Depositional History of the Pennsylvanian Rocks in Illinois

At the close of the Mississippian Period, about 320 million years ago, the sea withdrew from the Midwest. During this earliest Pennsylvanian time, erosion removed hundreds of feet of the pre-Pennsylvanian strata, stripping them away and cutting into older rocks. Ancient river systems scoured deep channels into the bedrock surface. Later, but also during early Pennsylvanian time, the sea level began to rise, interrupting the erosion and leading to filling of the valleys in the erosion surface with fluvial, brackish, and marine sands and muds.

During most of Pennsylvanian time, the Illinois Basin gradually subsided, leading to the accumulation and preservation of about 3,000 feet of Pennsylvanian sediments in the basin. Depositional conditions in the Illinois Basin during the Pennsylvanian were similar to those during the preceding late Mississippian. A river system flowed southwestward across a swampy lowland, carrying mud and sand from the highlands located to the northeast. This river system formed thin but widespread deltas that coalesced into a vast coastal plain or lowland that prograded (built out) into the shallow sea that covered much of present-day Illinois (see paleogeographic map, to the right). Because the lowland stood only a few feet above sea level, slight changes in relative sea level caused great shifts in the position of the shoreline.

The locations of the delta systems and the shorelines of the resulting coastal plain shifted, partly because of worldwide sea level changes, but also because of variations in the amount of sediment provided by the river systems and local changes in basin subsidence rates. These frequent shifts in the coastline position caused the depositional conditions at any one locality in the basin to alternate frequently between marine and nonmarine, producing a variety of lithologies in the Pennsylvanian rocks (see lithology distribution chart, on page 2).

Paleogeography of the Illinois-Indiana region during Pennsylvanian time. The diagram shows a Pennsylvanian river delta and the position of the shoreline and the sea at an instant of time during the Pennsylvanian Period.
General distribution of the four principal lithologies in Pennsylvanian strata of Illinois.
Conditions at various places on the shallow sea floor favored the deposition of sand, mud, or lime mud. Sand was deposited near the mouths of distributary channels, where it was reworked by waves and spread out as thin sheets near the shore. Mud was deposited in quiet-water areas—in delta bays between distributaries, in lagoons behind barrier bars, and in deeper water beyond the nearshore zone of sand deposition. Limestone was formed from the accumulation of the limy parts of animals and marine plants that were laid down in areas where only minor amounts of sand and mud were being deposited. The areas of sand, mud, and limy mud deposition continually shifted as the position of the shoreline changed and as the delta distributaries extended seaward or shifted their positions laterally along the shore.

Nonmarine sand, mud, and lime mud were deposited on the coastal plain bordering the sea. The nonmarine sand was deposited in delta distributary channels, in river channels, and on the broad floodplains of the rivers. Some sand bodies 100 or more feet thick were deposited in channels that cut through the underlying rock units by rivers. Mud was deposited mainly on floodplains. Some mud and freshwater lime mud were deposited locally in freshwater lakes and swamps.

Because of plate tectonics, Illinois was located close to the equator at this time. Beneath the quiet water, in the extensive swamps that prevailed for long intervals on the emergent coastal lowland, peat was formed, by accumulation of plant material. Lush forest vegetation covered the region; it thrived in the warm, moist Pennsylvanian-age tropical climate. The origin of the underclays beneath the coal is not precisely known, but most evidence indicates that they were deposited in the swamps as slackwater mud before the accumulation of significant plant debris. The underclays represent the soils upon which the lush vegetation grew in the swamps. Underclay commonly contains plant roots and rootlets that appear to be in their original growth position. The vast swamps were the culmination of nonmarine deposition. Resubmergence of the borderlands by the sea commonly interrupted nonmarine deposition, and, when this happened, marine sediments were laid down over the past.

