42nd Annual Virginia Geological Field Conference,
September 28-29, 2012

Geology of Page Valley: Stratigraphy, Structure, and Landscape Evolution

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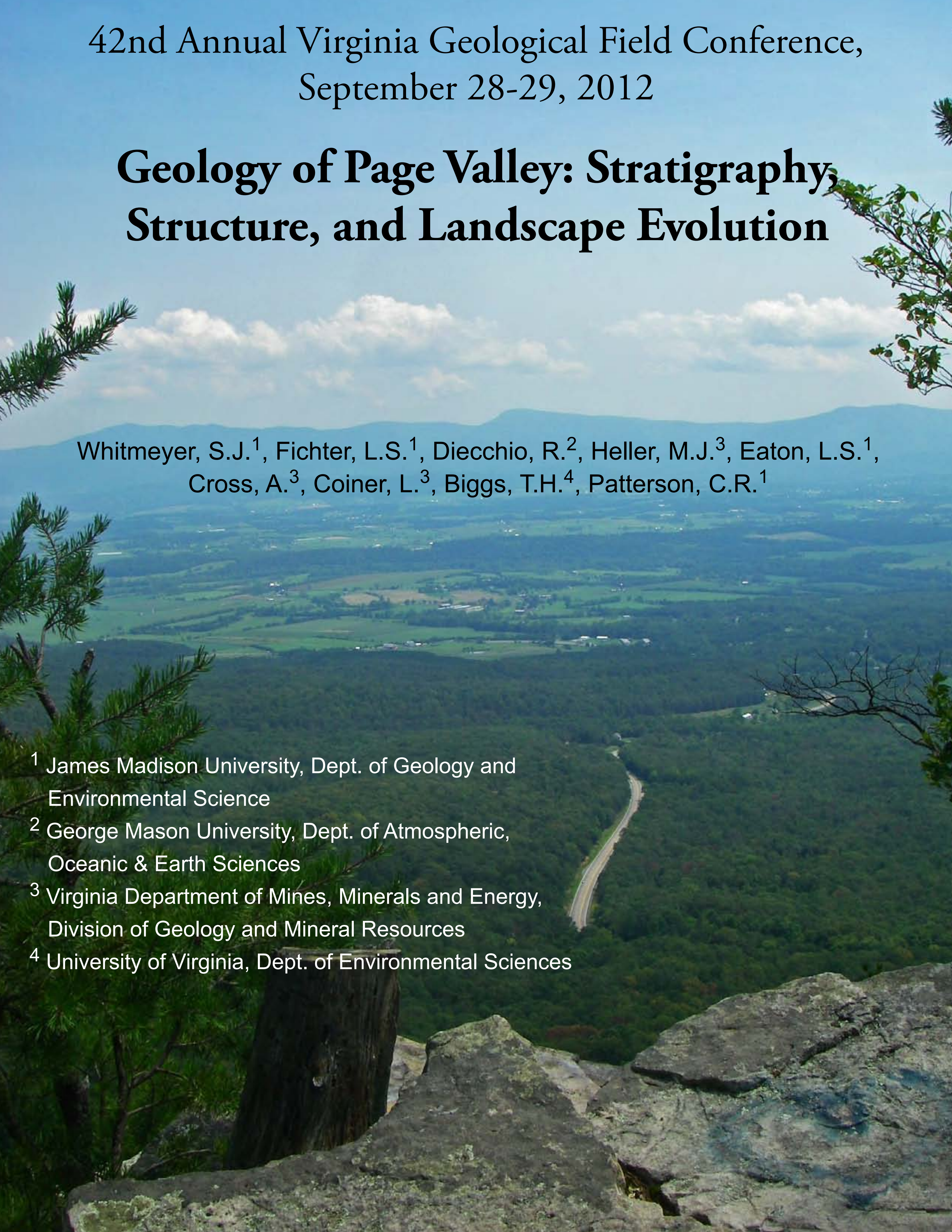

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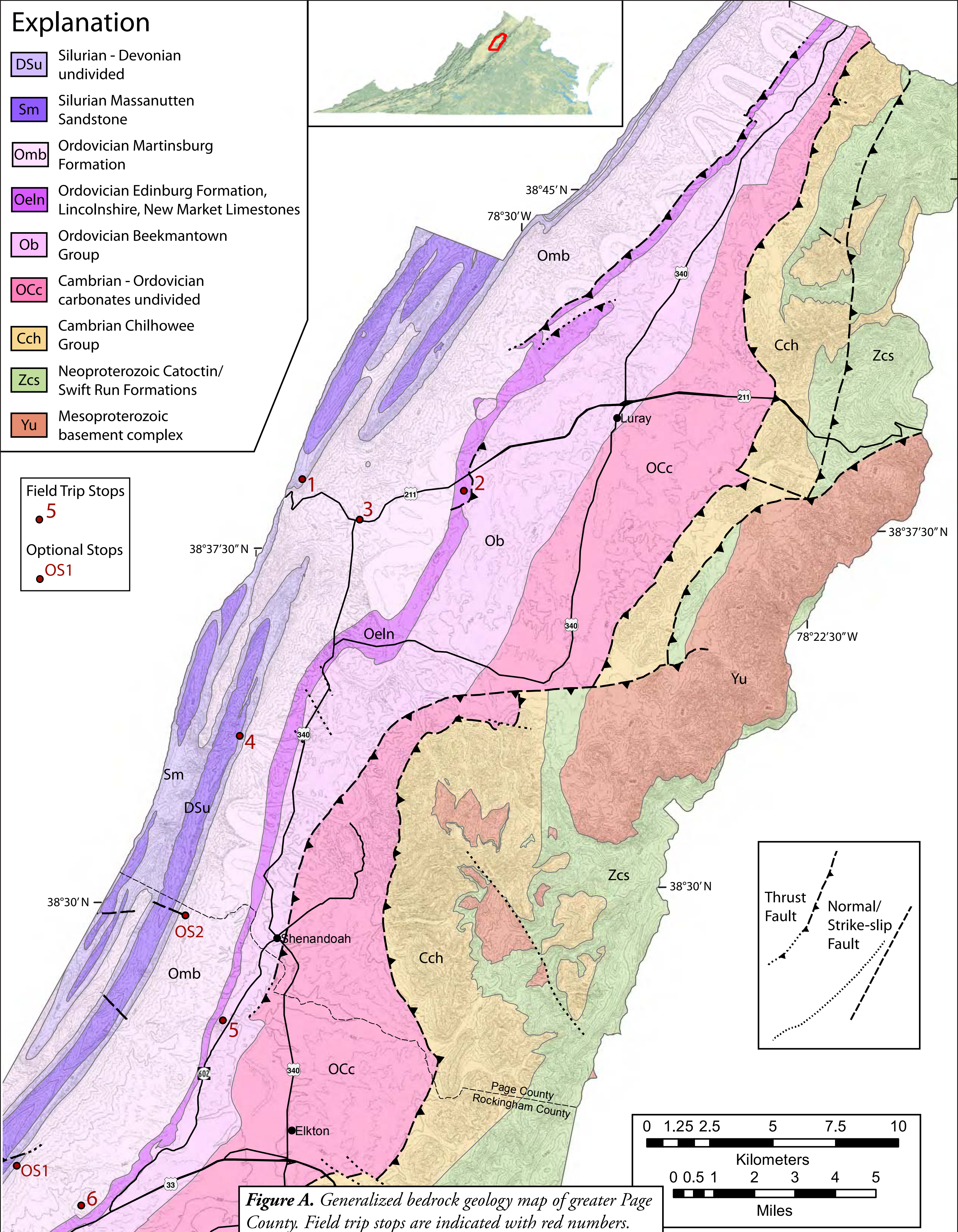


Figure A. *Generalized bedrock geology map of greater Page County. Field trip stops are indicated with red numbers.*

Dedication

The 42nd annual Virginia Geological Field Conference is dedicated to the memory of Dr. Roddy V. Amenta, professor of geology and environmental science at James Madison University from 1974 to 2011. After joining the Geology faculty at JMU in the fall of 1974, Roddy taught a variety of subjects, including mineralogy, igneous and metamorphic petrology, structural geology, and physical geology. Roddy's research linked petrology, computational science, and materials science, and he was an early pioneer in recognizing the future role of computers in geologic research. His work on computer modeling of crystallizing magmas resulted in a number of presentations and publications in the field. He was truly a multidisciplinary scientist, equally at home discussing geology, chemistry, physics, and mathematics. In addition to his contributions in education and research, Roddy was widely known for his friendly demeanor, great sense of humor, and uncanny ability to find the perfect nickname for a colleague or student. These attributes endeared him to colleagues across the disciplines and to generations of JMU students. He passed away on July 28, 2012 after battling a long illness and will be missed by all.

Front Cover. *View to the east of Page Valley from the Storybook Trail overlook (Stop 1) on Massanutten Mountain above New Market Gap. Massanutten Fm. quartz arenite is underfoot, and the Blue Ridge Mountains of Shenandoah National Park are visible in the distance.*

Introduction

The Massanutten Mountains and Page Valley of northwestern Virginia exhibit dramatic scenery and topography that resulted from several episodes of mountain building and subsequent erosion and denudation. On this field trip we will examine bedrock and surficial exposures to explore the geologic and tectonic history of Mid-Atlantic North America, from the tectonically quiet period prior to the Appalachian orogenic cycle through the culmination of the assembly of the supercontinent of Pangaea during the Alleghanian orogeny. Over the past decades several regional-scale mapping projects have included this region, such as King (1950), Brent (1960), Allen (1967), Sarros (1995), Rader and Gathright (2001), and Southworth et al. (2009). More recently, an abundance of 1:24,000-scale mapping projects in the Great Valley region (Shenandoah Valley, Massanutten Mountains, Page Valley; Figs. A, B) has produced more detailed representations of the geology of the area and enabled improved interpretations of the stratigraphy, structural geometry, surficial geology (Fig. C), and ultimately the tectonic history and modern topographic expression of the region. We will explore some of this new geologic mapping and discuss tectonic interpretations during our one-day field excursion (Fig. D).

The Mid-Atlantic Appalachian Mountains are divided into the Blue Ridge and Valley and Ridge provinces, each with a characteristic landscape that largely reflects the underlying bedrock and its structural geometry. The Blue Ridge Mountains form the easternmost range of the Appalachians and in northwestern Virginia stand with topographic relief that approaches 1000 meters (3300 ft.) and high peaks that reach 1200 meters (4000 ft.) in elevation. The Blue Ridge geologic province encompasses a basement massif of 1.2 to 1.0 Ga granitic and gneissic basement rocks overlain by a cover sequence of late Neoproterozoic to Early Cambrian greenschist facies volcanic and clastic rocks.

The Valley and Ridge geologic province, with its distinctive northeast-trending linear topography, is a classic fold-and-thrust belt that encompasses a thick sequence of Cambrian to Mississippian sedimentary rocks. In northwestern Virginia the easternmost part of the Valley and Ridge includes the Great Valley (consisting of Shenandoah Valley and Page Valley), a wide northeast-trending lowland underlain by Cambrian-Ordovician carbonate and clastic rocks. This is bisected by the Massanutten Mountains, a series of linear ridges underlain by Silurian quartz sandstones with restricted intervening valleys of Ordovician to Devonian rocks. The modern landscape is the result of differential erosion between rock types in the respective geologic provinces: hard, erosion-resistant granitoids, metabasalts, and quartz sandstones support the high country, whereas soluble and relatively soft carbonate rocks and shale underlie the valleys.

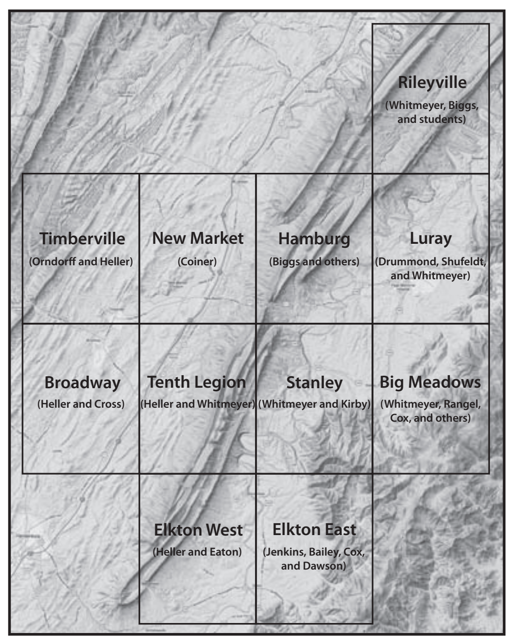


Figure B. *7.5 minute quadrangles in the Great Valley region with recent or ongoing mapping supported by the USGS EDMAP and STATEMAP programs. Authors and/or principal mappers are indicated in each quadrangle. Terrain map from Google Maps.*

In the course of this field trip we will visit outcrops that document: 1) Ordovician carbonate deposition during the tectonically quiet period following the breakup of the Rodinia supercontinent and preceeding the initiation of the Appalachian orogenic cycle, 2) Ordovician to Silurian deposition of predominently clastic detritus derived from the Taconic orogenic event, 3) contractional deformation, folding, and thrust faulting caused by collisional events during the Alleghanian orogeny in the late Paleozoic, and 4) localized brittle deformation likely related to Mesozoic rifting that ultimately broke up Pangaea and formed the Atlantic Ocean.

We will also examine more recent evidence for landscape denudation and modification through colluvial and alluvial processes. Finally, we will consider the historical and modern use of mineral resources in the Page Valley region, including quarrying of carbonate rocks and smelting of iron ore in 19th century furnace operations.

Stratigraphy

Proterozoic through Devonian rocks are exposed in the Great Valley region, but this field trip will focus on Ordovician and Silurian strata (Fig. E) in the Massanutten Mountains and western Page Valley. Regional relationships between these strata, and strata of equivalent age farther west in the Valley and Ridge, are illustrated in Figure F.

Age	formation (approx thickness)	description	depositional environment
Silurian	Bloomsburg Formation (100 meters)	Red and green mottled mudrock with red shale, red shaly sandstone, and red sandstone. White, cross-bedded sandstone near the middle of the unit.	Non-marine (meandering stream?) to nearshore marine
Silurian	Massanutten Sandstone (240+ meters)	Medium- to thick-bedded, white to gray, cross-bedded, conglomeratic quartz arenite with minor thin beds of dark gray and green shale with plant debris.	Braided river
	unconformity		
Ordovician	Martinsburg Formation (900-1200 meters)	Upper: ("Cub sandstone" of Thornton, 1953) Medium- to thick-bedded dark brownish gray, lithic arenite to lithic wacke with lesser shale, some fossiliferous beds, hummocky cross-stratification. Middle: Thin to thick graded beds of dark brownish gray lithic arenite, grading upward to lithic wacke to shale (bouma sequences), hummocky cross-beds near top. Lower: (Stickley Run Member of Epstein et al, 1995) Graded laminae of black lime mudstone grading upward to calcareous black shale, contains bentonites.	Upper: shelf to nearshore marine Middle: deep shelf to basin, proximal turbidites Lower: deep basin, distal turbidites
Ordovician	Edinburg Formation (180-400 meters)	Thin- to medium-bedded, black lime mudstone with black calcareous shale, contains bentonites (mainly Liberty Hall Facies of Cooper & Cooper, 1946).	mixed carbonate-clastic shelf to slope to ramp to basin
Ordovician	Lincolnshire Limestone (0-45 meters)	Thin- to thick-bedded, gray to black, fossiliferous grainstones and packstones with lesser wackestones and lime mudstones, and localized black chert nodules.	carbonate shelf
	unconformity		
Ordovician	New Market Limestone (0-75 meters)	Massive to thick-bedded, dove gray, micritic limestone with small birds-eye crystals of calcite.	carbonate tidal flat
	unconformity		
Ordovician, Beekmantown Gp	Rockdale Run Formation ? (730-750 meters)	Massive to medium-bedded, gray to brown dolomitized and non-dolomitized algal boundstone, lime mudstone, wackestone, and crystalline limestone, with lesser black chert.	evaporative carbonate supratidal flat (sabkha)
Ordovician, Beekmantown Gp	Stonehenge Limestone (150-180 meters)	Thin- to medium-bedded lime mudstone, wackestone, and crystalline limestone with silty interlayers and nodular chert	carbonate platform

Figure E. *Summary of Ordovician and Silurian stratigraphy of Page Valley after various sources: Cooper and Cooper (1946), Diecchio (1985), Edmondson (1945), Epstein and others (1995), Heller (2010), John T. Haynes (personal communication), Perry (1977), Pratt (1979), Rader & Biggs (1975, 1976), Eugene K. Rader (personal communication), Thornton (1953), Woodward (1941), and Young & Rader (1974).*

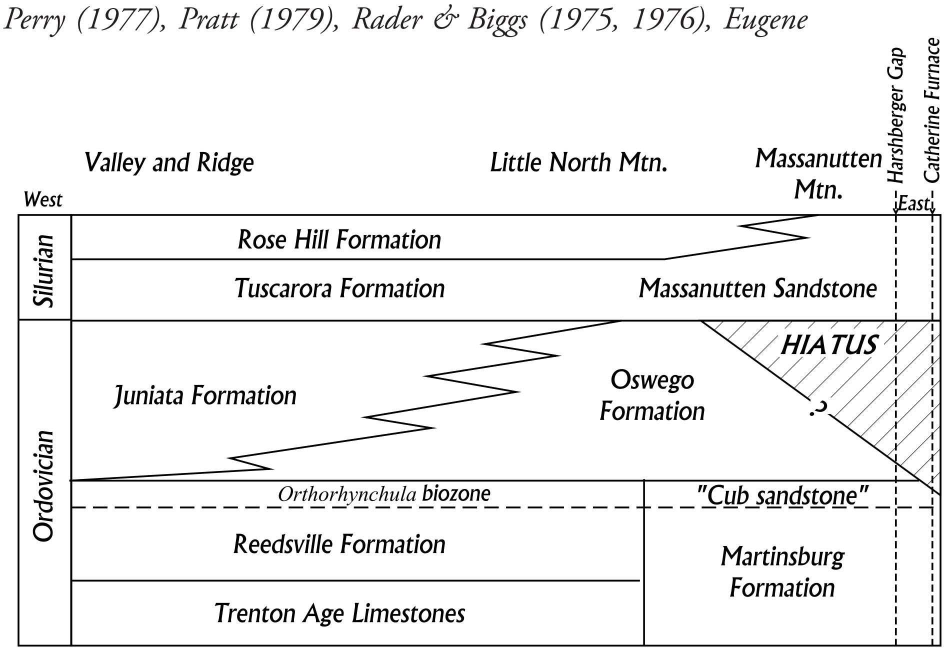


Figure F. *Regional, selected Ordovician and Silurian stratigraphic correlations in northwestern Virginia/ eastern West Virginia from the Massanutten Mountain region, across Little North Mountain, and into the western Valley and Ridge (modified from Diecchio, 1985).*

Tectonic setting

The most notable aspect of the Ordovician strata of Page Valley, similar to elsewhere in the central and southern Appalachians, is the transition from predominantly carbonate to predominantly clastic rocks. The clastic strata are part of the Queenston clastic wedge, considered the sedimentary record of the Taconic Orogeny (Leighton and Kolata, 1990).

The Lower and Middle Ordovician carbonates represent the carbonate bank that existed across much of the North American craton, including the passive continental margin of eastern North America. This region was situated in the low southern latitudes during the Ordovician, and high sea-level conditions flooded the craton with a shallow epicontinental sea. The shallow marine environment provided optimal conditions for limestones and dolomites, which dominated the stratigraphic column from the Middle Cambrian until the Middle Ordovician. The Beekmantown Group and New Market Limestone were deposited under these conditions in shallow supratidal to subtidal conditions.
During the Middle Ordovician, starting with deposition of the Lincolnshire Limestone, the limestones reflect deepening conditions, the start of what has been referred to as a ramp-to-basin transition (Read, 1980; Rader and Henika, 1978). The Edinburg Formation documents the initial onset of clastic sediments. Although they are not well exposed in Page Valley, bentonite beds are present in the Edinburg Formation (Kolata et al., 1996) and continue upward into the Martinsburg Formation (Haynes et al., 1998; Elliott and Haynes, 2002). By Edinburg time, the eastern edge of the continent was close enough to the volcanic arc that the arc began to contribute sediment in the form of clastics and volcanic ash beds. Interestingly, the lowermost arc-derived clastic rocks appear to coincide with the lowermost bentonites in Shenandoah and Page valleys, but are significantly younger than the bentonites in the western Valley and Ridge (John T. Haynes, personal communication). This likely reflects progressive westward progradation of the base of the clastic wedge through time.

Tectonic subsidence and presumably deep-water conditions continued during deposition of the black calcareous shales and argillaceous micrites of the lower Martinsburg Formation. Turbidites of the middle Martinsburg represent filling of the foreland ("Martinsburg") basin. By the upper Martinsburg ("Cub sandstone"), prograding hummocky sequences of a storm shelf shallowed and filled the basin. Evidence for a deep Martinsburg basin is not found west of the North Mountain front (west of the Shenandoah Valley). In those areas, the carbonate-clastic transition likely occurs in a shelf environment, and does not contain turbidites. We refer to this shallow western sequence as the Reedsville Formation, most of which is equivalent in age to the Martinsburg Formation (Fig. F); see Appendix A for more information on Martinsburg subdivisions and nomenclature.

In Page Valley and the Massanutten Mountains, the Massanutten Sandstone overlies the Martinsburg Formation and is, in turn, overlain by a relatively thin Silurian – Devonian sequence of sandstone, minor carbonate, and shale (Figure E). In the Valley and Ridge west of Shenandoah Valley the stratigraphy of units above the Martinsburg Formation is different. At Brocks Gap in Little North Mountain the Oswego Sandstone occupies the stratigraphic position between the Reedsville Formation (Martinsburg equivalent) and the Juniata Formation, that underlies a thin Tuscarora Sandstone (Massanutten equivalent; Woodward, 1955; Rader and Perry, 1976; Fig. F). West of Brocks Gap, the Oswego becomes a lateral facies of the Juniata Formation, while east of Brocks Gap the Oswego is significantly less apparent in outcrop.

The Oswego Sandstone has not been previously documented in Page Valley. However, two isolated outcrops at the southeast end of Massanutten Mountain consist of lithic sandstones and prominent lithic conglomerates that contain chert, quartzite, and shale pebbles. These conglomerates are similar in composition to the Oswego Sandstone at Little North Mountain and occur stratigraphically between the upper Martinsburg Formation and Massanutten Sandstone. We suggest that they are the eastern facies of the Oswego Sandstone. These sandstone/conglomerate outcrops are further discussed as optional field trip stops (OS1, OS2) at the end of the Road Log.

Ordovician Unconformities

Sea-level changes occur at many different scales and time spans, and may be caused by global/eustatic effects as well as localized subsidence, uplift, or sedimentation. Global unconformities are first-order sea-level cycles and delineate major cratonic stratigraphic sequences. Higher-order (smaller) sea-level changes are due to both global and local causes. This is discussed in more detail in Appendix B.

There are two significant Ordovician unconformities that occur in the Page Valley stratigraphy we traverse on this field trip. The Knox unconformity occurs at the top of the Lower Ordovician and separates the Sauk and Tippecanoe Sequences (Leighton and Kolkata, 1990). Locally, this unconformity represents the contact between the Beekmantown Group and New Market Limestone. We will not have an opportunity to see the Knox unconformity up close on this field trip, although Edmundson (1945) reported it near the top of the Elkton quarry (Stop 5).

The Late Ordovician unconformity (known in the central and northern Appalachians as the Taconic Unconformity) occurs nearly globally at the top of the Ordovician. In North America it separates the Tippecanoe I and Tippecanoe II Sequences and has been attributed, in part, to glacially-induced sea-level lowering (Sloss, 1988). In the Hudson Valley of New York, the Taconic Unconformity is a distinct angular discordance between the Middle Ordovician Austin Glen Formation and the Upper Ordovician Rondout Formation. At the Delaware Water Gap, the Lower Silurian Shawangunk Formation lies with a slight angular discordance on top of the Martinsburg Formation. Thus, the angular nature of the Taconic Unconformity in the northern Appalachians suggests tectonic enhancement of the glacially-induced sea level lowering.

Locally, the Taconic Unconformity is the contact between the Martinsburg Formation and Massanutten Sandstone, which we will examine at Catherine Furnace (Stop 4). Immature, shallow storm shelf hummocky sandstones (mainly litharenites and lithic wackes) and bentonites in the Martinsburg Formation indicate active tectonism in the source area. In contrast, the overlying Massanutten Sandstone is very mature, consisting mainly of quartz arenites and quartz pebble conglomerates (Pratt, 1979). The abrupt change from lithic sand to quartz sand is notable, and suggests that deposition of the Massanutten did not occur directly following the Martinsburg. The contact here is not angular, and thus the disconformity between the Martinsburg and the Massanutten is most likely due to a glacioeustatic lowering of sea-level.

A Subsidence/Accommodation Model for the Ordovician Sequence of Shenandoah and Page Valleys

Accommodation space, the space available for sediment to accumulate, is controlled by multiple variables, including tectonic subsidence, sediment-induced subsidence, and eustasy, each of which may be operating largely independent of the others, and in different time scales. Figure G shows a new subsidence/accommodation model for the evolution of the Middle and Upper Ordovician strata of Page Valley. It is based on known stratigraphic thicknesses and ages, interpreted changes in relative sea-level and depths of sedimentation, and calculated isostatic response. It illustrates the total subsidence necessary over time to deposit the strata between the top of the Beekmantown and the base of the Massanutten, both of which are interpreted to have been deposited at sea-level. The "Cumulative thickness" curve on Figure G is equal to the subsidence necessary to accommodate the strata from the top of the Beekmantown to the base of the Massanutten Sandstone. The "Total subsidence at top of Beekmantown" curve is the cumulative thickness curve adjusted according to the interpreted water depth (below storm wave base) that existed during deposition of the Lincolnshire Limestone, Edinburg and Martinsburg Formations. The sediment filling the basin is illustrated by adding the thickness of each formation to the adjusted total subsidence curve.

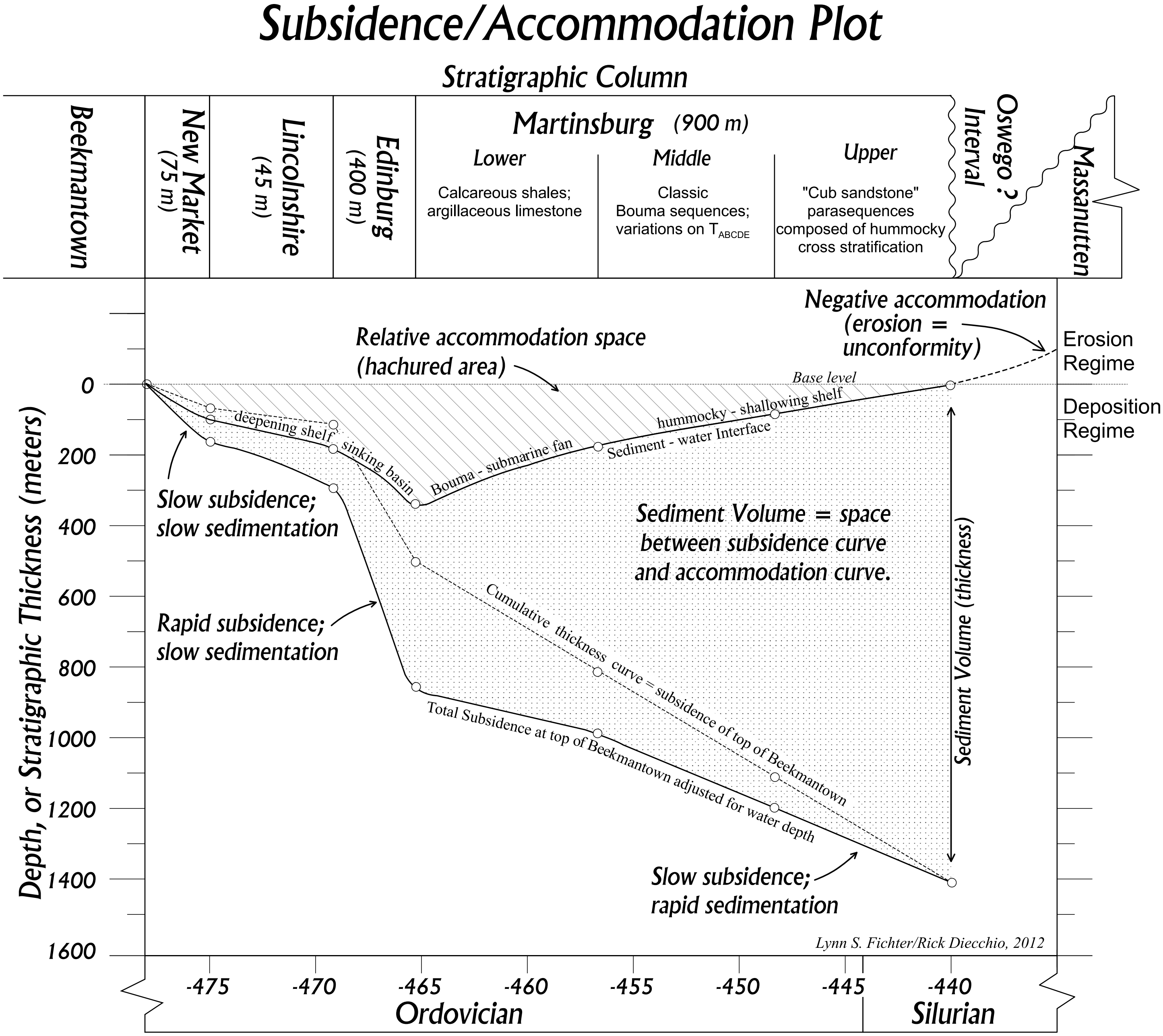


Figure G. *Model for the tectonic creation of a foreland basin, and the subsequent filling of the accommodation space by sedimentation, as applied to the Taconic foreland basin in Page Valley, Virginia.*

This subsidence/accommodation model illustrates a possible isostatic effect of Taconic over-thrusting onto eastern North America. It is based on the tectonic concept that during a collisional event an over-thrusting hinterland places a load on the foreland resulting in relatively rapid foreland basin subsidence (e.g. Shumaker and Wilson, 1996). The tectonic subsidence appears as the steepest part of the total subsidence curve, given that total subsidence is due to both tectonic loading and sediment loading, among other factors.

