2: Carboniferous of the Black Warrior Basin

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Geologic Setting

The Black Warrior Basin is a late Paleozoic foreland basin in Alabama and Mississippi that lies adjacent to the juncture of the Appalachian and Ouachita orogenic belts (Mellen, 1947; Thomas, 1973, 1977) (Fig. 2.1). The basin formed during the early stages of Pangaean supercontinent assembly, and the sedimentary fill reflects the tectonic evolution of the basin, as well as climatic changes related to drift through the southern tradewind belt into the equatorial zone (Thomas, 1988; Pashin, 1993, 1994a). The basin has a triangular plan and is bounded on the southwest by the Ouachita orogen, on the southeast by the Appalachian orogen, and on the north by the Nashville Dome. A southeast-plunging nose of the Nashville Dome separates the Black Warrior Basin from the Appalachian Basin (Thomas, 1988). Carboniferous strata are preserved throughout the Black Warrior Basin and in adjacent parts of the Appalachian thrust belt, and these regions originally constituted a single depositional basin that Thomas (1997) referred to as the greater Black Warrior Basin, which is the subject of this paper. Outcrops of these strata are accessible in the Appalachian thrust belt and the eastern part of the Black Warrior Basin, but the western two-thirds of the basin and adjacent parts of the Ouachita orogen are concealed below the Mesozoic-Cenozoic fill of the Gulf of Mexico Basin.

Intersection of the Appalachian and Ouachita orogens at nearly right angles had a strong effect on evolution of the Black Warrior Basin (Thomas, 1976, 1995) (Fig. 2.1). The basin is developed on the Alabama Promontory, a protuberance of the Laurentian continental margin that formed during Early Cambrian Iapetan rifting (Thomas, 1977, 1991). The southwest margin of the promontory remained passive until Late Mississippian time, when the Black Warrior foreland basin was initiated by obduction of a Ouachita accretionary prism (Thomas, 1976; Viele and Thomas, 1989). Convergence along the southeastern, or Appalachian, margin of the promontory began during the Ordovician Taconic Orogeny. Although rift-related basement faults were reactivated at various times during the Paleozoic (Thomas, 1968, 1986), it was not until the Early Pennsylvanian that an orogenic sediment source and subsidence center developed along the southeastern margin of the basin (Sestak, 1984; Pashin and others, 1991).

Lithostratigraphy

Mississippian System

The Devonian-Mississippian boundary is generally considered to be at the base of the Maury Shale (Fig. 2.2), which contains a late Kinderhookian–early Osagean conodont fauna and overlies the black, fissile Chattanooga Shale (Conant and Swanson, 1961; Drahovzal, 1967). The Maury is generally thinner than 1 m and is a gray shale containing glauconite and phosphate nodules. Conant and Swanson (1961) considered both contacts of the Maury to be disconformable. Above the Maury is the Fort Payne Chert, which is a fossilifer-

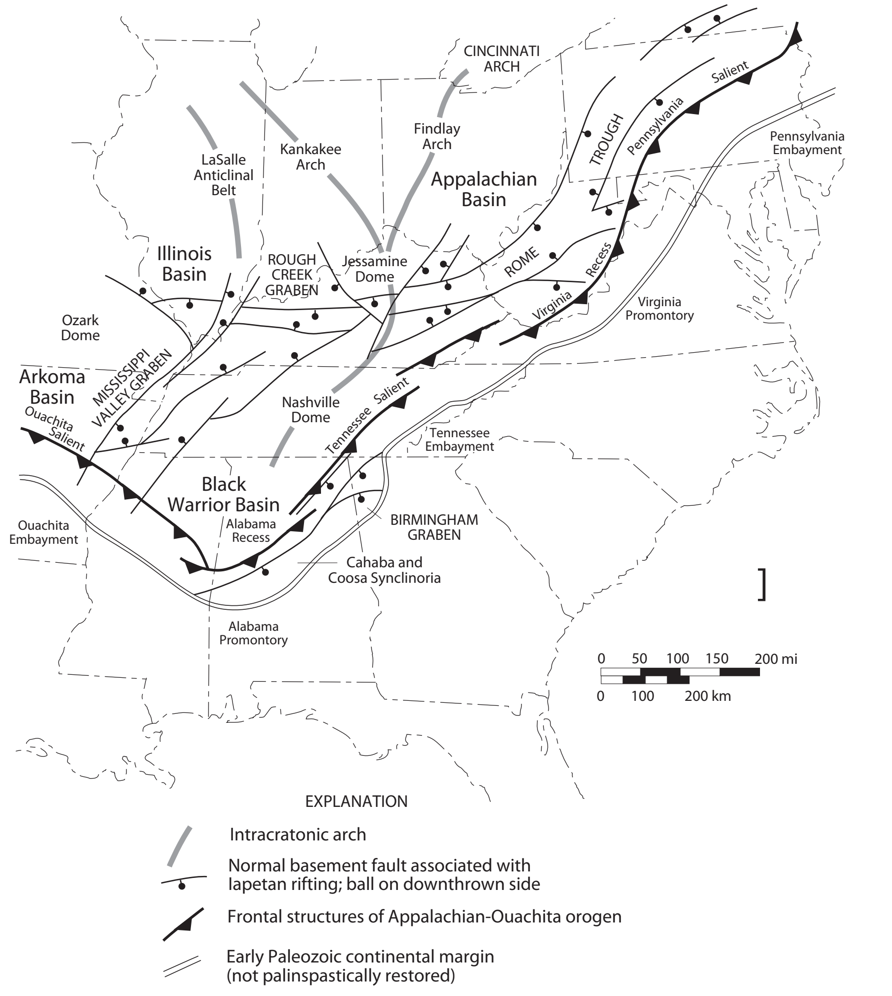

Figure 2.1. Tectonic setting of the Black Warrior foreland basin (after Thomas, 1988). Reprinted with permission of Geological Society of America.

