12th International Symposium on the Ordovician System

ORDOVICIAN OF GERMANY VALLEY, WEST VIRGINIA

MID-CONFERENCE FIELD TRIP

June 10th, 2015

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LEFT—Rick Diecchio examining a K-bentonite bed in the Nealmont Limestone at the Arc Hollow section, Stop 4. Photo by J.T. Haynes.

RIGHT—Rick Lambert looking at laminated and fenestral lime mudstones of the McGlone Limestone in the North Fork Quarry, Stop 4. Photo by J.T. Haynes

INTRODUCTION

Welcome to the Conference field trip that is a part of the 2015 International Symposium on the Ordovician System meeting! This trip will consist of stops at five locations (Fig. 1) that provide a detailed look at the strata in a major part of the Ordovician section in Germany Valley, Pendleton County, West Virginia. At these stops, we will highlight a varied sequence of carbonate and siliciclastic strata that accumulated during the Middle to Late Ordovician, and which record changes in depositional environments associated with Taconic tectonic activity.

The older carbonate strata record the final stages of deposition in a widespread epeiric sea that existed across much of the Laurentian craton and shelf margin from the Middle Cambrian into the Middle Ordovician. Going upsection, we will see how depositional environments changed from peritidal and shallow shelf settings (New Market Limestone, Lincolnshire Limestone, Big Valley Formation, McGlone Limestone, and McGraw Limestone), to deeper shelf settings (Nealmont Limestone, Dolly Ridge Formation, and lower part of the Reedsville Shale) that record a gradually but steadily increasing amount of siliciclastic mud coming into the basin, to deeper slope and basin margin settings (upper part of the Reedsville Shale) where dark gray mud accumulated in response to an increase in the accommodation space in the Taconic foredeep. Maximum flooding in this sequence occurred at the base of the Reedsville Shale, and was followed by a gradual shallowing during the later Ordovician to shelf and nearshore environments (upper part of Reedsville Shale, *Orthorhynchula* biozone, Oswego Sandstone, and Juniata Formation) that were dominated by siliciclastic rather than carbonate sediments.

BACKGROUND AND GEOLOGIC SETTING

In the Germany Valley area of West Virginia, an estimated 1200 m (4500 feet) of Ordovician strata are exposed, and a brief description of these stratigraphic units follows Table 1.

NAME	THICKNESS IN METERS (FEET)*	REFERENCES
Juniata Fm	224 m (736 ft)	Diecchio, 1985
Oswego Ss	56 m (182 ft)	Diecchio, 1985
Reedsville Sh	605 m (2000 ft)	Ryder, 1992
Dolly Ridge Fm	123 m (405 ft)	Perry, 1972
Nealmont Ls	80 m (265 ft)	Kay, 1956; Perry, 1972; Martin et al., 2014
McGraw Ls	9.5 m (31 ft)	Kay, 1956; Perry, 1972; Martin et al., 2014
McGlone Ls	18 m (60 ft)	Kay, 1956; Perry, 1972; Martin et al., 2014
Big Valley Fm	36.5 m (121 ft)	Kay, 1956; Perry, 1972; Martin et al., 2014
Lincolnshire Ls	10 m (33 ft)	Kay, 1956; Perry, 1972; Martin et al., 2014
New Market Ls	10.5 m (35 ft)	Kay, 1956; Perry, 1972; Martin et al., 2014

*These thicknesses are an average of reported prior measurements, including those herein.

TABLE 1.—Stratigraphic units exposed in Germany Valley, and their approximate thickness in the vicinity of the field trip stops. Fm = Formation; Ls = Limestone; Sh = Shale; Ss = Sandstone.

