Correlation Chart of Pennsylvanian Rocks in Alabama, Tennessee, Kentucky, Virginia, West Virginia, Ohio, Maryland, and Pennsylvania Showing Approximate Position of Coal Beds, Coal Zones, and Key Stratigraphic Units

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By Leslie F. Ruppert,[1] Michael H. Trippi,[1] and Ernie R. Slucher[1]

Introduction

The Appalachian basin, one of the largest Pennsylvanian bituminous coal-producing regions in the world, currently contains nearly one-half of the top 15 coal-producing States in the United States (Energy Information Agency, 2006). Anthracite of Pennsylvanian age occurs in synclinal basins in eastern Pennsylvania, but production is minimal. A simplified correlation chart was compiled from published and unpublished sources as a means of visualizing currently accepted stratigraphic relations between the rock formations, coal beds, coal zones, and key stratigraphic units in Alabama, Tennessee, Kentucky, Virginia, West Virginia, Ohio, Maryland, and Pennsylvania. The thickness of each column is based on chronostratigraphic divisions (Lower, Middle, and Upper Pennsylvanian), not the thickness of strata. Researchers of Pennsylvanian strata in the Appalachian basin also use biostratigraphic markers and other relative and absolute geologic age associations between the rocks to better understand the spatial relations of the strata. Thus, the stratigraphic correlation data in this chart should be considered provisional and will be updated as coal-bearing rocks within the Appalachian coal regions continue to be evaluated.

Most geologic formations are identified and defined by the distinctive lithologic features they contain. However, formations of Pennsylvanian age in the Appalachian basin and the Pennsylvania Anthracite region have traditionally been described and named to reflect the presence or absence of economic coal beds and coarse-grained sandstone units, most of which have since been proven to be locally or regionally discontinuous (Ruppert and Rice, 2001). Many of the stratigraphic names and boundaries used for the coals and other geologic units in the Pennsylvanian rocks differ between States or regions (fig. 1). Because local and regional stratigraphic complexities occur within some States, a multiplicity of State-specific names is introduced that may be confusing to those conducting regional geologic assessments in the basin.

Nonetheless, many of these stratigraphic names and boundaries have some elements that allow for regional stratigraphic correlation. For instance, many coals in the northern Appalachian basin coal region are easier to trace over greater distances than coals in the central and southern Appalachian basin coal regions (fig. 2). The Upper Pennsylvanian Pittsburgh coal bed (fig. 1) of the northern Appalachian basin coal region, for example, occurs as a synchronogenic bed deposited on a laterally continuous surface of sediments (Cross, 1954; Tewalt and others, 2001). The base of the Pittsburgh coal bed is designated as the contact between the Conemaugh Group (Upper Pennsylvanian) and the overlying Monongahela Group in western Pennsylvania, western Maryland, Ohio, and West Virginia (fig. 1). Therefore, in areas where the Pittsburgh coal bed is present, there is little controversy over its position or the placement of the boundary between the Conemaugh and Monongahela Groups.

In other regions of the basin, group and formation boundaries are more difficult to identify over extensive areas. One example is the placement of the contact between the New River Formation and the overlying Kanawha Formation—a boundary that is not easily defined beyond the area where these units were first defined in West Virginia. At the type section of the Kanawha Formation, the base of the Lower Douglas coal zone (fig. 1) defines the contact between the Kanawha Formation and the underlying New River Formation (Rice and others, 1994b). However, subsequent mapping has demonstrated that the Lower Douglas coal zone is regionally discontinuous and in many parts of West Virginia is absent (Blake and others, 2002). Where absent, the Nuttall Sandstone Member of the underlying New River Formation sometimes occurs in the stratigraphic position of the Lower Douglas

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coal zone. Yet, even the Nuttall Sandstone Member has been found to be regionally discontinuous and of varying thickness throughout its extent, features that hinder its use as a regional stratigraphic marker bed in the Appalachian basin.

Because of the many names used to identify individual coal beds and coal zones in the historic Appalachian basin coal-mining districts, coal bed designations may differ even more than stratigraphic nomenclature. In eastern Kentucky, northwest of the Pine Mountain thrust fault on the Cumberland overthrust sheet, for example, coal beds or coal zones equivalent to the Lower Elkhorn coal zone (within the Pikeville Formation) are identified also as the Eagle coal zone, Pond Creek coal zone, and Blue Gem coal bed (fig. 1). Southeast of the Pine Mountain thrust fault, yet still in Kentucky, equivalent coals in this same interval are known as the Imboden and Rich Mountain. Moreover, this same interval of coal is identified as the Blue Gem coal in Tennessee, the Imboden coal bed or Campbell Creek or Pond Creek coal zones in Virginia, and the Eagle coal zone in West Virginia.