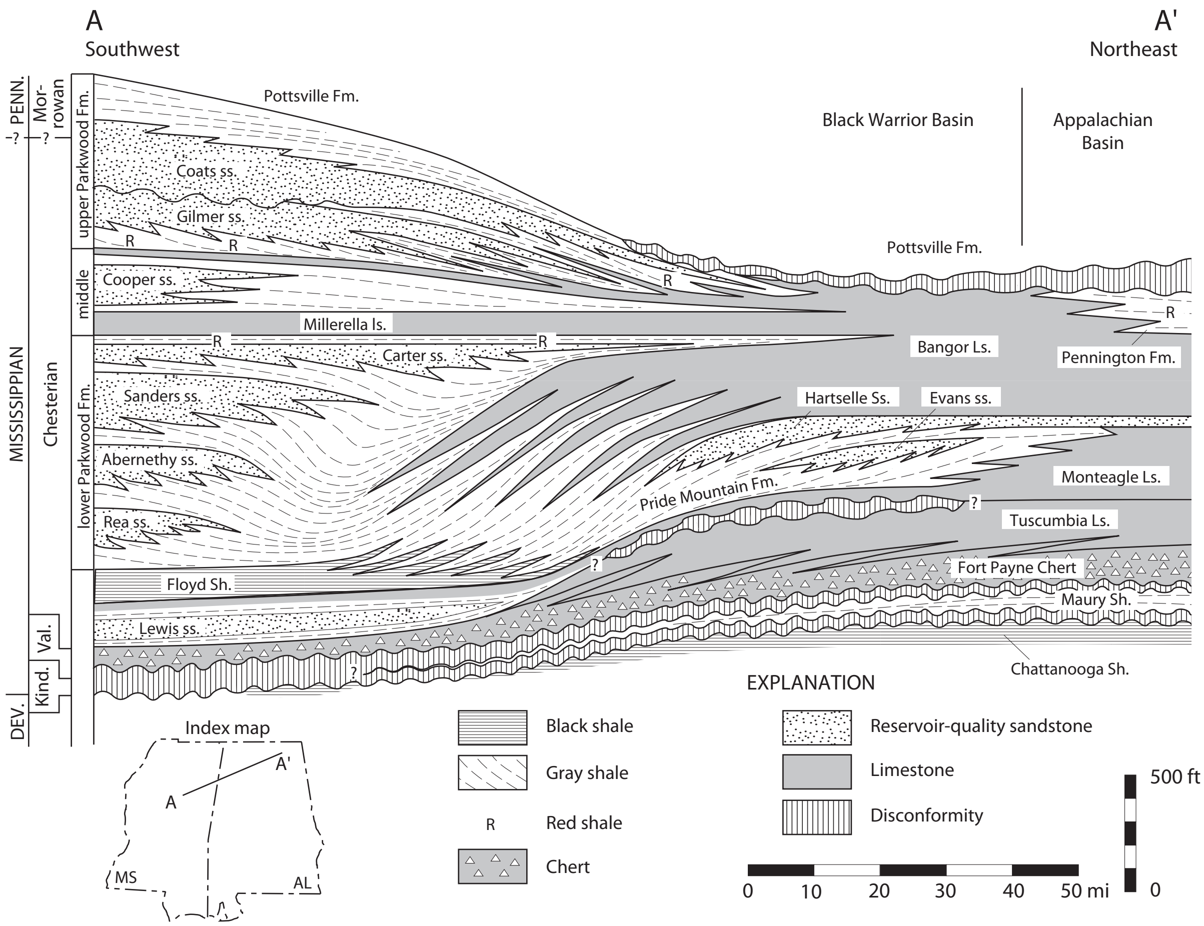

Figure 2.2. Generalized Mississippian stratigraphy of the Black Warrior Basin along a transect from northeastern Alabama to east-central Mississippi (after Pashin, 1994a). Reprinted with permission of Gulf Coast Association of Geological Societies.

ous unit dominated by dark micrite and nodular chert (Butts, 1926). The Fort Payne grades upward into the Tuscumbia Limestone, which is dominated by calcarenite (Thomas, 1972). The Fort Payne generally is considered to be of Osagean age, whereas the Tuscumbia bears Meramecian faunas (Ruppel, 1979). These two units thin southwestward from more than 125 m to less than 25 m, and as they thin, the Tuscumbia passes into a chert-rich facies that is indistinguishable from the Fort Payne (Thomas, 1972, 1988).