The subsidence model starts with cratonic or mature passive continental margin conditions driven primarily by sediment load-induced isostatic subsidence (slow subsidence rate, small accommodation space, slow sediment accumulation), interrupted by the onset of rapid tectonic subsidence into deep water conditions, followed by an exponential decay in subsidence rate as sediment load-induced conditions return. The model depicts an evolving basin that fills with a predictable sequence of carbonate and clastic sediment. The sequence starts with shallow water deposits, followed by deep basin deposits, followed by shallow water deposits. These facies might look like (bottom to top): 1. pre-tectonic shallow water (carbonate) deposits, 2. deep, quiet water, fine-grained, anoxic (carbonate to clastic) deposits, 3. mass transport clastic deposits (e.g. debris flows, turbidity flows, etc.) down an underwater slope, resulting in a coarsening, shallowing upward sequence as the accommodation space fills, 4. distal to proximal shelf, coarsening, shallowing-upward facies, 5. shoreface deposits, 6. coastal facies, 7. meandering fluvial deposits, and 8. braided fluvial deposits.

Applying this model to Page Valley, during New Market deposition accommodation space increases largely in concert with the increase in subsidence due to sediment loading. Depth increases at about the same rate as sedimentation, and the depth of the depositional surface stays about the same. This would have been the case during the period in which most of the Cambrian-Ordovocian carbonates were deposited. During Lincolnshire and Edinburg deposition, subsidence outpaces sedimentation rate and the basin gets deeper. During Martinsburg (immature submarine fan clastics) and Massanutten deposition (after the tectonic load has been emplaced) tectonic subsidence decreases exponentially. Subsidence rates slow while sedimentation rates increase resulting in rapidly decreasing accommodation space, filling of the basin, and shallowing upward water depths and facies. The shift from deepening due to increasing accommodation from subsidence, to shallowing due to decreasing accommodation from deposition, probably happens during the transition from Edinburg deposition to Martinsburg deposition.

Evidence From The Tumbling Run Section

The stops in Page Valley that we will visit on this field trip do not show complete sections of the Ordovician carbonate stratigraphy. However, a virtually complete, well-exposed Middle-Late Ordovician section exists along Tumbling Run near Strasburg, Virginia (Fig. H). It is described below as a framework for interpretations based on the subsidence/accommodation model outlined above.

At Tumbling Run the top of the Beekmantown Group displays evidence of deposition in an evaporitic/dolomitic system, the New Market Limestone is convincingly a carbonate tidal system, and the Lincolnshire Limestone is a deepening carbonate shelf (Fichter and Diecchio, 1986). These units are carbonates, which points to tectonic stability, and the tidal flat-to-shelf transition can be attributed to a sea level rise. The Lincolnshire is considered the transition from a stable platform to the beginning of a subsiding basin (Rader and Henika, 1978; Read, 1980). Carbonate deposition continues to fine up-section through the Edinburg Formation and get darker and more anoxic. This evidence suggests that these formations represent a rise in sea-level under conditions of tectonic stability. Similarly, interbedded fine-grained carbonates (micrites) and clastics (shales) at the base of the Edinburg suggest quiet water deposition, except that the micrites have loaded (sunk) down into the shales, and the shales are injected up into the micrites.

Load structures are common in the stratigraphic record, and typically form when an overlying unit rapidly deposits on an underlying hydroplastic unit, leading to instability, sinking (loading), and upward injection of the underlying unit. It is commonly seen in sandstone-shale couplets with the sand, rapidly transported in by a high-energy event, doing the loading. However, loading can occur when any sediment is deposited over mobile, unlithified sediment. Haynes et al. (1998) suggested that the shales had a high percentage of volcanic ash, which would enhance their mobility. A possible mechanism for loading is an underwater mass flow (debris, fluidized, turbidity, etc.) of micrite flowing down-slope. There is no reason carbonates—including fine grained ones—cannot form turbidites, as the conditions that set up and control energy dissipation down a slope are not dependent on sediment size. Deep shelves do not typically have slopes, but a subsiding basin would create one. Thus, the Edinburg Formation may reflect deposition in a subsiding basin.

In Page Valley, and throughout most of Shenandoah Valley, a deep Martinsburg basin had formed by the end of Edinburg deposition, before Martinsburg deposition. This is not the case west of the Little North Mountain front, or throughout most of the central and southern Appalachians. In those areas, the equivalent Reedsville Formation was deposited in conditions no deeper than mid to distal shelf (Diecchio, 1993). This suggests that pre-Martinsburg deepening was not caused by an eustatic sea-level change. This scenario is depicted schematically in Figure I, which shows the deep Martinsburg basin as a foreland basin in the eastern part of the Valley and Ridge, in contrast with shallower conditions that persisted farther west.

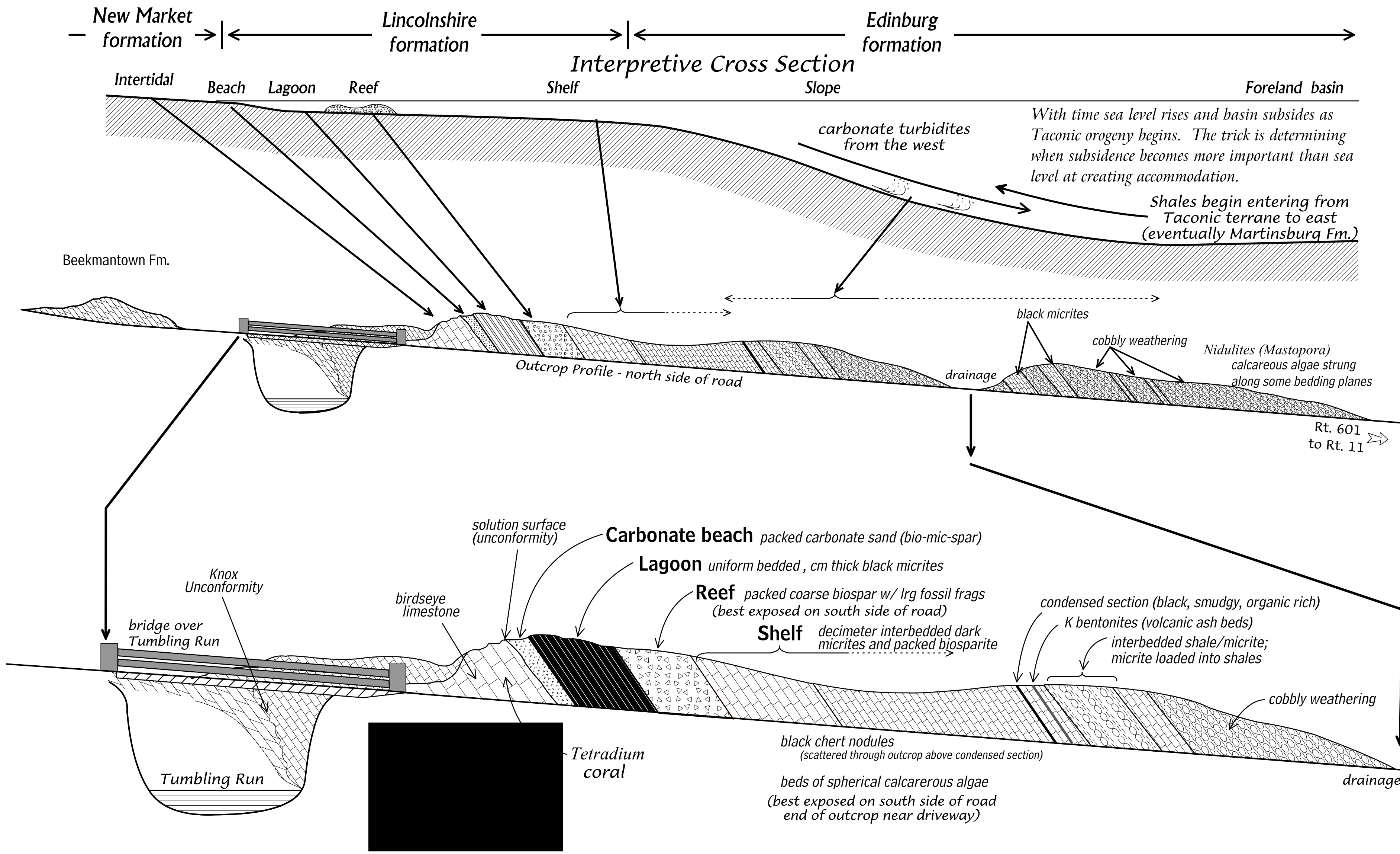


Figure H. *Stratigraphy and interpretation of the Tumbling Run section (north side outcrop profile), Route 601, Fisher's Hill Road, Strasburg, Virginia.*

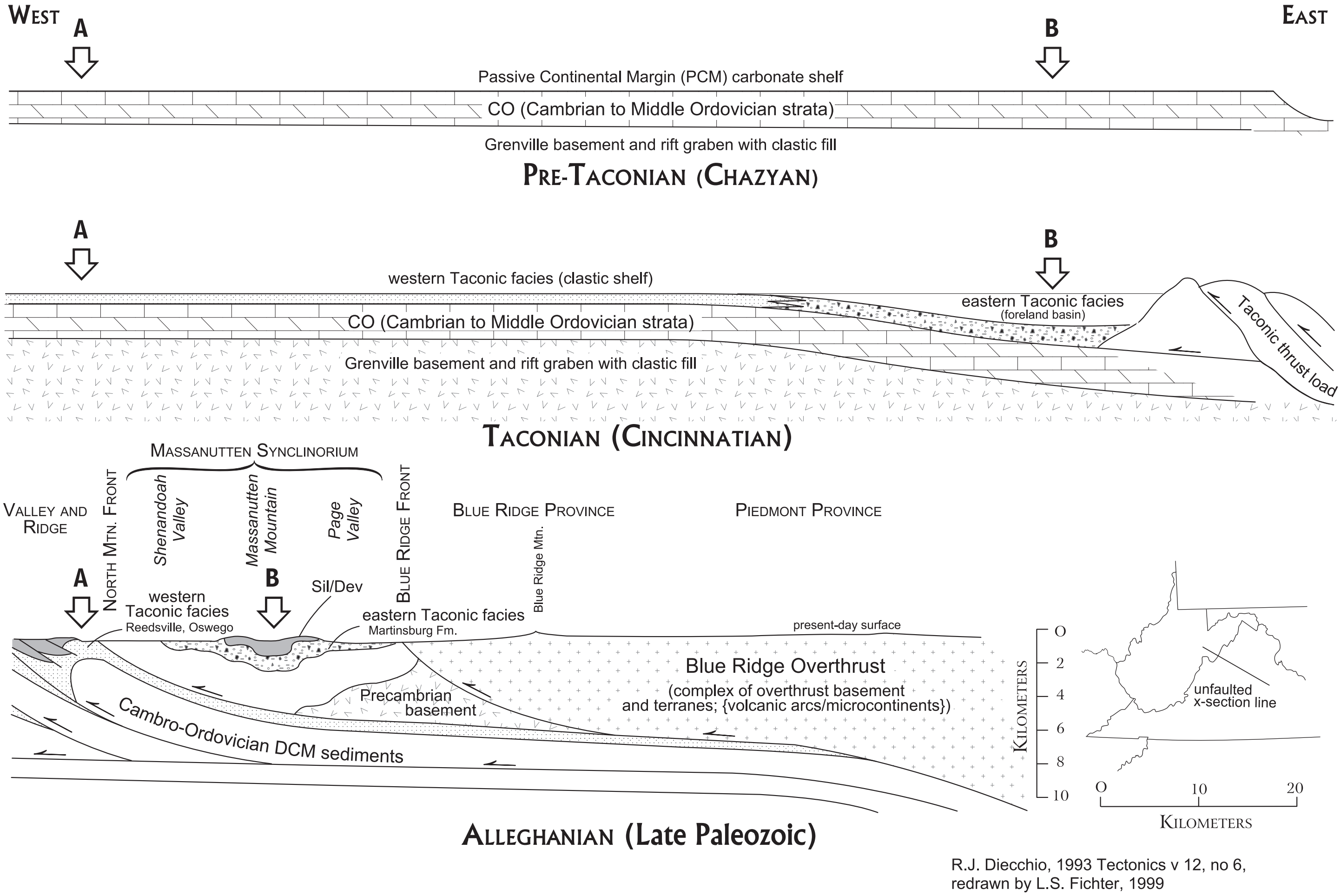


Figure I *- Interpretive cross sections across northern Virginia showing the progressive development of the Iapetan passive continental margin into the deep and shallow Taconic clastic basins (top two cross sections). Bottom cross section shows present-day geology after the Alleghanian orogeny foreshortened the orogenic belt. Rock units that are now geographically close were widely separated in the Ordovician (modified from Diecchio, 1993).*
Note: Outcrop observation tools for stratigraphic and sedimentological interpretations are included in Appendix B.

One complication to the sequence described above is that the Massanutten is interpreted as a braided river (Pratt, 1979), and these deposits lie directly on the "Cub sandstone" shelf deposits. The coastal facies (6) and meandering fluvial deposits (7) are not found. This is considered in more detail in the interpretation section of Stop 4b.

Structural Geology

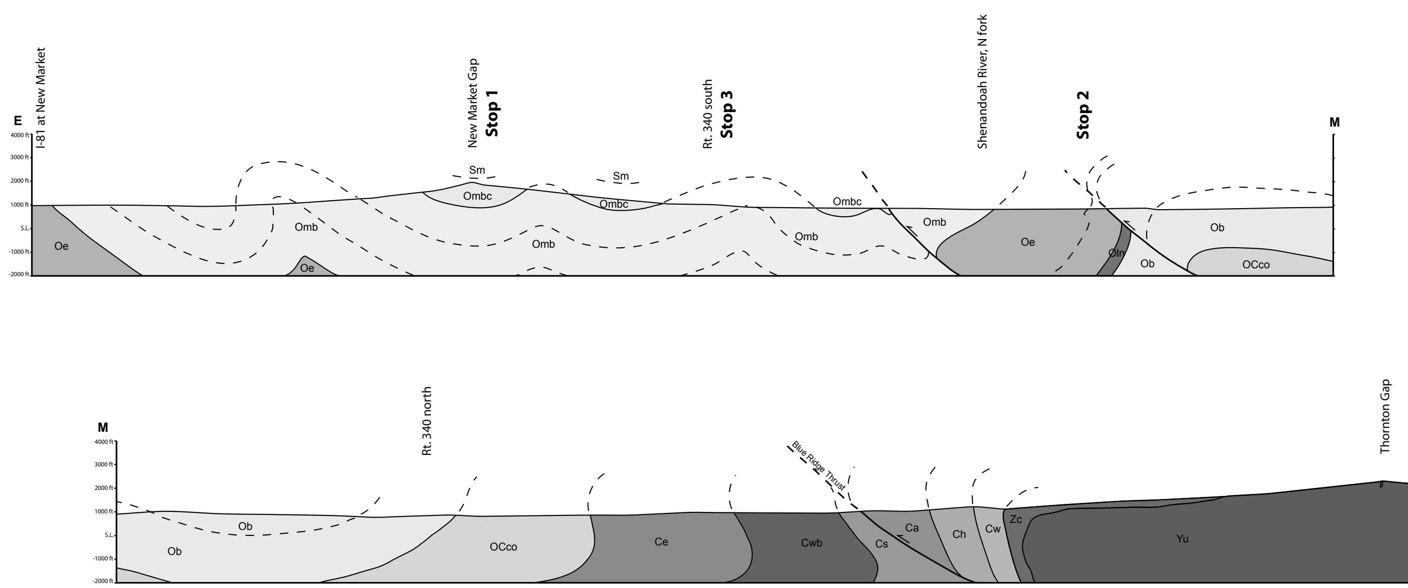
The Massanutten Mountain – Page Valley region of northwestern Virginia is a classic example of a foreland fold and thrust belt – the vanguard of brittle deformation that forms the leading edge of collisional orogenesis. Page Valley is especially interesting as it comprises the footwall to the Blue Ridge thrust system, a significant Alleghanian structure that transported basement gneisses and greenschist facies metamorphic cover sequences tens of kilometers to the west over supracrustal carbonates and clastic rocks (Evans, 1989; Faill, 1998; Southworth et al., 2009). Detailed examination of deformation features in Page Valley and the Massanutten Mountains provides important constraints on the kinematics and transport of the foreland to the Alleghanian collisional suture of Gondwana with eastern Laurentia – the culminating phase of the orogenic cycle that formed the Pangaean supercontinent.

Pre-Alleghanian Deformation

The Massanutten Mountain and Page Valley region has no documented evidence of deformation prior to Alleghanian orogenesis. Grenville ductile deformation can be seen in the basement gneisses of the Blue Ridge (e.g. at Mary's Rock near Thornton Gap; Bailey et al., 2006a; Southworth et al., 2009), and early Alleghanian (ca. 340-320 Ma) ductile deformation can be seen east of Shenandoah National Park in high strain zones of the Rockfish Valley system (Bailey et al., 2006a). However, none of these early fabrics are apparent west of the Blue Ridge province. Another tectonic puzzle is that, though we have abundant stratigraphic evidence of the Taconic and Acadian orogenies from thick sedimentary sequences derived from uplands created during these collisional events, we apparently have no preserved structural or deformational evidence from either the Taconic or Acadian orogenies.

Alleghanian Structures and Deformation

The late-Paleozoic Alleghanian Orogeny in the Mid-Atlantic region is dominated by westward-verging décollement tectonism. This was facilitated by a system of low-angle thrust splays and fold-and-thrust structures (Faill, 1998) that produced tens of kilometers of horizontal upper crustal shortening. In the Page Valley region, map-scale folds are generally northeast-trending and shallowly plunging, with an asymmetry that verges to the northwest (Fig. J). The most striking of these is the Massanutten Synclinorium, in evidence as a series of ridges supported by Massanutten quartz arenite (e.g. Stop 1), commonly in a syncline-anticline-syncline pattern of shallowly-plunging folds (Butts, 1940; Allen, 1967; among others; Figs. A, J). The broad, upright to slightly west-vergent folding throughout the region is likely attributed to large-scale Alleghanian compression, perhaps fairly early in the sequence of thin-skinned foreland deformation.



Sm	Massanutten Sandstone	Ce	Elbrook Formation
Ombc	"Cub Sandstone"	Cwb	Waynesboro Formation
Omb	Martinsburg Formation	Cs	Shady Formation
Oe	Edinburg Formation	Ca	Antietam Formation
Oln	Lincolnshire/New Market Limestones	Ch	Harpers Formation
Ob	Beekmantown Group	Cw	Weverton Formation
OCco	Conococheague Formation	Zc	Catoctin Formation (± Swift Run Formation)
		Yu	Mesoproterozoic basement complex

Figure J. *Simplified cross sections from west (W) to middle (M) and middle (M) to east (E) across the Massanutten Synclinorium and Page Valley, generally following US 211. Stops 1-3 are indicated on the upper (west) cross section. The region illustrated by the lower (east) cross section will not be visited on this field trip.*

Broad folds are frequently truncated by predominantly west-directed thrust faults, though east-directed back thrusts have been noted in the Massanutten Mountains and western Page Valley (Rader and Gathright, 2001; Heller et al., 2007). The Great Valley region is bounded by two significant west-directed thrust faults: the North Mountain Fault marks the western boundary of Shenandoah Valley and juxtaposes Ordovician carbonate rocks against Silurian-Devonian clastic rocks (Orndorff, 2012, and references therein), while the Blue Ridge thrust system marks the eastern boundary of Page Valley and juxtaposes Proterozoic basement and Chilhowee Group cover sequences against Cambrian clastic and carbonate rocks (Gathright, 1976; Southworth et al., 2009). Smaller-scale tight folding is likely related to localized faulting, either as hanging wall anticlines or footwall synclines (Heller et al., 2007; Kirby et al., 2008; Drummond et al., 2011). In places this has overturned bedding, occasionally producing isoclinal or recumbent folds (e.g. Stop 2; Patterson and Whitmeyer, 2012). However, in areas proximal to the Blue Ridge thrust system (Fig. J, lower/eastern cross section) pervasive development of foliation in Cambrian-Ordovician carbonate rocks may be related to a period of ductile deformation when these rocks were buried under several kilometers of overburden during uplift of Blue Ridge basement (Evans, 1989).

East-directed backthrusts and associated outcrop-scale folds have offset, and locally duplicated, the Massanutten Sandstone and upper Martinsburg Formation along the eastern limb of the Massanutten Synclinorium. East of this, the Martinsburg and Edinburg Formations are in fault contact along a west-directed thrust that extends through much of central Page Valley (Kirby et al., 2008; Heller, 2010; Drummond et al., 2011; Fig. A). West-directed thrusting has also locally juxtaposed Beekmantown dolomite and limestone against Edinburg limestone and calcareous shale (Patterson and Whitmeyer, 2012; Stop 2), and shortened the Conococheague-lower Beekmantown (Stonehenge) interval (Kirby et al., 2008). Often these localized thrusts are cryptic to poorly exposed, but can be located by tight, small-scale folds, or inferred by stratigraphic offset and/or duplication.

Post-Alleghanian Structures and Deformation

Structural features that likely post-date Alleghanian orogenesis include normal and transverse faults that clearly cross-cut Paleozoic folds and thrust faults. These structures typically strike northwest to north-northwest and dip steeply (Bailey et al., 2006b; 2012), similar to diabase dikes mapped throughout the region (e.g. Heller, 2010). Kinematics of the northwest-striking faults is often difficult to determine, but where apparent record a few meters to a few tens of meters of displacement. Our working hypothesis is that many of the northwest-striking normal and transverse faults formed contemporaneously with the intrusion of Mesozoic dikes and are likely related to extension associated with the opening of the Atlantic Ocean. Bear in mind, however, that none of these faults have good geochronologic constraints.

Geomorphology

(Author's note: Portions of this section are reproduced with permission from earlier work by Morgan et al., 2003; Eaton et al., in press; and Whittecar et al., in press)

Overview

The landscape of Page Valley is a mosaic of low, rolling hills underlain by residual and transported soils, river terraces and flood plains, and alluvial and debris fans; nearly all of which are underlain by Cambrian and Ordovician carbonate and siliciclastic rocks. The Massanutten Range topographically separates Page Valley from the larger Shenandoah Valley for approximately 80 km between the towns of Elkton and Front Royal with a drop in elevation of 150 meters along the valley floor. Local relief from ridge to valley floor can exceed 1000 meters in some locations. The northeasterly trend of the South Fork of the Shenandoah River roughly parallels the trends of the mountains. Where the main rivers and tributaries cross shale of the Martinsburg Formation, strong sets of northwest-southeast trending joints have encouraged the development of distinctive elongated patterns of meandering bedrock channels with amplitudes that are commonly two-to-four times the wavelength (Hack and Young, 1959; Whittecar et al., in press).

Large volumes of coarse siliciclastic sediment eroded from the Blue Ridge and the Massanutten Range lie draped over buried carbonate landscapes and line the margins of stream valleys (King, 1950; Hack, 1965). Some of these alluvial fans and terraces contain relatively old sediment (e.g., Whittecar and Duffy, 2000). These ancient deposits function as shallow aquifers in the karst system and contribute to the dissolution of the limestone while protecting the resulting insoluble residue from erosion. The resulting topography and surficial deposits include inset sequences of alluvial fans, flights of river terraces, and intervening hills of residual regolith and outcrops. Many of these landforms are punctuated by systems of sinkholes that frequently follow the linear trends of fractures and particularly soluble beds of various Cambrian-Ordovician carbonate formations (Whittecar *et al.*, in press).

Surficial Deposits and Landforms

The analogy of a conveyor belt transporting sediment and water best illustrates the geomorphic processes operating within the Page Valley landscape. Colluvium from the mountaintops is derived from the underlying bedrock whose rate of weathering and transport are largely a function of climate, geology, and time. This regolith is transported from the headwaters to the fans and floodplains through a multitude of geomorphic processes, including mass wasting, running water, and ice. The following text summarizes current models that hypothesize the connection between the observed landforms, and the processes responsible for their creation.

The summits of the Blue Ridge and the Massanutten of Page Valley have extensive areas of outcrop as well as mountain-top detritus and shallow colluvial deposits. The detritus is almost certainly a product of degradation of bedrock by action of ice wedging in the subsurface and other periglacial processes during colder climatic periods in the late Pleistocene. The detritus is most conspicuous in sparsely vegetated block fields and talus sheets underlain by orthoquartzites of the Antietam and Harpers Formations and the Massanutten Sandstone. One talus stream near Blackrock, located just southeast of Page Valley in the Shenandoah National Park, shows many characteristics of a rock glacier (Eaton et al., 2002). These quartzites produce extensive block fields that grade into slope and talus deposits, rock streams, and clusters or jumbles of balanced rocks, present as tors along ridge crests and summits. These features are also widespread in areas underlain by the Catoctin Formation and by granitic rock. A few of the block fields and talus sheets are as much as 500 m (1,640 ft) in longest dimension (Eaton et al., 2002), but most block fields and talus rarely exceed a few acres in area. Colluvial deposits of slope wash, both stratified and unsorted, occur throughout the area, and are usually several meters thick in outcrops along banks of streams. The slope wash is interpreted to be the result of solifluction of soils and weathered bedrock during periglacial conditions. Fragments of rock within the slope wash are within a clayey matrix and show a well-defined dip that parallels the surrounding slope. These deposits contain charcoal with 14C ages that range from 13,000 to greater than 50,000 ybp (Eaton and McGeehin, 1997). Outcrops of slope wash are difficult to find due to the combination of winter frost action and vegetation cover. Field work conducted in Shenandoah National Park noted that seeps or springs often indicate the presence of slope wash deposits; the high clay content in the matrix makes the slope wash relatively impermeable and favors formation of a perched water table.

The colluvium is eventually transported by gravity along slopes and into mountain tributaries that have the potential to be mobilized by fluvial or debris flow processes. With few exceptions, the eastern margins of Page Valley are bordered by extensive sand and gravel of fluvial origin that form a nearly continuous apron, or bajada, between the Blue Ridge and the low, hilly ground stretching to the Shenandoah River or its tributaries (Fig. K). Gravel deposits were described by King (1950) in the Elkton vicinity, and more broadly by Hack (1965). More detailed studies have been undertaken by Kochel and Johnson (1984), Kochel (1987, 1990, 1992), Duffy (1991), Kite (1992), Whittecar and Duffy (1992, 2000), Morgan et al. (2003), Wieczorek et al. (2006); and by thesis studies of Bell (1986), Wilson (1987), Simmons (1988) and Mason (1992). Together these studies have demonstrated that an extensive plexus of alluvial fan deposits extend, with gentle slopes of usually less than 6°, from the mountain front towards the Shenandoah River.

The sharp demarcation of bedrock resistance that exists between the siliciclastic-based mountains and the carbonate lowlands allows these fans to grow unrestricted, in the lateral sense, into the Shenandoah Valley. The sedimentology of these fans has a wide range of characteristics and is largely a function of the transport distance from the headwaters.

