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ALLOCYCLIC CONTROLS ON PALEOZOIC SEDIMENTATION IN THE CENTRAL APPALACHIAN BASIN

by

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Open File Report 98-577

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ALLOCYCLIC CONTROLS ON PALEOZOIC SEDIMENTATION IN THE CENTRAL APPALACHIAN BASIN

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FIELD TRIP STOPS

Stop 1 Late Precambrian and early Cambrian strata, US Route 340, Weverton, MD.

Stop 2 Early and middle Ordovician strata along the Chesapeake and Ohio Canal, Williamsport, MD.

Stop 3 Devonian Keyser Limestone and Oriskany Sandstone, I-68, Hancock, MD.

Stop 4 Late Devonian and early Mississippian strata, I-68, Sidling Hill, MD.

Stop 5 Late Silurian strata, I-68, Rocky Gap State Park, MD.

Stop 6 Late Ordovician and early Silurian strata, Wills Creek water gap, Cumberland MD.

Stop 7 Late Mississippian and Middle Pennsylvanian strata at the Mississippian-Pennsylvanian Unconformity, I-68, Savage Mt., MD.

Stop 8 Late Devonian and early Mississippian strata, I-68, Little Savage Mt., MD.

Stop 9 Late Mississippian strata, Keystone Mine, Springs, PA.

Stop 10 Middle Pennsylvanian high alumina clay deposit, I-68, Chestnut Ridge, WV.

Stop 11 Mississippian-Pennsylvanian unconformity and early Middle Pennsylvanian strata, I-68, Chestnut Ridge, WV.

Stop 12 Late Middle and early Late Pennsylvanian strata, I-68, west flank of Chestnut Ridge, WV.

Stop 13 Late Pennsylvanian paleosols, I-79, Goshen Rd. exit, Morgantown, WV.

Stop 14 Late Pennsylvanian coal-bearing strata, Morgantown Mall, Morgantown WV.

Abstract

ALLOCYCLIC CONTROLS ON PALEOZOIC SEDIMENTATION IN THE CENTRAL APPALACHIAN BASIN

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This trip will examine evidence for allocyclic controls on Paleozoic sedimentation and stratigraphy along an east-west transect across the Appalachian Basin from Washington's Dulles International Airport in northern Virginia to Pittsburgh International Airport in western Pennsylvania. Emphasis will be on variation in sediment supply as a function of long- to short-term paleoclimatic change. Relationships of climatic change to tectonic and eustatic processes will be discussed. Day one will include stops in strata that range in age from the Late Precambrian to the Early Mississippian. Ordovician and Silurian stops will include strata that primarily formed in response to Early Paleozoic aridity. Devonian and Mississippian stops will illustrate evidence for climatic controls on the origin of petroleum source rocks and reservoirs. The onset of the breakup of Pangea and Triassic rifting and climatically controlled rift basin cyclic sedimentation will also be illustrated during day one. Day two will illustrate climatic controls on Mississippian, Pennsylvanian, and Permian (?) sediment supply, and tectonic and eustatic controls on accommodation space. Factors that influenced the deposition of essentially coal-barren strata (Mississippian) and coal-rich strata (Pennsylvanian) will be a primary topic of discussion. The cyclic nature of Middle and Late Pennsylvanian coal occurrences, and the factors that influenced this cyclicity, will also be illustrated and discussed on day two.

INTRODUCTION

The objective of this field trip is to evaluate allocyclic controls (Beerbower, 1964), principally paleoclimate, on Paleozoic sedimentation and stratigraphy in the Appalachian foreland basin. The emphasis of the trip is to demonstrate long- to short-term paleoclimate change (Table 1) as a primary control on sediment supply, both chemical and siliciclastic (Fig. 1A and 1B). Long-term climatic change as used herein is an estimated running average over time of variation in intermediate- to short-term climatic changes in rainfall. Interpretations of climate variation are based on paleoclimate indicators such as paleosols, sediment supply, sedimentary geochemistry and mineralogy, and paleontology.

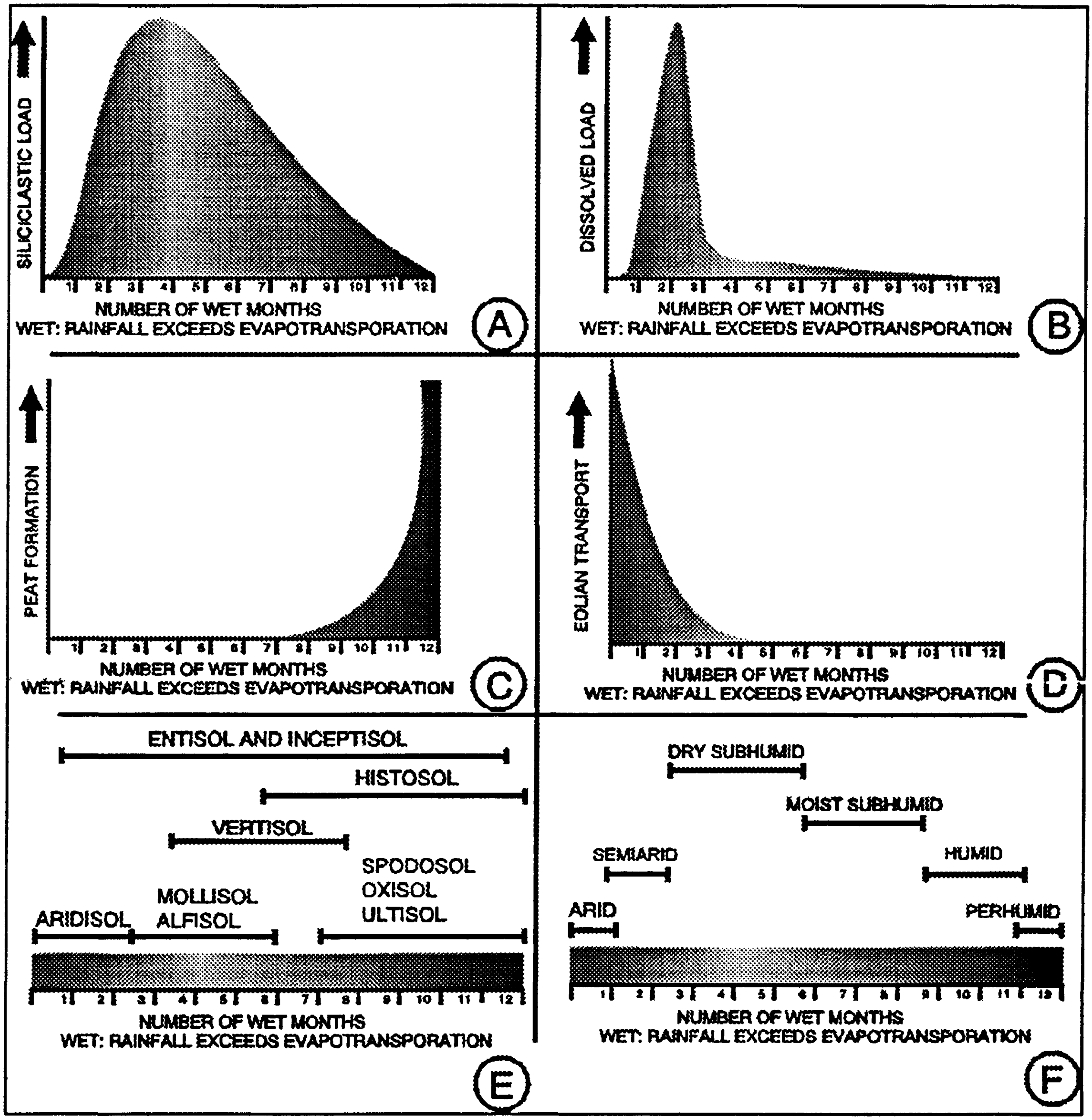


Figure 1. A) Potential for fluvial siliciclastic load as function of climate; B) Potential for fluvial dissolved load as function of climate; C) Potential for peat formation as function of climate; D) Potential for eolian transport as a function of climate; E) Formation of USDA soil orders as a function of climate; and F) Climate classification based on the number of wet months per year.

Field trip stops will examine Paleozoic strata that illustrate the sedimentary response to paleo-tropical rainfall regimes that ranged in duration from long-term to short-term (Table 1) and from arid to perhumid (Table 2, Figure 1F). Tectonic and eustatic processes also are discussed at each Stop. These later two allocyclic processes, which have been studied, modeled, and are the subject of numerous publications and field trips, are most commonly considered to control sediment supply in contrast to climate which is generally not considered. As an example, a rapid flux of siliciclastic material into depocenters is generally attributed to tectonic uplift whereas siliciclastic sediment starvation is usually explained by sea-level rise, trapping sediments in estuaries. Basal sandstone units of the Cambrian, Silurian, Mississippian, and Pennsylvanian in the Appalachian basin, are generally attributed to tectonically induced influx whereas laterally extensive shale deposits, such as the Ordovician Martinsburg shale and Devonian black shale units, are inferred to result from sediment trapping or autocyclic deposition of prodelta muds. Although tectonics clearly play a roll in uplift and subsidence, and eustasy contributes to accommodation space, variation in climate, particularly long- to short-term variation in rainfall in tropical conditions, is of greater importance as a control on sediment supply (e.g., Ziegler et al., 1987; Cecil, 1990 and references therein; Cecil et al. 1993). The trip stops illustrate that all three allocyclic processes, tectonics, eustatics, and climatics, require evaluation in order to understand and explain lithostratigraphy.

Table 1. Tropical and subtropical climate change classification (modified from Cecil, 1990)

RELATIVE DURATION	CAUSE	TIME (YEARS)
Long-term	Movement of continents through latitudes; orogenesis	10^6-10^8 10^5-10^7
Intermediate-term	100 and 400 ka cycles of orbital eccentricity	10^5
Short-term	Axial tilt and precession cycles	10^4
Very short-term (millennial)	not qualified	10^3
Instantaneous	Weather	10^{-2} (weeks, days, hours)

Table 2. Tropical climate regimes and degree of seasonality based on the number of consecutive wet months per year (modified from Thornthwaite, 1948).

Number of wet months	Climate regime	Degree of seasonality
0	arid	nonseasonal
1-2	semiarid	minimal
3-5	dry subhumid	maximum
6-8	moist subhumid	medial
9-11	humid	minimal
12	perhumid	nonseasonal

Many definitions of tropical climatic regimes are based on annual rainfall; few, however, attempt to incorporate seasonality (i.e., Thornthwaite, 1948). It is becoming increasingly apparent, however, that it is not the absolute amount of annual rainfall but the seasonality of annual rainfall that governs weathering, pedogenesis, erosion and sediment supply for a given catchment basin (e.g., Ziegler et al., 1987; Cecil, 1990). In order to assign degrees of seasonality, climate regimes, as used herein, are based on the number of wet months in a year. A wet month is defined as a month in which precipitation exceeds evapotransporation (Table 2, Fig. 1F).

By the limits set forth in Table 2 and Figure 1F, both arid and perhumid conditions are nonseasonal. All other rainfall conditions have some degree of seasonality. Maximum seasonality and maximum fluvial siliciclastic sediment supply occur under dry subhumid conditions when there are three to five consecutive wet months (Fig. 1A). Maximum dissolved inorganic supply occurs under semiarid to dry subhumid conditions (Fig. 1B). The most ideal conditions for the formation and preservation of peat, as a precursor to coal, occur under humid and perhumid conditions (Fig.1C) when both dissolved and siliciclastic sediment supply approach zero (Cecil et al., 1993). The well know conditions for eolian transport are illustrated in Figure 1D.

Climate is also a major control on weathering and soil formation; conversely, paleosols can be used to reconstruct paleoclimate and paleo-watertables. Climate may be the primary control on pedogenesis in epicontinental basins where other parameters such as parent material and relief are relatively constant. On the basis of structure, chemistry, and mineralogy, paleosols can be classified at the level of soil Orders using the U.S. Department of Agriculture classification (Soil Survey Staff, 1975). Once classified, paleosols can be used to interpret paleoclimate (Fig.1E) including the amount and seasonality of rainfall as we will see at a number of stops on the trip.

A major component in long-term climate variation, as expressed in Appalachian basin sedimentation, was movement of continents through paleolatitudes. What is now the

Appalachian basin moved northward from about 40° south in the Late Precambrian and early Cambrian to 30° south $\pm$ 5° during the Early Ordovician where it remained through the Middle Devonian (Scotese and Golonka, 1992). Northward movement continued from about 30° south in the Middle Devonian to about 2° north by the beginning of the Permian (Figs 2 through 9). From the perspective of zonal atmospheric circulation, the field trip study area moved from the dry subhumid belt of southern hemisphere prevailing easterlies in the Early Cambrian into the high pressure belt of aridity by Late Cambrian where it remained well into the Devonian. Late Precambrian and Early Cambrian sediments are dominated by siliciclastics whereas Middle Cambrian through Early Devonian strata contain abundant limestone, dolomite, and evaporites. These strata are totally consistent with paleogeographic interpretations (e.g., Scotese and Golonka, 1992). By the Late Devonian the region began to move northward toward the humid low pressure equatorial region. Movement continued through the equatorial region during the Pennsylvanian. Late Devonian through Pennsylvanian strata are dominated by siliciclastic materials but marine and nonmarine limestone units do occur; carbonate deposition, however, was controlled by intermediate- to short term-climatic processes rather than continental drift through latitudes. Figure 10 depicts long-term climate change for the Paleozoic of the central Appalachian basin.

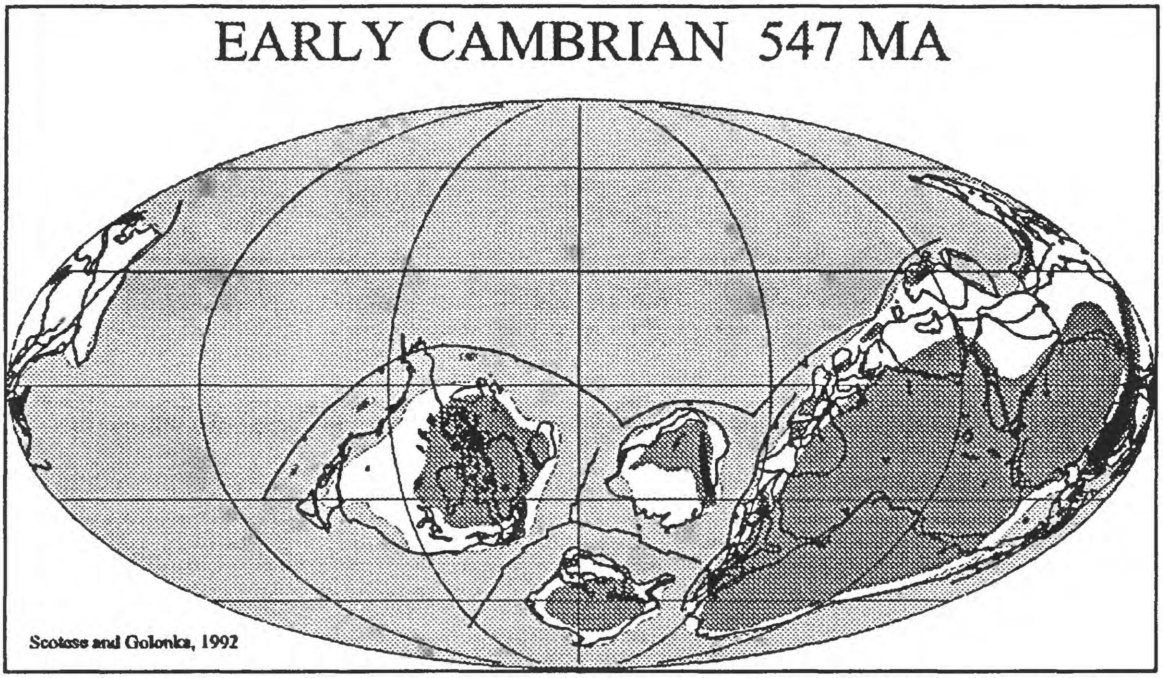


Figure 2. Paleogeographic reconstruction of Early Cambrian (547 MA). Black areas are mountains, medium-gray are landmass, white areas are continental margins, and light-gray areas are deep water for figures 2 through 9.

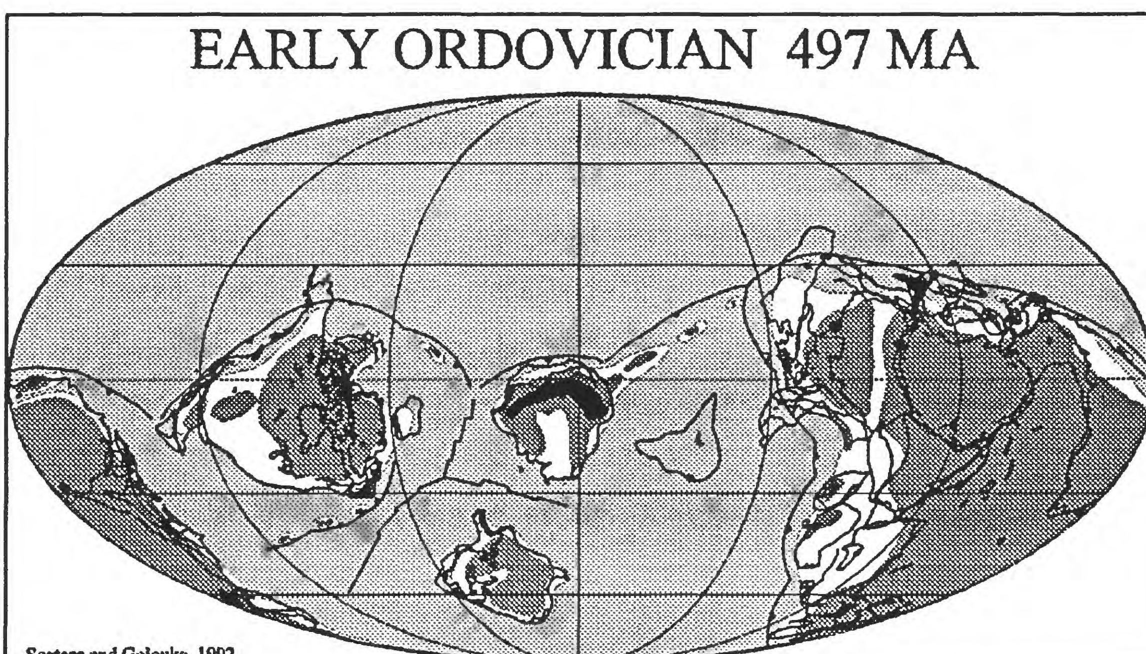


Figure 3. Paleogeographic reconstruction of Early Ordovician (497 MA).

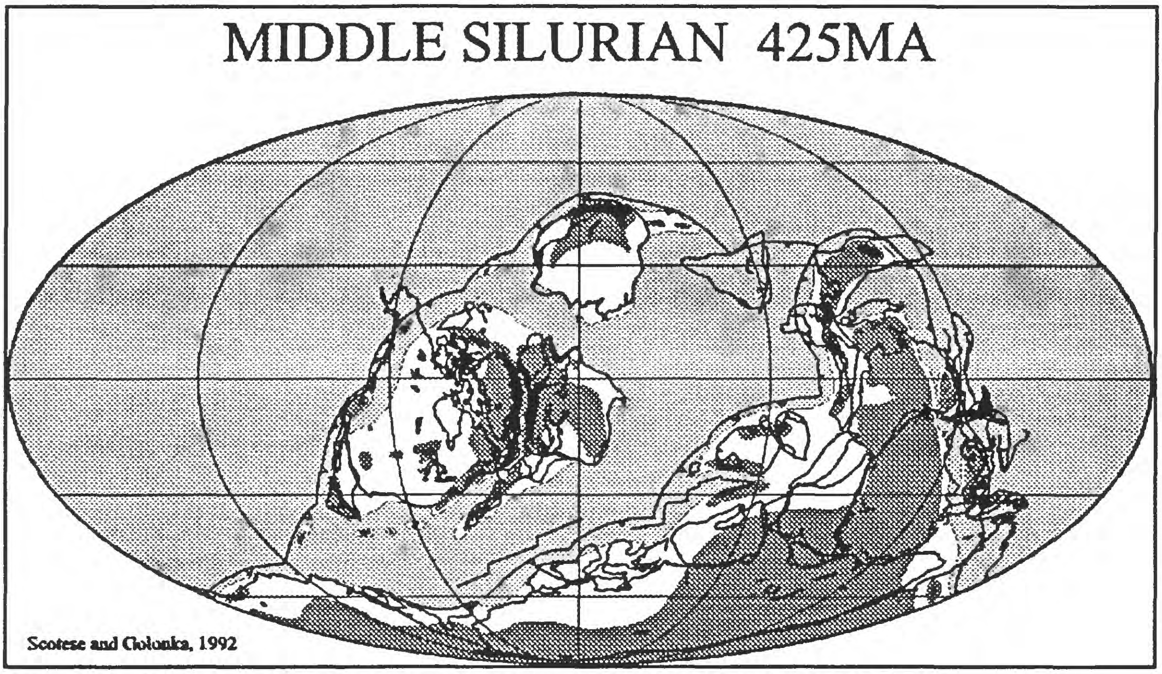


Figure 4. Paleogeographic reconstruction of Middle Silurian (425 MA).

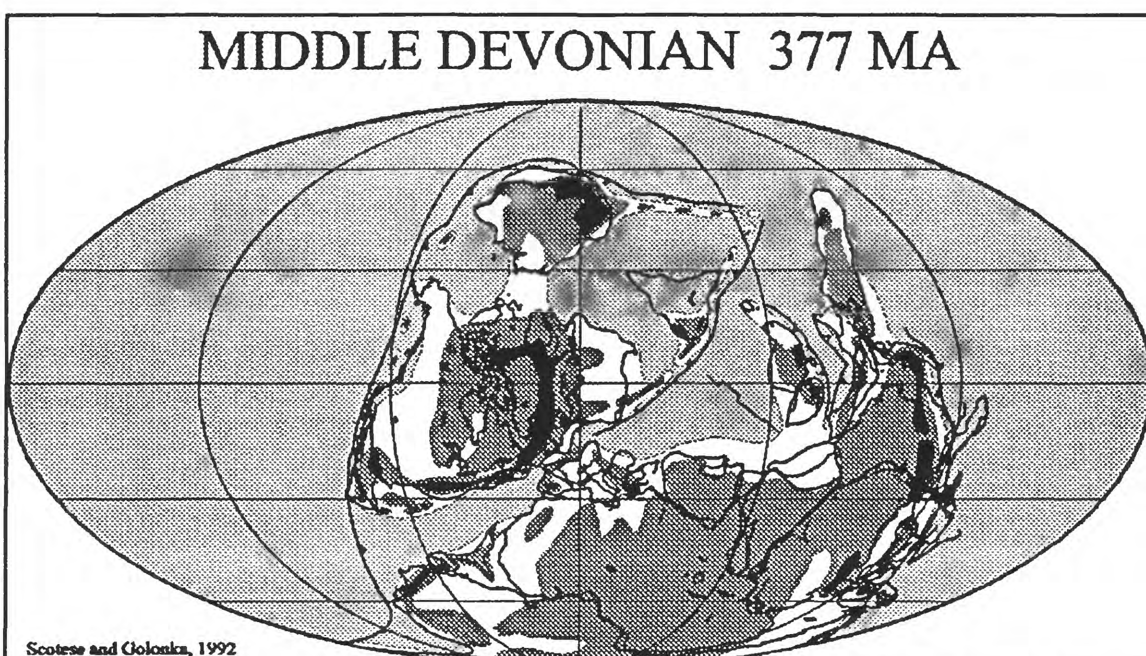


Figure 5. Paleogeographic reconstruction of Middle Devonian (377 MA).

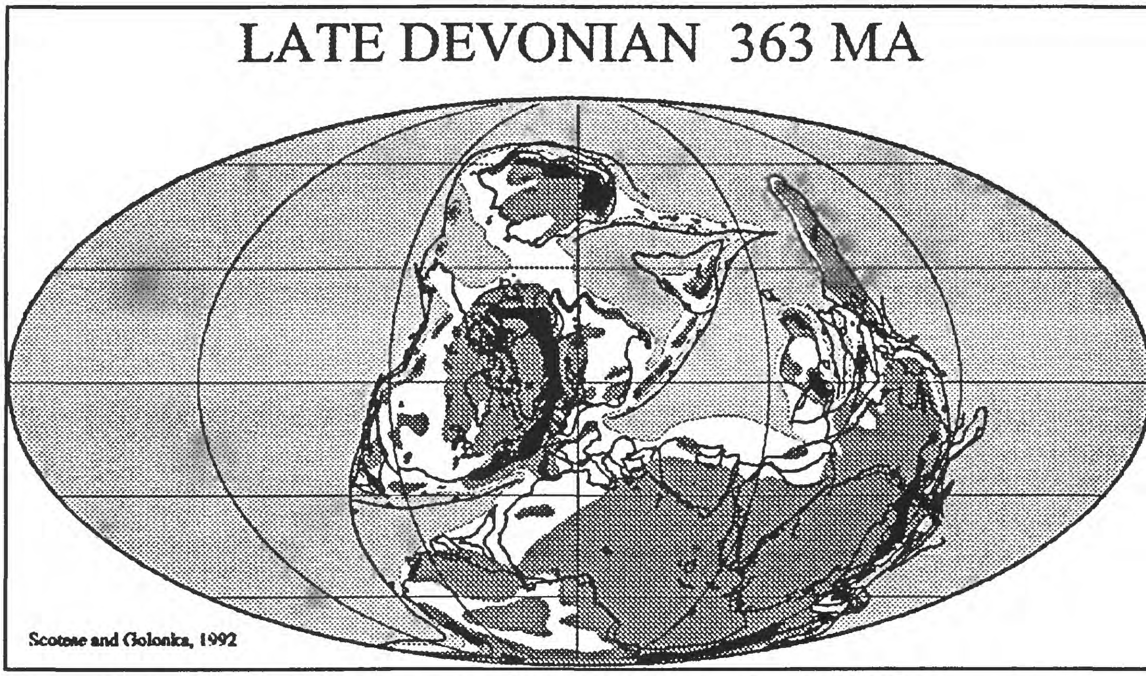


Figure 6. Paleogeographic reconstruction of Late Devonian (363 MA).