The Chesterian Series is cyclic and constitutes the bulk of the Mississippian System in the Black Warrior Basin, reaching a thickness exceeding 1,100 m adjacent to the Ouachita orogen in Mississippi. A subtle disconformity separates Meramecian and Chesterian strata along the northern margin of the basin (Pashin and Rindsberg, 1993) (Figs. 2.2–2.3). Carbonate rocks dominate the Chesterian Series in the northeastern part of the basin, whereas siliciclastic rocks are prevalent in the southwestern part. The Monteagle Limestone is the basal Chesterian unit in the northeastern part of the basin and is dominated by oolitic calcarenite (Handford, 1978). The Monteagle is generally thinner than 50 m and passes southwestward into cyclically interbedded shale, sandstone, and limestone of the Pride Mountain Formation (Welch, 1958, 1959). The Pride Mountain contains two quartzarenite units informally named the Lewis sandstone and the Evans sandstone, which are important hydrocarbon reservoirs in northeastern Mississippi and west-central Alabama (Cleaves, 1983). Above the Pride Mountain Formation is the quartzarenitic Hartselle Sandstone, which is locally thicker than 35 m and contains abundant asphaltic hydrocarbons (Thomas and Mack, 1982; Wilson, 1987). Together, the Pride Mountain Formation and Hartselle Sandstone reach a maximum thickness of 120 m.

The Hartselle Sandstone is overlain by the Bangor Limestone (Figs. 2.2–2.3), which extends to the top of the Chesterian Series in the northeastern part of the basin and is locally thicker than 135 m (Thomas, 1972; Thomas and others, 1979). The Bangor contains a spectrum of carbonate rock types; oolitic and skeletal calcarenite are the most characteristic lithologies. The upper part of the Bangor can be dolomitic and includes intervals of red and greenish-gray mudstone. Although a carbonate facies dominates the northeastern part of the greater Black Warrior Basin, siliciclastic facies of the Floyd Shale and Parkwood Formation dominate the southwestern part and locally are thicker than 950 m. Facies relationships between the carbonate and siliciclastic facies are com-

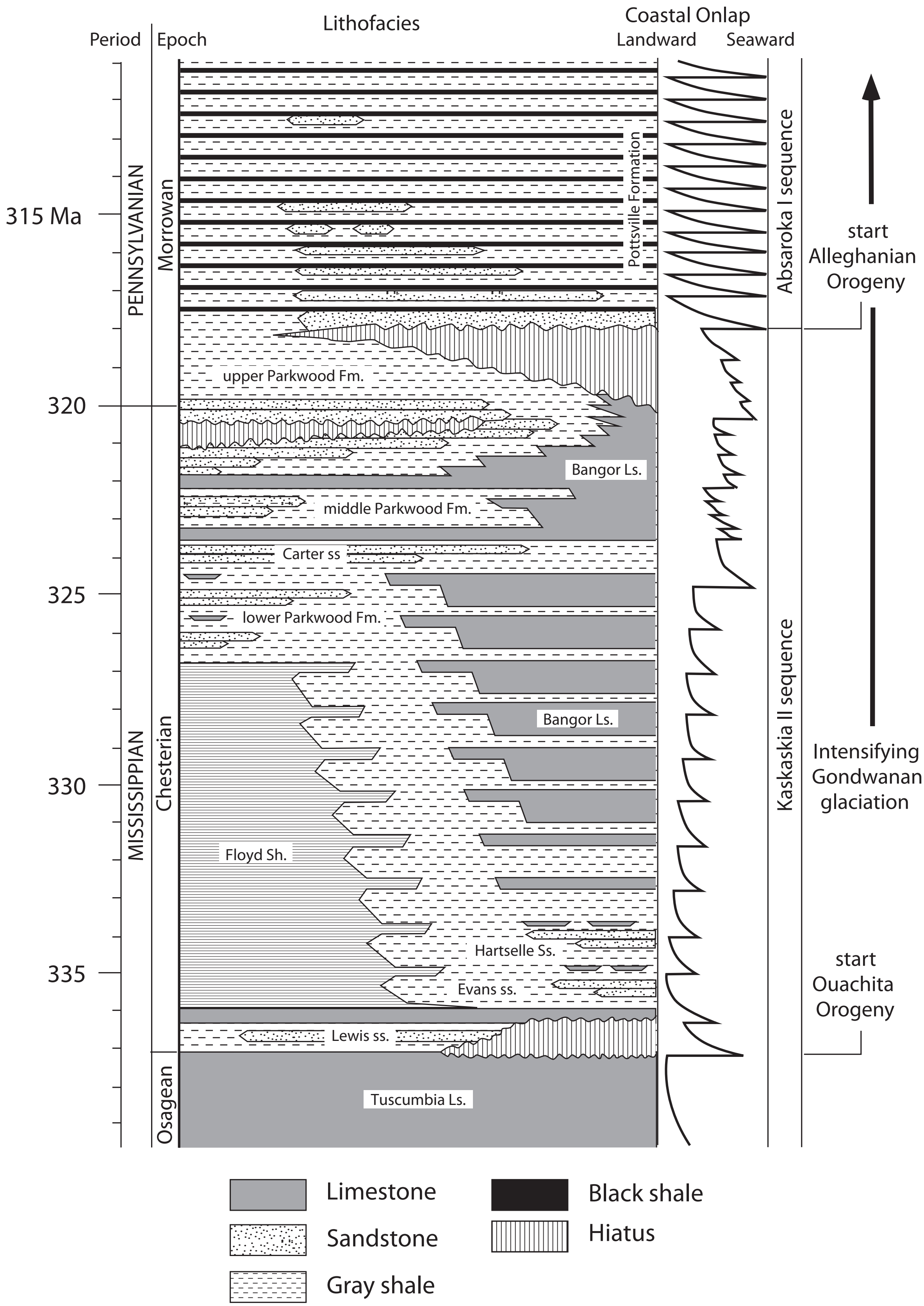

Figure 2.3. Wheeler diagram showing facies, cycles, and coastal onlap curve for Chesterian and Morrowan rocks of the Black Warrior Basin (after Pashin, 1994a). Reprinted with permission of Gulf Coast Association of Geological Societies.

