Field Trip Guidebook

National Association of Geology Teachers

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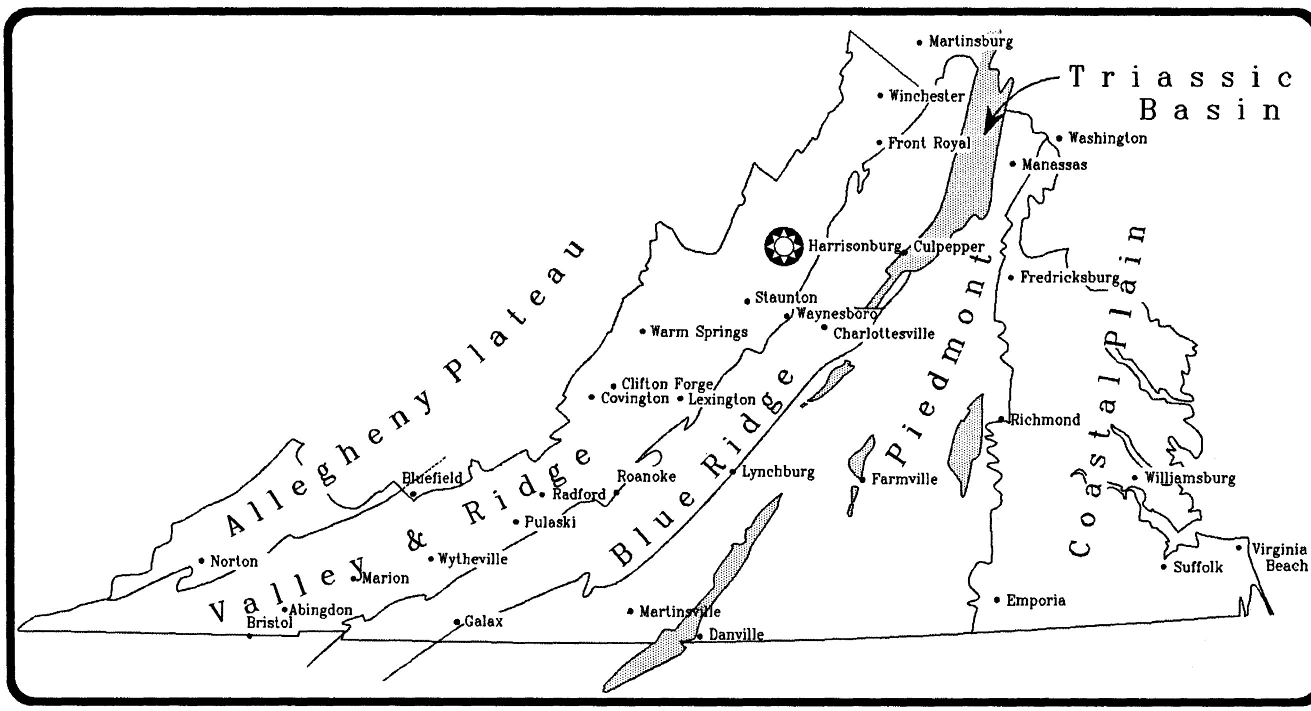

James Madison University

Harrisonburg, Virginia

Field Trip Guide

Evidence for the Progressive Closure Of the Proto-Atlantic Ocean in the Valley and Ridge Province Of Northern Virginia and Eastern West Virginia

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INTRODUCTION

PHYSIOGRAPHIC SETTING

This field trip runs entirely within the Valley and Ridge province of the Appalachians. The Valley and Ridge is underlain by Paleozoic strata that have been deformed during the Alleghenian orogeny into a fold and thrust belt. Topography and relief within the Valley & Ridge is controlled primarily by the differential erosion of these folded and faulted strata. Generally speaking, in this part of the Appalachians, sandstones are the most resistant strata, and are therefore the ridge formers. Limestones and shales are generally much less resistant, and are the valley formers.

The Valley and Ridge is bounded on the west by the Allegheny Plateau. The Plateau is underlain by basically the same strata as the Valley and Ridge, but does contain younger parts of the stratigraphic column. Structurally, the Plateau is much less severely deformed than the Valley and Ridge. The Plateau is underlain by flat-lying to gently-dipping strata, in contrast to the much steeper dips in the Valley and Ridge. The structural and physiographic boundary between these two provinces is referred to as the Allegheny Front, visible in the western part of the field area (Germany Valley overlook, Stop 4).

The Valley and Ridge is bounded on the east by the Blue Ridge, which is visible from some places along the field trip route. The Blue Ridge contains Precambrian plutonic and metamorphic rocks that are the oldest in the area, and which form the basement upon which the Valley and Ridge stratigraphic succession was deposited. The Blue Ridge is discussed in more detail in the field guide by Conley and Gathright in this volume.

The Piedmont Province is located east of the Blue Ridge, and will not be accessible at all on this field trip. References are made to the Piedmont, however, because many of the sedimentary, volcanic, plutonic, and metamorphic rocks of the Piedmont are of the same ages as some of the strata in the Valley and Ridge. These Piedmont rocks contains information about geologic events happening in the Proto-Atlantic east of the Appalachian margin while the strata of the Valley and Ridge were being deposited and deformed.

HISTORICAL BACKGROUND

Anyone who has collected fossils from the sedimentary rocks of the Appalachians realizes that many of these strata were deposited in shallow marine environments. These represent strata of both the ancient continental margin the bordered the Paleozoic Proto-Atlantic (Iapetus) ocean, and strata deposited in a variety of basins developed during the three orogenies that affected the Appalachians in the Paleozoic. Paleomagnetic data indicate that throughout this time the mid-Atlantic Appalachian region lay in tropical latitudes which favors carbonate deposition.

The Appalachian stratigraphic succession (Figure 1) contains the historical record of the eastern continental margin and orogenic basins of North America during the Paleozoic. This record includes all the stages in the Wilson Cycle of ocean basins. The Paleozoic Appalachian continental margin located along the edge of the Proto-Atlantic was created during a continental rifting represented by the Catoctin basalt flows (Fichter and Diecchio, 1986a) in the Blue Ridge. Following this rifting, the Appalachian area became part of a divergent (passive) continental margin that is represented by strata from the Lower

Stratigraphy of the Central and Northern Shenandoah Valley, and Eastern West Virginia

Sequence	AGE	FORMATION (West — East)	Thickness	DESCRIPTION	Interptetation
KASKASKIA	Miss.	Mauch Chunk		Coarse ss, silt, shale. Channels. Plant fossils common in places. Coal	Begin Allegheniaan Orogeny
	Miss.	Greenbriar		Carbonate dominated (oolites, biosparites)	Orogenic Calm
	Miss.	Pocono	300-1700′	Quartz sandstone & conglomerate; coarse, thick, large cross beds	Acadian Orogeny — Armorica terrane collides with east coast (survives as Avalon terrane).
	Devonian	Hampshire (Catskill)	2000′	Point Bar Sequences; red	
	Devonian	Greenland Gap Group (former Chemung): Foreknobs, Scheer	2000′	Thick hummocky sequences; at top interbedded red and green fine sands and silts	
	Devonian	Brallier (Portage in Pa.)	1500-1700′	Bouma sequences	
	Devonian	Millboro (Used south of Shenandoah Co.) — Tully, Harrel, Mahantango, Marcellus	900′ / 350-500	Dark gray to black silts and fine sands	
	Devonian	Needmore — Tioga bentonite	100-530′	Olive gray fine sands, silts, and shales; fossils abundant in places	
		Wallbridge Unconformity			
TIPPECANOE	Devonian	Oriskany	10-125′	Quartz arenite; white, gray, tan; abundant fossils	Orogenic Calm
	Devonian	Helderberg Group — Licking Creek, Mandata, New Scotland, New Creek, Keyser	70-150′ / 17-50′ / 70-600′	Carbonates of many kinds; sometimes with cherts, or interbedded with shale or quartz arenites; fossils very abundant	
	Silurian	(Salina in WVa.) Tonoloway	50-250′	Tidal carbonates; ALM, ALD; mud cracks; salt casts; evaporitic to west	
	Silurian	CAYUGA: Wills Creek, Williamsport — Bloomsburg	0-400′	Bloomsburg: red very fine sands/silts/shale	
	Silurian	CAYUGA: McKenzie	0-75′	Yellow calcareous shale; fossils	
	Silurian	CLINTON: Keefer, Rose Hill, Tuscarora — Massanutten	70′ / 650 / 50-250 (Massanutten 700-1200′)	Massanutten: coarse friable quartz arenites and conglomerates with large planar X-beds. Tuscarora/Keefer: quartz arenites; ripples Skolithus. Rose Hill: red fine - coarse sands and shales; loads, ripples, trace fossils	Taconic Orogeny — Chopawamsic/Arvonia Terrane collides with East Coast
	Ordovician	Juniata — Oswego — "Cub ss" ?	0-200′ / 0-375′	Red X-bedded ss; Skolithus; bedded w/sh — Gray/white, coarse X-bedded sands — Hummocky	
	Ordovician	Reedsville — Martinsburg	3000′	Clastic hummocky sequences — Feldspathic/lithic Bouma sequences	
	Ordovician	"Trenton Group" ? — Oranda	40-60′	Carbonate hummocky sequences ? — Gray silty/shale	
	Ordovician	"Black River Group" — Edinburg (Liberty Hall) (Lantz Mills)	425-600′	Carbonate hummocky sequences — Black massive micrites and shale	
	Ordovician	Lincolnshire	25-170′	Micrites, bio- and pelmicrites, chert; abundant fossils, darkens up section	
	Ordovician	New Market	40-250′	Very pure micrites; tidal features	
		Knox Unconformity			
SAUK	Ordovician	Beekmantown (Rockdale Run)	2500′	Thick bedded dolomite, black chert; tidal	Divergent Continental Margin
	Ordovician	Stonehenge (Chepultepec)	500′	Thick bedded micrite, blue; tidal features	
	Cambrian	Conococheague	2500′	LS/dolo/qtz arenite ; abndt tidal structures	
	Cambrian	Elbrook	2000′	LS/dolo/ blue-gray; tidal features	
	Cambrian	Rome (Waynesboro)	2000′	Red/green shale/dolo/micrite; very variable	
	Cambrian	Shady	1600′	Dolomite (granular); LS at top and bottom	
	Cambrian	CHILHOWEE: Antietam	500-1500′	Quartz arenite; abndt X-beds Skolithus	Rifting — Opening of the Protoatlantic
	Cambrian	CHILHOWEE: Harpers	2000′	Thin bedded shale and graded sandstones	
	Cambrian ?	CHILHOWEE: Weverton	800′	Crs feldspathic sands; large planar X-beds and Bouma sequences	
	Vendian	Catoctin	2000′	Subareal, tholeiitic, flood basalts (now greenschist)	
	Vendian	Swift Run — (Lynchburg) East of Blue Ridge			
		Grenville Basement			

L.S.Fichter, 1991

Figure 1

Cambrian Chilhowee Group probably to the Lower Ordovician Beekmantown Formation (Figure 1). Somewhere between the top of the Beekmantown and the Martinsburg Formation (as will be discussed in this guide) convergence began to affect the Proto-Atlantic coast, and continued sporadically for most of the rest of the Paleozoic (Taconic, Acadian and Alleghenian orogenies). Continental collision culminated this cycle (Alleghenian orogeny: Gondwana collides with North America) and resulted in the final deformation of the mountain belt.