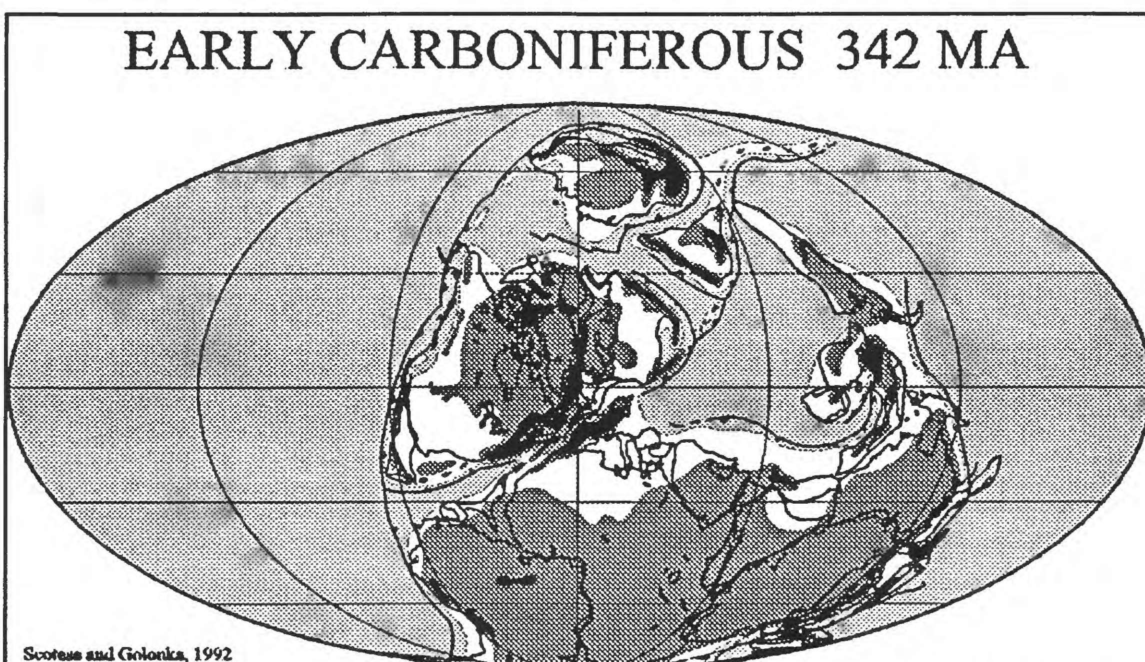


Figure 7. Paleogeographic reconstruction of Early Carboniferous (342 MA).

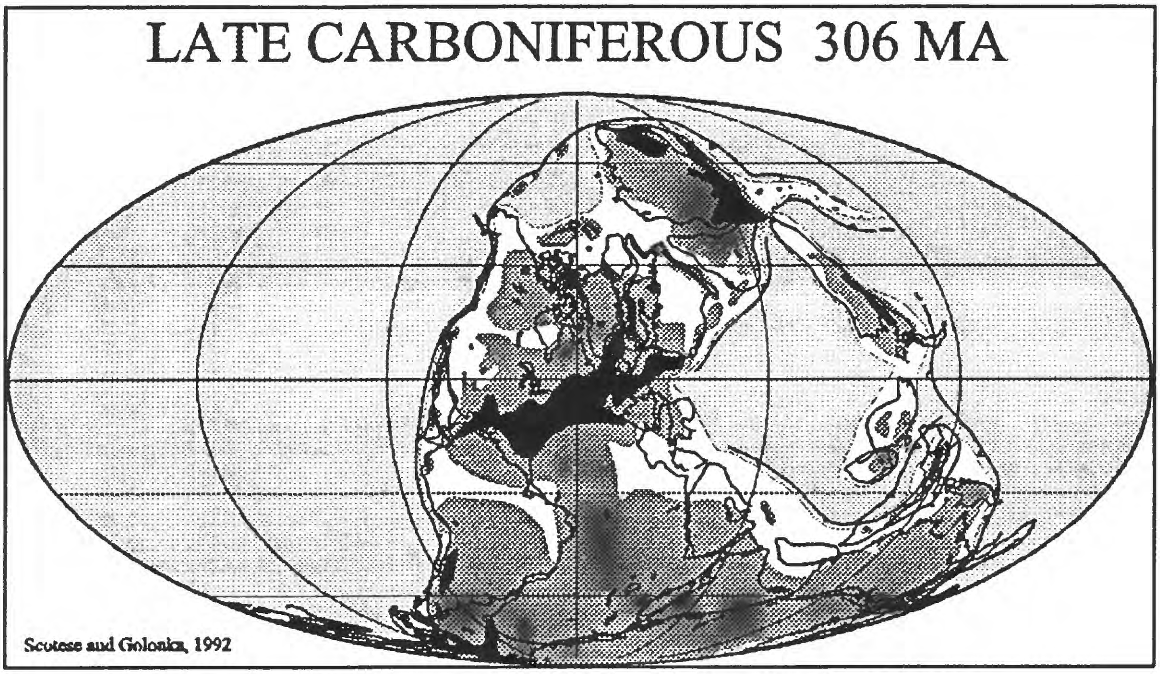


Figure 8. Paleogeographic reconstruction of Late Carboniferous (306 MA).

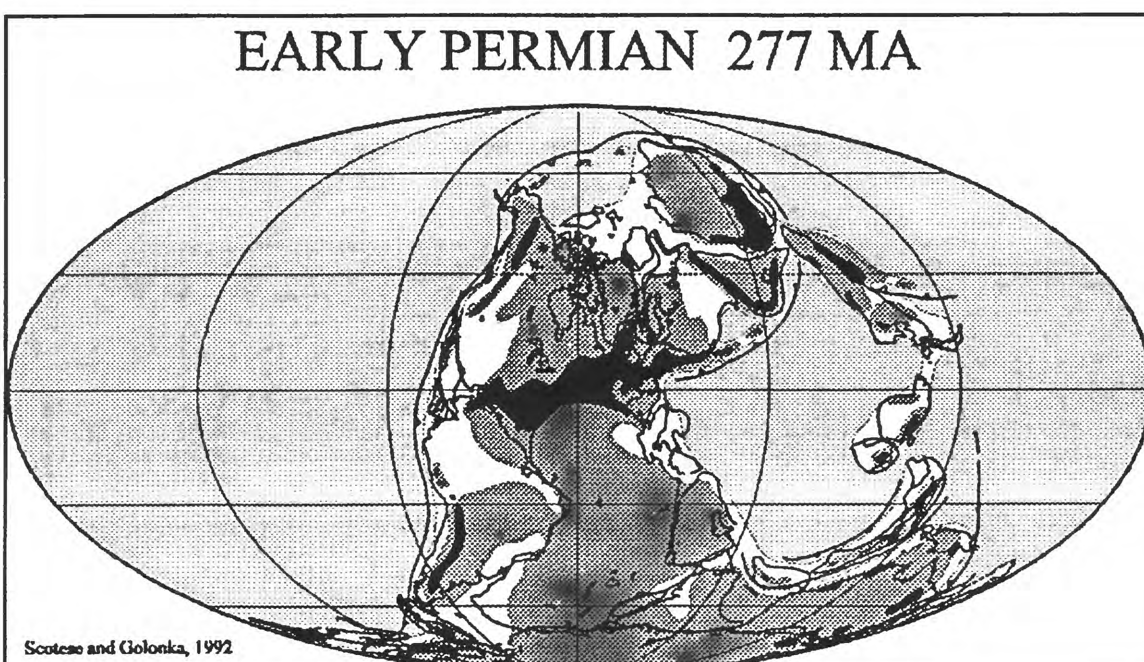


Figure 9. Paleogeographic reconstruction of Early Permian (277 MA).

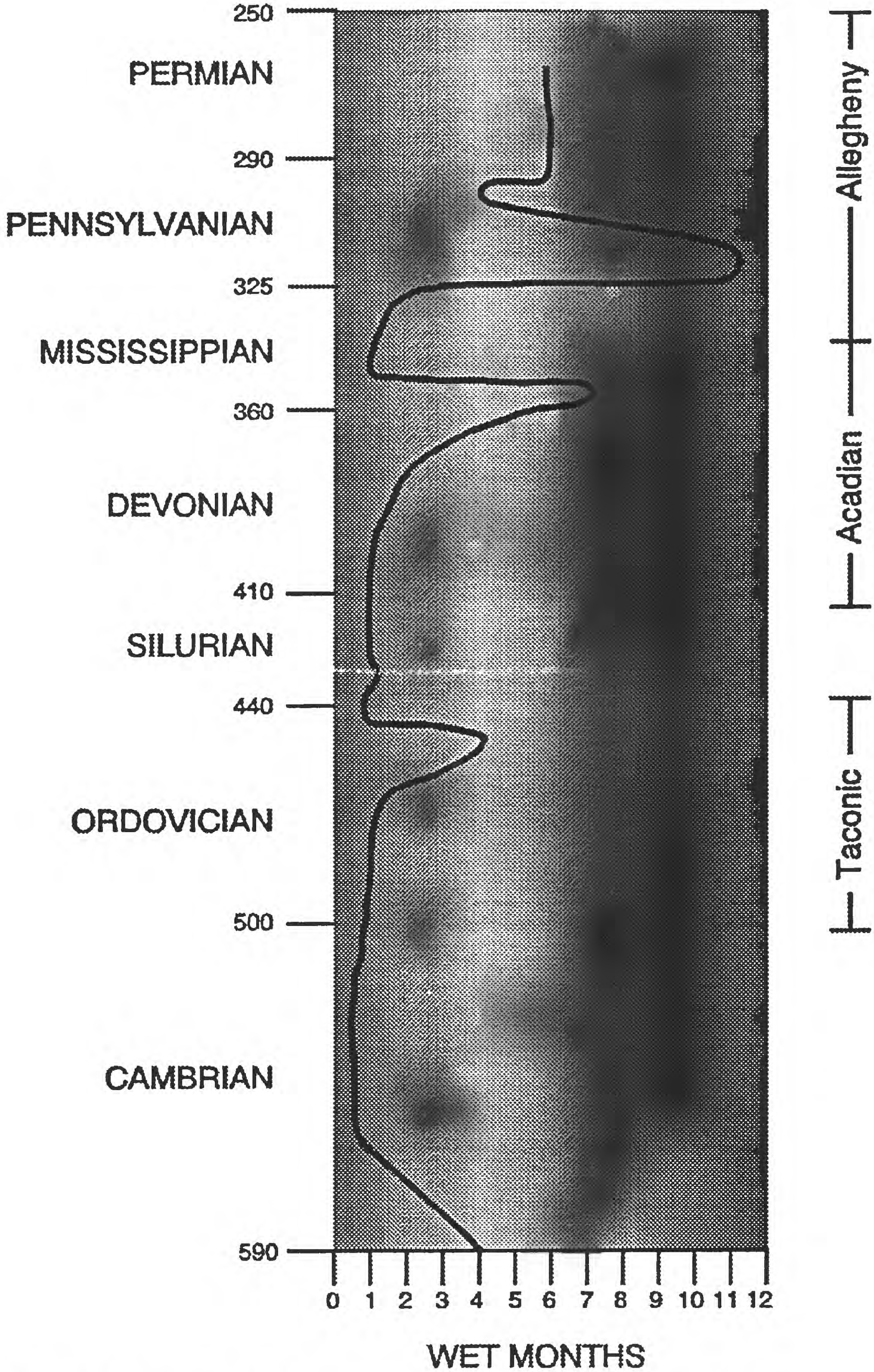


Figure 10. Paleozoic paleoclimate curve, central Appalachian basin.

As pointed out above, continental drift may explain some of the long-term climate change in the Appalachian basin, but it by no means explains all of such change. Some long-term climate change may be better explained by alteration of zonal circulation by mountain building. Such effects are well known, as illustrated by the development of the Asian monsoon in response to the formation of the Himalayan Mountains and the Tibetan Plateau, when the Indian subcontinent collided with Asia. Similar tectonic controls on late Paleozoic paleoclimate have been suggested for the development of a humid climate in the early Pennsylvanian by the formation of an equatorial high plateau which pinned the intertropical convergence zone to the plateau causing a permanent low pressure cell and high rainfall (Rowley et al., 1985). This permanent low pressure cell was modulated by orbital forcing parameters and southern hemisphere glacial conditions (Cecil, 1990). The Taconic and Acadian orogenies also may have effected long-term climate change from regional orographic to global scales although such effects have not been documented nor are they well understood. Although difficult to quantify, paleo-ocean circulation is yet another control on long-term climate change.

It is becoming increasingly apparent that intermediate- to short-term climate change, driven by orbital parameters, plays a major roll in sedimentation and stratigraphy. The lithostratigraphic signal induced by intermediate- to short-term climate change is somewhat suppressed during periods of long-term aridity or humidity, but not obliterated as is illustrated at Ordovician, Silurian, and Pennsylvanian stops. Orbital forcing is an important control on variation in sediment supply because orbital parameters have a marked effect on incoming solar radiation (insolation) which results in variation in seasonality of rainfall. As illustrated in Fig. 1A, it is the degree of seasonality of rainfall, rather than total annual rainfall, that controls erosion and siliciclastic sediment supply.

STOP 1: LATE PRECAMBRIAN AND EARLY CAMBRIAN CHILHOWEE GROUP, U.S. 340, WEVERTON, MARYLAND.

lat. 77°40.47'N, long. 39°19.29'W, Harper Ferry, WV, 7½' Quadrangle

Introduction

At this stop we will examine the Chilhowee Group of the northern Blue Ridge Physiographic Province. The Chilhowee Group, the basal Cambrian clastic unit in the northern Blue Ridge, is a main ridge-forming unit of the Blue Ridge. The Blue Ridge of northern Virginia, Maryland, and Pennsylvania consists of a large overturned fold called the South Mountain Anticlinorium (Cloos, 1971). The South Mountain Anticlinorium contains Grenville basement (1.1 by) at its core. The flanks are made up of Chilhowee strata. The eastern flank, known as Catoctin Mountain in Maryland and the Bull Run Mountains in Virginia, is the normal limb of the South Mountain Anticlinorium and dips southeastward at approximately 35 degrees. The western limb of the anticlinorium, know as South Mountain in Maryland, and Short Hill, in Virginia, is overturned and also dips to the southeast, but at a much steeper angle than Catoctin Mountain. The Grenville basement complex is overlain, in ascending order, by Late Proterozoic sediments of the Swift Run Formation, basaltic lava flows of the Catoctin Formation, and clastics of the Chilhowee Group. These units are generally termed the Blue ridge cover sequence. Both the Swift Run and Catoctin Formations exhibit considerable syndepositional thickness variation. Their geometries suggest that they were deposited in linear basins presumably formed by attenuation of the underlying basement complex (Schwab, 1972). Most of the Chilhowee units, on the other hand, appear to be more or less continuous throughout the northern Blue Ridge, indicating that much of the Late Precambrian topography had been filled prior to its deposition. At Stop 1 we will examine the type section of the Weverton Formation at the southern terminus of South Mountain and discuss the initial episodes of deposition within the Appalachian Basin (Fig. 11).

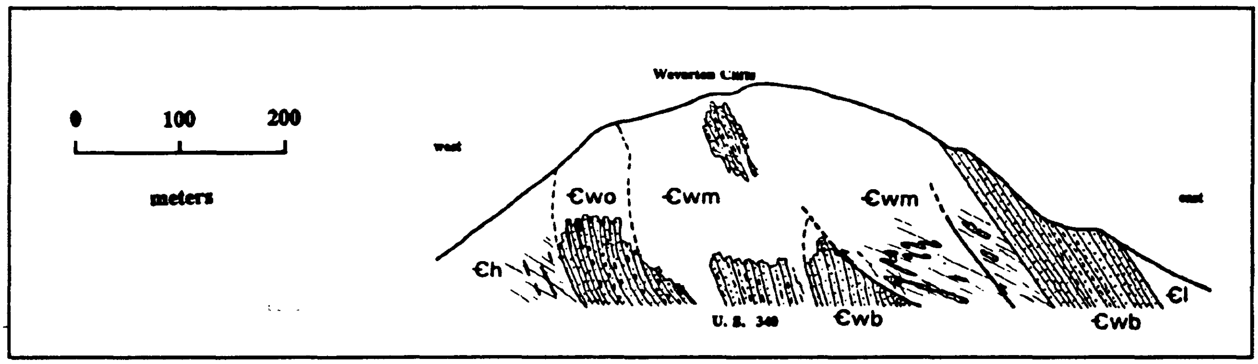


Figure 11. Diagrammatic sketch showing stratigraphy and structure of the Weverton Formation at the Maryland Heights section at the terminus of South Mountain. Ꞓwb, Ꞓwm, and Ꞓwo are the Buzzard Knob, Maryland Heights, and Owens Creek Members respectively of the Weverton Formation and Ꞓh is the Harpers Formation.

Lithostratigraphy

The Chilhowee Group in the northern Blue Ridges consist of in ascending order: the Loudoun, Weverton, Harpers and Antietam Formations. These units generally overly the Catoctin Formation, but at this location the Catoctin is absent, and the Chilhowee units sit directly on top of the Grenville basement rocks. The basal unit of the Chilhowee Group, the Loudoun Formation, consists of intercalated black tuffaceous, phyllites and polymictic, conglomerate. The Loudoun Formation exhibits considerable variation in thickness and extent. This patchy distribution has led some workers to abandon the name Loudoun and assign the conglomeratic intervals to the Weverton Formation, and the tuffaceous phyllites to the underlying Catoctin Formation (see Nunan, 1979). The Loudoun can vary from as little as 2 m to more than 70 m. At Stop 1 the Loudoun is represented by several loose blocks of gray, tuffaceous phyllite, and it is estimated that more than 30 m of the formation is present.

Weverton Formation. The Weverton Formation, unlike its subjacent units, is relatively continuously distributed throughout the northern Blue Ridge. It has been subdivided into three members by Brezinski (1992) who named these units the Buzzard Knob, Maryland Heights, and Owens Creek Members, in ascending order (Fig. 11).

Buzzard Knob Member : The Buzzard Knob Member of the Weverton Formation is the single most significant ridge-forming unit in the northern Blue Ridge. The Buzzard Knob Member consists of medium-bedded, light-gray to greenish-gray, chloritic, coarse-grained to very coarse-grained, subarkose to quartzose arenite. The cross bedding within this unit is poorly defined, and consists mainly of tabular to planar sets as well as horizontally stratified beds. At this location the basal 10 meters consist of a very coarse-grained sandstone to granular, feldspathic arenite. The upper 35 meters comprise a resistant, light-gray to medium-gray, coarse-grained quartzite with dusky-blue, grayish-olive, and grayish-yellow bands. Trough cross bedding is much more prevalent in this part of the unit although cross bed foresets are restricted to individual beds. Separating the two resistant intervals is approximately 10 m of interbedded, light-gray to dusky-yellow, platy, micaceous sandstone and light, olive-gray, quartzose siltstone. This interval weathers more readily than does the surrounding quartzite layers, and thus gives the member an apparent bifurcation that is manifested in less well exposed areas of the two separate arenite units.

Maryland Heights Member: The middle member of the Weverton Formation, named the Maryland Heights Member, is difficult to accurately and thoroughly describe, and varies from 100 to 150 meters in thickness. The unit is strongly deformed and less resistant to weathering than the massive units that make-up the upper and lower parts of the Weverton. The Maryland Heights Member is generally composed of alternating medium-dark-gray, conglomeratic graywacke, and dark-gray phyllite and metasiltstone. The incompetent metasiltstone and phyllite, being situated stratigraphically between the underlying and overlying resistant members are deformed to the degree that stratigraphic characteristics are obscured.

At this location the Maryland Heights Member consists of olive-gray, grayish-black, and olive-black, quartzose metasiltstones containing thin intervals, 0.33- 0.6 m thick, of conglomerate with white quartz pebbles and 3- to 30-foot intervals of gray and greenish-gray arenite and graywacke. The thicknesses of the metasiltstone intervals are obscured by isoclinal folds and pervasive foliation. Near the middle of the unit is a 25-m thick interval of medium-gray quartzite, which is nearly identical to the upper resistant quartzite of the underlying Buzzard Knob Member exposed at another point in the road cut. Folding can be observed within these units. This quartzite, which is truncated above road level by a small fault, has been interpreted to be a fragment of the Buzzard Knob Member (Southworth and Brezinski, 1996, Fig. 11).

Owens Creek Member: The upper member of the Weverton consists of another ledge-forming quartzite termed the Owens Creek Member (Brezinski, 1992). Although this member is more resistant and much better exposed than the Maryland Heights Member, rarely does it form the prominent ledges and ridge crests common to the Buzzard Knob Member. At this location, more than 35 m of the Owens Creek Member crop out. The lower 25 m consist of medium- to medium-dark-gray, medium-bedded, coarse-grained, cross bedded conglomeratic sandstone with numerous interbeds of dark-gray, sandy siltstone as well as conglomerate, which contains white, pink, and bluish quartz pebbles. Many of the beds in this interval exhibit an upward fining. The upper 7 - 10 m are composed of medium-light-gray to greenish-gray, medium-bedded, coarse-grained sandstone that is diagnostically trough cross bedded. The contact with the overlying Harpers Formation is not exposed at this location. From other locations the contact is gradational, with progressively thicker interbeds of shaly Harpers punctuating the sandstones of the upper Weverton.

Harpers Formation. Overlying the Weverton Formation is an interval of shale, siltstone, sandstone and quartzite called the Harpers Formation. The Harpers Formation is characterized by dark-gray to olive-black, medium-grained sandstone and siltstone in the lower 30 to 50 M. Above this basal sandy interval the Harpers consists of greenish-black to brownish-black, highly cleaved siltstone, fine-grained sandstone, and some silty shale. Somewhat higher in the stratigraphic section the first distinct trace fossils are present. These are mainly in the form of the vertical burrow *Scolithus.*

Several small exposures of the lower Harpers Formation are evident to the west. However, these are intensely sheared owing to the proximity of these exposures to a large thrust fault that is present approximately 200 m to the west of the Weverton-Harper contact.

Depositional environments

No detailed depositional studies have been conducted on the Chilhowee strata of the northern Blue Ridge of northern Virginia and Maryland. However, the similarity of vertically juxtaposed lithologies between the Weverton at this location and the correlative Unicoi Formation of central and southern Virginia allows extrapolation of correlative depositional processes. The following discussion is based on the work of Schwab (1972) and Simpson and Eriksson (1989) and their studies on the coeval Unicoi Formation of Virginia.

The underlying Swift Run and Catoctin Formations represent rift sedimentation and volcanism that filled grabens within the basement complex during extension (Wehr and Glover, 1985). The lack of Catoctin basalts at this location indicates that this site was located on an erosional horst between the southern Pennsylvanian graben and the central Virginia graben . The patchy distribution of the Loudoun Formation, as well as the apparent interfingering of the tuffaceous shales of the formation with the lavas of the underlying Catoctin Formation suggests that these two formations may have been in part coeval. The localized distribution of the cobble conglomeratic facies of the Loudoun appears to reflect localized depocenters, probably within small fault-created basins in the underlying Proterozoic rocks. The coarseness of these strata suggests deposition by high-gradient streams. An alluvial fan environment of deposition is suggested for this unit.

The planar bedded and trough cross bedded facies of the Buzzard Knob Member of the Weverton Formation appears to be similar to facies association C of the Unicoi Formation (Simpson and Eriksson, 1989). These lithologies were interpreted to be consistent with a distal facies of braided fluvial plain.

The interbbed shale and thin sandstone lithologies of the Maryland Heights Member are interpreted to represent alluvial plain deposition. In this scenario the shaly strata, including the thin (<1 m) sandy conglomerates, are suggestive of overbank deposits and the thicker sandstone (>10 m) are channel deposits. The Owens Creek Member is much coarser grained and exhibits thicker, trough cross bedded sandstones than does any subjacent unit of the Weverton. A similar relationship is present in the upper Unicoi of Virginia. This association of lithologies is interpreted to be formed in a shoreface or tidal setting (Simpson and Eriksson, 1989). Schwab (1972) interpreted this part of the stratigraphic section as fluvial channel sandstones.

The Harpers Formation exhibits a vertical arrangement of lithologies that suggest a transgressive relationship (Schwab, 1971; 1972). The lower Harpers contains numerous, *Scolithos*-burrowed sandstone intervals which is suggestive of littoral and sublittoral deposition (Brezinski, 1992). The upsection increase in shaly strata suggest a progression from nearshore to more offshore deposition within the lower Harpers.

Tectonics and Depositional Sequences

The Late Proterozoic to Early Cambrian depositional pattern of the central Appalachians suggests that the Chilhowee Group represents the progression of depositional environments from an alluvial fan (Loudoun) to braided and meandering fluvial (Weverton) to near shore marine (upper Owens Creek Member, lower Harpers) and deeper shelf environments (Harpers) (Table 3). This environmental progression indicates a depositional onlap. The resulting transgressive episode, which began in the latest Proterozoic, is equivalent to Sequence 1 of Read (1981). This apparent third-order eustatic event and the Late Proterozoic rift-basins and their accumulated sediments, resulted in the transitions from rift sedimentation to trailing margin sedimentation (Fichter and Diecchio, 1986).

Unit	Lithology	Environment	Tectonic Regime
Harpers Fm.	Dark, silty shale, and thin sandstone	shallow marine	transgressive-
Weverton Fm.	cross bedded arkosic and conglomeratic sandstones	meandering fluvial ↕ braided fluvial	trailing margin deposition
Loudoun Fm.	tuffaceous shale and conglomerate	alluvial fan-rift valley	
Catoctin Fm.	basaltic lava flows	extensional, rift volcanics	extension and rifting
Swift Run Fm.	arkosic sandstone and varved shales	rift valley	

Table 3. Interpreted stratigraphic relationships at Stop 1 and proposed depositional environments extrapolated from Schwab (1971; 1972), Simpson and Eriksson (1989) and interpreted tectonic regime from Wehr and Glover (1985, Table 2) and Fichter and Diecchio (1986, Fig. 1)

Climate of the Late Precambrian and early Cambrian

Climate interpretations of the Late Precambrian and the early Cambrian presented herein are primarily based on interpretations of lithologies and the depositional environment interpretations cited above. The massive influx of siliciclastic material in the Chilhowee Group is consistent with a moist subhumid climate (Fig. 1A, Table 1). Such a climate is compatible with a paleogeographic location of approximately 40° south (Scotese and Golonka, 1992). The paucity of calcareous materials in Chilhowee strata is a further indication of a subhumid or wetter climate setting where fluvial systems are low in dissolved solids precluding syndepositional precipitation of calcareous materials.

STOP 2: ORDOVICIAN BEEKMANTOWN THROUGH CHAMBERSBURG LIMESTONE

Lat. 39° 36.99', Long. 77° 52.99', C&O Canal Towpath, mile post 103, Hedgesville 7½' quadrangle.

Introduction

At this stop we are on the western flank of the Massanutten Synclinorium, a broad fold that is bordered on the east by the South Mountain Anticlinorium. The section here begins in the Lower Ordovician Stonehenge Limestone and continues eastward (and up section) along the C&O Canal through the Lower to lower Middle Ordovician Rockdale Run Formation, the lower Middle Ordovician Pinesburg Station Dolomite, into Middle Ordovician St. Paul Group, and Chambersburg Limestone. The basal strata of the Martinsburg Formation are the uppermost strata exposed.

Lithostratigraphy

The lowest strata encountered are assignable to the Stonehenge Formation. The Stonehenge is 150 to 250 m thick, although only the upper 30 m are exposed at this location. Three members of the Stonehenge are recognized. The basal member, the Stoufferstown Member is composed of ribbony limestone interbedded with thin intraclastic grainstones 3 to 6 cm thick. The middle member of the Stonehenge, unnamed, consists of thick-bedded, thrombolitic algal limestone, and rarely laminated limestone. The upper member is also unnamed and is lithologically similar to the Stoufferstown Member. The contact between the Stonehenge and the overlying Rockdale Run Formation is generally placed at the lowest tan-weathering laminated dolomitic limestone. This dolomite reflects the onset of peritidal cyclic sedimentation that characterizes the Rockdale Run Formation.

