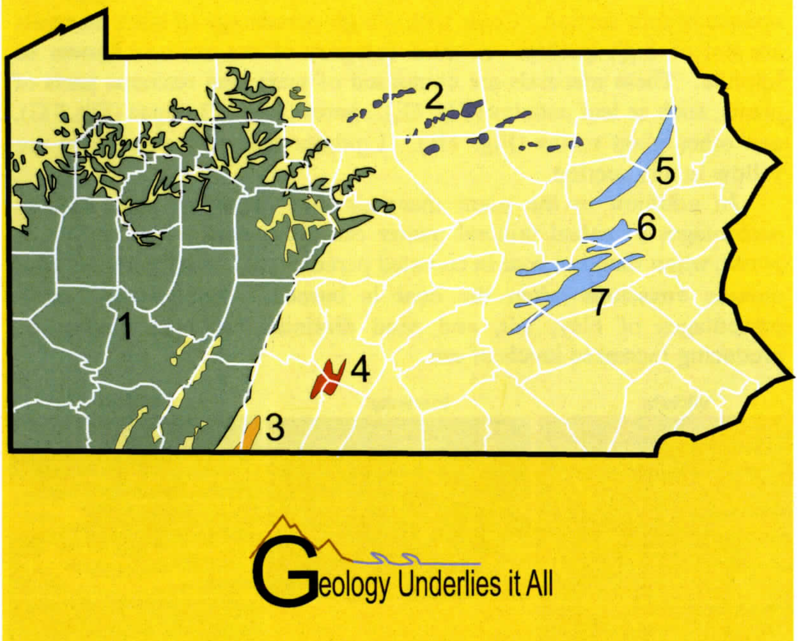
Geology of Pennsylvania's Coal



Geology Underlies it All

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David K. Brezinski and Carla Kertis Brezinski

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Coal is a Rock

A rock is defined as an aggregate of minerals. Coal is considered a rock even though it is not made up of minerals. Instead of inorganic mineral components, coal is made up of plant parts called macerals. Macerals can be considered the botanical equivalent to minerals. When coal is cut and polished into slices thin enough to let light pass through, called thin sections, the individual macerals can be identified. Macerals are subdivided into three categories based on their origin. Vitrinite is woody plant material and is identified in thin section by its red color. Most commonly the cellular structure of the wood is destroyed (Fig. 1A), but under some conditions the cells are preserved (Fig. 1B). High amounts of vitrinite are desirable for high quality coals. Also present in coal are inert parts of plants such a charcoal (Fig. 1C) or fungal spores (Fig. 1D). These macerals are typically opaque in thin section. Coals with a high percentage of such macerals are not of high quality. A third category of macerals is known as liptinite. These macerals are composed of waxy and resinous parts of plants, such as leaf cuticles (Fig. 1E), spores (Fig. 1F), algae (Fig. 1G), and other plant resins (Fig. 1H). Liptinite macerals commonly are yellow in thin section.

In addition to the plant macerals that make up coal, smaller percentages of actual mineral matter can be present. Iron sulfide or pyrite, when found in coal in elevated percentages, contributes to sulfur dioxide emissions when the coal is burned. Additionally, small percentages of clay, silt, and sand diminish the coal quality by producing increased levels of ash.

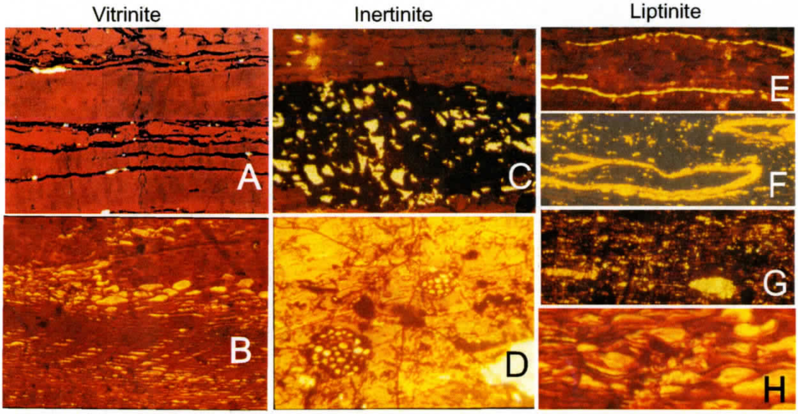

Figure 1. Coal macerals. A, Massive (red) vitrinite. B, Vitrinite (red) with cellular structure filled with plant resins (yellow). C, Inertinite, charcoal (black). D, Inertinite, fungal sclerota (spores) (black). E, Cutinite, plant cuticle (yellow). F, Sporinite, crushed plant spores (yellow). G, Algal bodies (yellow). H, Resinite, plant resins (yellow) in woody vitrinite (red).

