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Marine paleoecology of the Fivemile Member of the Hinton Formation, Upper Mississippian, West Virginia and Virginia

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MARINE PALEOECOLOGY OF THE FIVEMILE MEMBER OF
THE HINTON FORMATION, UPPER MISSISSIPPIAN, WEST
VIRGINIA AND VIRGINIA

Thomas R. Cawthern

Thesis submitted to the
Eberly College of Arts and Sciences
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Geology

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ABSTRACT

Marine Paleoecology of the Fivemile Member of the Hinton Formation, Upper Mississippian, West Virginia and Virginia

Thomas R. Cawthorn

The Fivemile and Eads Mill members of the upper part of the Hinton Formation are two significant marine zones that occur within the Mauch Chunk Group in southwestern Virginia and southern West Virginia.

Multivariate analyses of binary fossil data for the Fivemile Member were performed in order to determine any underlying paleoecologic signals. Analyses of the data sets indicate that this member is dominated by a euryhaline fauna in four of the five locations studied. Euryhaline fauna characteristic of the Fivemile Member include the brachiopod *Lingula*, the bivalves *Modiolus* and *Septimyalina*, and ostracods. The geographic distribution and richness of these dominant fauna decreases to the southwest and the northeast, whereas the overall thickness of the Fivemile Member decreases to the northeast. This pattern indicates that more open-marine conditions existed in the south-central field area during deposition of the Fivemile Member. The one locality containing an open-marine fauna is thought to represent a deeper portion of the Appalachian Basin in a possible marine embayment where more open-marine conditions were established.

A comparative analysis of the paleoecology between the stratigraphically older Fivemile Member and the overlying Eads Mill Member reveals a distinct difference in their respective fossil assemblages. Whereas the Fivemile Member represents a marine transgression of limited extent in the study area, the Eads Mill Member fauna suggests a subsequent, larger magnitude relative sea level rise. The Eads Mill Member fauna includes diverse assemblages of various brachiopods, rugose corals, and bivalves. The Fivemile Member faunal assemblage appears to be a subset of the taxa present within the Eads Mill Member. The primary control on the stratigraphic distribution of various taxa present within and between the Fivemile and Eads Mill members appears to have been salinity. This salinity contrast is remarkably clear when selected stratigraphic sections of the Fivemile and Eads Mill members are stacked on top of one another, and their Detrended Correspondence Analysis axis 1 (DCA 1) scores are plotted stratigraphically. The Fivemile Member, with its dominantly euryhaline fauna, has strong positive DCA 1 scores, whereas the Eads Mill Member, with its more stenohaline fauna, has low positive to negative DCA 1 scores. These results suggest that the use of DCA 1 scores can serve as a useful proxy for studying the relative salinity gradients that may be present in many other paleoecologic data sets of Late Paleozoic age.

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I owe a debt of gratitude to my friends who have worked just as hard as I have throughout the course of my studies here at West Virginia University by maintaining a stable balance in our relationships, and by providing me with much appreciated breaks from my work. In particular, I would like to thank Phil Morath for his frequent visits and his help with the drafting of stratigraphic columns found herein. Thanks are also in order for Eric Hazlinsky for providing me with limitless encouragement.

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INTRODUCTION

Upper Mississippian (Chesterian) rocks in southwestern Virginia and southern West Virginia were deposited in a cyclic succession of terrestrial, transitional-marine, and open-marine environments. These environmental conditions are believed to have resulted from a combined effect of glacio-eustatic fluctuations in sea level and tectonic subsidence in the Appalachian foreland basin (Miller and Eriksson, 2000). The stratigraphic architecture and paleoecologic conditions that existed during the deposition of the Fivemile Member of the Hinton Formation are reflected in faunal composition, diversity, and abundance in five stratigraphic sections of the Mauch Chunk Group in southwestern Virginia and southern West Virginia.

The present study had three primary objectives. First, fossil invertebrate taxa from the Upper Mississippian Fivemile Member of the Hinton Formation were identified and recorded by stratigraphic position. Identification of these fossil taxa provided a means by which possible marine communities could be recognized and evaluated. Because preexisting literature of paleoecologic conditions for the Fivemile Member is relatively sparse, the invertebrate fauna of the Fivemile Member were then compared to published studies of the paleoenvironments and paleoecology of other strata of Late Mississippian (Chesterian) age in order to determine similarities to aid in the Fivemile Member paleoecologic interpretations.

The second primary objective of this study was to determine whether the marine paleoecology in the Fivemile Member varied vertically and/or laterally along a transect of

the Hinton outcrop belt ranging from southwestern Virginia to southern West Virginia. This objective was completed using a variety of multivariate quantitative methods. The completion of multivariate analyses aided in understanding what important paleoenvironmental gradients were responsible for the observed distribution of fossil communities present within the Fivemile Member in the central Appalachian Basin during the Late Mississippian.

The third primary objective of this study was to perform a comparative paleoecologic analysis of the Fivemile and Eads Mill members of the Hinton Formation in southwestern Virginia and southern West Virginia. Using detailed stratigraphic and sedimentologic information collected by Dr. Jack Beuthin and Mitch Blake from numerous exposures of the upper Hinton Formation in southwestern Virginia and southern West Virginia, Tim Vance and I were able to individually study in detail the paleoecology of the Eads Mill Member and Fivemile Member, respectively. Because these members represent two separate marine zones persistent throughout the study area, and because they represent two marine transgressions in a dominantly terrestrial sequence of rocks (Fig. 1), a comparative study of the paleoecology of the Fivemile and Eads Mill members was performed with the intent of understanding the relationship between these two marine transgressions.

Figure 1: Generalized stratigraphy of the Upper Mississippian Bluefield Formation, Hinton Formation, Princeton Formation, and Bluestone Formation in southern West Virginia. The two marine study intervals, the Fivemile Member and Eads Mill Member, occur within, and are separated by, predominantly terrestrial facies of the upper Hinton Formation. (From Beuthin and Blake, 2004).

Five localities were examined in the present study. The areas of investigation included: Tazewell County, Virginia, and Mercer and Summers counties, West Virginia. The outcrops examined each occur as road cuts, and were selected based on outcrop quality, accessibility, and stratigraphic completeness.

The five outcrop localities examined in this study occur along a SW-NE transect through the Hinton outcrop belt in the central Appalachian Basin. The five localities were: (A) VA Route 102, Bluefield, VA, Tazewell County, VA; (B) U.S. Route 460, Mercer County, WV; (C) Pipestem Creek, Pipestem District, Summers County, WV; (D) Elk Knob, Greenbrier District, Summers County, WV; and (E) I-64 (Fisher Creek), Green Sulphur District, Summers County, WV (Fig. 2 and Table 1).

Figure 2: Study area showing the outcrop belt of the Hinton Formation and field localities. Locations are (A) VA Route 102; (B) U.S. Route 460; (C) Pipestem Creek; (D) Elk Knob; and (E) I-64 (Fisher Creek). (Adapted from Beuthin and Blake, 2004).

Table 1**Description of Field Localities**

A) VA Route 102

Located along the southbound lane of VA Route 102 on the west side of the highway, about 1 mile north of the intersection of VA Route 102 and U.S. Route 460 in Bluefield, VA, Tazewell County, VA. Bramwell WV-VA 7.5' Quadrangle. UTM Coordinates: Zone 17; 474,965mE; 4,124,179mN.

B) U.S. Route 460

Located along the westbound lane of U.S. Route 460, approximately 3 miles east of the junction of Route 460 and the West Virginia Turnpike (I-77), about 0.1 mile west of the junction of U.S. Route 460 and Harmon Branch Road, Mercer County, West Virginia. Princeton WV-VA 7.5' Quadrangle. UTM Coordinates: Zone 17; 499,195mE; 4,132,535mN.

C) Pipestem Creek

Located along WV Route 20 and in the stream cut below the road along Pipestem Creek, about 1.0 mile south of the junction of Tom Honaker Road with WV Route 20, Pipestem District, Summers County, West Virginia. Pipestem WV 7.5' Quadrangle. UTM Coordinates: Zone 17; 504,036mE; 4,155,921mN.

D) Elk Knob

Located south of Hinton along Keatley Springs Church Road (Summers County Route 9), just above the intersection of Keatley Springs Church Road and Esquire Cemetery Road, Greenbrier District, Summers County, West Virginia. Hinton and Talcott WV 7.5' Quadrangle. UTM Coordinates: Zone 17; 511,620mE; 4,165,733mN.

E) I-64 (Fisher Creek)

Located along the eastbound lane of I-64 on the north side of the highway about 2.2 miles east of the Green Sulphur Springs exit (Exit 143), and immediately east of the overpass over Fisher Creek and Elton-Dawson Road, Green Sulphur District, Summers County, West Virginia. Meadow Bridge WV 7.5' Quadrangle. UTM Coordinates: Zone 17; 519,931mE; 4,187,110mN.

GEOLOGIC SETTING

Chesterian rocks from southwestern Virginia and southern West Virginia occur within the Appalachian Basin as interbedded marine and nonmarine units. Deposition of Chesterian strata of the central Appalachian Basin occurred as a result of small-scale eustatic sea level fluctuations superimposed on large-scale sea level change. Small-scale fluctuations result from glacial and interglacial periods of the Late Paleozoic glaciation, whereas large-scale sea level fluctuations result primarily from regional tectonic readjustments during the formation of the Appalachian mountains.

The debate between tectonic versus glacial mechanisms for sea level change has been the focus of many papers (Brezinski, 1989; Ettensohn, 1994; Miller and Eriksson, 1997, 1999, 2000; Smith and Read, 2000, 2001; Wright and Vanstone, 2001; Beuthin and Blake, 2002; Butts, 2005). It has been suggested that tectonic mechanisms are not viable causes of high frequency or cyclic sea level change due to the non cyclical nature of these processes, the slow rate of change associated with tectonics, and inadequate magnitudes of change in sea level depth necessary to create maximum flooding surfaces and sequence boundaries (Weimer, 1992; Nichols, 1999). Glacio-eustasy, on the other hand, has been shown to fulfill these criteria rather well. In particular, the cyclical nature, and the rate and magnitude of sea level rise and fall are explicable by Milankovitch cycles, provided there are ice caps present in the polar regions (Weimer, 1992; Nichols, 1999).

Tectonics

During Early to Late Mississippian time, the Appalachian Basin underwent major episodes of deformation related to tectonic loading and relaxation as a result of the end of the Acadian and the onset of the Alleghanian orogenies (Ettensohn, 1994). The tectonic timing of these collisions produced the SW-NE trending orientation of the Appalachian Basin, which was situated at roughly 10-15°S latitude (Fig. 3) (Brezinski, 1989; Blakey, 2001; Smith and Read, 2001; Maynard et al., 2006). During this time, the flexural response of the colliding terranes resulted in the formation of tectonically-induced sequences throughout much of the Appalachian Basin.

As a consequence of these collisions, the broad carbonate shelves that dominated the Middle Mississippian were subsequently replaced by comparatively narrower, asymmetrical basins due to tectonic loading in the east. The concomitant formation of highlands to the east of these basins served as a source of siliciclastic sediment. Consequently, Early to Middle Mississippian carbonate settings were replaced by prograding clastic wedges of coarse siliciclastic sediments by the Late Mississippian (Chesterian) (Ettensohn, 1994).

The evolution of sedimentary sequences with respect to tectonic thrusting and folding resulted in regional second- and third-order, unconformity-bound sedimentary sequences in the Appalachian foreland basin. The basic mechanism for the creation of cyclic packages of second- (10-100 m.y.) and third-order (1-10 m.y.) cycles in foreland basins is the result of crustal loading resulting from convergence-related crustal

shortening that depresses or flexes the lithosphere cratonward of the orogen (Flemings et al., 1990; Ettensohn, 2005).

Figure 3: Maps showing the orientation of continental plates and intervening oceans, and tectonic elements during the Late Mississippian (above), and the hypothetical paleogeography during the Late Mississippian (below). (From Blakey, 2001).

During the final tectophase of the Acadian orogeny, the Appalachian Basin deepened and narrowed between the Early Mississippian Kinderhookian and Osagean stages (Flemings et al., 1990; Ettensohn, 2005). At this time, increased erosion of the highlands to the east resulted in progradation of the Pocono and Price formations and

broadening of the Appalachian Basin. By the Meramecian, tectonic quiescence permitted the accumulation of a widespread limestone shelf, where the Greenbrier Limestone was deposited (Flemings et al., 1990; Etensohn, 2005). However, by the Late Mississippian (Chesterian), isostatic rebound of the highlands caused renewed narrowing and deepening of the Appalachian Basin. Topographic relief between the rebounded highlands and the deepened basin resulted in increased erosion, thereby causing renewed siliciclastic progradation of the Mauch Chunk Group into the basin (Flemings et al., 1990; Etensohn, 2005). Deposition of this siliciclastic material had a strong influence on long-term, second- and third-order depositional cycles. However, the scale of this change occurs over too long a time span to provide a satisfactory explanation for the sea level changes associated with deposition of the Fivemile and Eads Mill members of the Hinton Formation.