The Rockdale Run Formation is approximately 850 m thick and consists throughout most of its thickness of peritidal cycles 1 to 5 m thick that are probably fifth-order in magnitude. The lithologic character of these cycles varies upsection with certain intervals containing cycles with thick limestone and thin dolomite subcycles and other intervals containing thicker dolomite and thin limestone subcycles (Fig. 12A and 12B).

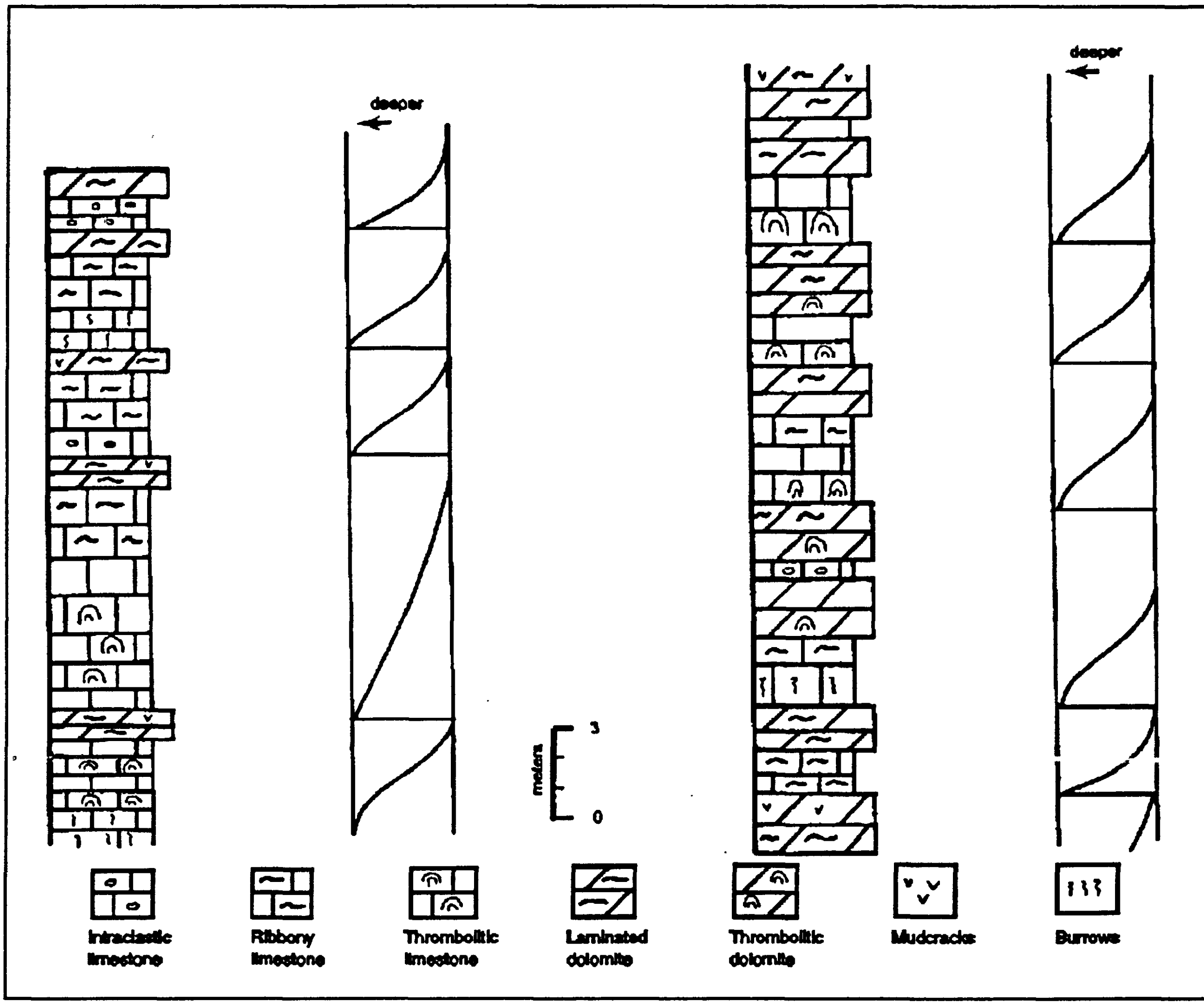


Figure 12A. Fifth-order cycle variations within the Rockdale Run Formation at Stop 2. Left column is limestone dominated subcycles with interpreted sea level curve (Hardie, 1989). Maximum water depth is during limestone deposition shallowing upward to peritidal conditions during dolomite deposition. Right column is from dolomite dominated subcycles.

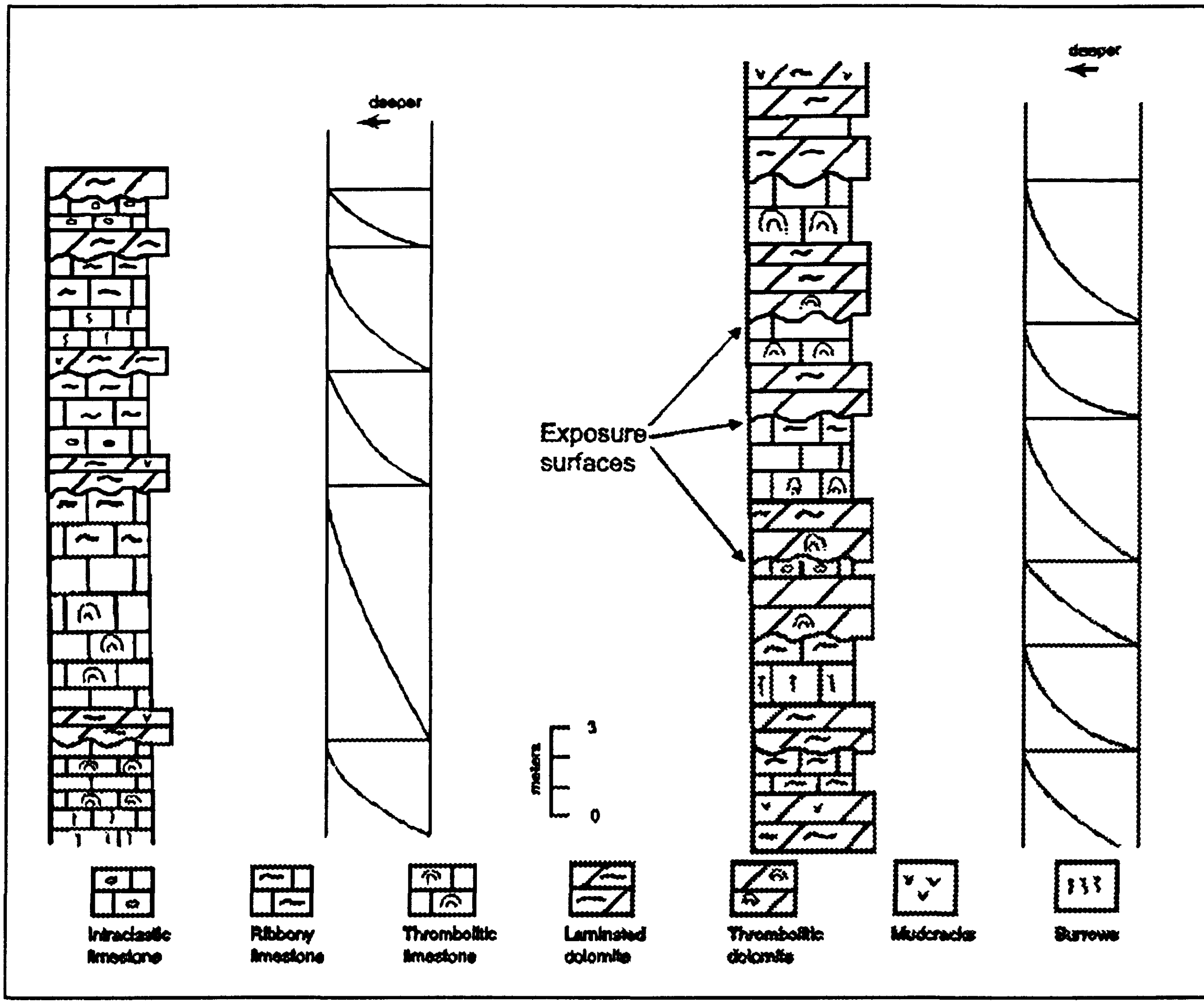


Figure 12B. Fifth-order cycle variations within the Rockdale Run Formation at Stop 2. Left column is limestone dominated subcycles with re-interpreted sea level curve based on exposure surfaces at the top of the limestone beds. Right column is from dolomite dominated subcycles.

Sando (1957) recognized three subdivisions to the Rockdale Run Formation in this region. He noted that the basal 30 to 50 m contained large silicified algal masses. Above these basal cherty beds the Rockdale Run Formation contained abundant oolitic beds. Much higher in the formation a thick dolomite interval is prevalent. Sando (1957, Plate 4) also recognized a number of vertically distributed faunas. These faunas include the *Bellefontia* fauna within the upper Stonehenge Formation, and macrofaunas characterized by *Lecanospira*, *Archaeoscyphia*, *Diparelasma*, and *Syntrophopsis-Clelandoceras* in the Rockdale Run Formation, in ascending order (Fig. 13). Hardie (1989) has shown that the faunas within the Stonehenge and lower Rockdale Run Formations can be equated with large scale deepening episodes that he believed were third-order in magnitude. This relationship is shown in Figure 13. The variations between limestone versus dolomite dominated cycles are the result of the large scale deepening episodes recognized by (Hardie 1989). It appears that those fifth-order cycles which formed near or at the transgressive apex of the larger scale cycles are limestone dominated, whereas fifth-order cycles that have been interpreted to have formed during regression or at the regressive nadir are dolomite dominated. Our observations in the Rockdale Run, however, indicate that regression was rapid and resulted in exposure surfaces at the top of the subtidal limestone units rather than at the top of the peritidal dolomite. Exposure at the top of the subtidal limestones is indicated by pedogenic brecciation and subaerial crusts (Fig. 12b). These subaerial exposure surfaces represent fourth or fifth order sequence boundaries. The peritidal dolomite formed during relatively slow transgression and is part of the transgressive systems tract.

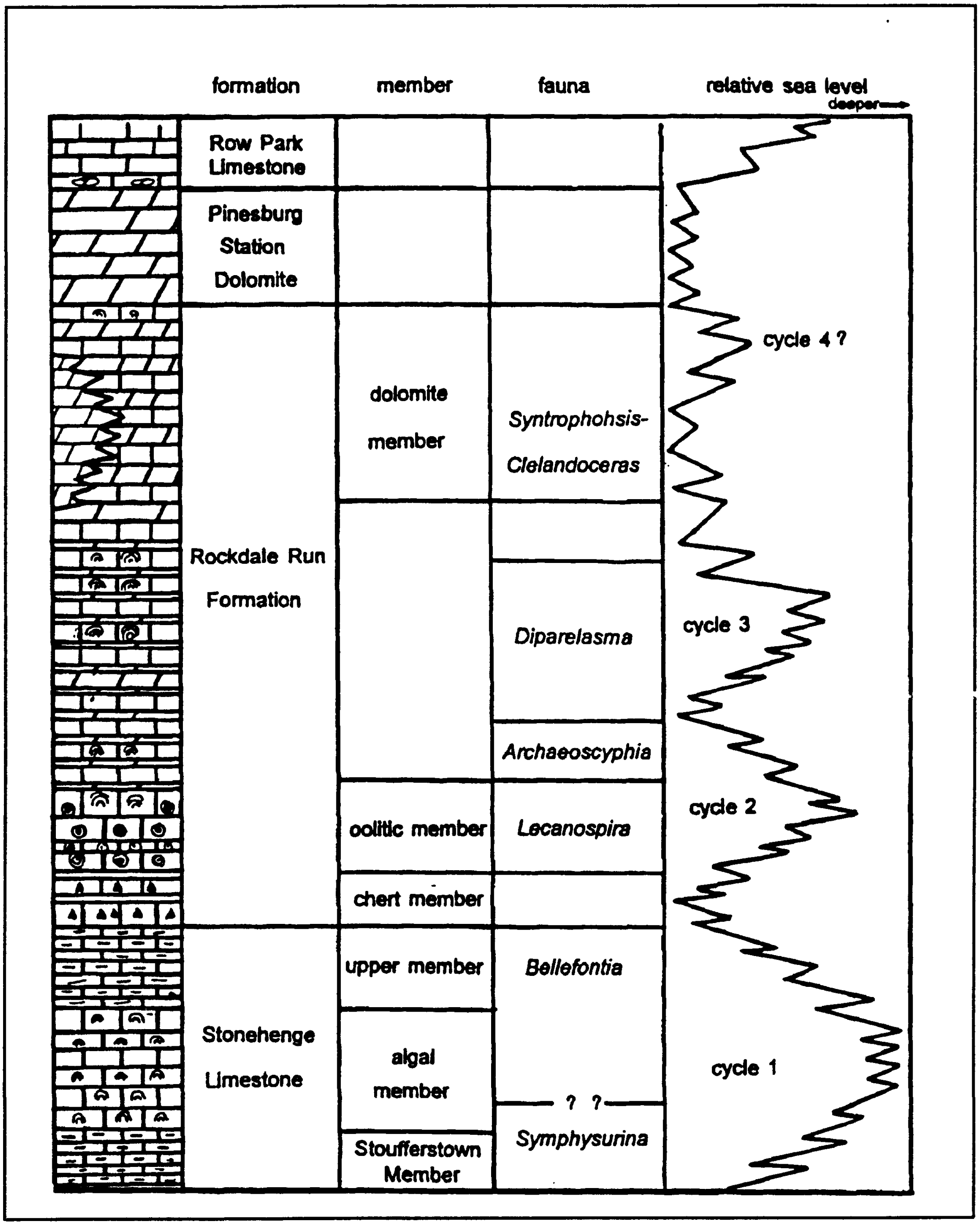


Figure 13. Relationships among stratigraphy, faunas and transgressive-regressive packages for the early Ordovician Stonehenge and Rockdale Run Formations. Larger scale deepening episodes are labeled cycles 1 - 4 and are third- to fourth-order in magnitude.

Within the dolomite member of the upper Rockdale Run (*sensu* Sando), cycles are difficult to recognize inasmuch as many of the internal features have been obliterated by diagenetic overprinting. However, it does seem likely that this dolomite tongue was deposited during a major sea-level low stand or slowly rising sea level during transgression.

Overlying the Rockdale Run Formation is the uppermost formation of the Beekmantown Group, the Pinesburg Station Dolomite. The Pinesburg Station Dolomite is 120 to 160 m thick and consists of cherty, laminated dolomite and burrow-mottled dolomite. The Pinesburg Station Dolomite is unfossiliferous, save for conodonts and numerous stromatolitic intervals. The Pinesburg Station Dolomite is overlain by a Middle Ordovician succession of interbedded limestone and dolomite, termed the St. Paul Group by Neuman (1951). Neuman subdivided the St. Paul Group into a lower formation, the Row Park Limestone, and an upper New Market Limestone. The Row Park Limestone consists of light gray, massive, micritic to fenestral limestone with thin interbeds of laminated dolomitic limestone. It is approximately 85 m thick. The overlying New Market Limestone is characterized by interbedded, medium-bedded, light gray, burrow-mottled limestone, stromatolitic limestone, and gray and tan, laminated dolomite and dolomitic limestone. It is capped by a light to medium gray, micritic limestone. The New Market is approximately 67 m thick. Fossils are not common in either of the St. Paul Group formations, however, they are present within horizons in the upper part of the New Market Limestone. The main macrofaunal components are macluritid snails. Conodonts occur throughout these units. Overlying the St. Paul Group is an interval of medium to dark gray, medium- to wavy bedded and even nodular-bedded, shaly, fossiliferous limestone termed the Chambersburg Limestone.

Depositional Environments

The Stonehenge Formation was deposited during a major deepening episode that was probably third-order in magnitude and appears to exhibit a symmetrical facies distribution (Hardie, 1989; Taylor et al., 1993). The sea level drop that was concurrent with the regression at the termination of Stonehenge deposition produced deposition of the fifth-order peritidal cycles of the basal Rockdale Run Formation. The peritidal mudflats that existed throughout most of the Rockdale Run deposition were periodically submerged by shallow subtidal waters that indicate larger scale cycles of a fourth or third- order are superimposed on the sequence. The thick dolomite in the upper part of the Rockdale Run Formation was previously thought to record a significant shallowing episode for the central Appalchians. Our observations, however, indicate that at the scale of the fifth order lithologic cycles, subtidal limestone deposition was followed by abrupt regression and subaerial exposure. Primary dolomite was deposited on the exposure surfaces during subsequent transgression and deepening. This cyclic sedimentation continued during the deposition of the Pinesburg Station Dolomite at the end of Beekmantown deposition.

Mitchell (1982) discussed in detail the vertical arrangement of lithologies within the St. Paul Group of Maryland. The vertical arrangement of lithologies within the Pinesburg Station Dolomite to New Market Limestone led Mitchell to interpret the sequence as two separate transgressive and regressive pairs.

The final deepening event in the Middle Ordovician of the central Appalachian basin produced the Chambersburg Limestone. This deepening episode resulted from the onset of downwarping that occurred with the onset of the Taconic orogeny. This deepening provided the accommodation space for the graptolitic black shales of the overlying Martinsburg.

Climate of the Early and Middle Ordovician

In contrast to the moist subhumid climate of the late Precambrian and early Cambrian at Stop 1, long-term aridity prevailed during deposition of Early Ordovician strata at Stop 2. Intermediate- to short-term climates fluctuated from arid to semiarid. Paleogeographic reconstructions indicate that deposition at Stop 2 occurred in the arid high pressure belt at approximately 30° south. Indications for long-term aridity at Stop 2 include: 1) the lack of fluvial siliciclastic influx, 2) stratigraphically equivalent evaporites to the west in the depocenter of the basin (Ryder et al., 1992), 3) intervals of nodular chert that presumably are replacements of gypsum or anhydrite, and 4) primary dolomite resulting from probable hypersaline conditions in peritidal environments.

At a continental scale, the eolian St. Peter Sandstone of the midcontinent was also being deposited during part of this time. Contemporaneous deposition in the sediment starved Ouachita basin consisted of deep water shale, chert, and limestone (Stone et al., 1986, p. 19). Sediment starvation in the deep water Ouachita basin during the Ordovician is consistent with low fluvial sediment supply to continental margins under arid conditions (Fig. 1A). Interestingly, the pulses of quartz sand deposition in the Ouachita trough represented by the Crystal Mountain and Blakely Sandstones appear well correlate with the central Appalachian shallowing episodes represented by the initiation of Rockdale Run deposition and the peritidal dolomite deposition of the upper Rockdale Run through Pinesburg Station, respectively.

The interpreted sea level history at Stop 2 is best explained by a glacial model even though direct evidence for Early and early Middle Ordovician glaciation is lacking (Frakes et al., 1992). The third order cycle of subtidal deposition of the Stonehenge followed by deposition of the Rockdale Run in peritidal environments may be best explained by greenhouse followed by ice house conditions. The fourth or fifth order cycles within the Rockdale Run have inferred sea level curves (Fig. 12B) that are similar to other glacial periods. Exposure surfaces at the top of subtidal limestone beds represent fourth or fifth order sequence boundaries. Following subaerial exposure in the fourth or fifth order cycles of the Rockdale Run, sea level appears to have slowly risen during deposition of the peritidal dolomite followed by subtidal carbonates which, in turn, was followed by a rapid fall and subaerial exposure (Fig. 12B). If the third through fourth order cycles were driven by the presence or absence of continental glaciation, then the third order Stonehenge deepening is likely the result of greenhouse conditions, whereas the fourth and fifth order cycles of the Rockdale Run and Pinesburg Station may be the product of long-term ice house conditions and intermediate to short-term glacial cycles and the accompanying sea level and climate cycles.

From a practical perspective, climate considerations become important in predicting porosity and permeability in carbonates and sandstones. Primary dolomitization in carbonates as well as texturally and mineralogically mature quartz arenites deposited by eolian processes may be the result of arid conditions. Both dolomitized limestone and quartz arenites (Stops 3 and 6) are often targeted as potential petroleum reservoirs.

STOP 3: U.S. SILICA PROPERTY ALONG SANDY MILE ROAD

Lat. 39°42.72'N, Long. 78°13.82'W, Hancock MD 7½' Quadrangle

Introduction

At this stop we will examine the Silurian-Devonian contact interval. The main units exposed are the Keyser Formation, which occurs in an abandoned quarry just to the east, and the Lower Devonian Oriskany Sandstone. The Keyser Formation is predominately a limestone unit and represents a Late Silurian submergence of the Appalachian Basin. The Oriskany on the other hand is a carbonate cemented sandstone, in some places grading into an arenaceous limestone, and is perhaps the most prolific gas-producing unit in the central Appalachians.

Lithostratigraphy

Helderberg Group

Although much of the Helderberg Group is encompassed by this stop only about 65 m of the lower part of the basal unit, the Keyser Formation, are accessible (Brezinski 1996). The Keyser Formation is exposed in the abandoned quarry located east of the road. At this location nearly the entire Keyser Formation is composed of nodular-bedded, argillaceous, fossiliferous lime wackestone. This interval contains thin (<5 cm) pelmatozoan packstone or grainstone intervals that are commonly graded and exhibit hummocky cross-stratification. The uppermost 10 m of the exposed Keyser becomes more regularly bedded and contains noticeably more and thicker layers of grainstone-packstone. The lithologies exposed at this location are included within the nodular facies of Head (1969) and the shaly/nodular-bedded/cherty limestone facies of Dorobek and Read (1986).

Although these rocks are highly fossiliferous, most faunal components have been comminuted. The most common faunal components include abundant ramose and fenestrate bryozoans, rugose corals, tabulate corals, trilobites, brachiopods, and pelmatozoans. The regularly bedded intervals near the top of the exposure contain brachiopod coquinas and more pervasive indications of current activity such as cross bedding and graded beds.

Based on conodont ranges, the Silurian/Devonian contact can be placed within the upper Keyser near the contact with the overlying New Creek Limestone (Denkler and Harris, 1988). Consequently, the Keyser Formation here is almost totally Silurian (Pridolian) in age. Between the Keyser exposure and the outcrop of the overlying Oriskany Sandstone farther along the road is a covered interval approximately 35 m thick. Based on regional stratigraphic relationships this covered interval contains the intervening units of the New Creek Limestone Corriganville Limestone, Mandata Shale, and Shriver Chert. New Creek Limestone consists of thick-bedded lime grainstone that is intensely cross bedded. The Corriganville Limestone is characterized by nodular-bedded, shaly limestone. The Mandata Shale and Shriver Chert are composed of dark-gray, calcareous shale and siliceous shale and siltstone. All of these intervening units are Early Devonian in age.

Oriskany

The Oriskany Sandstone at this location is approximately 50 m thick and consists of light gray, medium-bedded, fine- to medium-grained, carbonate cemented, quartz sandstone. Cross bedding is prevalent in only a few intervals. This unit is mined to the south in West Virginia by U.S. Silica, mainly as a glass sand. As a consequence of the carbonate cementation, this sandstone is easily leached on exposed surfaces, leaving behind a residue of pure quartz sand.

The Oriskany Sandstone is highly fossiliferous in some intervals. These fossiliferous intervals are concentrated near the top of the formation and the fossils occur in the form of internal and external molds. The faunal components are primarily large, thick-shelled, coarsely plicate brachiopods, and more rarely large, platyceratid gastropods. These coarsely plicate brachiopods are indicative of turbulent, current-swept environments. The preponderance of brachiopod valves are disarticulated and convex-up; this indicates that they have been rearranged post-mortem by traction currents.

Depositional Environments

The Helderberg Group has been examined from a regional perspective by Dorobek and Read (1986). Their interpretations are summarized in Figure 14. From their interpretations it is possible to recognize two separate transgressive-regressive episodes within the Helderberg Group of the central Appalachians. The first of these episodes is manifested in the Keyser Formation. The Late Silurian deepening episode that submerged the tidal flat facies of the underlying Tonoloway Limestone continued into the latest Silurian, completely drowning the Appalachian Basin. At maximum deepening the center of the basin was the site of deposition of nodular-bedded, argillaceous lime wackestone seen at this stop. Dorobek and Read (1986) interpreted this facies as a deeper-ramp deposit formed below fair-weather wave base. The burrowed character of the sediments and the paucity of shallow water features suggested water depths of up to 50 m. Head (1969) also interpreted these lithologies as occurring near the center of the Keyser sea way. The increased numbers of cross bedded intervals near the top of the exposure suggest that this is a regressive interval.

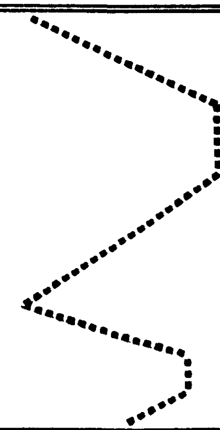
unit	lithology	environment	sea level deeper→
Oriskany Sandstone	white sandstone	shallow marine	
Shriver Chert	black shaly siltstone	basinal	
Mandata Shale	black shale	basinal	
Corriganville Limestone	nodular-bedded limestone	deep ramp	
New Creek Limestone	cross-bedded encrinites	tidally dominated shelf	
Keyser Limestone	nodular-bedded limestone	deep ramp	

Figure 14. Relationships between stratigraphy and sea level curve at stop 3.

The overlying New Creek Limestone marks the base of the second of the two transgressive episodes, and is interpreted as a skeletal sand bank that formed in water depth of less than 15 m (Dorobek and Read, 1986). The upsection transition of the New Creek encrinites into the nodular-bedded Corriganville Limestone indicates a continued deepening of the early Devonian sea. Like the Keyser lithologies at this stop, the Corriganville nodular-bedded lithologies are interpreted as deeper-ramp deposits. Upsection the Corriganville Limestone passes into the Mandata Shale and Shriver Chert. These two lithologies represent basinal lithologies that formed at the apex of the Helderberg transgression. Water depths are estimated in excess of 50 m (Dorobek and Read, 1986).

Presumably the regressive phase of this episode resulted in the shallow water deposition of the Oriskany Sandstone. The presence of cross-bedding, coarsely plicate and thick-shelled brachiopods, and the disarticulated, convex-up brachiopod valves suggest strong, current-swept conditions.

Paleoclimate

The origin of quartz-rich sandstones in Paleozoic strata in the Appalachian basin is generally attributed to multicycles of sedimentation, reworking within aqueous depositional environments, and (or) diagenesis. However, tropical paleoclimates also may have been a factor in both textural and mineralogical maturity. From the Ordovician through the early Devonian, the eastern United States was in the southern hemisphere tropical dry belt and moved northward into the equatorial tropical rainy belt in the Late Mississippian and Pennsylvanian. Texturally mature quartz and trace amounts of unaltered detrital feldspars in late Cambrian through Devonian quartz arenites appear to be indicative of a mechanical weathering by eolian processes in an arid or semiarid climate rather than chemical weathering in a humid tropical climate (Cecil et al., 1991). Grabau (1940, p. 220) suggested that the Oriskany was an eolian deposit that was reworked by a marine transgression. An eolian component may be equally viable for the origin for the Silurian Tuscarora Sandstone at Stop 6. Furthermore, the Oriskany and Tuscarora are associated with other strata that appear to be the result of deposition under arid conditions. Although both the Oriskany and parts of the Tuscarora sandstones were deposited in aqueous environments, they may have been blown into a marine environment analogous to the modern Persian Gulf where massive amounts of sand are being blown into a marine carbonate environment.