plex. The lower part of the Bangor has clinoform geometry and passes southwestward into dark shale of the Floyd Shale (Pashin, 1993; Mars and Thomas, 1999). The Floyd Shale coarsens upward into the lower part of the Parkwood Formation, which is composed primarily of interbedded sandstone and shale, and contains the Carter sandstone, which is the most prolific conventional hydrocarbon reservoir in the basin. The middle part of the Parkwood is dominated by limestone and shale, and contains a major carbonate tongue that extends basinward above the lower Parkwood from the main body of the Bangor Limestone. Near the base of the Bangor tongue is the Millerella limestone, which contains oobiosparite with the distinctive endothyrid *Eostaffella (Millerella) chesterensis*. The upper Parkwood Formation is composed primarily of siliciclastic rocks and contains some thin, subeconomic coal beds. The upper Parkwood intertongues with the youngest Bangor strata in the northeastern part of the basin, and sandstone within the upper Parkwood ranges in composition from quartzarenite to litharenite (Mack and others, 1981).

Pennsylvanian System

The Mississippian-Pennsylvanian boundary is in the upper Parkwood Formation but has yet to be located precisely in the main part of the Black Warrior Basin. Foraminifera indicate that the upper part of the Bangor Limestone may cross the systemic boundary on the southeast-plunging nose of the Nashville Dome (Rich, 1980) (Figs. 2.2–2.3). In the Appalachian thrust belt, the systemic boundary may be in the upper part of the Parkwood Formation, where a macroflora of mixed affinity has been identified (Butts, 1926; Jennings and Thomas, 1987). The Pennsylvanian part of the Parkwood appears to comprise approximately 10 percent of the formation in the main part of the Black Warrior Basin, whereas approximately 50 percent of the formation is of Pennsylvanian age in parts of the Appalachian thrust belt. Here, the upper Parkwood is lithologically heterogeneous and contains gray shale, sandstone ranging in composition from quartzarenite to litharenite, underclay, and coal.

The Pottsville Formation contains the youngest strata preserved in the greater Black Warrior Basin and forms the majority of the foreland basin fill, with thickness locally exceeding 2,500 m (Fig. 2.4). The Pottsville sharply overlies the Parkwood Formation in the northeastern part of the basin, whereas farther southwest the contact is gradational (Thomas, 1974; Pashin, 1993). The Pottsville Formation is overlain with an angular unconformity by poorly consolidated Cretaceous deposits. The Pottsville is composed principally of shale and sandstone and contains numerous economic coal zones (e.g., Squire, 1890; McCalley, 1900; Rothrock, 1949; Culbertson, 1964) (Fig. 2.4). The coal is used extensively for electric power generation and metallurgy, and forms prolific coalbed methane reservoirs.

Pottsville strata are in three major coal fields (Fig. 2.4). The Warrior coal basin corresponds with the main part of the Black Warrior Basin, and the Cahaba and Coosa Coal Fields are in the Appalachian thrust belt. In the Warrior Coal Field, the Pottsville Formation contains numerous marine-nonmarine depositional cycles, or cyclothems (Fig. 2.5). Each cyclothem begins with a ravinement surface that is overlain by an interval thinner than 1 m containing condensed marine fossil assemblages (Liu and Gastaldo, 1992; Gastaldo and others, 1993; Pashin, 1998). Above this is a thick (10–100 m) gray mudstone unit that coarsens upward into sandstone and conglomerate ranging in composition from quartzarenite to litharenite. The sandstone, in turn, is overlain by a heterogeneous coal zone that forms the top of each cycle and consists of mudstone, sandstone, conglomerate, underclay, and coal.

Pashin and others (1995) subdivided the Pottsville Formation of the Cahaba Coal Field into three magnafacies called the Quartzarenite measures, the Mudstone measures, and the Conglomerate measures (Figs. 2.4, 2.6). The Quartzarenite measures are approximately 300 m thick and contain two regionally extensive sandstone units called the Shades and Pine Members. The Mudstone measures are in places thicker than 1,400 m and contain gray mudstone, sandstone, underclay, and coal. These strata resemble the cyclic, economic coal-bearing strata of the Warrior Coal Field. The frequency of marine deposits decreases markedly upsection, however. The Conglomerate measures form the upper 750 m of the Pottsville, and conglomerate containing extraformational lithoclasts is the signature lithology of the magnafacies. Conglomerate units are commonly thicker than 60 m and are separated by coal zones. Only one marine interval has been identified in the conglomerate measures.