Most fans are dominated by quartz arenite gravels and sands, and become increasingly imbricated and well-sorted with distance downstream. They display a broad fan shape in plan view, and range in area from approximately 2 to 10 km2 (Simmons, 1988). The aerial extent of the fans is proportional to the drainage basin area, similar to the fans in the southwestern Unites States (Mills et al., 1987). Typically, fan thickness is greatest in the mid-fan region, but overall fan thickness varies depending upon vertical accommodation space from the dissolution of underlying carbonates, which is strongly influenced by the dip of the carbonate bedrock underlying the fans (Simmons, 1988). The older fans have collapsed into the karst so that accumulations of alluvial deposits commonly reach 30 m (100 ft) (King, 1950); and drill records reveal that they can be as much as 180 m (600 ft) thick in places (Simmons, 1988). Some debris-flow sediments are common in the proximal areas of these fans, but most of the fans are formed by streamflows and hyper-concentrated flows. Watersheds feeding these fans are typically larger than those directly producing debris flows (e.g., basins draining the eastern flank of the central Blue Ridge (Kochel, 1990), and thereby able to dilute sediment yields with enough water volume to retard debris flow transport. Flash floods of significant magnitude are historically common on these fans, as exemplified in the floods produced by the remnants of Hurricanes Juan (1985), Fran (1996), and, most recently, Isabel (2003).

In contrast, the western margins of Page Valley are largely dominated by debris flow processes and landforms that originate from the Massanutten Range (Fig. K). Debris fans have drainage basins that are usually smaller and steeper than fans formed by streamflow. This feature is readily apparent when the two flanking mountain ranges are compared, where in some instances the streams of Massanutten have average slopes that are two orders of magnitude greater than those of the Blue Ridge where the South Fork of the Shenandoah is used for the local base level. Fan shapes are often irregular (Kochel 1987, 1990) because of their restricted lateral accommodation space, having formed within rocks of low solubility in clastics of the Massanutten Range. In the Massanutten range, debris fan slopes average 5 – 17°, and are composed of poorly-sorted sediments that range in size from boulders of several meters in diameter to clay (Eaton et al., 2003; Cheung et al., in press). These deposits are relatively thin (several meters thick), and possess both matrix-supported and clast-supported units. Stratification of these units is usually lacking, but the boundary between individual deposits is typically sharp. Paleosols are partially preserved at some contacts between these units, indicating a period of quiescence of debris flow activity sufficiently long enough to create soil profiles. Lower magnitude floods are usually incapable of remobilizing the largest of the material, leaving it to weather in situ or to be remobilized by the next event of similar or greater magnitude.

The alluvial deposits and landforms, which include river terraces and flood plains, extend beyond the terminus of the debris and alluvial fans of the mountain ranges, as well as parallel the South Fork of the Shenandoah. Commonly these deposits consist of cobbles and pebbles that are clast-supported and imbricated, and overlain by slack-water deposits of fine gravel, sand, and silt. Rather than a simple time-stratigraphic sequence, this pair of strata is produced by the meandering of the stream scrolling across the flood plain, scouring previous alluvial deposits and leaving a track of channel material that is overlain by later overbank deposits during periods of flooding.

Bell (1986) recognized at least five levels of terraces along the south fork of the Shenandoah River between Grottoes and Elkton. In southern Page Valley, three subdivisions of terraces are commonly mappable at the 7.5-minute quadrangle scale: younger terraces 3 to 20 meters above river level that are intact, relatively undissected, and have relatively flat upper surfaces; older terraces 20 to 50 meters above river level that are intact or remnant, somewhat incised, and have uneven upper surfaces, especially when underlain by carbonate bedrock; and oldest terraces 50 to 75 meters above river level that are intact or remnant, highly dissected, and have uneven upper surfaces. The average degree of weathering of clasts, redness of soil, and clay content of matrix all increase with elevation.

In Page Valley, streams such as Hawksbill Creek, Pass Run, and Jeremy Run initially emerge from the fans and are able to rework these deposits from bankfull or greater flows, and create flights of fluvial terraces and floodplains in the central part of the valley. Within less than two kilometers of merging with the South Fork of the Shenandoah, nearly all of these Blue Ridge-originating streams show signs of incision through rapids and waterfalls, thereby decoupling the stream from the floodplain, and bypassing sediment and water directly into the mainstem stream. This interesting phenomenon of tributary stream incision is even more pronounced in the tributaries that enter the South Fork,

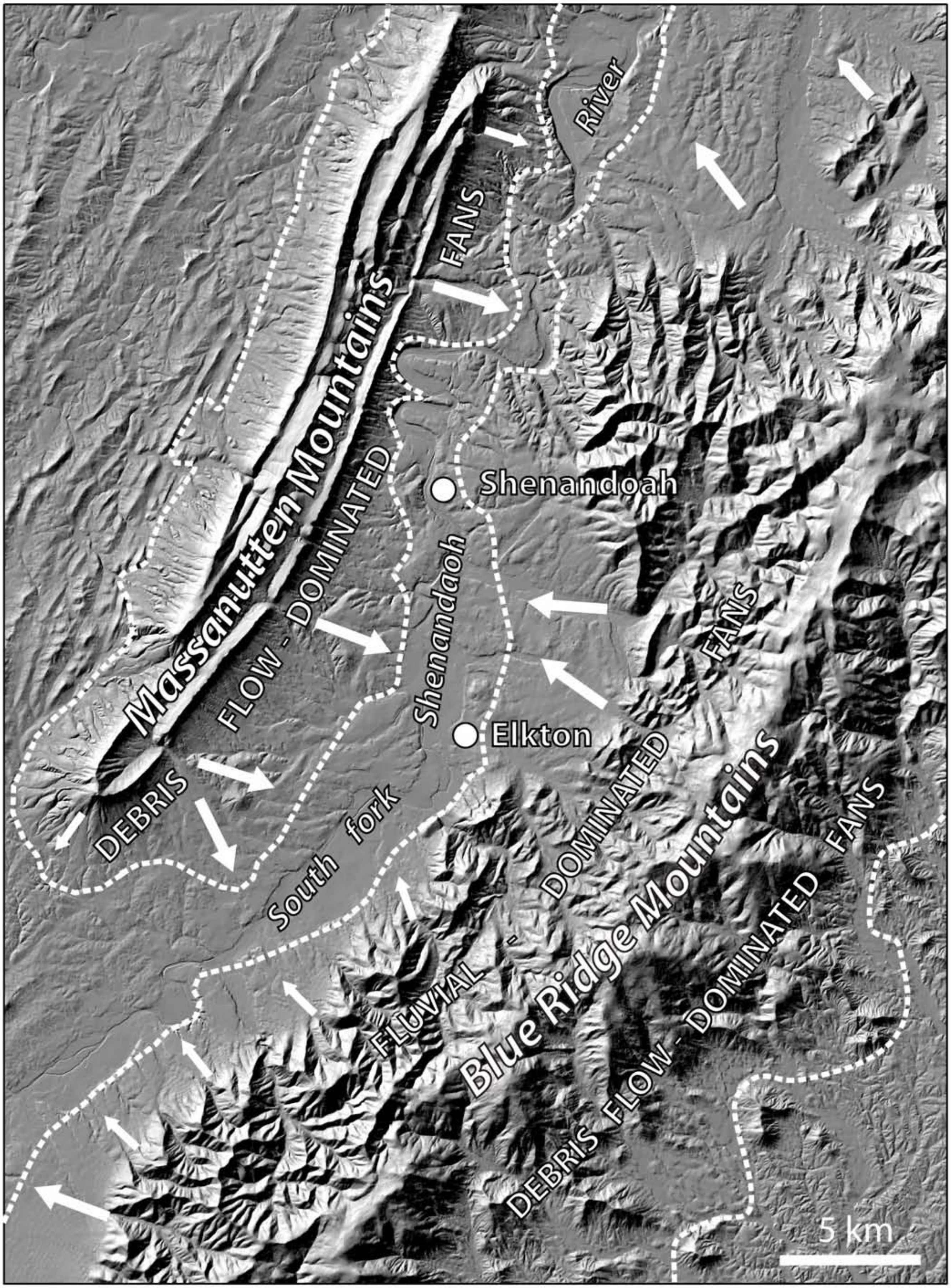


Figure K. *Shaded relief map of southern Page Valley depicting dominant debris flow and alluvial fan types. Source areas and areas of fan development are outlined. Arrows show down slope flow directions within Page Valley.*

but is nearly absent in the headwaters of this basin beginning around the Grottoes region near Elkton. One possible hypothesis is that a wave of stream incision is actively migrating upstream on the Shenandoah, and its tributaries are not in equilibrium with what is occurring on the mainstem river. The fact that river terraces and related alluvial deposits are best developed and preserved upstream of Page Valley to the south, and progressively become more and more negligible to the north and are nearly absent (presumably by stream incision) at the latitude of Front Royal indicates a landscape that is not in equilibrium.

Fan Evolution

Examination of the Massanutten Range of western Page Valley reveals numerous first and second order mountain streams that terminate into the South Fork of the Shenandoah. In areas where the streams are able to breach the easternmost ridge and further extend their drainage area into the core of the range, large debris fans dominate the landscape (Fig. L). The apex of each fan resides at or near major water gaps, and each landform extends downslope for 4 to 6 kilometers to the South Fork of the Shenandoah. In some instances, the toe of a fan is truncated by the South Fork; in other cases such as the Catherine Furnace area along Cub Run, the volume of sediment within the fan may have forced the modern position of the South Fork of the Shenandoah River further east. Recent field work along the western margin of Page Valley revealed three large (over 3 km in longitudinal profile) debris fans; specifically, the Harshberger Gap Fan, the Runkles Gap Fan, and the Cub Run Fan (Heller and Eaton, 2010). These fans show multiple surfaces as well as a range of soil development, presumably due to differing ages of deposition of older debris flow deposits (Fig. M).

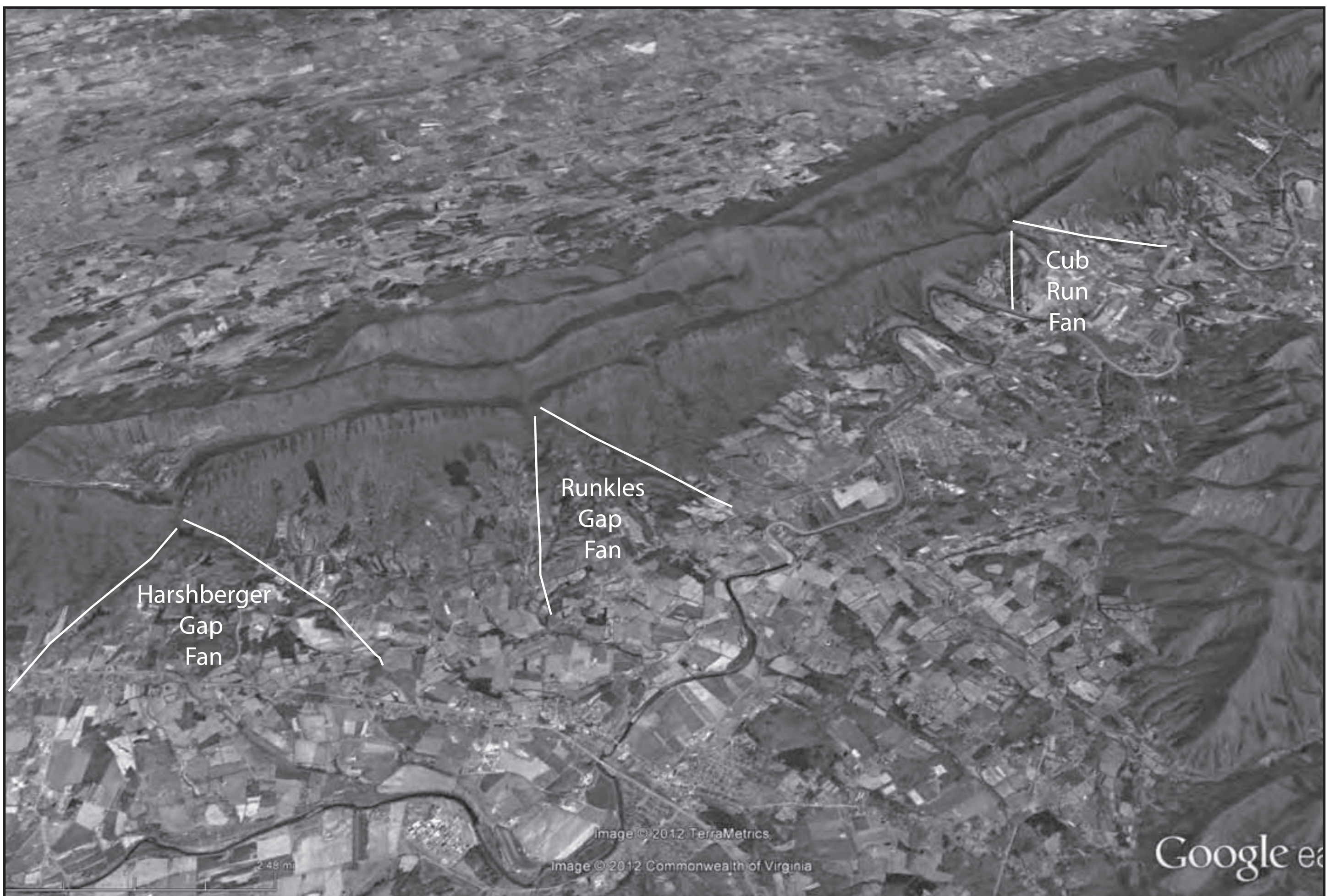


Figure L. *Major debris fans of the eastern margins of the Massanutten Range, Page Valley.*

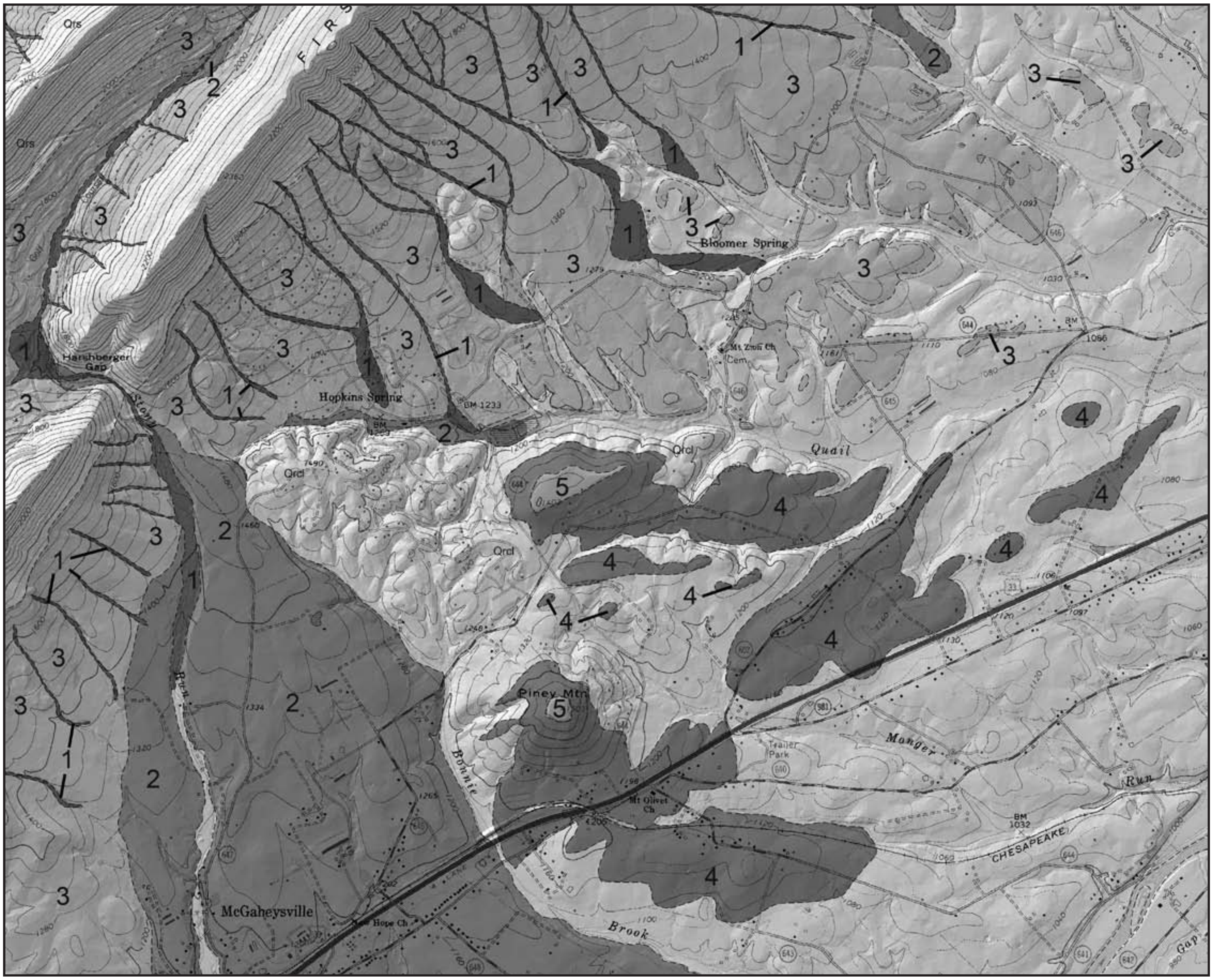


Figure M. *Debris flow fans and associated deposits in the vicinity of Harshberger Gap (Heller and Eaton, 2010). Deposits are numbered via increasing degree of weathering and age, where "5" is the oldest.*

Additionally, the surfaces of these fans are dissected by a plexus of stream channels that served as avenues to transport debris flow deposits; and in some cases represent discrete stream piracy events. In most cases, the modern stream channel resides along the margin of each fan complex. For example, Stony Creek currently tracks along the western margin of the Harshberger Gap fan. Interestingly, the topography of the fan shows the drainage basin of Quail Run terminating at the apex of the fan (located at Harshberger Gap); and, if extended, would intersect the current stream channel of Stony Creek (Fig. N). A similar trend is also noted for Bonnie Brook, which also terminates at the fan apex. Each of these streams is flanked by debris flow deposits that are pedogenically older than the modern Stony Run debris flow deposits and presumably represent prehistoric positions of the fan drainage. Similar trends were noted for both the Runkles Gap fan, and the Cub Run fan. The field evidence from these sites and other studies in the Blue Ridge (i.e., Eaton et al., 2003) suggests that the positions of the streams are temporary, their movements are likely episodic during catastrophic flooding, and that repeated stream piracy likely created by the redirection of flows from debris flow blockage of active channels, or from headward erosion has redirected the trajectory of debris flow deposits throughout the Pleistocene. The analogy of 'a fire hose out of control' is a good visual of how the stream episodically migrates across the fan surfaces.

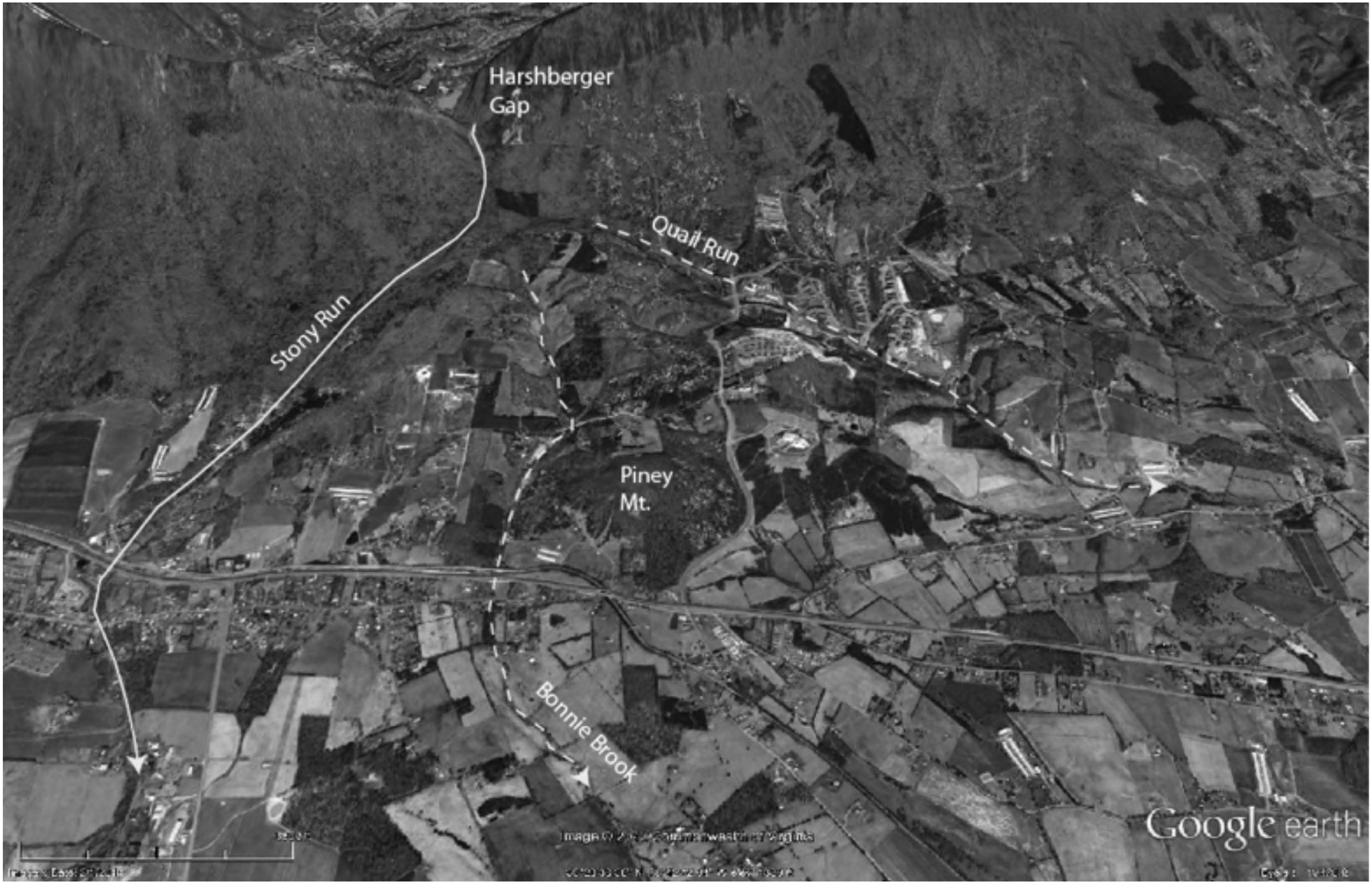


Figure N. *Streams in the vicinity of Harshberger Gap. Quail Run and Bonnie Brook may have flowed through Harshberger Gap in the past.*

Acknowledgements

Thanks to Charles and Betty Dixon for graciously allowing access to their property, and to Tom Brazell and Billy Sanders with Vulcan Materials Company for allowing us to visit the Elkton Quarry. Thanks to Molly Cox for typesetting and Anne Witt for cartographic assistance. This field guide was substantially improved by reviews from John Haynes, and Steve Leslie.

ROAD LOG and Stop Descriptions

The field trip road log begins in Harrisonburg, Virginia, in the parking lot of James Madison University's Memorial Hall (the old Harrisonburg High School). Field trip stops will be on national forest land (stops 1 and 4), private land (stops 2 and 6), exposed roadcuts (stop 3), and a working quarry (stop 5). Two optional stops (OS1, OS2) are included for future investigations but will not be visited on this trip. Participants should be mindful of field conditions and traffic and exercise prudence. Stay off the active roadway / median, and always watch for traffic. Hardhats, safety glasses, and steel toe boots MUST be worn at all times in the quarry.

Cumulative Trip Mileage	Point to Point Mileage	Directions and Comments
0.0	0.0	Load buses at Memorial Hall parking lot, JMU. Exit parking lot and drive east on Cantrell Ave
1.5	1.5	Turn right (southeast) onto US 22 (East Market Street
1.9	0.4	Bear right onto entrance ramp for I-81 north. Drive north on I-81
19.4	17.5	Take exit 264 and turn east onto US 211
23.5	4.1	Just west of apex of New Market Gap, turn left onto Chrisman Hollow Road.
25.0	1.5	Park at Storybook Trail parking lot. Unload buses. Hike 0.3 miles to overlook

STOP 1

Storybook Trail overlook above New Market Gap

Location: 38.648898 N, 78.603868 W

Unit: Massanutten Sandstone

A short walk (approximately 550 m) along the paved (wheelchair accessible) Storybook Trail brings you to a spectacular overlook atop one of the Massanutten ridges. The view is to the east, overlooking Page Valley below, with the Blue Ridge Mountains of Shenandoah National Park on the eastern horizon. Differential erosion, largely based on rock type, is dramatically displayed here: the quartz sandstone of the Massanutten ridges and granitic rocks of the Blue Ridge Mountains strikingly contrast with the carbonate and fine-grained clastic rocks of the valley below.

The rocks underfoot are relatively clean quartz arenite of the Silurian Massanutten Sandstone. Trough and planar cross beds are apparent on Massanutten Sandstone boulders located next to the paved trail to the overlook. Sandstone ledges in the vicinity of the overlook display abundant trace fossils on the bedding planes. The Massanutten Sandstone quartz arenites are interpreted to have been deposited in a braided stream environment (Pratt, 1979) during the tectonically quiet period between the Taconic (Ordovician) and Acadian (Devonian) orogenies. The Massanutten Sandstone is discussed in more detail in the Stop 4 text.

The overlook is located on the eastern limb of the westernmost Massanutten syncline (Fig. J). Broad folding of the Massanutten Synclinorium occurred during the late Paleozoic Alleghanian orogeny – the culminating tectonic event in the formation of the Pangaea supercontinent. New Market Gap is located just south of this location (Fig. 1.1), and represents a saddle in the sub-horizontal synclinorium (Spencer, 1896), such that on the south side of New Market Gap folds plunge shallowly to the southwest, whereas here on the north side of New Market Gap folds plunge shallowly to the northeast.

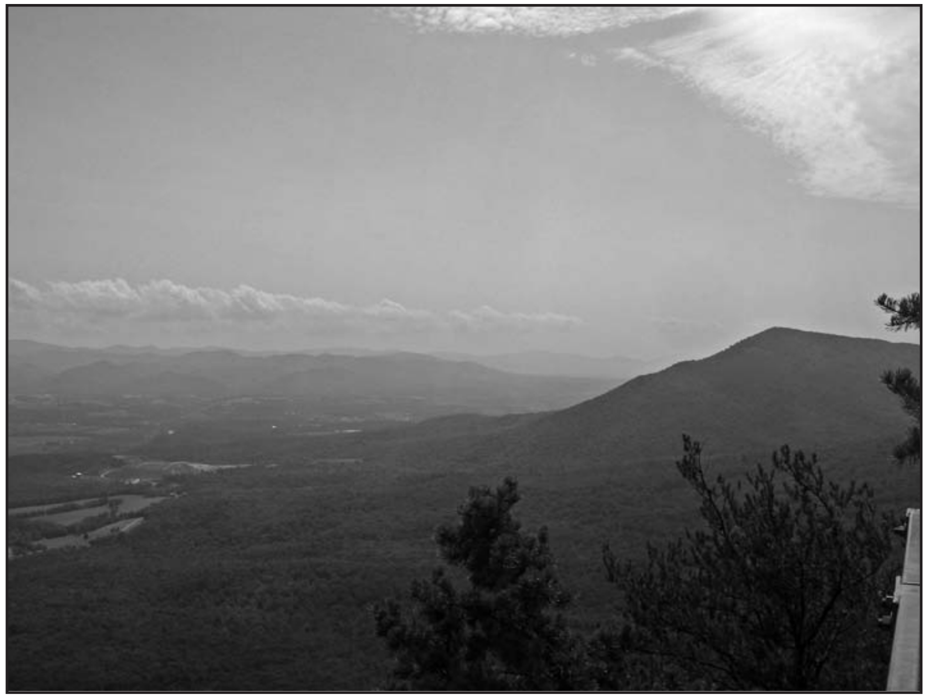


Figure 1.1. *View to the south of Page Valley from the Storybook Trail overlook. The eastern ridge of the Massanutten Synclinorium, south of New Market Gap, is visible at the right.*

Cumulative Trip Mileage	Point to Point Mileage	Directions and Comments
25.0	0.0	Load buses. Drive back down Chrisman Hollow Rd. (south)
26.5	1.5	Turn left (east) onto US 211
29.4	2.9	*Drive past junction with US 340 (stop 3)*
32.2	2.8	Continue on US 211 east. Cross Shenandoah River, South Fork. *Note old river terraces on south side of highway.*
32.3	0.1	Turn right (south) on Ganders Dr. *Note White House Farm on north side of highway.*
32.6	0.3	Park at old quarry on east side of road.