In contrast, late Mississippian and Pennsylvanian quartz arenites in the Appalachian basin tend to be texturally immature and nearly devoid of feldspars and, therefore, appear to be a product of chemical weathering under humid conditions rather than mechanical weathering under arid conditions. Regional occurrences of residual kaolin deposits of late Mississippian and early Pennsylvanian age, which are the result of chemical weathering in humid tropical environments, are consistent with this interpretation. Thus, mature sandstones in Cambrian through Devonian strata may, in part, be the result of mechanical processes in eolian environments, prior to deposition in aqueous systems, whereas chemical weathering appears to have been a primary factor in the genesis of quartz arenites in Mississippian and Pennsylvanian strata.

STOP 4: UPPER DEVONIAN AND LOWER MISSISSIPPIAN STRATA, I-68, SIDELING HILL, MD

Lat. 39°38.9''N, Long. 79°50.0'W, Bellegrove, MD, 7½' Quadrangle

Introduction

As we continue to move up stratigraphically we will now look at the Upper Devonian and Lower Mississippian strata exposed in a syncline at Sidling Hill, MD. At this stop we will examine the transition from the red alluvial plain deposition at the end of the Devonian to the coal-bearing strata of the early Mississippian.

Lithostratigraphy

The road cut through Sideling Hill exposes the Lower Mississippian Rockwell and Purslane Formations. The Rockwell Formation, the lower of the two units, extends from the lowest strata exposed up to the base of the first thick (> 10m) sandstone unit. The Purslane Formation, which is composed mainly of sandstone, is resistant to erosion and as a result forms the prominent ridge, Sideling Hill.

The Rockwell Formation consists of interbedded, thin sandstone, siltstone, and coaly and marine shale. This exposure of the Rockwell Formation possesses a polymictic diamictite at its base. This basal diamictite is an unsorted mass, containing clasts ranging in size from mud through boulders. Some of the larger cobbles and boulders are composed of granite, chert, and graywacke. At some locations large masses of the underlying Hampshire Formation, meters in diameter, are incorporated in the diamictite lithology. Overlying the diamictite is an interval, (10 m thick) of herringbone cross-bedded, medium- to coarse-grained, sandstone. Upsection from the herringbone cross-bedded sandstone is a 30-m interval of interbedded sandstone and siltstone with thin coal beds that contains marine fossils along some horizons. This interval has been correlated with the Riddlesburg Shale of central Pennsylvania, an early Mississippian marine transgression equivalent to the Sunbury Shale of Ohio (Bjerstedt, 1986a; Bjerstedt and Kammer, 1988; Brezinski, 1989a). Some of the brachiopods contained within this interval include lingulid brachiopods; the articulate brachiopods, *Rugosochonetes*, *Macropotamorhyncus*, and *Schuchertella*; as well as indeterminate bivalves (Brezinski, 1989b).

Overlying the Riddlesburg Shale is the upper Rockwell Formation. This 50 m interval contains interbedded channel-phase sandstones, 3 to 10 m thick, and reddish-brown and medium gray, root-mottled siltstone and mudstone.

The base of the overlying Purslane Formation is marked by the lowest thick (15 m) sandstone in the section. At Sideling Hill the lowest Purslane unit is a 25 m thick medium-grained, sandstone exhibiting epsilon cross-bedding and basal lag gravels. This unit is overlain by a thin interval (7 m) of root-mottled, reddish mudstone and then another (15 m) thick, cross-bedded sandstone unit. Overlying this second sandstone unit is an interval of interbedded coaly shale and thin coal. The ridge is capped by a third sandstone unit 30 m thick which is much coarser-grained than either of the lower units. This capping sandstone contains numerous cross-bedded conglomeratic intervals (Brezinski, 1989b).

Depositional Environments

The Lower Mississippian sequence at Sideling Hill represents a foreland prograding clastic wedge that progressively replaced marine deposits with coastal plain, meandering fluvial, and braided fluvial deposits (Fig. 15) (Brezinski, 1989a). The basal polymictic diamictite is a locally developed enigmatic lithology. The unsorted character, strike-localized extent, and presence of slump-blocks of the Hampshire lithologies led Bjerstedt and Kammer (1988) to interpret these deposits as a mud and debris flow that occupied an older sediment dispersal system. The consistent stratigraphic relationship between the diamictite and overlying tidal sandstone deposits further led Bjerstedt and Kammer to propose that these deposits represented tidal inlet-fill sequences created by the drowning of the pre-existing channels during the Riddlesburg transgression. Suter (1991) similarly proposed that the polymictic diamictite is the result of an estuarine debris flow.

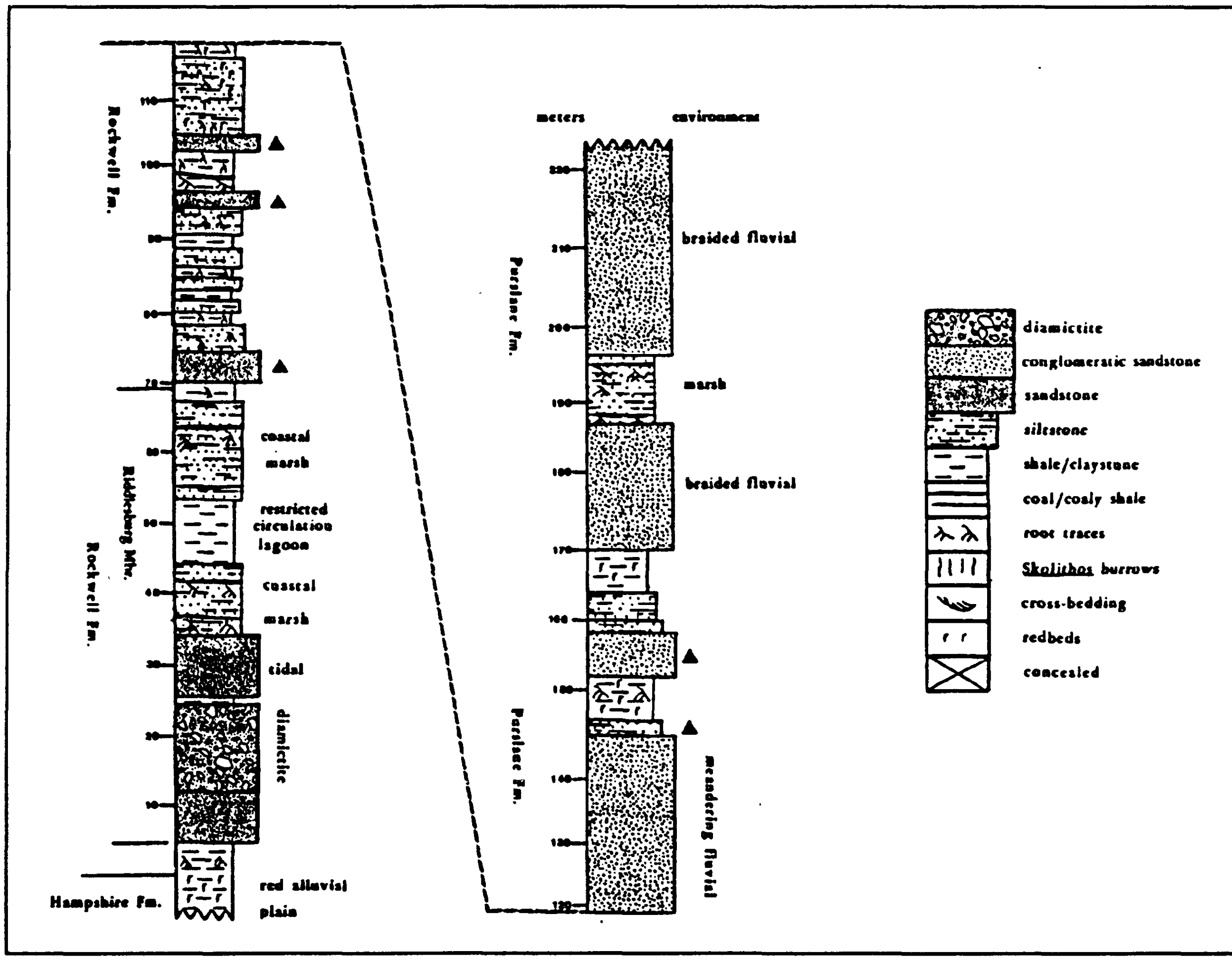


Figure 15. Stratigraphic section exposed at stop 4 and interpreted depositional environments (modified from Brezinski, 1989a).

The strata overlying the diamictite and tidal sandstone become increasingly darker in color and consist of interbedded coaly shales and siltstone. These coaly strata grade upsection into marine strata of the Riddlesburg Shale. The restricted brachiopod-bivalve fauna present in these shales indicates deposition in an estuarine or restricted lagoonal setting (Brezinski, 1989a). The return up section to coaly shales indicates progradation of the tidal marsh environments back over previously deposited lagoonal deposits. The upper Rockwell's characteristic interbedded thin channel sandstone and finer grained, overbank deposits that are pervasively root-mottled, indicate that the upper Rockwell was deposited in an alluvial/coastal plain environment.

The thick, channel-phase sandstones with epsilon cross-bedding and thin overbank deposits of the lower Purslane Formation indicate a channel-dominated, meandering fluvial environment. The coarser conglomeratic deposits in the upper part of the formation may indicate that gradients increased and environments changed from a meandering fluvial to braided fluvial facies near the end of Purslane deposition (Brezinski, 1989)(Fig. 15).

Late Devonian and early Mississippian paleoclimate

The late Devonian and early Mississippian strata exposed at Stop 4 are indicative of tropical paleoclimates that ranged from dry- to moist-subhumid to humid in sharp contrast to early Devonian arid conditions. Upper Devonian paleo-Vertisols and Histosols (coal beds), the influx of siliciclastic material, and a paucity of calcareous materials, are all indicative of relatively wet climatic conditions during the latest Devonian. Mineral paleosols include weakly to moderately developed non-calcic paleo-Vertisols. Such Vertisols are the result of a soil moisture regime and chemistry in which concentrations of exchangeable cations are low precluding precipitation of pedogenic carbonate. Non-calcic Vertisols primarily form under a moist subhumid climate. The soil structures, including mukkarra structures and slickensides, are clear and unequivocal evidence, however, for a climate with a distinct dry season (Retallack, 1989).

The early Mississippian sandstone exposed at the top of the cut is exceedingly wide spread and extends from New York and Pennsylvania (Pocono sandstone) at least as far south as Kentucky (Borden Formation) and Tennessee (Price Formation). This clastic wedge with its sporadic coal beds was a period during which massive amounts of sand were transported into the basin. Rainfall conditions ranged form dry subhumid to moist subhumid and rainfall was strongly seasonal (Fig. 1A). The transition from meandering steam deposition in the lower Purslane to braided stream deposition in the upper Purslane can be attributed to increasingly seasonal rainfall and a progression from a humid or moist sub-humid climate to dry subhumid conditions and finally arid conditions during deposition of the overlying MacCrady and Greenbrier Formations (Cecil, 1990). This interpretation is consistent with coal occurrences in the Pocono and equivalent units and evaporites, Aridisols, and carbonates in overlying Mississippian strata (Cecil, 1990). It is highly unlikely that these changes in paleoclimate were the result of long-term climate change associated with continental drift through paleolatitudes.

STOP 5. SILURIAN STRATA OF THE WILLS CREEK AND TONOLOWAY FORMATIONS, I-68

Lat. 39°41.48'N, Long. 78°39.37W, Evitts Creek 7½' Quadrangle

Introduction

At this stop, along the north side of I-68, we will have an opportunity to examine Late Silurian tidal flat facies of the Wills Creek Shale and Tonoloway Limestone. This section is discontinuously exposed though the upper Rose Hill Formation, Keefer Sandstone, McKenzie Formation, including the Rochester Shale Member at the base, with the Wills Creek and Tonoloway Formations at the top. The Bloomsburg Formation is not exposed. We will concentrate on the upper part of the section which is Late Silurian in age (Fig. 16).

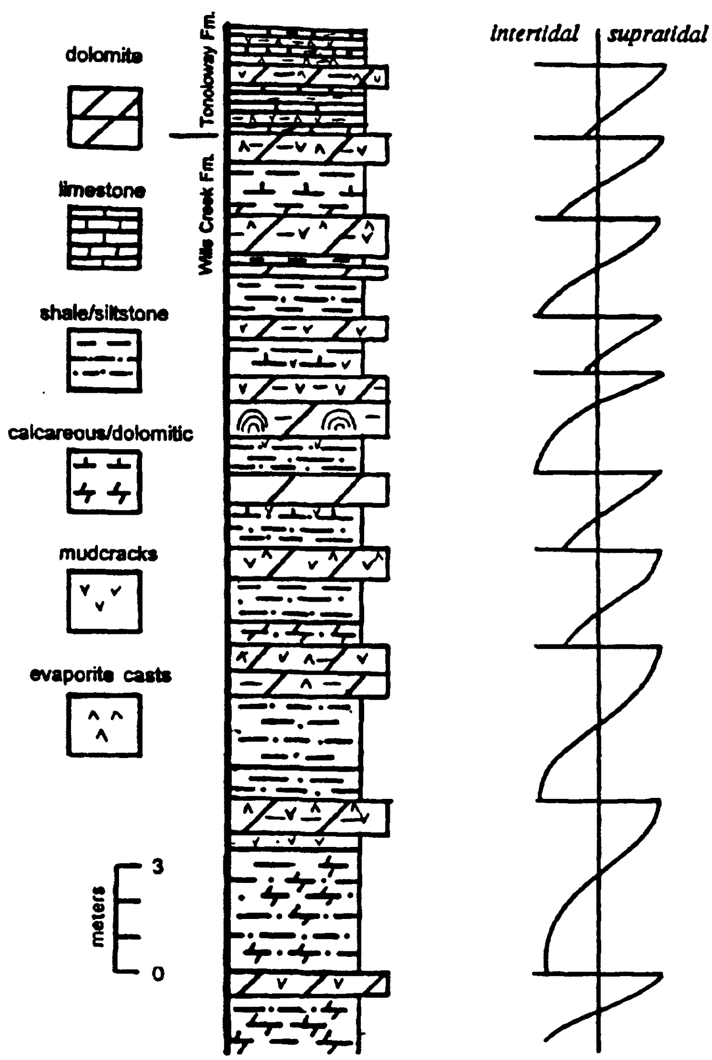


Figure 16. Stratigraphic section exposed at stop 5 of the upper Wills Creek and basal Tonoloway Formations and their interpreted depositional environment.

Lithostratigraphy

The section begins along the entrance ramp of westbound I-68 within the basal strata of the Tonoloway Limestone. Although the Tonoloway is more than 120 m thick, only about 10 m of this unit is exposed at this location. The Tonoloway consists of thinly bedded to thinly laminated shaly limestone. The formation characteristically weathers into tan, platy and shaly chips. The only fauna known from this part of the Tonoloway are leperditiid ostracodes, eurypterids, and a low diversity conodont association. Many of the platy limestone chips exhibit casts of gypsum and halite crystals. Continuing westward (down section), the strata become increasingly shaly. With this increase in siliciclastics the laminated Tonoloway passes into the underlying Wills Creek Formation. The Wills Creek is characterized by thin- to medium-bedded, gray-green to tan weathering, calcareous shale and laminated, silty dolomite. The formation contains horizons of desiccation cracks and domal stromatolites. Halite and gypsum casts are also common in some intervals near the top of the formation. The Wills Creek Formation is approximately 150 m thick in this area (Swartz, 1923). It is correlative with the salt beds of the Salina Formation that occur in the subsurface to the west in Pennsylvania and West Virginia, and to the north in New York (Allings and Briggs, 1961; Smosna and Patchen, 1978).

Depositional Environments

During the late Silurian much of the Appalachian Basin became a restricted salt basin. The

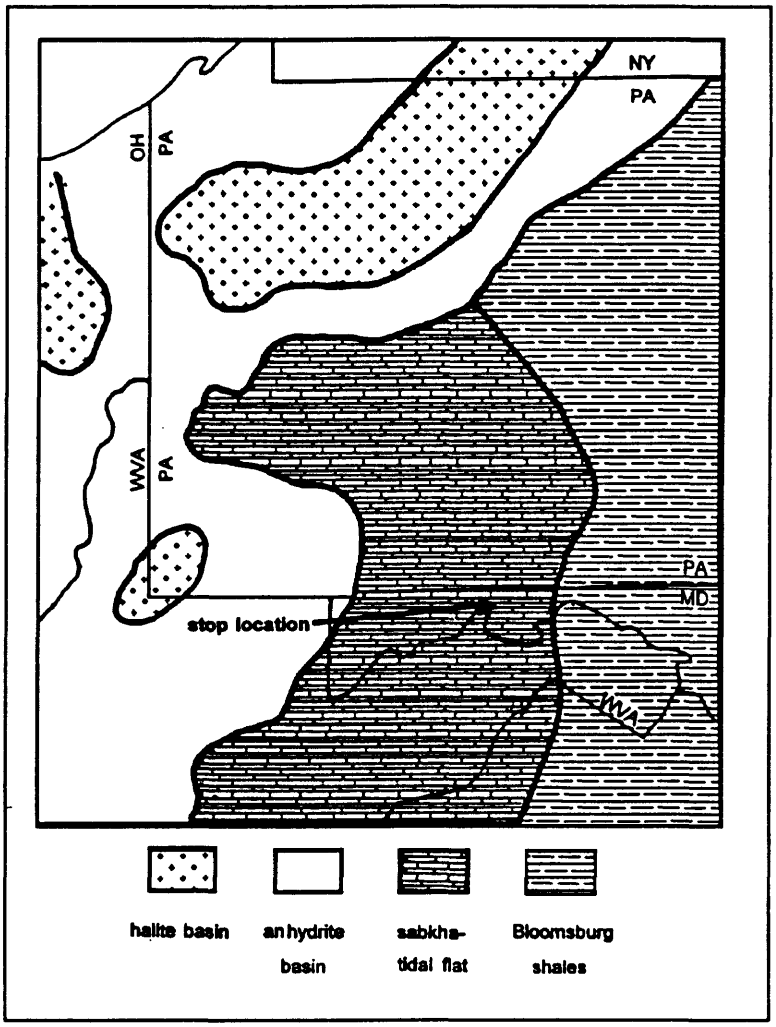


Figure 17. Regional-scale environments of deposition for Middle to lower Upper Sillurian.

greatest thickeness of salts (halite and anhydrite) was formed in an elongate basin stretching from northern West Virginia through western Pennsylvania into western New York (Alling and Briggs, 1961; Smosna and Patchen, 1978) (Fig. 17). Along the eastern margin of this salt basin, extensive supratidal mud flats and sabkhas formed. It was on these mud flats that the peritidal lithologies of the Wills Creek and Tonoloway Formations were deposited. The regional extent of these peritidal units documents basin-scale tidal sedimentation. The shaly component of these formations appears to have been either 1) the distal facies of a Silurian clastic wedge that formed to the east and resulted in the deposition of the Bloomsburg Formation or 2) the result of eolian (dust) deposition as suggested by Grabau (1932, p. 569) for equivalent strata in New York . The great thickness of mud flat lithologies records a large number of small scale (fifth-order?) shallowing cycles (Fig. 16). Rarely are any subtidal lithologies preserved within these cycles, indicating that most of the deposition occurred within the intertidal and supratidal setting. Indeed, the preponderance of evaporite casts in some horizons attest to the supratidal, salt flat (sabkha) environment of deposition.

The shaly evaporite flats persisted through most of the Late Silurian with the deposition of the Tonoloway Formation. During the latest Silurian, the Appalachian Basin was once again submerged with normal marine waters as a deepening sea way resulted in the deposition of the Keyser Formation as seen at Stop 3.

Late Silurian Paleoclimate

There is abundant evidence for long term aridity in the late Silurian in the Appalachian basin.

It was during this time that extensive salt deposition was occurring in deeper parts of the basin and in the Michigan basin. The common evaporite casts are indicative of aridity as well as supratidal, salt flat (sabkha) environment of deposition. The interstate extent of the formations seen at this stop record mixed tidal and eolian processes on the flat floor of a continental basin under arid climatic conditions.

STOP 6: UPPER ORDOVICIAN JUNIATA FORMATION AND LOWER SILURIAN TUSCARORA SANDSTONE, WILLS CREEK WATER GAP, CUMBERLAND, MD

Lat. 39° 39.75' N, Long. 78° 46.81' W, Cumberland, MD, 7½' Quadrangle

Introduction

The Upper Ordovician Juniata and Lower Silurian Tuscarora Sandstone Formations are exposed in the Wills Creek water gap, Wills Mountain anticline, Cumberland, Md. The accommodation space and sediment supply for the underlying Middle Ordovician Martinsburg Shale, the Upper Ordovician Juniata Formation and the basal Silurian Tuscarora Sandstone are generally thought to be the result of the Taconic orogeny when an island arc or microcontinent collided with eastern Laurentia (Drake et al., 1989). Clastics for these units were supplied from mountains created by the Taconic orogeny.

The Lower Silurian Tuscarora Sandstone is a major ridge former in the Appalachian Valley and Ridge geomorphic province and, at Stop 6, the Tuscarora is exposed on the west limb of Wills Mountain anticline. The Tuscarora and equivalent sandstone strata extend from central New York (Medina Group) through Pennsylvania, Ohio ("Clinton" Sandstone), Maryland, West Virginia, Virginia, and Kentucky to the Valley and Ridge in northeast Tennessee (Clinch Sandstone).

Lithostratigraphy

The Upper Ordovician Juniata Formation, which is approximately 600 feet thick at this locality (Dennison, 1982), primarily consists of interbedded red lithic wacke interbedded with dark red mudstone. In Pennsylvania, the Juniata is subdivided into three members based on differences in the relative proportions of sandstone and mudstone (summarized in Cotter, 1993). In the lowest member, sandstones dominate over mudstones and the sandstones are laterally extensive and sheetlike. The middle member contains more mudstone than sandstone. The upper member contains more sandstone than mudstone (Cotter, 1993, and references therein). The lower contact is generally placed at the first occurrence of red beds at the top of the underlying marine Martinsburg Shale (Cotter, 1993). The upper contact is placed where quartz arenite defines the base of the overlying Tuscarora Sandstone (Cotter, 1983).

In contrast to the underlying Juniata, the Tuscarora primarily is a quartz arenite. In New York, strata equivalent to the Tuscarora are referred to as the Medina Group, and in eastern Pennsylvania equivalent strata are referred to as the Shawangunk conglomerate (Thompson and

Sevon, 1982).

Depositional environments

Depositional environment interpretations on the Juniata Formation and Tuscarora presented herein are primarily based on the summaries by Cotter (1983, 1993) and references therein. According to Cotter (1993), most workers agree that the Juniata Formation was deposited in a lower alluvial plain setting and that sandstones of the lower and upper members were deposited by braided streams (Cotter, 1993). The medial member, however, may have been the result of a glacioeustatic induced transgression toward the southeast with deposition occurring in a paralic, coastal, or lower delta plain setting (Dennison, 1976). Allocyclic changes in sea level, therefore, may have been the dominant control on accommodation space and the depositional environments of the three members of the Juniata.

Many of the mudstones in the Juniata are paleosols (Retallack, 1993). According to Retallack (1993) the Juniata paleosols, some of which are calcic, formed on stream terraces and along alluvial fan streams. According to these interpretations, the Juniatia paleosols are autocyclic in origin and not the result of allocyclic fluctuations in sea level.

The origin of the Lower Silurian Tuscarora Sandstone remains enigmatic. Cotter (1983) summarized earlier work and presented his own comprehensive sedimentological analyses of the Tuscarora in Pennsylvania. Cotter (1983) suggested that the Tuscarora was the result of an early Silurian transgressive event and renewed tectonic elevation of the Taconic terrane. He divided the Tuscarora into five regional and stratigraphic lithofacies. Lithofacies one, his eastern cross-laminated lithofacies, was attributed to braided stream deposition. He interpreted the second lithofacies, or western cross-laminated lithofaces, to marine shelf sand waves and shore-face connected sand ridges. Cotter noted that sand grains in lithofacies two were well rounded. Lithofacies three, his basal horizontal laminated facies, was deposited in foreshore and shoreface environments; quartz grains in this lithofacies also were well rounded. Lithofacies four, basal pink transitional lithofacies, was deposited in paralic conditions. Texturally mature grains were also noted in this lithofacies in contrast to the lithic arenites of the underlying Juniata. Cotter's (1983) fifth lithofacies, the uppermost part of the Tuscarora, is the red Cacapon Sandstone of West Virginia and Maryland (Castanea of Pennsylvania), which he suggested was deposited in a low energy coastal flat complex that prograded over the underlying quartz arenite facies during regression.

Paleoclimates of the Late Ordovician and Early Silurian

Based on carbonate occurrence and other paleosol features, Retallack (1993) suggested that the climate of the Late Ordovician was semiarid and that rainfall, though limited, was seasonal. This interpretation is consistent with braided stream deposits in the upper and lower members. However, Late Ordovician sea-level oscillations, controlled by advance and retreat of ice sheets in what is now North Africa (Dennison, 1976), must have been accompanied by global climate change. Given a paleolatitude of approximately 30° south for the Appalachian basin in late Ordovician time, climate change likely would have been in the amount and seasonality of annual rainfall. Such changes in rainfall patterns could account for the variation in sediment supply within and among members of the Juniata. The braided stream sheet sands of the upper and lower members of the Juniata may represent increased sediment supply whenever the climate shifted form semiarid to dry subhumid conditions. In an alluvial plain setting, the return dry subhumid to semiarid conditions would favor a reduction in sediment supply, deposition of finer grained material, and a lowering of the water table resulting in conditions necessary for soil development.

The change in lithologies from the immature red wacke sands of the Juniata to the mature quartz arenite of the Tuscarora and equivalent strata remains enigmatic. Most interpretations attribute the textural and mineralogical maturity of the Tuscarora to marine depositional processes (e.g., Cotter, 1983). An eolian mechanism for winnowing and rounding of grains is far more likely because, unlike gravel and cobbles, sand and silt-size quartz are far more susceptible to rounding under eolian conditions than in aqueous environments (e.g., Kuenen, 1960).

It appears much more likely that the Tuscarora was derived from a mature regolith that primarily consisted of quartz. Dennison and Head (1975) and Brett et al. (1995) recognized an unconformity at the contact between Upper Ordovician and Lower Silurian strata that extends from Ontario southward through the central Appalachian basin. This regional unconformity separates the immature lithic sands and mudstones of the Upper Ordovician from quartz arenite of the Lower Silurian. It is highly probable that an eolian regolith developed on the exposed surface as a result of mechanical weathering and winnowing given the long-term semiarid to arid conditions of the latest Ordovician and earliest Silurian.