Glacio-Eustasy

Fluctuations in sea level have numerous effects on depositional systems, and thus on the resultant stratigraphy of an area. Sea level fluctuations influence stratigraphic boundary types, and the ways in which the rocks created within a depositional system are preserved (Walker, 1992). Similarly, relative changes in sea level cause a distinct characteristic landward and seaward migration of the shoreline. Whereas both tectonics and glacio-eustasy may create the same stratigraphic architecture, glacio-eustasy is the only one of these two mechanisms capable of producing the high frequency stratigraphic sequences prevalent throughout the central Appalachian Basin.

In general, relative sea level falls increase the gradient of coastal plains and river systems, resulting in increased erosion and sediment supply, and causing sediment deposition to shift farther basinward (progradation) (White, 1980; Reading and Levell, 1996). In contrast, a rise in relative sea level reduces the gradient of coastal plains and river systems, causing a reduction in the clastic supply of sediment, and ultimately leads to a shift in deposition of sediments vertically (aggradation) and landward (retrogradation) (White, 1980; Reading and Levell, 1996).

There are three principal orbital rhythms that have been found to be responsible for glacio-eustatically driven sea level change through time, and especially in the formation of Carboniferous cyclothems. These three factors are: 1) changes in the eccentricity of the Earth's orbit around the sun (400,000 and 100,000 year cycles); 2) changes in the tilt of the Earth's axis with respect to the plane in which it orbits the sun

(41,000 year cycle); and 3) a wobble (precession) due to the tilt axis sweeping out in a cone shape (21,000 year cycle) (Van Tassell, 1987; Algeo et al., 1988; Plint et al., 1992).

Importantly, these factors cause cyclical variations in the intensity and seasonal distribution of incoming solar radiation, which thereby affects the length of the summer melt period (Van Tassell, 1987; Plint et al., 1992). Consequently, any changes in these factors will produce differences in the length of summer melt periods, and therefore, increased melting and/or freezing of continental ice sheets. Additionally, humid conditions established in the low latitudes during interglacial periods most probably resulted in greater erosion on land, causing increased sedimentation of siliciclastics on the shallow water shelves in the Late Mississippian (Miller and Eriksson, 1999). These factors are important to consider for Late Mississippian stratigraphy because of significant ice accumulation on Gondwana during these times (Smith and Read, 2000; Butts, 2005).

Various models have been suggested to explain the creation of Carboniferous cyclothems; however very few of them can accommodate all of the criteria necessary for the complete description of their observed characteristics. In general, models for cyclothem formation must consider their global extent and extreme change in the amplitude of sea level (Weimer, 1992). In general, high-frequency and high-amplitude fourth-order (500,000-200,000 year) and fifth-order (200,000-10,000 year) sea level fluctuations resulting from the Late Paleozoic glaciation have been found to produce sea level changes on the order of 50-100 meters in the Antler Foreland Basin of the western

United States (Butts, 2005). In another study of the central Appalachian Basin and Illinois Basin, the magnitude of sea level change was estimated to be approximately 100 meters, which is on the order of change (60 ± 15 meters) from various other studies (Miller and Eriksson, 2000). Similarly, Smith and Read (2001) determined that fourth-order glacio-eustatic sea level changes in the Illinois Basin varied on the order of 30-100 meters.

The only mechanism that can account for the high-frequency and high-amplitude change persistent in Late Mississippian cyclothems in basins throughout North America and the world is a eustatic change in sea level as a result of variability in astronomical controls (Brezinski, 1989; Ettensohn, 1994; Miller and Eriksson, 1997, 1999, 2000; Smith and Read, 2000, 2001; Wright and Vanstone, 2001; Beuthin and Blake, 2002; Butts, 2005). Only glacio-eustatic control on sea level is widespread enough, has good enough cyclicity, and varies the ocean depths adequately enough to result in the formation of cyclothems (Van Wagoner, 1990; Weimer, 1992).

Stratigraphy

Most Upper Mississippian rocks that form the high frequency transgressive-regressive cycles (cyclothems) throughout the central Appalachian Basin are part of the Mauch Chunk Group of southern West Virginia (Figs. 1 and 4); the remainder comprise the underlying Greenbrier Limestone.

In southern West Virginia, the Late Mississippian Greenbrier Limestone unconformably overlies the Maccrady Shale, and consists predominantly of thick-bedded, carbonate mudstone and grainstone with few interbeds of greenish-gray and grayish-red shale (Englund et al., 1986). The Greenbrier Limestone ranges from oolitic to cherty and argillaceous, and often contains whole or fragmented marine invertebrate fossils, including numerous productid brachiopods, gastropods, and various bryozoans. Marine conditions prevailed for most of the duration during which the Greenbrier Limestone was deposited.

Figure 4: Generalized stratigraphy of the Upper Mississippian Mauch Chunk Group in southern West Virginia and the underlying Mississippian formations. (From McDowell and Schultz, 1990).

The Mauch Chunk Group of southern West Virginia is composed of four distinct formations: the Bluefield Formation, Hinton Formation, Princeton Sandstone, and Bluestone Formation (Figs. 1 and 4).

The Bluefield Formation conformably overlies the Greenbrier Limestone, and consists of intermixed carbonate grainstones and packstones, and heterolithic siliciclastic strata (Maynard et al., 2006). The predominant lithology within the Bluefield Formation consists of greenish-gray, and grayish-red calcareous shale interbedded with limestone and argillaceous limestone (Englund et al., 1986). Limestone and calcareous shale beds within the Bluefield Formation contain abundant marine fossils, including brachiopods, bryozoans, crinoids, and blastoids. These characteristics suggest that marine conditions prevailed for most of the duration during which the Bluefield Formation was deposited, but was periodically inundated with nearshore clastics, consisting of mud, sand, and marsh deposits (Englund et al., 1986).

Until recently, the stratigraphic nomenclature of the Hinton Formation has been highly inconsistent in the literature; however, new studies by Beuthin and Blake (2004) have permitted a more unified nomenclature to be assigned based on previously overlooked fossil-bearing marine intervals (Figs. 1 and 5). Historical attempts by various authors (Krebs and Teets, 1916; Reger, 1926; Englund, 1968) to independently identify and name small, laterally discontinuous units present within the upper Hinton Formation in southwestern Virginia and southern West Virginia resulted in redundancy in the naming of these units. The stratigraphically lower marine zone within the upper Hinton

Formation is now identified as the Fivemile Member, whereas the stratigraphically higher marine zone is now identified as the Eads Mill Member (Beuthin and Blake, 2004).

These two members represent two generalized packages of marine-dominated units identified earlier by Krebs and Teets (1916), Reger (1926), and Englund (1968) (Fig. 5).

The inclusion of the smaller, discontinuous units from the previous studies into these two larger, laterally continuous marine zones resolved the problematic nomenclature of upper Hinton Formation units, and emphasized the occurrence of two previously overlooked marine transgressions during the Chesterian.

This Report			Krebs and Teets, 1916	Reger, 1926	Englund, 1968		
Upper Mississippian (part)	Bluestone Formation (part)	undivided	Pluto Coal undivided	numerous members	gray and red members		
		Pride Shale Member		Pride Shale	Pride Shale		
	Princeton Formation		Princeton Sandstone	Princeton Sandstone	Princeton Sandstone		
	Hinton Formation	"upper"	undivided	undivided	Terry Shale	upper shale member	
			Eads Mill Member	Terry Limestone	Terry Limestone		
					Upper Pluto Shale		Falls Mills Sandstone
					Pluto coal		
					Pluto Limestone		
					Lower Pluto Shale		
			undivided	undivided	Falls Mills Shale	Pratter Shale Member	
			Fivemile Member			Falls Mills Limestone	middle shale member
		Upper Fivemile Shale					
		Fivemile Coal					
		Lower Fivemile Shale					
		Tallery Sandstone					
		Tallery Limestone					
		Upper Tallery Shale					
		Tallery Coal					
		undivided				Lower Tallery Shale	
			Low Gap Sandstone				
			Low Gap Limestone				
			Low Gap Shale				
			Avis Sandstone				
		"lower"	Avis Limestone of Reger (1926)	Hinton Limestone	Avis Limestone	Little Stone Gap Member (expanded from Miller, 1964)	
	undivided		undivided	Lower Avis Shale			

Figure 5: Subdivisions of the upper Hinton Formation comparing previous stratigraphic nomenclature with newly defined members. (From Beuthin and Blake, 2004).

The Late Mississippian Hinton Formation consists predominantly of grayish-red calcareous to non-calcareous shale and siltstone; however, greenish-gray shale, sandstone, fossiliferous limestone, and thin beds of coal and carbonaceous shale are also present in lesser abundance (Englund et al., 1986). Based on the revised stratigraphy of the Hinton Formation, these strata have been divided into four main members: (1) the basal Stony Gap Sandstone, a quartzose sandstone deposited as part of a fluvial-estuarine environment, which is a highly resistant ridge-former (Englund et al., 1986; Miller and Eriksson, 2000); (2) the middle Avis Limestone Member, an argillaceous limestone and calcareous shale unit ranging up to 100 feet thick, deposited in open-marine conditions, that serves as an indicator bed marking the top of the upper part of the Hinton Formation (Miller and Eriksson, 2000); (3) the Fivemile Member; and (4) the Eads Mill Member (Beuthin and Blake, 2004). Additionally, there are numerous undivided or unnamed beds of terrestrial strata, mainly redbeds and fluvial sandstones, which occur between these named members (Figs. 1 and 5).

The Fivemile Member is situated above the Avis Limestone between terrestrial redbeds and/or fluvial sandstones below, and an unconformity-bound unit above, consisting of either a channel-fill complex containing cross-bedded sandstone and conglomerate in some places, or mudstone in other places throughout the basin (Reger, 1926; Beuthin and Blake, 2004). The Fivemile Member is lithologically heterogeneous, however, in most localities it consists predominantly of fossiliferous shale, mudstone, siltstone, and sandstone.

The Eads Mill Member is situated above the Fivemile Member, and below the Princeton Sandstone. The basal contact of the Eads Mill Member is marked by a sharp transition from rooted mudstone to dark gray-black fossiliferous shale (Beuthin and Blake, 2004). In most localities, the Princeton Sandstone unconformably overlies the Eads Mill Member. In other localities, where the Princeton Sandstone does not serve as the upper contact of the Eads Mill Member, the member grades up into unnamed heterogeneous nonmarine units, comprised of sandstone, siltstone, mudstone, shale and impure coal (Beuthin and Blake, 2004). Where exposed, the Eads Mill Member consists of greenish-gray shale with interbedded shelly limestone, which contains abundant marine fauna dominated by brachiopods, bryozoans, corals, bivalves, cephalopods, gastropods, ostracods, and pelmatozoans (Beuthin and Blake, 2004).

The Princeton Sandstone unconformably overlies the Hinton Formation, and is thought to have been deposited as incised valley fill (Miller and Eriksson, 2000; Beuthin and Blake, 2004). The Princeton Sandstone is composed of light-gray coarse conglomerate to conglomeratic subgraywacke. The thickness of the formation is thinner toward the south, where it becomes less conglomeratic and more ripple-bedded (Englund et al., 1986).

The Bluestone Formation is an upward-coarsening succession of coal, shale, siltstone, sandstone, and concretionary limestone (Miller and Eriksson, 2000). In general, the Bluestone Formation conformably overlies undivided red terrestrial mudstone and thin coals, or the Princeton Sandstone, and is either capped by thick paleosols, or is

truncated by an erosional contact with overlying Pennsylvanian sandstones (Beuthin, 1997). Fossils present within the heterolithic facies of the Bluestone Formation include freshwater or brackish-water ostracods, bivalves, and inarticulate brachiopods, and marine bivalves, brachiopods, and cephalopods. Heterogeneity of the lithologies and fossils within the Bluestone Formation suggests that parts of this formation were deposited as an estuarine fill succession (Miller and Eriksson, 2000).