Geology of the Appalachian Basin and the Pennsylvania Anthracite Region

The proto-Appalachian basin first developed on Mesoproterozoic (1.1 billion years old) continental crust that extended along the thinned continental margin of Iapetus, the proto-Atlantic Ocean. During Mississippian time, the basin was located at about 20° S. latitude, but by Pennsylvanian time had migrated north and was mostly in the equatorial region (Cecil, 1990). Between 330 and 265 million years ago, the Appalachian Mountains were formed by the collision of the southern part of Laurentia (composed of the North American and Greenland continental plates) and Gondwana (composed of the African, South American, Indian, Antarctica, Australian, New Guinean, and New Zealand continental plates) (Hatcher and others, 1989). The collision caused downwarping, or subsidence, west of the mountains and formed an elongated foreland basin (Hatcher and others, 1989). The newly created accommodation space within the Appalachian basin was filled with a wedge of clastic sediments that generally thickened southeastward towards the pre-thrusting axis of the basin. The axial region has been broken by Appalachian thrust sheets so that now much of the younger part of the stratigraphic section has been uplifted and eroded away. However, the axial region is inferred to have been east of, and parallel to, the eastern edge of the present-day Pennsylvanian outcrop belt. The western edge of the basin is marked by the Cincinnati arch (fig. 3), which, in part, separates the Appalachian foreland basin from the Eastern Interior basin of the midcontinent. It is believed that some Pennsylvanian sediments may have been eroded from the newly formed Appalachian Mountains, transported across the Cincinnati arch, and deposited into the Eastern Interior basin (Siever and Potter, 1956; Rice and Schwietering, 1988). Presently, the eastern limit of Pennsylvanian rocks in the Appalachian basin is generally defined by the west- and northwest-facing northeast-trending Allegheny structural front (fig. 3), a feature that marks the boundary between the Appalachian Plateaus and the Valley and Ridge physiographic provinces.

The Black Warrior basin of Alabama is also a late Paleozoic foreland basin that extends westward into the subsurface of Mississippi (fig. 3). This basin formed in the structural recess between the Appalachian and Ouachita fold and thrust belts (Ryder, 1987; Pashin, 2004). The southeastern edge of the Black Warrior coal basin is strongly deformed into a series of synclinal basins that delineate the western edge of the Appalachian fold belt (Davis and Ehrlich, 1974; Thomas, 1988). Cretaceous and Tertiary coastal sediments of the Mississippi embayment and the Gulf Coastal Plain conceal most of the Pennsylvanian strata to the south and west (Thomas, 1988). Abundant Lower Pennsylvanian coal resources of the Black Warrior, Cahaba, Coosa, Sand Mountain, and Lookout Mountain fields have historically been included within the Appalachian basin coal resource base as part of the southern Appalachian basin coal region (fig. 2). That traditional treatment continues in this paper.

The oldest preserved Pennsylvanian rocks are found in three areas within the Appalachian basin. They are (1) the deepest part of the central Appalachian basin coal region in southeastern West Virginia and western Virginia, near Pocahontas, Va.; (2) the Eastern Middle, Western Middle, and Southern fields of the Pennsylvania Anthracite region in eastern Pennsylvania; and (3) the Black Warrior, Cahaba, and Coosa fields of Alabama (fig. 2). Near Pocahontas, Va., the maximum thickness of the Pocahontas Formation in this area exceeds 700 feet (ft) (Englund, 1979). A pre-Pennsylvanian unconformity exists in the Black Warrior coal basin. However, in this region, greater subsidence preserved Lower Pennsylvanian sediments that exceed 5,700 ft in maximum thickness (R.E. Carroll, Geological Survey of Alabama, written commun., 2006).

The youngest Pennsylvanian (and overlying Permian) strata are preserved in the northeast-trending Dunkard basin, which is found in the northern and central Appalachian basin coal regions (figs. 2 and 3). In general, Pennsylvanian-age rocks slowly rise in elevation away from this structural axis—in all directions—and crop out at the surface around the perimeter of the Appalachian basin (Ruppert and Rice, 2001, and references contained therein).