Coal Rank

Although thick accumulations of plant remains are needed for coal formation, just as important is the means to transform that material into coal, the rock. This transformation process can be considered a low temperature form of metamorphism. The coalification process starts with thick accumulations of plant material in reducing environments where the organic matter does not decay completely. As more plant material is laid down and/or the plant accumulation is covered by sediment, the deposit is compacted by the overburden. This compaction causes the collapse of the plants' cellular structure, expulsion of air and water pockets, and an increase in density. Some estimates suggest that to form one foot of coal requires more than 10 feet of plant accumulation. Increased burial and time produces a progression of the maturity, or "rank," of the organic deposits (Fig. 2). With an increase in rank comes an increase in density, reflectance, and heating value of the coal along with a decrease in the moisture content.

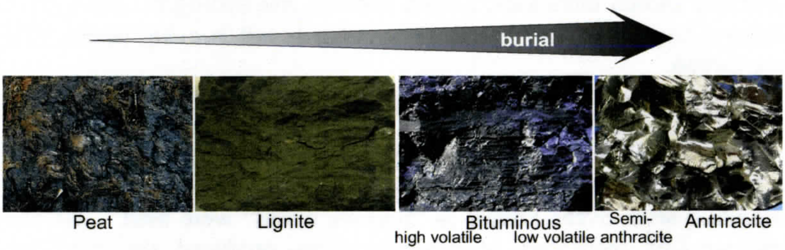

Figure 2. The coalification process. Increased pressure compacts plant matter from peat to lignite, to bituminous coal, to anthracite coal.

One of the first products of the coalification process is peat, a semi-carbonized combustible accumulation of compacted plant residue. Peat formation commonly occurs in freshwater swamps at high latitudes. Next to develop is lignite, or brown coal. Lignite is a low-rank coal that is typically brown in color and low in heating value. The woody structure of the plant material is commonly retained in lignite. Bituminous coal, often called "soft coal," is a higher rank coal with a higher percentage of carbon. Most bituminous coals display a banded pattern of alternating layers of bright and dull coal. Anthracite, or "hard coal," is brightly reflective, high in carbon content, and low in volatile (gaseous) hydrocarbons. Figure 3 illustrates the generalized west to east progression of rank in Pennsylvania's coals.

Climate and the Origin of Pennsylvania's Coal

Although coal is a relatively rare type of rock, it can be found in strata ranging in age from Precambrian to Tertiary. However, coal did not become common until woody plants developed in the Devonian. The first extensive coal deposits are found in the Pennsylvanian Period. Approximately 300 million years ago, Pennsylvania was situated near the equator. In western Pennsylvania a low-lying coastal plain lay between a

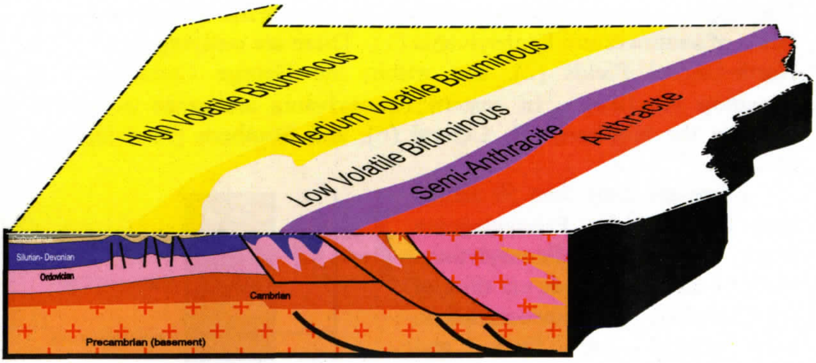

Figure 3. Distribution and extent of coal rank across the State of Pennsylvania. Eastward increase in rank parallels the increase in mountain-building forces that produced the Appalachian Mountains.

large continental seaway to the west and mountains to the east (see PA/S Publication 1). The climate was warm and tropical, but fluctuated through time. When the global climate grew warm, polar glaciers melted and that runoff filled the ocean basins. This resulted in a rise in sea level and submergence of low-lying areas of the land masses. During these flooding events, fossiliferous limestone and shale were deposited over vast areas of the continents. When Earth's climate cooled, increased precipitation in the high latitudes produced polar glaciers that spread into the middle latitudes. As a result, much of the water in the ocean basins became caught up in glacial ice on the continents. This produced a sharp global sea level drop that exposed continental shelves to erosion. Large rivers flowed out of the mountain range to the east, swept across the coastal plain, and cut deep new courses. In these river channels silt and sand were deposited which later would form sandstone. During global cooling episodes the increased precipitation not only produced glaciers at high latitudes, but also raised local water tables within the tropics. Extensive swamps developed between the river channels and along the receding continental seas. Plant accumulations in these swamps eventually became coal.

This pattern of repeatedly changing climate and subsequent rapid sea level fluctuation persisted for many millions of years. This cycle of events produced repetitive packages of coal, limestone, shale, and sandstone layers called "cyclothems." Cyclothems are characteristic of rocks of the Pennsylvanian Period throughout the world, but nowhere are they better developed than in western Pennsylvania.

Pennsylvania's Geologic Record of Coal Deposition

A map of Pennsylvania's coal fields is illustrated on the cover. The largest contiguous area underlain by coal is the main bituminous fields of southwestern Pennsylvania (1). There are outlying areas in the North-Central Fields (2), and within the George Creek (3) and Broadtop (4) fields. In eastern Pennsylvania anthracite coal beds underlie the Northern (5), Central (6), and Southern (7) Anthracite fields.