In general, the Mauch Chunk Group of southern West Virginia is a southeasterly-thickening wedge of siliciclastic material deposited as a result of sediment accumulation in a foreland basin created during the collision of Gondwana and Laurussia. Episodic marine inundation from interglacial episodes of the Late Paleozoic ice age produced interbedded marine facies within a predominantly nonmarine wedge of siliciclastic rock throughout much of the central Appalachian Basin (Englund et al., 1986; Brezinski, 1989; Miller and Eriksson, 1997, 1999, 2000; Smith and Read, 2000). These marine facies are laterally continuous throughout southern West Virginia and may be used as indicator beds within the Mauch Chunk Group. However, marine influence noticeably decreases from south to north as southerly exposed marine facies become replaced with terrestrial siliciclastic material in northern West Virginia (Henry and Gordon, 1992; Kammer and Lake, 2001; Beuthin and Blake, 2004). Importantly, marine facies present within the Mauch Chunk Group in southern West Virginia consist of both open-marine and restricted marine or brackish-water environments.

METHODS

Field Methods

Fossils were sampled and collected from the Fivemile Member of the upper Hinton Formation at each of the five study locations. Initial collections were made by bulk sampling of the outcrop during a preliminary weekend excursion to the five locations in November 2005. Bulk samples were marked, dated, and bagged according to each locality.

The bulk samples were cleaned using tap water and scrub brushes to ensure that fossil identification on sample surfaces were catalogued prior to disaggregating the sample. Bulk samples were disaggregated using various hammers and chisels in order to identify any remaining non-exposed fossil taxa.

Although bulk sampling of the Fivemile Member is not a highly useful method for collection due to the variable succession of lithologies present within the member, it did enable preliminary evidence of fossil diversity and composition to be explored, including aiding in the identification and compilation of fossil taxa found in each sampled unit at each location.

Following initial investigation and bulk sampling of the study areas, more detailed stratigraphic sampling was performed at each outcrop locality in May 2006. Detailed stratigraphic sampling consisted of sampling individual fossiliferous units within each measured section separately. Field sampling of fossiliferous units was facilitated by the

use of detailed field notes provided by Jack Beuthin and Mitch Blake. Verification of these fossiliferous units provided the opportunity to annotate lithologic observations made by Beuthin and Blake's (2004) field investigations. Fossils collected from individual units were marked, dated, and bagged according to each locality and precise stratigraphic position. When sample collection was completed, each sample was cleaned using tap water and scrub brushes, and disaggregated using various hammers and chisels.

Individual fossiliferous zones were marked according to an alphanumeric numbering system. The letters correspond to the study area, with A corresponding to VA Route 102; B corresponding to U.S. Route 460; C corresponding to Pipestem Creek; D corresponding to Elk Knob; and E corresponding to I-64 (Fisher Creek). The numbers correspond to different stratigraphic units identified by Beuthin and Blake (2004), with unit numbers beginning at 1 at the base of the measured section, and increasing upwards to the top of the outcrop. As a result of differences in the number of measured units at each outcrop, and the total thickness of the exposure, units comprising the Fivemile Member at the five localities begin and end at different numbers (Table 2).

Table 2**Stratigraphic Sampling Localities**

Field Locality	Samples Collected (Unit #)		Sample Code	
<i>VA Route 102</i>	40	58	A40	A58
	35	53	A35	A53
	34	52	A34	A52
	32	49	A32	A49
	24	47	A24	A47
	23	45	A23	A45
	22	41	A22	A41
<i>U.S. Route 460</i>	41		B41	
	35		B35	
<i>Pipestem Creek</i>	38	44	C38	C44
	35	43	C35	C43
	34	42	C34	C42
	33		C33	
<i>Elk Knob</i>	52	56	D52	D56
	51	55	D51	D55
	43		D43	
<i>I-64</i>	29		E29	

Once samples were collected, disaggregated, and cleaned, fossil specimens were identified. Taxa were identified using various sources (bivalves: Busanus and Hoare, 1991; Hoare, 1993; brachiopods: Henry and Gordon, 1992; cephalopods: Gordon, 1964; conularids: Babcock, 1996; gastropods: Thein and Nitecki, 1974; trilobites: Brezinski, 1988), including the *Treatise on Invertebrate Paleontology*. The characteristics used to identify taxa are listed in the Appendix. Most specimens recovered from fossiliferous beds were identified to the genus level, except for ostracods, bryozoans, crinoids, and gastropods due to extensive weathering and/or poor preservation. Identification of these specimens was made only to the class or phylum level. As it was noted by Kammer and

Lake (2001), genus level identifications are sufficient because often times, poor preservation or fragmentation of specimens create uncertainty in species-level identifications. Furthermore, genus level identification provides sufficient information for paleoecologic analysis because differences between species within a single genus are probably much less than those between genera (Kammer and Lake, 2001).

The raw presence/absence (binary) data for genera were recorded in an Excel spreadsheet that would later be used for multivariate analyses. Additionally, the raw binary data were assembled into guilds in order to reduce the number of variables affecting the data set. Guild constructions categorize organisms by autecological similarities, including food source, morphology, and life habits (Kammer and Lake, 2001; Lebold and Kammer, 2006).

Table 3 is a listing of the taxa identified in the study area and their guild classification. Bivalves were divided into epifaunal and infaunal bivalves, based on habitation preference of the bivalve on or within the sediment. Brachiopods were divided into tethered and productid brachiopods. Tethered brachiopods included those brachiopods with a functional pedicle. *Lingula* was differentiated from the tethered brachiopods because of its persistent abundance throughout many of the sampled horizons. Productid brachiopods included those brachiopods that did not have a functional pedicle. The bryozoa were not identified to the class, genus, or species level, and were thus left as the guild bryozoans. Similarly, due to incomplete and/or poor preservation of gastropods, crinoids, and ostracods within sampled horizons, these classes

were left as the guilds gastropods, crinoids, and ostracods. The cephalopod *Reticycloceras*, the trilobite *Paladin*, and the conularid *Paraconularia* were three rare occurrences of taxa within sampled horizons, and therefore formed their own guilds.

Multivariate Statistical Analyses and Computational Methods

A variety of multivariate techniques were used to determine the underlying patterns of similarity between the fossil occurrences for the five field locations. The multivariate techniques included: Q-Mode and R-Mode Cluster Analysis, Q-Mode and R-Mode Multidimensional Scaling (MDS), Correspondence Analysis (CA), and Detrended Correspondence Analysis (DCA). These multivariate techniques were available using PAST (PAleontological STatistics) software version 1.62, which is a comprehensive statistical software package developed by Oyvind Hammer, D.A.T. Harper, and P.D. Ryan, at the University of Oslo. PAST version 1.62 is available online as freeware from the website <http://folk.uio.no/ohammer/past/>.

Table 3 Taxonomic listing from the Fivemile Member and guild classification

<u>Genera, Class, or Phylum</u>	<u>Class or Phylum</u>	<u>Guild Classification</u>
Bryozoans (undifferentiated)	Bryozoan	Bryozoans
Crinoids (undifferentiated)	Crinoid	Crinoids
<i>Aviculopecten</i>	Bivalve	Epi-Biv
<i>Modiolus</i>	Bivalve	Epi-Biv
<i>Septimyalina</i>	Bivalve	Epi-Biv
Gastropods (undifferentiated)	Gastropod	Gastropods
<i>Ectogrammysia</i>	Bivalve	In-Biv
<i>Phestia</i>	Bivalve	In-Biv
<i>Schizodus</i>	Bivalve	In-Biv
<i>Wilkingia</i>	Bivalve	In-Biv
<i>Lingula</i>	Brachiopod	Lingula
Ostracods (undifferentiated)	Ostracoda	Ostracods
<i>Paladin</i>	Trilobite	Paladin
<i>Paraconularia</i>	Conularid	Paraconularia
<i>Fluctuaria</i>	Brachiopod	P-Brach
<i>Ovatia</i>	Brachiopod	P-Brach
<i>Reticycloceras</i>	Cephalopod	Reticycloceras
<i>Anthracospirifer</i>	Brachiopod	T-Brach

Cluster analysis arranges samples and/or taxa into clusters according to their overall similarities. More specifically, these groupings are arranged in a dendrogram such that clusters are formed based on shared environmental and/or biological similarities (Dodd and Stanton, 1990). There are two approaches to cluster analysis, Q-Mode and R-

Mode Cluster Analysis. Q-Mode Cluster Analysis arranges samples into clusters such that samples are clustered together that have the greatest similarities based on their taxonomic composition. In contrast, R-Mode Cluster Analysis arranges taxa into clusters based on their similarity in distribution within samples. Therefore, taxa that occur together in clusters are taxa that co-occur in samples (Dodd and Stanton, 1990). As with Q-Mode Analysis, R-Mode Analysis is graphically represented as a dendrogram.

Sample and taxa data obtained from the five field locations must be treated differently, depending on the data set being analyzed and the type of analysis that is being performed. For presence-absence (binary) data, the Jaccard Coefficient is used as a measure of similarity between both samples and taxa. The Jaccard coefficient is an equation in which the number of shared variables occurring in both samples is divided by the sum of the number of shared and unshared variables occurring in all the samples. Mathematically, the Jaccard Coefficient may be represented by the equation:

$$J = \frac{a}{a + b + c}$$

where a is the number of shared variables occurring in both samples; b is the number of variables present in sampling unit A but not in sampling unit B; and c is the number of variables present in sampling unit B but not in sampling unit A (Harper, 1999).

For combined taxa count data, different coefficients are used for both Q-Mode and R-Mode analyses. In particular, the measure of similarity for Q-Mode analyses is the

cosine theta coefficient, or index of proportional similarity. The distance between points on the MDS plot corresponds to the complement of cosine theta, so that the shortest distance corresponds to the greatest similarity (Kammer and Ausich, 1987). Values for this measure range from 0 to 1.0. In general, the higher the cosine theta value, the smaller the angle between the vectors, and thus, the more similar the samples (Dodd and Stanton, 1990). For R-Mode analyses, the coefficient measuring similarity between taxa is the correlation coefficient. The correlation coefficient is a measure of the degree of correlation between taxonomic groupings (Dodd and Stanton, 1990). Values for this measure range from -1.0 to 1.0. In general, the closer the correlation coefficient value is to -1.0 or 1.0, the better the correlation between the two taxa being studied (Harper, 1999).

Multidimensional Scaling (MDS) is an ordination technique that arranges variables or samples in two-dimensional space, such that the distance between the points corresponds to similarities between the data. Both Q-Mode and R-Mode analyses may be run using MDS with the similarity coefficients discussed above for either binary or combined taxa count data. The measure of how well the plotted data points correspond to the actual similarities between points is called the stress. The lower the value of stress, the better the fit of the plotted points to the actual similarities between points; the higher the value of stress, the poorer the fit. In general, stress has a range from 0 to 1. The goodness-of-fit of the data is commonly defined in the following manner (Rohlf, 1998; Lebold and Kammer, 2005):

0.0	Perfect
0.05	Excellent
0.10	Good
0.20	Fair
>0.40	Poor

Correspondence Analysis (CA) is a method for ordination, which shows the correspondence between taxa and samples in multidimensional space. Correspondence Analysis is an eigenvector technique that partitions the data variance along new axes, with the first plotted axis accounting for more variance than each subsequent axis. In many cases, the plots produced when Correspondence Analysis is run often exhibit an arching of the data points. This “arch-effect” is a function of the algorithm associated with data along a unimodal gradient (Gauch, 1982). Despite this artifact, in some cases ecologic gradients are still resolvable; however, in other cases, further analysis is needed to make any notable observations (Harper, 1999). One way to resolve this arching is to run a Detrended Correspondence Analysis, which eliminates the arch effect by dividing axis 1 into many segments and then adjusting the axis 2 scores within each segment to have an average of zero (Harper, 1999). The result is the distribution of variables along the DCA 1 axis.

DATA

Outcrop Descriptions

VA Route 102

The VA Route 102 section (Fig. 6) is the most heterolithic outcrop locality in the study area. The various environments inferred at this locality by differences in lithology and fossil occurrences provide evidence of instability that existed between high frequency sea level change and variable rates of siliciclastic input occurring at this location during the Late Mississippian.

Figure 6: VA Route 102 outcrop exposure of the Fivemile Member looking N-NW, foreground is unit 22; vehicle is ~10m updip of the top of the Fivemile Member.

The base of the Fivemile Member at VA Route 102 begins as a series of mudstone, shale, and silty shale facies, starting with unit 22 (mudstone containing densely packed shell beds comprised of ostracods, gastropods, the bivalves *Ectogrammysia*, *Modiolus*, *Septimyalina*, and *Wilkingia*, and the brachiopod *Lingula*) and continuing up section to unit 61. Fossil-bearing units that were sampled at this study locality are indicated on the stratigraphic column (Fig. 7).