Sediments of Pennsylvanian age were deposited in many types of aqueous environments that range from piedmont and limnic settings to coastal settings containing deltaic channels, marshes, peat-forming swamps, lagoons, and shallow-marine embayments (Ferm and Horne, 1979; Donaldson and others, 1985; Englund and others, 1986; Slucher and Rice, 1994; Greb and others, 2004). During the Pennsylvanian, sediments derived from the newly formed Appalachian Mountains, and the Canadian craton to the north, prograded west, northwest, and south as fluvial channels and deltaic fans across a broad coastal plain. Periodically, especially during the Middle and early Late Pennsylvanian, shallow-marine incursions inundated the coastal environments. The occurrences of these marine incursions may have been partly controlled by the waxing and waning of continental-scale glaciation in the southern hemisphere (Ruppert and Rice, 2001, and references contained therein), repetitive processes that affected eustatic levels worldwide.

Coal Fields of the Appalachian Basin

The Appalachian basin has informally been subdivided into three coal regions—the northern, central, and southern Appalachian basin coal regions—on the basis of characteristics of the sediments and the coals that are found there (fig. 2). The three coal regions contain both formal and informal coal fields.

Two types of coal fields occur in the northern Appalachian basin coal region (fig. 2): bituminous-rank fields and anthracite-rank fields. Bituminous-rank fields include the Main Bituminous field, the North-Central field, the Broad Top field, the Upper Potomac field (which includes the Lower and Upper Youghiogheny basins and the Castleman and Georges Creek basins), and the Northern West Virginia coal field. The coal-bearing region in Ohio is not subdivided into named coal fields or regions (fig. 2). Anthracite fields include the Western Northern field, the Southern and Northern fields, and the Eastern Middle and Western Middle fields. These named anthracite coal fields occur only in the Valley and Ridge physiographic province but have historically been placed in the resource base of the northern Appalachian basin coal region.

The central Appalachian basin coal region coal fields include the Southern West Virginia coal field, the Southwest Virginia coal field, the Eastern Kentucky coal field, and the Northern Tennessee coal field (fig. 2). Coal rank is generally medium- and high-volatile bituminous throughout the central region except in the southeastern part of the Southern West Virginia coal field (fig. 2), where coal rank is low-volatile bituminous.

Coal fields of the southern Appalachian basin coal region include the Southern Tennessee coal field and the Black Warrior field of Alabama. Coal rank is medium- and high-volatile bituminous in both coal fields (fig. 2). Four small coal fields occur east of the Black Warrior field: the Sand Mountain, Lookout Mountain, Cahaba, and Coosa fields of Alabama.

Coal Production Within the Appalachian Basin

Pennsylvanian coal in the Appalachian basin has been mined nearly continuously since the 18th century and was a major factor in the economic development and industrial growth of the Eastern United States. Over 36.3 billion short tons (BST) of coal have been mined in the basin over the last 215 years (see Tewalt and Ruppert, this volume, chap. D.4). The northern Appalachian basin coal region (fig. 2) is the largest historic producer (19.6 BST), followed by the central Appalachian basin coal region (16.7 BST), and the southern Appalachian basin coal region (1.9 BST) (Tewalt and Ruppert, this volume, chap. D.4). Although the northern Appalachian basin coal region is the overall largest producer of coal within the basin, coal production in the central Appalachian basin coal region has outpaced that of the northern region over the last three decades because of the increased demand for low-sulfur coal. See Milici and Polyak (this volume, chap. D.3) for a more detailed discussion of coal production within the basin.

Pennsylvanian Strata Within the Appalachian Basin and the Pennsylvania Anthracite Fields

Placement of the boundaries between Upper, Middle, and Lower Pennsylvanian rocks in the Appalachian basin tends to differ between States of the region because of various historic lithostratigraphic and economic subdivisions used to define coal-bearing intervals. For example, the boundary between Middle and Upper Pennsylvanian rocks is traditionally placed at the top of the Upper Freeport coal bed of the Allegheny Formation (Bradley, 1956). This usage coincides with the long-standing placement of the contact between the Allegheny Formation and the overlying Conemaugh Group at the top of the Upper Freeport coal bed. In areas where the Upper Freeport coal bed is absent, the boundary between the Allegheny Formation and the Conemaugh Group is defined by a gradual change in the lithologic character of the rocks. Strata below the Upper Freeport coal bed consist, in general, of rocks that are mostly shades of gray and black in color, whereas rocks above the Upper Freeport coal bed commonly contain intervals of red and green mudstone, shale, and siltstone.

