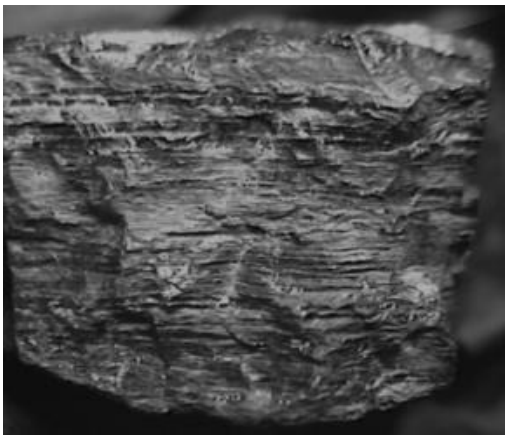
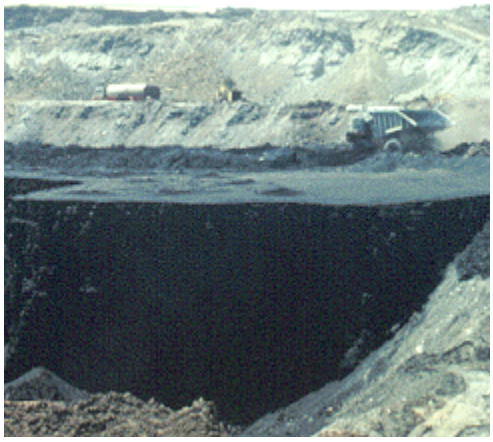
How Did Coal Form?

Coal is the compacted and preserved remains of plant matter. Although most plant matter decomposes where it falls, when plant life containing cellulose-rich stems and leaves is highly abundant and special conditions exist, the plant matter does not totally decompose and is preserved in fossilized form. These types of plants had evolved by the Devonian Period and coal deposits are found in rocks dating from the Devonian period forward. Many coal deposits in Europe and North America date from the Carboniferous periods of the Paleozoic when these areas were covered with forests dominated by large ferns and scale trees. Learn more about geologic time here.

Most coals that are mined for energy production are humic coals which are derived from peat. These coals are examples of organic sedimentary rocks and composed of substances or aggregates called macerals. If you look at the picture the picture of a lump of coal, you can see stratification which results from the organic matter being deposited layer upon layer. The formation of humic coals begins when plant debris accumulates in a swamp where the stagnant water prevents oxidation and total decomposition of the organic matter. These swamps are called peat swamps. It is estimated that about 10% of the plant matter is coverted to peat in these swamps. It appears that many coal deposits formed when peat deposits in near-coastal basins subsided allowing the sea to flood the

area covering the peat with sand and mud. Much of the area that now is found in Europe and North America were located closer to the equator during the Devonian and Carboniferous periods, and the seawater was warm allowing lime muds to accumulate on top of the peat deposits. Over time these areas experienced cyclical periods of subsidence and reemergence. As a result many coal deposits are composed of layers of coal separated by layers of sandstone, shale or limestone. The coal layers range in thickness from a few centimeters to 50 feet or more. Although coal formation began in the Devonian, the great coal beds found in Australia, the eastern United States and England were formed during the Carboniferous periods and those of the western U.S. were formed during the Jurassic to the mid-Tertiary.





http://chemistry.anl.gov/carbon/coaltutorial/coalgeneral.html#coalification

A coal seam in the Powder River Basin, WY
http://enterprise.cc.uakron.edu/geology/natscigeo/Lectures/smrocks/sedmeta.htm#sedimentary

Coal Reserves

In the peat swamp as dead plant matter accumulates, aerobic bacteria rapidly oxidize cellulose and other components producing methane (CH_4), carbon dioxide and ammonia (from the nitrogen containing components). The resulting decomposed material compacts about 50% and is largely composed of lignin, a complex, 3-dimensional polymer rich in benzene rings. These bacteria quickly use up the available oxygen and die ending the first stage of the process. Anaerobic bacteria take over the decomposition process. They produce acids as metabolic waste products. When the pH reaches ~4, these bacteria die. The product at this stage is a gel-like material called Gytta. When the Gytta is buried to a depth of 2,000 to 3,000 feet, the temperature is about 100°C and a thermal process known as bituminization begins. At this temperature water and other volatiles are driven off. Learn more about how swamps are converted to coal here.