The Appalachian Paleozoic succession also contains the record of many different scales of sea-level fluctuations. The largest of these have resulted in the formation of unconformity-bounded sequences. The unconformities (or discontinuities) represent lowstands of sea-level that exposed much of Appalachian area and caused widespread erosion surfaces. As illustrated in Figure 1, the Sauk, Tippecanoe, and Kaskaskia sequences are well documented in the Appalachian area.

GEOLOGIC EVIDENCE FOR OCEANIC CONVERGENCE AND SUBDUCTION

There are certain geologic events and features that occur in association with plate convergence and subduction. These features are evident in various parts of the Appalachian Mountain system: the Piedmont, Blue Ridge, Valley and Ridge, and Plateau. The discussion below focuses on all the evidence, even though this trip visits stops only in the Valley and Ridge.

Plutons, Volcanics, and Bentonites

Probably the most noticeable effects of plate convergence are the various igneous features resulting from the melting of the subducting oceanic lithosphere (Figure 2). Today, volcanic arcs line one side of almost all oceanic trenches. On the surface of these arcs, the thick piles of volcanic strata certainly provide testimony to the prolonged history of volcanism associated with these arcs. Such volcanic strata is present in the Virginia Piedmont in such units as the Chopawamsic/Arvonia volcanic suites just west of Fredricksburg, Virginia.

Although not apparent on the surface of a volcanic arc, plutons are present deep below the surface. These features become apparent when one investigates ancient volcanic arcs that have been eroded deeply enough to expose their cores. In such terrains, granites, diorites, and various other plutonic rocks exist as batholiths. Well known examples include the Sierra Nevada, Stone Mountain, and more locally the Petersburg and Occoquan Granites of the Virginia Piedmont. Ages of the plutonic rocks of the Virginia Piedmont cluster into a few time intervals: Cambrian, Silurian-Devonian, and Pennsylvanian-Permian (Wright and others, 1975). This suggests that plutonism in the Piedmont was sporadic during the Paleozoic.

Eruptions associated with volcanic arcs are typically explosive, as was the case for Mt. St. Helens, Pinatubo, Vesuvius, Paricutin, Katmai, Krakatoa, and so many others. Ash from these types of eruptions can be carried by the wind for long distances. The dust from Pinatubo reached such heights that atmospheric circulation carried it around the world. In some places, up to a distance of a thousand kilometers or two from the volcano, thin layers of ash are detected.

In the Paleozoic strata of the Valley and Ridge, thin, and frequently almost unnoticeable layers of volcanic ash, called bentonites, are found (Stop 3). These document the existence of a volcanic arc. The stratigraphic position of these Appalachian bentonites are Middle Ordovician and Middle Devonian.

Lithospheric Flexure

Subduction involves the thrusting of one plate margin over another. The subducting slab therefore is loaded with the mass of the overriding plate. This load is responsible, at least in part, for the subsidence of the subducting slab, and accounts, at least in part, for the bathymetric feature known as a trench. Other loads, such as the volcanic arc itself, or the accretionary prism (melange belt under the outer arc ridge in Figure 2) of sediment scraped off the subducting plate, are also responsible for this subsidence. Geophysicists have predicted (Beaumont and others, 1988, for example) that the depression of the crust adjacent to the overthrust load (flexural moat) is accompanied by an adjacent peripheral bulge (Figure 3) for much the same reason as if you stepped into the front of a canoe the back of the canoe would rise. According to these models, it is also predicted that the flexural rigidity of the lithosphere lessens with time after the initial loading, causing the peripheral bulge to migrate toward the flexural moat and overthrust

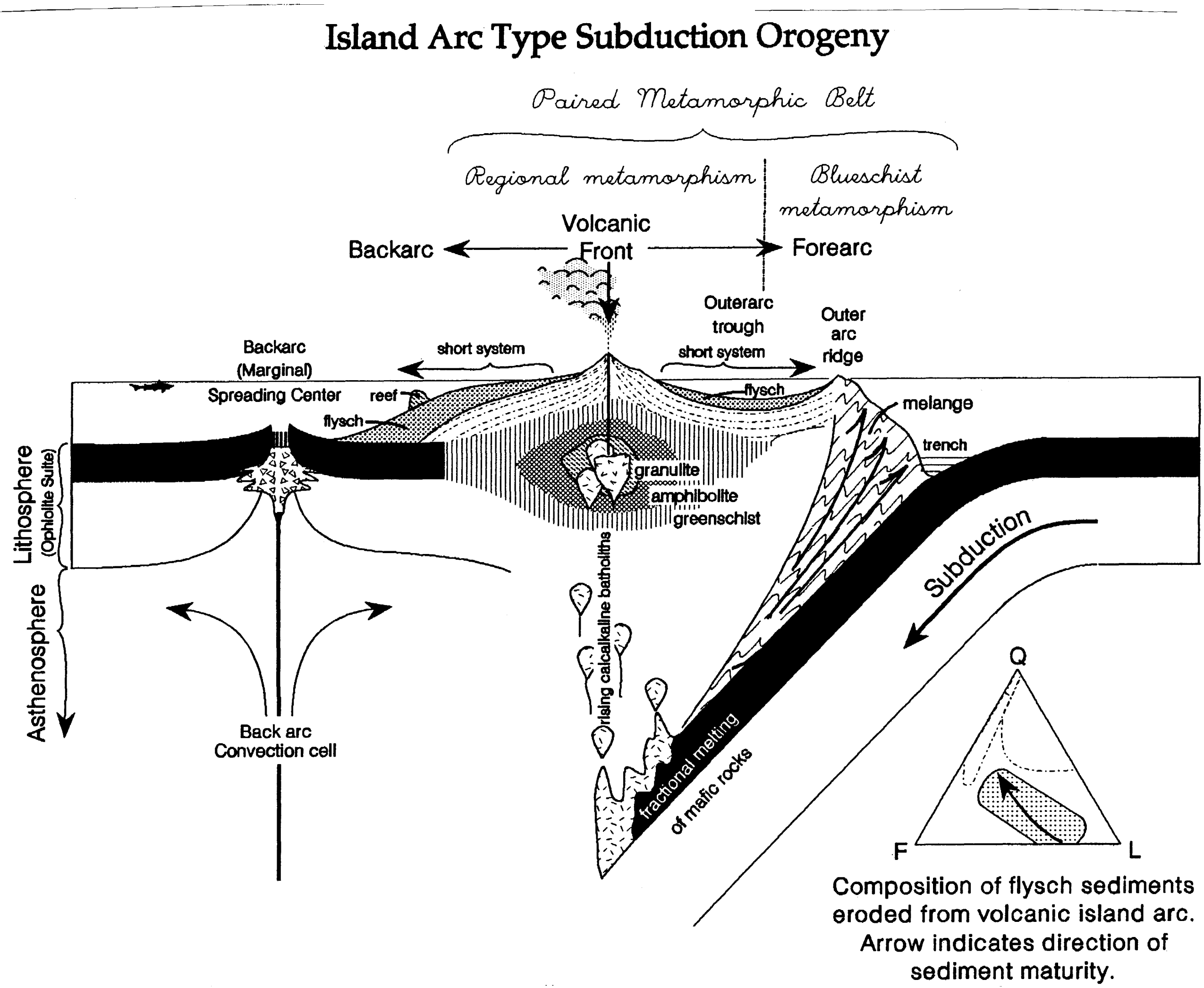

Figure 2

load (Figure 3).

Models of lithospheric flexure have been applied to the stratigraphy of the Appalachians, as well as other mountain belts, in an attempt to reconstruct the flexural moat and peripheral bulges associated with these ancient convergence events. To do so, individual episodes of regionally isolated deepening (flexural moat), accompanied by synchronous and laterally adjacent episodes of shallowing (peripheral bulge), must be identified in the stratigraphic record. It is important to realize that these strata have subsequently been structurally deformed by later orogenic events and we cannot necessarily distinguish features formed by lithospheric flexure from those due to later structural deformation. We must therefore depend on the stratigraphy to tell us what structural events happened in the past. One must also realize that these areas of deepening and shallowing must have formed at the same time, but in different places. It is sometimes difficult to differentiate relative changes in sea-level due to lithospheric flexure from those due to global sea-level change. For example, the sea-level drop that resulted in the widespread unconformity at the top of the Beekmantown (Knox unconformity) has been interpreted as being due to worldwide lowering of sea-level (Vail and others, 1977), and alternatively being due to uplift of a peripheral bulge (Mussman and Read, 1986).

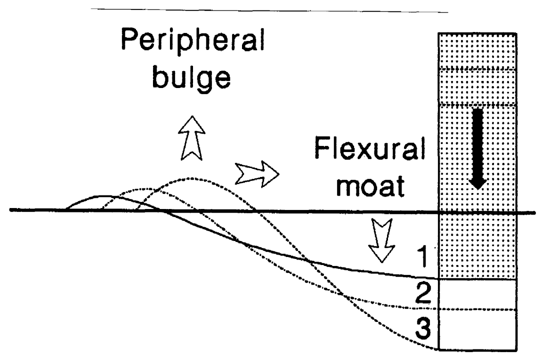

Figure 3 Development of peripheral bulge and flexural moat associated with thrust loads. After Beaumont, and others (1988)

Models for different stages of lithospheric flexure in the Appalachians are varied. Beaumont and others (1988) propose that the entire Appalachian basin area was a flexural moat, and the Cincinnati Arch/Nashville Dome was part of the peripheral bulge. On this trip we will see evidence suggesting that in the Ordovician, these features were much more localized, and probably existed within the area of the Valley and Ridge Province.

Flexure of the lithosphere in the Appalachian area probably occurred sporadically during the Paleozoic. Ettensohn (1987, 1991) has proposed that episodes of flexure occurred during the Ordovician and again during the Devonian in the Appalachians.

Controls on Carbonate Deposition

In tropical shallow marine areas today, sedimentation can be considered under two categories: that influenced by river runoff, and that which is not. In the absence of rivers, as is the case on the Bahama banks today, tropical shallow marine waters typically have just the right combination of factors that favor the precipitation of calcium carbonate as limestone.

Precipitation of a compound occurs as its solubility decreases. Calcium carbonate is less soluble under high pH (alkaline) conditions. Normal seawater is slightly alkaline, and very close to the critical pH that controls the saturation point of seawater relative to calcium carbonate. Small changes in pH are all it takes to drastically alter the solubility of calcium carbonate.

Sea water pH is controlled by the amount of dissolved carbon dioxide. If carbon dioxide declines, carbonic acidity decreases and carbonate precipitation occurs. Each of the following conditions favors the removal or escape of carbon dioxide: higher temperature; agitation of the water by waves; and photosynthesis by marine plants. It is observe that limestone forms most prominently in warm (tropical), shallow, agitated, algal rich seawater. The Appalachian area during the Paleozoic was in this default condition.

The default condition would not hold under different circumstances. For example, in tropical areas today, limestone is not actively forming in deep water, presumably due to the lack of agitation by waves, the lack of sunlight allowing photosynthesis, and the cooler water temperature at depth.

Another example of a situation where the default condition does not hold is coastlines receiving significant river runoff. Rivers typically contribute lower pH (if not acidic) water, which raises the solubility of calcium carbonate, and retards or prevents the formation of limestone. In addition, rivers carry siliciclastic sediment (gravel, sand, silt, clay). Clastics and carbonate therefore tend to be mutually exclusive (Walker and others, 1983).