However, Phillips and Peppers (1984) discovered that the placement of this boundary was unsubstantiated by biostratigraphic criteria. They found that both the Upper Freeport and overlying Mahoning coal beds of the lower Conemaugh Group (see figure 1) are dominated by the presence of *Lycospora*, an important Early and Middle Pennsylvanian palynomorph. Furthermore, the Brush Creek coal bed, the next persistent coal bed above the Mahoning coal bed in the lower Conemaugh Group of Ohio, Pennsylvania, and Maryland, rarely contains this palynomorph (abundance <2 percent) (Phillips and Peppers, 1984). Hence, on the basis of their analysis, the traditional stratigraphically based placement of the Middle-Upper Pennsylvanian boundary at the top of the Upper Freeport coal bed is untenable. Rather, the lower part of the overlying Conemaugh Group is clearly Middle Pennsylvanian in age, and the boundary between Middle and Upper Pennsylvanian rocks occurs just above the Mahoning coal bed in the lower part of the Conemaugh Group (see Blake and others, 2002, and figure 1 of this report). In this report, we use the divisions of Blake and others (2002) for the Lower and Middle Pennsylvanian boundary.

The boundary between the top of Upper Pennsylvanian sediments and the base of the overlying Permian sediments has generally been placed in the lower part of the Dunkard Group, at the base of the Washington coal or, where it is absent, the stratigraphic position of the Washington coal. This has traditionally been supported by the occurrence of the fossil plant *Callipteris (Autunia) conferta*, a diagnostic Permian seed fern in the seat rock of this coal bed (see Berryhill, 1963; Ruppert and Rice, 2001, and references contained within). However, spores found in coal beds in this interval only support a Late, but not latest, Pennsylvanian age (Clendening, 1974, 1975). Blake and others (2002) concluded that earlier workers (Berryhill, 1963; Havlena, 1975) may have placed unwarranted emphasis on first occurrences of extrabasinal forms such as *Callipteris (Autunia) conferta* now known to have been contemporaneous with, and sporadically occupying specific paleoenvironments within, typical Dunkard lowland flora settings in the Appalachian basin region. The Pennsylvanian-Permian transition in the Appalachian basin was a period of tectonically induced climatic change produced by the newly formed Appalachian Mountains during the Alleghany orogeny; thus, occurrences of these highly climate sensitive extrabasinal plant fossils are suspect. It is believed further age refinement will be possible if specific types of marine fossils can be identified within Dunkard rocks. Yet, to date, the only known marine or marginal marine fossils found in Dunkard strata are those with only limited biostratigraphical usefulness (*Lingula*, for example); thus, the exact age of the Dunkard Group cannot be refined beyond a Pennsylvanian to Permian age assignment (Martin, 1998; B.M. Blake, Jr., West Virginia Geologic and Economic Survey, oral commun., 2005).

Lower Pennsylvanian Rocks

Lower Pennsylvanian strata extend, in general, across the Appalachian basin as northwestward prograding, time-transgressive sequences with a depositional strike parallel to the Appalachian Mountains. The pre-Pennsylvanian unconformity that developed on Mississippian rocks in most regions of the basin formed an irregular surface, particularly along the western basin margins where deeply incised valleys developed in Mississippian rocks and controlled sedimentation patterns well into Middle Pennsylvanian time (Slucher and Rice, 1994). Many of these valleys are filled with hundreds of feet of Pennsylvanian-age coarse-grained clastic sediments —for example, the Livingston Conglomerate Member of Kentucky and the "Sharon" Conglomerate of southern Ohio. The contact between these Pennsylvanian sediments and underlying Mississippian rocks is clearly erosional in most places in the basin.