http://www.lignin.info/01augdialogue.html

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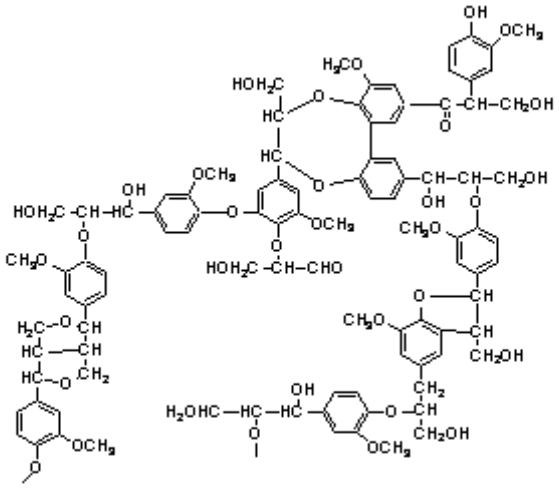
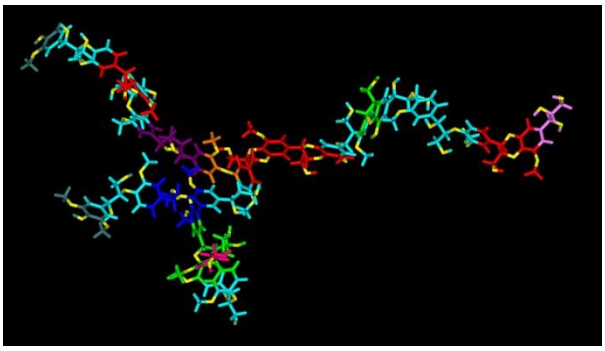
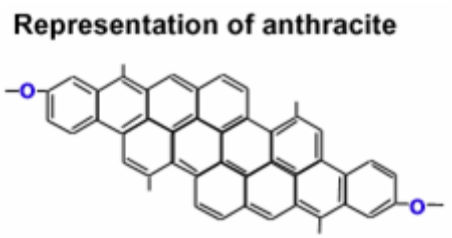
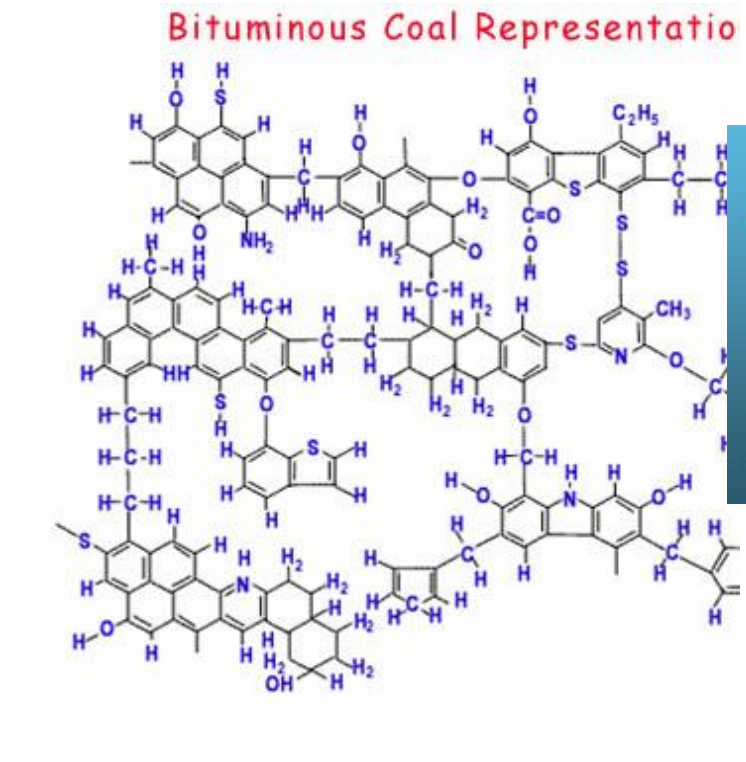




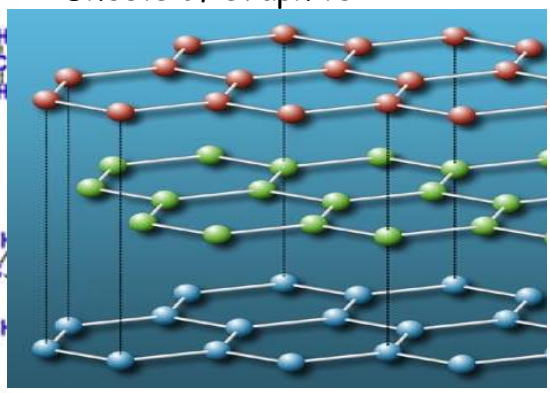
As this decomposed peat is buried deeper and deeper, the pressure and temperature to which it is exposed increases causing chemical reactions

to occur which reduce the lignin (remove oxygens via expulsion of carbon dioxide and water). In this process, carbon-carbon bonds form between the aromatic rings producing the hard, black carbon-rich material we call coal. Under extreme conditions of pressure and temperature, the end product or most reduced form is graphite. Graphite is a form of carbon in which the carbon layers are arranged into layers of fused aromatic rings. The process of converting organic plant material into coal is called coalification.