Although there appears to be some fluvial depositional along the eastern outcrop belt, many workers believe that the Tuscarora was deposited under marine conditions during transgression (e.g., Cotter, 1983). Reworking of a texturally and mineralogically mature regolith by marine trangressive processes may account for the widespread distribution of the Tuscarora and equivalent strata over the Cherokee unconformity. The textural and mineralogical maturity, however, was probably the result of mechanical weathering and winnowing of an eolian regolith in an arid or semiarid climate during a low stand in sea level.

STOP 7: UPPER MISSISSIPPIAN AND MIDDLE PENNSYLVANIAN STRATA, THE MID-CARBONIFEROUS UNCONFORMITY, I-68, BIG SAVAGE MOUNTAIN, FROSTBURG, MD

Lat. 39° 40.36'N, Long. 78° 57.77W, Frostburg, MD 7½' Quadrangle

Introduction

The Upper Mississippian Mauch Chunk Formation and Middle Pennsylvanian Pottsville and Allegheny Formations are exposed in the I-68 roadcut at the top of Big Savage Mountain. The Mauch Chunk exposure is 56 m thick and the Pottsville and Allegheny exposures are 31 m and 27 m respectively (Fig. 18). The Mississippian-Pennsylvanian contact is unconformable. The laterally extensive units exposed at this locality, and their correlatives, occur throughout the central Appalachian basin.

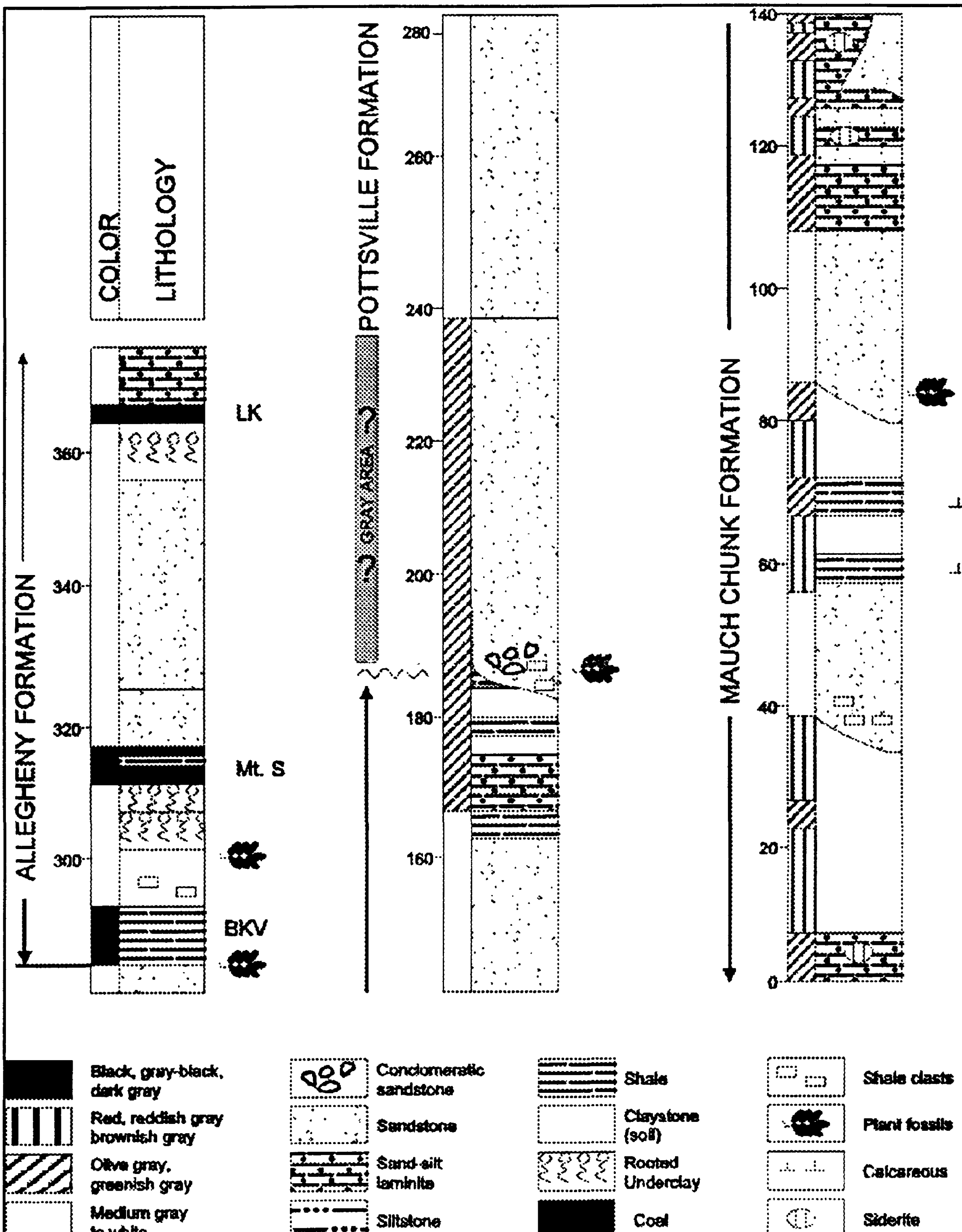


Figure 18. Interstate Route 68 road cut at Big Savage Mountain, Maryland. Mauch Chunk Formation (west end of outcrop) through Pennsylvanian Allegheny Formation (east end of outcrop). Modified from Shaulis et al, 1993.

Lithostratigraphy

The Mauch Chunk formation in Maryland, approximately 170 m, extends from the top of the Wymps Gap (Alderson) Limestone Member of the Greenbrier Formation to the base of the Pottsville Formation (Brezinski, 1989b). . The Mauch Chunk, as defined in adjacent Pennsylvania, extends from the base of the Loyalhanna Member (Stop 9) or any subjacent redbeds to the base of the Pottsville. In southern WestVirginia, the Mauch Chunk has Group status and extends from the top of the Greenbrier Formation to the base of the Lower Pennsylvanian Pocohontas Formation. The Mauch Chunk Group in southern West Virginia includes the Bluefield, Hinton, and Bluestone Formations in ascending order. Collectively, these formations are over 2,500 m thick.

The Loyalhanna through Wymps Gap interval is a facies of the upper Greenbrier Limestone sequence to the south and west and the upper part of the Maxville Limestone of Ohio. The Mauch Chunk Formation correlates, in part, with the marginal marine Mauch Chunk Group of southern West Virginia and western Virginia and with the Bangor Limestone and Pennington Formations of Georgia, eastern Tennessee, and eastern Kentucky.

The Mississippian-Pennsylvanian boundary is unconformable (White, 1891). The Chesterian age Mauch Chunk Formation is disconformably overlain by the Atokan base of the Pottsville Formation. This unconformity is part of the mid-Carboniferous unconformity discussed by Saunders and Ramsbottom (1986), a major eustatic sea-level drop in the early Morrowan. Section from the late Chesterian to late Atokan is missing here within the disconformity because of erosion and/or nondeposition. At this stop the disconformity is at a thin claystone (Fig. 18).

The Pottsville usually contains a large proportion of sandstone with lesser amounts of shale and mudstone as at Stop 11. Here, the Pottsville primarily is sandstone. The olive gray coloration of the lower part of the sandstone is atypical as the Pottsville is usually medium gray to light gray.

The thickness of the Pottsville in this area ranges from 18 m near the Maryland-Pennsylvania border 7 miles (11 km) to the northeast to 100 m near Kitzmiller, 22 miles (35 km) to the southwest (Waagè, 1950). The Pottsville here at Stop 7 is relatively thin (32 m). The Pottsville here may be equivalent to the upper part of the Kanawha Formation of southern West Virginia. If so, it would be late Atokan and early Desmoinesian age.

The Allegheny Formation coal beds and, therefore, the Pottsville-Allegheny boundary is based on correlations by Waagè (1950). His coal-bed correlations were based on numerous long drill holes from the Conemaugh Formation to the Mauch Chunk Formation.

It is often difficult to separate the Mauch Chunk and Pottsville Formations in western Pennsylvania, Maryland, and northern West Virginia because it is often difficult to distinguish non-red Mauch Chunk sandstones from those of the Pottsville Formation. The last occurrence of red coloration is not a consistently reliable criterion for separation of the two units (Shaulis et al., 1993).

Pennsylvanian and Mississippian Depositional environments

According to Shaulis and others, (1993) the Mauch Chunk Formation exposed at Stop 7 was deposited in an upper-delta-plain setting. If so, then deposition was controlled by autocyclic processes. They recognized four fining upward cycles, which they interpreted as fluvial (Fig. 18). Only the top of their lowest cycle is exposed. Their second cycle consists of a medium gray, fine-grained sandstone with a scoured base and a basal lag gravel of shale chips and caliche nodules. This is succeeded by reddish- and greenish-gray silt shales and hackly siltstone and claystone. Their third fluvial cycle grades up from a medium gray, fine-grained sandstone with incised base with a zone containing preserved plant fragments into reddish- and greenish-gray sand-silt laminate and hackly silt shale and claystone. Their fourth fluvial cycle is medium light gray to pinkish-gray fine-grained sandstone with a scoured base. The lower part of the sandstone also grades laterally into the upper part of the hackly shales and siltstone of the underlying cycle. They interpret this sequence as a distributary building across and into the terminal fine clastics of the previous cycle. The sandstone passes upward into medium gray and olive gray interbedded hackly shales and fine-grained sandstones. The upper part of the fourth cycle has been removed by the sub-Pottsville erosion surface.

The Mauch Chunk at Stop 7 also contains calcic paleosols of unknown lateral extent. These paleosols are indicative of a drop in the paleo water table which generally is the result of a drop in base level or a decrease in rainfall, both of which are allocyclic processes.

Shalis and others (1993) interpret the Pottsville Formation here as a high energy fluvial-alluvial deposit. They suggested that the olive color of the lower part of the Pottsville sandstone reflects the high content of clay altered from rock fragments. This olive color, however, is the result of modern weathering of syngenetic or early diagenetic pyrite, probably the opaque minerals noted in Shalis and others (1993). The pyrite is the result of reducing conditions and relatively high sulfate concentrations at the time of deposition. The sulfate was from either marine influence or high dissolved solids in fluvial systems. We suggest that the sulfate was derived from marine influence in what may have been an estuarine setting.

The Allegheny Formation clastics and coal were attributed to autocyclic delta plain deposition by Shalis and others (1993). Based on our current work (unpublished) it seems clear, however, that allocyclic processes were the primary controls on sedimentation and stratigraphy. Basin and interbasin scale paleosols (underclays and coalbeds) clearly document low stands of sea level and major fluctuation of the water table. The apparent lack of marine or brackish fossils and the general coarseness of the clastics noted by Shalis and others (1993) is part of a facies mosaic within high-stand deposits. Eastern or proximal facies along the eastern outcrop belt are of probable deltaic origin whereas distal facies in western Pennsylvanian, West Virginia, and Ohio contain marine or brackish water deposits.

According to Shalis and others (1993) the Mauch Chunk Formation in this area is a sequence of litharenite and sublitharenite sandstones (McBride, 1963) intercalated with mudstones and shale. Illite, mixed-layer clay, kaolinite, calcite, and siderite are common. Metamorphic and igneous rock fragments, and both potash feldspars and plagioclase are common. Grains appear to be angular, poorly-sorted and generally immature.

In contrast to the Mauch Chunk, the Pottsville Formation here consists of coarse-grained quartz-arenites and sublitharenites. Clay minerals are generally less abundant than in the Mauch Chunk; feldspars and calcite are generally absent.

Paleoclimate

Based on the occurrence of calcic paleosols, calcic nodules as channel lags in paleostream channels, and the textural and mineralogical maturity of the sandstones, the paleoclimate of the late Mississippian must have been semiarid to dry subhumid. Unaltered feldspars, illite, mixed layered clays in Mauch Chunk sandstones are a good indication of a limited chemical weathering in the source area and a relatively dry paleoclimate. Syngenetic and early diagenetic calcite are an indication for high dissolved solids contents of fluvial systems. In contrast, Pottsville sandstones contain mostly quartz that is texturally immature. The absence of feldspar, mixed layered clays, and illite, and the texturally immature quartz are indicative of chemical weathering in a humid climatic regime. The absence of syngenetic and early diagenetic calcite in Pottsville sandstones is indicative of fluvial systems that were low in dissolved solids, which is consistent with a leached source area regolith that was deeply weathered under a humid tropical climate. This stop illustrates the production of quartz arenites through humid tropical weathering in contrast to Stops 3 and 6 where the quartz arenites appear to be the product of mechanical weathering under an arid or semiarid tropical climate.

Although the Mississippian unconformity is erosional at Stop 7, residual weathering deposits commonly are developed on Mississippian and older strata as we will see at Stop 11. In the Appalachian basin, these deposits consist of high alumina clays such as the Mercer clay in Pennsylvania and the Olive Hill clay in Kentucky. On the margins of the Ozark dome, residual deposits include the Cheltenham clay and unnamed chert residuum in the tristate district of Kansas, Missouri, and Oklahoma. These residual deposits resulted from humid tropical weathering on topographic highs during the latest Mississippian and Early and, to some extent, early Middle Pennsylvanian. They were buried by onlap of Middle Pennsylvanian strata.

STOP 8: UPPER DEVONIAN HAMPSHIRE AND LOWER MISSISSIPPIAN ROCKWELL FORMATIONS, INTERSTATE 68, LITTLE SAVAGE MOUNTAIN, FINZEL, MARYLAND

Lat. 39° 40.95' N, Long. 78° 58.44' W, Frostburg, MD, 7½' Quadrangle

Introduction

The stratigraphic sequence exposed in the highway cut through Little Savage Mountain comprises the upper Hampshire and lower Rockwell Formations (Upper Devonian-Lower Mississippian). The Rockwell succession here is part of a regional, paralic lithosome that records the ultimate foundering of the Catskill delta during latest Devonian (Famennian) time, and the subsequent evolution of an early Mississippian (Tournaisian) coastal plain that was alternately submergent and emergent (Beuthin, 1986a,b,c; Bjerstedt and Kammer, 1988.) Our discussion focuses on sedimentologic and stratigraphic evidence for late Devonian-early Mississippian shoreline shifts in this area, the implications of these shifts for placement of the Devonian-Mississippian boundary, and the relationship of the Rockwell marine zones to Famennian-Tournaisian eustatic events.

Lithostratigraphy

Data for the Finzel outcrop presented herein are compiled mostly from measured sections of the Hampshire-Rockwell sequence made by Dennison and Jolley (1979), Beuthin (1986a), Bjerstedt (1986a, and Brezinski (1989a). Regionally, the Hampshire-Rockwell contact is placed at the horizon where the predominantly red strata of the Hampshire pass upward into dominantly green and gray strata of the lower Rockwell. At Finzel, the color change is abrupt, making the formational contact easy to pick.

The uppermost Hampshire consists of thin- to thickly-interbedded, grayish-red mudstone, siltstone, shale, and fine-grained sandstone with a few thin beds of green sandstone and siltstone. Many of the redbeds have abundant root impressions, and pedogenic slickensides appear to be weakly developed in some of the mudstones. These strata were deposited on the Catskill deltaic-alluvial plain, mostly by aggradational overbank processes.

The Rockwell is 220 feet (67 m) thick here, but it ranges from 0-400+ feet (0-120+ m) in the Maryland-Pennsylvania-West Virginia tristate area (Fig. 19). The basal 70 feet (21 m) of the Rockwell at Finzel constitutes a marine zone that records the final transgression over the Catskill coastal plain (Fig. 20). Dennison and others (1986) informally termed the marine zone the "Finzel marine tongue" and correlated it with the marine Oswayo Formation of western Pennsylvania, and the black Cleveland Shale of Ohio. Bjerstedt and Kammer (1988) and Brezinski (1989a,b) also have equated the basal Rockwell marine zone with the Oswayo Formation of northwestern Pennsylvania. The Finzel tongue also correlates with the "upper sandy zone" of the Venango Formation that crops out in the Conemaugh Gorge through Laurel Mountain, Pennsylvania. The Venango upper sandy zone in the Conemaugh Gorge was reported and described by Harper and Laughrey (1989) and Laughrey and others (1989). Although various names have been used for the basal Rockwell marine zone, this body of strata is a lithologically distinctive and mappable lithostratigraphic unit throughout western Maryland and Somerset County, Pennsylvania (Beuthin, 1986a). In western Maryland, the basal beds of the Oswayo transgression are intercalated with red alluvial-plain strata of the Hampshire (Fig. 20). Along the Allegheny Front, the Oswayo marine zone grades into coeval Hampshire red strata, so that at Sideling Hill (location I of Fig. 19) no Oswayo facies is evident.

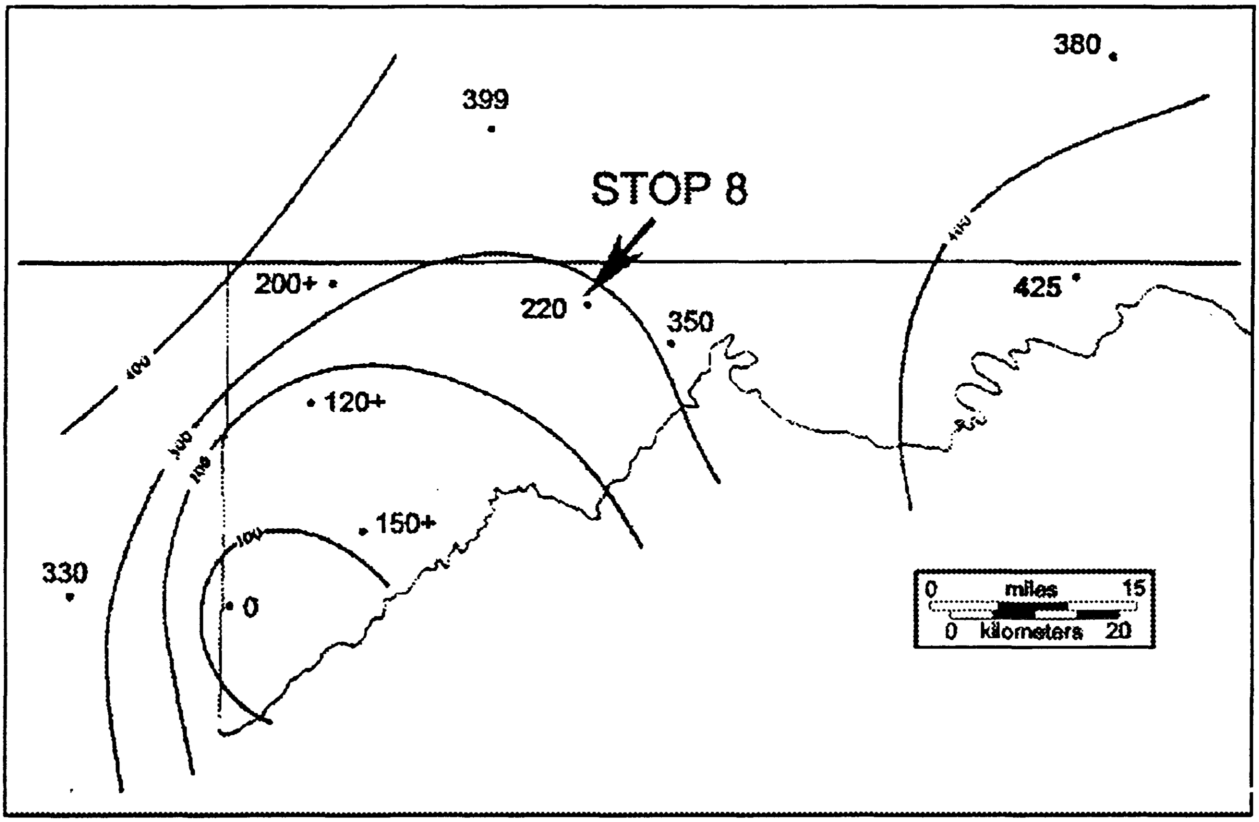


Figure 19. Isopach map of the Rockwell Formation of western Maryland and adjacent Pennsylvania. From Brezinski, 1989a.

The Oswayo marine facies at Finzel is a coarsening-upward (shoaling) sequence of intensely burrowed, green and gray shale, siltstone, and sandstone. The lower 30 feet (9 m) of the sequence consists mostly of gray to black silty shale interstratified with thin to medium beds of gray fine-grained sandstone. Wave-ripples and ball-and-pillow structures are common in the sandstones. Fossils from throughout the basal 30 feet of the marine zone include a *Planolites*-dominated assemblage of bedding-plane traces, and a low diversity shelly fauna of *Lingula, Camarotoechia,* and unspecified bivalves. Several distinctive, thick beds of *Scolithus.*-burrowed, fine-grained, greenish-gray sandstone are interbedded with gray and green shale in the upper 40 feet (12 m) of the marine zone. Body fossils are unknown from the upper part of the marine zone. Brezinski (1989b) inferred a shallow shelf environment for deposition of the Finzel marine tongue. Beuthin (1986a,b) and Bjerstedt and Kammer (1988) favored a restricted bay environment, and interpreted the *Scolithus.*-burrowed sandstones as the sand-bar complex of a prograding tidal or bayhead delta.

A 115-foot-(35 m)-thick interval of lenticular, greenish-gray sandstone and reddish-brown and greenish-gray siltstone and shale overlies the Oswayo facies at Finzel. The sandstones exhibit erosional bases, shale-pebble basal conglomerates, crossbedding, and fining-upward texture.

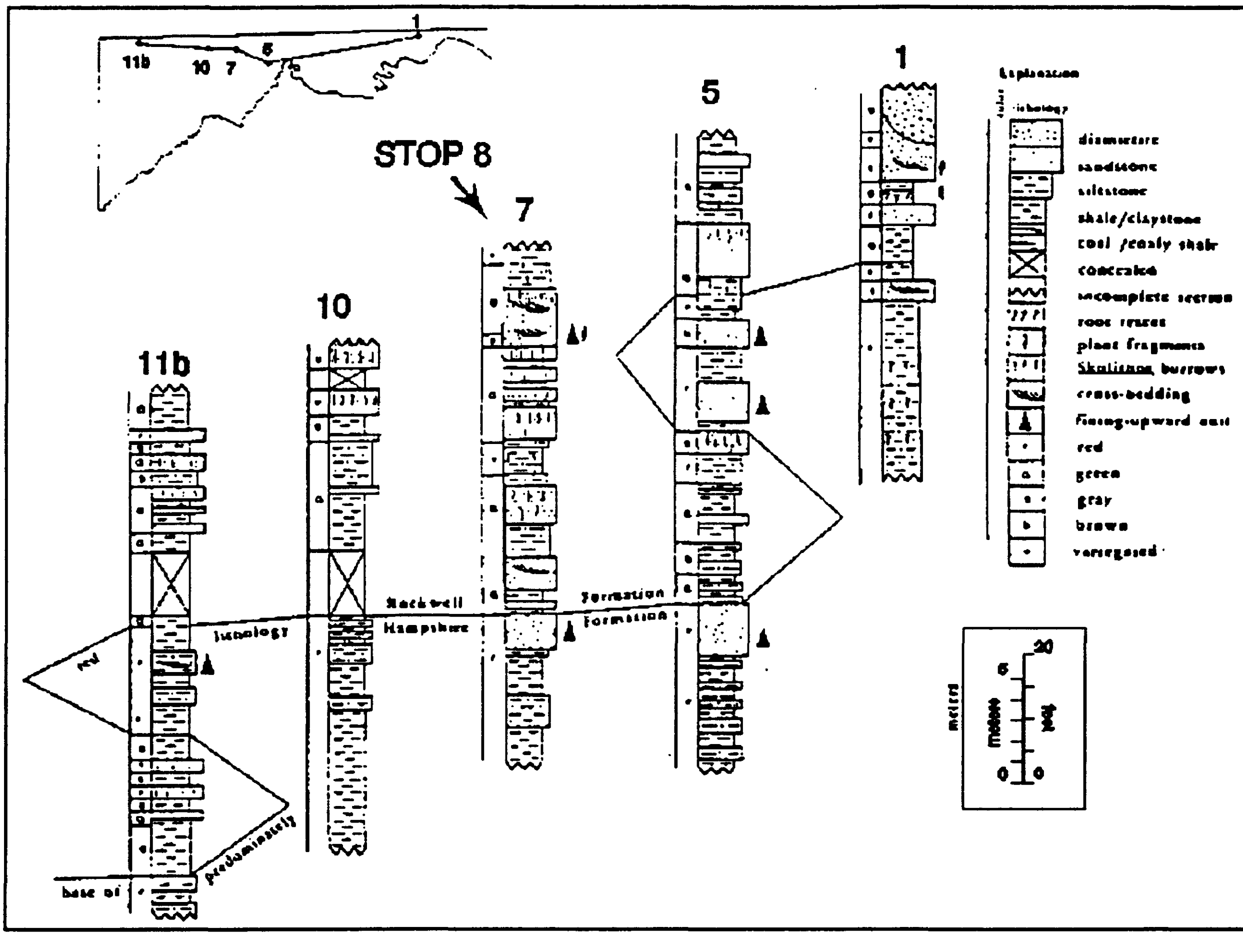


Figure 20. Intertonguing relationship between the Devonian Hampshire and Rockwell Formations in western Maryland. Locality 7 in the figure is same as stop 2. From Brezinski (1989a).

These beds probably were deposited on a prograding alluvial plain concomitantly with Oswayo regression (Brezinski, 1989b). Just west of Finzel, the nonmarine Rockwell sequence is punctuated with a thin marine unit that Dennison and others (1986) equated with the Bedford marine shale of eastern Ohio. The "Cussewago equivalent" (lower Murrysville sandstone) exposed in the Conemaugh Gorge through Laurel Mountain (Harper and Laughrey, 1989; L.aughrey and others, 1989) is probably equivalent to the middle Rockwell nonmarine unit at Finzel.

A second Rockwell marine unit overlies the nonmarine Rockwell facies at Finzel. Although it is not well-exposed, this upper marine zone is represented by a tan, fine-grained, medium-bedded, bioturbated sandstone. This sandstone is lithologically recognizable at other Rockwell exposures in western Maryland and adjacent Pennsylvania (Fig. 21A and 21B). This marine sandstone correlates with the Riddlesburg Shale of the Broadtop synclinorium of Pennsylvania (Bjerstedt and Kammer, 1988; Brezinski, 1989a,b) and of the Conemaugh Gorge through Laurel Mountain (Harper and Laughrey, 1989; Laughrey and others, 1989). Throughout most of western Maryland, the Riddlesburg transgression is represented by littoral sandstones rather than black

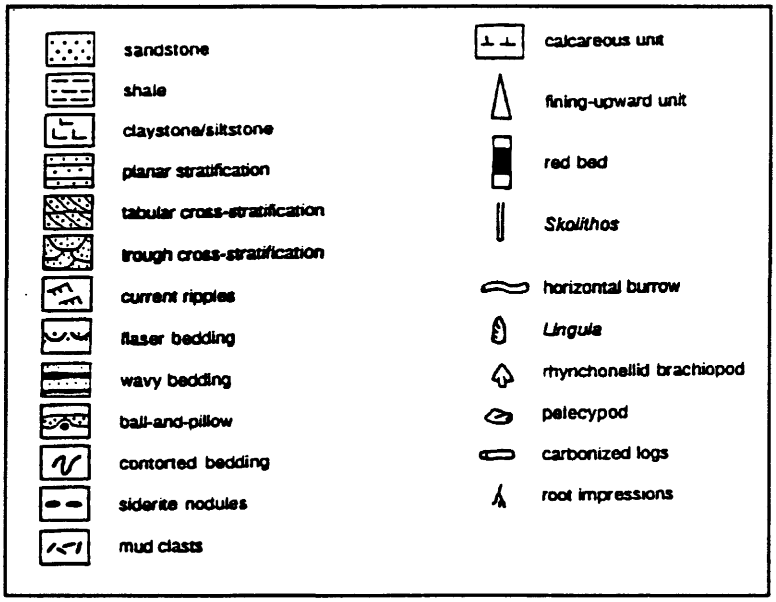


Figure 21A Explanation of symbols used in Figure 21B.

silty, lagoonal shales, as in the Broadtop region of Pennsylvania. However, a black-shale facies of the Riddlesburg marine zone has been reported at Altamont, Maryland, about 24 miles southeast of Finzel (Beuthin, 1986a).

