3.1. New Albany and Ohio Shales: An Introduction

by
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The Middle to Upper Devonian black shales of the eastern U.S. are part of an epicontinental succession that was deposited over vast areas of the North American craton (de Witt et al., 1993) during a time characterized by a general rise in sea level (Johnson et al., 1985), atmospheric decline in pCO_2 (Berner, 1990), and major diversity change and extinction in biota. In particular, the Frasnian-Famennian mass extinction event is considered one of the five greatest biotic crises of the Phanerozoic (Sepkoski, 1986; Scotese and McKerrow, 1990; Jablonski, 1991; McGhee, 1996; Hallam and Wignall, 1999; House, 2002). During this time, eastern portions of North America were located approximately between 15^0 and 30^0 south latitude (Scotese and McKerrow, 1990; Ettensohn, 1992a; Day et al., 1996). As relative sea level rose, flooded continental areas of the eastern U.S. became parts of shallow seas where muds accumulated and became shales such as the New Albany Shale of the Illinois Basin and the Ohio Shale of the Appalachian Basin.

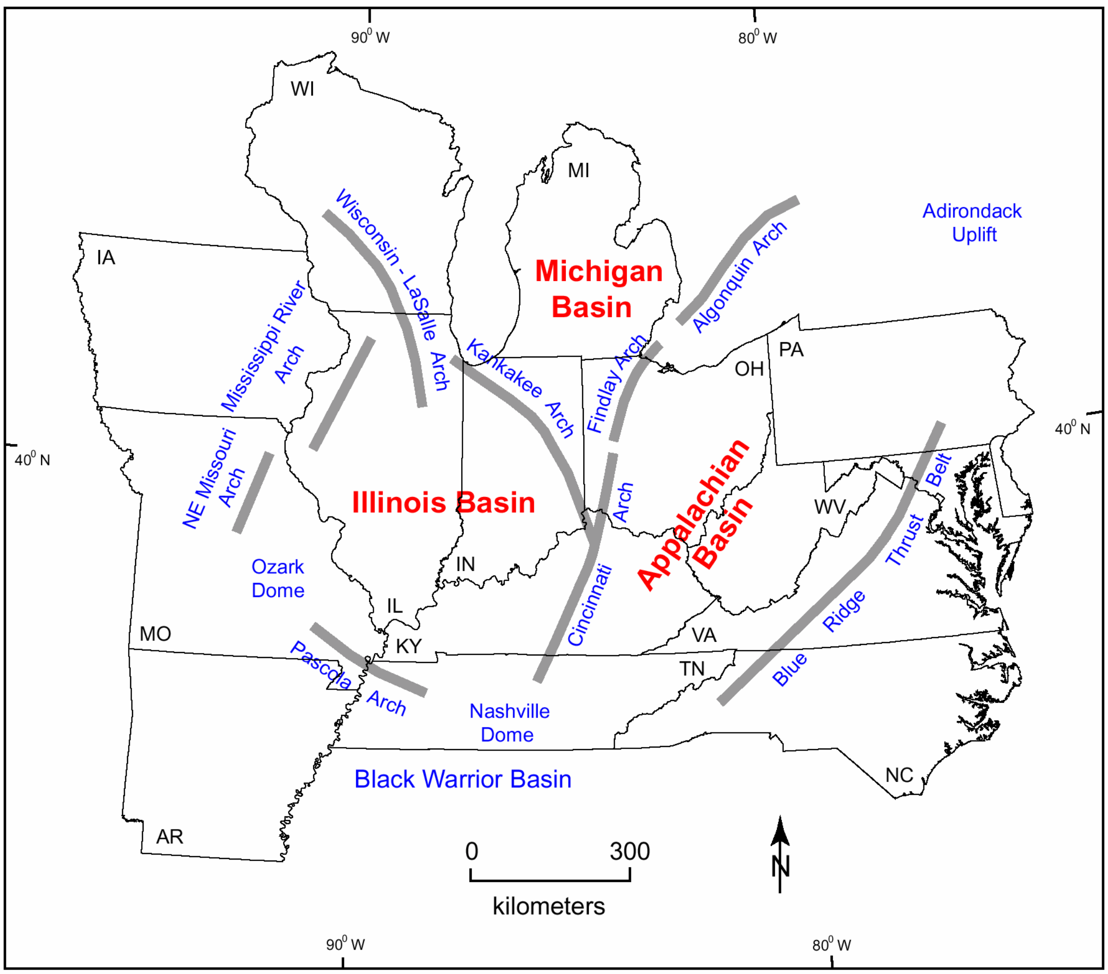

Figure 3.1.1: Major structural features outlining the Illinois and Appalachian Basins (modified after Kepferle and Roen, 1981; Buschbach and Kolata, 1991; Ettensohn, 1992a; de Witt et al., 1993; Mathews, 1993; Lumm et al., 2000).