PENNYSYLVANIAN CYCLOTHEMS

The Pennsylvanian strata exhibit extraordinary variations in thickness and composition both laterally and vertically because of the extremely varied environmental conditions under which they formed. In many places, individual sedimentary units are only a few inches thick, and only a few units exceed 30 feet thick. Sandstones and shales commonly grade laterally into each other, and shales may interfinger with and grade laterally and vertically into limestones and coals. The underclays, coals, black shales, and some limestones, however, display remarkable lateral continuity for such thin units. Some coal seams have been laterally traced (correlated) in mines, outcrops, and subsurface drill records over areas comprising several states.

The rapid and frequent changes in depositional environments during Pennsylvanian time produced regular or cyclical successions of sandstone, shale, limestone, and coal in response to the shifting shoreline. Each succession of these lithologies, called a cyclothem, consists of a series of marine and nonmarine rock units that record a complete cycle of marine invasion and retreat. Geologists have determined, after extensive studies of the Pennsylvanian strata in the Midwest, that an “ideally” complete cyclothem consists of ten sedimentary units (see illustration on following page contrasting the model of an “ideal” cyclothem with a model showing the dynamic relationships between the various members of a typical cyclothem).

Approximately 50 cyclothems have been described in the Illinois Basin, but only a few contain all ten units at any given location. Generally, one or more of the expected units are missing because conditions of deposition were more varied than indicated by the “ideal” cyclothem. However, the order of units in each cyclothem is almost always the same: a typical cyclothem includes a basal sandstone overlain by an underclay, coal, gray shale, black sheety shale, marine limestone, and gray marine shale. In general, the sandstone-underclay-coal-gray shale portion (the lower units) of each cyclothem is nonmarine: it was deposited as part of the coastal lowlands from which the sea had withdrawn. However, some of the sandstones are entirely or partly marine. The units above the coal and gray shale are marine sediments deposited when the sea advanced over the coastal plain.
It is generally accepted that the Pennsylvanian coals originated by the accumulation of vegetable matter, normally in place, in extensive, fresh- to brackish-water swamps. They represent the last deposits of the nonmarine portion of a cyclothem. The swamps occupied vast areas of the coastal lowland, which bordered the shallow Pennsylvanian sea. A luxuriant growth of forest plants, many quite different from those of today, flourished in the warm, humid Pennsylvanian climate. The deciduous trees and flowering plants that are common today had not yet evolved. Instead, the jungle-like forests were dominated by giant ancestors of present-day club mosses, horsetails, ferns, conifers, and cycads. The undergrowth also was well developed, consisting of many ferns, fernlike plants, and small club mosses. Most of the plant fossils found in the coals and associated sedimentary rocks show no annual growth rings, pointing to the rapid growth rates and lack of seasonal climatic variations typical of tropical lowland areas. Many of the Pennsylvanian plants, such as the seed ferns, eventually became extinct.

Plant debris from the rapidly growing swamp forests—leaves, twigs, branches, and logs—accumulated as thick mats of peat on the floors of the swamps. Normally, vegetable matter rapidly decays by oxidation, forming water, nitrogen, and carbon dioxide. However, conditions within these ancient swamps, which were probably low in oxygen, prevented oxidation, and any decay of the peat deposits was due primarily to bacterial action.
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Generalized stratigraphic column of the Pennsylvanian in Illinois (1 inch = approximately 250 feet).
Periodic invasions of the Pennsylvanian sea across the coastal swamps killed the forests, and the coals were commonly buried by marine sediments. During and after the marine transgressions, the peat generally became saturated with sea water containing sulfates and other dissolved minerals. The marine sediments deposited on top of the drowned peat also were saturated with sea water, which further infiltrated the peat. As a result, wherever the peat was buried by marine sediments, the coal that eventually formed from it is high in sulfur. However, in a number of areas, nonmarine muds, silts, and sands from the river system on the coastal plain were deposited on the peat where flooding broke through natural levees or the river changed its course. Where these sediments (unit 6 of the cyclothem) directly overlie the coal and are more than 20 feet thick, we find that the coal is low in sulfur. Although the seas eventually covered the areas where these nonmarine, fluvial sediments overlay the peat, the peat was protected from most sulfur infiltration by these thick fluvial sediments.