The Riddlesburg Sandstone is exposed on the north side of the Interstate Route 68 at Finzel. The remaining Rockwell and overlying Purslane Formation are not exposed at this stop.

Devonian-Mississippian contact

As concerns the Devonian-Mississippian boundary in the central Appalachians, Harper and Laughrey (1989) stated that "the exact placement of this boundary is still up for grabs and should provide some interesting discussion during this Field Conference." Their words are no less true for the present Field Trip.

Using brachiopod species considered to be index fossils, Kammer and Bjerstedt (1986) correlated the Oswayo Member of northern West Virginia with the type-Oswayo of northwestern Pennsylvania. Those workers assigned a Late Upper Devonian age to the Oswayo of northern West Virginia (except for the uppermost portion) on the basis of fossil content. Biostratigraphically significant fossils from the Riddlesburg Shale generally support a Mississippian age for that unit (Kammer and Bjerstedt, 1986). Furthermore, several recent studies (Dennison and others, 1986; Beuthin, 1986c; Bjerstedt, 1986b; Kammer and Bjerstedt, 1986; Bjerstedt and Kammer, 1988) have interpreted the Riddlesburg marine zone as an eastern facies equivalent of the Sunbury Shale of Ohio which conventionally is assigned to the lower Mississippian System (Pepper and others, 1954; DeWitt, 1970; Eames, 1974). On the basis of the foregoing age determinations, the Devonian-Mississippian contact in western Maryland apparently falls within the interval comprising the uppermost Oswayo beds and the middle Rockwell nonmarine zone.

Bjerstedt (1986b) and Bjerstedt and Kammer (1988) placed the base of the Mississippian System in West Virginia and Maryland at what they interpreted to be a regional unconformity that is equivalent to the interval of the Berea Sandstone of Ohio and the West Virginia subsurface. This unconformity occurs at the base of the Riddlesburg Member of the Rockwell Formation at Sideling Hill, Town Hill, and La Vale, Maryland. At those locations the lower Riddlesburg consists of interbedded diamictite and cross-bedded, light-gray sandstone. Lower Riddlesburg beds apparently were deposited in shallow marine or shoreline settings. These environments were quite likely highly erosive in nature. As a result, one would expect unconformable contacts at the

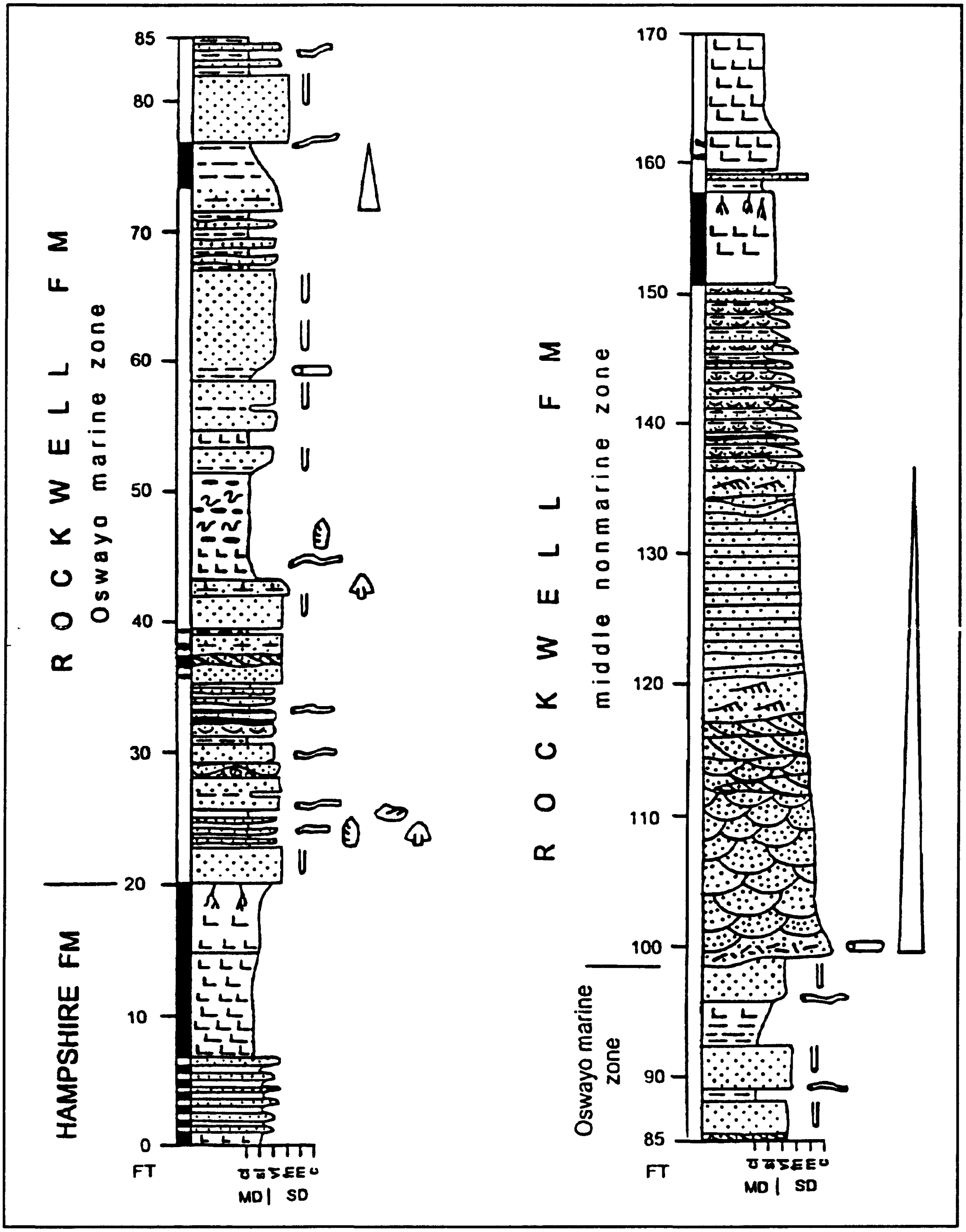


Figure 21B Measured section of upper Hampshire-lower Rockwell Formations along Interstate 68 at Finzel Road interchange, Garrett County, Maryland. Section is based on exposure along eastbound entry-ramp.

base of such units. Where these beds are absent, physical evidence of a "Berea-age" sub-Riddlesburg unconformity is lacking. At Keyser's Ridge, the Riddlesburg grades into the underlying Rockwell strata, indicating apparent conformity. Consequently, deposition during the Devonian-Mississippian transition probably was continuous throughout much of western Maryland, and Berea equivalents are likely present, even through they may be represented by a more terrestrial facies than the type-Berea. Harper and Laughrey (1989) and Laughrey and others (1989) have reported a Berea equivalent (upper Murrysville sandstone) from the section exposed in the Conemaugh Gorge through Laurel Mountain. At Finzel, the top of the Finzel marine tongue approximates the Devonian-Mississippian contact, although it probably occurs slightly higher in the overlying nonmarine interval. At Sideling Hill, the Devonian-Mississippian boundary is relatively closer to the Hampshire-Rockwell contact because the diamictite and the overlying Riddlesburg Member occur near the base of the Rockwell.

The intertonguing nature of the Hampshire-Rockwell contact, the eastward pinchout of the Oswayo tongue, and apparent upsection migration of the contact from west to east (Fig. 22) indicate that the Hampshire-Rockwell transition is diachronous; therefore, this lithostratigraphic boundary cannot be equated with the Devonian-Mississippian systemic boundary across the region.

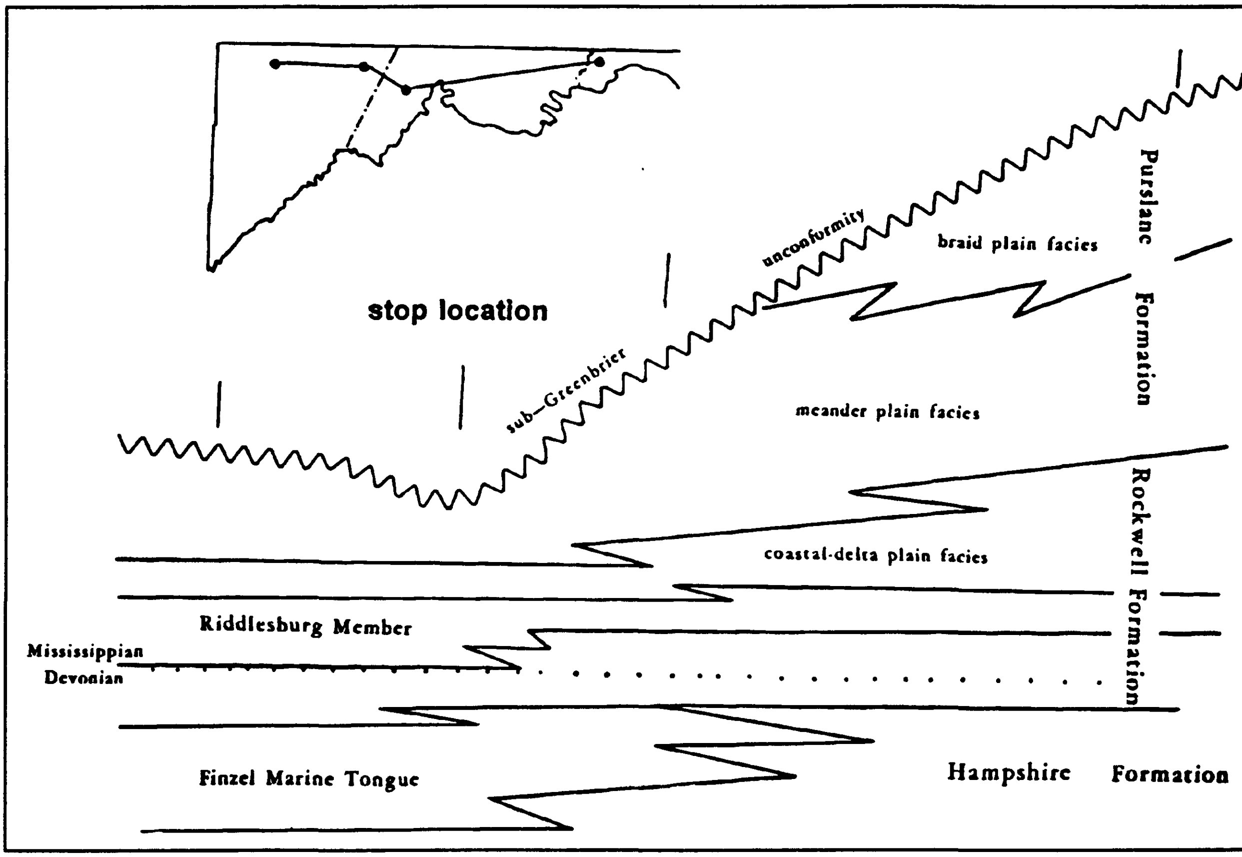


Figure 22. Environments of deposition within the Rockwell Formation of western Maryland. From Brezinski (1989b).

Depositional environments

Figure 23 charts the relative sea-level changes in western Maryland and vicinity during Rockwell deposition. Shaly beds of the basal Finzel tongue record the culmination of a late Famennian sea-level rise. The *Scolithus.*-burrowed sandstones of the upper Finzel tongue and the cross-bedded channel sandstones of the overlying nonmarine Rockwell interval indicate progradation of coarse clastics and shoreline regression during highstand. In Maryland, the sea-level drop associated with the Berea Sandstone of Ohio and West Virginia locally caused emergence above base level, sedimentary bypassing, and fluvial incision. Shortly thereafter, sea level rose again, causing the Riddlesburg transgression. Because the Riddlesburg extends farther east than the Oswayo transgression a larger rise in sea level is inferred for the former. Rockwell nonmarine beds overlying the Riddlesburg probably represent post-Riddlesburg highstand.

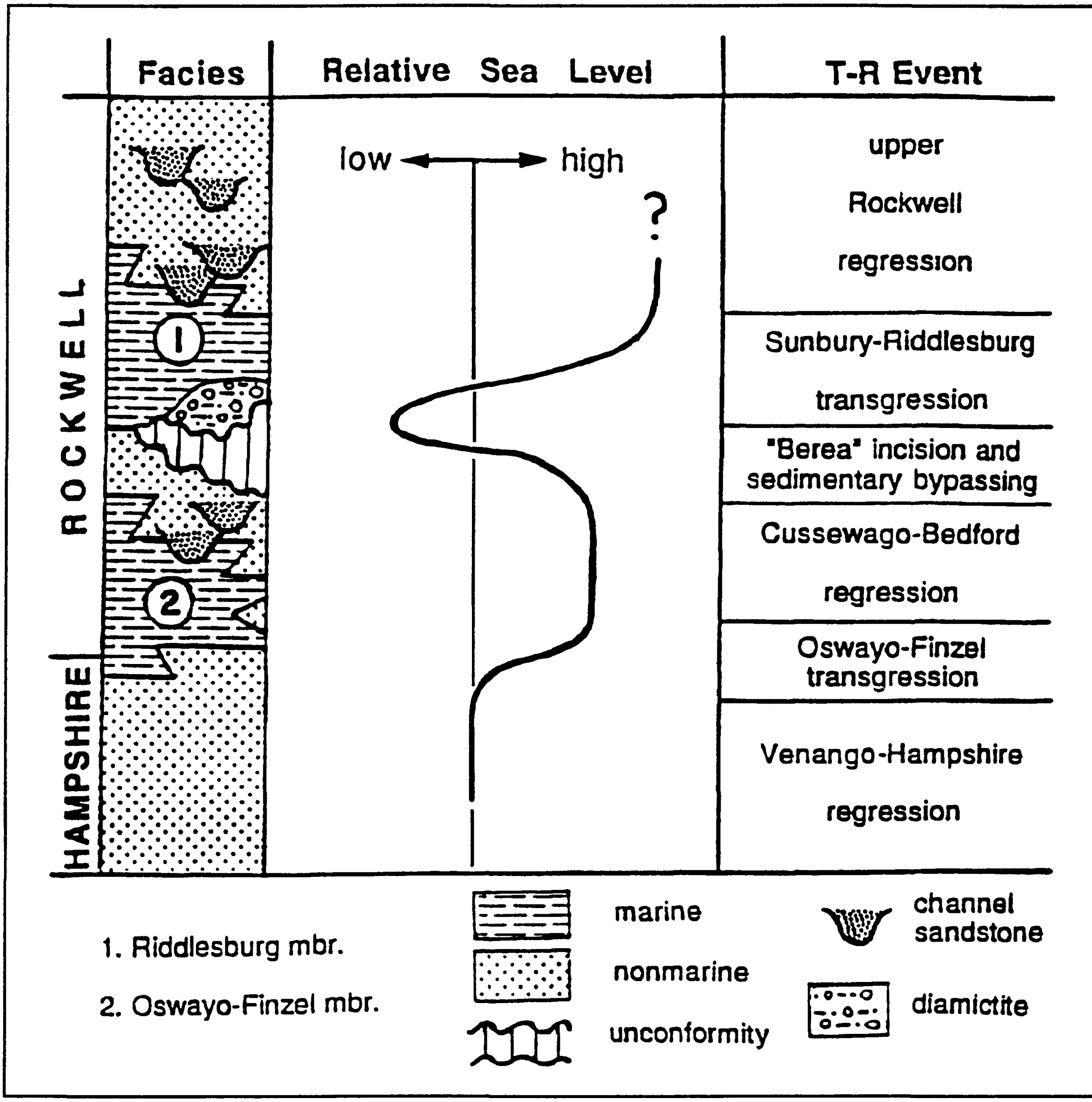


Figure 23. Relative sea-level curve for the upper Devonian-lower Mississippian (upper Famennian-lower Toumaisian) Rockwell Formation of western Maryland (based on Beuthin (1986a) with minor modifications). Curve does not indicate absolute magnitude, nor absolute duration of any sea-level event. Devonian-Mississippian transition probably occurred during the time-interval encompassing Cussewago-Bedford regression or "Berea" incision and sedimentary bypassing.

Using microspore zonation of strata enclosing the Devonian-Mississippian boundary, Streel (1986) demonstrated the presence of two interregional transgressions on the Old Red continent

(Euramerica). The earlier of these two events was initiated during the late Famennian and is represented in Pennsylvania and Maryland by the Oswayo marine zone. The later transgression occurred during the early Tounaisian and corresponds to the Sunbury black shale of Ohio. Interregional correlations therefore strongly indicate that the Oswayo sea-level rise was eustatic. If, as inferred by Dennison and others (1986), Beuthin (1986c), and Bjerstedt and Kammer (1988), the Riddlesburg marine zone is an eastern facies equivalent of the Sunbury Shale (or a portion of it), then it also was probably eustatically controlled. Streel (1986) further suggested that the interregional late Famennian transgression was a glacio-eustatic event. Caputo and Crowell (1985) and Veevers and Powell (1987) documented evidence for a mid-Famnennian glacial episode in Brazil and adjacent (then) northwest Africa. Late Famennian waning of the Gondwana ice sheet perhaps was the major control on the Oswayo transgression. A glacio-eustatic mechanism for the early Tournaisian (Sunbury) sea-level rise remains totally speculative because early Mississippian glaciation on Gondwanaland is unresolved (Caputo and Crowell, 1985).

STOP 9: LOYALHANNA LIMESTONE AND MAUCH FORMATION, KEYSTONE MINE, SPRINGS, PENNSYLVANIA.

Lat. 39°44.65' N, Long. 79° 12.28' W, Grantsville, MD/PA 7½' Quadrangle

Introduction

At this stop we will examine the late Mississippian Loyalhanna Limestone. Also exposed are is the Deer Valley and Savage Dam Members of the Greenbier Formation. The Loyalhanna's origin, with its large cross-bed sets, has long been debated.

Lithostratigraphy

The Loyalhanna Limestone as it is called in Maryland is equivalent to the Loyalhanna Formation of Pennsylvania (Fig. 24). The Loyalhanna at this location is 15 m thick and consists of festoon cross-bedded, arenaceous grainstone to calcareous sandstone. The Loyalhanna in this area and adjacent Maryland has a reddish tint. This is caused by a small admixture of red clays that appear to be syndepositional. The Loyalhanna is an arenaceous lime grainstone. The quartz sand is medium to fine grained, and the carbonate grains consists of ooids, coated grains, intraclasts, and fossil fragments. The fossil fragments consist of brachiopod, bryozoan, crinoids, and endothyrid foraminifers. Although typically the fossils have been comminuted to sand-size grains in this high-energy environment; at some localities complete articulated brachiopods have been recovered from this unit. Adams (1970) has shown that much, if not most, of the quartz sand has its origin from a northern, Pocono source. This is indicated by the increase in terrigenous sand content in the Loyalhanna in that direction.

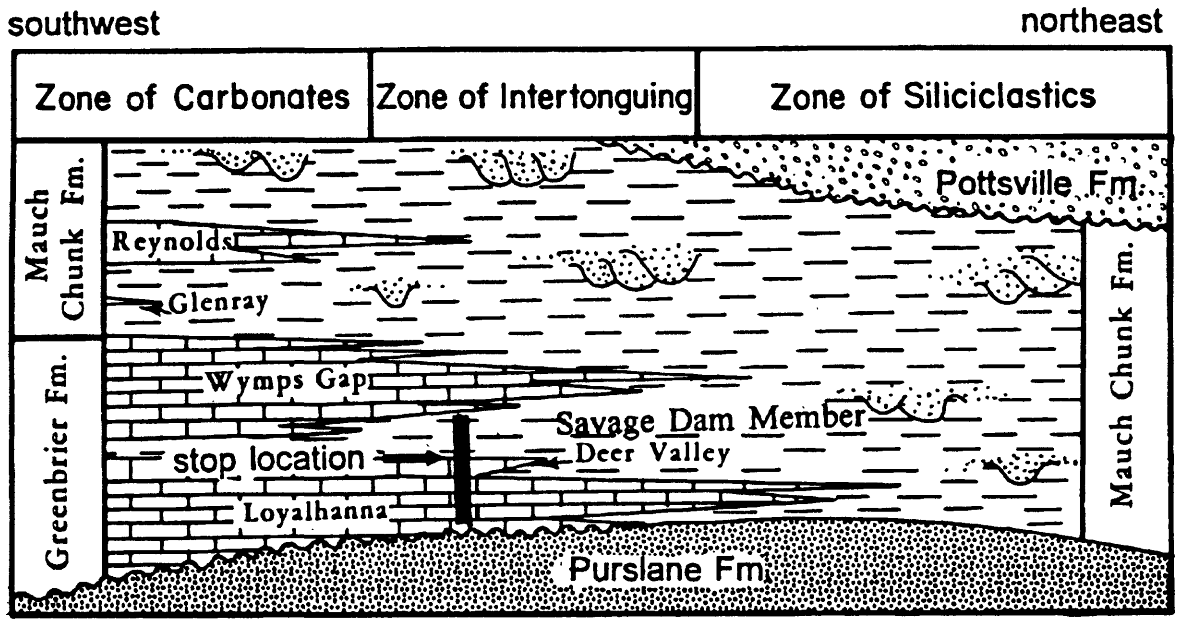


Figure 24. Regional stratigraphic relationship of Loyalhanna Formation.

The large-scale crossbeds are accentuated on weathered joint faces along the entrance into the main working face of the Keystone mine. This typical weathering character is caused by the the more arenaceous layers which are less soluble than the carbonate rich layers. Thus, the more arenaceous layers stand out in relief on weathered surfaces. The cross-beds are mainly directed to the east and northeast (Adams, 1970; Hoque, 1975).

At numerous locations on the worked face one can usually observe thin (<1.0 ft.), tan, siltstone lenses. These lenses pinch out laterally, are convex downward, and are truncated on the upper surface. Brezinski (1989b) interpreted these lenses as representing remnants of shallowing episodes or slack water deposits preserved in swales between submarine dunes, that later were scoured and largely removed by subsequent dune migration.

Overlying the Loyalhanna is a white limestone 3m thick that Flint (1965) named the Deer Valley Limestone. The Deer Valley is separated from the subjacent Loyalhanna by a 6 inch red siltstone. The Deer Valley differs from the underlying Loyalhanna in that the former is wavy-bedded, rather than cross-bedded, and lacks the quartz-sand that characterizes the Loyalhanna. Furthermore, the Deer Valley Limestone contains a more abundant, although low diversity, brachiopod fauna. The Deer Valley is composed of a peloidal lime packstone-grainstone. carbonate sand. Many of the carbonate grains are ooids and intraclasts.

The Deer Valley depositional basin is largely confined to northern West Virginia and Maryland. It extends only slightly into Pennsylvania and feathers out only a short distance to the north of this location (Brezinski, 1989c). In the southern Garrett County, Maryland, the Deer Valley Member interfingers with dark-gray limestone contained within the Loyalhanna Member of the Greenbrier Formation and attesting to at least partial contemporaneity of the two units.

Overlying the Deer Valley Limestone is an interval ranging in thickness from 15 to 70 m thick of red and green clastics. Brezinski (1989 b) named this unit the Savage Dam Member of the Greenbrier Formation. In Pennsylvania this interval is considered the basal part of the Mauch Chunk Formation, although it can only be recognized where it separates the Deer Valley and/or Loyalhanna from the overlying Wymps Gap Limestone. The Savage Dam Member is characterized by white cross-bedded sandstones, red and green, fossiliferous, calcareous and thin limestone intervals, especially near the top of the member. These marine lithologies are interbedded with red-brown, mudcracked siltstone, shale, and mudstone that are commonly mudcracked and contain pedogenic surfaces. The alternation of marine and nonmarine lithologies led Brezinski (1989c) to contend that these strata were deposited during a number of short-lived sea level cycles. As many as 6 marine/nonmarine cycles can be recognized within the Savage Dam Member (Brezinski, 1989c).

Depositional Environments

The depositional origin of the Loyalhanna Formation has been debated for some time. Although the large scale cross-bed forsets are suggestive of an eolian depositional setting, the abundant ooids, intraclasts, fossils and fossil fragments, intertonguing with marine carbonates, basin geometry, and interpreted shallowing-up facies in presumed nearshore facies indicate a shallow marine origin for the unit.

The Deer Valley Limestone represents a submarine sand shoal environment that submerged a small area of southern Somerset County, Pennsylvania and Garrett County, Maryland. It represents a distinct depositional episode from the Loyalhanna as indicated by the red siltstone that invariably separates the Deer Valley from the Loyalhanna. The cyclic marine and nonmarine lithologies that characterize the Savage Dam Member were deposited in a peritidal setting, with shallow marine sandstones and shales forming during short -lived marine transgression, and tidal flat, rooted mudstones forming during periods of shallowing. Brezinski (1989c) interpreted these shallowing episodes as representing 5th-order cycles.

Paleoclimate

The Loyalhanna limestone can be traced from as far north as Scranton, Pennsylvania to south central West Virginia (Fig. 25). According to Ahlbrandt, (1995) the Loyalhanna is an eolianite, as evidence by sand sheets, sand flow toes, inverse graded bedding, and wind ripples. Most earlier interpretations have suggested a high energy marine environment of deposition. If the Loyalhanna is an eolianite, then the basin scale distribution of this sand sea attests to aridity during a low stand of sea level during the late Mississippian when eastern North America was approximately 15° south of the paleoequator (Fig. 7). These arid conditions contrast sharply with the subhumid conditions of the early Mississippian and the long-term perhumid climate of the Early and early Middle Pennsylvanian. Aridity during deposition of the Loyalhanna cannot be caused by long-term climate controls but rather appears to be related to short- to intermediate-term climate forcing parameters.