The New Albany Shale

The Middle to Upper Devonian New Albany Shale occurs in outcrops and in the subsurface throughout much of the Illinois Basin (Lineback, 1968, 1970; Hasenmueller and Comer, 2000). The Illinois Basin formed primarily during the Paleozoic Era (Buschbach and Kolata, 1991; Kolata and Nelson, 1991) and began as a rift complex that gradually evolved into a cratonic embayment (Buschbach and Kolata, 1991). Subsequent modification by major tectonic events led to structural closure and to the present geometry of the basin (Buschbach and Kolata, 1991). Today, the Illinois Basin covers approximately 60,000 mi^2, mostly in parts of Illinois, Indiana, and Kentucky (Fig. 3.1.1) (Barrows and Cluff, 1984; Lumm et al., 2000). It is bounded by the Cincinnati Arch in the east, the Kankakee Arch in the northeast, the Wisconsin-LaSalle Arch in the north, the Mississippi River Arch in the northwest, the NE Missouri Arch and the Ozark Dome in the west, and the Pascola Arch in the south (Fig. 3.1.1). The southern part of the Illinois Basin covers the northeastern tip of the New Madrid Rift Complex (Lumm et al., 2000).

The name New Albany was proposed by Borden (1874) for the shale exposures along the Ohio River at New Albany, Floyd County, Indiana (cf. Lineback, 1968). Huddle (1933, 1934) and Cross and Hoskins (1951) were among the earliest authors to describe the fauna and flora present in the New Albany Shale. Based on a combination of fossil content, lithology, and joint patterns, Campbell (1946) proposed the first detailed stratigraphic subdivisions of the New Albany Shale. Campbell's stratigraphy was significantly revised by Lineback (1964, 1968, and 1970). The New Albany Shale has received increasing attention after 1970 with studies addressing questions regarding shale stratigraphy (e.g., Ettenson 1992a; Roen, 1993; Sandberg et al., 1994; Over, 2002), geochemistry (e.g., Beier and Hayes, 1989; Hatch et al., 1991; Ingall et al., 1993; Calvert et al., 1996; Frost and Shaffer, 2000), environment of deposition (e.g., Cluff, 1980; Ettensohn and Barron, 1981; Schieber and Riciputi, 2004), and hydrocarbon potential (e.g., Cluff and Byrnes, 1991; Seyler and Cluff, 1991; Hamilton-Smith et al., 2000).

Considerable stratigraphic variability characterizes the New Albany Shale throughout the Illinois Basin. In southeastern Indiana, for example, the New Albany Shale unconformably overlies the Middle Devonian North Vernon Limestone (Fig. 3.1.2) and is subdivided into five members (Blocher, Selmier, Morgan Trail, Camp Run, and Clegg Creek in ascending order). A phosphatic lag, usually less than 10 cm thick (the Falling Run Bed; Campbell, 1946), occurs at the top of the Clegg Creek Member. Early Mississippian, fossiliferous, gray, and brownish-black shales (the Underwood, Henryville, and Jacobs Chapel Beds; Campbell, 1946), less than 1 m thick, overly the Falling Run Bed (Fig. 3.1.2). Locally, these beds are absent and the Clegg Creek Member is directly overlain by the Mississippian Rockford Limestone. Where the Rockford Limestone is absent, the Clegg Creek Member is overlain unconformably by the Mississippian New Providence Shale (Fig. 3.1.2) (Lineback, 1970). The lag deposit at the top of the Clegg Creek Member (Falling Run Bed), followed by Mississippian strata, marks a regional truncation surface that is recognized in Indiana, Kentucky, and Tennessee and separates Upper Devonian from Early Mississippian strata. Although the Early Mississippian package of Falling Run through Jacobs Chapel Beds has traditionally been included in the New Albany Shale, from a genetic (sequence stratigraphic) perspective the top of the New Albany Shale should be redefined to coincide with the top of the Clegg Creek.