As the basin continued to subside and more and more layers of sediment accumulated, the peat deposits were gradually transformed into coal by slow physical and chemical changes in which pressure (compaction by the enormous weight of overlying sedimentary layers), heat (also due to deep burial), and time were the most important factors. Water and volatile substances (nitrogen, hydrogen, and oxygen) were slowly driven off during the coal-forming (“coalification”) process, and the peat deposits were changed into coal.

Coals have been classified by ranks that are based on the degree of coalification. The commonly recognized coals, in order of increasing rank, are (1) brown coal or lignite, (2) subbituminous, (3) bituminous, and (4) anthracite. Each increase in rank is characterized by larger amounts of fixed carbon and smaller amounts of oxygen and other volatiles in the coal. The hardness of coal also increases with increasing rank. All Illinois coals are classified as bituminous.

Underclays occur beneath most of the coals in Illinois. Because underclays are generally unstratified (unlayered), are leached to a bleached appearance, and generally contain plant roots, many geologists consider that they represent the ancient soils on which the coal-forming plants grew.

The exact origin of the carbonaceous black shale that occurs above many coals is uncertain. Under current thinking, the black shale is interpreted to represent the deepest part of the marine transgression. Maximum transgression of the sea was coupled with upwelling of nutrient-rich ocean water near the edge of the continental shelf and the accumulation of mud and animal remains on an ocean floor that became depleted of oxygen by the decay of the organic matter. This led to the deposition of black organic mud over vast areas stretching from Texas to Illinois. Deposition occurred in quiet-water areas where very fine-grained, iron-rich mud and finely disseminated plant debris were washed in from the land. Most of the fossils found in the black shale represent planktonic (floating) and nektonic (swimming) forms—not benthonic (bottom-dwelling) forms. The depauperate (dwarf) fossil forms previously reported in black shale in some places were thought to have been forms that were stunted by toxic conditions in the sulfide-rich, oxygen-deficient water of the lagoons. However, recent study has shown that this “depauperate” fauna actually consists mostly of normal-size individuals of species that never grew any larger.

REFERENCES


**Illinois State Geological Survey, Coal Section**  
*Revised by Russell J. Jacobson, 2000*
Common Pennsylvanian plants: lycops, sphenophytes, and ferns

Lepidodendron aculeatum X0.8
Lepidophloios laricinus X0.63
Sigillaria mammilaria X0.5
Sigmania ficoidea X0.32
Lepidostrobus ovatifolius X0.8
Sphenophyllum cuneitifolium X0.4
Annularia stellata X0.63
Calamites suckowii X0.5
Pecopteris sp. X0.32
Pecopteris miltonii X2.0
Pecopteris heinitelloides X1.0
Common Pennsylvanian plants: seed ferns and cordaites

Alethopteris seril X0.63
Alethopteris ambuga X0.63
Neuropteris rarinervis X0.5
Maripterus nervosa X0.8
Neuropteris scheuchzeri X0.63
Sphenopteris rotundiloba X0.8
Trigonocarpus parkinsonii X1.25
Artisia transversa X0.63
Cordiarcron major X2.0
Cordaites principalis X0.63
BRACHIOPODS

Wellerella tetrahedra 1\(\frac{1}{2}\) x

Juresania nebrascensis 2\(\frac{1}{3}\) x

Derbya crossa 1x

Composita argentia 1x

Neospirifer camratus 1x

Ghonetes granulifer 1\(\frac{1}{2}\) x

Mesolobus mesolobus var. evamphygyus 2\(\frac{1}{2}\) x

Marginifera splendens 1x

Gurithyris planoconvesa 2x

Linapductus "cara" 1x