Clastic Wedges

The above explanation of carbonates emphasizes the significance of the Appalachian clastic wedges. A clastic wedge is a thick (up to several kilometers), widespread (more than a million square kilometers), fan-shaped, wedge of clastic strata. These clastic wedges commonly, but not always, fill flexural moats created by lithospheric flexure. Flexural moats developed when one plate overrides another are often called foreland basins (see Figure 4). The overriding plate is a hinterland. In the Appalachians of the Paleozoic several clastic wedges alternate with carbonate sequences through time. These clastic wedges represent times and places when the normal default conditions (limestones) were overridden, and rivers carried clastic sediments into the Appalachian area. Clastic wedges of Ordovician, Devonian, and Mississippian-Pennsylvanian age occur in the Appalachians (Figure 1).

Thickness patterns and paleocurrents indicate that the clastic wedges were derived from the east, and not from the North American craton to the west. Each clastic wedge contains a generally coarsening- and shallowing-upward stratigraphic succession. This is consistent with the progradation of a clastic shoreline into a marine basin. The clastic material suggests that it was derived from continental and/or volcanic source areas. In fact, volcanic bentonites are associated with strata just below, or in the lower parts of Ordovician and Devonian clastic wedges. Therefore volcanic arcs, or volcanic arcs associated with continental blocks now found in the Piedmont are the likely sources of the clastic wedges.

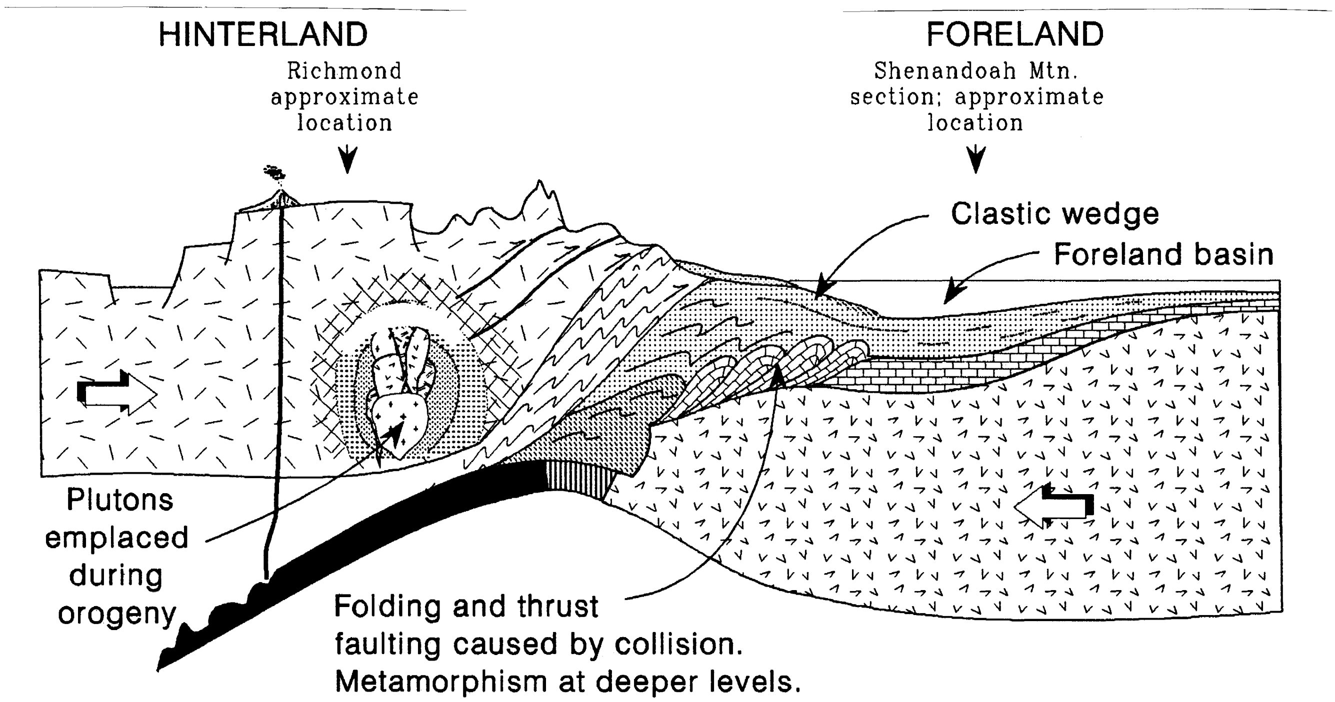

Figure 4 Deformation and other features associated with mountain belts resulting from plate collision.

Structural Deformation and Metamorphism

Structural deformation, in the form of folding and thrust faulting, is a process associated with subduction and mountain building (Figure 4). The structural deformation has involved the Valley and Ridge, Blue Ridge, and Piedmont Provinces. As illustrated in the geologic map (Figure 5), the structural deformation of the Valley and Ridge has involved strata of Cambrian to Mississippian age. This relationship indicates that this deformation occurred after the deposition of these strata. This late stage of deformation occurring after the Mississippian is the Alleghenian Orogeny. It was responsible for the majority of structures in the Valley and Ridge.

The severity of the Alleghenian deformation has overprinted older deformational features, making these older features much harder to recognize. As discussed above, lithospheric flexure deformation did occur earlier in the Paleozoic, during deposition of the Valley and Ridge strata. This pre-Alleghenian deformation occurred as basins (flexural moats) and uplifts (peripheral bulges). These basins and uplifts are now recognized in the stratigraphic record, not necessarily as deformational structures, but as changes in thickness and other characteristics of the strata. These stratigraphic features are discussed in the stop descriptions.

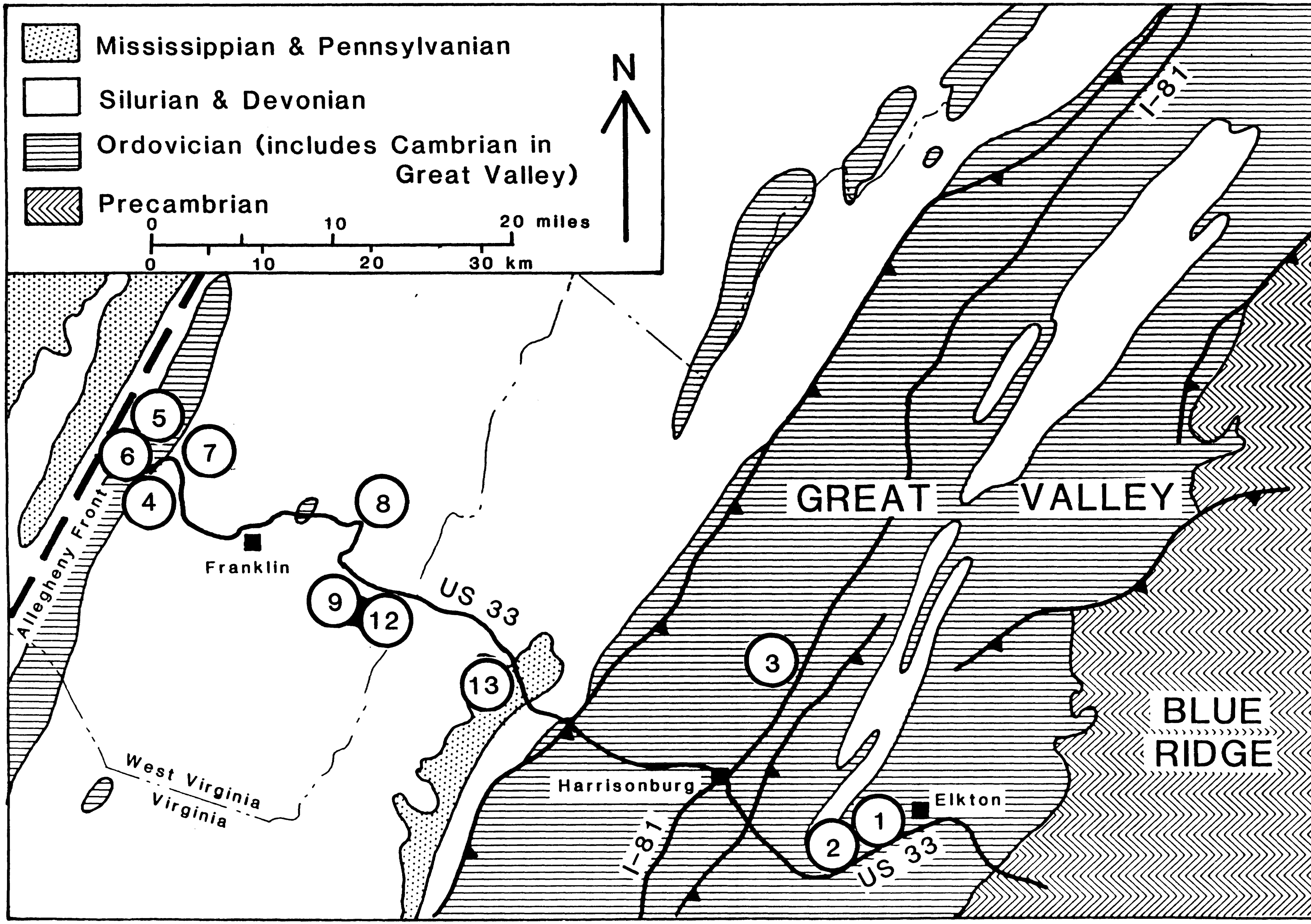

Figure 5 Geologic map showing the location of field trip stops.

Metamorphism can be considered another type of deformational event associated with subduction and mountain building (Figures 2 and 4). Paleozoic metamorphism has affected the Piedmont and Blue Ridge Provinces. Metamorphic ages, determined for rocks of the Piedmont and Blue Ridge, indicate two distinct events: a high-grade metamorphic event during the Ordovician, and a low-grade event during the Devonian (Hatcher, 1978). Generally speaking, there is a temporal and spatial coincidence between metamorphic events, lithospheric flexure, and deposition of clastic wedges.

EVENTS IN THE CLOSURE OF THE PROTO-ATLANTIC

As discussed above, structural deformation, metamorphism, deposition of clastic wedges, volcanism, and to some degree plutonism, are events that "cluster" around several time intervals throughout the Paleozoic in the Appalachians. We refer to each of these tectonic episodes as orogenies.

Taconic Orogeny

There are several geologic occurrences which suggest that a major tectonic event, the Taconic Orogeny, occurred during the Middle Ordovician (Rodgers, 1971). A major metamorphic event occurred in the Appalachian Piedmont and the New England Appalachians during the Ordovician (Rodgers, 1971; Hatcher, 1978).

A major lithospheric flexural event is recognizable in the Middle Ordovician strata of the Valley and Ridge. The flexural event created two basins, an eastern basin (moat) in which the Edinburg and Martinsburg were deposited (Stops 2 and 3), and a western basin in which the Reedsville, Oswego, and Juniata were deposited (Stop 6). The two basins were separated by an arch (peripheral bulge) between them. The Virginia portion of the clastic wedge is described in detail by Diecchio (1985, 1986a, 1986b; and Fichter and Diecchio, 1986b).