There are more than 50 named coal beds in the Pennsylvanian strata of western Pennsylvania. Most of these coal beds are thin, of poor quality, and uneconomical, but several are thick and economically significant. Irrespective of thickness all of these coal beds reflect global cooling events. The stratigraphic column in Figure 4 illustrates some of the more notable coals. The Kittannings, Freeports, Pittsburgh, Redstone, and Sewickley are recognized as principal commercial coals in western Pennsylvania. The economically useful coal beds are clustered within the Allegheny and Monongahela groups. The coals found in the Conemaugh Group, while numerous, tend to be thin and uneconomical. The concentration of the more economically valuable coal beds within the same stratigraphic intervals suggests that similar environmental conditions persisted during deposition of the Allegheny and Monongahela groups. Indeed, research has shown that these two groups of rocks were deposited during times when western Pennsylvania was wetter and more humid, whereas the Conemaugh Group was deposited during a protracted period of drier climate. Consequently, global climate played a critical role in the formation of western Pennsylvania's coal resources.

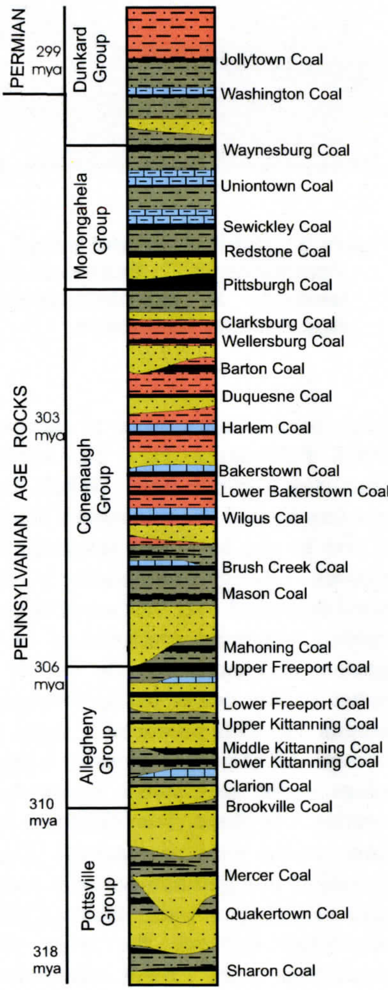

Figure 4. Stratigraphic column of noteworthy coal beds found in the strata of western Pennsylvania.

Coke and Other Uses of Coal

Most of the coal mined in Pennsylvania is used for electric power generation. The coal is burned to convert water to steam, and this steam turns turbines to produce electricity. Coal for that purpose is often called "steam coal" and can contain moderate levels of sulfur and ash. Other uses of Pennsylvania's coal are for residential and commercial heating, industrial applications, and coke making.

Coke, short for coal cake, is actually metamorphosed coal. To make coke, coal is baked in an oven, rather than burned. Its temperature is gradually increased to approximately 2000° Fahrenheit. As the coal is heated, volatile gases held within the coal macerals are altered and driven off. Many of these volatiles are contained within the liptinite macerals. Therefore, coals high in vitrinite are preferred for coking over those rich in liptinite or inertinite. Coal for coke-making is called "metallurgical coal," which has strict limits on the levels of sulfur and ash. The baking process removes several products from the coal including coal tar, ammonia, carbon monoxide, carbon dioxide, and hydrogen. After these chemical byproducts are baked away, what is left is coke, nearly 90% pure carbon.

Historically, most of the coal used in western Pennsylvania's coke production was from the Pittsburgh Coal, but the Upper Freeport and Kittanning Coals were used to a lesser degree. Coke production began in the 1800's in Fayette and Westmoreland counties where groups of individual brick ovens known as "beehive ovens" were built. At one time tens of thousands of beehive ovens produced the coke for Pittsburgh's steelmaking industry. Figure 5 is a simplified cross-section through a 19th Century beehive oven. Today coke is produced in rows of narrow parallel ovens known as coke batteries. In these batteries, coal is heated to the requisite temperature for the necessary time, then removed to a holding area where it is rapidly cooled by water, and then crushed and shipped for steelmaking and other foundry uses.

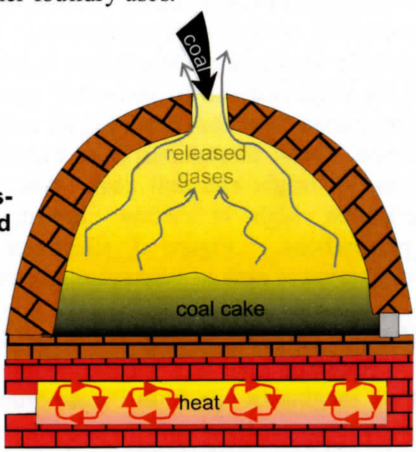

Figure 5. Generalized cross-section through an idealized beehive coke oven.

Coal+Heat (~2000° F) = H_2+CH_4 +CO+CO_2+Coal Tar+Ammonia+C(80-90%)