The Pottsville section in the Coosa Coal Field also has been divided into three magnafacies named the Quartzarenite measures, the Redbed measures, and the Mudstone measures (Pashin, 1997) (Fig. 2.4). The Quartzarenite measures are approximately 500 m thick and contain abundant quartz pebbles compared to the Cahaba Coal Field. The Redbed measures, which are approximately 1,200 m thick, are characterized by intervals of brownish-gray (red) mudstone that are up to 15 m thick (Butts, 1927). Between the red intervals, the Redbed measures resemble the Cahaba Mudstone measures. The Mudstone measures form the upper 1,000 m of the Coosa section and resemble the lower part of this magnafacies in the Cahaba Coal Field.

The Pottsville Formation of Alabama has long been thought to be of Early Pennsylvanian age (Butts, 1926), but biostratigraphic subdivision has been elusive (Cropp, 1960; Upshaw, 1967; Eble and Gillespie, 1989) (Figs. 2.2, 2.4). The base of the Pottsville is not dated, but palynomorphs from near the top of the Parkwood Formation indicate a Namurian C or younger age (Eble

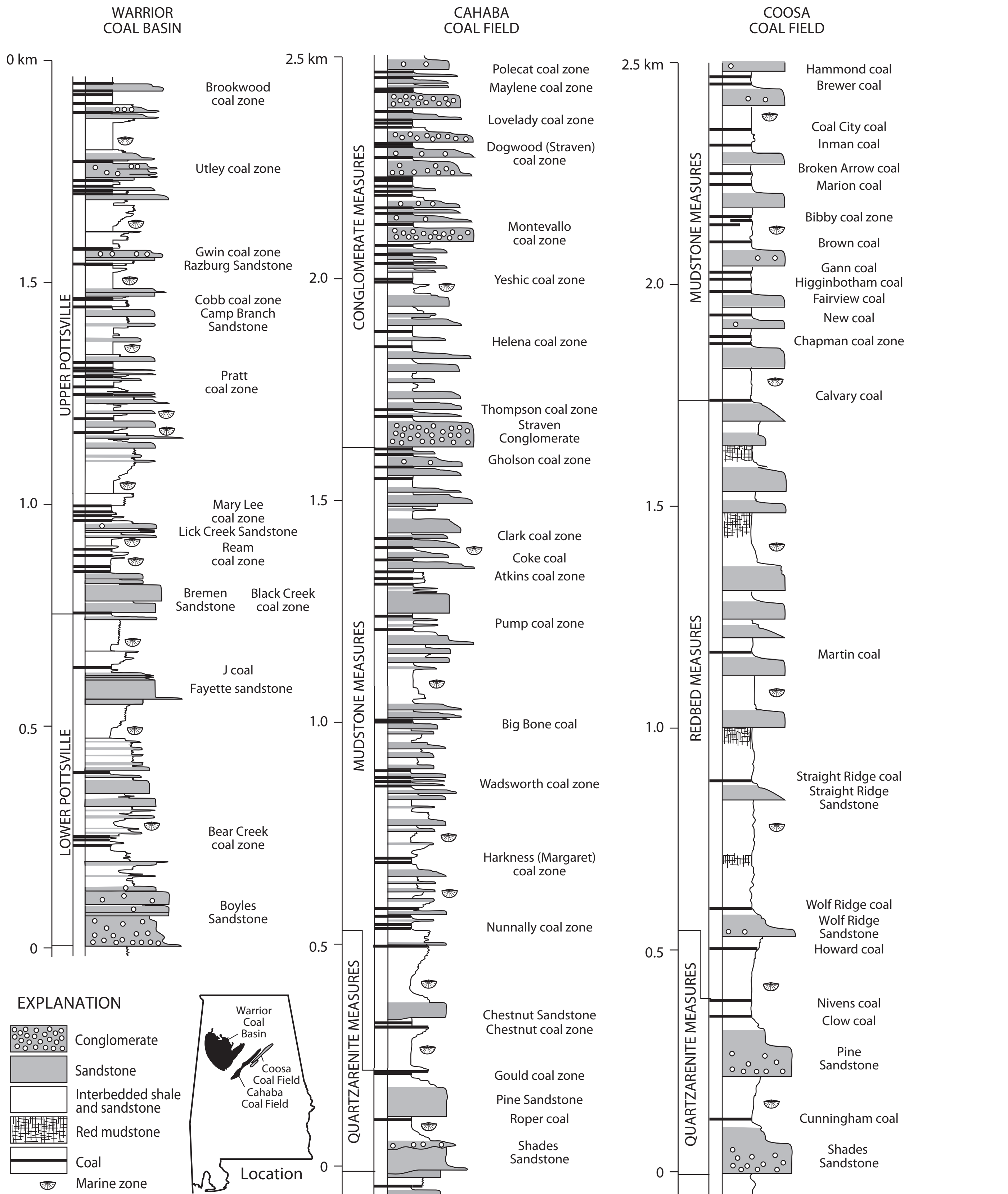

Figure 2.4. Generalized stratigraphic sections of the Pottsville Formation in the three major coal fields of the greater Black Warrior Basin in Alabama.