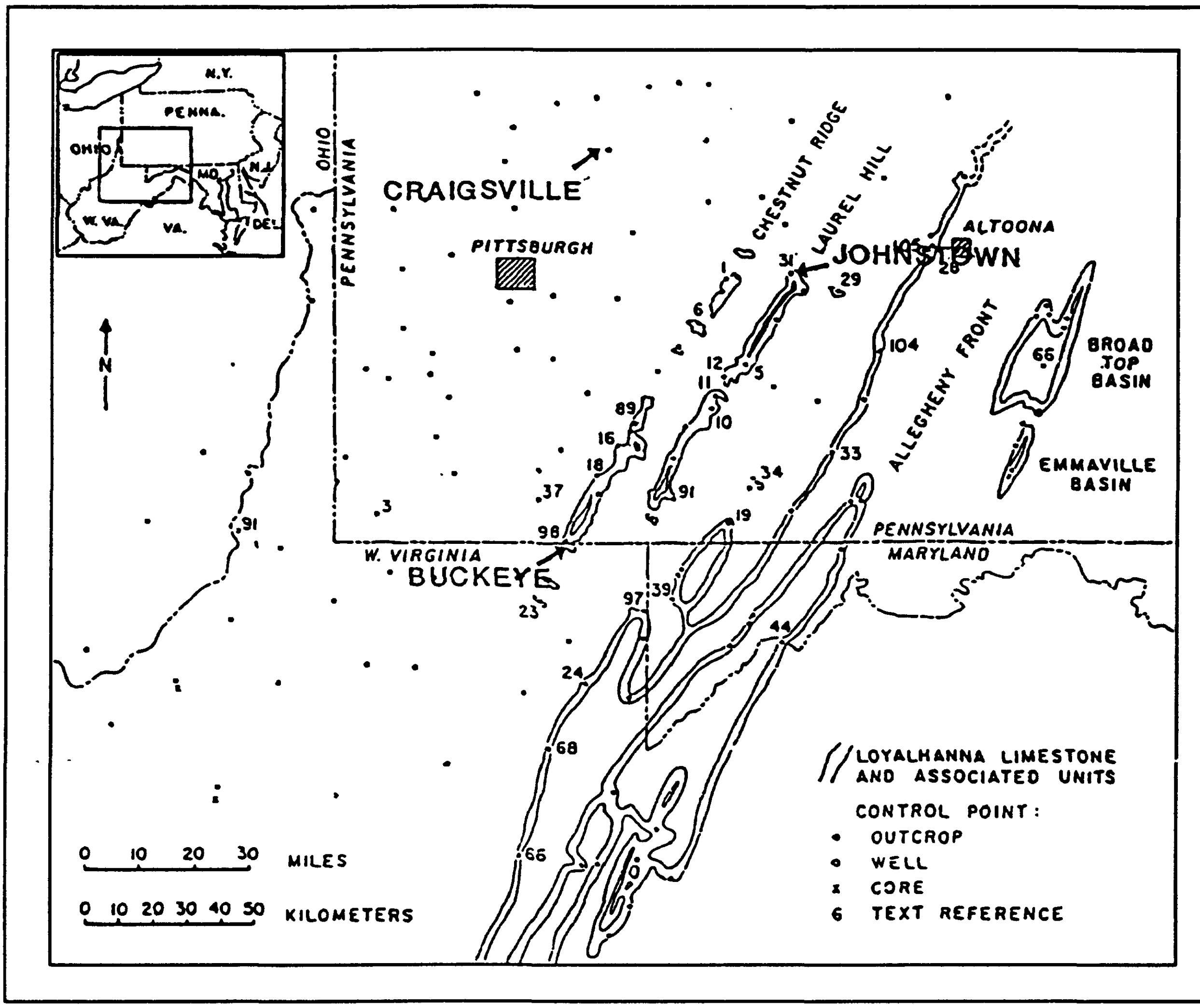


Figure 25. Map of Loyalhanna Limestone and associated units, showing outcrop, well and core occurrences. Numbers refer to localities defined by Adams (1970). Johnstown, Craigsville and Buckeye study localities shown on base map by Adams (1970).

STOP 10. I-68 (M.P. 15.9) HORIZON OF THE LOWER KITTANNING COAL BED AND UNDERLYING FLINT CLAY

Lat. 39°39'21"N, Long. 79°45'47"W, Lake Lynn, WV, 7½' quadrangle.

Introduction

The Lower Kittanning coal bed has been correlated with the No. 6 Block coal bed in southern West Virginia (Kosanke, 1984), with the Princess No. 6 coal bed in eastern Kentucky, the Colchester No. 2 coal beds of the Eastern Interior Basin, and the Croweburg coal bed of the

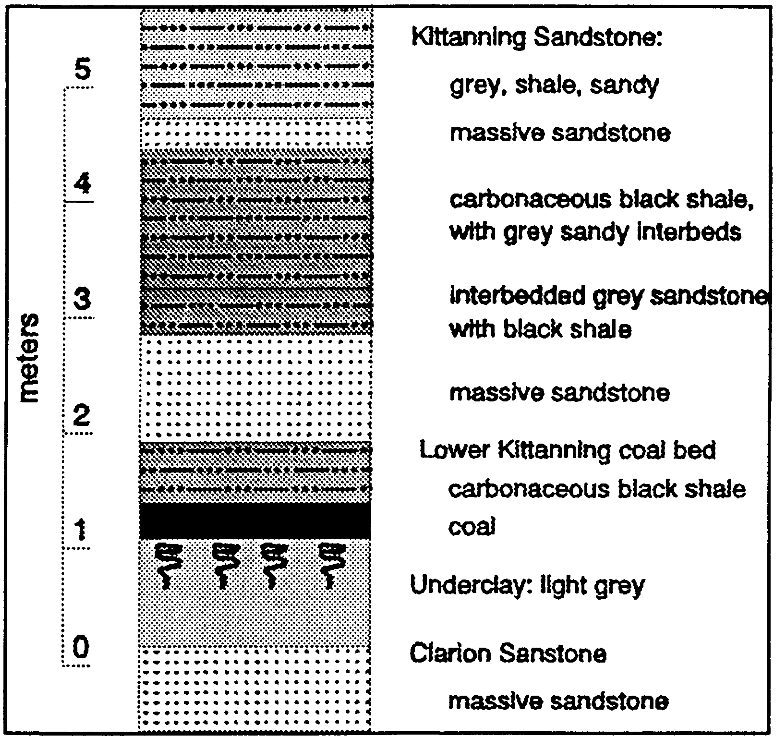


Figure 26. Measured section (portion of WVGS section 16) at Stop 10 containing the Lower Kittanning coal bed.

Western Interior Basin (Kosanke, 1973; Peppers, 1970, Ravn, 1986). These correlations are indicative of a period of widespread peat formation throughout eastern North America during a lowstand in sea level. Although thin in the Chestnut Ridge area, the Lower and Upper Kittanning coal beds attain mineable thickness, and represent a significant coal reserve in northern West Virginia, eastern Ohio, and western Pennsylvania. The Lower Kittanning at Stop 10 is represented by a thin coal bed at the top of the flint clay. It is the interval between the Lower Kittanning and the Middle Kittanning coal beds that has been the focus of interbasinal correlations across the United States.

Lithostratigraphy

The interval considered at Stop 10 commences with the flint clay at the base, Kittanning coal bed, overlying siliciclastic unit capped by another underclay and finally the Middle Kittanning coal bed horizon. This generalized lithostratigraphy (Fig. 26) can be traced throughout the central Appalachian basin. The underclay horizons, including the flint clay here, are intensely weathered paleosols. As noted above, the coal beds have been correlated among basins across the eastern United States. Our recent work has shown (unpublished) that the underclay deposits are even more continuous than the overlying coal beds. The siliciclastic unit overlying the coal varies from a marine black shale and limestone in Ohio, northern West Virginia, and western Pennsylvania to coarse sand along the Allegheny Front in eastern outcrops. The sequence is capped by another laterally extensive underclay paleosol and the overlying Middle Kittanning coal bed.

Depositional environments

The underclay or paleosol horizons have characteristics of intensely weathered, well drained, mineral soils that had high soil moisture regimes. These features include gleying, angular peds, high alumina clay content, mukkarra structures, slickensides, and distinct soil horizonation. The interbasinal extent of these Middle Pennsylvanian paleosols is indicative of major eustatic draw down of sea level and continental-scale exposure. In contrast, the overlying coal beds are the result of a rising water table and the onset of peat formation when the water table perpetually remained above the surface of the underlying mineral paleosol. At some point, rising water table outpaced peat formation and the vast peat swamps were flooded with marine, brackish, or nonmarine waters (Cecil and others, 1985). This rise in water table was likely driven by either rising sea level, increased rainfall, or both. This flooding resulted in black shale deposition over most of the basin followed by input of sand from the east and southeast. Deposition of clastic materials was terminated by an eustatic fall, subaeral exposure, and pedogenesis. The interbasinal extent of paleosols including coal beds provides clear and unequivocal evidence that sedimentation and stratigraphy was primarily controlled by allocyclic processes.

Paleoclimate

The paleosols, including coal beds, developed in environments that must have had low fluvial sediment yield, both dissolved and siliciclastic (Cecil et al., 1985). Such environments require perhumid or humid climates where soils are intensely leached and vegetation inhibits soil erosion as in equatorial Indonesia (Cecil et al., 1993). During sea level rise, fluvial sediment supply must have increased as evidenced by the input of coarse siliciclastic material along the eastern margin of the basin. This change in sediment supply appears to be the result of a drier and more seasonal paleoclimate. Therefore, sea level cycles that controlled accommodation space were accompanied by climate cycles that controlled sediment supply.

STOP 11: MISSISSIPPIAN-PENNSYLVANIAN UNCONFORMITY, EXIT 15, INTERSTATE 68

Lat. 39°39'29"N, Long. 79°47'00"W, Lake Lynn, WV, 7½' quad.

Introduction

Stop 11 is at the Mississippian-Pennsylvanian (mid-Carboniferous) unconformity (White, 1891), on the axis of Chestnut Ridge Anticline (Figs. 27A and 27B). The unconformity is exposed along the east-bound lanes of Interstate 68 (formerly U.S. route 48) just east of the exit for Coopers Rock State Forest (mile post 14.7).

Lithostratigraphy

The red beds, which crop out at the west end of the east bound exit, are assigned to the Upper Mississippian Mauch Chunk Group (Namurian A). Three Pottsville coal beds are present at or near Stop 11. All three are thin (<O.3 m) and contain low to moderate ash yields and high sulfur contents. The stratigraphically lowest coal bed occurs approximately 4 m above the level of the interstate highway drainage ditch. This coal bed, like most coal beds assigned to the Pottsville Group in the northern West Virginia area, is laterally discontinuous and irregular in occurrence

(Presley, 1979). This coal bed was palynologically analyzed and yielded a miospore assemblage that correlates with the lower part of the Middle Pennsylvanian Kanawha Formation (unnamed coal bed below the Matewan coal) (Eble, 1994). This indicates that the stratigraphically youngest Pennsylvanian strata at this location are early, but not earliest, Middle Pennsylvanian (Westphalian B) in age. Lower Pennsylvanian strata, assignable to the Pocahontas and New River Formations are absent here. As compared to thicknesses of equivalent Mississippian and Pennsylvanian strata in southern West Virginia and southeastern Virginia, over 1500 m (5,000 ft) of Upper Mississippian (Chesterian), Lower (Morrowan) and lowest Middle (early Atokan) Pennsylvanian strata are missing at Stop 11. Here, the Mississippian-Pennsylvanian systemic boundary occurs within the 4 m (13 ft) interval between the lower Middle Pennsylvanian unnamed coal bed and the Mississippian Mauch Chunk Group red beds. Petrographically, these coal beds contain high percentages of vitrinite and low to moderate amounts of inertinite. Despite their thinness, these coal beds display petrographic characteristics similar to age-equivalent Kanawha coal beds in southern West Virginia.

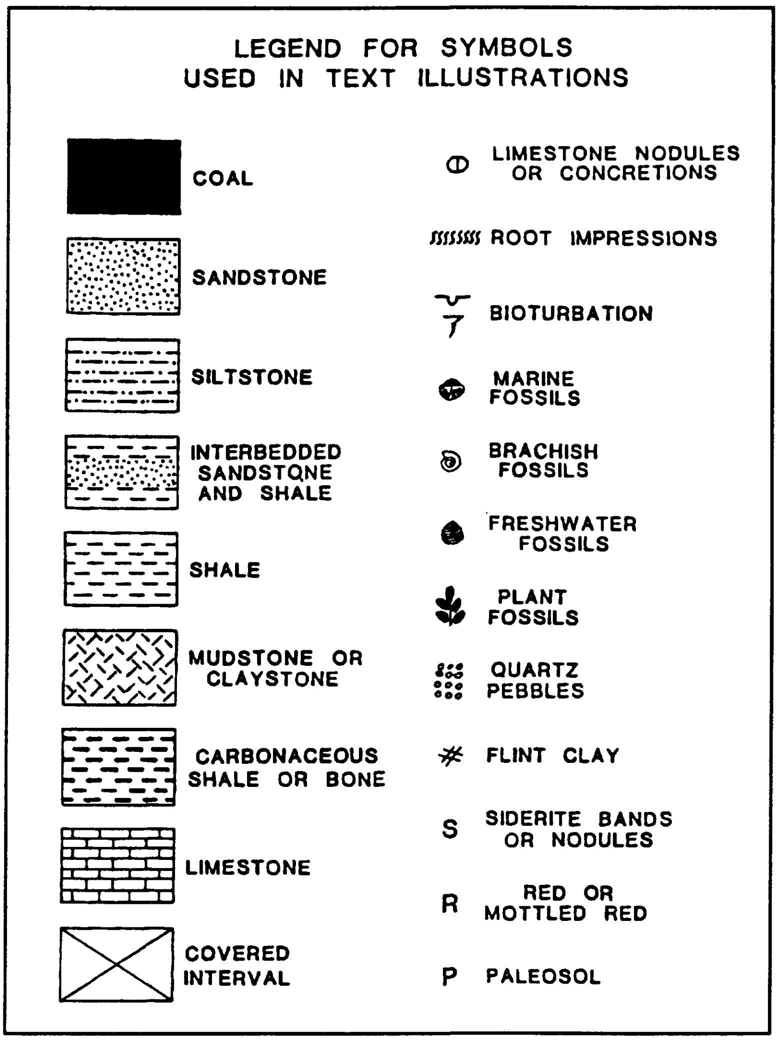


Figure 27A. Symbols used in figures 27b through 31.

Depositional environments

The interval exposed at Stop 11 appears to contain at least two siliciclastic paleosols, and a paleo-Histosol represented by the coal bed at the top of the paleosol sequence. The stratigraphy of the siliciclastic paleosols is quite complex at this locality, but they appear to

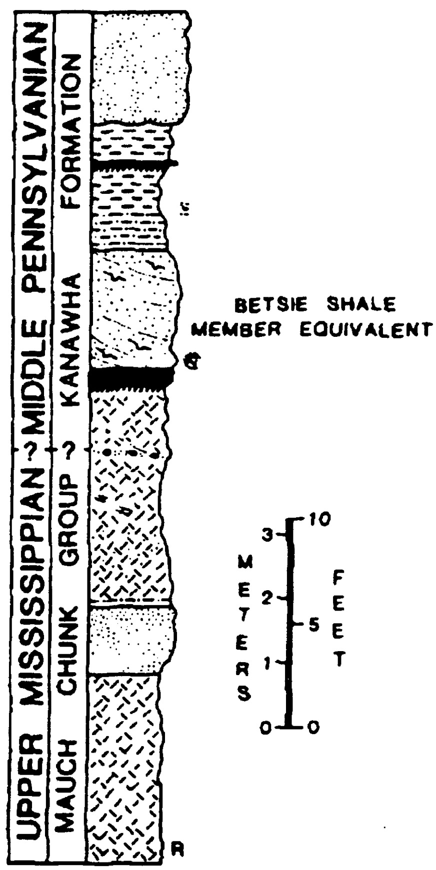


Figure 27bB. Stratigraphic section, Mississippian / Pennsylvanian unconformity along I-68, exit 15.

represent at least two periods of deposition each followed by subaerial exposure and weathering. The top of the lowermost paleosol occurs about 2.1 m below the base of the overlying coal bed. The lower paleosol overlies and appears to grade downward into green and red strata of the Upper Mississippian Mauch Chunk Group; thus, deposition may have occurred during the Mississippian whereas subaerial exposure and paleosol development appears to have been during the Early Pennsylvanian. The well-developed lower paleosol may be classified as a paleo-Ultisol whereas the poorly-developed upper paleosol may be more properly classified as a paleo-Inceptisol or Entisol using the U.S. Department of Agriculture classification system (Soil Survey Staff, 1975; Retallack, 1989; Buol, et al., 1989).

On the basis of the analysis of the "mid-Carboniferous eustatic event" of Saunders and Ramsbottom (1986), up to 4.5 Ma may be represented in the 4 m interval exposed at Stop 11. The complex paleosol and exposure surface stratigraphy at the Mississippian-Pennsylvanian systemic boundary appears, therefore, to be the source of a great deal of confusion as to the "age" of the unconformity.

Paleoclimate

On an interbasinal scale, high alumina refractory clay deposits, such as the Mercer clay in Pennsylvania, the Olive Hill clay in eastern Kentucky, and the Cheltenham clay on the flanks of the Ozark dome in Missouri, also occur at the Mississippian-Pennsylvanian systemic boundary. These high-alumina deposits are also probable paleo-Ultisols. The paleogeography of paleo-Ultisols (?) at the systemic boundary appears to be the result of intense weathering under high annual rainfall, which was fairly evenly distributed throughout the year. Weathering may have commenced as early as 330 Ma during the Late Mississippian at the on-set of a global eustatic event (Saunders and Ramsbottom, 1986). Exposure may have persisted for up to 4.5 Ma in much of North America, including the aforementioned areas, as the continent was moving northward through the paleo-equatorial zone. Weathering appears to have been particularly protracted and intense in those regions that contain diaspore clay deposits (Missouri, Kentucky, and Pennsylvania). Compared to the paleosol at Stop 11, the diaspore clay regions may have been somewhat more elevated, which allowed intense weathering on relatively well-drained soils. Paleosol development may have progressed during this 4.5 Ma period during subaeral exposure from the latest Mississippian into the Middle Pennsylvanian.

Pottsville Group on Chestnut Ridge, I-68:

As the trip descends the west side of Chestnut Ridge from Stop 11 we traverse strata of the Pottsville Group equivalent to Stop 7. The first outcrop has an unnamed marine zone that occurs in a siderite bed beneath the Lower Connoquenessing Sandstone, which is at the top of the cut. This previously unreported unit contains a marine fauna that compositionally is similar to the Dingess marine Shale (middle Kanawha Formation, early mid-Middle Pennsylvanian) in southern West Virginia (T.W. Henry, personal communication). The Dingess Shale crops out and is found in core from southern West Virginia northward into central West Virginia, but was not previously known to onlap into the Morgantown West Virginia area. A miospore analysis of the thin (0.3 m, 1.0 ft), discontinuous coal bed, designated herein as Pottsville coal 2, that occurs directly beneath the Lower Connoquenessing Sandstone but above the marine siderite zone at this location has shown the palynoflora to correlate with the No. 2 Gas Cedar Grove coal interval (Eble, 1994). This biostratigraphic age assignment is consistent with the invertebrate data from the marine siderite bed.

The next rolling stop contains a large exposure of the Upper and Lower Connoquenessing Sandstones. Rocks of the Pottsville Group in northern West Virginia typically consist of massive pebbly sandstones and sandy conglomerates intercalated with shale, siltstone and thin, discontinuous coal beds. It has been suggested that this group of rocks was deposited by bed load, braided fluvial systems onto an alluvial plain (Presley, 1979). Pottsville sediments in the Chestnut Ridge area are thought to have been derived from orogenic highlands located to the east and southeast (Meckel, 1967; Donaldson and Schumaker, 1981). Pottsville Group Sandstones, like the ones shown in this outcrop, generally occur as multi-storied units up to 30 m (100 ft) thick, averaging 9 to 12 m (30 to 40 ft).

A palynological analysis of a thin, discontinuous coal bed, designated herein as Pottsville coal j, in a shale lens in the Upper Connoquenessing Sandstone near the top of this cut indicates that it is age equivalent with the early Middle Pennsylvanian Fire Clay - Chilton coal interval of the Kanawha Formation in southern West Virginia (Eble, 1994).

The next outcrop as we descend Chestnut Ridge Anticline contains an exposure of the Homewood (?) Sandstone, the top of which marks the boundary between the Pottsville Group and the overlying Allegheny Formation in the northern Appalachian Basin. The top of the Pottsville is approximately time-equivalent with the Kanawha Formation - Charleston Sandstone (Allegheny Formation) contact in southern West Virginia. Pottsville Group strata on Chestnut Ridge contain marine units that are indicative of marine flooding of the Mississippian-Pennsylvanian (Mid-Carboniferous) unconformity unlike Stop 7 where the unconformity is erosional.

STOP 12: UPPER FREEPORT COAL BED AND ASSOCIATED STRATA: MIDDLE - UPPER PENNSYLVANIAN BOUNDARY, INTERSTATE 68, MILE POST 11.4.

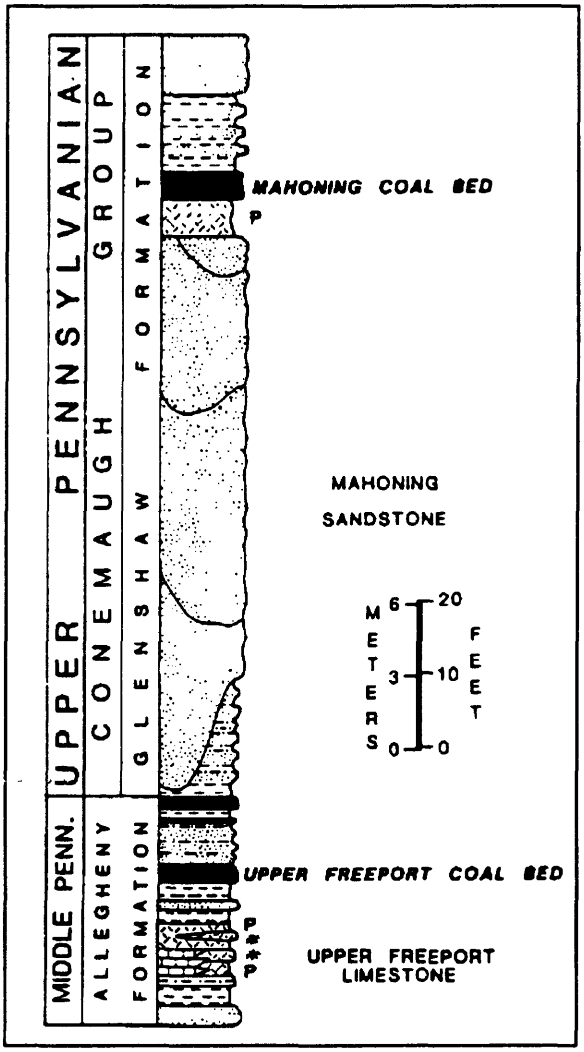


Figure 28. Stratigraphic section, Upper Pennsylvanian, Conemaugh - Allegheny Mahoning coal bed, Mahoning sandstone, Upper Freeport coal bed, Upper Freeport Limestone.

Lat. 39° 42.5'N, Long. 78° 17.6'W, Lake Lynn, PA/WV 7½' Quadrangle

Introduction

The section at Stop 12 includes the stratigraphic interval from the Upper Freeport Limestone Member of the Middle Pennsylvanian Allegheny Formation (Wilmarth, 1938) up to the Mahoning coal bed of the Glenshaw Formation of the Upper Pennsylvanian Conemaugh Group (Fig. 28). The primary emphasis at this stop is the stratigraphic interval from the base of the Upper Freeport Limestone to the top of the Upper Freeport coal bed.

Lithostratigraphy

The top of the Upper Freeport coal bed, which is exposed as three benches of coal at this locality, is defined as the top of the Allegheny Formation and the base of the overlying Conemaugh Group (Stevenson, 1873). The Upper Freeport coal bed horizon occurs throughout the Appalachian basin in Pennsylvania, Maryland, West Virginia, and Ohio. Where it is sufficiently thick, this laterally extensive coal bed has been mined from the eastern outcrop belt in western Maryland and eastern Pennsylvania to the western outcrop belt in east central Ohio, a distance of over 150 miles (250 km). This coal bed is underlain by nonmarine strata that include underclay, siltstone, shale, flint clay, and the Upper Freeport Limestone.

The stratigraphic succession overlying the Upper Freeport coal bed includes the Uffington Shale, Mahoning Sandstone, an Mahoning Fire Clay (underclay of the Mahoning coalbed), and the Mahoning coal bed. At Stop 12, the Uffington Shale has been cut out by the overlying Mahoning Sandstone. The Mahoning Fire Clay and coal are exposed at the top of the road cut on the south side of I-68.

The top of the Upper Freeport coal bed represents the Allegheny Formation - Conemaugh Group boundary in the Dunkard Basin. Above this contact at Stop 12 is the massive Mahoning sandstone and overlying Mahoning coal bed. The Mahoning coal bed is of particular significance in that it is the stratigraphically highest coal bed that contains abundant *Lycospora* sp., the dispersed spore of some of the giant lycopsid trees (e.g. *Lepidophloios and Lepidodendron*) that dominated many Lower and Middle Pennsylvanian coal beds throughout Euramerica. This coal is similar to the Upper Freeport in composition and floral contribution with one bench consisting of low ash, low sulfur coal.

Above the Mahoning coal bed, at approximately the level of the Brush Creek limestone, is the Middle - Late Pennsylvanian floral transition, where all but one of the major arboreous lycopsid genera, several tree fern and one sphenopsid spore genera become extinct. This transition is time-equivalent with the Westphalian - Stephanian boundary in western Europe, and is believed to represent the culmination of a major climatic shift from a basically perhumid climate in the Early through mid-Middle Pennsylvanian, to one that was moist subhumid, and probably more seasonal in the Late Pennsylvanian (Cecil and others, 1985).

Depositional environments and paleoclimate

The interval from the base of the laterally extensive Upper Freeport Limestone to the top of the coal bed is interpreted to be the result of complex variations in sediment flux that occurred in response to a cyclic paleowater table and paleoclimate (Cecil et al., 1985). The limestone is nonmarine and probably was deposited in large, shallow, lakes as indicated by multiple subaeral exposure features that include subaeral crusts, pedogenic brecciation, and residual clay. Intermittent deposition and subaeral exposure of the limestone is indicative of a fluctuating lake level and water table. The frequency of water level fluctuation is unknown but may have been controlled by short-term or very short-term variations in paleoclimate (Table 1). Lake waters must have been alkaline, Ph 7.8 or greater, (Krumbein and Garrels, 1952) during deposition of the limestone. The alkalinity and probable high concentrations of dissolved solids in lake waters during deposition of the limestone was, in part, the result of a relatively dry paleoclimate that concentrated dissolved solids through evaporation (Cecil, et al., 1985; Cecil, 1990).

Subsequent to deposition, the Upper Freeport limestone appears to have been subjected to an extended period of subaeral exposure and weathering (Cecil, et al., 1985). The weathering and resultant residual clay deposits imply a drop in the water table during the onset of increasing pluvial conditions. The increasing rainfall also contributed to an influx of siliciclastic sediment, which is shown by the exposed siliciclastic strata overlying the Upper Freeport Limestone at this stop (Cecil, 1990). Further increases in rainfall led to increased vegetative cover, rainfall dilution of runoff, and leaching of residual soils, which reduced the influx of siliciclastic sediment and dissolved solids. Extensive leaching of the landscape, under the pluvial part of climate cycles, restricted the buffering capacity of surface water systems by reducing the concentration of dissolved solids. A rising water table with low buffering capacity led to acidic water (Ph <6) from decaying vegetal matter. These conditions of a high water table and low Ph are necessary for the formation of thick, laterally extensive, high quality peat (Cecil and others, 1985).