Stop 2

Quarry on the east bank of the Shenandoah River, South Fork; Hamburg
Location: 38.643176 N, 78.530324 W
Unit: Edinburg Formation

Figure 2.1. *Photo from 30 years ago looking northeast into Edinburg Formation quarry with recumbent fold. Note: no trees!*

This quarry on the eastern bank of the South Fork of the Shenandoah River and exposures along the road display limestone beds of the Edinburg Formation, which are recumbently folded in the northeastern quarry wall (Fig. 2.1). The Edinburg Formation is the uppermost Ordovician carbonate, deposited at the time of the arrival of the Taconic arc system offshore of the eastern margin of Laurentia (ancestral North America). It consists of black (weathering gray), amalgamated micrite, sometimes interbedded with thin black shale. It is interpreted to have been deposited in a deep-water anoxic environment by mass transport processes (turbidity or debris flows) from the west during maximum subsidence of the Taconic foreland basin. Folding and development of horizontal axial-planar cleavage (Fig. 2.2) likely occurred during one or more shortening episodes during the Alleghanian orogeny.

Figure 2.2. *Photo of northeastern quarry wall showing folded beds with horizontal axial-planar cleavage.*

Features

Stratigraphic and sedimentary features are best observed not in the quarry but along the road just south of the quarry. Here the beds are sub-horizontal and overturned with minor folding and faulting. Beds are generally a few cm thick, but some reach a thickness of half a meter or more.

Structural features at a variety of scales are apparent on the quarry walls. These include large-scale recumbent folds; note that the left and right quarry walls are dipping opposite directions. The southeastern quarry wall contains the large-scale fold hinge.

Sedimentary features that might be apparent
1. Scours on the bottom of the micrite beds, or evidence of load structures
2. Graded bedding, or Bouma sequences
3. Soft sediment deformation
4. Coarsening/thickening or fining/thinning upward sequences

Structural features

1. Horizontal cleavage on the back (northeast) wall
2. Large S fold at the left side of the northeast wall
3. Down-dip slickenlines on bedding surfaces
4. Bent/warped cleavage in finer-grained beds (e.g. Fig. 2.3)

Points of Discussion

1. What is the evidence for water depth during Edinburg deposition?
2. Is the model for upright folding followed by subsequent fault-induced rotation of the folds to horizontal the most reasonable interpretation? What are other possible tectonic interpretations for how the current fold geometry was produced?

Interpretations

It is not obvious from this stop alone that the Edinburg was deposited by mass flows down a slope into a deep-water anoxic basin. In other locations there are good examples of scours, slump, and soft sediment deformation features (e.g. Lowry and Cooper, 1970; Pritchard, 1980; Read, 1980) that suggest down-slope mass movement. Contextual evidence for this interpretation is found at the Tumbling Run section discussed earlier in the subsidence/accommodation model.

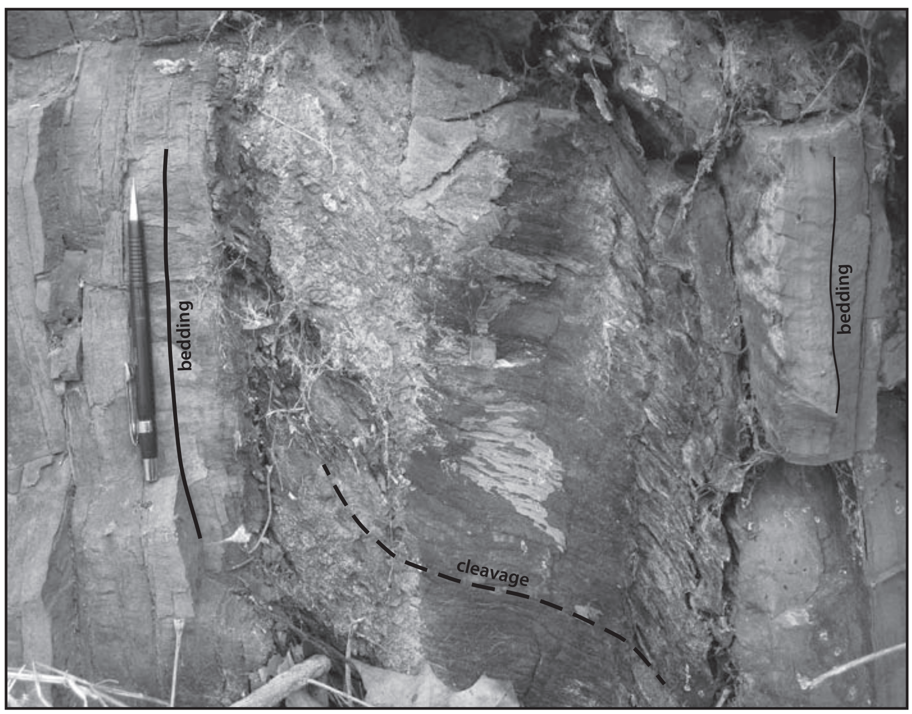


Figure 2.3. *Detail photo of bedding and cleavage in the hinge region of the recumbent fold. Note that the cleavage is warped into an S pattern, reflecting dextral flexural slip along the bedding planes.*

Folding in the quarry occurred during the Alleghanian Orogeny, potentially in two episodes. Most folds that we have observed in Page Valley are upright with sub-vertical axial planes. In contrast, the large-scale folds in this quarry have sub-horizontal axial planes (Fig. 2.2). This fold pattern has been traced to the northeast in fields of the White House Farm on the north side of US 211 (Patterson and Whitmeyer, 2012). Detailed mapping in this area suggests that the Lincolnshire and New Market Limestones are absent. The narrow regions between Edinburg and Beekmantown outcrops (e.g. directly east of the quarry) are grassy with several low, water-filled depressions. We suggest that this zone of no outcrop represents the surface expression of a cryptic west-directed thrust fault that locally has juxtaposed Beekmantown dolostones and limestones against Edinburg limestones (Fig. 2.4), thereby facilitating the removal of the Lincolnshire and New Market Limestones at the surface through subsequent weathering and denudation. The fault does not extend far to the south, as Edmundson (1945) and Cooper and Cooper (1946) document both New Market (Mosheim) and Lincolnshire (Lenoir) Limestones near Leaksville, less than a mile south of the quarry. In our interpretation, the folds in the quarry initially formed as upright, open folds similar to geometries seen elsewhere in Page Valley. The cryptic, west-directed thrust occurred later in the Alleghanian orogenic cycle and tightened and rotated the pre-existing footwall folds to horizontal.

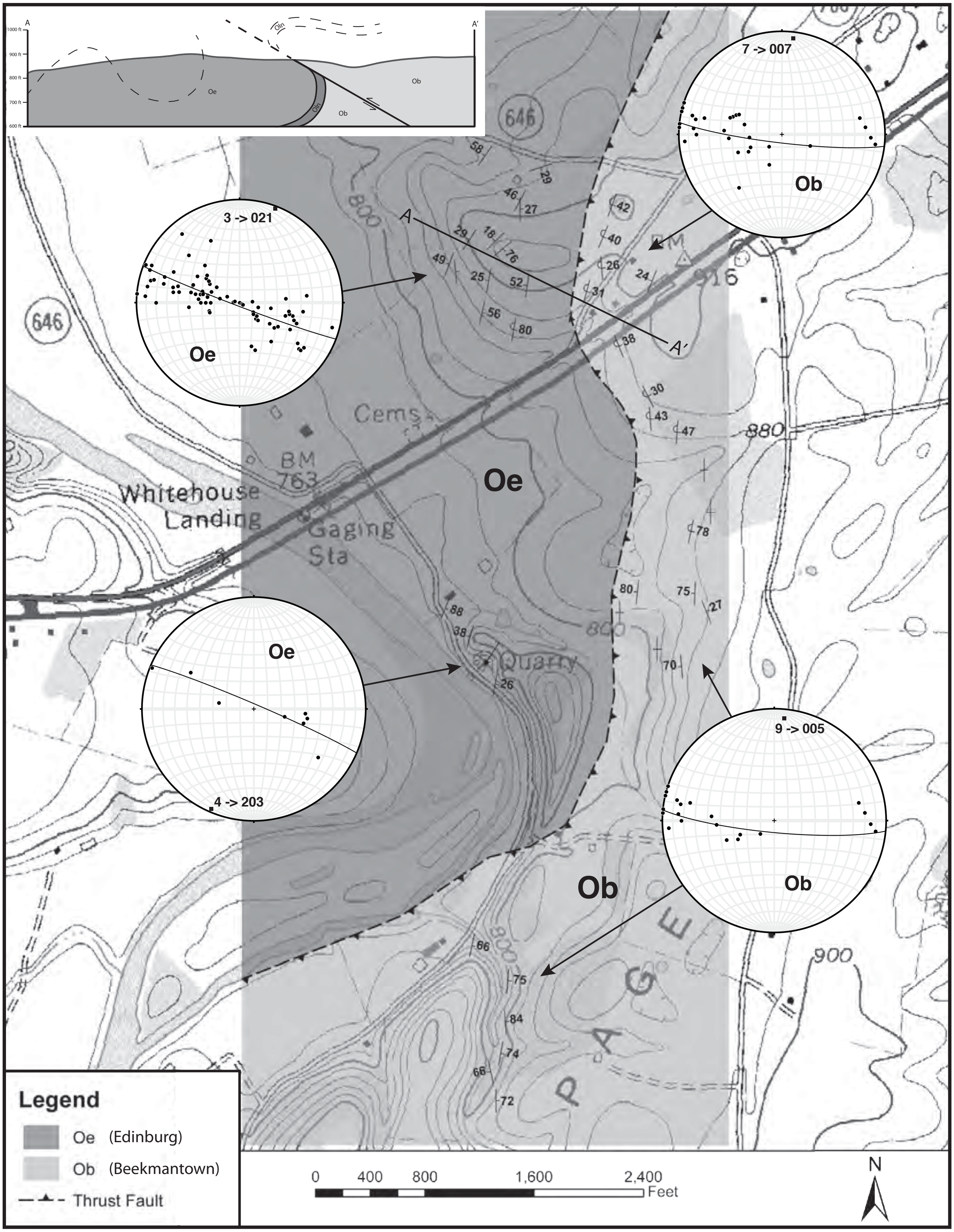


Figure 2.4. *Detailed geologic map of the White House Farm and quarry region showing an interpreted west-directed thrust fault that juxtaposes the Beekmantown Group (Ob) against the Edinburg Formation (Oe), thereby cutting out the Lincolnshire and New Market Limestones (Oln). Cross-section interpretation through the White House Farm is shown in the upper left inset. Stereonets indicate that the axial trends of folds in the Beekmantown Group (007 & 005) are demonstrably different from the axial trends of folds in the Edinburg Formation (021 & 203 – which is equivalent to 023, given the very shallow plunge). Map modified from Patterson and Whitmeyer, 2012.*

Cumulative Trip Mileage	Point to Point Mileage	Directions and Comments
32.6	0.0	Load buses. Drive back north up Ganders Dr. to intersection with US 211.

We will take a diversion here and travel east on Rt. 211 for about 2.5 miles to the West Luray Shopping Center for a quick pit stop. This is not reflected in the mileage log

32.9	0.3	Turn left (west) onto US 211.
35.8	2.9	Park along north side of US 211, across from junction with US 340 S. Roadcut is just east of junction

Stop 3

Roadcut on US 211 across from intersection with US 340 South; Hamburg

Location: 38.633905 N, 78.578302 W

Unit: Lower Martinsburg Formation

An extensive, but weathered, roadcut on the north side of US 211 exhibits Bouma sequences with well developed T_A (graded beds), T_B (high velocity laminations), capped by T_{DE} (laminated silts/shales) deposited by turbidity currents during filling of the Taconic foreland basin. Beds dip steeply to the west with sub-vertical cleavage well-developed in the shales.

Sedimentary features

1. Bouma sequences and variations: the ideal Bouma sequence (T_{ABCDE}) is shown in Figure 3.1, but is rarely found in outcrop. Instead variations such as T_{AE}, T_{ABDE}, T_{BCDE}, T_{CDE}, etc. are common, each found in different portions of a submarine fan.

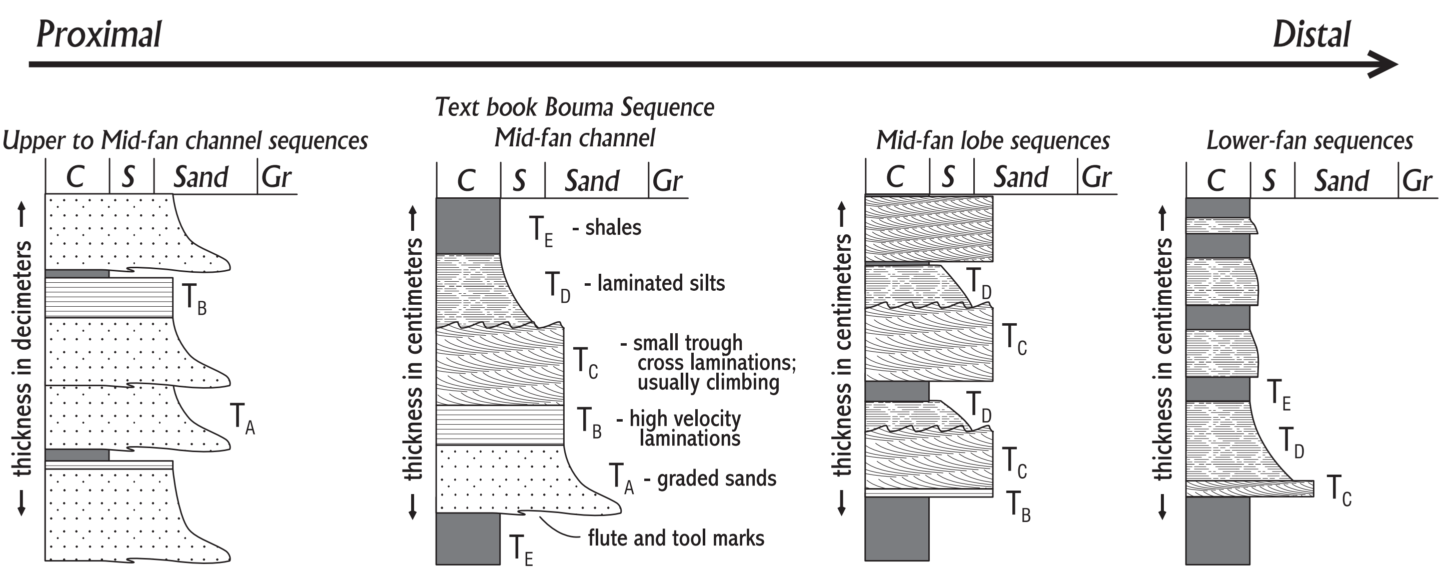


***Figure 3.1**. Bouma sequence variations typical of different parts of a submarine fan. The ideal sequence (second from left) is rarely found in outcrop, but is most typical of mid-fan channels. More proximally thick, amalgamated T_A and T_{AB} sequences dominate. More distally T_A and T_B units drop out and T_C units increase in importance. Distal sequences contain rare, thin T_C units, but mostly T_{DE} units.*

2. Note that the sandstone-shale couplets (Bouma sequences) maintain thickness for long distances; this is typical of turbidite deposits (and not of hummocky sequences).
3. Parasequences: look for thicker sand beds at the bottom of a parasequence that thin and fine upward to shale-rich, thin sandstones at top. The shale-rich zone should abruptly shift into thick sands of the next parasequence. These are used to map 5th, 4th, and 3rd order sea level signatures.
4. The composition of the sandstones at the base of each Bouma sequence. Highly lithic sandstone with lesser feldspar (feldspathic litharenites) indicate a tectonically active (volcanic arc) sourceland (Fig. 3.2).

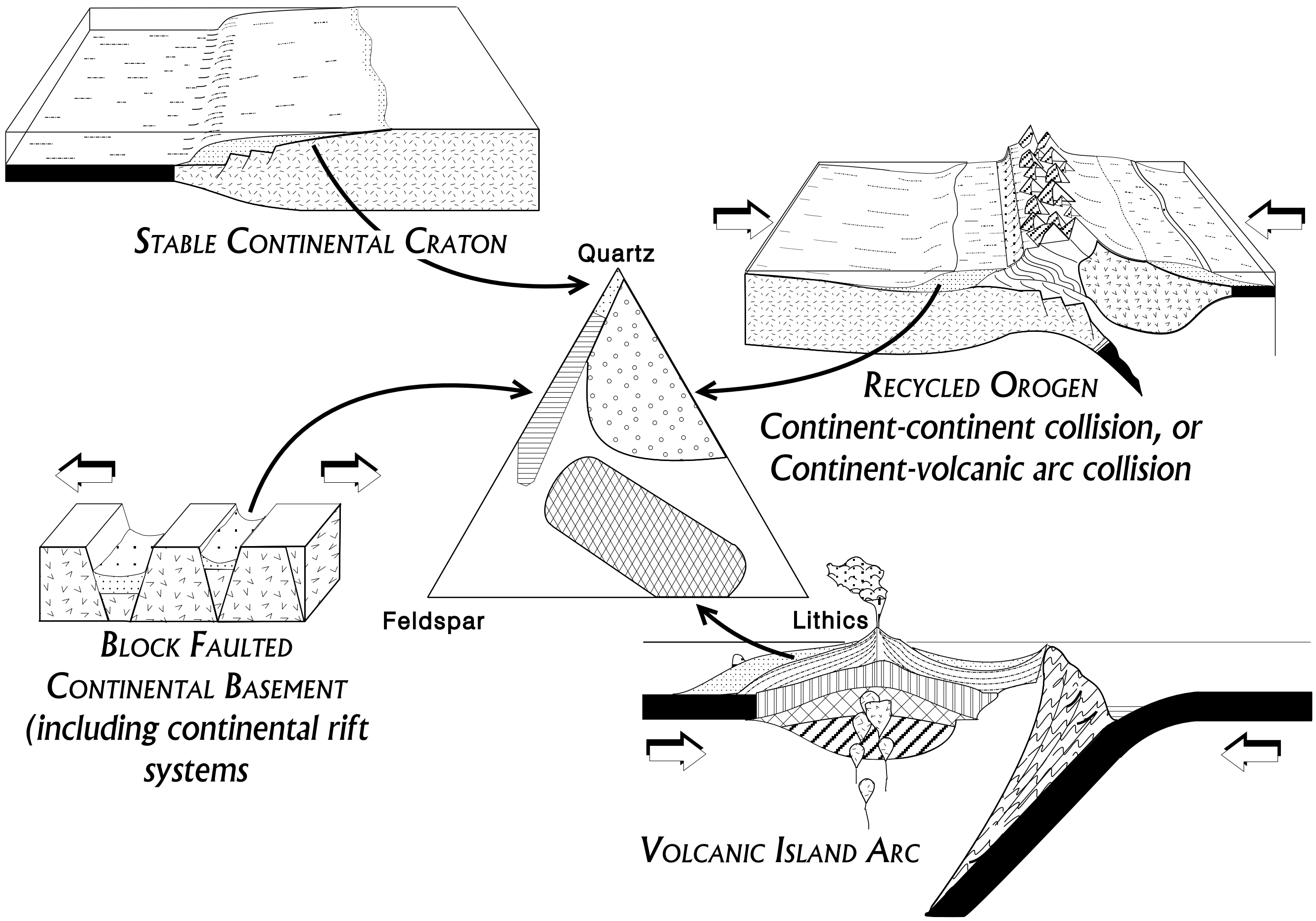


Figure 3.2. *QFL-Tectonic diagram showing the compositions of sandstones derived from various tectonic terranes.*

Structural features

1. Good examples of bedding/cleavage relationships are abundant and particularly well exposed at the eastern end of the outcrop (watch out for poison ivy).
2. Compare the orientation of cleavage here with Stop 2.

Interpretations

This outcrop is typical of the middle portion of the Martinsburg Formation, with well-developed Bouma sequences. The Martinsburg was responsible for filling a significant proportion of the accommodation space created by tectonic subsidence and sediment loading. The Martinsburg basin was likely narrow and elongate (trapped between the volcanic arc to the east and the Little North Mountain arch to the west). In this case these turbidites may have been flowing long distances along the basin floor, parallel to the trend of the present-day fold system (McBride, 1962).
Steeply west-dipping beds show well-developed sub-vertical cleavage in the finer-grained beds (Fig. 3.3), indicating that these beds are upright; syncline to the west, anticline (200 m) to the east. The vertical cleavage demonstrated here is axial planar to upright folds that are prevalent in the Page Valley region.

Figure 3.3. *Coarser-grained layers highlight bedding that dips steeply to the west. Finer-grained layers exhibit sub-vertical cleavage.*

Cumulative Trip Mileage	Point to Point Mileage	Directions and Comments
35.8	0.0	Load buses. Turn left (south) onto US 340
39.5	3.7	*Entrance to parking area on east side of US 340, with access point to Shenandoah River, South Fork. Impressive cliffs of Beekmantown and Lincolnshire carbonates can be seen along riverbank to the north*
39.8	0.3	Turn right (southwest) onto Newport Rd. *We will be driving across the Cub Run fan surface, look for boulders of Massanutten Sandstone and other evidence for transported deposits*
42.1	2.3	Turn right (west) onto Cub Run Rd. Enter National Forest
42.5	0.4	Park in parking lot in front of old iron furnace

Stop 4

Catherine Furnace and Cub Run Road; north of Shenandoah
Location: 38.557595 N, 78.635510 W
Units: Martinsburg Formation, Massanutten Sandstone, etc.

This stop incorporates four distinct locations/areas of investigation, each of which is covered in turn below: a. an extensive (120 meters thick), weathered roadcut of sub-vertical shale and sandstone beds that comprise the middle to upper ("Cub sandstone") sections of the Martinsburg Formation, b. sub-vertical, indurated medium- to coarse-grained quartz arenites of the Massanutten Sandstone, with planar and trough cross bedding, c. Catherine Furnace, and d. clastic and minor carbonate rocks that contain an ironstone bed similar to the source material for Catherine Furnace. We will start at the base of the section (east end of Cub Run Road near the intersection with Newport Road) and walk up-section (west down the gravel road) toward Catherine Furnace.

Stop 4a – middle to upper Martinsburg Formation ("Cub sandstone")

Location: 38.558428 N, 78.630205 W

The east end of Cub Run Road features an extensive roadcut of sub-vertical, extensively weathered shale and sandstone, approximately 120 meters thick, containing 8 to 12 meter-thick parasequences with hummocky stratification, indicating a storm shelf environment. Over the full extent of the outcrop, the parasequences generally coarsen and thicken upward (Fig. 4.1), indicating a shallowing trend.

Note on Martinsburg Formation stratigraphic divisions

The Martinsburg Formation is traditionally, but informally, subdivided into lower, middle, and upper sections. The outcrop near Catherine Furnace starts in the middle Martinsburg, and continues through the upper Martinsburg and into the Massanutten Sandstone. The middle Martinsburg, which is delineated by relatively equivalent proportions of sandstone and shale, is present in the lower 46.5 meters of the measured section (Fig. 4.1). The middle Martinsburg is overlain by 70 meters of section dominated by sandstone, which represents the upper Martinsburg ("Cub sandstone"). The Cub is overlain disconformably by the conglomeratic quartz arenite of the Massanutten Sandstone.

It is important to note that this part of the middle Martinsburg, unlike the Bouma sequences we saw at Stop 3 which are lower in section, is a hummocky shelf sequence. Due to the lack of continuous section, the transition from the lower Bouma units to the hummocky stratification in the middle part of the Martinsburg has not been observed. In our discussion of this stop, we treat the middle and upper Martinsburg as one continuous unit with similar depositional processes – storm dominated shelf conditions.

Features

1. Parasequences and parasequence boundaries: Parasequences represent invervals of progradation punctuated by abrupt sea level rises. In the lower portion of the outcrop (middle Martinsburg) look for 8 to 12 meter-thick coarsening- and thickening-upward progradational packages beginning with several meters of shale with thin sand beds and ending with several decimeters-thick sand beds, sometimes amalgamated. Parasequence boundaries mark an abrupt change from coarse sediment (sandstone) at the top of a parasequence to fine sediment (shale) at the base of the overlying parasequence. The strip log (Fig. 4.1) indicates six parasequence boundaries (flooding surfaces) that we delineated in the lower part of the section. Toward the top of the section parasequence boundaries are not as obvious.
2. Hummocky sequence variations within parasequences: Hummocky "cross bedding" is highly variable. An ideal hummocky sequence is shown in Figures 4.2 and 4.3, but one rarely sees the entire sequence. The ideal model is useful for predicting what might be expected in a stratigraphic column, but natural variations occur both horizontally across a shallow shelf and vertically within a parasequence. The two models described below