Numerous Middle Ordovician bentonites are found in the Valley and Ridge (Haynes, 1992). There are several post-Middle Ordovician (Silurian and Devonian) plutons in the Piedmont of the Carolinas (Wright and others, 1975). All of these related geologic phenomena are the basis for our understanding of the Taconic orogeny.

It has been proposed that the Taconic event represents the collision between eastern North America and a volcanic arc, or a microcontinent (Hatcher, 1978, Diecchio, 1980), with subduction toward the east. In any case, this is one event that occurred during subduction associated with closure of the Proto-Atlantic Ocean.

The time of onset of subduction is controversial. Mussman and Read (1986) suggest that the sea-level drop at the end of the Early Ordovician (Knox-Beekmantown unconformity) represents uplift of a peripheral bulge associated with the onset of subduction. Others (Vail and others, 1977) relate this to a global sea-level drop. Strata we will visit on this trip suggest that deepening, possibly associated with the development of a flexural moat (Martinsburg basin), occurred during the Middle Ordovician. The oldest bentonites are Middle Ordovician, suggesting the onset of volcanism.

Acadian Orogeny

An event, similar in nature to the Taconic, occurred during the Middle Devonian, and is referred to as the Acadian Orogeny. Devonian metamorphism is represented by a low grade event in the Central and Southern Appalachians (Hatcher, 1978). Lithospheric flexure of Devonian age is recognized in the Appalachian Basin (Ettensohn, 1987). We will visit one stratigraphic section (Stops 9-13) representative of the Devonian clastic wedge (Catskill "delta"), described in detail by Fichter (1986). A prominent Middle Devonian age volcanic ash deposit (Tioga bentonite) has been recognized throughout the Appalachian basin (Dennison and Textoris, 1970). There are a cluster of post-Devonian (Pennsylvanian-Permian) plutons in the Piedmont of the Southern Appalachians (Wright, and others, 1975). These phenomena are interpreted as representing the Acadian Orogeny and represent another stage of closure of the Proto-Atlantic.

The Acadian event has been interpreted as plate convergence and collision between a continental block (Avalon) and North America. It is on the Avalon terrane that Richmond now stands. Subduction was to the east, so Avalon had a volcanic arc along its western edge. Avalon did not converge directly on North America but slid in obliquely, colliding and scraping at a number of points from the maritimes of Canada to the southern Appalachians. A major impact in the southeastern New York area created a large foreland basin into which poured the Catskill clastic wedge. Many of the formations of the clastic wedge in Virginia and West Virginia (Stops 9-12) are associated with this basin. The Pocono formation (Stop 13) was derived from the last impact occurring in the southwest Virginia area.

Alleghanian Orogeny

The major deformation of the Appalachian Valley and Ridge, and final uplift of the Blue Ridge occurred late in the Paleozoic and is called the Alleghanian Orogeny. This event is represented by the development of the fold and thrust belt that is so characteristic of the Valley and Ridge and Blue Ridge. This event overprinted many previously formed structures, and was responsibly for the primary structures we see today. The Alleghanian event occurred during the Pennsylvanian and Permian.

The Alleghanian is not associated with a metamorphic event, nor a recognized bentonite. There is a late Paleozoic clastic wedge spreading westward. In short, this orogeny is very different from the earlier two. To many investigators, there is not a distinct boundary between the Acadian and Alleghanian orogenies. But, in any case, the Alleghanian represents the culmination of Appalachian mountain-building associated with the collision between North America and Africa.

DESCRIPTION OF FIELD STOPS

Formations of the Divergent (Passive) Continental Margin, and Deposited in the Eastern Flysch Basin During the Taconic Orogeny

These three stops illustrate the transition from the Lower to Middle Ordovician carbonate bank of the passive margin, to the eastern facies of the Middle to Upper Ordovician deep orogenic basin and clastic wedge (Figure 6). The regional paleogeography and plate tectonic relationships responsible for the orogeny are shown in Figure 7. The eastern flysch basin is interpreted as a flexural moat (Figures 7 and 8) into which the clastics were deposited.

The regional unconformity at the top of the Beekmantown has been interpreted as due to a global sea-level drop. Alternately, this unconformity is interpreted as due to uplift of a peripheral bulge that would have included most of the Appalachian basin. The carbonate-clastic transition is associated with the development of a deep basin (Martinsburg basin) that was present in the area now known as the Shenandoah Valley. Volcanic bentonites are also found within this transition.

See Figure 6 for the sequence and description of formations which represent the divergent (passive) continental margin and the Taconic orogeny in the eastern flysch basin.

Stop 1 - Shenandoah Valley Section: Beekmantown, New Market, Lincolnshire, and Edinburg Formations.

The field guide begins at the bridge where Rt 33 (Market Street) cross I81 heading east past a shopping strip and the Valley Mall. From the bridge travel 8.5 miles to Rt 991. As you travel east you will occasionally glimpse the Blue Ridge Mountains in front of you. As you approach Stop 1, Massanutten Mountain will appear as a long ridge on your left. At route 991, make a U-turn and return east about .2 miles.

The outcrop is a road cut along the south side (east lane) of Rt. 33. The outcrops are sparse, patchy and not well exposed. These rocks are on the east flank of the Massanutten syncline. They are nearly vertical and strike nearly parallel to the roadcut.

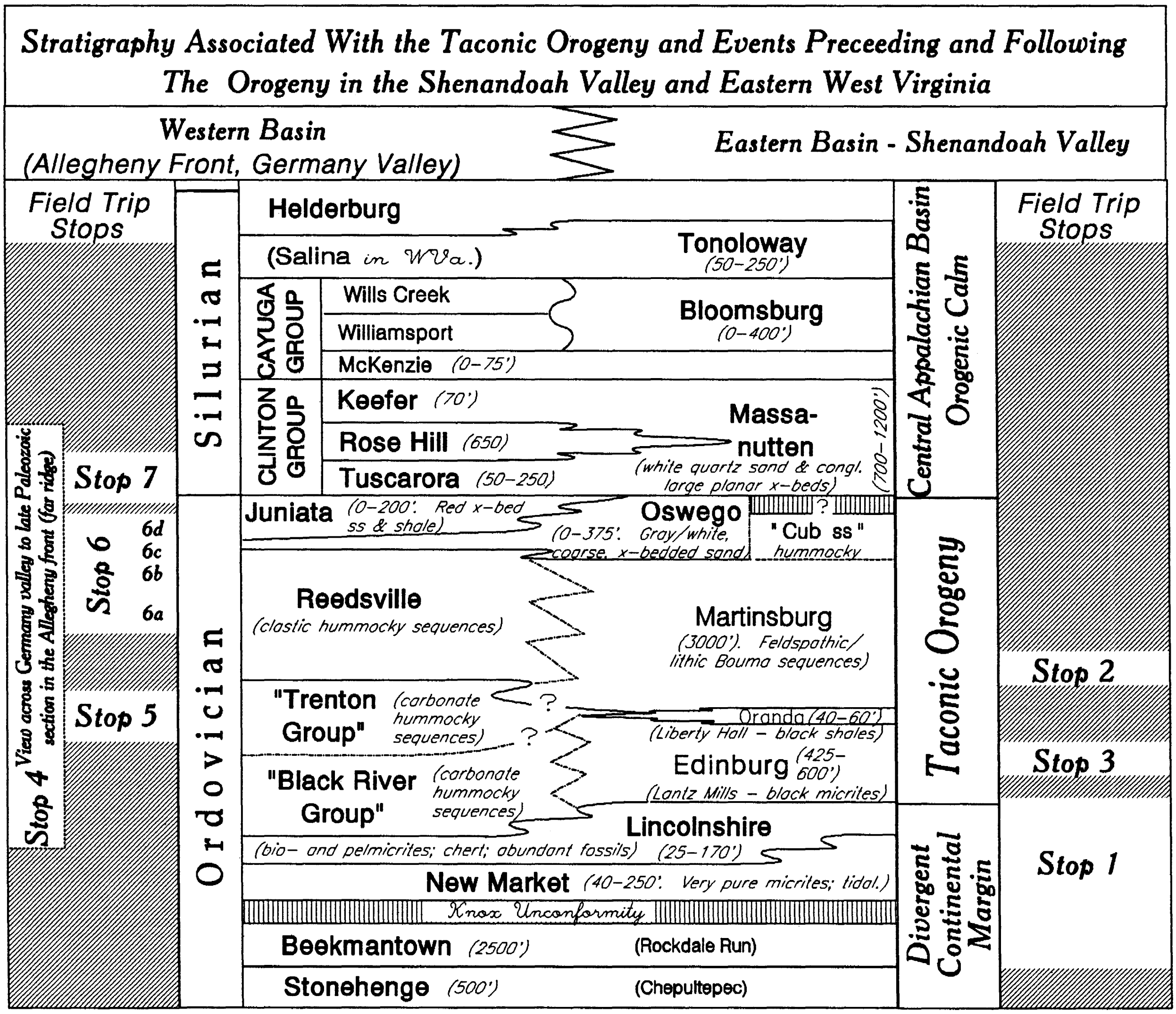

Figure 6

These formations at other places have distinct contacts, or are gradational over short distances. At this roadcut facies typical of each formation tend to alternate in the first half of the outcrop. The section may be repeated by faulting, or facies relationships at this locality may be more complex than other places. In any event, our purpose is to compare the facies upsection and their environmental interpretations, rather than delineate formation contacts. Be alert for facies changes.

The **Beekmantown formation** is interpreted as upper intertidal to supertidal. It consists of interbedded light and dark gray dolomites and micrites (ribbon rock). It weathers to a very fine sandy texture (feels slightly gritty). On a fresh surface the rock looks very clean, and light gray.

Beekmantown-New Market contact. Regionally this contact is a well-developed unconformity (Knox). But because the unconformity lessens to the east it may not be present at this stop. In any event, the contact between the Beekmantown and New Market Formations is not exposed here, although it can be narrowed down to within a few feet.