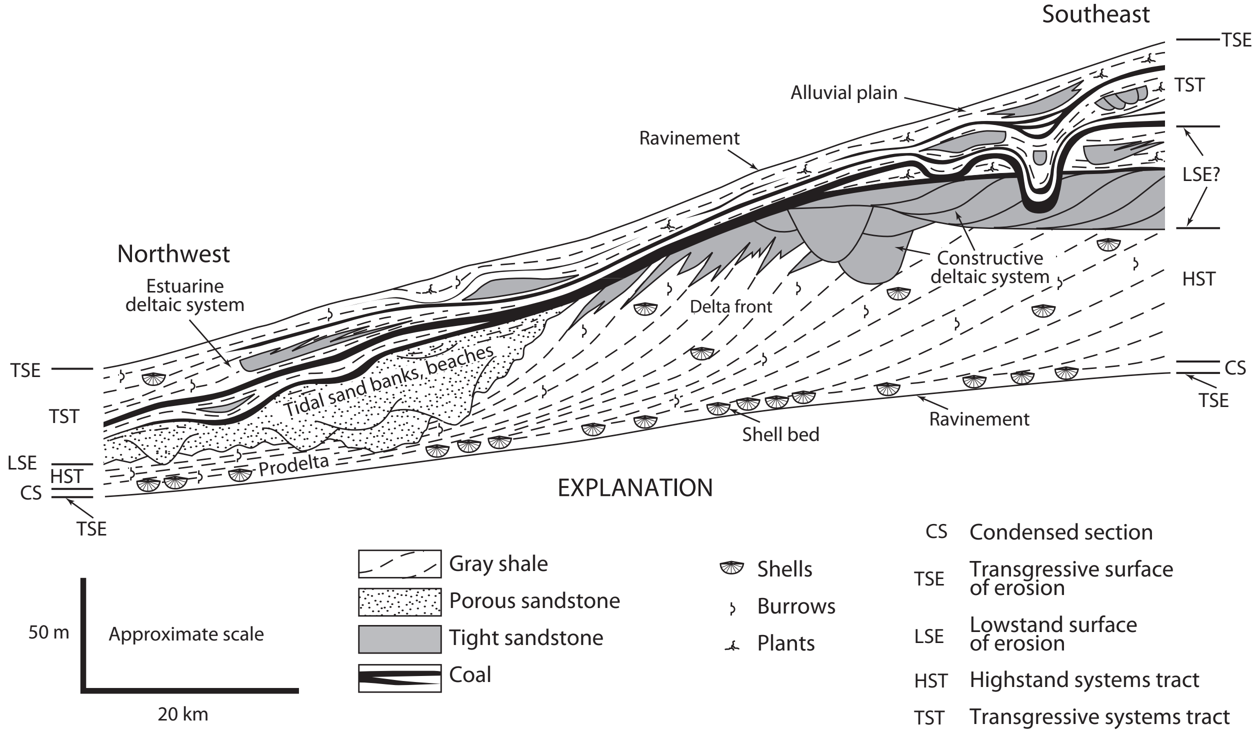

Figure 2.5. Idealized cyclothem in the Pottsville Formation of the Warrior coal basin (after Pashin, 1998). Reprinted from *International Journal of Coal Geology*, v. 35, with permission of Elsevier.

and others, 1991). Palynomorph and marine invertebrates suggest that strata from the Black Creek through Brookwood coal zones are of Langsettian age (Eble and Gillespie, 1989), although macroflora may suggest that some strata are of Duckmantian age (Lyons and others, 1985). Several depositional cycles younger than the Brookwood coal zone are preserved in the structurally deepest parts of the Warrior Coal Field (Henderson and Gazzier, 1989), but the age of these strata is unknown. Eble and others (1991) suggested on the basis of palynomorphs that the youngest strata in the Cahaba Coal Field are approximately equivalent to the Brookwood coal zone in the Warrior field. Presence of marine strata throughout the Mudstone measures of the Coosa field led Pashin (1997) to suggest that these strata are no younger than the Mudstone measures in the Cahaba field.

Depositional History

Mississippian System

The Devonian-Mississippian transition was marked by cessation of Chattanooga black-shale deposition and accumulation of the thin, phosphatic, and glauconitic Maury Shale (Fig. 2.2), thus signaling regional oxygenation, extreme condensation, and perhaps upwelling during Kinderhookian time (Pashin, 1993). Carbonate ramp deposition dominated Osagean and Meramecian time, as exemplified by the Fort Payne Chert and Tuscumbia Limestone. The Fort Payne is considered a lower ramp deposit. Abundant chert, sponge spicules, and a crinoid-bryozoan fauna indicate cool water, and upwelling along the Ouachita margin is thought to have been a source of silica and nutrients (Gutschick and Sandberg, 1983). The Tuscumbia Limestone contains mid- and upper-ramp deposits and includes a skeletal-shoaled bank rim (Fisher, 1987).

The mixed carbonate-siliciclastic deposits of the Chesterian Series reflect major changes of the tectonic and paleoceanographic setting of the Black Warrior Basin (Figs. 2.2–2.3). The disconformity at the base of the Pride Mountain Formation marks inception of major Ouachita orogenesis on the Alabama Promontory (Pashin and Rindsberg, 1993), and part of the Pride Mountain Formation, which includes the Lewis sandstone, was deposited as part of a lowstand wedge (Stapor and Cleaves, 1992). At this time, carbonate ramp deposits, as embodied by the oolitic Monteagle Limestone, retreated to the extreme northeastern part of the basin. The Pride Mountain Formation and Hartselle Sandstone contain mainly beach and tidal facies. The source of the siliciclastics is controversial; some workers favor cratonic sources (e.g., Cleaves and Broussard, 1980; Driese and others, 1994) and others favor sources in the Ouachita orogen (e.g., Thomas, 1974; Thomas and Mack, 1982).