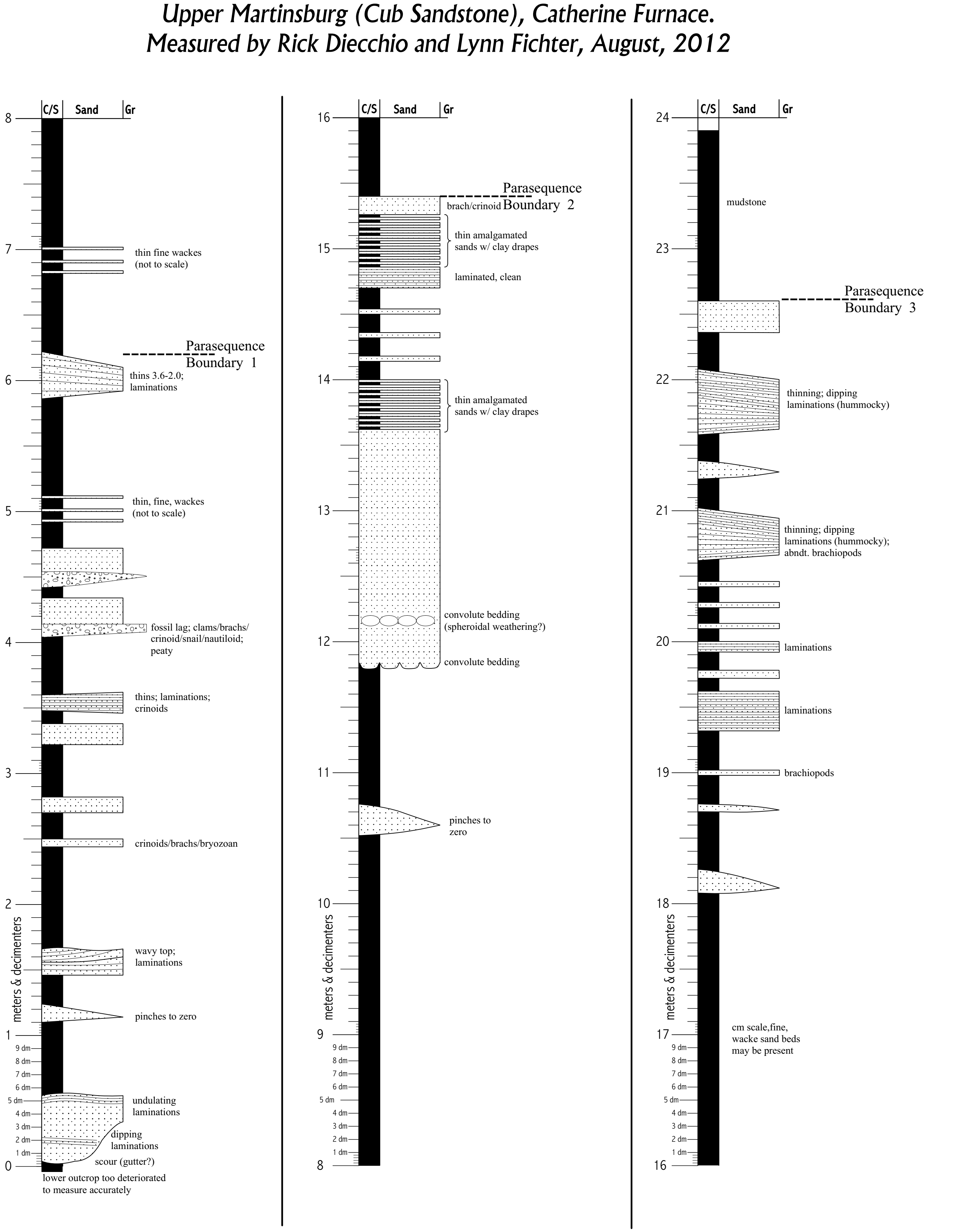
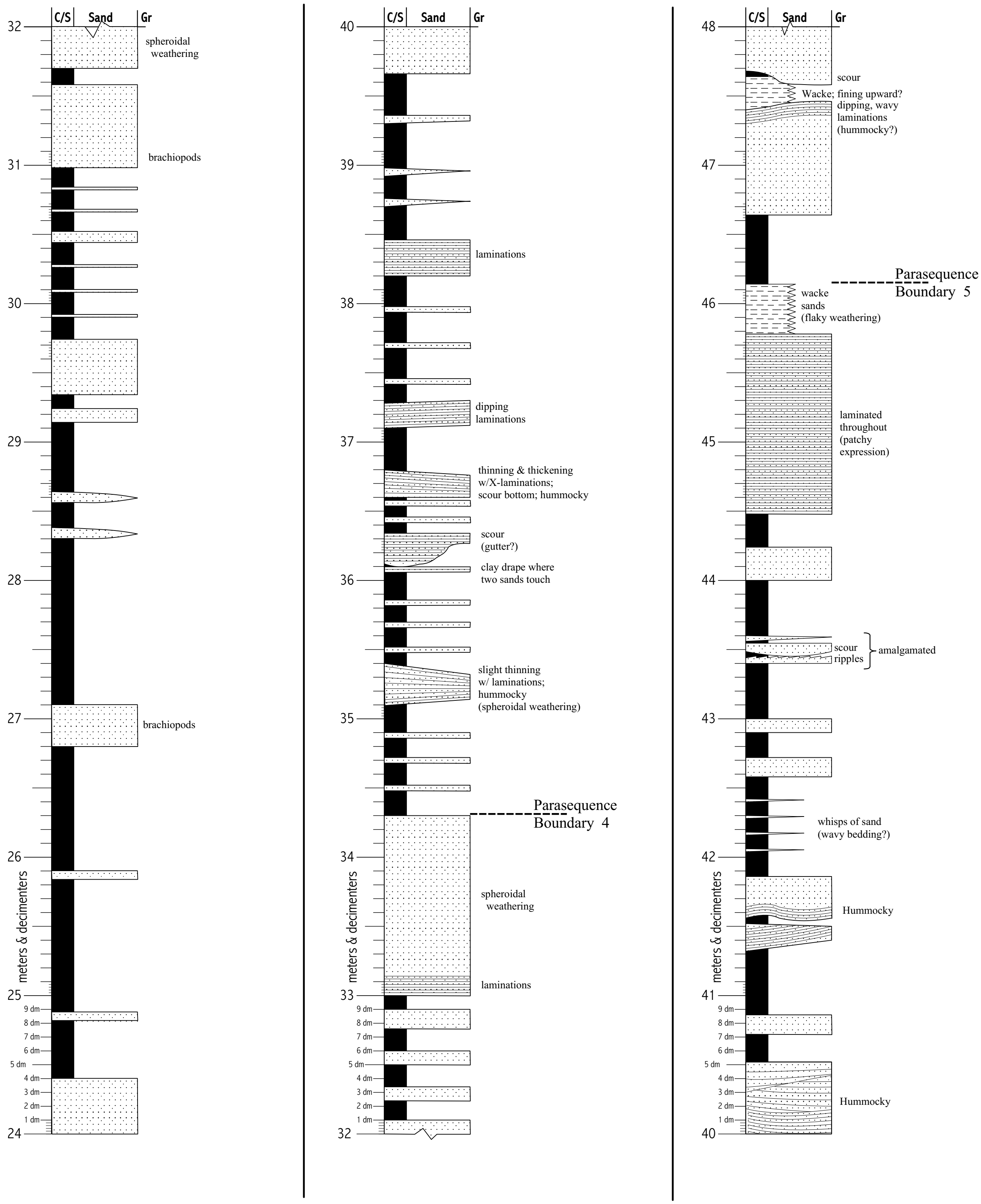
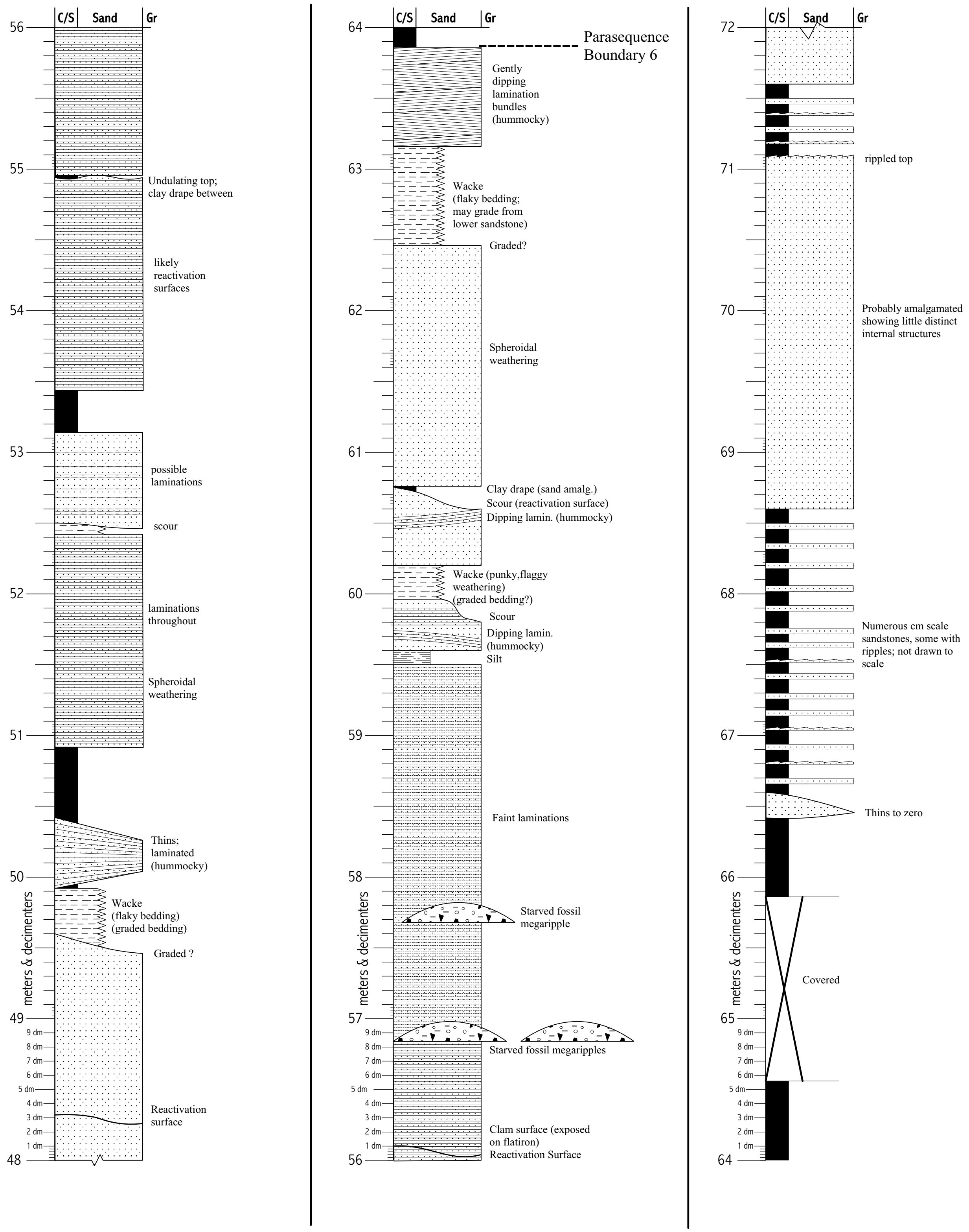


Figure 4.1. *Measured section strip log of the Martinsburg "Cub sandstone" roadcut on Cub Run Road, just east of Catherine Furnace.*

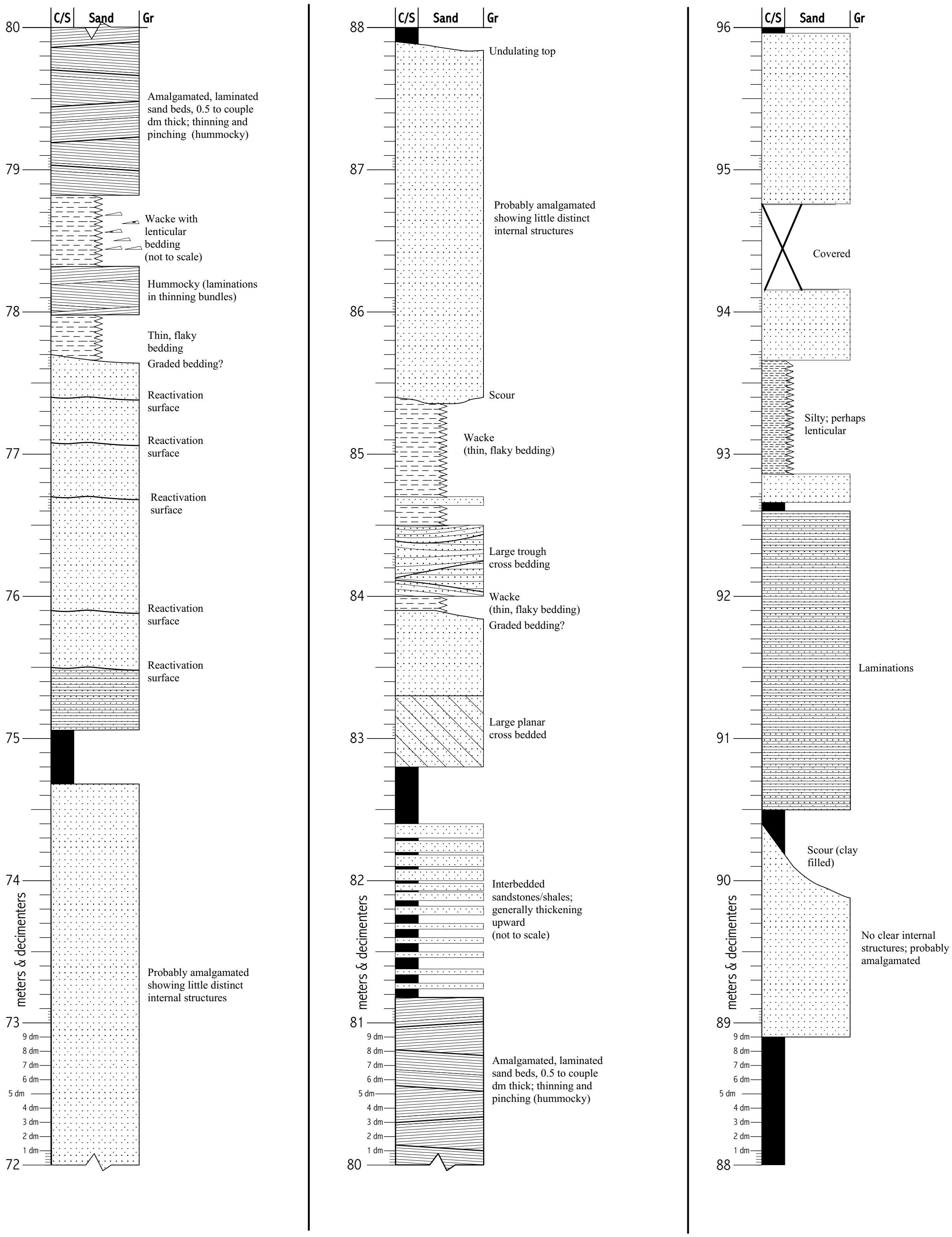
Upper Martinsburg (Cub Sandstone), Catherine Furnace. Measured by Rick Diecchio and Lynn Fichter, August, 2012



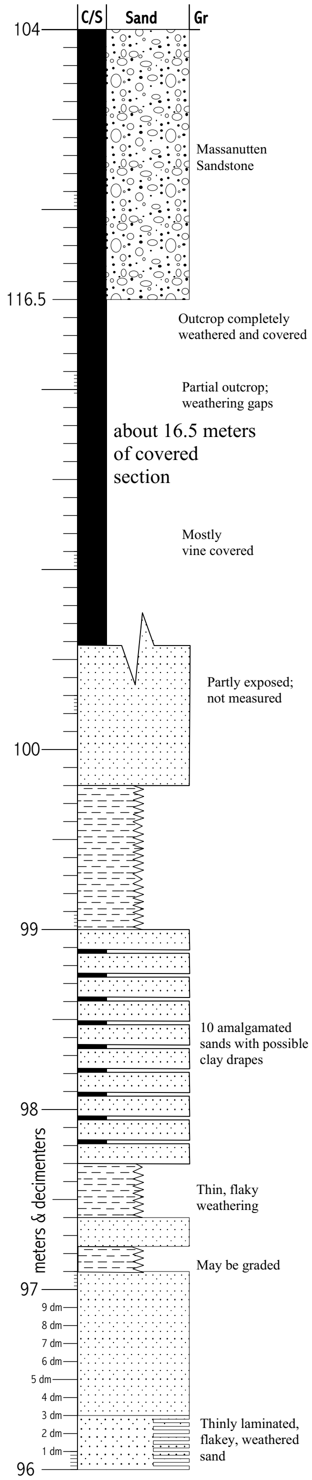
Upper Martinsburg (Cub Sandstone), Catherine Furnace.
Measured by Rick Diecchio and Lynn Fichter, August, 2012



Upper Martinsburg (Cub Sandstone), Catherine Furnace.
Measured by Rick Diecchio and Lynn Fichter, August, 2012



Upper Martinsburg (Cub Sandstone), Catherine Furnace.
Measured by Rick Diecchio and Lynn Fichter, August, 2012



State of the Outcrop and Measured Section

The Catherine Furnace section of the upper portion of the middle Martinsburg and the "Cub sandstone" is badly deteriorated by weathering, masking many of the sedimentologic and stratigraphic signatures. Some relatively clean arenite beds do stand out, but wacke beds are more common and often have diffuse boundaries, especially at the top where they may grade or fine upward into flaky weathered units looking superficially like weathered silt or shale but on close examination are sand rich. Many parts of the outcrop that look to be dominated by weathered shale/silt have sand rich zones that may be lenticular, wavy, or flaser-type bedding, but without distinct bed contacts to identify them. Sand rich zones were not mapped as beds unless distinct contacts were visible. We frequently used the cleavage to distinguish shale layers because the shale cleavage differs by a few degrees from the bedding fissility of weathered wacke or silt beds.

Many of the sand beds change thickness laterally, thickening and/or thinning, or pinching to zero, but it is easy to miss these changes. The thickening/thinning may occur on both the top and bottom of the bed; or on one or the other; often it is not possible to tell. Some sandstones shows internal layering (laminations or cross bedding), and were indicated as such on the strip log, but many do not, or have only a faint hint of internal layering. We assume that all the sandstone beds were deposited by flow regime conditions that would result in laminations, beds, or bedsets (as opposed to mass transport mechanisms), consistent with the beds for which we do have flow regime structures

Many of the thicker sandstone beds are almost certainly amalgamated (composed of more than one deposition event separated by reactivation surfaces, such as scours, clay drapes, or pebble lags). In some cases the reactivation surfaces were visible, but often they were not. Flow regime and environmental interpretations are based on a composite of all the information in the section and extrapolated to parts of the section where evidence was sketchy or missing. Our interpretation is most consistent with storm shelf parasequence models.

It is difficult to be entirely objective when measuring a section like this. We strove to be consistent in the accuracy and precision of the data collected, especially across the coarsening/thickening upward changes in the section, but someone else might make different judgements about what is significant or not, and therefore what patterns are present. We welcome discussion and debate on these differences of observation and opinion.

provide some predictive tools for interpreting environmental changes in storm shelf deposits on outcrop.

Figure 4.2 models a storm wave traveling across a shallowing shelf toward the shore. As the storm wave touches bottom its energy is translated into oscillatory flow. But, as the wave moves closer to the shore into shallower water, the wave cone begins to drag along the bottom, which adds unidirectional components to the oscillatory component. Some of these combined to produce hummocky cross stratification, but many other structures are possible. By the time the waves wash onto the shoreface most of the energy has been translated into unidirectional currents that result in planar and trough cross bedding. Thus, a single storm wave can produce a diversity of bedforms as it travels into shallower water. The actual sedimentation sequences will depend on the size of the storm waves, how long they last, whether there are also storm surge currents, etc.

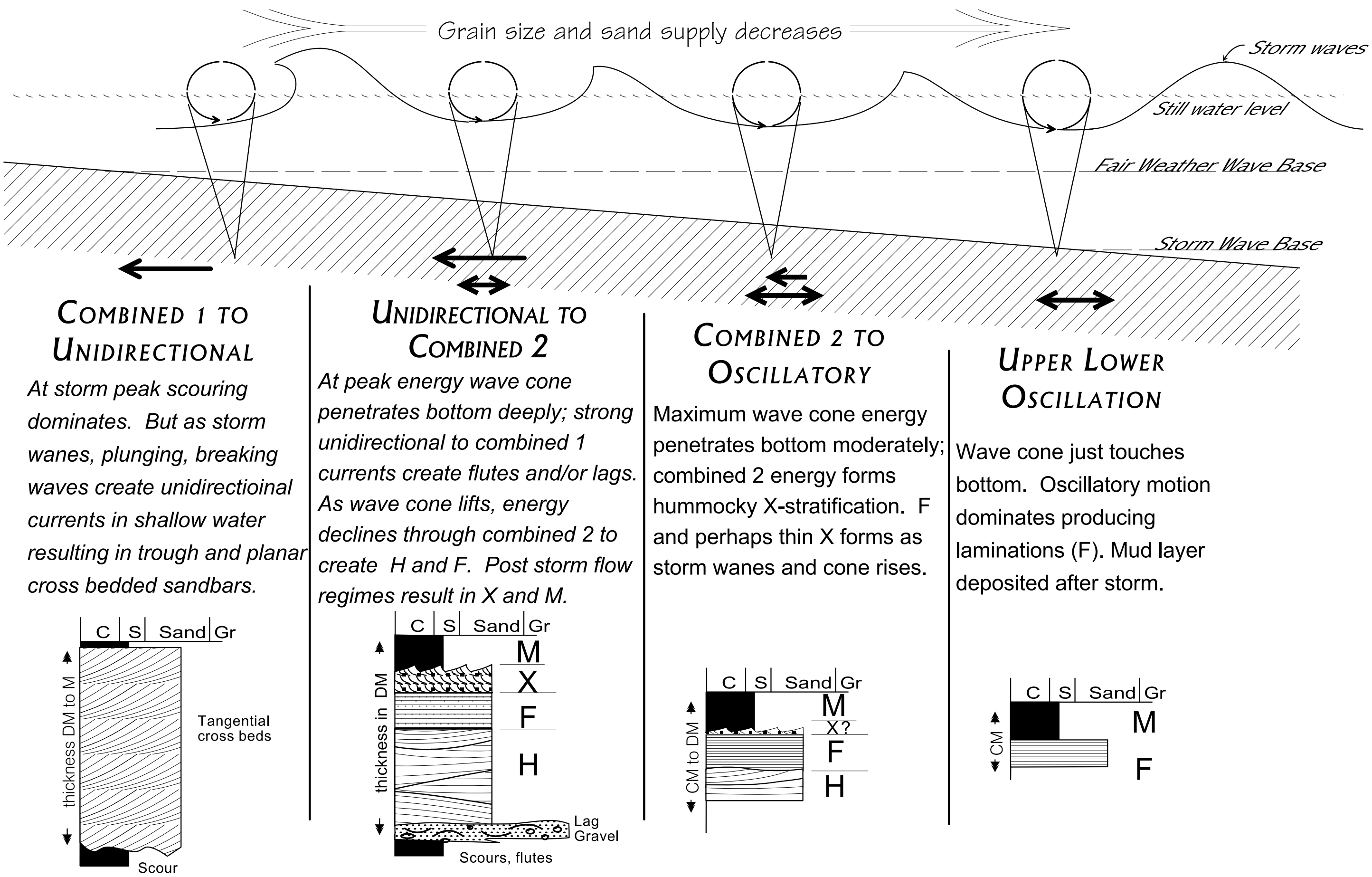


Figure 4.2. *Model of changing energy dissipation of storm waves across a shallowing shelf. As moving waves touch down more and more of the energy translates from oscillatory to combined 2 (oscillatory > unidirectional), to combined 1 (unidirectional > oscillatory), to unidirectional on the shoreface. The result is that a single storm wave can produce different bedforms in different places as the water shallows.*

In a prograding system, individual shelf parasequences thicken and coarsen upward. This reflects decreasing water depth and increasing storm energy dissipation, which results in systematic changes in the hummocky sequence from bottom to top. Figure 4.3 illustrates a representative coarsening-/thickening-/amalgamating-upward prograding parasequence and predicted bedforms.

A complication to this representative sequence is that storms that produce hummocky sequences range from frequent small storms that produce thin beds to very infrequent massive storms that produce thick sands. In a time series the appearance of storms of a particular size may appear almost random, and their appearance in the section may seem random. Thus, a prograding parasequence will rarely show an ideal coarsening/thickening upward pattern. Instead random, abnormally thicker sand units may appear anywhere in a section. In addition, depositional sequences that result from individual storm events will vary widely depending on variables like sand supply, size and depth of waves, and the duration and frequency of storms. We use the term "hummocky" to refer to a variety of bedforms and internal structures that result from storm waves shallowing across a shelf.

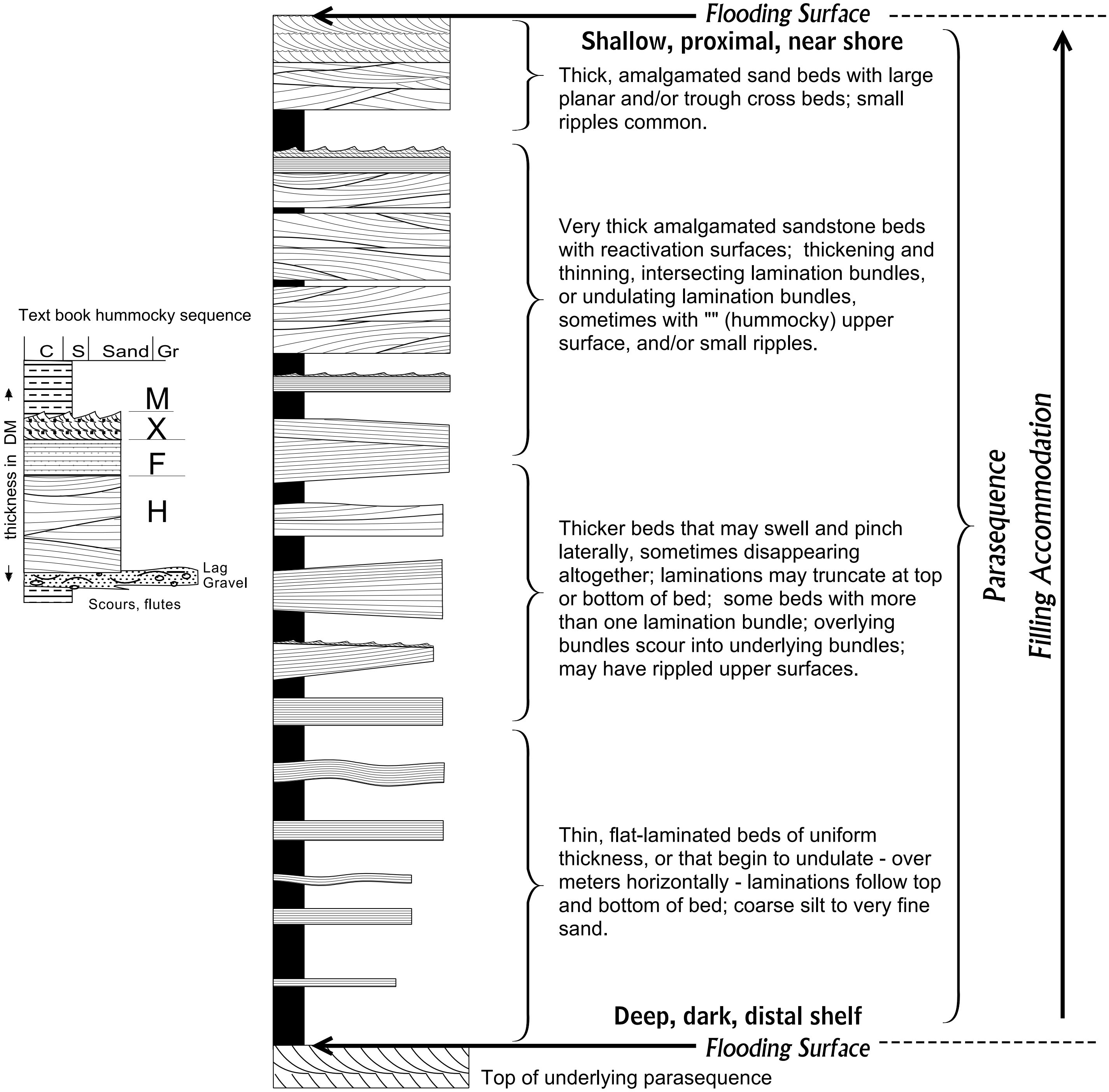


Figure 4.3. *Representative kinds of bedding and cross stratification found in the "Cub sandstone" of the Martinsburg Formation at Catherine Furnace, set within a representative coarsening/thickening/amalgamating upward parasequence. In distal parasequences shale may dominate and the most proximal sands at the top of the parasequence may be thin and flat laminated. It is also common for anomalous sand beds to appear out of place in a parasequence, the result of storms that touch bottom more deeply and distally.*

3. Note changes from parasequence to parasequence, and note that parasequence-like patterns may exist at two different scales at this outcrop (4th order and 5th order, see Figure B1). Parasequences coarsen and thicken upward through the entire outcrop. Above about 50 meters they are dominated by several meter-thick amalgamated sands and thin or non-existent shales. Here a boundary may be a relatively thin shale between thick amalgamated sands. We did not delineate these parasequence boundaries on the strip log.

Stop 4b – Massanutten Sandstone just east of Catherine Furnace

Location: 38.557135 N, 78.633206 W

The Massanutten Sandstone consists of indurated, medium to coarse quartz arenite beds with planar and trough cross bedding. These have been interpreted as braided river deposits (Pratt, 1979).

Sedimentary features

1. Lithologic changes: There is a stark difference between the lithology of the ("Cub") sandstone of the upper Martinsburg as compared with the Massanutten sandstone.
2. Large planar and trough cross beds are occasionally apparent.
3. Practical observational problems: The Catherine Furnace section of the Massanutten Sandstone does not give a lot of sedimentologic information and our description/interpretation is partly based on better exposures along Rt. 675 (Fort Valley Road) on the east flank of Massanutten Mountain near Luray. There, we find a nearly complete Massanutten section. The sandstone beds are friable and virtually every one has well-expressed large planar and trough cross bedding, often in 3 dimensions. Rare granule beds in the cm range are also present.

Structural features

1. Truncations in cross beds in the Massanutten Sandstone are useful for determining the stratigraphic younging direction.
2. Subhorizontal slickenlines are apparent on some joint/fracture surfaces in the Massanutten Sandstone

Points of Discussion

1. The Disconformity: The Martinsburg-Massanutten contact is not exposed here. East of here where the contact is exposed, it is abrupt and definitely not gradational. We get a sense of that here as the litharenites of the upper Martinsburg ("Cub") change abruptly to the quartz arenites of the Massanutten.
2. Braided River Interpretation: Pratt et al. (1978) and Pratt (1979) proposed that the Massanutten Sandstone represents a braided river system (Figure 4.4). Supporting evidence for the braided river interpretation includes: 1. Trough and planar cross bedding (transverse bars). 2. Gravel beds (longitudinal bars), especially at the northern end of Massanutten Mountain, becoming cm-scale granule beds near Luray. No gravel beds are known at Catherine Furnace, although quartz pebble conglomerates can be found in exposures of the Massanutten Sandstone on the ridges east of this location. Overall, the implication would be a proximal braided system to the north and a more distal braided system in the south. 3. The absence of significant silts and shales, which would otherwise indicate a meandering fluvial system.

   Contra-indicators for a braided river are the common trough cross beds, and the pure quartz content (braided rivers, being proximal, are typically lithic rich). Thus, the Massanutten Sandstone may reflect a different kind of braided river, sometimes called a low sinuosity river or a coarse-grained meander belt, which transitions from a classic braided river to a classic meandering river. This transitional interval often exhibits trough cross bedding (lunate ripple migration) mixed with planar cross beds (transverse bars), similar to what we see in the Massanutten Sandstone.
3. Missing beach and meandering river facies: In an ideal prograding system we would expect a shelf (upper Martinsburg) to be overlain by a beach, and in turn, by a meandering river and then a braided river. Here the Martinsburg shelf facies is directly overlain by the Massanutten braided river facies. Bretsky (1970) and Kreisa (1980) recognized that the beach and meandering river facies were missing, and suggested that a disconformity may exist between the Martinsburg and Massanutten.