On a regional scale, a complex of kaolin enriched paleosols occur in a facies mosaic within the interval from the base of the Upper Freeport Limestone up to, and including, the Upper Freeport coal bed. These paleosols appear to be the result of a fluctuating water table and weathering during humid parts of climatic cycles. The most intensely developed paleosols probably formed on well-drained paleotopographic highs. The kaolin enriched deposits have been locally mined and used in the manufacture of refractory brick.

Interruption of peat formation, as illustrated by the three benches of coal and inter-bedded partings at Stop 12, are sometimes interpreted as crevasse splays or other autocyclic depositional events (e.g., Ferm and Horne, 1979). Alternatively, these interruptions may be the result of allocyclic controls such as climatic events that cause an influx of siliciclastic sediment and (or) change in water table. The latter interpretation is supported by the regional extent of many partings, which suggests a drowning of the peat-forming environment by a prolonged elevation of the water table, and concomitant siliciclastic deposition in a lacustrine environment (Cecil and others, 1985).

Peat formation in the Upper Freeport paleoswamp was terminated by an allocyclically-controlled rising water table that finally out-paced peat formation (Cecil and others, 1985). The lacustrine environment of the drowned paleoswamp became the site of an autocyclic facies mosaic of siliciclastic deposition that includes the Uffington Shale Member of the Conemaugh Group, whose type section is just south of Morgantown, WV, and the Mahoning Sandstone Member, as represented by the large sandstone paleo-channel fill at Stop 12. The Uffington Shale may represent deposition in a lacustrine environment, whereas the Mahoning Sandstone is the result of a prograding fluvial system (Cecil and others, 1985). Channel incision may have been by down cutting in response to a drop in base level (allocyclic) or progradation of a fluvial system (autocyclic). In the climate model of cyclic stratigraphy (Cecil, 1990), the Uffington Shale and Mahoning Sandstone also are the result of an increase in siliciclastic influx in response to a return to somewhat drier and more seasonal conditions. This increased siliciclastic influx was coeval with the lacustrine system where a rising water table was controlled by tectonic subsidence and (or) rising sea level. The Mahoning Coal bed, which overlies the Mahoning Sandstone at Stop 12, is the result of a return to a pluvial period and reduced siliciclastic influx, and the correct climatic and chemical conditions necessary for peat formation.

The Upper Freeport coal at Stop 12 consists of 3 splits over a 4.3 m (14 ft) interval. The main (lower) split is 0.9 m (3 ft) thick, is vitrinite-rich, especially the >50 micron vitrinite types, and is low in ash-yield and sulfur. Palynologic results show a tree fern spore-dominant swamp palynoflora throughout, but with a moderate arboreal lycopsid spore contribution. At this location development of the Upper Freeport swamp was not at its best (mineable) quality, but the lower and middle benches of this split probably represent paleoenvironments of the thicker coal to the north. Initial peat accumulation was in a planar swamp (Cecil and others, 1985) with minor emplacement of minerals and sulfur. Tree ferns dominate the flora and the pre-vitrinite plant debris was moderately preserved with little oxidation of the peat. With further peat accumulation (middle bench) the planar swamp may have become slightly elevated. Mineral and sulfur emplacement was low. Tree fern spores dominate the palynoflora, but increased arboreal lycopsid spore abundance may indicate a standing water cover.

Well-preserved pre-vitrinite was an important part of the peat. With the buildup of the peat oxidation became more frequent in a paleoclimate that delivered insufficient seasonal rainfall to allow for extensive domed peat formation. Oxidation of the peat surface and an increase in inertinite abundance preceded the ultimate drowning of the Upper Freeport coal. The paleoclimate at the time of Upper Freeport peat accumulation probably was transitional between the perhumid Early and early Middle Pennsylvanian climate and the drier (more seasonal) climate of the Late Pennsylvanian. The paleoclimate was obviously wet enough to allow for the wide-spread development of the Upper Freeport coal, and for the accumulation of some low ash and sulfur, pre-vitrinite-rich peat. However, while the annual rainfall may have been insufficient to allow for extensive domed peat formation (i.e. to the extent inferred for many Lower and Middle Pennsylvanian swamps), it certainly was adequate to allow for the development of an extensive peat swamp that, in some areas, may have attained some elevation above the regional water table.

STOP 13: PALEOSOLS IN THE PITTSBURGH SHALE, CONEMAUGH GROUP, EXIT 146, INTERSTATE 79

Lat. 39°32'25"N, Long. 79°59'23"W, Morgantown South, WV 7½' Quadrangle.

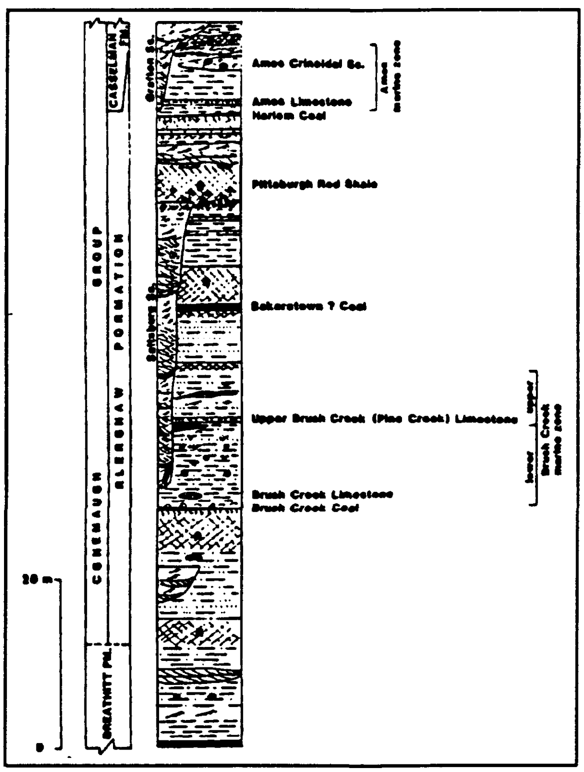


Figure 29. Stratigraphic section, Late Pennsylvanian, Conemaugh, Ames marine zone, Pittsburgh Red Beds, Bakerstown coal bed, Brush Creek Marine zone, Brush Creek coal bed.

Introduction

Upper Pennsylvanian strata assigned to the Conemaugh Group are exposed in a road cut along I-79 adjacent to the Goshen Road exit (exit 146) in Monongalia County, West Virginia. The cut exposes approximately 34 m (110 ft) at, and just above road level, including the following units, in descending order: Grafton sandstone, Ames Limestone, Harlem coal bed and Pittsburgh Shale sequence. This stratigraphy is depicted on the upper half of Fig. 29.

Lithostratigraphy

The Grafton sandstone, exposed at the top of the section, marks the base of the Casselman Formation, and consists of interbedded siltstone and sandstone. Strata below the Grafton are assigned to the Glenshaw Formation. The Ames Limestone and shale occurs directly below the Grafton sandstone and represents a major marine transgression in the Dunkard Basin. As such, the Ames serves as an important lithostratigraphic correlation unit across the basin. The Ames is generally an impure, shaley limestone to calcareous shale, and is locally fossiliferous.

The Harlem coal bed, which underlies the Ames Limestone and shale, is a thin, generally less than 0.6 m (2.0 ft thick), laterally persistent unit that occasionally attains mineable thickness. Compositionally, the Harlem coal bed generally contains high percentages of vitrinite group macerals, and low to moderate amounts of liptinite and inertinite group macerals. Ash yields and sulfur contents commonly are moderate to high. Other Conemaugh Group coal beds of regional extent include the Mahoning, Bakerstown, Elk Lick and Little Clarksburg.

The unit underlying the Harlem coal bed at this stop consists of alternating beds of impure limestone and variegated red/green claystone that often contains calcium carbonate nodules. This unit, referred to as the Pittsburgh red beds, contains features indicative of repeated and (or) prolonged subaerial exposure. These features include calcareous peds, mukkara and cone-in-cone structures, which indicate that the Pittsburgh red beds are a series of ancient seasonally "dry" paleosols. The lateral persistence of this unit across the Dunkard Basin indicates that climatic and depositional conditions necessary for its formation were of basinal extent.

Depositional environments and paleoclimate

The abundant calcium carbonate in the paleosol section is indicative of a prolonged dry season. A nonmarine limestone, which often occurs as discontinuous pods at the top of the Pittsburgh reds is of mixed lacustrine and pedogenic origin. It is developed in topographic lows on the gilgai surface of the Pittsburgh reds. Lacustrine carbonate deposition apparently occurred during and following rainy periods that may have lasted months to a few years. Lakes dried up and pedogenesis of the lacustrine carbonates followed during drier periods.

Unlike the Pottsville Group and Allegheny Formation strata, the Conemaugh Group contains mainly red shales and mudstones. These red sediments regionally first appear in the section 30 to 60 m (100 to 200 ft) below the Ames marine zone and are present to varying degrees in the upper two thirds of the Conemaugh Group throughout its area of occurrence. The calcium carbonate content of Conemaugh Group rocks is higher compared to Middle Pennsylvanian sections (Cecil and others, 1985). Carbonate occurs as beds and admixture in marine intervals, as nonmarine lacustrine beds (e.g. Clarksburg Limestone of I.C. White (1891), and as pedogenic nodules, discontinuous lenses, and admixture within mudstones and shales.

Conemaugh Group coal beds are thinner, and more impure than those in the underlying Allegheny Formation or overlying Monongahela Group. The Little Clarksburg coal bed rarely exceeds 0.6 m (2 ft) in thickness in this region. It is thicker and mineable in the Potomac Basin of eastern West Virginia and western Maryland, but is of poor quality, locally known there as the "Dirty Nine-foot". The Elk Lick coal bed, exposed just above the first bench at the rolling stop on I-68, has also been mined in the Potomac Basin in western Maryland and also in central West Virginia. The Elk Lick is 0.9 m (3 ft) thick in this cut, but has not been commercially exploited locally. As a group Conemaugh coal beds are higher in ash yield and sulfur content than the underlying Allegheny Formation coal beds, and comparable in sulfur content with the overlying Monongahela Group coal beds but higher in ash yield. The Elk Lick coal bed exposed in the I-68 road cut is 4 feet thick and represents peat that accumulated during the Conemaughian drier interval than the stratigraphically lower Upper Freeport or Mahoning coal bed. The Elk Lick coal was formed after the demise of the peat-swamp arboreous lycopsids at the Westphalian-Stephanian boundary. The Elk Lick coal bed is high in ash yield and high in sulfur and contains significantly greater inertinite, and less well-preserved (>50 micron) vitrinite than the Upper Freeport or coals lower in the Pennsylvanian. At the top of the section the Little Clarksburg coal is exposed, although the stratigraphically lower Harlem and West Milford coals are exposed in nearby outcrops. These coal beds are all similar in ash yield, sulfur content, petrographic composition and floral character to the Elk Lick, and typify Conemaugh coal beds that apparently accumulated in planar swamps with significant surface and groundwater influx of minerals and dissolved solids in moderate pH waters. Sulfur emplacement, especially as pyrite, was extensive and coincided with severe degradation of the peat and loss of >50 micron vitrinite components, probably by anaerobic microbes. These attributes suggest a seasonal paleoclimate with insufficient annual rainfall to maintain a highly acid ombrogenous swamp.

STOP 14: UPPER CONEMAUGH AND LOWER MONONGAHELA GROUP STRATA, NORTH SIDE OF THE MORGANTOWN MALL COMPLEX, INTERSTATE 79, EXIT 152, MORGANTOWN, WV

Lat. 39°37.82'N, Long. 80°00.03'W, Morgantown North, WV 7½' Quadrangle.

Introduction

Approximately 18 m (58 ft) of Upper Conemaugh Group rocks and 32m (106 ft) of lower Monongahela Group rocks are exposed in cuts made for the construction of the Morgantown Mall and upper commercial area (Fig. 30). The section features five coal beds (some multi-benched) and an abundance of non-marine, lacustrine limestone beds. Starting at the eastern end of the exposure, several benches of the Little Pittsburgh coal bed are interbedded with shales, mudstones, and lacustrine carbonates. The Little Pittsburgh coal bed is of minor economic importance, but is persistent enough to serve as an important stratigraphic marker. Important to our discussions of climatic impact on the rock record is the development of the soil profile beneath the Pittsburgh coal bed. Here, where the coal facies is well-developed, the subjacent soil profile is poorly-developed, thin and contains some carbonate in the form of nodules. A transect from this stop southward for 60 miles illustrates the effects of the "Pittsburgh coal climate" on the substrate where the coal facies is poorly-developed or absent.

The Pittsburgh coal bed exposed in the Mall cut has an 2.6 m thick main coal of generally low ash-yield and moderate sulfur content. Including roof shales and rider coal beds the Pittsburgh is 5.2 m thick. At this location the coal consists of six benches, two more than are present six miles to the northeast where the coal was extensively studied in a surface mine at the Greer estate. The basal bench (lower 0.3 m) is present across most of the areal extent of the Pittsburgh coal. It is high in sulfur and moderate ash-yield, and has a tree fern dominant palynoflora with distinct calamite and cordaite contributions. This lower bench is interpreted to represent the pioneering

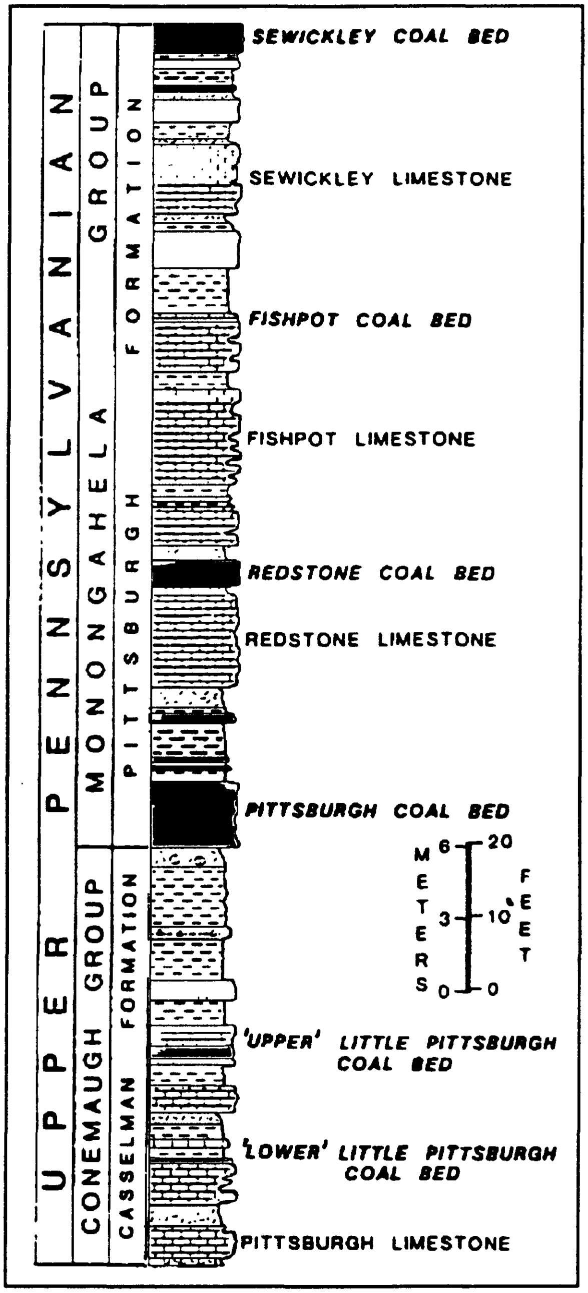


Figure 30. Stratigraphic section, Upper Pennsylvanian, Monongahela - Conemaugh, Sewickley coal bed, Sewickley Limestone, Fishpot coal bed, Fishpot Limestone, Redstone coal bed, Redstone Limestone, Pittsburgh coal bed, 'Upper' Little Pittsburgh coal bed, 'Lower' Little Pittsburgh coal bed, Pittsburgh Limestone.

plant community of the Pittsburgh swamp. The ash yield and sulfur contents indicate that these plants grew in a planar swamp with a significant influx of surface and ground water. Peat oxidation was minor and the preservation of plant debris was moderate. Above the basal bench, up to the parting at the 1.2 to 1.4 m level, the coal is low ash and moderate sulfur content and petrographically shows two trends in swamp development. These trends of increased peat preservation, as shown by increased >50 micron vitrinite components, are reflected in the sulfur content and palynofloral succession, but not in ash yield. The first, terminated by a fusain parting, displays an upward increase in vitrinite content, especially >50 micron component, an increase in calamite and arboreous lycopsid spores, and increased sulfur content. A second similar trend is terminated by the bone coal parting at four feet. Increased vitrinite and >50 micron vitrinite, arboreous lycopsid and calamite spores suggest a slight increase in surface water depth as peat accumulation proceeded. The increased sulfur content probably represents increased introduction of sulfur into the swamp by surface or groundwater as water depth increased. The termination of these trends by fire and sediment deposition demonstrates a rapid and significant change in the water table. The fusain parting changes laterally into a bone coal parting and is present sporadically throughout the Pittsburgh coal areal extent. The four foot parting was extremely widespread and occurs throughout the Pittsburgh coal at approximately the same level in the bed (Cross, 1952).

Allocyclic factors in addition to climate doubtless contributed to the vast areal distribution of the Pittsburgh coal bed. However, the thickness and quality of the coal appears to be strongly climate-controlled. During the initial stages of accumulation of the Pittsburgh paleopeat, annual rainfall, augmented with surface water flow, was sufficient to allow the development of a large planar swamp. During later stages of peat development the influential effects of rainwater vs. surface/groundwater on peat composition, which in-turn influenced ash yield, sulfur content and maceral composition, varied with location and time. Ash yield and sulfur content, as well as the degree of degradation of the peat plant debris, were greater to the west of the Morgantown area probably because of more frequent and extensive incursions of fresh surface and ground water into the peat swamp. To the east, in western Maryland, the Pittsburgh coal is thicker, lower in ash yield and sulfur content than in the Morgantown area, and appears to have been, except for the basal high ash and sulfur bench, more influenced by rainfall. The paleoclimate during accumulation of the Pittsburgh paleopeat was, therefore, wet enough to allow initial swamp development and to allow parts of the swamp to be maintained primarily on rainfall, but not wet enough to inhibit the regular influx of surface and groundwater into the swamp along the western margins. The Pittsburgh coal thins southward and is thin, or completely absent in south-central West Virginia. These thin Pittsburgh coal occurrences, sixty miles to the south, correlate with the coal in the Morgantown area. The thickening to the east and thinning to the south of the Pittsburgh coal is the result of paleotopographic controls on the development of the Pittsburgh swamp and contemporaneous paleosols.

The Redstone Limestone, a well-developed non-marine, regionally extensive, lacustrine carbonate occurs above the Pittsburgh coal bed. Lacustrine limestones such as this one are most abundant in the Monongahela Group in the region encompassing northern West Virginia, southwest Pennsylvanian, and eastern Ohio. These carbonates are exclusively micrites, occurring in complexes interbedded with argillaceous limestones, calcareous mudstones, and calcareous and non-calcareous shales. The Redstone Limestone generally occurs as a monolithic micrite, the result of deposition in an aerially extensive lake.

The Fishpot coal is only 2.5 cm thick in this section and, with few exceptions, rarely exceeds 0.6 m in thickness. However, thin coal or carbonaceous shale can be found at this stratigraphic position at widely separated points throughout the Dunkard Basin.

The thickest sandstone in this section occurs in a clastic interval above the Fishpot coal bed. It is tabular, varying in thickness from 0.9 to 2.3 m. Another clastic interval occurs above the Sewickley Limestone. Thin sandstone and shale beds are interbedded with the Sewickley coal bed here. The association of the Sewickley coal with fine to coarse clastic rocks is characteristic basin-wide. Lower coal benches or "splits" of the Sewickley are sometimes miscorrelated with the underlying Fishpot coal bed. The main mineable bench of the Sewickley coal bed is not well-exposed at this location. The weathered blossom, 1.2 m thick, can be seen at the top of the section at the extreme western end of the cut. This bed has also been extensively mined underground in the Morgantown area.

SUMMARY AND CONCLUSIONS

This trip traversed and included Stops in Paleozoic strata from the earliest Cambrian to the latest Pennsylvanian within the central Appalachian basin. The Early Cambrian illustrates the tectonic influence of rifting and siliciclastic sediment supply in response to a long-term dry subhumid to subhumid climate (Table 1), which is consistent with a paleolatitude location of approximately 40° S. In contrast, Early Ordovician strata at Stop 2 consisted of carbonates that were deposited in response to allocyclic changes in sea level and climate. Sea level fluctuated from subtidal to total withdrawal with protracted subaeral exposure. By the Early Ordovician, the region was located in the high pressure climate zone near 30° S, which is consistent with inferred climate ranges of arid to semiarid conditions.

As a result of the Acadian orogeny, the Appalachian foreland basin was well developed by the Late Ordovician and the red continental siliciclastic strata of the Juniata Formation (Stop 6) were deposited in response to semiarid to dry subhumid conditions. There was a hiatus in deposition at the end of the Ordovician that was followed by deposition of the Early Silurian Tuscarora Sandstone during transgression. The origin of the Tuscarora (Stop 6) remains enigmatic even though most workers agree that both marine and fluvial processes contributed to its deposition. Neither process adequately explains the textural and mineralogical maturity of the Tuscarora. These maturities, however, can be attributed to mechanical weathering and the development of an eolian regolith under arid to semiarid climatic conditions. If so, then this regolith was reworked and deposited by hydraulic processes during sea level rise in the Early Silurian.

The long-term climate remained arid through the remainder of the Silurian and into the Devonian while intermediate- to short-term climate fluctuations ranged from arid to semiarid or dry subhumid as evidenced by intermediate to short term allocyclic variation in sediment supply. Regional-scale Upper Silurian peritidal carbonates (Stop 5) with abundant halite casts are indicative of these dry conditions. Latest Silurian and earliest Devonian sea-level rise resulted in subtidal carbonate deposition (Stop 3) throughout the central Appalachian basin. Such deposition is consistent with long-term aridity and very low fluvial siliciclastic sediment supply.

The textural and mineralogical maturity of the Lower Devonian Oriskany Sandstone (Stop 3) may be best explained by continuation of Silurian long-term aridity and mechanical weathering by eolian processes. The lithology of the Oriskany, which regionally ranges from a pure quartz arenite to an arenaceous limestone, may indicate eolian transport of sand into the carbonate environments of the Early Devonian seaway. This inferred origin for the Oriskany is in contrast to that of the Lower Silurian Tuscarora Sandstone which was the result of transgressive reworking of an eolian regolith. Both the Tuscarora and the Oriskany may owe their textural maturity to eolian processes.

Following deposition of the Oriskany Sandstone, there was an apparent deepening of the Appalachian foreland basin as indicated by widespread deposition of finer grained siliciclastic materials including black shale. Abundant terrestrial organic matter in some black shale facies appears to indicate high terrestrial organic productivity in response to a paleoclimate that became wetter. The deepening of the foreland basin was likely in response to the Taconic orogeny. Following depositing of the black shale, basin fill coarsened upward culminating in a major influx of sand in the Late Devonian and Early Mississippian (Stops 4 and 8). The widespread distribution of this sand, from New York to Tennessee, is indicative of an allocyclic control on sediment supply. The amount of sand and the types of paleosols, including coal, associated with these sands indicates that the allocyclic control was climatic rather than tectonic and, furthermore, that the long-term climate was moist subhumid. Based on the occurrence of coal and variation in siliciclastic sediment supply, the intermediate- to short-term climate fluctuations ranged from dry subhumid to humid.

Early Mississippian sand deposition under subhumid conditions was followed by a return of aridity as evidenced by gypsum deposition in southwest Virginia and coeval terrestrial redbeds containing Aridisols in southern West Virginia, herein after referred as the Pocahontas basin. Transgression under these arid conditions resulted in deposition of the overlying Late Mississippian Greenbrier Limestone. In the vicinity of the field trip route, the low-stand Loyalhanna Limestone eolianite (?) further indicates Late Mississippian aridity. Latest Mississippian strata are missing in the vicinity of the field trip route as a result of the world wide mid-Carboniferous unconformity. However, relatively rapid subsidence in the Pocahontas basin resulted in nearly continuous deposition during the Late Mississippian and Early Pennsylvanian. In the Pocahontas basin, Late Mississippian deposition was only interrupted by eustatic drops in sea level that resulted in low-stand pedogenesis of regional subaerial exposure surfaces. These paleosols record both eustatic cycles and climate cycles that ranged from semiarid to humid.

Although Early Pennsylvanian strata are also missing in the vicinity of the field trip route, deposition in the Pocahontas basin recorded a fluctuating water table, probably related to eustatic changes in sea level, and climate cycles that were much wetter than those of the Late Mississippian. Paleosols in the Early Pennsylvanian of the Pocahontas basin as well as those at the Mississippian-Pennsylvanian unconformity (Stop 11) indicate that the climates of the Early Pennsylvanian ranged from moist subhumid to perhumid.

By the late Middle Pennsylvanian (Desmoinsian of the U.S.; Westphalian D of Europe) the long-term climate shifted from humid to moist subhumid conditions. Intermediate- to short-term climate cycles ranged from perhumid to dry subhumid conditions as evidenced by a marked but cyclic change in the sedimentary geochemistry of nonmarine strata. Dry subhumid conditions are indicated by increased siliciclastic flux, abundant pyrite and calcite, including nonmarine limestones (Stops 10 and 12). In contrast, humid to perhumid conditions produced chemically weathered and highly leached mineral paleosols and coal beds during low stands.

A pronounced long-term dry subhumid climate developed in the early Late Pennsylvanian (Missourian) as evidenced by low-stand calcic-Vertisols, calcareous red beds, and far fewer economic coal deposits (Stop 13). A shift toward moist subhumid conditions during deposition of latest Pennsylvanian strata (Virgilian) in the central Appalachian basin resulted in increased coal formation (Stop 14) under moist subhumid conditions. Peat developed in topographic lows while coeval Ultisols formed around the basin margins. Moist subhumid conditions were followed by dry subhumid conditions that lead to clastic influx and burial of the underlying peat. The driest parts of climate cycles, which were dry subhumid to semiarid, were conducive to nonmarine limestone deposition in topographic lows in the basin while coeval calcic-Vertisols formed around the basin margins. Climate change, therefore, was the primary control on the lithostratigraphy of Late Pennsylvanian strata in the Appalachian basin.

By the examples included herein, we have attempted to illustrate the relative importance of allocyclic and autocyclic processes as controls on sedimentation and stratigraphy in the central Appalachian basin. Allocyclic processes appear to be the dominant control on lithostratigraphy. Autocyclicity seems to control facies relationships within allocyclic packages and perhaps fifth or sixth order cycles and higher. Clearly long-term tectonic subsidence was a primary control on accommodation space. Tectonic influence on fluvial sediment supply, while commonly suggested, is unclear and may be highly over emphasized. Intermediate- to short-term eustatic changes in sea level were also important controls on accommodation space, but probably had little influence on sediment supply. Long-to short-term changes in climate, however, were the primary controls on variation in fluvial sediment supply, both chemical and siliciclastic, and a primary control on lithostratigraphy.

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