Above the basal mudstone of unit 22 is a laminated shale containing abundant, thin (2-4mm thick) shell pavements comprised of the bivalve *Modiolus*, and ostracods (unit 23). Laminations are evident within this unit by distinct color banding between the medium to dark gray shale and the lighter, more olive colored laminae (Fig. 8). These laminations are thought to be tidal in origin. Immediately overlying this unit is a thin silty shale containing the bivalves *Modiolus* and *Septimyalina*, and abundant ostracods (unit 24). Overlying unit 24 is a succession of seven units relatively devoid of fossil invertebrates. In particular, unit 25 (dark gray shale) and unit 26 (dark gray sandstone) comprise much of the thickness of this succession (3.15 meters out of a total thickness of 4.63 meters). Unit 25 is a dark gray shale containing distinct silty laminations, and thin beds of flaser to wavy bedding. Unit 26 is a dark gray sandstone containing flaser bedding, pyritized vertical trace fossils (*Skolithos*), and ripple marks (Figs. 9 and 10). The remaining five units (27: gray mudstone containing plant debris and sandy laminations; 28: carbonaceous shale; 29: greenish-gray mudstone; 30: greenish-gray carbonaceous mudstone containing plant debris; 31: gray carbonaceous mudstone containing plant debris) are much less remarkable, sedimentologically.

Route 102, Virginia

Figure 7: Measured section and stratigraphic profile of the VA Route 102 locality, showing lithology and fossil content of fossiliferous units.

Figure 8: Laminated shale of unit 23 at the base of the Fivemile Member at VA Route 102.

Figure 9: Ripples and flaser bedding within unit 26 at the VA Route 102 locality.

Figure 10: Pyritized vertical burrow within unit 26 at the VA Route 102 locality, belonging to the *Skolithos* Ichnofacies.

The fossiliferous shale of unit 32 (Fig. 11) contains abundant bivalve “crinkle beds,” consisting of densely packed *Modiolus* and *Septimyalina* bivalves, and occurrences of ostracods, gastropods, bryozoans, and the bivalve *Aviculopecten*. Above this unit is an unfossiliferous gray shale (unit 33), which is itself overlain by a dark gray channelized silty shale containing numerous packed beds of *Modiolus* bivalves, and ostracods (unit 34). Overlying this unit is the thick (2.8 meters) sandstone of unit 35. This bivalve and ostracod-dominated sandstone is overlain by a grayish-red calcareous paleosol that contains abundant root mottles and calcrete nodules (unit 36) (Fig. 12). This unit is itself overlain by a succession of three very fine-grained to silty sandstone units (37: gray, very fine-grained argillaceous sandstone; 38: dark gray, very fine-grained sandstone; 39: gray siltstone, becoming argillaceous upwards). Above these units are two fossiliferous units. Unit 40 is a dark gray limestone comprised of packed *Modiolus*

bivalves, and occurrences of the brachiopod *Lingula* and numerous ostracods. Unit 41 is a dark gray shale containing very thin silty laminae and occasional, 2-3 mm thick beds of packed *Modiolus* bivalves, and ostracods. Overlying this unit are two unfossiliferous units. Unit 42 is a medium gray shale coarsening upwards to siltstone. Unit 43 is a channelized red-gray micaceous sandstone containing ripple cross-laminations and mud-draped foresets.

Figure 11: Fossiliferous shale of unit 32 at the VA Route 102 locality. Centimeter-scale limestone interbeds within this shale unit are comprised of densely packed bivalve shells.

Figure 12: Unit 36 paleosol at the VA Route 102 locality. This unit is characterized by root mottles and calcrete nodules.

The succession between units 43 and 47 ranges from the red-gray micaceous channel sandstone of unit 43, to an interbedded sandstone and shale containing ripple cross-laminations, mud-draped foresets, and few burrows (unit 44), to a fossiliferous dark gray shale (unit 45), which is overlain by dark gray calcareous shale and micrite (unit 46), and finally to the dark gray fossiliferous shale of unit 47 (Fig. 13). Both units 45 and 47 contain 2-3 mm thick crinkle beds, predominantly comprised of packed *Modiolus* and *Septimyalina* bivalves, and numerous ostracods. Unit 45, however, also contains the bivalves *Aviculopecten*, *Ectogrammysia*, and *Wilkingia*, and the brachiopod *Lingula*. This entire succession can be inferred to represent a marine transgression; however, the inferred water depth remains relatively deep through units 48 and 49. In particular, unit 48 consists of gray silty shale containing abundant laminations, whereas unit 49 is a dark gray calcareous shale containing packed beds of *Modiolus* bivalves, and ostracods.

Above unit 49 is a medium gray, calcareous siltstone containing relict laminations and root traces (unit 50). This unit is overlain by a lateritic paleosol (unit 51), identified by its characteristic internally massive, blocky fracturing, mottled color, and root traces. This unit is capped by a carbonaceous shale layer (Fig. 14). This succession of units is once again followed by fossiliferous limestone and silty shale units (52 and 53, respectively), suggesting sea level rose once again. Both units 52 and 53 contain abundant ostracods; however, unit 53 also contains the bivalve *Modiolus*. These small scale, high frequency sea level changes repeat frequently throughout much of the remainder of the outcrop, and emphasize the instability that existed between sea level change and variable rates of siliciclastic input.

Figure 13: Units 43 through 47 at VA Route 102. An inferred marine transgression occurs between unit 43 (an unfossiliferous channel sandstone), unit 46 (dark calcareous shale and micrite), and unit 47 (a dark gray fossiliferous shale).

Figure 14: The carbonaceous shale layer capping the top of unit 51 at the VA Route 102 locality. This contact marks the top of a shallowing upward trend. Overlying this contact are the limestone and silty shale facies of units 52 and 53, respectively.

Above unit 53 is a succession of four units relatively devoid of fossil invertebrates. Unit 54 is a thick (1.8 meters) unit consisting of interbedded sandstone and mudstone. This unit contains abundant relict laminations, stigmarian root traces, and orange-brown mottles. Unit 55 is a dark gray carbonaceous shale containing plant debris. Unit 56 is a light gray silty to very fine-grained sandstone containing laminations and stigmarian root traces. Unit 57 is a mudstone containing root traces.

The final fossiliferous unit is 58, which consists of greenish-gray interbedded sandstone and shale, and contains abundant ripple cross-laminations with mud-draped foresets, wavy laminations, flaser bedding, and packed beds of the bivalves *Modiolus* and *Septimyalina*. The remaining three units of the Fivemile Member at this locality consist

of gray mudstone containing orange-brown mottles and stigmarian root traces (unit 59), dark gray silty shale containing numerous laminae (unit 60), and gray silty shale coarsening upward to sandstone, which contains numerous laminations, and has lenticular to wavy bedding in places.

U.S. Route 460

The U.S. Route 460 outcrop contains the most diverse and abundant assemblage of fossil taxa in the study area. Diversity and preservation of fossil taxa is best studied within the medium- to dark-gray fissile shales, which contain a diverse assemblage of fully marine fossil invertebrates, including various brachiopods, bryozoans, bivalves, gastropods, nautiloids, crinoids, trilobites, and conularids (Figs. 15 and 16). Isolated beds of siderite nodules occurring within these dark gray fissile shales aided in the preservation of these fossils, and offer evidence for paleoecologic conditions in this area at the time of deposition.

Figure 15: Bivalves and bryozoans on the exterior of a siderite nodule from unit 35 at the U.S. Route 460 locality.

Figure 16: Bivalves and a cephalopod on the exterior of a siderite nodule from unit 35 at the U.S. Route 460 locality.

The basal two units (33 and 34) of the Fivemile Member at this locality consist of a lower unit of gray shale containing abundant plant debris (unit 33), whereas the overlying unit (34) consists of medium-gray laminated to ripple-bedded sandstone, with abundant bioturbation. Overlying these units is the 8.7 meter thick medium- to dark-gray fissile shale of unit 35. This shale contains abundant beds of siderite nodules, where a diverse assemblage of fossil invertebrates has been preserved. The bands of siderite occur as distinct horizons parallel to bedding throughout the shale unit. The distribution of the siderite nodule horizons are closely spaced (~10-30 cm apart) in the base of the unit, and become spaced farther apart in the upper part of the unit (100's of cm apart) (Figs. 17 and 18). Fossils concentrated on the exterior of these nodules, and, to a lesser degree, within the shale itself in thin shell beds, include the brachiopods *Anthracospirifer*, *Fluctuaria*, and *Ovatia*, the bivalves *Aviculopecten*, *Ectogrammysia*, *Modiolus*, *Phestia*, *Schizodus*, and *Septimyalina*, the nautiloid *Reticycloceras*, the trilobite *Paladin*, the conularid *Paraconularia*, and numerous bryozoans, gastropods, crinoids, and ostracods.

Figure 17: Siderite nodule occurrence in the lower portion of unit 35 at the U.S. Route 460 locality. Bands of siderite occur as distinct beds within the shale unit parallel to bedding. In the lower portion of this shale unit, these concretions are closely spaced (~10-30 cm apart).

Figure 18: Siderite nodule occurrence in the upper portion of unit 35 at the U.S. Route 460 locality. Bands of siderite occur as distinct beds within the shale unit parallel to bedding. In the upper portion of this shale unit, these concretions are spaced farther apart (100's of cm apart).

Above unit 35, is a succession of five units relatively devoid of invertebrate fossils (Fig. 19). Unit 36 is a greenish-gray shale containing plant debris. Unit 37 is a gray calcareous mudstone containing reddish-brown mottles in the lower half, and calcite-lined fractures in the upper half. Unit 38 is a gray argillaceous limestone, which is overlain by a gray mudstone containing orange-brown mottles along fractures (unit 39). Unit 40 is a calcareous mudstone, grading vertically into an argillaceous limestone. Overlying this succession is the final fossiliferous unit of the locality (unit 41). This unit is a medium gray laminated shale containing abundant ostracods. Unit 41 is capped by the unfossiliferous ripple cross-laminated sandstone of unit 42.

US 460, West Virginia

Figure 19: Measured section and stratigraphic profile of the U.S. Route 460 locality, showing lithology and fossil content of fossiliferous units.

Pipestem Creek

The Pipestem Creek locality is similar to the VA Route 102 locality in that the units within this outcrop consist of a heterolithic suite of sedimentary rocks (Fig. 20).

Pipestem Creek, West Virginia

Figure 20: Measured section and stratigraphic profile of the Pipestem Creek locality, showing lithology and fossil content of fossiliferous units.

At the base of the outcrop is the first of many sandstone units (unit 30). In particular, unit 30 is a greenish-gray quartzose sandstone, capped by a carbonaceous shale. Immediately overlying this unit, the exposure is concealed for approximately 0.1 meters. Above this concealed zone (unit 31) is the gray unfossiliferous silty shale and limestone of units 32 and 33, respectively. The limestone is a packed shell bed consisting of *Modiolus* and *Septimyalina* bivalves, and the bivalve *Ectogrammysia* and numerous ostracods (Fig. 21). Above this unit is a series of alternating fossiliferous and unfossiliferous beds consisting mostly of limestone (units 34-38) (Figs. 20 and 22). In particular, unit 34 is dark gray and contains the bivalves *Aviculopecten*, *Modiolus*, and

Septimyalina, and numerous ostracods and gastropods, whereas unit 35 is a carbonaceous shale to impure limestone that contains thin beds of packed *Modiolus* and *Septimyalina* bivalves, the brachiopod *Lingula*, and numerous gastropods and ostracods. Overlying this unit is a gray micritic limestone (unit 36), the unfossiliferous dark gray shale of unit 37, and the dark gray limestone of unit 38, which consists of 0.25 meters of packed *Modiolus* and *Septimyalina* bivalves, the brachiopod *Lingula*, and numerous ostracods.

Figure 21: Densely packed bivalve shell pavements (crinkle beds) present within unit 33 at the Pipestem Creek locality.

Above these fossiliferous units is a massive sandstone unit (39) (4.60 meters thick) containing silty-, wavy-, and ripple cross-laminations, and mud drapes. Directly overlying this unit is a channel sandstone (unit 40) containing plant debris and ripple cross-laminations. Immediately above this sandstone is a series of units of shale and limestone (units 41-43). In particular, unit 41 is an unfossiliferous greenish-gray shale to

claystone, unit 42 is a gray shale containing the bivalves *Aviculopecten*, *Modiolus*, *Phestia*, and *Schizodus*, the brachiopod *Lingula*, and numerous ostracods, and unit 43 is a dark gray argillaceous limestone containing the bivalve *Modiolus*, the brachiopod *Lingula*, and numerous ostracods. In contrast to the underlying units (39-40), this succession of fossiliferous units suggest a deepening of the water column had occurred upward, based on lithology and fossil content (Fig.20).

The top of the Fivemile Member at this locality is the planar- to ripple cross-laminated sandstone and shale of unit 44. This unit contains moderate bioturbation and fossil occurrences of the brachiopod *Lingula*, and numerous ostracods.

Figure 22: Vertical succession of units 33 (limestone) through 39 (sandstone) at the Pipestem Creek locality, illustrating an overall shallowing upwards trend.