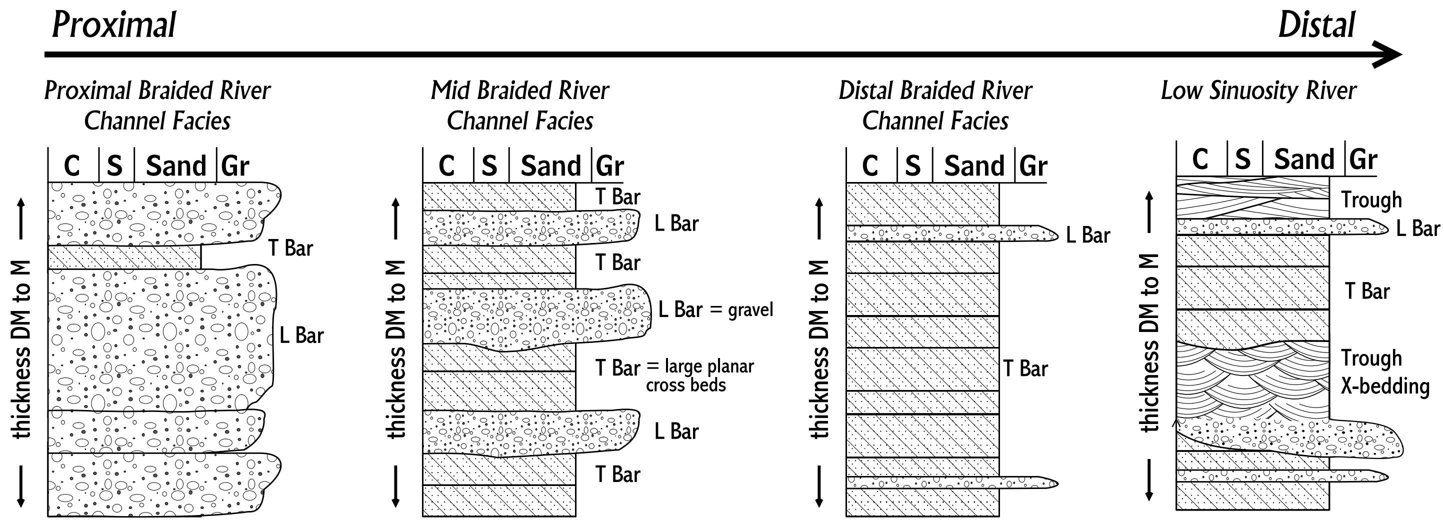


Figure 4.4. *Braided River environments. From proximal to distal, gravel (L-Bars) decline and sand (T-Bars) increase. At the transition to sinuous rivers large trough cross bedding increases in abundance mixed with T-Bar planar cross bedding.*

4. The abundance of quartz in the Massanutten: If we view the Massanutten Sandstone as a braided river system, then its preponderance of very clean quartz arenite is an enigma. One possible scenario is that headward erosion of river systems worked their way back through and across the Taconic volcanic systems until they tapped a veneer of mature quartz sands and gravels in the interior. The mountainous foreland of the continent could have been similarly breached to access mature quartz sands. Lower Silurian quartz arenites are widespread (Dorsch and Driese, 1995), but discontinuous and isolated from each other (e.g. Massanutten Sandstone, Tuscarora Formation, Shawangunk Conglomerate, Clinch Formation). Lithologic variations among these units suggests different sourcelands, perhaps from both foreland and hinterland regions. It is also possible that these quartz arenites were derived from a sourceland that only generated quartz-rich sediment (a first-cycle quartz arenite, e.g. Johnsson et al., 1988). Overall, the sourceland(s) for the abundant quartz in the lower Silurian is an interesting problem, ripe for discussion.

Structural Interpretations

Vertical beds of the upper Martinsburg Formation ("Cub sandstone") along Cub Run Rd. transition to steeply east-dipping, overturned beds of Massanutten Sandstone quartz arenite closer to Catherine Furnace. Sub-horizontal slickenlines are apparent on some northwest-striking joint surfaces in the Massanutten Sandstone. Coupled with an apparent offset in the Massanutten ridge at the Catherine Furnace gap, this suggests a few meters of left-lateral offset. The offset at this gap in the ridge is similar in orientation to normal and/or strike-skip faults observed at several other gaps in the Blue Ridge and Massanutten ridges (Bailey et al., 2006; 2012; Heller, 2010). Though unconstrained at this location, we suggest that these lateral offsets are post-Alleghanian and perhaps related to Mesozoic extension during opening of the Atlantic Ocean.

Stop 4c – Catherine Furnace and Charcoal Iron Production in Page Valley

Catherine Furnace stands on the southeastern flank of Massanutten Mountain where Roaring Run and Cub Run converge before tumbling down to the Shenandoah River. The Forrer brothers, Daniel and Henry, built an iron furnace here sometime around 1840, and it is believed that they named it for their mother. The massive stone chimney, a truncated pyramid constructed of blocks of Massanutten Sandstone, hand laid without mortar, stands in excellent condition (Fig. 4.5), although attendant structures such as the charging bridge and the bellows are long gone, as is the charcoal iron industry.

Figure 4.5. *Catherine Furnace: the chimney for a 19th century iron furnace.*

A Charcoal Iron Industry Primer

All commercial iron ores are compounds of iron, usually bound to oxygen in a mineral such as hematite (Fe_2O_3), magnetite (Fe_3O_4), or goethite (FeO•OH), or more rarely a sulfur compound such as pyrite (FeS_2) or pyrrhotite ($Fe_{1-x}S$). The problem for the refiner is to break the bonds that form the compound and drive off anything that isn't iron. To free up the iron you need sustained temperatures much greater than those used to separate copper or tin from their ores, hence it took early civilizations longer to develop the technology.

During the American Colonial period and well into the 19th century, the fuel that supplied the heat was charcoal. Roasting hardwood logs under an earth-covered mound drives off water and volatiles, leaving behind pure, high-grade carbon. Later, during combustion in the furnace, this carbon bonds with oxygen in the air, forming carbon monoxide (CO), which then reacts with the iron ore to produce carbon dioxide gas (CO_2) and metallic iron (Fe).

This process requires a lot of trees. A cord of wood yields about forty bushels of charcoal, and it takes about two hundred bushels to make one ton of pig iron. As a result, it was necessary to harvest about one acre of hardwood for each ton of iron produced. For many 19th century furnaces, this meant clearing three acres per day, thus keeping hordes of woodchoppers busy across the countryside, leaving behind huge swaths of open, erodible land in their wake.

Iron ores contain various earthy impurities that need to be removed to make useful metal. This requires a flux, a substance that readily bonds with those unwanted impurities and creates new compounds that can be removed as slag. Calcite ($CaCO_3$), the constituent mineral in limestone, fluxes out silica (SiO_2), the most common impurity in iron ores. Under intense heat, calcite burns to lime (CaO), which readily bonds with silica, as well as other common impurities such as aluminum and phosphorous compounds. Every ton of ore consumes about four hundred pounds of limestone flux.

The process requires a massive chimney built with large blocks of refractory sandstone, insulated with clay and lined with firebrick. These structures, with an opening at the top and another at the bottom, were usually square in plan, some twenty feet on a side at the base, and tapered upward, forming a flat-topped pyramid about thirty feet tall. Furnaces were invariably built near hills or slopes in order to facilitate access via a bridge to the top opening, where the iron ore, limestone, and charcoal, in very specific proportions, was fed down the throat of the chimney. The fuel was ignited and the fire stoked until the bottom layer of ore was reduced to molten iron and slag. To increase the temperature and insure complete melting, blasts of air were forced into the hearth, and most furnaces were located near streams so that these blasts could be delivered using water-powered bellows. When a sufficient quantity of ore was completely melted, the slag was drawn off the top of the melt and the hearth was tapped into a channel in the casting floor — a level, sandy area in front of the furnace with a series of small pits scraped into the sand, feeding off a main, central channel. When these pits were filled with molten iron the hearth was closed. Then the furnace was recharged from the top.

Blast furnaces could be operated continuously — periodically being loaded at the top with a mix of ore, fuel, and flux, while periodically being drained from the bottom into sandy molds and cooled in ingots. This product is known as cast iron, and the castings were called pig iron because the molds on the casting floor looked like suckling piglets on a sow.

Cast iron is brittle, but by heating and pounding the metal it can be further refined and its strength and malleability improved. This product is called wrought iron and the industrial site is called a forge. At the forge, pig iron was beaten using a water-powered trip hammer, transforming it into bar iron, which was the source metal for village blacksmiths to produce a variety of tools, horseshoes, rims for wagon wheels, and miscellaneous hardware such as braces and hinges. Another type of manufacturing facility was the foundry, a place where pig iron was re-melted and cast into a variety of useful items such as stoves, skillets, pots, pans, firebacks, andirons, and axle pivots.

Iron operations at Catherine Furnace

During the early 19th century iron became increasingly cheaper and more readily available, thereby ushering in the Industrial Revolution. Virginia was certainly a player in the new world of iron technology. According to the US Census, in 1840 Virginia had forty-two iron furnaces in blast, cranking out 18,810 tons of cast iron that year, ranking fifth among the twenty-five states in the nation. However, the Commonwealth lagged far behind Pennsylvania, which set the pace with 213 furnaces producing almost a hundred thousand tons annually.

Sometime in the mid-1830s, Daniel and Henry Forrer, two brothers from Pennsylvania who were scouting Virginia for possible iron enterprises, formed a partnership with a local Page Valley resident named Samuel Gibson. In 1836 they purchased 6,249 acres of land where the town of Shenandoah now stands. There they built a cold-blast furnace on the banks of the river and established a post office under the name Shenandoah Iron Works. A few years later, the partnership pursued an opportunity to expand their operation, buying a large chunk of land on the east side of Massanutten Mountain where they built Catherine Furnace.

Considerable disagreement exists concerning the actual date of construction. The historical marker that now stands on the site, erected by the Shenandoah Valley Battlefields Foundation in 2003, clearly says that the furnace was built in 1846, while the nomination for the National Register of Historic Places definitively states it was built in 1836. Then there is the Historical Inventory of the Work Projects Administration published in 1937, which unequivocally says that the furnace was built in 1840. This latter date seems more likely considering that courthouse documents (Page County, Deed Book C, pages 337 and 340) record that Forrer, Gibson & Forrer purchased the property in 1837. All in all, the partnership bought 22,500 acres, which was necessary not only to provide mines for iron ore and quarries for limestone flux, but also vast forests for charcoal, not to mention housing sites for as many as forty workers and fields to grow the crops to feed them.

The furnace was situated at the confluence of Roaring Run and Cub Run near a large ore deposit in a sandstone stratigraphically up-section from the Massanutten Sandstone, along the west side of the valley of Cub Run. The sandstone had become impregnated with iron-bearing groundwater migrating downward from overlying, pyrite-rich Devonian Needmore and Millboro shales. Not long after the construction of the furnace, another large ore deposit was discovered near Pitt Spring. Miners dug the ore from hillsides in what were called "monkey drifts." When a hole got too deep, they just moved a dozen yards away on strike and started a new pit.

At the furnace, the ore was melted and molded into pig iron, and when everything was working smoothly three tons of pigs could be produced during a twenty-four-hour run. Wagons hauled the solidified pigs to the mouth of Cub Run where it enters the Shenandoah River. There the iron was loaded onto flat-bottom boats and floated downstream (north) to Harpers Ferry. The boats were broad, shallow-draft vessels, seventy-feet-long, carrying about fifteen tons of iron. Eight or ten flatboats comprised a fleet, and when the furnace was "in blast" about one fleet per week headed down the river. At Harpers Ferry the boatmen sold the iron, as well as the wood in the boats, and then walked back home.

Iron operations during the War Between the States

During the War Between the States, as the Civil War was called back then, iron was the raw material for more than two million rifles, several hundred thousand pistols, and thousands of cannons, along with innumerable artillery projectiles as well as sundry sabers, bayonets, and an unknown number of personal knives. Iron not only provided weapons, but also canteens, skillets, cauldrons, canned rations, shovels, saws, axes, chains, barrel hoops, surgeon's tools, and countless other pieces of now-esoteric hardware. At least one million horses participated in the war, willingly or otherwise, requiring more than four million iron horseshoes and fifty million nails. And there was no end to new and gruesome contrivances made of iron — complex, deadly menaces such as land mines and Gatling guns, as well as monstrous machines of war such as railroad artillery and ironclad warships. During a span of four years, iron helped re-define the concept of warfare.

Catherine Furnace was one of three Page County furnaces contributing to the Confederate war effort. Labor was scarce, and a cross-cultural workforce of slaves, local whites, and free blacks toiled for the Forrer brothers to supply pig iron to the Confederacy. With their normal northerly distribution route via the Shenandoah River now cut off, transportation became difficult. Wagons had to haul their heavy load over the Blue Ridge at Swift Run Gap, then traverse thirty miles of bad road to Gordonsville, where the iron was taken by rail to Richmond and the Tredegar Iron Works, the largest manufacturer of ordnance in the South.

Near the end of the war, the partnership leased the furnace to a man named Noah Foltz. Confederate government records show that Foltz enlisted on May 28, 1864, as a 49-year-old Private in Company B, 8th Battalion, Virginia Reserves. Closer examination shows that Company B was a paper organization that never saw active service, and Foltz remained primarily in Page County. It appears that his enlistment was largely an effort to avoid combat in the Confederate Army, because Foltz was secretly a Union sympathizer who helped several Federal soldiers escape across Massanutten Mountain into Fort Valley. When he inadvertently assisted several decoys disguised as Union soldiers, he was arrested. However, due to the "Iron Famine" that had beset the South, he was released on bond to continue managing the furnace. Noah Foltz is buried in the St. Paul Cemetery on US 340 just east of the furnace.

During the years of 1862 and 1864, bitter fighting raged up and down the Shenandoah Valley, but Catherine Furnace somehow remained unscathed. On May 7, 1862, the 1st Vermont Cavalry made the only known foray toward the furnace, but they were rebuffed at Somerville Heights.

Iron operations in the Post-Bellum period

In the aftermath of the Civil War the Forrer brothers found themselves to be land-rich but desperately cash-poor. They subsequently sold their business to the first wave of carpetbaggers, a Pennsylvania coal company spearheaded by William Milnes, Jr. In 1867, Milnes and his Yankee consortium purchased 32,000 acres of land in Page County, including the entire Forrer iron operations.

Only a few summers passed before the new owners endured a Mid-Atlantic hurricane season that hit the Valley hard. On September 28th, 1870, it had been raining hard for several days, and that night the Shenandoah River went over its banks and did not stop. Residents who fled to the high ground recalled listening to the mournful tolling of a steeple bell from a church that rocked and swayed, lurching slowly down the river on the crest of the flood. Most of the town was washed away, including the flourmill and some of the finest residences.

Undaunted, industrial activities resumed. Mr. Milnes was a bold, dynamic person, a man of influence, and he was instrumental in bringing the railroad to Page Valley, reaching the Shenandoah Iron Works in 1881. As the railroad was becoming a reality, Milnes borrowed $800,000 from northern investors, a ridiculous sum at that time, money that he poured into the creation of the Big Gem Cast Iron Furnace. The Big Gem, a state-of-the-art facility with its coke-fired furnaces, expansive casting room, and hundred-foot-high brick smoke stacks, was completed in 1882. The facility employed four hundred people and was easily capable of producing over a hundred tons of iron during twenty-four hours in blast. In 1883, it produced 32,537 tons.

Soon the little town was thriving. Located at the midpoint of the Shenandoah Valley Railroad between Roanoke and Hagerstown, it became a major rail and industrial center and the largest community in Page County. In June 27, 1882, the name of the post office was officially changed to Milnes, because, after all, he had donated land to churches and schools. The town was incorporated in 1884 as Milnes, only to be changed to Shenandoah a few years later. Meanwhile, Catherine Furnace began its descent into obscurity. Compared to the Big Gem operation, it was antiquated and unnecessary, and completely out of blast by 1885. For the next three decades it lay idle, drifting into the weeds, until in 1915 when it was included in a parcel of land transferred to the Federal government and the George Washington National Forest, the current custodian. Catherine Furnace received a National Historic Register nomination in 1973.

Meanwhile, in the town of Shenandoah the iron industry began to struggle, and unable to compete with the vast and incredibly rich iron deposits discovered in Michigan, ceased operations in 1907. Railroad activity continued, and the engine repair shops employed more than four hundred people during the first half of the 20th century, peaking during WWII. Since then, the town of Shenandoah has become a quieter place, and the Forrer Mansion, built ca. 1855 of bricks imported from England, was dismantled in the 1960s.

Stop 4d – Silurian-Devonian clastic and minor carbonate rocks
Location: 38.55954 N, 78.63597 W

At this stop we examine an exposure of bedrock along Roaring Run, upstream (north) of Catherine Furnace. The outcrop contains one or more layers of ironstone that may be similar to the ore mined nearby and processed at Catherine Furnace. Roaring Run flows between the First and Second Massanutten Mountains, which are held up by resistant beds of Massanutten Sandstone. This synclinal valley is underlain by clastic and minor carbonate sedimentary rocks of Silurian and Devonian age.

Features

1. When walking from Catherine Furnace to stop 4d, note slag in the trail and old building foundations. Also observe outcrops of Massanutten Sandstone on the east side of the trail. These beds are up-section from exposures at stop 4b, overturned dipping southeast, and close to the upper contact, which is not exposed. If this contact is not a fault, the bedrock under the trail is likely red and green sandstone, siltstone, and shale of the Bloomsburg Formation.
2. Bedrock along this portion of the trail is overlain by a coarse, poorly sorted deposit consisting of cobbles, boulders, and blocks of Massanutten Sandstone in a sandy loam to loamy sand matrix. Upstream of stop 4d, similar deposits appear to be debris flows.
3. The outcrop at stop 4b consists of blue-gray, fine-to medium grained, thin-bedded sandstone with lesser non-calcareous siltstone and shale. At stream level, a bed of weathered, mottled ironstone is also present. An outcrop in a cut above the stream outcrop exposes massive, fossiliferous limestone with abundant crinoid stems.

   This stop is on the east limb of a large syncline and the bedrock has a gentle west dip. The stratigraphic position of the bedrock exposed here is above the Massanutten Sandstone and perhaps the Bloomsburg Formation and below siltstone and shale of the Needmore and Millboro Formations.

Points of discussion

1. Can the outcrops at this location be assigned to a specific formation, and in particular, is the sandstone the Clifton Forge Sandstone (in the Keyser Formation), as speculated by Woodward (1943) for the Moreland Gap section of the Massanutten Synclinorium at the Shenandoah-Page County line?
2. What is the mineralogy of the ironstone at this location?
3. What processes concentrated iron in this location?

Interpretation

Due to limited exposure and structural complexity along strike, the exact stratigraphic position of this outcrop is uncertain. Thornton (1953) assigned limestone exposures along Roaring Run to the Tonoloway Formation, but described the exposures as shaly. He also assigned limestone exposures along strike in Pitt Spring Run to a new map unit, the Catherine Limestone; at least one interval of the Catherine Limestone is reported to contain crinoid fossils. Brent (1960) also describes crinoid-bearing limestone within the overlying Helderberg Group, which may support the speculation by Haynes (personal communication) that this interval represents part of the Keyser Formation.

Cumulative Trip Mileage	Point to Point Mileage	Directions and Comments
42.5	0.0	Load buses. Drive back (east) up Cub Run Rd.
42.9	0.4	Bear right (east) onto continuation of Newport Rd.
44.2	1.3	Turn right (south) onto US 340
45.8	1.6	*Long roadcut of Beekmantown carbonates on east side of road, just north of bridge over Shenandoah River, South Fork*
49.6	3.8	Turn right (west) onto Rt. 602 at traffic light in town of Shenandoah

Note: Due to the height of the buses, we have to deviate from the road log and continue south on US 340, and then take a side road back to Rt. 602. The road log assumes that you have typical height vehicles that can fit through the tunnels under the railroad on Rt. 602 just east of the Shenandoah River

Cumulative Trip Mileage	Point to Point Mileage	Directions and Comments
50.0	0.4	*Cross Shenandoah River, South Fork (again!)*
52.0	2.0	Turn right (west) onto Dovel Rd.
52.1	0.1	Turn left (south) onto Humes Run Rd.
52.2	0.1	Turn right into entrance to Elkton Quarry. Park at office

Stop 5

Vulcan Materials Quarry in Elkton
Location: 38.45235 N, 78.64984 W
Unit: Beekmantown Group

At this stop we examine the upper part of the Beekmantown Group in the southern section of the Elkton quarry. The Elkton quarry was opened in 1935 by T.W. Mundy (King, 1950) and acquired by Luck Stone in the 1980s. Ownership was transferred to the Vulcan Materials Company in 2008. The primary product of this quarry is crushed stone. Agricultural lime has also been produced.

The active pit exposes the upper 300 meters of the Beekmantown Group (Figs. 5.1, 5.2). Raymond Edmundson visited the quarry in the early 1940s and measured 1,202 feet of section that was exposed in and immediately east of the pit (Edmondson, 1945). He classified 576 feet of the exposed beds as dolomite, 276 feet as magnesian limestone, and 247 feet as limestone.

Note: Hard hat, safety glasses, and steel-toed boots are required at this stop. Pay careful attention to your surroundings and follow all instructions from quarry personnel and field trip leaders. Stay away from high walls.

Features

1. Bedrock in the quarry consists of gray, fine-grained, medium- to thick bedded dolomite interbedded with blue-gray to dark-gray, fine-grained, medium-bedded limestone and magnesian limestone (Fig. 5.2). Sedimentary features such as algal laminations, mud cracks, rip-up clasts, and bioturbation are likely present, but can be difficult to see in fresh exposures. Gastropod fossils have also been reported at this site (King, 1950), and may be present in some beds.
2. The contact of the Beekmantown with the overlying New Market Limestone was visible when P.B. King visited this quarry in the 1940s (King, 1950). Weathered limestone beds that appeared to be New Market or Lincolnshire were observed at a distance in the uppermost bench of the quarry during a field review for the Elkton West quadrangle in 2009, and may still be visible during this trip.
3. The quarry is located on the eastern limb of the Massanutten Synclinorium. The structure in the quarry is relatively uncomplicated with beds steeply dipping to the northwest, vertical, or slightly overturned to the southeast (Fig. 5.1). Minor faults, including southwest-dipping reverse faults, have been observed on previous visits to this quarry and may be apparent.

Points of discussion

1. Is a systematic change in depositional environment apparent in these rocks?
2. Is this section equivalent to the Rockdale Run Formation?

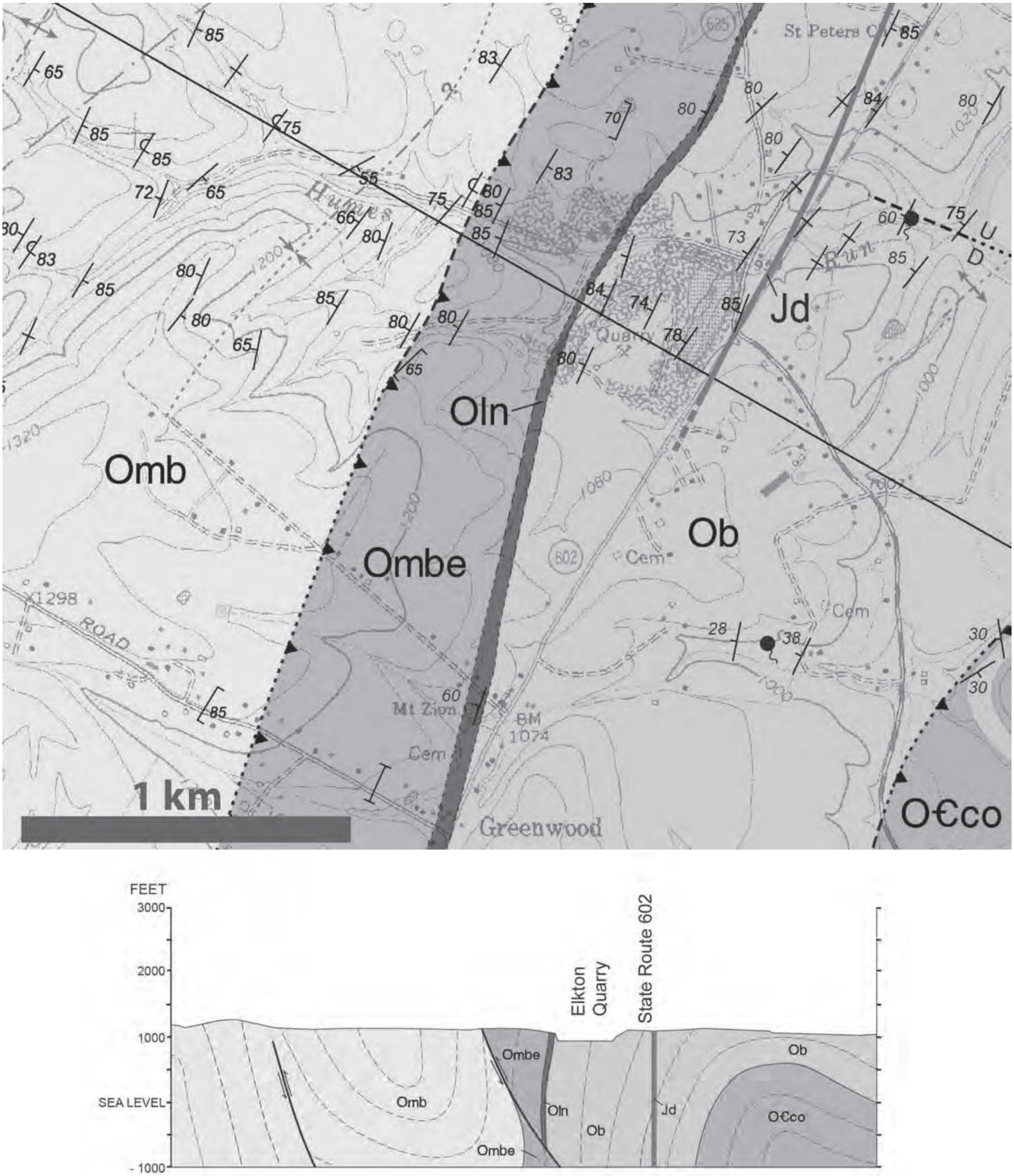


__Figure 5.1.__ Bedrock geologic map and interpretive cross section in the vicinity of stop 5, after Heller (2010). Jd = Jurassic diabase; Omb = Martinsburg Formation; Ombe = lower Martinsburg and/or Edinburg Formation; Oln = Lincolnshire and New Market Limestones, undivided; Ob = Beekmantown Group; OCco = Conococheague Formation.

Interpretations

The depositional environment for the Beekmantown Group is interpreted to be a carbonate platform under supratidal to shallow subtidal conditions. Based on Edmundson's measured section (Edmundson, 1945), the relative abundance and thickness of dolomite increases upsection to within 200 feet of the upper contact, and then decreases (Fig. 5.3).

The thickness of the Beekmantown Group appears to be consistent on both sides of the Massanutten synclinorium, but apparent differences in the stratigraphy exist (Figure 5.4). To the west, the upper part of the formation, based on field mapping of discontinuous exposures, is primarily dolomite. An interval of interbedded limestone and dolomite is present in the middle of the section to the west, but it is much thinner than that exposed in the quarry. In addition, two separate intervals of bedded chert were observed on the west side of the synclinorium, while only one interval was identified to the east.