Paleogeography Associated with the middle Ordovician Taconic Orogeny in Virginia and Surrounding Areas

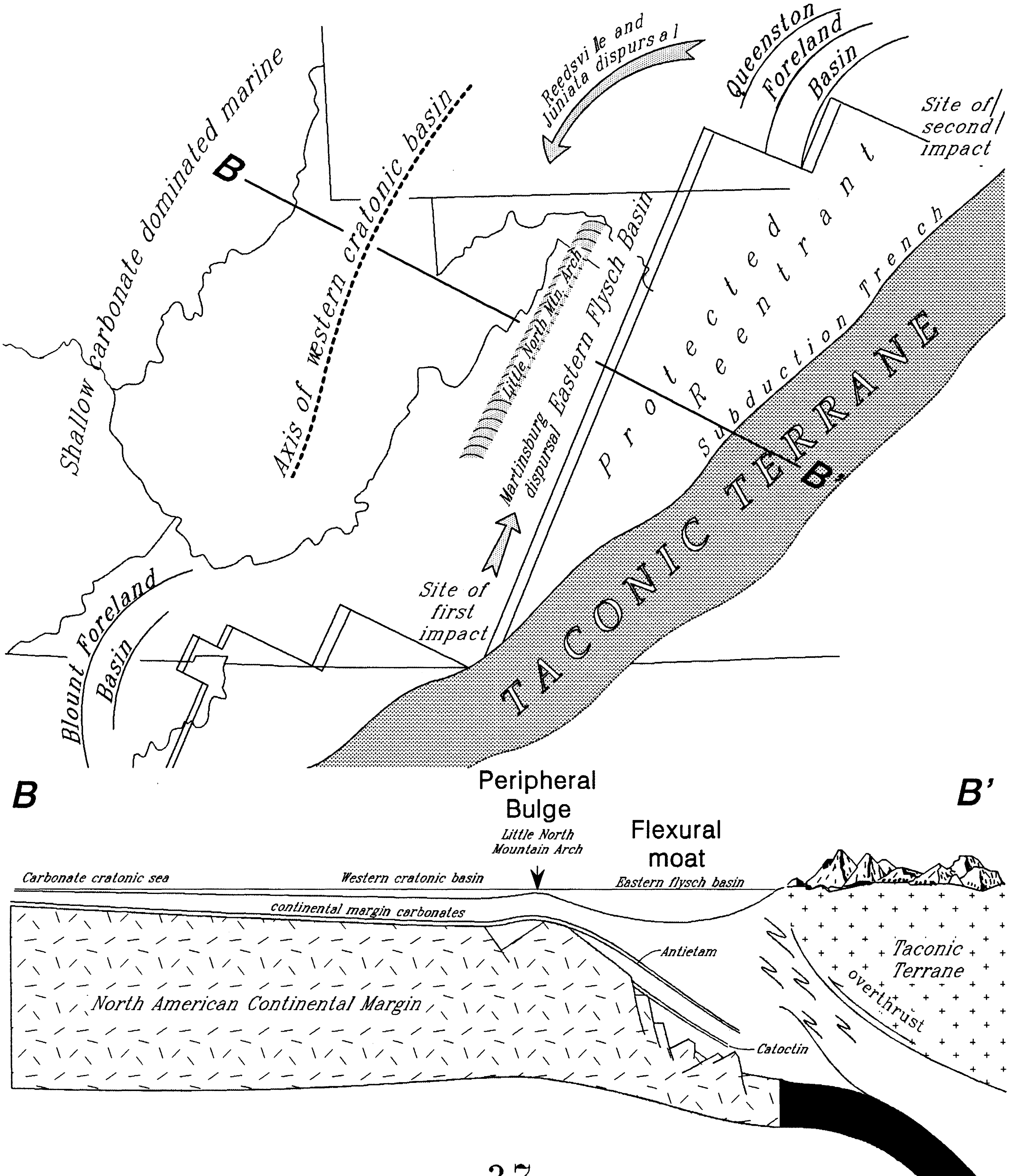

Figure 7

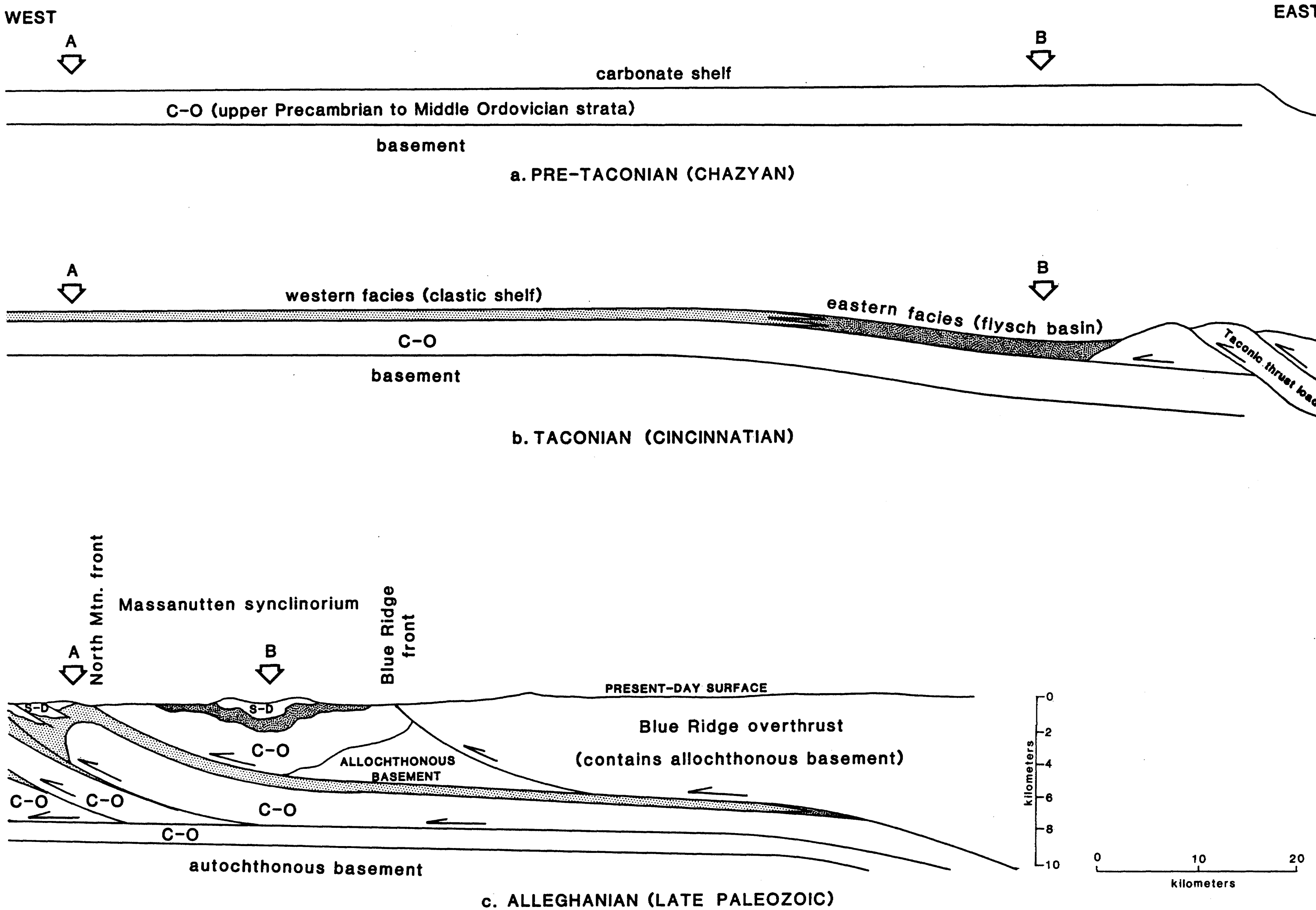

Figure 8 Interpretation of the deep and shallow Taconic facies relative to present geology.

The **New Market formation** is a change from Beekmantown supertidal dolomites to inter- to subtidal New Market limestones. The change represents a relative rise in sea-level during the Early Middle Ordovician. The New Market is a very pure, light gray (fresh and weathered) birdseye limestone (micrite). Birdseyes are calcite crystals deposited in vugs in the original sediment. They look like dark gray flecks or blebs scattered randomly through the micrite. On weathered surfaces birdseyes are more resistent and stand out in high relief forming a rough textured surface.

The **Lincolnshire formation** is interpreted as a carbonate shelf environment, probably deepening up section. The micrites are dark gray to black, and are interbedded with medium to coarse calcarenites (fossil fragmental sands). Bedding planes are often very fossiliferous. Black chert nodules are a characteristic feature, and become more pronounced up section.

The **Edinburg formation** is a transition from the passive continental margin to an orogenic foreland basin. At this stop it consists of black (weathered tan) graptolitic shales.

Stop 2 - Shenandoah Valley Section: Martinsburg Formation

Stop 2 is 1.6 miles west of Route 991 (the U-turn) about 100 yards east of the entrance road to Spotswood School. The outcrop is low but well exposed at the east end of the right turn lane.

These rocks strike diagonally out of the cut, and are nearly vertical. Up is to the left. First impressions are of interbedded gray sands and shales. Sands are a foot or more thick, shales about half a foot. On close inspection graded bedding is seen in the sands. Flutes and scours are visible on the bottoms of some sands. Rare laminations are at the top of some sands.

These are Bouma sequences produced by turbidity currents flowing into a deep water basin. Of the complete Bouma sequence T_{ABCDE}, these represent primarily T_{ABD}. These sands tend to be feldspathic-lithic wackes, a very immature sediment typical of those eroding from volcanic arcs (see QFL ternary diagram on Figure 2).

Stop 3 - Shenandoah Valley Section: Middle Ordovician bentonite in the Edinburg Formation

From Stop 2 return to I81 at Harrisonburg, and get on I81 heading north toward Winchester. At the next exit (Mauzy/Broadway) get off. When the exist ramp joins Rt 11 turn right, and then about 100 yards down Rt 11 turn right again onto Rt. 608. The stop is .2 miles down Rt. 608, on the north side of the road.

This is a low, obscure outcrop covered with vegetation. This is the Edinburg formation, but is different in make up from the Edinburg at Stop 1. There the Edinburg was a black, graptolitic shale. Here the Edinburg is mostly black micrites with interbedded shaley micrites producing a cobbly weathering. The difference in Edinburg at these two stops reflect the two sources feeding the now tectonically subsiding basin. The micrites are coming off the carbonate platform to the west (Dolly Ridge = Trenton equivalent) and sliding down the western slope of the basin. The shales are the first clastics coming from the rising Taconic mountains to the south. The shales are followed by the Martinsburg turbidites.

The significance of this stop is, however, the bentonite layers, the weathered remains of ash falls. We will not visit the Piedmont, but the mountain building, and roots of the volcanic arc are there. The ash falls seen here are direct evidence the arc came in and caused the Taconic orogeny.

After Stop 3 we travel westward a little over an hour to reach Stop 4 at Germany Valley. We then turn around and work our way back toward Harrisonburg, making Stops 4-13 on the way. The stops are conveniently arranged in sequence upsection from older to younger formations.

The Taconic Clastic Wedge Of the Western Cratonic Basin

This series of stops shows the transition from the Middle Ordovician carbonates of the passive margin to the Middle to Upper Ordovician formations deposited in the clastic wedge of the western cratonic basin (Figure 6). This entire section contains facies that range from intertidal to subtidal shelf, but no deeper. This is in sharp contrast to the deep basinal clastics of the Martinsburg basin. This western belt was exterior to the flexural moat (Figure 7 and 8).

See Figure 6 for the sequence and description of formations which represent the shelf and clastic wedge west of the divergent (passive) continental margin during the Ordovician. These stop descriptions are adapted from Diecchio (1986a).

Stop 4 - Germany Valley Overlook

At the overlook you can observe Germany Valley (Ordovician limestones at the culmination of the Wills Mountain anticline); the ridge crest of North Fork Mountain (Tuscarora Sandstone on the east limb of Wills Mountain anticline) to the east; and River Knobs (Tuscarora Sandstone on the west limb of Wills Mountain anticline), which also form the first set of "razorback" hills or ridges to the west. At the northeast end of Germany Valley the Tuscarora ridge forms a spectacular example of closure at the nose of the plunging anticline. Also to the west, beyond the River Knobs, are the Fore Knobs that are developed along the Upper Devonian Greenland Gap Group/Hampshire Formation contact east of the Allegheny Front. West of the Fore Knobs is Spruce Mountain, atop of which is Spruce Knob, formed on a resistant bed of Pennsylvanian Pottsville Sandstone.