Elk Knob

The Fivemile Member outcrop at Elk Knob is the second northern-most field locality in the study area (Fig. 2 and 23). The basal unit of the Fivemile Member at this locality (unit 43) is a laminated, ripple cross-laminated, flaser- and wavy-bedded sandstone, which contains a packed bed of *Modiolus* bivalves at the base, the presence of gastropods and ostracods, scattered plant debris, and horizontal burrowing. Overlying this unit is a vertical succession of units relatively devoid of invertebrate fossils, beginning with unit 44, and ending with unit 50.

Unit 44 is an interbedded sandstone and shale unit containing root traces, mud drapes, and relict laminae. This unit is overlain by a dark gray mudstone (unit 45), which is overlain by a carbonaceous shale (unit 46) (Fig. 24). These units are, in turn, overlain by a greenish-gray calcareous mudstone containing gray-red mottles, thick shaly laminae, and plant debris (unit 47), a gray shale containing plant debris (unit 48), and a gray calcareous mudstone (unit 49). This shallowing upwards succession continues upward into unit 50, which consists mostly of unfossiliferous calcareous mudstone and shale that contains green-gray to red mottles.

Elk Knob, West Virginia

Figure 23: Measured section and stratigraphic profile of the Elk Knob locality, showing lithology and fossil content of fossiliferous units.

Figure 24: Vertical succession of units 43 (laminated to wavy-bedded sandstone) through 47 (calcareous mudstone) at the Elk Knob locality, illustrating a shallowing upward trend. Unit 46 is a black carbonaceous shale.

Units 51 and 52 represent a renewed deepening of the water column due to continued transgression, or a decrease in the supply of siliciclastics from land. Unit 51 is a gray calcareous sandstone containing laminations and faint ripple cross-laminations, the bivalves *Modiolus* and *Septimyalina*, few gastropods, and numerous ostracods. Unit 52 is a coarsening upward unit of shale to sandstone (unit 52) that contains wavy beds with silty drapes in the upper-most sandstone, and occurrences of the bivalve *Modiolus*, and numerous ostracods.

Overlying these fossiliferous units is a vertical succession of rocks (units 53-54), that is highly suggestive of decreasing water depth (Figs. 23 and 25). In particular, unit 53 consists of unfossiliferous sandstone fining upwards into siltstone. This unit is

overlain by grayish-red to greenish-gray mottled mudstone, containing root traces (unit 54). This unit is suggestive of sediment exposure during periods of aridity.

Figure 25: Vertical succession of units 53 (unfossiliferous sandstone fining upwards into siltstone), 54 (mottled gray mudstone), and 55 (fossiliferous shale), at the Elk Knob locality, illustrating a shallowing upwards trend (from units 53-54), followed by a deepening upwards trend (from 54-55).

Overlying units 53-54 are the final two fossiliferous units at this locality. In particular, unit 55 consists of greenish-gray shale and contains the bivalve *Septimyalina* and numerous ostracods. This unit is overlain by laminated to ripple-laminated interbedded fossiliferous limestone and calcareous mudstone that contains the bivalves *Modiolus* and *Septimyalina*, and ostracods (unit 56).

The remaining units (57-62) are all relatively devoid of fossil invertebrates, yet share many of the same sedimentary structures as other unfossiliferous units found at this locality and those previously discussed. In particular, unit 57 is a greenish-gray shale

containing ripple cross-laminations and some root traces. Overlying this unit is a gray mudstone containing orange-brown mottles (unit 58), which is consistent with paleosol development. Above this unit is a dark gray shale containing plant debris (unit 59), which is overlain by an interbedded siltstone and sandstone unit that coarsens upward, and contains faint laminae (unit 60). Unit 61 is a greenish-gray shale that contains laminae at its base. The final unit (62) is another greenish-gray shale, containing some ripple bedded sandstone beds, and stigmarian root traces.

I-64 (Fisher Creek)

The final field locality is the I-64 outcrop. This outcrop of the Fivemile Member is the northern-most outcrop examined in the study area and consists predominantly of interbedded shales and siltstones (Figs. 2 and 26). Importantly, this outcrop approximately represents the northeastern-most extent of marine inundation associated with the deposition of the Fivemile Member.

Figure 26: Measured section and stratigraphic profile of the I-64 locality, showing lithology and fossil content of fossiliferous units.

The basal unit of the Fivemile Member (unit 27) consists of shale coarsening upward to siltstone. This unit lacks direct evidence of fossil invertebrates, however, it contains tubular burrows oblique to bedding. Abundant wavy laminations and clay drapes are also present in this unit. The top of this unit displays some indication of root traces, suggesting that it was exposed to air for a period of time. Immediately overlying this unit is another unit of shale coarsening upwards to siltstone (unit 28). This unit also contains planar- to wavy laminations and mud drapes. The final unit in this outcrop (unit 29) is the only fossiliferous unit at this locality (Fig. 27). This unit consists of gray-black shale and contains abundant plant debris and the bivalve *Modiolus*. This unit pinches out laterally, and is unconformably overlain by an erosive channel sandstone (Fig. 27). Both the increasing dominance of unfossiliferous siliciclastics at this locality, and the thinness of the section suggest that transgressive inundation was much less prominent here than in the other areas discussed previously.

Figure 27: The Fivemile Member at the I-64 locality consists of three units, 27, 28, and 29. Unit 29 (shale) represents the top of the Fivemile Member at this locality. The Fivemile Member is overlain by an erosive channel sandstone, as seen above.

Outcrop Comparison

Correlation of units within the five field localities of the Fivemile Member is difficult due to the heterolithic differences between outcrops. Despite these difficulties, numerous observations of the facies successions, geographic distribution of fossil content, and thickness of the outcrops provide useful information regarding paleoecologic gradients that existed during the Late Mississippian (Chesterian).

The lithologic diversity of units identified at the five study localities suggests that deposition was unique at each locality and was considerably variable through time. However, sedimentary structures present within these units, along with the identification of constituent fossil genera, provided the opportunity to interpret the depositional character of the Fivemile Member across the study area. From the previous discussion, it

is evident that both fossiliferous and unfossiliferous units within the Fivemile Member are laminated to wavy-laminated, and contain an abundance of mud drapes, small-scale ripples, and flaser bedding. These sedimentologic features, along with the predominance of the fossils *Modiolus* and *Septimyalina* (bivalves), *Lingula* (brachiopod), and numerous ostracod-bearing beds, suggests that much of the Fivemile Member was deposited in brackish-water to marginal-marine nearshore, tidally influenced environments (Greb and Chestnut, 1994; Mangano et al., 1998; Boggs, 2001; Olszewski and Patzkowsky, 2001; Prothero and Schwab, 2004). Other stratigraphic units contain channel-form sandstones, calcareous and lateritic paleosols, calcrete nodules, root mottling, stigmaria traces, and abundant plant debris. These represent terrestrial facies. Still other units comprise fossiliferous limestones deposited in an offshore marine setting.

Across the study area, the Fivemile Member ranges in thickness from (SW-NE) 30.19 meters (VA Route 102) to 18.95 meters (U.S. Route 460) to 12.06 meters (Pipestem Creek) to 22.40 meters (Elk Knob) and finally, to 2.90 meters (I-64). The thickness of each of these outcrops is presumably dictated by various factors, including, but not limited to: apparent paleogeographic topography, rate of sediment influx, rate of tectonic subsidence, extent of the marine transgression, and erosional truncation of the top of the Fivemile Member.

The generalized thickness of the Fivemile Member distinctively thins toward the northeast most likely as a result of the combined effects of the southwestward deepening of the Appalachian foreland trough, and a concomitant decrease in the amount of

accommodation space to the northeast. Similarly, subsidence around the West Virginia Dome to the north in north-central West Virginia created a hinge-line zone along which sediment thickness noticeably increased toward the south (Carney and Smosna, 1989).

Similarly, both the extent of the Fivemile Member marine transgression and the southwestward deepening of the Appalachian foreland basin have a notable affect on the extent of marine influence across the field area. In particular, a decrease in water depth from SW-NE should have noticeable effects on substrate type, salinity variation, temperature variation, oxygenation of the water column, and turbidity. In general, the increase in environmental factors affecting the occurrence of invertebrate fauna as a function of water depth can be summarized when bivalve diversity of the Fivemile Member, and total taxonomic diversity per outcrop are mapped across the study area (Figs. 28 and 29). These maps show that both the bivalve generic richness and total taxonomic richness are highest in the south-central portion of the study area, where the extent of marine transgression was apparently greater. In the southern-most and northern portions of the study area, both the generic bivalve richness and total taxonomic richness are lower, suggesting that water depth shallowed to the north and south.

Figure 28: Map showing bivalve generic richness by locality. Bivalve generic richness is greater in the southern two thirds of the study area where the extent of the transgression was apparently greater. Shallowing to the north and south is supported by decreased bivalve generic richness.

Figure 29: Map showing total taxonomic richness by locality. Total taxonomic richness may reflect the extent of marine transgression, which was greatest at the U.S. Route 460 locality. Shallowing to the north and south is supported by decreased taxonomic richness.

The distinctive distribution of total taxonomic richness and bivalve generic richness suggests that the U.S. Route 460 locality may have existed as an embayment during the time of deposition. An embayment at this locality would have enabled a more diverse assemblage of fauna to inhabit this area due to a decrease in the number and

degree of environmental stresses acting farther basinward. A probable paleoshoreline may be drawn such that the shoreline is recessed to the east around the U.S. Route 460 locality (Figs. 28 and 29). Freshwater influx originating from the north or east would have created high degrees of environmental stress in nearshore environments, whereas environments located farther basinward would have been much less stressed.

Additionally, shallower water depths closer to shore would have contributed to the degree of stress in nearshore environments because these localities are more susceptible to such factors as evaporation, storms, and turbidity. The inferred paleoshoreline represented in this study is one interpretation that explains the observed faunal distributions from this study. Additional sedimentologic research may further elucidate the patterns described herein.

Table 4 provides a comparison of taxonomic occurrence by outcrop locality within the study area. Table 5 is a list of the taxa occurring within the Fivemile Member by locality and the number of the unit sampled.

Table 4 Presence-absence data for taxa of the Fivemile Member by locality

	<i>VA Route 102</i>	<i>U.S. Route 460</i>	<i>Pipestem Creek</i>	<i>Elk Knob</i>	<i>I-64</i>
<u>Brachiopods</u>					
<i>Anthracospirifer</i>		X			
<i>Fluctuaria</i>		X			
<i>Lingula</i>	X		X		
<i>Ovatia</i>		X			
<u>Bivalves</u>					
<i>Aviculopecten</i>	X	X	X		
<i>Ectogrammysia</i>	X	X	X		
<i>Modiolus</i>	X	X	X	X	X
<i>Phestia</i>		X	X		
<i>Schizodus</i>		X	X		
<i>Septimyalina</i>	X	X	X	X	
<i>Wilkingia</i>	X			X	
<u>Gastropods</u>					
<i>Euphemites</i>		X			
Undifferentiated	X		X	X	
<u>Cephalopods</u>					
<i>Reticycloceras</i>		X			
<u>Trilobites</u>					
<i>Paladin</i>		X			
<u>Bryozoans</u>					
<i>Fenestrate</i>		X			
<i>Encrusting</i>	X				
<i>Stick</i>		X			
<u>Conularids</u>					
<i>Paraconularia</i>		X			
<u>Crinoids</u>					
Undifferentiated		X			
<u>Ostracods</u>					
Undifferentiated	X	X	X	X	
<i>Total</i>	9	17	9	5	1

Table 5 Presence-absence data for taxa from the Fivemile Member by locality sample numbers

	A22	A23	A24	A32	A34	A35	A40	A41	A45	A47	A49	A52	A53	A58	B35	B41
Brachiopods																
<i>Anthracospirifer</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Fluctuaria</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Lingula</i>	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
<i>Ovatia</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Bivalves																
<i>Aviculopecten</i>	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0
<i>Ectogrammysia</i>	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
<i>Modiolus</i>	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
<i>Phestia</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Schizodus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Septimyalina</i>	1	0	1	1	0	0	0	0	1	1	0	0	0	1	1	0
<i>Wilkingia</i>	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Gastropods	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
Nautiloid																
<i>Reticycloceras</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Trilobites																
<i>Paladin</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Bryozoans	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
Conularids																
<i>Paraconularia</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Crinoids	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Ostracods	0	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1
Totals	6	1	3	6	2	2	2	2	7	3	2	1	2	2	16	2

Table 5 (cont.) Presence-absence data for taxa from the Fivemile Member by locality sample numbers