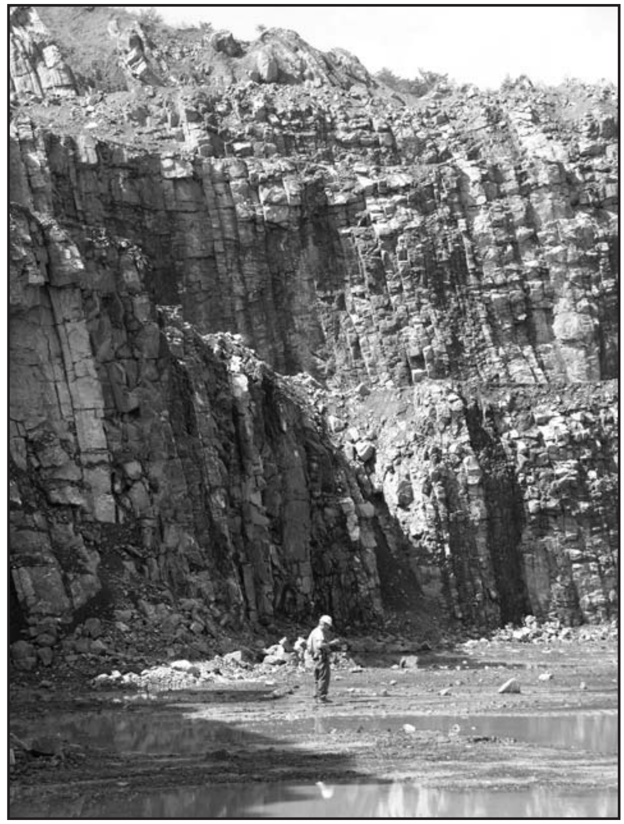


Figure 5.2. *Steeply dipping dolomite and limestone in the upper part of the Beekmantown, Vulcan Materials Elkton quarry. View is to the southwest.*

The New Market and Lincolnshire Limestones are not well exposed in the vicinity of the quarry and along strike between Greenwood and St. Peter's Church. This lack of exposure prompted Brent (1960) to map the Beekmantown in fault contact with the Edinburg Formation in the vicinity of the quarry. Recent drilling by the Vulcan Materials Company west of the quarry, however, did intersect a few thin beds of micrite between the Beekmantown dolomite and calcareous shale of the lowermost Edinburg Formation. In addition, Heller (2010) determined that the New Market, while thin, is present along strike in both directions. The Lincolnshire may be absent in places.

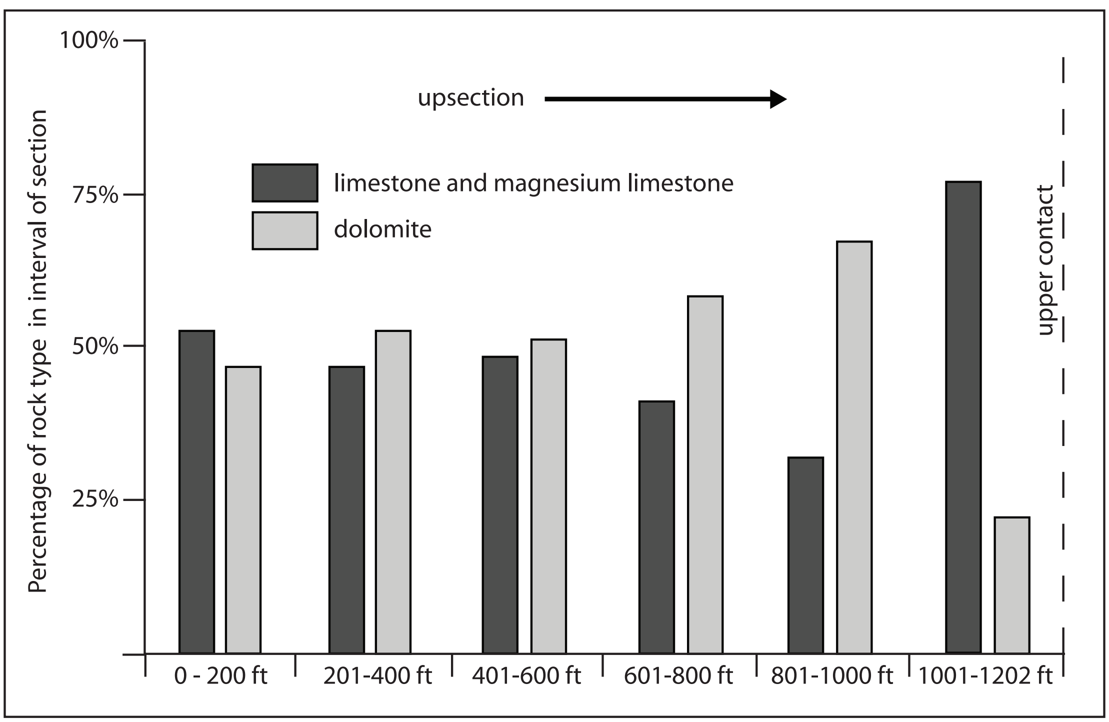


Figure 5.3. *Change in the percentage of dolomite and limestone in the upper Beekmantown at Elkton Quarry, based on the 1,202 foot section measured by Edmundson (1945).*

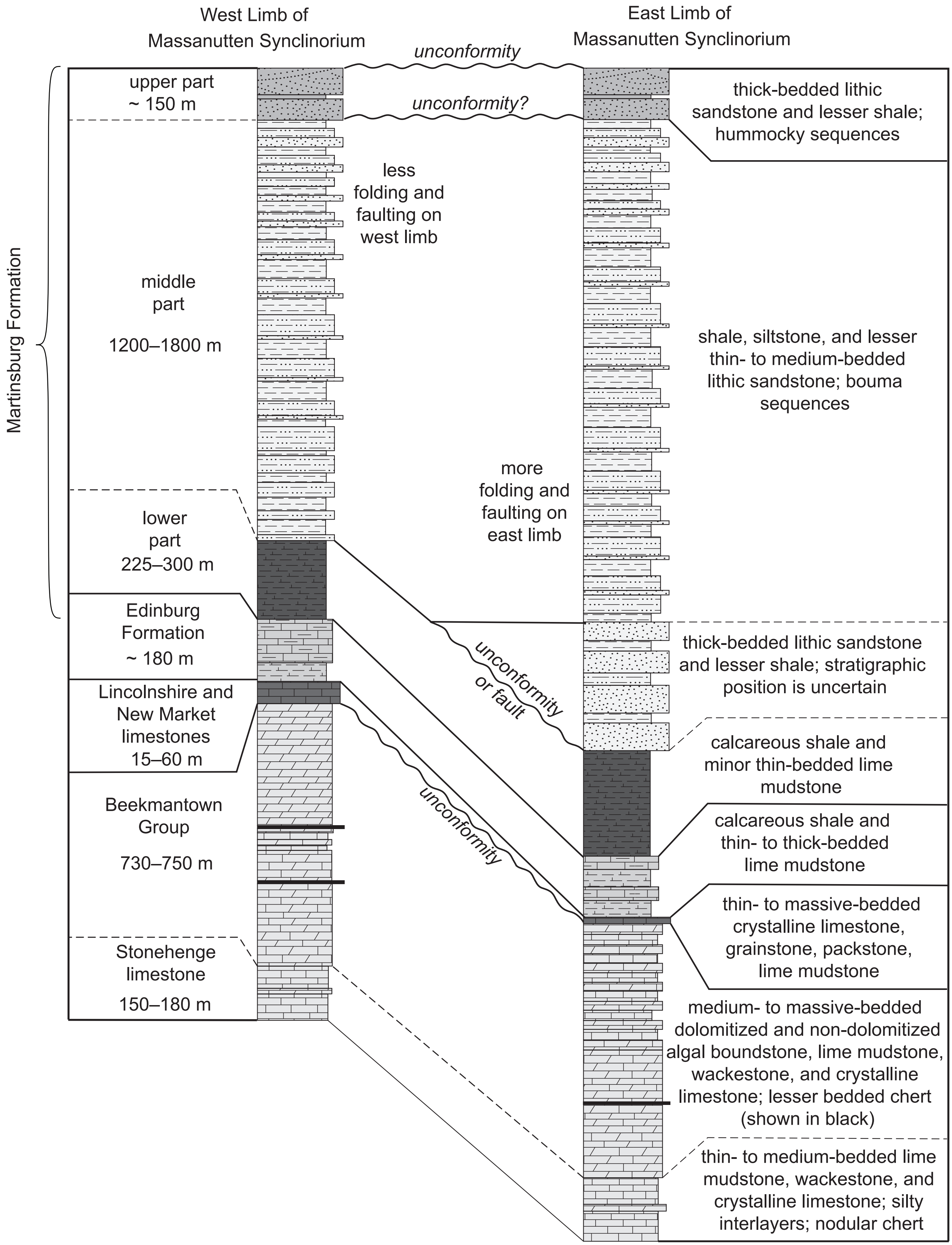


Figure 5.4. *Generalized stratigraphic columns showing differences in Ordovician stratigraphy on both sides of the Massanutten synclinorium, based on geologic mapping in the Elkton West 7.5-minute quadrangle (Heller, 2010). Thicknesses, especially in the Martinsburg on the east limb of the synclinorium, are exaggerated due to folding and faulting.*

Cumulative Trip Mileage	Point to Point Mileage	Directions and Comments
52.2	0.0	Load buses. Exit quarry, turn right (south) on Humes Run Rd.
52.4	0.2	Turn right (south) onto US 340.
56.1	3.7	Bear right (southwest) onto Rt. 644. Note: Don't make a sharp right.
58.1	2.0	*Pass golf course and Woodstone Meadows clubhouse.*
59.4	1.3	Turn right (south) onto Bloomer Springs Rd. (Rt. 646).
59.7	0.3	Turn left into driveway of Shenandoah Valley Farm and Inn.

Stop 6

Shenandoah Valley Farm and Inn; south of Massanutten Mtn.
Location: 38.390921 N, 78.713062 W
Unit: Martinsburg Formation; Alluvial fans

At this stop we examine: a. a thick-bedded sandstone sequence in the structurally lower part of the Martinsburg Formation, and b. and c. two distinct alluvial fan deposits that originated from the Massanutten Mountains.

History of the farm

According to the Shenandoah Valley Farm and Inn web site: "The farm was first named Bonnie Dell Farm...the land was part of the original Harmon Grant. Tobias McGahey [the first postmaster of McGaheysville] bought this farm for his daughter Isophena and her husband Joseph J. Littell. The house and outbuildings, constructed of logs, were built in 1825. The main house has had many additions and renovations over the years, and the log walls have been covered with wood siding. During the Civil War, on the orders of General Philip Sheridan, the Union Army burned down the original barn, along with most of the other barns and granaries in the Valley. There have been five owners since the house was built in 1825. During the 1900s, the farm was owned by John Bader and his wife Calivares, the first female physician in the state of Virginia. Poet Sidney Lanier visited here often, spending time on the farm and at nearby Rockingham Springs." Charles and Betty Dixon have owned the Shenandoah Valley Farm and Inn since 1967.

Stop 6a - Martinsburg outcrop in creek

Location: 38.38921 N, 78.71963 W
Unit: Martinsburg Formation

Bedrock of the Martinsburg Formation is exposed discontinuously in Bonnie Brook, and consists of gray, fine- to medium-grained, thick-bedded lithic sandstone with lesser siltstone and shale. Sandstones are amalgamated, composed of TA and TAB Bouma sequences deposited by turbidity currents in a submarine fan. Poorly preserved brachiopods have been reported in the vicinity (Brent, 1960). To the northwest of this locality, the percentage and thickness of sandstone beds decreases rapidly. To the southeast, the bedrock changes abruptly to thin-bedded shale and calcareous shale. Calcareous shale and lime mudstone of the Edinburg Formation are exposed in Bonnie Brook approximately 600 meters downstream. Thornton (1953) described variations in the Martinsburg Formation as, "East of the Massanutten Range (as opposed to the west) the character of the lower part of the (Martinsburg) Formation is greatly changed. Here, instead of the black shales and limestone, the strata consist of black shales and argillites interbedded with rather thick beds of sandstone."

Features

1. Bedding in these outcrops is nearly vertical. Dip reversals across strike suggest that the beds in this area are tightly folded. Facing direction in the immediate vicinity is unclear, with apparently opposing stratigraphic indicators from sedimentary structures; this may be consistent with localized folding.
2. Shallow southeast-dipping cleavage can be observed in the outcrop. This cleavage has been observed along strike to the northwest but is inconsistent with the more prevalent upright folding mapped throughout Page Valley (c.f. Stops 2 and 3).
3. The bedrock geology here is further complicated by a mapped cross-fault and a northwest-trending diabase dike (Fig. 6.1). Minor northwest-directed reverse faults have been observed along strike and may also be present in this area.

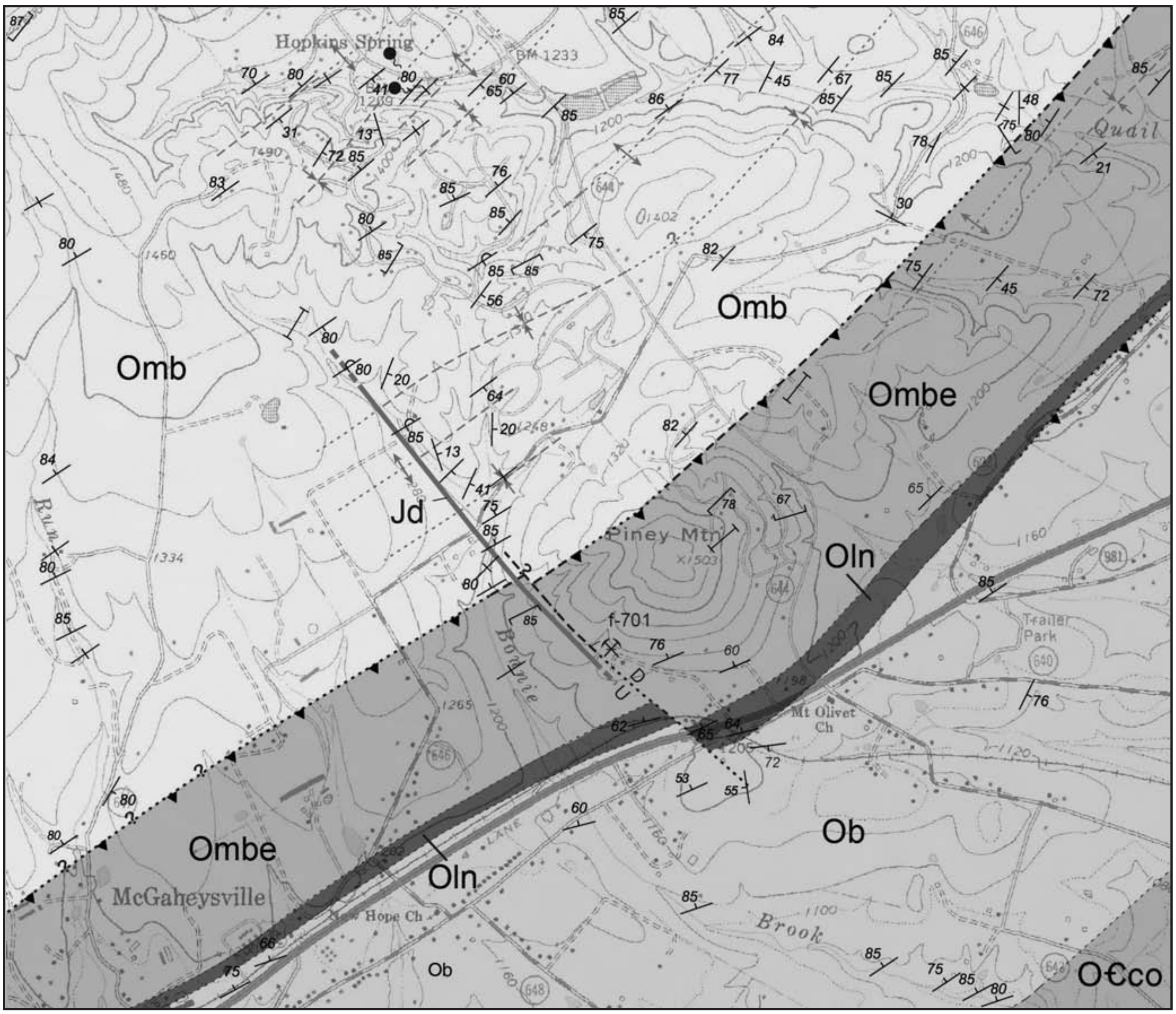


Figure 6.1. *Bedrock geologic map in the vicinity of stop 6, after Heller (2010). Jd = Jurassic diabase; Omb = Martinsburg Formation; Ombe = lower Martinsburg and/or Edinburg Formation; Ob = Beekmantown Group; OCco = Conococheague Formation.*

Points of discussion

1. Stratigraphic interpretations: Bouma sequences typically thicken and coarsen up section as a submarine fan progrades. Thick, amalgamated TA and TAB units, sometimes with thin shale partings, are typical of the channeled portions of supra fan lobes. Assuming these sands are indeed in the lower Martinsburg, we have a problem.
2. What is the stratigraphic facing direction? The localities where we examine these rocks display way-up indicators that seem to point in opposing directions. Bedding/cleavage relationships suggest that the steeply southeast-dipping beds are overturned.

Interpretations

At Stop 3 the thinner and coarser Bouma sequences in the Martinsburg are a more distal and deeper facies than the thicker, shallower, and finer grained more proximal Boumas here. But, the thinner sands at Stop 3 could be stratigraphically above the Martinsburg at this stop. As is generally thought, and as the subsidence/accumulation model predicts, the Martinsburg progressively gets shallower upward, as would be the case for a typical submarine fan. These fan deposits are overlain by shelf deposits indicating that conditions do get shallower. The model therefore would imply a coarsening and thickening of the Bouma sequences up-section as the fan progrades, the basin shallows, and the paleoslope diminishes. However, if the thicker Bouma sequences at this stop are lower in the section than the thinner Boumas at Stop 3, that would necessitate a more complex model. An additional complication is that even though these sands are thicker they are still fine to medium grained; we would expect a prograding system to coarsen to medium to coarse sands, or even gravels.

The contact between the thick-bedded sandstone sequence and the underlying shale and lime mudstone sequence is interpreted to be a fault in this area (Fig. 6.1). In addition, several small-scale folds are mapped upstream of this location. However, overall map patterns suggest the thick sandstones observed here are at a lower stratigraphic position in the formation, consistent with the conclusions of Thornton (1953) along strike to the northwest. Possible working hypotheses include:

Hypothesis 1: The thick sandstones in the lower Martinsburg have been displaced by faulting and/or other structural deformation. The structural relationships in the region are complex and a number of different interpretations are possible.

Hypothesis 2: A basic coarsening- and thickening-upward submarine fan model does not fit the Martinsburg. For one, these sands are in fact finer grained than the classic Boumas further up-section (e.g. Stop 3). As an

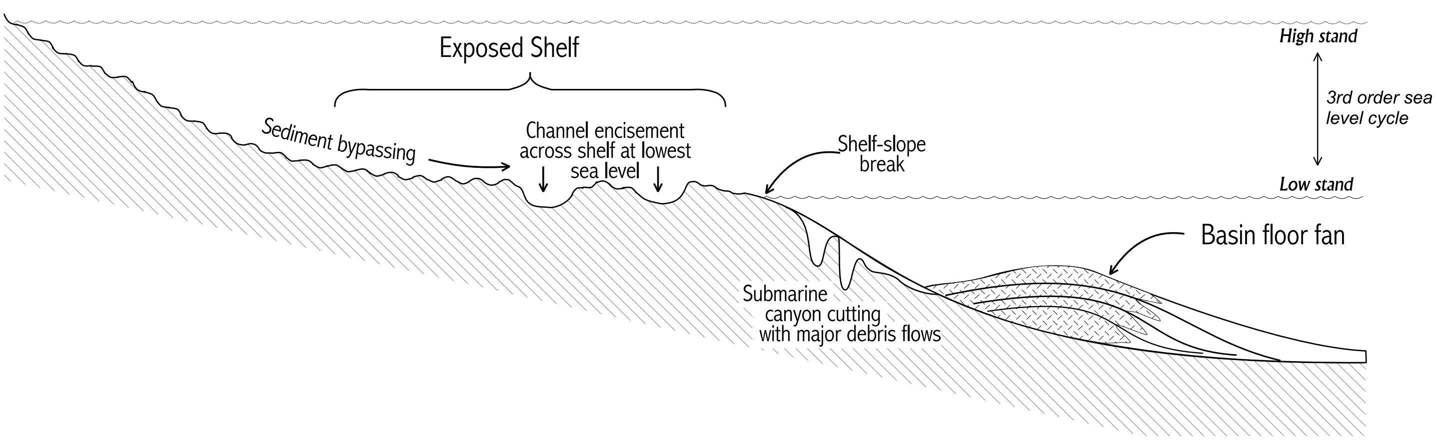


Figure 6.2. *The basin floor fan is created when sea level is at its lowest and the shoreline drops below the shelf-slope break. River channels incise across the exposed shelf and the sediment, dumped at the top of the shelf-slope break, flows down the slope depositing as the basin floor fan. Basin floor fans are stratigraphically lower and more distal than slope fans but have many features of more proximal fan facies such as thick, amalgamated T_A and T_{AB} units.*

alternative, the thicker, but not coarser, sandstones could be interpreted not as the proximal facies of a fan sequence but as a low stand fan (a.k.a. low stand systems tract; Fig. 6.2). This implies that these thick sandstones were deposited more distally from the source, out on the basin floor rather than on the basin slope near the margin of the basin. This would also account for the fine to medium grain size of the sand; basin floor fans are often finer grained than more proximal fans.

Stop 6b - Harshberger fan deposits

Location: 38.38744 N, 78.72104 W
Unit: Martinsburg Formation overlain by alluvial fan deposits

The western part of the Shenandoah Valley Farm is underlain by alluvial deposits that are believed to originate from the valley between First and Second Massanutten Mountains via Harshberger Gap. Harshberger Gap is located approximately 3 km northwest of this stop. These deposits are part of a complex fan deposit that extends more than 5 km from Massanutten Mountain (Fig. N; Bell, 1986; Heller and Eaton, 2010).

Features

1. Bonnie Brook has developed along western edge of this fan, referred to in this report as the Harshberger fan, and separates transported material from residual soil on the slopes of Piney Mountain to the east. The modern drainage that discharges from Harshberger Gap is Stoney Run, which is located approximately 2 km to the southwest.
2. Harshberger fan deposits consist of poorly sorted, sub-round to sub-angular cobbles and boulders that are comprised almost entirely of Massanutten sandstone within a sandy loam matrix.
3. Bedding features have not been observed in other exposures of Harshberger fan deposits. Some upstream exposures appear to be matrix-supported and may have been deposited as debris-flows. In downstream exposures, the deposits are clast-supported.

Points of discussion

1. Are the sandstone clasts in this deposit similar in composition to Massanutten Sandstone?
2. What is the likely transport process that created this deposit?
3. How does this deposit compare to older fan deposits along Newport Road on the drive to stop 4, younger alluvial deposits at stop 4, and river terrace deposits along US 340 and US 33 between stop 4 and stop 5?

Figure 6.3. *Sub-rounded cobbles and pebbles of Massanutten sandstone in a loamy sand matrix, in the Harshberger fan, approximately 5 km southeast of Harshberger Gap. Hammer for scale.*

Interpretation

The Harshberger fan is mapped as an intermediate-age fan (Heller, 2010). Modern streams have developed along its flanks, but the fan is intact and not deeply incised. Deposits at the apex of the fan are as much 25 meters above the modern stream channels. The absolute age range of these fan deposits is unknown. The Harshberger fan is interpreted to be older than debris-flow and fan deposits that occur in and adjacent to active streams and younger than elevated, deeply incised or remnant fan deposits down slope from Cub Run and Runkles Gaps, and the deposit that caps the top of Piney Mountain.

Stop 6c - Piney Mountain deposit

Location: 38.38962 N, 78.71176 W
Unit: Martinsburg Formation overlain by alluvial fan deposits

This stop is located at the top of Piney Mountain, accessed from a private trail on the farm.

Features

1. Soil along the trail to Piney Mountain is residual and developed on the Martinsburg Formation, except where a diabase dike is mapped across the trail.
2. Near the top of the hill, unconsolidated deposits of cobbles and boulders of Massanutten Sandstone are observed. The deposit on top of Piney Mountain has not been observed in cross-section prior to this field conference. When exposed, it is expected to consist of sub-angular boulders and blocks of Massanutten Sandstone in a loamy sand to sandy loam matrix. At the top of the hill, the sandstone occurs as an intact capping of angular to sub-angular boulders and blocks of quartz sandstone and orthoquartzite in a loamy sand matrix.

Figure 6.4. *Boulders of Massanutten sandstone on top of Piney Mountain, approximately 3.6 km southeast of Harshberger Gap. These boulders occur as a capping that is believed to be a remnant of an older fan downslope from Harshberger Gap. Brunton for scale.*

Points of discussion

1. Is the sandstone in this deposit similar in composition to Massanutten Sandstone?
2. Is the sandstone derived from the weathering of in situ bedrock or transport-derived?
3. How does this deposit compare to older fan deposits along Newport Road on the drive to stop 4, younger alluvial deposits at stop 4, and river terrace deposits along US 340 and US 33 between stop 4 and stop 5?

Interpretation

Two origins have been offered for the quartz sandstone at this location. Brent (1960) suggested that the sandstone could have been derived from an intact layer of Massanutten sandstone preserved in a syncline. Bell (1986) interpreted the sandstone to be part of a pediment of transported material. Field work on the Elkton West quadrangle (Heller and Eaton, 2010) identified similar transport-derived cappings on other hill tops to the north and east, supporting the second interpretation. The distribution of these deposits is consistent with the presence of a second older, completely dissected, and largely remnant fan downslope of Harshberger Gap (Fig. N).

Cumulative Trip Mileage	Point to Point Mileage	Directions and Comments
59.7	0.0	Load buses. Leave B&B driveway, turn left on Bloomer Springs Rd.
61.0	1.3	Hank's Smokehouse on right - good barbeque!
61.1	0.1	Turn right (southwest) onto US33
71.0	9.9	Continue west on US 33 around southern toe of Massanutten Mountain (the nose of the eastern Massanutten syncline) and return to Harrisonburg.
72.5	1.5	Turn left on Cantrell Ave. and follow Memorial Hall parking lot.

End of Road Log

Optional Stops – Oswego(?) conglomerate and sandstone

Thick-bedded lithic conglomerate and lithic sandstone are reported at two localities at the southern end of Massanutten Mountain. With the possible exception of some imbrication, these gravels show no sedimentary structures. They are similar to the Oswego Sandstone that has been identified at Brock's Gap in Little North Mountain (Woodward, 1955; Brent, 1960; Diecchio, 1985), and in Duck Run Gap in Frederick County (Butts and Edmundson, 1966), but has not been previously mapped in Shenandoah or Page Valleys. Aside from the two specific localities discussed below no other Oswego-like exposures are known in the Massanutten Mountain region.

Localities

We will not visit these localities during the 2012 Field Conference, but they illustrate stratigraphic complexities related to the Ordovician-Silurian regional stratigraphy and geologic history. The two localities are:

OS1. Harshberger Gap (38.405737 N, 78.741978 W) at the southern end of Massanutten Mountain. This exposure has been observed by a number of geologists. Diecchio (1985) provides a measured section and location.