Stop 5 - Germany Valley Section: Trentonian (Dolly Ridge Formation)

Stop 5 is about 2.5 mi (4.1 km) east of Judy Gap on U.S. 33. (Judy Gap is several miles west of the Germany Valley overlook, and is easily recognized by the spectacular cut through the nearly vertical Tuscarora sandstone.) Turn left on to Bland Hills Road. The Dolly Ridge Formation (upper Trenton Group) is most accessible along Bland Hills Road on Dolly Ridge, about 1.6 mi (2.7 km) north of U.S 33.

The Dolly Ridge Formation is a dark gray, dense, fine grained, medium to thinly bedded limestone that weathers yellowish brown and contains olive gray shale beds and bentonites. These limestones represent the waning stages of an expansive carbonate bank that was situated on the eastern margin of North America during the Cambrian and Ordovician prior to Taconian flexure folding and clastic sedimentation. The onset of these clastic sediments is evident here as shale beds in the Dolly Ridge Formation. The bentonites are not identifiable here.

Stop 6 - Western facies of the Ordovician clastic wedge

Stop 6a (lower Reedsville) *The lower, calcareous part of the Reedsville Formation is observed along U.S. 33 where it begins to climb the western slope of North Fork Mountain, about 0.8 mi (1.1 km) east of the junction with Bland Hills Road.*

At this locality the Reedsville consists of medium gray to grayish olive, calcareous shale that weathers to a light olive gray limestone-like surface. It is interbedded with laminae of very thin beds of medium gray, bioclastic calcarenite that weathers moderate yellow brown and rare thin interbeds of medium gray, calcareous siltstone that weathers light olive gray. Fossils in this part of the section include the brachiopods *Rafinesguina*, *Sowerbyella*, and *Zygospira*; the bryozans *Prasopora* and *Hallopora*; the gastropod *Sinuites*; the trilobite *Cryptolithus*; the cephalopod *Orthoceras*; crinoid stalks and columnals; and the graptolites *Diplograptus* and *Climacograptus*. The bioclastic layers are probably storm rip-up deposits as described by Kreisa. This outcrop represents the transition from the carbonate-dominated regime below, to the clastic-dominated lower part of the Taconian clastic sequence.

Stop 6b (middle Reedsville) *is at the Germany Valley overlook along U.S. 33, about 0.7 mi (1.1 km) east of Stop 6a.*

Exposed at this stop is the shaley middle part of the Reedsville Formation that is composed of light olive-gray shale, with thin interbeds of medium gray, calcareous siltstone that weathers grayish orange (storm shelf hummocky bedding), rare thin interbeds of medium gray, bioclastic calcarenite (often megarippled) that weathers grayish orange, and rare medium to thin interbeds of yellow brown, fine-grained sandstone that weathers light olive gray. The percentage of sandstone increases up-section, and the percentage of calcarenite decreases upward, typical of a clastic wedge.

Stop 6c (upper Reedsville, Oswego) *is the next outcrop uphill (east) along U.S. 33, about(0.2 mi (0.3 km) from Stop 6b.*

Exposed here is the upper Reedsville Formation and the transition to the Oswego Sandstone. The Reedsville is a bioturbated, medium gray, fossiliferous mudstone that weathers light olive gray. The upper Reedsville contains a completely different fauna (*Orthorhynchula* assemblage biozone) than in its lower beds, including the brachiopods *Orthorhynchula* and *Lingula*; the bivalves *Ambonychia, Ischyrodonta, Modiolopsis*, and *Tancredopsis*, the trilobite *Isotelus*; and phosphatized remains of the gastropod *Plectonotus. The Orthorhynchula* zone is a shallow water fauna. Small phosphate nodules and *Lingula* are common in the uppermost part of the Reedsville. The abrupt lithologic and faunal change that occurred in the upper part of the Reedsville (*Orthorhynchula* Zone) is thought to represent a eustatic sea-level drop associated with the Late Ordovician glaciation. The phosphate and *Lingula* zone probably represents continued shallowing to shoaling or brackish water conditions.

The Oswego Sandstone, which overlies the Reedsville Formation in a gradational contact, is a light brownish gray, medium fine-grained, medium bedded, cross-bedded sublitharenite, with interbedded silt-shale. The lower contact of the Oswego is arbitrarily chosen at the base of the lowest cross-bedded sandstone above the *Orthorhynchula* zone. The Oswego represents the culmination of the upward-coarsening cycle that started at the base of the Reedsville. The immature composition of the Oswego reflect its provenance in an orogenic sourceland to tho east.

Stop 6d (Oswego-Juniata) *is the next exposure uphill along U.S. 33, about 0.3 mi (0.5 km) east of stop 6c, and across from the picnic area.*

This outcrop contains the contact between the Oswego and the Juniata Formations. This contact is chosen at the base of the lowest red mudstone, but is uncertain here because of the large covered interval that occurs between the top of the outcrop at 6c and the base of the outcrop at 6d. The Oswego makes up about the lower 10 ft (3 m) of the exposure at Stop 6d. The overlying red beds of the Juniata Formation clearly exhibit their cyclical nature at this exposure. A typical cycle consists of a lower red, cross-bedded, fine-grained sandstone (sub-litharenite); a middle red, sub-lithic wacke with vertical burrows; and an upper red bioturbated mudstone. The Juniata represents deposition in nonmarine to marginal marine conditions, probably a delta plain that existed during the glacio-eustatic low stand of sea level.

Stop 7 - Juniata and Tuscarora Formations

The Juniata Formation and its contact with the overlying Tuscarora Sandstone are well exposed along U.S. 33 on the east slope of North Fork Mountain, about 1.5 mi (2.5 km) east of Stop 6d.

Rt. 33 cuts through the Tuscarora three times, and this stop is the middle of these three exposures. The top of the Juniata is very similar to its base, implying that the same conditions existed until the end of the Ordovician. The contact with the overlying Tuscarora Sandstone is gradational. This contact is arbitrarily regarded as the Ordovician-Silurian boundary.

The Tuscarora Sandstone is a very fine-grained to very coarse-grained quartzarenite. Vertical *Skolithos* burrows occur near the base, overlain by a thinly bedded to massive cross-bedded interval that is in turn overlain by a burrowed interval. This probably represents nearshore marine conditions, implying that sea level rose at the beginning of the Silurian. About two-thirds of the way up through the Tuscarora section is an interval of thinly bedded sandstone interbedded with dark gray shale, containing *Arthrophycus* (annulated bedding plane trails) at the base of the sandstone beds. This interval may represent lagoonal, or possibly marine conditions. The upper part of the Tuscarora, like the lower part, contains cross-bedded sandstone and *Skolithos*, probably indicating a return to nearshore marine conditions. The Tuscarora Sandstone, on the eastern limb of the Wills Mountain anticline, is about 170 ft (52 m) thick and dips about 25 degrees to the east. The Tuscarora Sandstone is overlain by the Rose Hill Formation, a sequence of interbedded hematitic sandstone and olive-gray marine shale. Because a covered interval occurs at the top of the Tuscarora exposure, the contact with the Rose Hill is not observable. In fact, much of the remainder of the Silurian is poorly exposed in the field area.

The Silurian and Lower Devonian Calm Between The Taconic and Acadian Orogenies

As described in the introduction, the geologic record largely consists of alternations between carbonate domination and the influx of clastic wedges. On stratigraphic evidence alone this is the way orogenic episodes are recognized. Carbonates represent periods of tectonic stability, and large influxes of clastics indicate a mountain source being eroded. The carbonate rocks at this next stop (9) are sandwiched between clastic wedges of the Taconic and Acadian orogenies and represent a period of tectonic calm.

See Figure 8 for the sequence and description of formations which represent the period of tectonic calm between the Taconic and Acadian orogenies.

Stop 9 - Oak Flat Section

Stop 8 is 6.7 mi (11.2 km) east of the U.S. 220 and 33 junction in Franklin, W.Va. (1.1 miles [1.8 km] west of Oak flat) on the south side of U.S. 33, across the highway from a small roadside park. The exposure is a large but discontinuous 0.3 mi (0.5 km) long road cut.

Seven steeply dipping Upper Silurian and Lower Devonian formations from the Tonoloway to the Oriskany are exposed. This stop is an excellent example of almost the full Helderberg Group and the overlying Oriskany (and down the road a little, the Needmore).

Tonoloway carbonate tidal flat. At the west end of the cut the Tonoloway Formation is exposed in a broad, gentle anticline extending a couple of hundred yards along the highway. The (algal) laminated micrites appear uniformly monotonous at first, but on closer study many other features can be found, including: ostracods (*Leperditia*) and intraformational conglomerates. Near the formation top, clay content increases and the rocks weather out in thin, fissile plates with occasional mud cracks and salt casts. All of these features indicate a tidal flat environment with occasional restricted circulation and high evaporation. (The Salina salt beds to the west are a facies of the Tonoloway.)

Keyser carbonate barrier or shallow subtidal. The Keyser is divided into a lower and upper member separated by the Big Mountain Shale Member. The Lower and Upper Keyser are largely structureless, coarse-grained, fossiliferous calcarenites. The abundant well-washed fossils imply a shallow, clear-water, high energy environment such as a carbonate barrier or large areas of fossil debris in a shallow subtidal region. With the Keyser Formation a major transgression began to advance northeastward into the Silurian Central Appalachian Basin easing the restricted circulation that prevailed during the Tonoloway.

Big Mountain shallow subtidal. The Big Mountain Shale, although exposed, may be hard to see, especially with summer vegetation. The shale is brown, fissile, and locally calcareous and fossiliferous. The Big Mountain is interpreted as a clastic influx transported north and northeastward by longshore currents during a minor regressive phase of the basin. The source was the roots of the now eroded, low, and tectonically stable Taconic mountain region in the Clifton Forge, Virginia area.

Coeymans deep subtidal. The Coeymans is well exposed above the Upper Keyser in the large, prominent road cut. The base of the formation can be recognized by a bed with numerous, large bryozoan colonies. Although the Coeymans is very fossiliferous, it contains more calcisiltite and is darker than the Upper Keyser, and is interpreted as a deeper subtidal environment than the Keyser. It represents a continuation of the major transgression that began with the Lower Keyser.

New Scotland, Mandata, and Licking Creek deep subtidal. The New Scotland is a thick-bedded fossiliferous limestone with numerous chert beds that are easily visible from the road. The Mandata and Licking Creek (Shriver Chert) are poorly exposed, badly weathered, and hidden in the trees. The New Scotland, Mandata, and Licking Creek, like the Coeymans, are deeper subtidal, closer to the basinal axis, and were deposited during the maximum stages of the transgression.

Oriskany quartz arenite beach. The quartz arenitic Oriskany contains, in places, abundant molds of brachiopods. Near the top of the formation is a very thick bed with laminations parallel to bedding. Above that are large-scale planar cross beds, usually seen because brachiopod molds are aligned along the foresets.

Systematic environmental studies of the depositional environments of the Oriskany have not been done, but it is generally interpreted as a beach and near shore sand.

Unconformities have been recognized both below and above (the Wallbridge discontinuity) the Oriskany at various places in the Central Appalachians, but no direct evidence for their presence exists at this stop. Overall, however, the Oriskany represents a time of shallowing and even complete withdrawal of the Devonian sea from the craton at the boundary between the Tippecanoe and Kaskaskia sequences, just prior to the Acadian Orogeny.