The New Albany Shale reaches more than 90 m in thickness in parts of southeastern Illinois, western Kentucky, and southwestern Indiana, as well as in west-central Illinois (Lineback, 1970; Barrows and Cluff, 1984; Hasenmueller et al., 2000). The shale thins towards the basin margins where it can be less than 30 m in thickness (Lineback, 1970).

Generally speaking, the New Albany Shale consists of dark-colored, organic-rich (up to 20 percent TOC; Type II kerogen), laminated, banded, or bioturbated shales, and lighter-colored and rather organic-poor (less than 2 percent TOC; Type III kerogen) bioturbated shale (e.g., Lineback, 1968, 1970; Barrows and Cluff, 1984; Ingall et al., 1993; Calvert et al., 1996; Frost and Shaffer, 2000; Lazar and Schieber, 2003). Beds of siltstone, sandstone, limestone, and dolostone are also present, but they are limited in extent and thickness (Lineback, 1968). Analyses of the isotopic composition of organic matter in the shales of the Camp Run Member show that, on average, $\delta^{13}C_{org}$ values are 1.9‰ lighter in the laminated intervals (-29.17‰) than in the bioturbated intervals (-27.30‰; Calvert et al., 1996). This suggests either a larger input of terrestrial organic matter in the latter intervals (Calvert et al., 1996), or (more likely) a difference in diagenetic alteration of organic matter between laminated and bioturbated intervals (preferential loss of ^{13}C from laminated intervals, enrichment of ^{13}C in bioturbated intervals; Calvert et al., 1996). Increasing carbon content in the laminated shales is traditionally considered to indicate increasingly anoxic depositional environments (e.g., Barrows and Cluff, 1984; Calvert et al., 1996; Frost, 1996). The New Albany Shale is enriched in trace metals, especially towards the top of the formation (Shaffer et al., 1983; Ripley et al., 1990; Calvert et al., 1996; Frost and Shaffer, 2000; Lazar and Schieber, 2003).

Illite is the dominant clay mineral, and chlorite and expandable clays are present in varying but smaller proportions (Lineback, 1968; Frost and Shaffer, 2000). Illite was found more abundant relative to chlorite in the bioturbated shale compared with the laminated intervals of the Camp Run Member (Calvert et al., 1996). Quartz, calcite, dolomite, and pyrite are other main components of the mineral fraction (Lineback, 1968; Frost and Shaffer, 2000). Pyrite occurs in several different forms including framboids and very fine and closely spaced pyritic laminae (Frost and Shaffer, 2000; Lazar and Schieber, 2003).