	C33	C34	C35	C38	C42	C43	C44	D43	D51	D52	D55	D56	E29
Brachiopods													
<i>Anthracospirifer</i>	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Fluctuaria</i>	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Lingula</i>	0	0	1	1	1	1	1	0	0	0	0	0	0
<i>Ovatia</i>	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalves													
<i>Aviculopecten</i>	0	1	0	0	1	0	0	0	0	0	0	0	0
<i>Ectogrammysia</i>	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Modiolus</i>	1	1	1	1	1	1	0	1	1	1	0	1	1
<i>Phestia</i>	0	0	0	0	1	0	0	0	0	0	0	0	0
<i>Schizodus</i>	0	0	0	0	1	0	0	0	0	0	0	0	0
<i>Septimyalina</i>	1	1	1	1	0	0	0	0	1	0	1	0	0
<i>Wilkingia</i>	0	0	0	0	0	0	0	0	0	0	0	1	0
Gastropods	0	1	1	0	0	0	0	1	1	0	0	0	0
Nautiloid													
<i>Reticycloceras</i>	0	0	0	0	0	0	0	0	0	0	0	0	0
Trilobites													
<i>Paladin</i>	0	0	0	0	0	0	0	0	0	0	0	0	0
Bryozoans	0	0	0	0	0	0	0	0	0	0	0	0	0
Conularids													
<i>Paraconularia</i>	0	0	0	0	0	0	0	0	0	0	0	0	0
Crinoids	0	0	0	0	0	0	0	0	0	0	0	0	0
Ostracods	1	1	1	1	1	1	1	1	1	1	1	1	0
Totals	4	5	5	4	6	3	2	3	4	2	2	3	1

Fivemile Member Invertebrate Fossils

The fauna of the Fivemile Member of the Hinton Formation is dominated by the Phylum Mollusca. When the presence of bivalves, gastropods, and cephalopods are compared to the total number of taxa found at each outcrop locality, the percent of samples containing molluscan-dominated taxa range accordingly: VA Route 102, 66%; U.S. Route 460, 50%; Pipestem Creek, 59%; Elk Knob, 64%; and I-64, 100% (Table 5).

By studying the different bivalve, gastropod, and cephalopod taxa in each fossiliferous unit at all five outcrop localities, it is possible to determine what the dominant molluscan genera are within the Fivemile Member (Table 5). Based on the presence-absence data for taxa by locality and unit sample numbers, the bivalves *Modiolus* and *Septimyalina* occur most frequently, and comprise the majority of the total composition of molluscan diversity at each locality. The percent of samples containing the bivalves *Modiolus* and *Septimyalina* when compared to the total number of molluscan taxa at each locality range accordingly across the study area: VA Route 102, 70%; U.S. Route 460, 33%; Pipestem Creek, 59%; Elk Knob, 67%; and I-64, 100%. These results, along with the results from above, suggest that even at the most diverse sampling locality (U.S. Route 460), molluscan taxa, in particular the bivalves *Modiolus* and *Septimyalina*, occur most frequently in a quantitative sense.

In general, *Modiolus* and *Septimyalina* represent two bivalves that share similar life habits. Both bivalves are considered to be euryhaline, which means they have a high tolerance for salinity variations (Watkins, 1975; Mangano et al., 1998; Kammer and

Lake, 2001). Therefore, it would not be uncommon to find them in both brackish- to marginal-marine (5-35‰ salinity) and open-marine (35-45‰ salinity) environments. In particular, brackish-water environments experience the highest salinity variability with salinity ranges on the order of between 5-30 ‰, whereas open-marine environments experience the greatest salinity stability. Similarly, both of these bivalves are epifaunal, meaning they spend their life living on top of the substrate. Because of their resiliency to withstand various salinities that allows them to live in a wide range of environments, these organisms are referred to as generalists.

Besides the bivalves *Modiolus* and *Septimyalina*, other fossil invertebrates are present. In particular, ostracods and the inarticulate brachiopod *Lingula* comprise the next most dominant taxa. Ostracods were reported only when their abundance was high enough to be readily observed on bedding planes. Although the various ostracods were unidentifiable at the genus level because of poor preservation as molds, their co-occurrence with *Modiolus*, *Septimyalina*, and *Lingula* suggests they inhabited the same ecospace as these genera. Their presence in all but one of the outcrops studied parallels the dominance of the bivalves *Modiolus* and *Septimyalina*.

Like *Modiolus* and *Septimyalina*, *Lingula* is considered to be an opportunist because of its high tolerance for salinity variations and temperature variations. In fact, the persistence of *Lingula* throughout the Phanerozoic fossil record testifies to its ability to withstand a wide variety of environmental change (Ferguson, 1963; Kowalewski, 1996; Rodland and Bottjer, 2001). Although *Lingula* is infaunal, it is not surprising that

this brachiopod co-occurs with the bivalves *Modiolus* and *Septimyalina*, and the ostracods, because all seem to share the same tolerance for rapidly changing environmental gradients.

Throughout the rest of the Fivemile Member, rare occurrences of other invertebrate marine fossils have been observed. In particular, samples from B35 from the U.S. Route 460 outcrop comprise the majority of the remaining fossils not yet discussed. These taxa include various brachiopods (*Anthracospirifer*, *Fluctuaria*, and *Ovatia*), bivalves (*Aviculopecten*, *Ectogrammysia*, *Phestia*, *Schizodus*, and *Wilkingia*), bryozoans, crinoids, the trilobite *Paladin*, and the conularid *Paraconularia* (Tables 4 and 5). Some of these genera are considered to be stenohaline in nature, meaning that their tolerance for changes in salinity is very narrow. In particular, characteristic stenohaline organisms include bryozoans; crinoids; *Paraconularia*; the brachiopods *Anthracospirifer*, *Fluctuaria*, and *Ovatia*; and the bivalves *Phestia* and *Schizodus* (Kammer and Lake, 2001). These organisms are considered to be specialists because of their narrow tolerance for environmental change. Unlike euryhaline organisms, stenohaline organisms can not tolerate the variable salinities persistent within brackish- and marginal-marine environments. Consequently, the co-occurrence of euryhaline and stenohaline organisms results when euryhaline organisms occupy the open-marine realm.

Fivemile Member Data Sets

The multivariate techniques previously described were used on data sets from each locality. These data sets include taxonomic information for fossils collected from each locality. The data sets were analyzed initially as raw presence-absence data; however, the data sets were also collapsed into common guild associations by combining the number of taxa based on taxonomic membership and/or trophic mode (Table 3). The creation of guild associations is thought to reduce the number of variables affecting the data set by combining taxa with shared similar morphologies, food preferences, and characteristic life habits. Reduction of the number of variables improves the signal to noise ratio of ecologic patterns by increasing the magnitude of shared variables in each guild association (Lebold and Kammer, 2006). Arrangement of Fivemile Member taxa into guilds reduced the stress of Q-mode MDS analyses from 0.2912 to 0.2895. Similarly, stress for R-mode MDS analyses were reduced from 0.1461 to 0.1303. However, the overall trends in the collapsed and non-collapsed data sets were otherwise unaffected. Although analyses were performed with genera as well as with guilds, analyses run on the generic data are not presented herein because they are similar to results obtained using the guild construction.

Other methods to reduce the noise of the data set were applied, including eliminating single taxon occurrences, or units with only one occurrence; however, these methods were abandoned due to the elimination of important units within the Fivemile Member. For instance, if single occurrences of taxon were eliminated from the Fivemile Member data set, then many of the stenohaline marine invertebrates would be removed,

effectively destroying the important paleoecologic interpretations of the U.S. Route 460 outcrop. Similarly, elimination of units with only one occurrence would remove the northern-most sampling location, I-64.

All multivariate analyses were applied to the guild-organized binary data set for the Fivemile Member (Table 5). Specimen count data were not available because some sampled horizons were difficult to disaggregate. Despite this, Kammer and Lake (2001) noted that multivariate analyses applied to binary data sets should show the same faunal patterns as specimen count data if the environmental gradients are strong enough.

FIVEMILE MEMBER ANALYSIS AND DISCUSSION OF RESULTS

Many studies of Late Mississippian paleoecology have noted the important control salinity gradients had in the distribution and abundance of marine invertebrates (Rollins et al., 1979; Fursich, 1994; Greb and Chestnut, 1994; Kammer and Lake, 2001; Olszewski and Patzkowsky, 2001; Buatois et al., 2005; Allison and Wright, 2005; Lebold and Kammer, 2006). Because of this, salinity variation was a leading hypothesis for the control of the Fivemile Member fossil taxa composition. Other factors, such as substrate type and turbidity are believed to be less important due to the repeated occurrence of these taxa in various lithologies. Similarly, temperature and oxygen content of the water column are believed to be secondary controls based on the dominance of generalist taxa in Fivemile Member fossil-bearing units. In particular, oxygen availability was not an issue because fossil taxa were not stunted, nor were they pyritized.

As it was previously discussed, the combination of fossil taxa and sedimentary structures identified within the Fivemile Member across the study area indicates the main depositional environment of the Fivemile Member ranged from brackish- to marginal-marine. Only one locality contained fossil taxa that indicated open-marine conditions.

R-mode Cluster Analysis and Q- and R-mode MDS analyses of the Fivemile Member data set distinguishes between marginal-marine and open-marine environments. As it was previously discussed, the differentiation between marginal-marine and open-marine environments is made based primarily on the fossil occurrence within fossiliferous units at the five study localities. In particular, *Paraconularia*,

Reticycloceras, crinoids, and bryozoans are all distinctive stenohaline organisms that serve as key indicators of normal marine salinities. Similarly, gastropods, ostracods, and *Lingula* are generally considered to be euryhaline organisms that can tolerate variable salinities. The dichotomy that is evident between the stenohaline and euryhaline guilds on the R-mode Cluster Analysis suggests that salinity acted as a primary environmental gradient affecting the distribution and abundance of particular fossil organisms within the Fivemile Member (Fig. 30). These interpretations are further supported by the Q- and R-mode MDS analyses (Figs. 31 and 32), which show a separation of taxa occurs according to salinity tolerance. In particular, the faunal content of sampled units separates those units which were deposited in marginal-marine and brackish-water environments from those which were deposited in more environmentally stable open-marine environments. Salinity values are expected to be more stable farther offshore as a result of a decrease in the degree in freshwater influx and mixing in that direction. Furthermore, the results from the Detrended Correspondence Analysis visually enhance these interpretations (Fig. 33). The Detrended Correspondence Analysis illustrates the relationships between the Fivemile Member samples and guilds. In particular, the largest number of samples contain marginal-marine to brackish-water (euryhaline) taxa, while only one sample (unit 35 from the U.S. Route 460 locality) contains open-marine (stenohaline) taxa. The relative closeness of epifaunal bivalves (including *Modiolus* and *Septimyalina*), *Lingula*, and ostracods with respect to the majority of the samples from the five localities suggests that these three guilds comprise much of the fossil occurrences across the study area. Consequently, many of the fossiliferous units present within the Fivemile Member must

have been deposited in either brackish-water or marginal-marine environments, where salinities were variable and the overall environmental stress was high.

Figure 30: R-Mode Cluster Analysis showing groupings among Fivemile Member guilds, based on their salinity tolerances.

Figure 31: Q-Mode MDS plot showing similarities among sampled units. The faunal content of sampled units indicates an increase in salinity stability towards more open-marine conditions from right to left. Salinity stability increases from marginal-marine and brackish-water environments to open-marine environments due to decreasing freshwater influx and mixing.

Figure 32: R-Mode MDS plot showing similarities among guilds within the Fivemile Member. The groupings of guilds indicate a separation of guilds by salinity tolerance.

Figure 33: Detrended Correspondence Analysis showing similarities between Fivemile Member samples and guilds. The distribution of samples and guilds indicates an increase in salinity stability towards more open-marine conditions from left to right.

A model set forth by Ettensohn and Elam (1985), and later by Allison and Wright (2005), aids in the interpretation of the paleoecologic differences that exist within the Fivemile Member. In their studies, Ettensohn and Elam (1985) and Allison and Wright (2005) proposed that the broad, shallow shelves of epeiric seas in tropical to sub-tropical regions were salinity and temperature stratified due to high rates of freshwater runoff during wet (monsoonal) seasons and to poor mixing leading to temperature differences between shallow water and deeper water portions of the shelf. These conditions help to explain the observed paleoecologic trends in the Fivemile Member (Fig. 34).

Figure 34: Schematic model for the depositional environments of the Fivemile Member. (Adapted from Allison and Wright, 2005).

The Fivemile Member is composed largely of heterolithic units that consist predominantly of tidally-influenced sandstones, siltstones, and shales. According to Allison and Wright's (2005) model, the depositional setting for many of these facies occurs within the reduced salinity lens within the siliciclastic-dominated "window" (Fig. 34). As it was previously discussed, and as Buatois et al. (2005) showed, these environments are mostly inhabited by fossil generalists, including the euryhaline bivalves *Modiolus*, and *Septimyalina*, the brachiopod *Lingula*, and various ostracods.