The Bangor Limestone indicates renewed progradation of a shoal-rimmed carbonate ramp into the basin (Thomas and others, 1979), although the dark, organic-rich Floyd Shale suggests that circulation in lower ramp environments became restricted by tectonic closure (Pashin, 1993) (Figs. 2.2–2.3). The lower Parkwood Formation is of deltaic origin and includes delta-de-

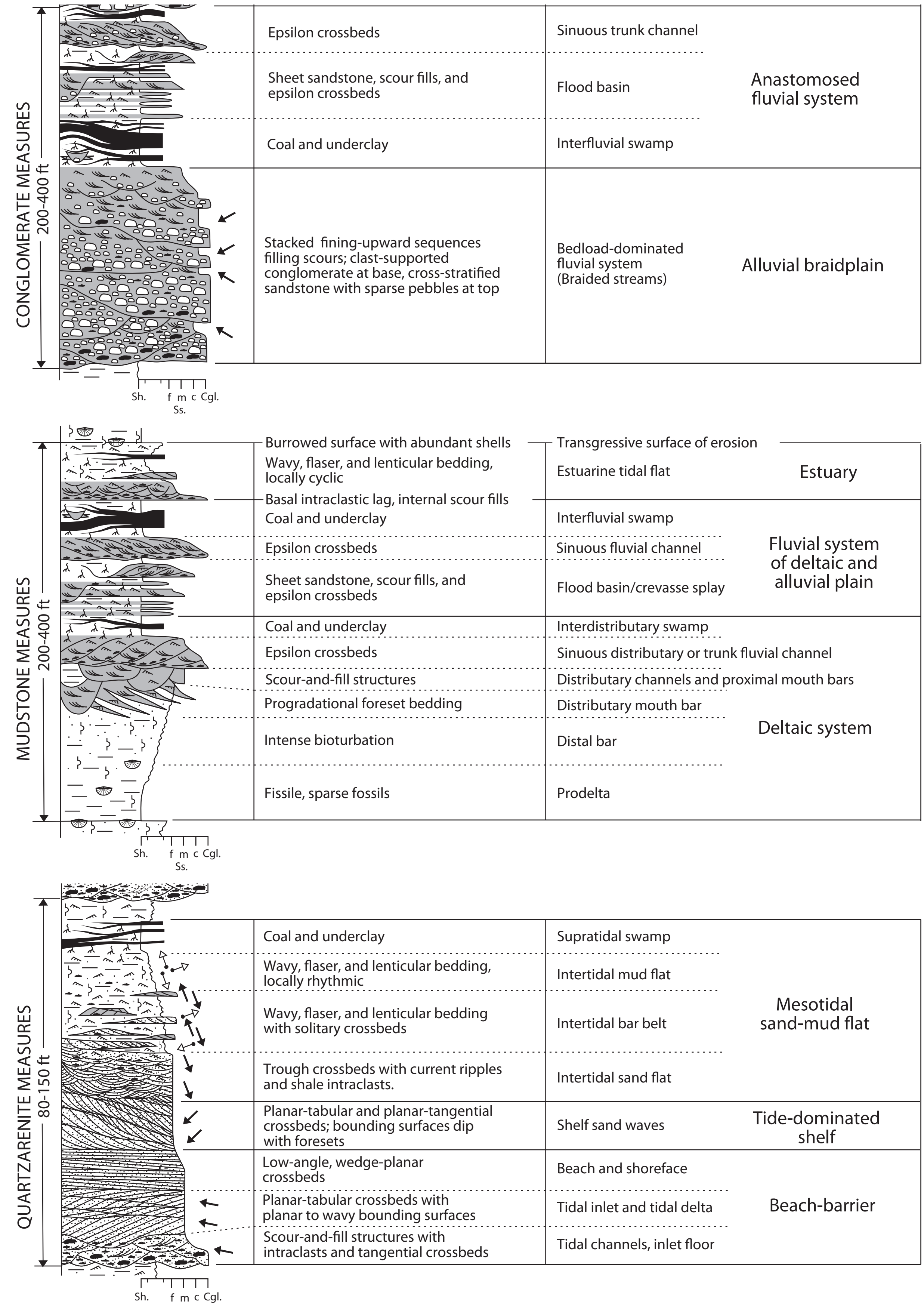

Figure 2.6. Paleonvironmental interpretation of Pottsville magnafacies in the Cahaba Coal Field (after Pashin and others, 1995). See explanation on next page. Reprinted with permission of the Geological Survey of Alabama.

structive beach facies (Pashin and Kugler, 1992). Again, some workers postulate cratonic sediment sources (e.g., Welch, 1978; Cleaves, 1983), and others postulate orogenic sources (e.g., Thomas, 1988; Mars and Thomas, 1999). The middle Parkwood heralds marine transgression and a brief return to regionally extensive carbonate sedimentation. The upper Parkwood represents a renewed progradation of deltaic sediment that spans the Mississippian-Pennsylvanian boundary (Thomas, 1972; Thomas and others, 1991).