OS2. Batman Lane (38.493839 N, 78.662429 W). Travel west from Shenandoah, Virginia on Rt. 602, across the Shenandoah River. Turn right (north) on Rinacas Corner Road; follow it for several miles and turn left on Batman Road. In a few miles bear right on Batman Lane; park at the right angle bend in the road. Outcrop is in the woods to the west, a couple of hundred yards off the road towards the mountain. This approach crosses private property, so be sure to get permission before leaving the road. The outcrop can also be accessed by parking at the north end of the forest service road that runs parallel to, and east of, First Mountain and following

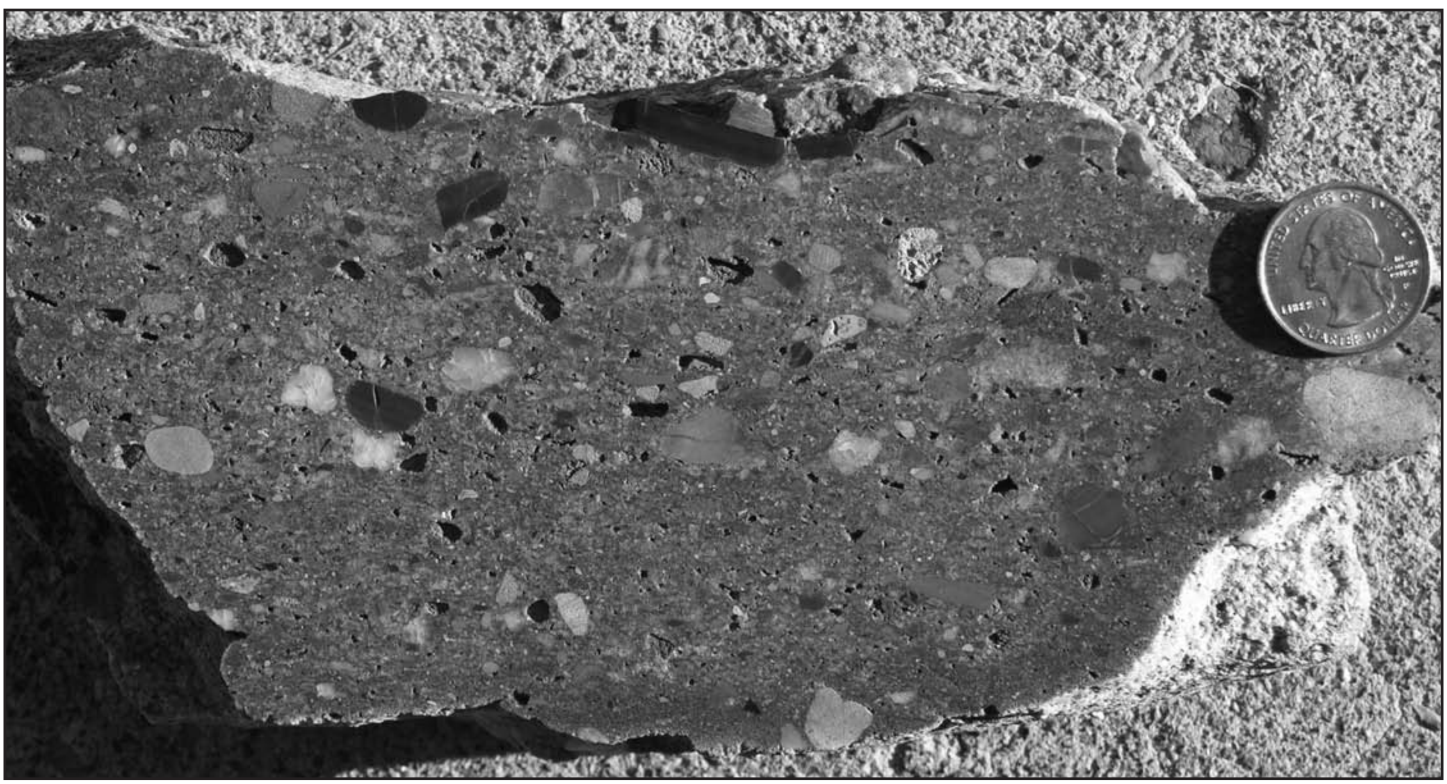


Figure OS2.1. *Polished slab of lithic conglomerate from the Batman Lane locality of the Oswego(?) exposure at Massanutten Mountain. This specimen has petrologic features similar to those of the Oswego Formation outcrop at Brocks Gap, Little North Mountain, and along VA 55 in Duck Run Gap through Short Mountain in Frederick County (Butts and Edmundson, 1966).*

the trail northeast to the stream. The outcrops are just upstream from the trail intersection. This road is not always open to traffic.

At this locality the Oswego(?) outcrops are next to a debris flow of Massanutten Sandstone, and superficially these rocks can look similar. However, a polished slab from this locality (Fig. OS2.1) shows an immature lithic conglomerate of similar composition to Oswego Formation outcrops in the western Valley and Ridge. Conglomerate was also observed approximately 600 meters NE along strike, but was not observed on a traverse near Peterfish Gap, approximately 2.5 km to the SW (Heller, 2010).

Features

The exposures tend to be weathered and partially covered (Harshberger Gap), or heavily lichen covered (Batman Lane) making it hard to see internal structures. The three things to look for are:

1. The composition of the gravels.
2. Any internal structures that will give depositional mechanisms.
3. Stratigraphic bedding patterns that might give information on depositional processes and/or incisement.

Interpretation

These outcrops have important implications for regional stratigraphy, paleogeography, and the evolution of both the foreland and hinterland. Diecchio (1985) provides an isopach map of the Oswego Formation in Little North Mountain and westward into the Valley and Ridge. The Oswego is thickest at Brock's Gap and thins south, west, and north. It is a lithic-rich, coarse, locally conglomeratic sandstone with generally <15 % matrix, and with abundant large scale planar and trough cross bedding; nominally a fluvial system.

If the Oswego was derived from a fluvial source to the east of Brock's Gap, we would expect to find an Oswego equivalent in the Massanutten Mountain area and might expect it to be thick. The only convincing outcrops of an Oswego-type lithology found in the Massanutten area are the Harshberger Gap (Diecchio, 1985) and the Batman Lane localities, and at both localities the stratigraphy is much thinner than would be expected if it is an Oswego equivalent. Working hypothesis: The Oswego is the fluvial system feeding the Juniata shoreline in the Valley and Ridge to the west during a sea level low stand (which led to the Martinsburg-Massanutten unconformity). The paucity of Oswego deposits in the Massanutten area is because this region, being closer to the source land, was an exposed region of Oswego river incisement. The Oswego river channel cut down into the exposed "Cub sandstone" shelf deposits. Most Oswego sediment flushed through the incised channels and got dumped in the west or northwest (e.g. Brock's Gap and Duck Run Gap). Left behind in the incised channel are more proximal fluvial gravels; e.g. Batman Lane and Harshberger Gap outcrops. It is important to remember that Brock's Gap and Massanutten Mountain, although geographically close today, were more widely separated in the past.

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The Shenandoah Iron Works, historic marker was erected in 2006 by Summers-Koontz #490, in partnership with the Shenandoah Valley Battlefields Foundation, Virginia Civil War Trails, and the Town of Shenandoah.

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Page County Records

Appendix A

Subdivisions and nomenclature of the Martinsburg Formation

The true Martinsburg Formation is restricted to the Massanutten Synclinorium, which underlies the Shenandoah and Page valleys and the Massanutten Mountain area. The Martinsburg Shale was named by Geiger and Keith (1891) after exposures in Martinsburg, West Virginia, its type area. The top of the Martinsburg, and overlying units are not present around Martinsburg, WV, having been removed by erosion. The upper contact of the Martinsburg Formation with the Massanutten Sandstone is preserved farther south within the Massanutten synclinorium, between Front Royal and Harrisonburg, Virginia, including the western part of the Page Valley.

Formal stratigraphic subdivision and nomenclature of the Martinsburg Formation is not straightforward. A discussion of the various stratigraphic designations is provided by Diecchio (1985). At the Northern end of Page Valley and in the Strasburg area, Rader and Biggs (1976) subdivided the Martinsburg into three informal lithologic units. The lower part is black shale and limestone, the middle part is sandstone and shale, and the upper part is sandstone. Their Martinsburg overlies the Oranda Formation, and is overlain by the Massanutten Sandstone. Just south of Page Valley in the Harrisonburg and Grottoes areas, the Martinsburg has been divided into a lower calcareous slate member, a middle argillite and slate member, and an upper sandstone and slate member (Gathright et al., 1978; Gathright and Frischmann, 1986). Their Martinsburg overlies the Oranda or Edinburg Formation, and is overlain by Massanutten Sandstone.

The only formally defined subdivision is that of the lower Martinsburg which has been formally named the Stickley Run Member by Epstein et al. (1995) after exposures along Stickley Run near Strasburg, Virginia. They define the Stickley Run Member as follows:

> "all rocks above the highest knobbly-weathering limestone of the Edinburg Formation up to and including all platy limestones that are interbedded with shale and graywacke of the Martinsburg; this includes rocks previously assigned to the Oranda Formation (abandoned herein). Consists of dark-gray, laminated to thin-bedded shaly limestone and calcareous shale. Thickness is 610 to 900 feet. Member is recognized on both limbs of the Massanutten synclinorium and thins to 350 feet at the south end of the synclinorium. Overlies the Edinburg Formation and underlies shale, siltstone, and graywacke of the Martinsburg Formation."

The Stickley Run Member is not well exposed in southern Page Valley, and we will not see it on this field trip.

In this field guidebook, we follow Rader and Biggs (1976) and Epstein et al. (1995), and designate the Martinsburg as lying above the Edinburg Formation, below the Massanutten Sandstone, and comprising three subdivisions which are, lower to upper, black shale and limestone, sandstone and shale, and sandstone.

Thornton (1953) notes that the lower Martinsburg is different on either side of Massanutten Mountain. On the Shenandoah Valley side of the mountain, the lower Martinsburg contains black shale and limestone. On the east side of the mountain, in the Page Valley, the lower Martinsburg contains black shale, argillite and thick beds of sandstone. Recent mapping by Heller (2010) in southern Page Valley has confirmed the presence of thick sandstone beds lower in the section (e.g. Stop 6a). These sandstone beds are interpreted to be in fault contact with calcareous shale of the Martinsburg or Edinburg Formation.

The middle part of the Martinsburg Formation, sandstone and shale, has not been assigned a formal name. We will see the middle part of the Martinsburg at Stop 3 where it is a series of Bouma sequences. At Stop 4, the sandstone and shale at the base of the section is mapped as middle Martinsburg however it is a hummocky bedded shelf sequence.

The upper Martinsburg is primarily sandstone and is commonly and informally referred to as the "Cub sandstone." However, Thornton (1953) informally designated the "Cub sandstone" as a unit that overlies the Martinsburg Formation. Today, the "Cub sandstone" is generally considered the upper part of the Martinsburg Formation.

Further confusion about the Martinsburg arises from differences found in equivalent age strata west of the Massanutten Synclinorium. Most workers have extended the name Martinsburg to include any shale that occurs between the Middle Ordovician limestones below, and the Oswego or Juniata Formations above. However, west of Little North Mountain this stratigraphic interval does not contain the black shale and limestone of the lower Martinsburg, or the Bouma sequences of the middle Martinsburg (Fig. F). Instead, equivalent strata, which we refer to as the Reesdville Formation, contain hummocky-bedded gray to brown shale, with interbedded limestones (micrites and mega-rippled bioclastic grainstones and packstones) in the lower horizons, and interbedded siltstone and sandstone in the upper horizons.

Appendix B

Outcrop Observational Tools for Stratigraphic/Sedimentologic Interpretations

Signatures in the Stratigraphic Record

Signatures are patterns in the stratigraphic record that nest in a fractal hierarchy (e.g. laminations nested within beds, beds nested within bedsets, bedsets nested within parasequences, etc.), as illustrated in Figure B1. Beds and bedsets can be observed in small, single outcrops. Parasequences (4th and 5th order sequences) can usually be delineated with several 10s of meters of section. 3rd order sequences (a.k.a. composite sequences composed of two or more parasequences) require up to a couple of hundred meters (in sequence theory these are systems tracts). 2nd order sequences and above cannot be picked up in one outcrop, except on cratons where stratigraphic sequences tend to be thinner, or in the west where sparse vegetation and dramatic uplift provide much thicker exposures. In some circumstances we focus on laminations (hummocky delineation and interpretation in the "Cub sandstone"), in others bedsets (e.g. Bouma and hummocky sequences), and in others parasequences ("Cub sandstone"). Most of the outcrops we visit restrict us to signatures smaller than 3rd order, except for the unconformity at the base of the Massanutten Sandstone which is a 1st order sequence boundary.

Types of Cross-Stratification

Depositional energy is not preserved; it is dissipated. However, while it is being dissipated it may mold sediments into patterns—sedimentary structures—such as ripples, cross beds, and graded bedding. Energy dissipation may be

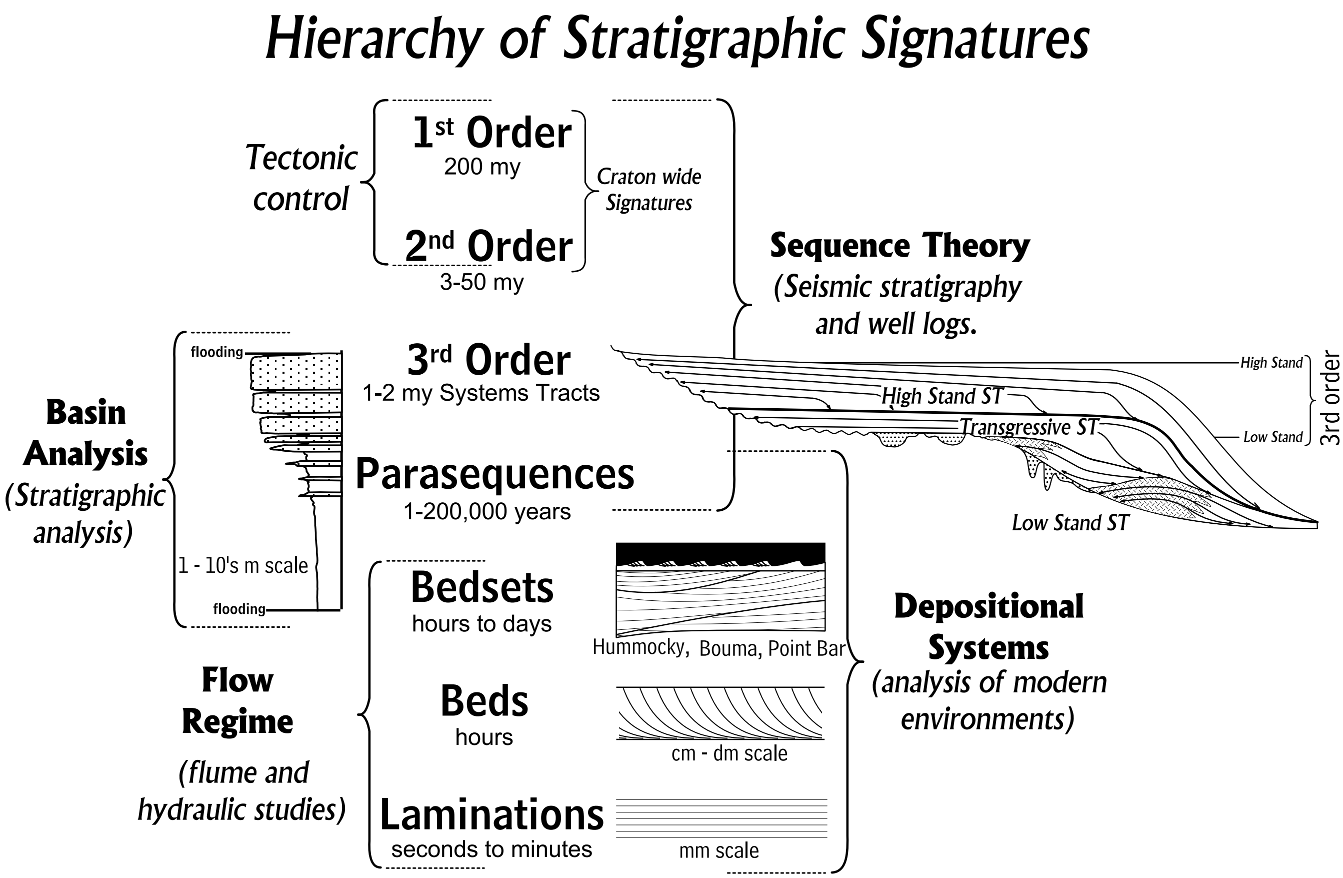

Figure B1. Hierarchy of stratigraphic signatures. Patterns in the stratigraphic record form from a diversity of mechanisms, over a range of time scales. They are studied with different tools and cannot all be observed at the same time. Making sense of the stratigraphic record requires knowing where one is in the hierarchy at all times. Tectonic interpretations are made with evidence from several of the levels, but they do not all tell us the same thing, and are not all equally useful.

unidirectional, or oscillatory, or any combination in between. Cross stratifications (cross beddings) are diverse and ubiquitous, and are sometimes unique to specific environments.

One step up from beds in the signature hierarchy (Fig. B1), bedsets are distinctive to depositional environments, e.g. Bouma, point bar, hummocky, L-Bar-T-Bar, etc. Bedsets vary in systematic ways across a depositional environment, facilitating interpretations of environmental facies and environmental evolution. On this field trip we will see two major kinds of cross stratification: hummocky cross stratification (a combined flow regime) such as we find in the upper Martinsburg "Cub sandstone", and large scale planar and trough cross stratification (a unidirectional flow regime) like we find in the Massanutten Sandstone. Hummocky cross stratification is almost always associated with a shelf facies, although it grades into trough cross stratification. Planar and trough cross stratification are typical of shoreface and river environments, but are not confined to them. Differentiation can be subtle, since even within one kind of cross bedding there are many variations, and what we have available to observe is subject to the exposure and weathering of the outcrop. Figure B2 illustrates some of the features that distinguish different kinds of cross stratification. Some of the observations and interpretations we need to make on this field trip to test the subsidence/accommodation model are based on stratification types. For example, the representation of the "Cub sandstone" as a shallower facies (less accommodation in the basin evolution) than the middle Martinsburg is based on its interpretation as a shelf environment though the identification of hummocky cross stratification at the outcrop.

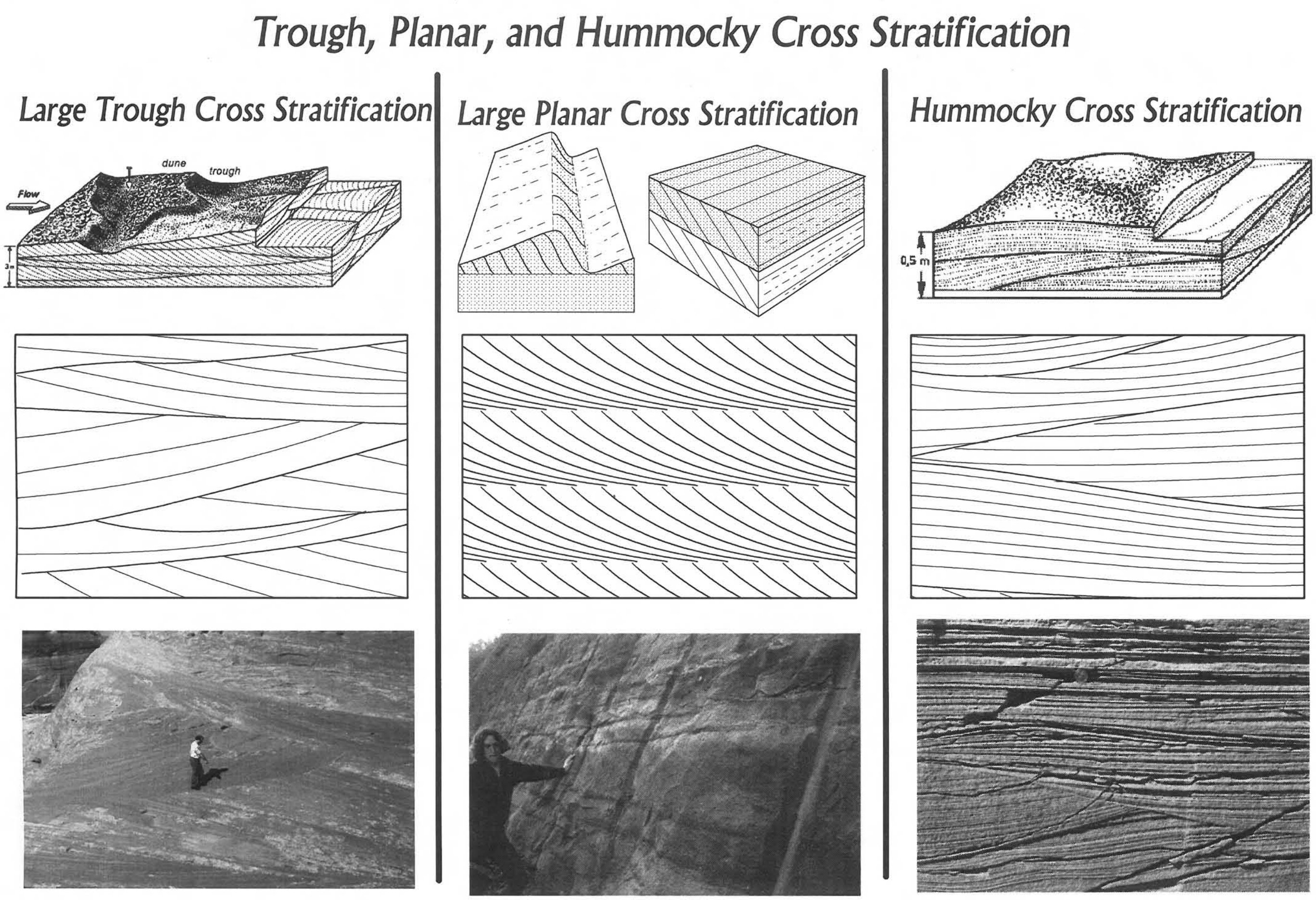

Figure B2. *Hummocky cross stratification consists of bundles of laminations ranging from almost flat to undulating bundles that thicken and thin. Except when scoured by overlying bundles the bundles rise and fall at angles that are almost always less than 15°. Conversely, planar and trough crossbed foresets always curve upward with no hint of rolling over, and abruptly truncate at the top of the cross bed. Planar cross beds in side view maintain thickness for extended distances down the outcrop, and several sets may stack on top of each other. Trough cross beds, because overlying troughs are always cutting into underlying ones, result in cross beds sets sharply angling downward and away from each other, like teepee structures.*

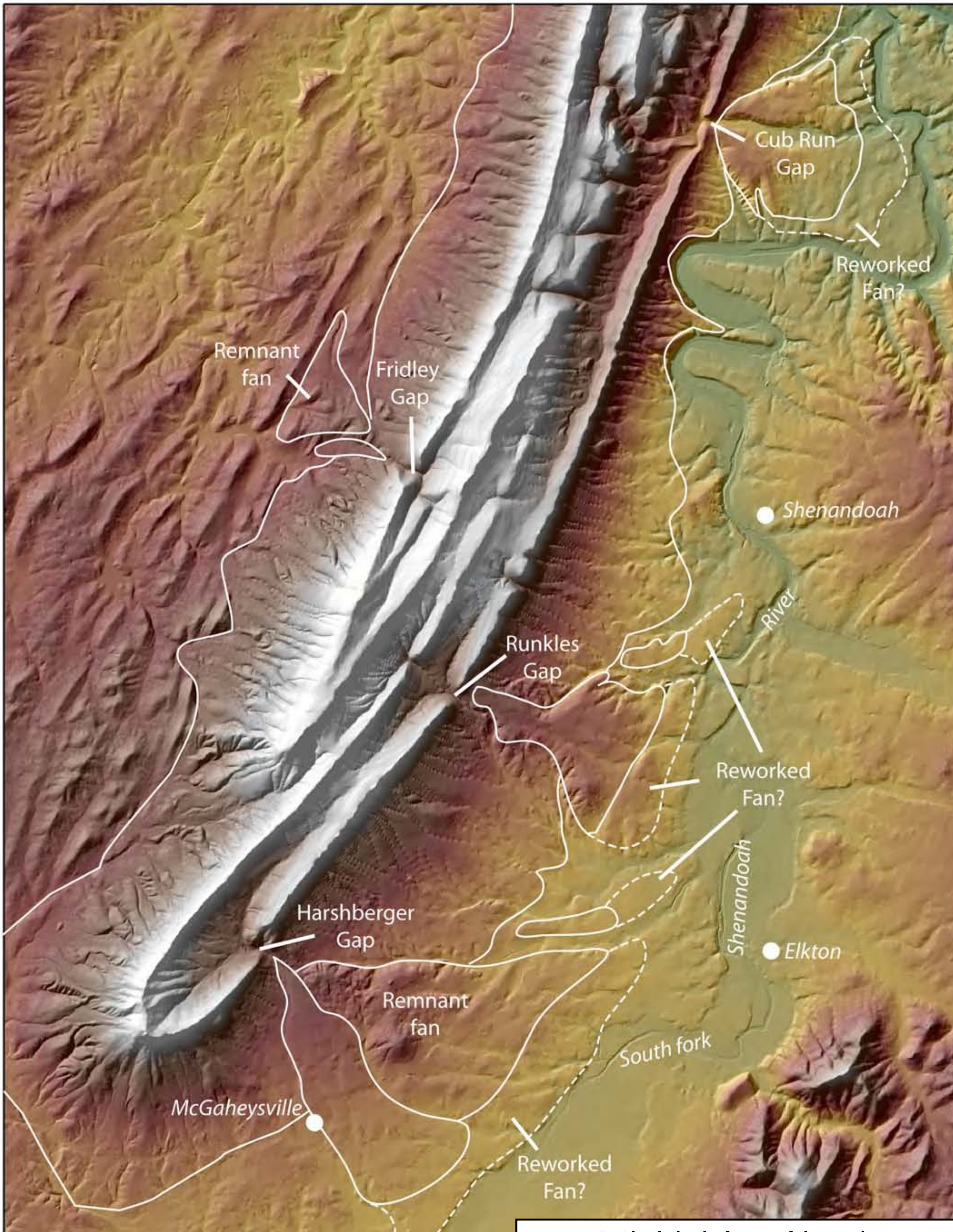

Figure C: *Shaded relief map of the southern part of the Massanutten Mountains showing the locations of significant water gaps and associated fans, and the approximate extent of debris-flow and associated deposits.*

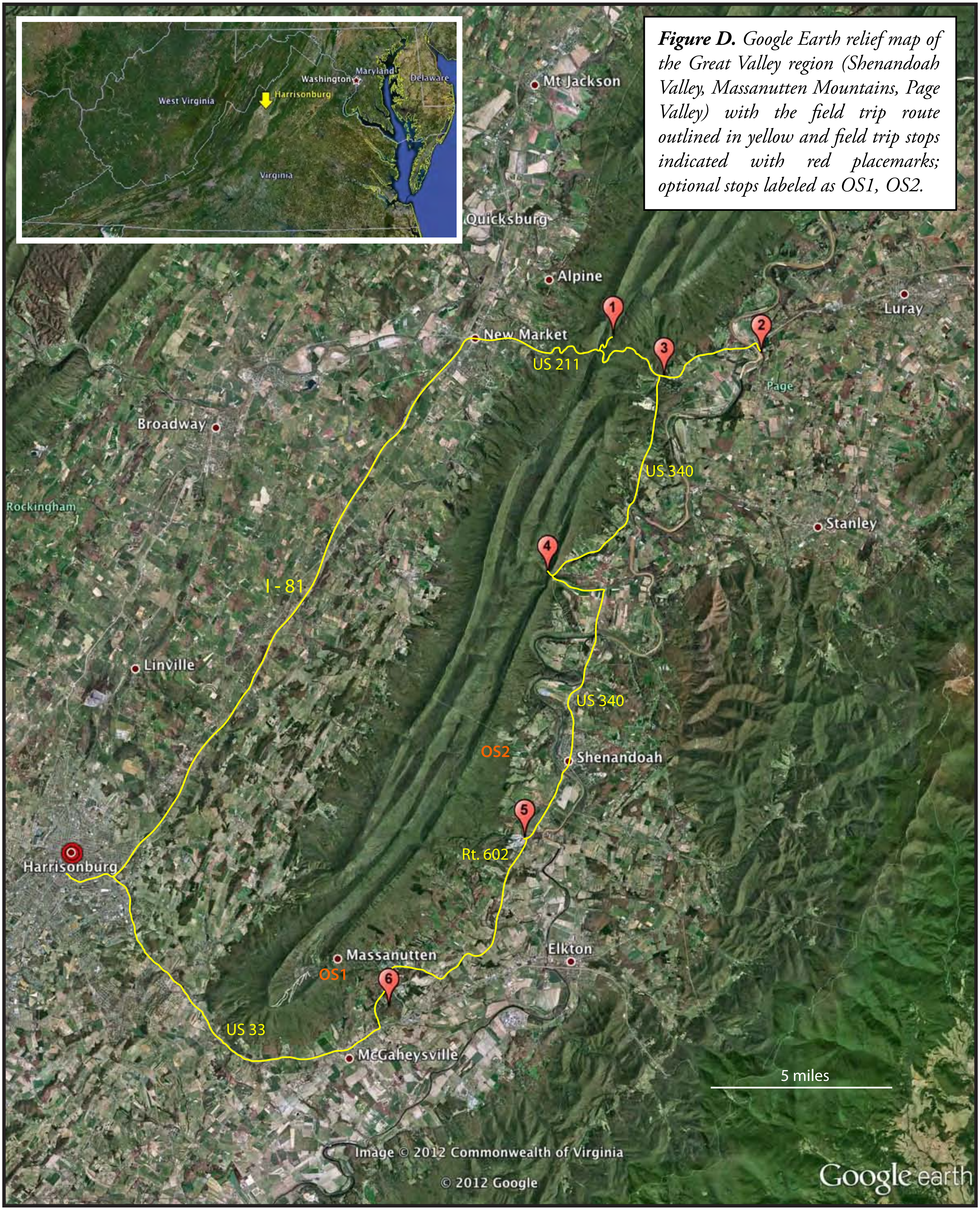

Figure D. *Google Earth relief map of the Great Valley region (Shenandoah Valley, Massanutten Mountains, Page Valley) with the field trip route outlined in yellow and field trip stops indicated with red placemarks; optional stops labeled as OS1, OS2.*