The lack of limestone facies in the Fivemile Member suggests that either the magnitude of marine transgression that resulted in deposition of the Fivemile Member was not great enough to result in deep enough waters to promote carbonate deposition, or that freshwater runoff from land was sufficient enough during most of the duration of the Fivemile Member deposition to preclude the development of the carbonate factory. The facies closest to what may be considered a carbonate rock identified in the Fivemile Member at any of the localities studied were the "crinkle beds" identified at the VA Route 102 and Pipestem Creek localities. These units are actually densely packed bivalve beds, similar to modern day oyster beds.

The U.S. Route 460 outcrop differs considerably from the lithologies and faunal composition of the other outcrops. In particular, the U.S. Route 460 outcrop contains the most diverse fossil assemblages present in the study area. Most of the fossil occurrences, however, are derived from only two units in the outcrop. In particular, this locality is dominated by stenohaline organisms such as crinoids, conularids, cephalopods, and

bryozoans; however, euryhaline organisms such as various bivalves, brachiopods, and gastropods are also common (Kammer and Lake, 2001). Nearly all of these fossils are derived from the dominant shale unit at this locality.

The plausible paleoecologic conditions that prevailed during deposition of the Fivemile Member at this locality were most likely deeper water shelfal environments below a stratified water column. This locality corresponds to the sediment-water interface located below the reduced salinity lens within the carbonate/shale dominated window of the adapted schematic model for the depositional environments of the Fivemile Member (Fig. 34). This deeper water environment most likely occurred at this locality due to the presence of a marine embayment. This embayment would have provided a deeper water environment away from the shoreline where freshwater, sediment-laden runoff would not have been able to reach on a regular basis. Stratification of the water column most likely occurred due to both temperature and salinity differences between portions of the upper water column and portions of the lower water column as the extent of freshwater runoff extended distally over deeper water environments. These conditions, however, were probably variable as a result of seasonality, which would have affected local precipitation and therefore runoff.

Composite Data Set Comparison

The occurrence of fossil genera in the Fivemile Member is distributed within a similar range of lithologies at each of the five localities. As a result, it does not appear as though substrate is a primary defining paleoecologic criterion for the distribution of fossil

genera. Instead, fossil occurrences appear to be more strongly controlled by salinity differences that existed within and between the five localities. This relationship is pronounced when the DCA 1 scores obtained from Detrended Correspondence Analysis are plotted stratigraphically (Fig. 35). This method of using DCA 1 scores to plot trends in sample scores was employed by Scarponi and Kowalewski (2004) to indicate water depth trends. Here, instead of indicating sea level rise and fall, the DCA 1 scores provide a useful measure of the change in salinity between sampling horizons within and between units of the Fivemile Member. A strong positive shift in DCA 1 score indicates a shift toward more variable salinity environments, whereas a shift toward more negative values in DCA 1 score indicates a shift toward more stable marine salinity environments. These shifts are more pronounced when the VA Route 102, U.S. Route 460, Pipestem Creek, and Elk Knob localities are plotted together (Fig. 36). The I-64 locality is excluded here because it has only one data point (one sampled unit).

Figure 35: Stratigraphic patterns of DCA 1 scores for fossiliferous units within the Fivemile Member at localities containing two or more sampled units. The base of the Fivemile Member coincides with zero on the y-axis. The following list indicates the top of the Fivemile Member in meters above the base: VA Route 102 = 30.19m; U.S. Route 460 = 18.95m; Pipestem Creek = 12.06m; and Elk Knob = 22.40m. DCA 1 scores with greater positive shifts are indicative of environments with wider salinity ranges.

Figure 36: Combined stratigraphic patterns of DCA 1 scores for fossiliferous units within the Fivemile Member at localities containing two or more sampled units. Sample unit numbers correspond to numbers displayed in Fig. 34. The base of the Fivemile Member coincides with zero on the y-axis. The following list indicates the top of the Fivemile Member in meters above the base: VA Route 102 = 30.19m; U.S. Route 460 = 18.95m; Pipestem Creek = 12.06m; and Elk Knob = 22.40m. DCA 1 scores with greater positive shifts are indicative of environments with wider salinity ranges.

FIVEMILE AND EADS MILL MEMBERS COMPARATIVE ANALYSIS

The results for the Fivemile Member were compared to results from a parallel study of the younger Eads Mill Member in order to better understand the paleoecologic differences between these two members.

Data from the Eads Mill Member were collected by Tim Vance, and were analyzed using the same set of multivariate analyses. However, in order to have both data sets conform to the same guild classifications, some data from the Fivemile Member were eliminated, whereas new guilds were added. Eliminated data include units A23, A52, A58, and E29, and taxa that have less than two occurrences. Elimination of these units and taxa (including conularids from the Fivemile Member data set) does not change the primary characteristics of the Fivemile Member data set, because the dominant brackish-water to marginal-marine signal is still prevalent, and the one unit containing open-marine fauna is still present. Elimination of units with a single occurrence of taxon does not affect the overall signal within the Fivemile Member data set because these units do not provide a high level of control of the overall paleoecologic signal in comparison to units with more than one taxon. Similarly, new guilds were added to accommodate the Eads Mill Member data set, including a guild for rugose corals. Table 6 is a list of the combined presence-absence data for the Fivemile and Eads Mill members that were used for multivariate analyses. Recall that the Fivemile Member samples are designated by an alphanumeric system with the letter corresponding to the sampling locality and the number corresponding to the sample unit number. A similar system was used with the Eads Mill Member; localities are designated by the following abbreviations: RTVA:

Route 102 VA; CFL: Christian Fork Lake; BRB: Bluestone River Bridge; PIPE: Pipestem Creek; and INT: Interstate 64, which are followed by the number of the sampled unit.

Table 6: Binary guild data for the Eads Mill Member

Locality and sample number	T-Brachs	Lingula	P-Brachs	Epi-Biv	In-Biv	Gastropods	Nautiloid	Trilobite	Bryozoans	Crinoids	Corals	Ostracod
RTVA88	0	0	0	1	1	0	0	0	0	0	0	1
RTVA92	1	0	1	1	1	0	1	0	1	1	0	0
RTVA96	1	0	1	1	1	1	1	1	1	1	1	0
RTVA97	0	0	0	1	1	1	1	0	0	0	0	0
CFL	1	0	1	1	1	0	0	0	1	1	1	0
BRB5	1	0	1	1	1	1	1	0	0	0	0	0
BRB6	1	0	1	1	1	1	0	0	0	0	0	0
BRB7	1	0	1	0	0	0	0	0	1	1	0	0
BRB8	1	0	1	0	0	0	0	0	1	0	0	0
BRB10	1	0	1	0	0	0	0	0	0	0	0	0
BRB12	1	0	1	0	0	0	0	0	1	1	1	0
BRB13	1	0	1	1	0	0	0	0	0	1	0	0
PIPE66	0	0	0	1	1	0	0	0	0	0	0	0
PIPE67	1	0	1	0	0	1	0	0	1	1	1	0
PIPE68	1	0	1	1	1	1	0	1	1	0	0	0
PIPE71	1	0	1	1	0	0	0	0	1	0	0	0
INT62	0	1	0	1	0	0	0	0	0	0	0	0
INT63	0	0	0	1	1	1	1	0	0	0	0	0
INT64	1	0	1	0	0	1	0	0	1	1	0	0
INT66	0	0	1	0	1	0	1	0	0	0	0	0

Table 6 (cont.): Binary guild data for the Fivemile Member

Locality and sample number	T-Brachs	Lingula	P-Brachs	Epi-Biv	In-Biv	Gastropods	Nautiloid	Trilobite	Bryozoans	Crinoids	Corals	Ostracod
A22	0	1	0	1	1	1	0	0	0	0	0	0
A24	0	0	0	1	0	0	0	0	0	0	0	1
A32	0	0	0	1	0	1	0	0	1	0	0	1
A34	0	0	0	1	0	0	0	0	0	0	0	1
A35	0	0	0	1	0	0	0	0	0	0	0	1
A40	0	1	0	1	0	0	0	0	0	0	0	0
A41	0	0	0	1	0	0	0	0	0	0	0	1
A45	0	1	0	1	1	0	0	0	0	0	0	1
A47	0	0	0	1	0	0	0	0	0	0	0	1
A49	0	0	0	1	0	0	0	0	0	0	0	1
A53	0	0	0	1	0	0	0	0	0	0	0	1
B35	1	0	1	1	1	1	1	1	1	1	0	1
B41	0	0	0	1	0	0	0	0	0	0	0	1
C33	0	0	0	1	1	0	0	0	0	0	0	1
C34	0	0	0	1	0	1	0	0	0	0	0	1
C35	0	1	0	1	0	1	0	0	0	0	0	1
C38	0	1	0	1	0	0	0	0	0	0	0	1
C42	0	1	0	1	1	0	0	0	0	0	0	1
C43	0	1	0	1	0	0	0	0	0	0	0	1
C44	0	1	0	0	0	0	0	0	0	0	0	1
D43	0	0	0	1	0	1	0	0	0	0	0	1
D51	0	0	0	1	0	1	0	0	0	0	0	1
D52	0	0	0	1	0	0	0	0	0	0	0	1
D55	0	0	0	1	0	0	0	0	0	0	0	1
D56	0	0	0	1	0	0	0	0	0	0	0	1

The results from the comparative analysis were once again organized into different salinity zones, based on the results from the Q- and R-mode Cluster Analysis. In particular, these zones include brackish-water (5-30‰ salinity), transitional-marine (30-35‰ salinity), and open-marine (35-45‰ salinity) (Figs. 37 and 38).

The overall trend in the data based on the Q- and R-mode Cluster Analyses suggests that the Fivemile Member consists primarily of taxa that existed in marginal-marine (transitional-marine plus brackish-water) environments, whereas the Eads Mill Member contains lithologies and taxa indicative of open-marine, and to a lesser degree, transitional-marine conditions. These results are supported further by the R-mode MDS Analysis and Detrended Correspondence Analysis (Figs. 39 and 40).

Figure 37: Q-Mode Cluster Analysis of combined Fivemile Member and Eads Mill Member data showing similarities among sampled units, based on salinity tolerances of constituent fossil guilds. The majority of Fivemile Member samples are clustered into either transitional-marine or brackish-water environments. The Eads Mill Member consists predominantly of open-marine samples.

Figure 38: R-Mode Cluster Analysis of combined Fivemile Member and Eads Mill Member data showing similarities among guilds, based on their salinity tolerance. The majority of fauna found in the Fivemile Member data set are clustered into either transitional-marine or brackish-water environments. Fauna from the Eads Mill Member consist predominantly of open-marine taxa.

Figure 39: R-Mode MDS plot showing similarities among guilds within the Fivemile Member and Eads Mill Member. The distribution of guilds indicates an increase in offshore conditions from right to left. Fivemile Member fauna are clustered into either transitional-marine or brackish-water environments, whereas fauna from the Eads Mill Member consist predominantly of open-marine taxa.

Figure 40: Detrended Correspondence Analysis showing similarities between Fivemile Member and Eads Mill Member samples and guilds. The distribution of samples and taxa indicates an increase in offshore conditions from right to left. Fivemile Member fauna and lithologies are clustered into either transitional-marine or brackish-water environments, whereas the lithologies and fauna from the Eads Mill Member consists predominantly of open-marine taxa.

DCA 1 scores were once again used as a proxy for defining salinity differences between the Fivemile Member and Eads Mill Member data sets. The composite stratigraphic pattern of DCA 1 scores clearly displays the dichotomy that exists between the two members primarily as a result of the salinity tolerance of constituent fossil taxa (Fig. 41). Although salinity is determined here to explain the greatest amount of difference between the Fivemile Member and Eads Mill Member, it is not the only variable affecting the observed trends. Therefore, patterns observed in the combined data set are identified here as indicating relative increases or decreases in offshore conditions.

This chart further supports the multivariate analyses of the Fivemile Member and combined Fivemile Member and Eads Mill Member results, which suggest that the Fivemile Member consists primarily of euryhaline organisms from marginal-marine environments, while the Eads Mill Member consists primarily of stenohaline organisms from open-marine environments. In general, high positive DCA 1 scores are indicative of brackish-water environments, whereas low positive to negative DCA 1 scores are indicative of open-marine environments. Transitional marine environments plot in between high positive and low positive to negative DCA 1 scores, somewhat arbitrarily.

