with regular diesel. Related schemes involve processing organic waste into synthetic fuels
  - Works well. . . but remember that much of the fertilizer used to grow oil-producing plants is derived from petroleum. Not likely to replace petroleum, although it could stretch supplies. . .