The Pocahontas Formation consists mostly of coal-bearing sequences of carbonaceous shale and siltstone with minor sandstone and does not extend into the more distal parts of the basin beyond the Pocahontas area of Virginia (Englund, 1979). Northwest of Pocahontas, Va., Lower Pennsylvanian rocks in the central Appalachian basin coal region typically consist of thick sequences of conglomeratic quartzose sandstones that overlie units equivalent mostly to the upper part of the Pocahontas Formation (Greb and others, 2004). These younger strata reach a maximum thickness of more than 1,600 ft along the border between Virginia and Kentucky (Englund and others, 1979; Rice and others, 1979). Included in this interval of thick quartzose sandstones are the New River, Lee, and Norton Formations and the lower part of the Wise Formation in southwestern Virginia; the New River Formation and the lower part of the Kanawha Formation in West Virginia; the lower part of the Breathitt Group—Bottom Creek Formation, Sewanee Sandstone, Alvy Creek Formation, Bee Rock Sandstone, and Grundy Formation—in eastern and southeastern Kentucky; and the uppermost part of the Gizzard Group, Crab Orchard Mountains Group, and Crooked Fork Group, and the lowermost part of the Slatestone Formation in Tennessee (fig. 1). In Alabama, Lower Pennsylvanian strata are subdivided into the Lower and Upper Pottsville Formations (fig. 1). Lower Pennsylvanian strata of Alabama and Tennessee reach maximum thicknesses of 5,700 ft and 2,500 ft, respectively (Luther, 1959; Pashin and Raymond, 2005).

In the northern and westernmost areas of the bituminous coal fields of the northern Appalachian basin coal region (fig. 2), most Lower Pennsylvanian strata, particularly those parts equivalent to the Pocahontas Formation, appear to have never been deposited. Sediments of this age do exist, however, in parts of the Southern, Western Middle, and Eastern Middle fields in the Pennsylvania Anthracite region of eastern Pennsylvania, and in southeastern Ohio, West Virginia, Maryland, and the Broad Top field in Pennsylvania.

In the Pennsylvania Anthracite region, the Mississippian-Pennsylvanian boundary is gradational as mostly red, fine-grained clastics of the Upper Mississippian Mauch Chunk Formation intertongue with and grade upward into gray, conglomeratic, clastic sediments typical of the Pennsylvanian Pottsville Formation (Wood and others, 1986; Edmunds, 1996; Brezinski, 1999). Lower Pennsylvanian Pottsville strata in the northern Appalachian basin coal region reach a maximum thickness of about 1,500 ft in the Southern field of the Pennsylvania Anthracite region (Wood and others, 1986).

In Ohio, Pennsylvania, and Maryland, the separation between Lower and Middle Pennsylvanian rocks is problematic because of the time-transgressive nature of the Pennsylvanian sediments deposited on the eroded Mississippian surface. For instance, traditionally the "Sharon" coal of Ohio and Pennsylvania is considered the first coal above the Mississippian-Pennsylvanian boundary (fig. 1). In Ohio, the "Sharon" occurs in two widely separated areas: northeastern Ohio, in the vicinity of Sharon, Pa. (type section), and southern Ohio, near the city of Jackson (fig. 2). Although these deposits have long been assumed to be synchronous, palynological and lithostratigraphic data indicate otherwise (Bebel, 1982; Kosanke, 1984; C.F. Eble, Kentucky Geological Survey, written commun., 1999; Eble, 2002). These workers conclude that the "type" Sharon can best be correlated with lower Middle Pennsylvanian coal beds or coal zones (for example, the Pond Creek to Upper Elkhorn No. 3 interval in eastern Kentucky). Yet the "Sharon" at Jackson, Ohio, is more likely equivalent to a Lower Pennsylvanian coal, perhaps the Fire Creek or Beckley coal zones in the New River Formation of West Virginia. A similar diachronous relationship between the "type" Quakertown coal bed of northeastern Ohio and western Pennsylvania and the southern Ohio coal identified as "Quakertown" is suggested as well (Eble, 2002). Until definitive ages can be determined, ages of and correlations between coal beds in this part of the Pennsylvanian section are tentative (Slucher and Rice, 1994).

Middle Pennsylvanian Rocks

Middle Pennsylvanian strata are present in the northern, central, and southern Appalachian basin coal regions. As mentioned earlier, defining the exact base of the Middle Pennsylvanian in parts of Ohio, Pennsylvania, and West Virginia is problematic. Middle Pennsylvanian rocks are only partially preserved in the Black Warrior basin in Alabama and in the Wartburg basin in Tennessee (fig. 3). In southwestern Virginia, southeastern Kentucky, and northeastern Tennessee, southeast of the Pine Mountain thrust fault, post-Pennsylvanian erosion has removed all of the middle and upper Middle Pennsylvanian (Desmoinesian) rocks. Only lower Middle Pennsylvanian (Atokan) rocks remain (see figure 1).