To further delineate the limits of these salinity-based zones, DCA 1 scores with respect to the fossil guilds were plotted (Fig. 42). Based on DCA 1 scores from fossil content, brackish-water environments have DCA 1 scores of 2.5 or greater. Open-marine environments have DCA 1 scores of 1 or less. Transitional-marine environments have DCA 1 scores between 1 and 2.5.

Figure 41: Combined stratigraphic patterns of DCA 1 scores for fossiliferous units based on guilds within the Fivemile Member and Eads Mill Member at localities containing two or more sampled units. The base of the Fivemile Member coincides with zero on the y-axis. The Fivemile Member and Eads Mill Member are located at their approximate stratigraphic positions. The gap separating the Fivemile Member and Eads Mill Member is an arbitrary thickness, representing approximately 30 meters of siliciclastics found between these two members. Based on DCA 1 scores from fossil content, brackish-water environments have DCA 1 scores of 2.5 or greater. Open-marine environments have DCA 1 scores of 1 or less. Transitional-marine environments have DCA 1 scores between 1 and 2.5.

Figure 42: Bar graph illustrating the distribution of various guilds with respect to their DCA 1 score. The value of the DCA 1 score is a proxy for the environment in which the guilds are found. Brackish-water guilds have DCA 1 scores of 2.5 or greater. Open-marine guilds have DCA 1 scores of 1 or less. Transitional-marine guilds have DCA 1 scores between 1 and 2.5.

Based on these multivariate analyses, it is apparent that although both marine members were deposited as a result of two marine transgressions, either the magnitude of sea level change resulting in the deposition of these two marine zones was drastically different, or the magnitude of sea level change was the same, but freshwater siliciclastic-laden influx during deposition of the Fivemile Member precluded the deposition of carbonates and assemblage of stenohaline organisms. If sea level was the sole mechanism responsible for the observed differences between the Fivemile Member and Eads Mill Member, the Fivemile Member must have been deposited during a relatively low magnitude sea level rise, based on the heterolithic nature of its units, and the dominance of euryhaline fauna. In contrast, the Eads Mill Member would have been deposited during a relatively larger magnitude sea level rise, based on the dominance of stenohaline fauna, and the deposition of the carbonate rocks. Regardless of which factor was more important, the primary paleoecologic gradient affecting the distribution, abundance, and occurrence of various marine fauna within and between the Fivemile Member and Eads Mill Member is salinity. Multivariate analyses of both the individual Fivemile Member data set, and the combined Fivemile Member and Eads Mill Member data set support the presence of a salinity gradient. Furthermore, these differences are most notable when stratigraphy is plotted with respect to DCA 1 score for each fossiliferous unit. The difference in DCA 1 scores between the Fivemile Member and Eads Mill Member suggests that the transgression that resulted in deposition of the Fivemile Member was not as extensive as the transgression that resulted in the deposition of the Eads Mill Member. A higher magnitude sea level rise without a significant degree of freshwater runoff would result in greater marine inundation, causing open-marine

environments to shift farther inland than if the transgression were of smaller magnitude, or experienced greater freshwater influx. As sea level rises, marginal-marine environments become open-marine due to flooding of the shelf, which results in an observed shift in molluscan-dominated communities from those that have a notable euryhaline dominance to those that have a more stenohaline assemblage of fossil taxa (Rollins et al., 1979; Olszewski and Patzkowsky, 2001; Clapham et al., 2006).

These results also conform to the model of the colonization of marginal-marine (brackish-water) ecosystems through time, proposed by Buatois et al. (2005). In general, euryhaline (generalists) organisms initially occupy marginal-marine settings. If environmental conditions stabilize, then more stenohaline organisms will migrate from deeper water environments into shallower water environments. As a result of these deep-to-shallow migrations, taxa present early on in marginal-marine environments simply represent a subset of the most opportunistic taxa present in the open-marine environment. This trend is also expressed in the combined Fivemile Member and Eads Mill Member data sets.

CONCLUSIONS

The Fivemile Member of the upper Hinton Formation was deposited during a marine transgression that occurred across southwestern Virginia and southern West Virginia during the Late Mississippian (Chesterian). Detailed paleoecologic analyses suggest that marine inundation was extensive enough to create an expansive marginal-marine depositional environment, in which the Fivemile Member was largely deposited. As a consequence, the Fivemile Member is dominated by a heterolithic suite of facies that include the presence of euryhaline generalist organisms, including *Modiolus*, *Septimyalina*, *Lingula*, and ostracods. These results are consistent with the lithology and fossil content of the Late Mississippian Bluestone Formation (Englund et al., 1986) and the Late Mississippian Bickett Shale of the Bluefield Formation (Kammer and Lake, 2001), and are similar to the results from the Late Pennsylvanian Ames Member in the northern Appalachian Basin (Lebold and Kammer, 2006).

The Fivemile Member stratigraphic thickness varies significantly across the field area. The stratigraphic thickness of the Fivemile Member thins from SW-NE, resulting from the combined effects of the southwestward deepening nature of the Appalachian foreland trough, and a concomitant decrease in the amount of accommodation space to the northeast. Similarly, subsidence around the West Virginia Dome in north-central West Virginia created a hinge-line zone along which sediment thickness noticeable increases toward the south (Carney and Smosna, 1989). Specifically, both the deepening of the Appalachian foreland basin and the small magnitude of sea level rise resulting in the deposition of the Fivemile Member limited the amount of space available for

sedimentation to occur toward the northeast of the study area, and enabled freshwater runoff to inundate many areas of the broad, shallow shelf, creating variability among paleoenvironmental gradients such as rapidly changing substrates and salinity. This trend is noticeable by comparing the stratigraphic thickness and fossil content of the five study localities. In particular, the stratigraphic thickness of the Fivemile Member noticeably decreases from SW-NE, from 30.19 meters at the southwestern-most locality (VA Route 102), to 2.90 meters at the northeastern-most locality (I-64). Similarly, the degree of freshwater and terrestrial influence increases most notably to the north as a result of a decrease in accommodation space. However, sedimentologic and paleontologic evidence from the southern-most field area suggests freshwater influx was also significant there as well. The increased magnitude of freshwater runoff in the southern-most and northern portions of the study area is most notable when bivalve generic richness and total taxonomic richness are plotted across the field area (Figs. 28 and 29). Specifically, both bivalve generic richness and total taxonomic richness of fossil fauna decrease to the north and southern-most localities in concert with a concomitant increase in the degree of terrestrial influence. In contrast, the U.S. Route 460 locality, with its diverse assemblage of mixed stenohaline and euryhaline taxa and lack of tidally-dominated siliciclastic facies, must have been deposited in deeper waters, most probably within an embayment.

Multivariate analyses of both the individual Fivemile Member data set and the combined Fivemile Member and Eads Mill Member data set reveal a dichotomy between fossil content within the Fivemile and Eads Mill members. In particular, taxa belonging to the Fivemile Member constitute a molluscan-dominated fauna, including: *Modiolus*,

Septimyalina, *Lingula*, and ostracods. In contrast, taxa within the Eads Mill Member consist of bryozoans, rugose corals, crinoids, and numerous productid brachiopods. The differences among fauna within the Fivemile and Eads Mill members suggest that the increase or decrease in overall offshore conditions controlled the distribution of fossil taxa present within both members. Specifically, the degree of salinity stability explains the greatest amount of differences between these two members. This gradient is most noticeable when results from axis 1 of the Detrended Correspondence Analyses (DCA 1 score) are plotted with respect to stratigraphy (Fig. 41). Similarly, DCA 1 scores obtained for various taxa present within both the Fivemile and Eads Mill members provide further support for a salinity gradient (Fig. 42).

The difference in DCA 1 scores between the Fivemile and Eads Mill members suggests that the Fivemile Member transgression was less extensive than the Eads Mill Member transgression. A second plausible explanation for these differences is that the magnitude of marine transgression was the same during deposition of both members, but that freshwater influx into the basin was greater during deposition of the Fivemile Member. In general, however, a higher magnitude sea level rise accompanied by low sedimentation rates would have resulted in greater marine inundation, causing open-marine environments to shift farther inland than if the transgression was of smaller magnitude, or was accompanied by high sedimentation rates. Following deposition of the Fivemile Member, and subsequent sea level fall, sea level rose sufficiently such that the marginal-marine environments recognized in the Fivemile Member were superseded by more open-marine environments during deposition of the Eads Mill Member due to more

extensive flooding of the shelf. This resulted in the observed shift from euryhaline molluscan-dominated communities of the Fivemile Member to more stenohaline assemblages of fossil taxa of the Eads Mill Member.

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APPENDIX: FOSSIL TAXA CHARACTERISTICS

Bivalves

Aviculopecten

This bivalve has a characteristic umbonal angle of 80-90° on a moderately convex left valve. Body ornamentation is common, with unequal, rounded, radial costae that alternate in size. Valve lengths range from 5.5-35.6 mm; the hinge length ranges from 5.2-28.9 mm. (From Hoare, 1993; pg. 382-384; and Busanus and Hoare, 1991; pg. 471).

Ectogrammysia

This bivalve has an elongated subrhomboidal shape, and is typified by a prominent hinge plate. The anterior and posterior margins are nearly evenly convex. The ventral margin is gently convex and subparallel to the dorsal margin. The hinge plate is well developed and contains numerous coarse growth lines. (From Hoare, 1993; pg. 389).

Modiolus

This bivalve has a straight hingeline with small beaks that overhang the hingeline close to the anterior margin. The posterior margin and dorsal margin meet at an obtuse angle of 150°. The surface of the shell is ornamented with numerous, fine, growth lines. (From Hoare, 1993; pg. 379; and Busanus and Hoare, 1991; pg. 467).

Phestia

This bivalve has a narrowly rostrate posterior margin. The beaks are located near midlength, and the hinge contains at least three denticles anterior to the beak, and five posterior denticles posterior to the beak. Faint numerous, closely spaced lirae ornament the shell exterior. (From Hoare, 1993; pg. 378; and Busanus and Hoare, 1991; pg. 466-467).

Schizodus

This bivalve has a subovate shape and moderate low convexity. The anterior and ventral margins form a continuous curve. The posterior margin is slightly convex. The beak is located approximately 1/3 the length from the anterior margin. Some specimens are ornamented with faint growth lines. (From Hoare, 1993; pg. 386).

Bivalves (cont.)

Septimyalina

This bivalve has a characteristic straight hingeline. The angle between the dorsal and posterior margins averages 120°, while the angle between the dorsal margin and the umbonal ridge averages 50°. Both valves are slightly lamellose. (From Hoare, 1993; pg. 379).

Wilkingia

This bivalve has a subrectangular shape. The beaks are located nearly proximal to the anterior margin. The posterior of the shell is spatulate in form. (From Hoare, 1993; pg. 392-394; and Busanus and Hoare, 1991; pg. 477).

Brachiopods

Ovatia

This brachiopod has an elongate shell with a long trail and steep flanks. This brachiopod is characteristically “egg-shaped”. The pedicle valve is highly convex, while the brachial valve is deeply concave. The hinge length is equal to the greatest width of the brachiopod. Spines are rare to absent. (From Muir-Wood and Cooper, 1960; pg. 311-312).

Fluctuaria

This brachiopod is medium to small and subcircular or elongate-oval in outline. The pedicle valve is highly convex with a slightly curved trail. The brachial valve is concave. No spines are present on this brachiopod. (From Muir-Wood and Cooper, 1960; pg. 303-304).

Lingula

This brachiopod is elongated with slightly convex lateral margins. Concentric growth lines ornament the exterior. The shell is characteristically thin, but thickens slightly toward the muscle attachments. (From Moore, 1965; H263).

Brachiopods (cont.)

Anthracospirifer

This brachiopod is characterized with having plicate shells with a wide hinge line. Bifurcations and bundling of placations on the shell surface is common. Well developed dorsal fold present. (From Moore, 1965; H704).

Cephalopods

Reticycloceras

This cephalopod is approximately circular in cross section, and contains a subcentral siphuncle. Camerae are long, and lirae appear fine and crowded in young shells, but more widely spaced in mature shells. This cephalopod is restricted to the upper part of the Upper Mississippian. (From Gordon, 1964; pg. 116-117).

Conulariids

Paraconularia

This conularid can be up to 20 cm in length, and is relatively narrow compared to its length. Ridges are widely spaced and have a distinct offset at the midline. Multiple crests are typically present between the ridges. This conularid is common in Mississippian rocks. (From Babcock, 1996; pg. 67).

Trilobites

Paladin

This trilobite is characterized by a longitudinally elongate glabella that is moderately convex in transverse and longitudinal profiles. The anterior margin of the glabella is rounded. The pygidium has a well-developed border that is slightly convex, and is 1.04-1.05 times longer than it is wide. This trilobite is the most pervasive trilobite genus in late Mississippian strata of the Appalachian Basin. (From Brezinski, 1988; pg. 938-940).