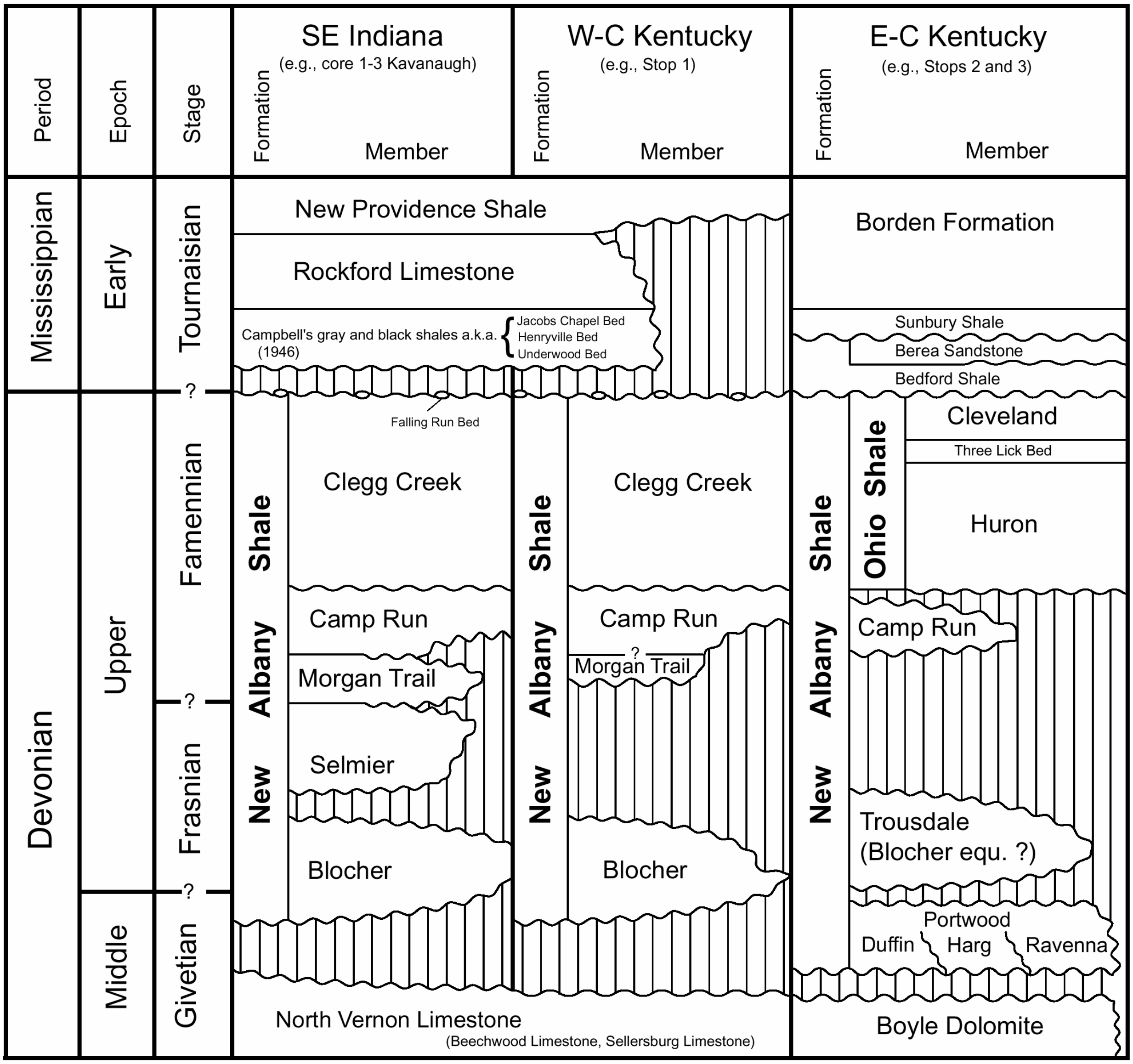

Figure 3.1.2.: Middle Devonian-Early Mississippian stratigraphy in southeastern Indiana, west-central Kentucky, and east-central Kentucky. Thickness not to scale (modified after Campbell, 1946; Lineback, 1970; Provo et al., 1978; Kepferle and Roen, 1981; Ettensohn et al., 1988b; Ettensohn, 1992a; Hamilton-Smith, 1993; Brett et al., 2003).

Tasmanites, *Foerstia (Protosalvinia*), logs of *Callixylon*, conodonts, brachiopods, pteropods, arthropods, and fish fossils have been found in the New Albany Shale (e.g., Huddle, 1933, 1934; Lineback, 1968, 1970; Niklas, 1976; Cluff, 1980; Sandberg et al., 1994; Over, 2002; Lazar and Schieber, 2004). *Foerstia (Protosalvinia*) occurs in the Clegg Creek Member of the New Albany Shale and is a useful biostratigraphic marker for correlation of the New Albany Shale with laterally equivalent Devonian black shales of the Appalachian and Michigan Basins (e.g., Kepferle, 1981; Hasenmueller et al., 1983; Roen, 1993). Trace fossils, including *Zoophycus*, *Chondrites*, and *Planolites*, have been identified in or just below the light-colored shale intervals (e.g., Lineback, 1968, 1970; Cluff, 1980).

Ohio Shale

The Upper Devonian Ohio Shale occurs in outcrops and in the subsurface in the western portion of the Appalachian Basin (Ettensohn et al., 1988a,b; Ettensohn, 1992a; de Witt et al., 1993). The Appalachian Basin is a foreland basin that developed during the late Proterozoic and Paleozoic (Ettensohn, 1992a; Roen, 1993). Northeast-trending, the basin is elongate and asymmetrical, approximately 1,500 km in length, and less than 150 km (Tennessee) to about 500 km (southeastward across Ohio to Virginia) in width (Fig. 3.1.1) (Roen, 1993). It extends from the Adirondack Uplift in the north to the Black Warrior Basin in the south. Along the northwestern border, the Appalachian Basin is separated from the Michigan Basin by the Findlay and Algonquin Arches (Ettensohn, 1992a; Roen, 1993) (Fig. 3.1.1). To the west, the Cincinnati Arch separates the Appalachian Basin from the Illinois Basin, whereas to the east, the Appalachian Basin is bordered by a belt of metamorphic and igneous rocks of the Blue Ridge Thrust Belt (Fig. 3.1.1) (Ettensohn, 1992a; Roen, 1993).