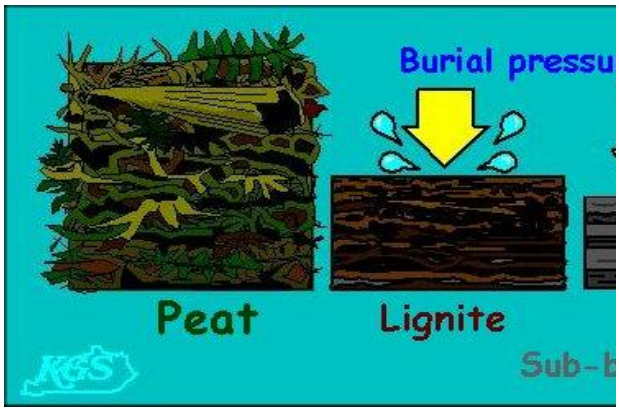
Sheets of Graphite:



http://www.scifun.ed.ac.uk/card/images/flakes/graphite-layers.jpg

Coal Rank

Since different coal beds form under different conditions of temperature and pressure, the amount of oxygen removed will differ in different coal samples. The products of coalification are divided into four major categories based on the carbon content of the material. It is the carbon content of the coal that supplies most of its heating value. The greater the carbon to oxygen ratio the harder the coal, the more reduced the state of the carbons and the more potential energy it contains. These major categories may be divided into subdivisions usch as high volatile A or high volatile B bituminous coal.



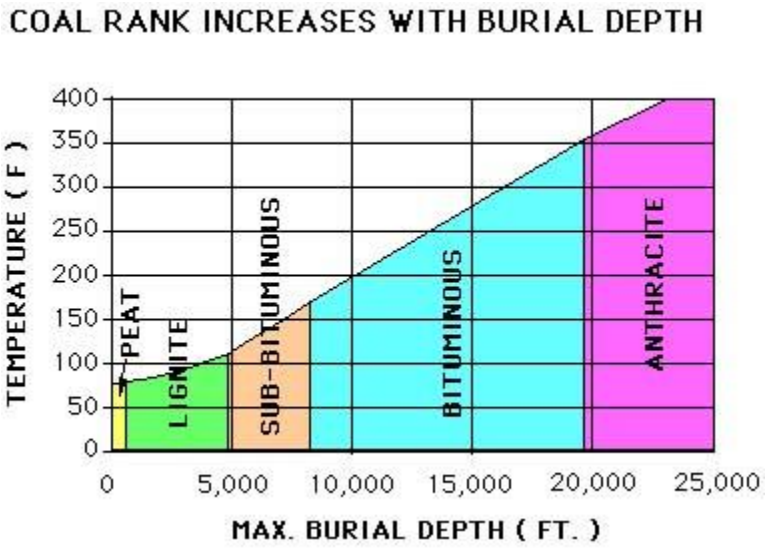
http://www.uky.edu/KGS/coal/coalkinds.htm

Peat

Anthracite

Notice the obvious presence of plant matter present in the sample of peat at the left. As coalification proceeds the product becomes more "mineral-like" in its appearance. The higher the rank of a piece of coal, the harder and more lusterous it is. Compare the peat to the anthracite shown at the right which is quite hard, very shiny and looks like a "mineral".

As you travel from the earth's surface toward the center, temperature increases. This geothermal gradient averages about a 1.5°F increase per 100 feet of depth. As coal is buried deeper and deeper by accumulating sediments,



much or the water and volatile components are extruded (de-volatilization) leaving behind fixed carbon, ash, sulfur often in the form of pyrite and other trace elements. The normal geothermal gradient will produce bituminous coals at burial depths between 8,500 and 20,000 feet.

http://www.geocraft.com/WVFossils/coal_rank.html

Lignite

Lignite is geologically the youngest of the coal types. It is soft and brown in color. It is composed primarily of compressed, dehydrated woody material. The fixed carbon content ranges from about 20-35% by mass. This type of coal often is called brown coal. It is used mainly for electric power generation and produces 9-17 million BTU/ton. Lignite deposits are found in Texas, Montana, North Dakota and the Gulf Coast region.