Typically, Middle Pennsylvanian rocks consist mostly of coal-bearing sequences of carbonaceous shale, mudstone, and siltstone with minor sandstone (Arndt, 1979). The rocks were deposited in coastal and deltaic systems and, unlike Lower Pennsylvanian rocks, commonly contain intervals of marine carbonate or shale (see figure 1). These marine intervals, particularly those in the lower Middle Pennsylvanian of eastern and southeastern Kentucky, southwestern Virginia, and West Virginia, consist mainly of coarsening-upward shale sequences tens of feet thick (Rice and others, 1994b). Conversely, marine units in all but the lowest Pennsylvanian intervals in Kentucky, Ohio, Pennsylvania, and Maryland, are typically thin (about 3 ft thick) and in many areas are cherty (Slucher and Rice, 1994). Commonly, marine units of the upper Middle Pennsylvanian in the northern Appalachian basin coal region are mostly thin shale and limestone intervals (see figure 1). Freshwater limestone beds first occur in the interval just above the Lower Kittanning coal bed (fig. 1) and generally occur in the seat rock of coals or in paleosol intervals, particularly in the overlying Conemaugh, Monongahela, and Dunkard Groups. Cecil (1990) attributed the development of these deposits to continental-drift-induced climatic shifts.

Middle Pennsylvanian strata contain many valuable beds of coal, clay, and limestone. These rocks, which reach a maximum thickness of more than 2,000 ft in southwestern Virginia (Arndt, 1979; Englund and Thomas, 1991) include the Pottsville and Llewellyn Formations in east-central Pennsylvania, the upper part of the Pottsville Group, Allegheny Group or Formation (in West Virginia), and lowermost Conemaugh Group in western Pennsylvania, western Maryland, Ohio, and West Virginia; and the Wise and Harlan Formations in southwestern Virginia (fig. 1). Middle Pennsylvanian rocks in southeastern and eastern Kentucky and northeastern Tennessee include the middle and upper parts of the Breathitt Group (Pikeville, Hyden, Four Corners, and Princess Formations) and lowermost Conemaugh Formation. In east-central and southern Tennessee, Middle Pennsylvanian rocks include all but the lowest part of the Slatestone Formation, the Indian Bluff, Graves Gap, Redoak Mountain, Vowell Mountain, and Cross Mountain Formations (fig. 1).

Upper Pennsylvanian Rocks

Upper Pennsylvanian sediments include the Monongahela Group and all but the basal part of the Conemaugh Group in the northern Appalachian basin coal region, the upper part of the Llewellyn Group in the Pennsylvania Anthracite region, and the Conemaugh Formation in the central Appalachian basin coal region (fig. 1). Upper Pennsylvanian strata are absent in southwestern Virginia, southeastern Kentucky, all of Tennessee, and Alabama. The part of the Conemaugh Group included in the Upper Pennsylvanian is characterized by sequences of red and green mudstone, shale, siltstone and thin, non-economic coal beds. The lower part of the Upper Pennsylvanian, mainly the Ames Limestone and older (fig. 1), contains many thin marine limestone beds and shale intervals that are particularly widespread in western areas of the northern Appalachian basin coal region. The lack of economic coal and overall abundance of "nonproductive" intervals of rocks within the group earned it the formerly applied name "Lower Barren Measures" (Wanless, 1939).

In contrast, the overlying Monongahela Group consists mostly of sandstone, siltstone, shale, and mudstone with some limestone. The Monongahela Group, formerly known as the "Upper Productive Measures" (Wanless, 1939) contains several commercial coal beds, the most famous being the Pittsburgh coal bed (Tewalt and others, 2001). Upper Pennsylvanian strata within the Appalachian basin range in thickness from about 650 ft in Ohio (Collins, 1979) to as much as 1,300 ft in West Virginia (Arkle and others, 1979; Edmunds and others, 1979). Thicker strata, as much as 1,900 ft, are observed in the Southern anthracite field of Pennsylvania (Wood and others, 1969), which is located in the Valley and Ridge province.

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