Pennsylvanian System

Paleogeographic reconstructions indicate that the Black Warrior Basin migrated through the southern tradewind belt into the equatorial rainy belt during the Carboniferous (Scotese and Golonka, 1992). This migration is reflected in the transition from a thick carbonate succession containing red, vertic paleosols to a siliciclastic-dominated succession containing coal and underclay (Pashin, 1994a). This transition indicates a change from a semi-humid or semi-arid climate to the everwet equatorial climate that prevailed in eastern North America during the Early Pennsylvanian (Cecil, 1990). In concert with this climatic change was development of the sub-Absaroka cratonic sequence boundary, which corresponds with the base of the Pottsville Formation in the greater Black Warrior Basin (Thomas, 1988). Pottsville strata are locally in contact with Mississippian strata (Henry and others, 1985), but the sub-Absaroka boundary is developed within the Pennsylvanian System across most of the greater basin, having minimal time value and minimal paleotopographic relief (Thomas, 1988). The sub-Absaroka sequence boundary marks a significant tectonic reorganization of the main Black Warrior Basin in which an Appalachian subsidence center was superimposed on the older Ouachita foreland basin. It was not until deposition of the Mary Lee coal zone (Fig. 2.4) that the Appalachian orogen began supplying a significant quantity of coarse-grained sediment to the main part of the Black Warrior Basin (Pashin, 1999).

McCalley (1900) recognized the clustering of coal beds into discrete zones, and Butts (1926) recognized evidence for repeated marine transgressions and regressions during Pottsville deposition. The Warrior coal basin played a central role in the development of fluvial-deltaic and barrier-shoreline facies models for Pennsylvanian coal-bearing strata (e.g., Ferm and others, 1967; Hobday, 1974; Ferm and Weisenfluh, 1989). It was not until recently, however, that investigators acknowledged the importance of allogenic depositional cyclicity in these strata (e.g., Gastaldo and others, 1993; Pashin, 1994a; Demko and Gastaldo, 1996). Following the lead of Liu and Gastaldo (1992), Pashin (1994a, b, 1998) defined 13 regionally extensive, flooding-surface-bounded depositional cycles between the base of the Pottsville and the top of the Brookwood coal zone (Figs. 2.4–2.5). Although there is considerable geochronologic uncertainty, these cycles appear to be the products of glacial-eustatic forcing associated with Milankovitch orbital eccentricity (Fig. 2.2).

Similar forcing mechanisms were probably active in the Quartzarenite and Mudstone measures of the Cahaba Coal Field (Fig. 2.6), but evidence for progressive terrestrialization stands in stark contrast to the persistent cyclicity in the Warrior coal basin. Indeed, extraformational conglomerate in the Conglomerate measures has been interpreted as bedload-dominated fluvial deposits (Osborne, 1991), and the intervening coal zones are thought to contain anastomosed fluvial deposits (Pashin and others, 1995). There is evidence for limited tectonic translation of the Cahaba thrust sheet and direct evidence for growth strata in the Sequatchie Anticline of the Warrior coal field (Pashin, 1994c, 1998). Consequently, Pashin and others (1995) suggested that accumulation of sediment behind an uplifting blind thrust ridge facilitated terrestrialization of the Cahaba field while permitting free oscillation of the shoreline in the Warrior field.

The Cahaba and Coosa Coal Fields contain the thickest successions of Lower Pennsylvanian strata in the United States. Considering that the youngest strata in the Coosa field may be no younger than the Mudstone measures in the Warrior field (Fig. 2.4), the tectonic subsidence rate must have been remarkable in

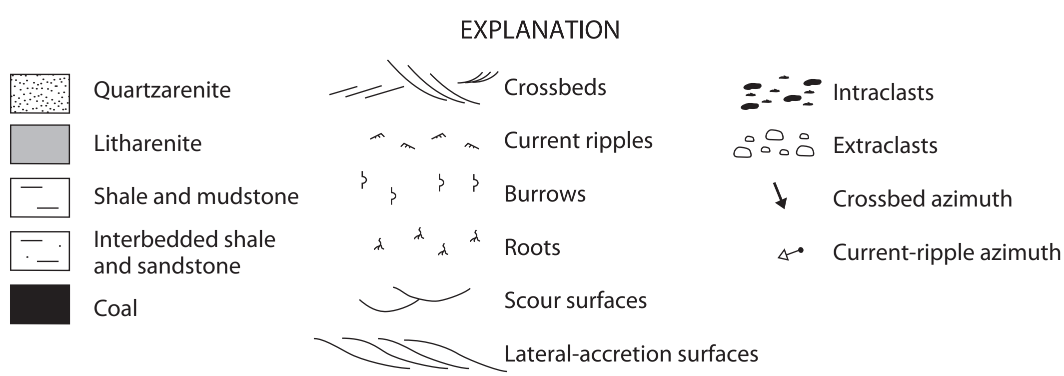

Figure 2.6. Paleonvironmental interpretation of Pottsville magnafacies in the Cahaba Coal Field (after Pashin and others, 1995). Explanation—Continued from previous page. Reprinted with permission of the Geological Survey of Alabama.

the Coosa Synclinorium, perhaps exceeding 400 m/my. Depositional history in the Coosa Coal Field roughly paralleled that in the quartzarenite measures and mudstone measures of the Cahaba Coal Field, but the Coosa redbeds represent a unique facies in the Pennsylvanian strata of North America. On the basis of extreme oxidation and possible occurrences of plinthite, Pashin (1997) and Bearce and Kassaw (1999) interpreted the redbeds as lateritic paleosols that formed upland of the major peat swamps that flourished in the Warrior and Cahaba Coal Fields.

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