The Middle Devonian-Early Mississippian shales of the Appalachian Basin in Kentucky have been studied since the middle of the nineteenth century (cf., Pollock et al., 1981). East of the Cincinnati Arch, in the east central part of Kentucky, the name “Ohio Shale” is commonly used for the shale interval of Upper Devonian age (e.g., Provo et al.,1978; Pollock et al., 1981; Ettensohn, 1992a; de Witt et al., 1993). The Ohio Shale comprises the bulk of the Middle Devonian-Early Mississippian shale succession and is the only one that occurs over a large area (Kepferle et al., 1982; Ettensohn, 1992a; Hamilton-Smith; 1993). It consists of the Huron Member, the Three Lick Bed, and the Cleveland Member (Fig. 3.1.2) (Provo et al., 1978; Ettensohn et al., 1988a; Ettensohn, 1992a; de Witt et al., 1993), and overlies various locally occurring Middle Devonian to early Upper Devonian units (e.g., Boyle, Portwood, Dowelltown) (Pollock et al., 1981; Ettensohn et al., 1988a; Ettensohn, 1992a; de Witt et al., 1993) (Fig. 3.1.2). The complexity of the lower part of the black shale succession is a result of multiple erosive interludes that removed some units partially or entirely, and its correlation to units in the Illinois Basin is still tenuous and in flux. The Ohio Shale is overlain by the Early Mississippian Bedford Shale, Berea Sandstone, and Sunbury Shale (Fig. 3.1.2) (Hamilton-Smith, 1993). In south central Kentucky and in Tennessee the entire sequence is called the Chattanooga Shale (Jordan, 1985; Hamilton-Smith, 1993; Schieber, 1998b). The entire black shale sequence thins from nearly 560 m in the eastern part of Kentucky to less than 10 m on the crest of the Cincinnati Arch in south central Kentucky (Ettensohn et al., 1988a).

Generally, the Ohio Shale consists of grayish-black, brownish-black, and black shale; beds of gray shale are more commonly cited in the lower Huron Member and the Three Lick Bed of the Ohio Shale. A few beds of limestone, up to 10 cm in thickness, may also be present (Provo et al., 1978; Pollock et al., 1981; Ettensohn et al., 1988a; de Witt et al., 1993). Organic-carbon content, concentration in heavy elements, and abundance in phosphate and pyrite nodules increase towards the top of the Ohio Shale (Ettensohn and Barron, 1981; Pollock et al., 1981; Ettensohn et al., 1988a; Moody et al, 1988; Rimmer, 2004).

Although it contains the same range of lithologies as the New Albany Shale, overall organic-carbon contents are lower in the Ohio Shale (Maynard, 1981; Curtis, 2002). The average organic-carbon content and the amount of Type II kerogen of the black shale sequence increases westward, whereas the amount of Type III kerogen, presumably derived from organic matter of terrestrial plants of the Appalachian source area, increases eastward (Maynard, 1981; Roen, 1984; Hamilton-Smith, 1993). Analyses of the isotopic composition of organic matter show that, on average, $\delta^{13}C_{org}$ values are lighter in the Three Lick Bed (-27.4‰) when compared to the Huron Member (-29.3‰) and the and Cleveland Member (-28.9‰) (Maynard, 1981). The Ohio Shale contains a higher proportion of clays than the New Albany Shale (Hosterman and Whitlow, 1983; Frost and Shaffer, 2000). Quartz, calcite, dolomite, and pyrite are the most common authigenic minerals (Ettensohn et al., 1988a). Pyrite most commonly occurs as framboids, nodules, and lenses (Ettensohn et al., 1988a).

Tasmanites, *Foerstia (Protosalvinia*), logs of *Callixylon*, conodonts, brachiopods, fish fossils, as well as trace fossils (*Zoophycus*, *Chondrites*, *Planolites*, *Cruziana*, *Teichichnus,* and *Rhizocoralium)* have been described from the Ohio Shale (e.g., Cross and Hoskins, 1951; Schopf and Schwietering, 1970; Niklas, 1976; Barron and Ettensohn, 1981; Jordan, 1985; Ettensohn et al., 1988a; Savrda, 1991; Ettensohn, 1992a; Roen, 1993; Over, 2002; Brett et al., 2003).