The Catskill Clastic Wedge Of the Acadian Orogeny

The next series of formation represent the Catskill clastic wedge. Unlike the last series of thin formations, most of these formations run from hundreds to thousands of feet thick. The first formation we see (Needmore) represents the onset of basin subsidence corresponding to the collision of Avalon in the New York area. The Millboro was likely deposited as the basin bottomed out. The remaining formations successively fill the basin as the clastic wedge progrades into it.

See Figure 9 for the sequence and description of formations which represent the Catskill clastic wedge. Figure 4 shows a generalized model of the tectonic events of a continent-continent collision. Figure 10 is a reconstruction of part of the foreland basin showing the environments in which some of the formations are deposited, and the accompanying fieldtrip stops.

Stop 9 - Needmore Formation

Stop 9 is 0.5 mi (0.8 km) east of Stop 8 and 2.3 mi (3.8 km) west of Stop 10. It is a high, vertical road cut on the south side of U.S. 33. The rocks here are nearly horizontal, but large folds can be seen along the highway between Stops 8 and 9, which bring the Needmore into the same steeply dipping attitude as the Oak Flat section.

The bottom half of the Needmore at this stop is made up of dark gray to black, laminated shales and silts. Fossils are scattered through the section but tend to concentrate in richly fossiliferous zones of gastropods, cephalopods, brachiopods, and trilobites. Two black beds a few centimeters thick about a third the way up are especially rich in fossils. Bioturbated beds are also common. These characteristics indicate a quiet (shelf) environment with generally good circulation and oxygen levels. The black beds represent intervals of stagnation on the shelf, perhaps due to a sea level rise.

In the upper half of this outcrop a few fine sands a few cm thick appear. They have laminations and thicken and thin down the outcrop and may represent distal hummocky units.

The Needmore is an abrupt change from the underlying Oriskany. The simplest interpretation is that the Oriskany to Needmore sequence was the result of a transgressive sea onto the craton. The Millboro Formation overlying the Needmore suggests a different hypothesis, however. At Stop 10 the fossils in the Millboro are dwarfed, implying lower oxygen levels. To the north of Pendleton County there is a facies change and the Millboro name is dropped and replaced by the (older to younger) Marcellus. Mahantango, and Harrell formations, but at Stop 10 the Marcellus is black and highly organic implying anoxic conditions. This trend to anoxic conditions from the Needmore to the Millboro and Marcellus implies a rapidly subsiding basin rather than a shelf in a simple transgressing sea. Support for the rapidly subsiding basin interpretation is in the overlying formations (Stops 10, 11, and 12). Therefore, the Needmore most likely marks the first clastic influx from the Acadian mountains rising to the east into a rapidly subsiding foreland basin to the west. Thus, in Figure 9 the Needmore lies under the Millboro, Brallier and, likely, Chemung and Hampshire, and was deposited before them at the earliest subsidence stage.

Stop 10 - Millboro Formation

Stop 10 is 2.3 mi (3.8 km) east of Stop 9 and 2.0 mi (3.3 km) west of Stop 11; 1.5 mi (2.5 km) west of the U.S. 33 and West Virginia junction at Brandywine, West Virginia. The road cut is about 300 ft (77 m) long

The Devonian Stratigraphic Section, Pendleton Co. West Virginia Containing the Acadian Orogeny Catskill Clastic Wedge

Period	Epoch	Formation		Thickness	Description and Interpretation		Field Trip Stops
M		Pocono		305 ft	Marine and near shore grayish-brown crossbedded conglomeratic sandstone, sandy shale and shale	Catskill Clastic Wedge / Acadian Orogeny	Stop 13
Devonian	350 my; Upper	Hampshire		2800 feet	Meandering River Point Bar Sequences of thick, red sands and silts		
Devonian	Upper	Greenland Gap (Chemung)		4000 feet	Storm shelf; hummocky sequences; otherwise highly variable		Stop 12
Devonian	Upper	Brallier		2700 feet	Bouma sequences of mid fan type		Stop 11
Devonian	360 my; Mid	Millboro		200 feet	Laminated to very thin shales, silts, sands; dwarf clam/brach fauna		Stop 10
Devonian	375 my; Lower	Needmore		1000 feet	Dark gray to black shales/silts; laminated; abundant fossils		Stop 9
Devonian	Lower	Oriskany		130 feet	Quartz arenite; abundant brachiopod molds; cross bedding; laminations		
Devonian	Lower	Helderberg Group	Licking Creek	63 feet	Cherty, siliceous, dark limestone weathering sandy, abundant fossils	Central Appalachian Basin / Orogenic Calm	Stop 8 Oak Flat
Devonian	Lower	Helderberg Group	Mandata	57 feet	Black chert, weathering buff; with shale		
Devonian	Lower	Helderberg Group	New Scotland	160 feet	Fossiliferous limestone; very cherty; thick bedded		
Devonian	Lower	Helderberg Group	Coeymans	18 feet	Crinoidal calcarenites; large bryozoan colonies		
Devonian	Lower	Helderberg Group, Keyser LS	Upper LS Mbr.	140 feet	Massive, coarse grained fossil calcarenites with corals, algae, brachs, bryozoan		
Silurian	405 my	Helderberg Group, Keyser LS	Big Mtn. Shale	18 feet	Yellowish gray shale; calcareous; fossiliferous; (mostly covered)		
Silurian		Helderberg Group, Keyser LS	Lower LS Mbr.	25 feet	Massive, coarse grained fossil calcarenites with corals, algae, brachs, bryozoan		
Silurian		Tonoloway		305 feet	Micrites, algal laminates, mud cracks, ostracod hashes, salt casts		

Figure 9

on both sides of the highway. Here, the Millboro dips a few degrees to the south.

The Millboro consists of dark gray to black, laminated to very thin bedded shales, siltstones, and fine grained sandstones. Small-scale cross laminations are sometimes seen in the rust weathering sands. In the east cut a 6 in (15 cm) thick zone is convolute bedded, produced by fluid escape and loss of grain-to-grain contact causing flowage. On some bedding planes the fauna are abundant, but consist mostly of dwarf brachiopods and clams which are current oriented. Occasional straight and coiled nautiloids can also be found but these are generally larger than the brachiopods and clams.

The Millboro reflects a deeper, more anoxic environment (the dwarf fauna) with periods of higher energy deposition (cross-laminated sand and current oriented fossils) than the Needmore at Stop 9. These two interpretations seem paradoxical since deeper environments are usually quieter. One major source of energy in a deep water environment is a turbidity current. Support for the idea that these deposits in the Millboro are the first, thin, distal deposits of a submarine fan prograding into the foreland basin can be found in the overlying Brallier Formation at Stop 11.

Stop 11 - Brallier Formation

Stop 11 is 2.0 mi (3.3 km) east of stop 10, 0.5 mi (0.8 km) east of the U.S. 33 and West Virginia 23 junction at Brandywine, and 4.1 mi (6.8 km) west of Stop 12. The cut is on the north side of the highway at

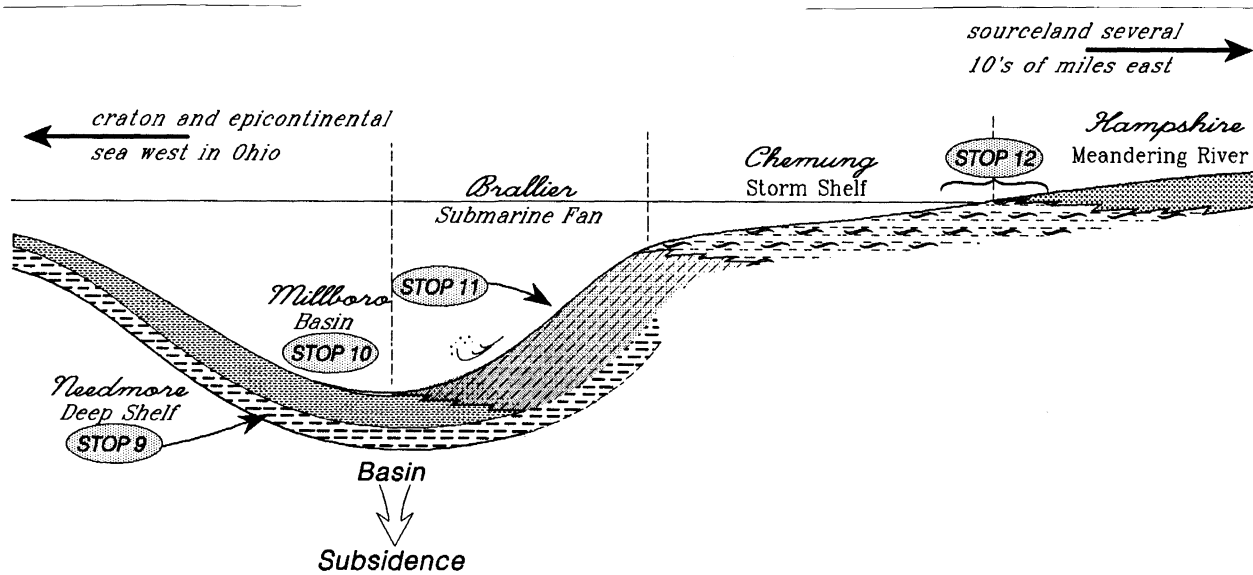

Figure 10 Reconstructed cross section of the Catskill foreland basin.

a salt storage shed.

These rocks represent Bouma turbidite sequences of a mid-fan type (T_{CDE} dominates, but other sequences including T_{ABCDE} are present). In some of the coarse silts between the sandstones abundant cross laminations may be the result of contour currents. These sequences are clearly visible and easily studied in the lower part of the cut. The upper portion of the cut is more weathered and illustrates the typical weathering pattern of the Brallier, which consists of jutting sand beds alternating with weathered shales. Various pieces of sandstone float have a variety of trace fossils and current marks such as shallow flutes and grooves.

By the time the Brallier Formation appears in the section the former deep water, nearly anoxic basin of the Millboro Formation has begun to rapidly fill in with large submarine fans prograding from the east.

Stop 12 - Chemung-Hampshire Transition

Stop 12 is 4.1 mi (6.8 km) east of Stop 11 and 2.6 mi (4.3 km) west of the crest of Shenandoah Mountain. The long road cut begins (traveling east) at a gentle "S" curve in the highway and extends up the hill for several hundred yards (meters).

The Chemung consists of gray, brownish-gray, green, and red shales, siltstones, red sandstones (becoming thicker upsection), occasional quartz pebbles or conglomerates, and scattered marine fossils and drifted plant fragments. It is one of the most variable formations in the region. Contacts with the underlying Brallier and overlying Hampshire are not lithologically distinct. The formation contacts are defined paleontologically, but for purposes of this field guide the base of the Hampshire is defined as the first appearance of distinctive point bar sequences.

The strip log in Figure 12 (two pages; location map on second page) summarizes some detailed environmental interpretations of the Chemung-Hampshire transition at Stop 12. The Chemung exhibits many shelf features, including well developed hummocky sequences seen in Facies II, III, and IV. Zones of nearshore facies with red color, oscillation ripples, and/or root traces are also common, such as Facies I and VII. Facies IVB, VA, VB, and VI include an unusually thick sequence of quartz pebble conglomerate. We have interpreted this as a submarine fan feeder channel, but other interpretations are encouraged.

Some of the fining upward point sequences of the Hampshire (Facies XII) are close to the ideal model with scoured bases, mud-pebble lag gravels, and large-scale trough cross beds grading up into small-scale trough cross beds. Many variations of the point bar sequence are present, however. On the strip log point bar sequences come in at Facies XII, but continue for the next 2.5 mi (3.8 km) to the top of Shenandoah Mountain.