Sub-Bituminous

Sub-bituminous coal is typically dull black in color. It has a carbon content ranging from 35-45% and prduces 16-24 million BTU/ton. Although the heat value of sub-bituminous coal is lower than bituminous, it tends to be relatively low in sulfur content and cleaner burning than other types of coal. This type of coal is found in a number of Western states and Alaska.

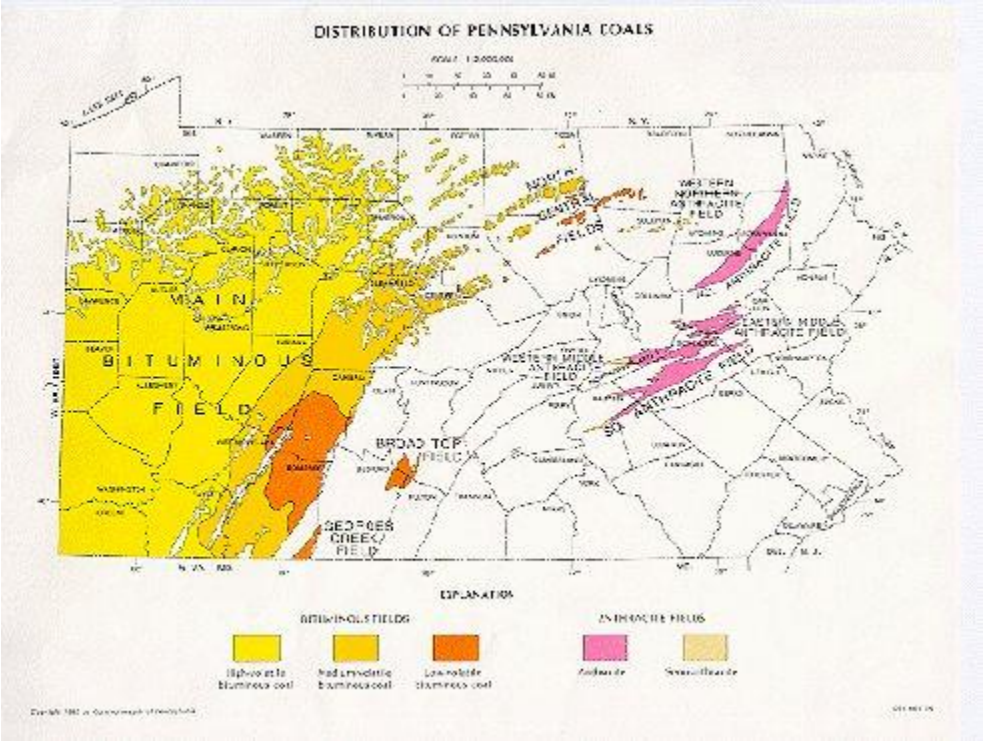
Bituminous

Bituminous coal is soft, dark and dense. It has little water content and has lost most other impurities except for sulfur. It is ignited easily producing a smoky yellow flame, ash, and volatile sulfur compounds. The carbon content ranges from 45-80% and produces 19- 32 million BTU/ton. Bituminous coal is the most commonly found type of coal in the U.S. with major deposits in the Appalachians, the Great Plains, and the Colorado

Plateau. It is used to generate electricity and is converted to coke for use in the steel industry.

Anthracite

Anthracite has the highest carbon content (80-96%) and produces the most energy per ton (20-28 million BTU/ton). It burns very cleanly and is sometimes called "smokeless" coal. Whereas other ranks of coal are classed as sedimentary rocks, anthracite is metamorphic. Anthracite forms when coal deposits are exposed to abnormally high temperatures often resulting from tectonic mountain building episodes. Anthracite is a relatively rare form of coal which in the U.S. is found primarily in a small area of Pennsylvania. These deposits were formed during the Allegheny Orogeny of the Carboniferous Period when the the continents of North America, South America and Europe collided forming the supercontinent Pangea. This collision formed the Appalachian Mountains which at the time reached elevations of 15,000 to 23,000 feet burying the forming coal to great depths. Subsequent glacial action eroded the Appalachians to the highlands they are today. It is estimated that nearly 95% of the anthracite formed in this region eroded away before man began mining coal.



A Map of Pennsylvania Anthracite (pink) Coal Deposits
http://www.dep.state.pa.us/dep/deputate/enved/go_with_inspector/coalmine/Anthracite_Coal_Mining.htm