Allen and Friend (1968: p. 58) stated that the Hampshire (their Catskill) "was deposited in a vast coastal plain of alluviation" with the characteristics of a meandering river (point bar sequences). Thus, the Chemung is environmentally transitional between the submarine fan of the Brallier below and the alluvial plain of the Hampshire above. Beyond that, specific environmental interpretations of the Chemung are as widely different as is its color and lithology.

Stop 13 - Pocono Formation

Stop 13 is 13.7 mi east of Stop 12 (11.1 mi east of the crest of Shenandoah Mountain.). This outcrop is a large body (10-12 feet high) of large cross bedded sandstones on the north side of the road. There is a pull off directly opposite it on the south side of the road. If you get to Rawley Springs you are a mile or so past the stop.

Little or no recent work has been done on the Pocono in this region. There is a generalized description in Figure 9. In various places the Pocono contains evidence of nearshore marine as well as subareal delta deposits.

The sandstone body at this stop is interpreted as a tidal sand bar, although the evidence and arguments are indirect. Sand bodies with large cross bedding like this form in only a few environments, including tidal shelves and some river systems. If we could find a marine fossil in this outcrop it would help to narrow the interpretation down. Looking up and down the road other sand bodies representing additional sand bars are seen. At another cut east about half a mile a coal bed has been reported, indicating transitional or terrestrial environments there.

The significance of this formation is this. Below the Pocono is 2-3000 feet of meandering river deposits indicating terrestrial conditions were well established in this region during its deposition. The presence of the Pocono near shore and marine shelf deposits on top of the Hampshire indicates that the sea has begun to transgress back across the Hampshire terrestrial environments. The Pocono was deposited during the waning stages of the Acadian Orogeny as sediment supply decreased and sediment winnowing increased. To the west the carbonates of the Greenbrier formation overlying the Pocono (see Figure 1) indicate orogenic activity has finally ceased in this area.

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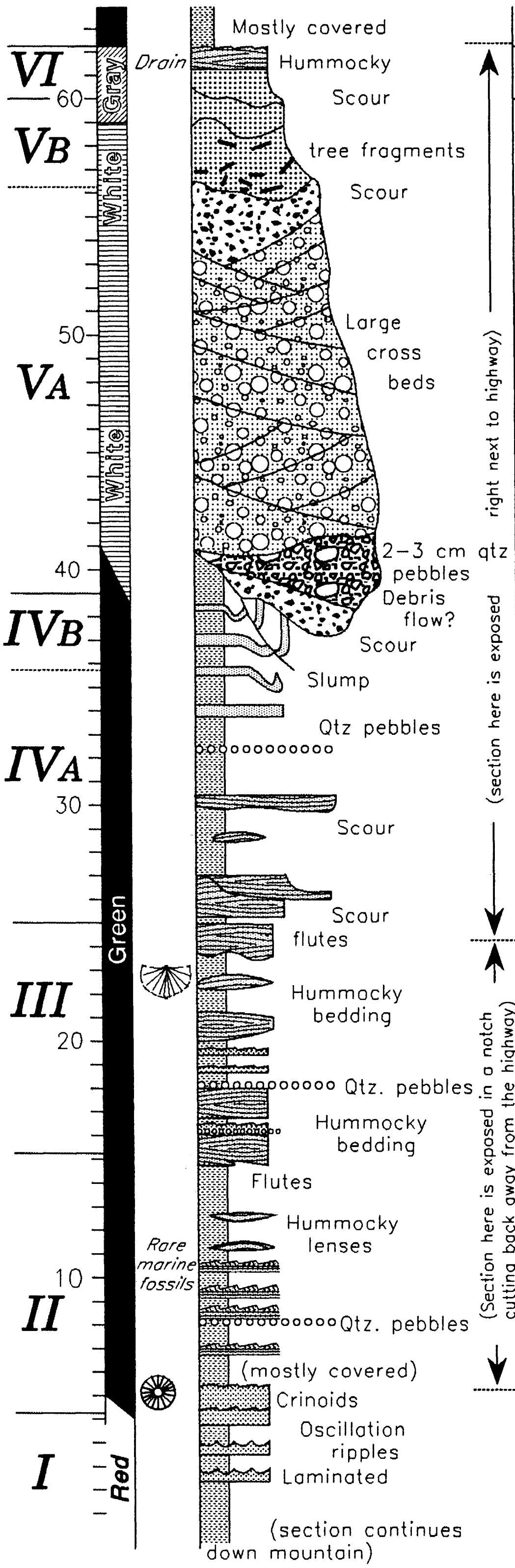
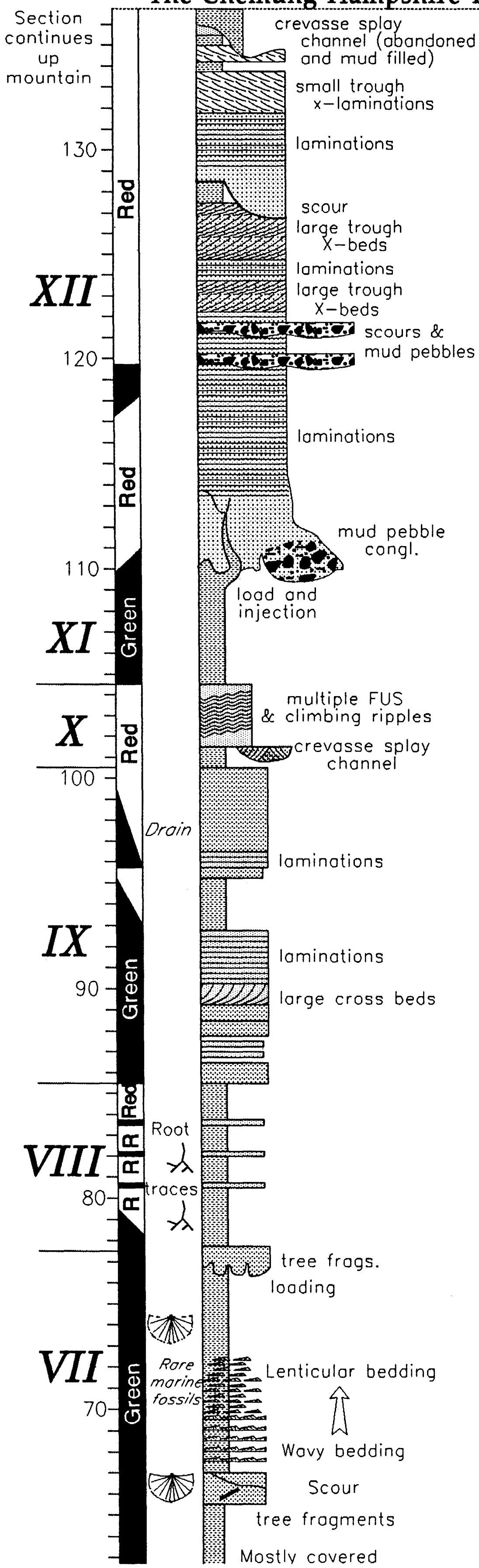
The Chemung-Hampshire Transition
At Shendandoah Mountain, Pendleton Co. W.Va.
(Page One - Lower half of section)

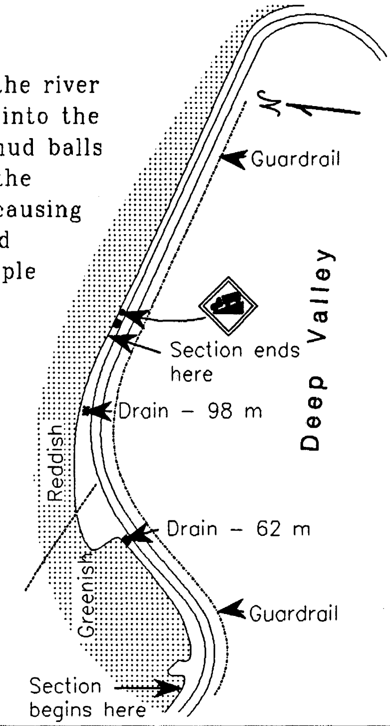


River Mouth Bar	Abandonment of river channel, and final reworking of the bar/shoal sands.
Submarine Fan Feeder Channel	Final stages of submarine channel filling with several small scours. One channel choked with small logs and twigs..
	Deeply scoured submarine fan feeder channel cutting across shelf. This channel, at this point, results from the fortuitous juxtaposition of two events: (1) a river channel migrating onto the shoreline directly onshore from this point, at the same time, (2) a large deposit of quartz conglomerate, unroofed in the source area is fed onto the shelf scouring out the deep channel. The quartz conglomerate is a relatively short term event for although some quartz pebbles show up downsection, they fade out before the top of the channel deposit and not appears farther upsection.
Storm Dominated Deep, Distal Shelf	Outer shelf shales and thin sands penecontemporaneously slumped and folded into the side of a large submarine fan feeder channel Facies V.
	Multiple thinning and fining upward sequences, some hummocky, some with flat laminations. Sea level has risen from the last facies. Sand bars here are either the last remnants eroded from the river mouth bars, or sands lateral and offshore to the major sand bars (Facies III).
Storm Dominated Deeper Mid-Shelf	Storm shelf dominated by migrating hummocky sand bars. From Facies II this is a deeper environment likely due to a sea level rise. Flute casts, meter thick hummocky units, and quartz pebble lags indicate the high energy on the storms. Sands and gravels are probably migrating down the coast from river mouths.
Shallow Nearshore Shelf	Mud dominated. Occasional sands brought in by storms and reworked into hummocky lenses. From Facies I this is a transgression of the shelf across the nearby coastal mudflat. Due either to a sea level rise, or because the river supplying the flood deposits has shifted down the coast or been abandoned.
Muddy Shoreline	Muddy shoreline built by a prograding alluvial plain, which, flood by flood, builds the shoreline farther out into the sea.

The Chemung-Hampshire Transition: Page Two - Upper Half of Section



Map of Outcrop



Meandering River

During a flood the river suddenly shifts into the area dumping mud balls and sand onto the soft bay muds causing loading and mud injection. Multiple point bar sequences alternate with flood plain deposits to the top of the mountain.

Bay or Nearshore Shelf

Crevasse Splay

River has moved into the nearby area; this facies may represent one major flood event.

Fluctuating Nearshore/ Terrestrial Conditions

In this part of the section marine and terrestrial influences are struggling for dominance. The area may hae been a small embayment adjacent to a broad prograding fluvial meander belt. When the river meanders close flood deposits washed into the bay. When the river migrated away marine conditions reestablished, including sand shals migrating into the bay.

Prograding Muddy Shoreline

Establishment of prograding muddy shoreline; first red sediment since the base of this section; very thin bedding, fine clay drapes, some mud cracks, and root traces. A river has migrated into the nearby shore area and associated alluvial plain progrades out into the shelf with successive floods building the muddy shoreline.

S H E L F

Flood/storm generated sand body?

Mud dominated shelf with tiny silt lenses. Sea is regressing; lack of sand is due either to a river having moved downshore, OR this area is an embayment and river mouth bars are too far offshore to readily enter the bay.

Migrating sand shoal. Fining and thinning upward.

Reestablishment of the mud-dominated shelf following abandonment of the submarine channel below. Facies V.