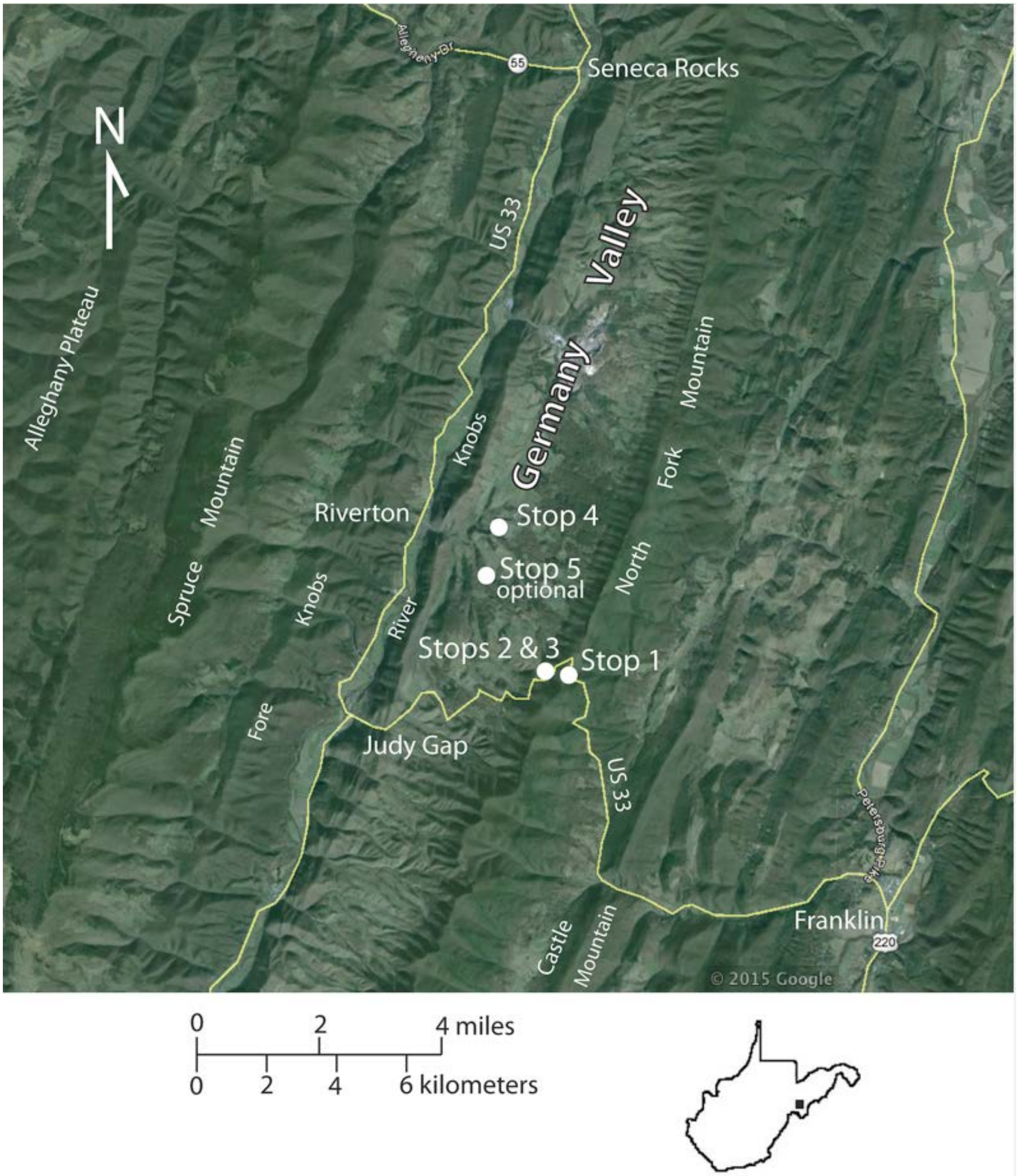

Figure 1.—Location of field trip stops and selected features in and around Germany Valley, in west-central Pendleton County, West Virginia.

New Market Limestone

The New Market Limestone, which has its type section in Shenandoah County, Virginia (Cooper and Cooper, 1946), is typically a light to medium gray fenestral ("birds eye") lime mudstone that commonly breaks with a conchoidal fracture. A few fossil gastropods, ostracodes, and corals have been reported at some outcrops (Butts, 1940; Kay, 1956), although at many outcrops it appears that most of the numerous examples of what have long been thought to be the coral *Tetradium syringoporoides* are in fact just fenestral pore spaces ("birdseyes") or burrows, which have subsequently been filled with sparry calcite. On account of its compositional purity and homogeneity, the New Market Limestone is valued for cement manufacturing operations. For this reason, the New Market Limestone is the main rock being obtained in the large quarrying operation to the north of Arc Hollow, in the center of Germany Valley along the axis of the Germany Valley anticline (Fig. 2).

The fenestral lime mudstone of the New Market Limestone is interpreted as having accumulated in a quiet muddy environment, probably shallow subtidal to high intertidal to supratidal, with the abundant fenestrae originally being gas bubbles from decaying organic matter that were trapped in the sediment and preserved as fenestral porosity (Grover and Read, 1978). If fossil corals are as abundant as Butts (1940) and Kay (1956) suggested, then the presence of coral in the New Market should be accompanied by other marine organisms that were common at this time and that thrived in open marine environments, perhaps especially brachiopods, bryozoans, trilobites, and crinoids. Yet when compared to the younger Lincolnshire Limestone and Big Valley Formation with their small reefs and buildups in this region (Kay, 1956; Cuffey, 2003; Cuffey et al., 2000), the overall lack of a diverse and open marine fauna in most exposures of the New Market seems problematic. This observation further supports our conclusion that much "*Tetradium*" in the New Market Limestone is actually just fenestrae.

The New Market – Lincolnshire contact in this region is a disconformity with relief up to 30 cm. At many outcrops along and across strike from here east and southeast toward the Shenandoah Valley, the contact between the New Market Limestone and the overlying Lincolnshire Limestone displays small pinnacles (up to approximately 20 cm relief), which have been described in some published measured sections (Kay, 1956; Read and Grover, 1977). At the Arc Hollow section (Stop 4), however, no pinnacles have been observed thus far along the contact, even though it is well exposed in several places. Nonetheless, there is an abrupt lithologic change from the lighter gray fenestral lime mudstone of the New Market Limestone to the darker gray bioclastic packstone and grainstone of the Lincolnshire Limestone.

The abrupt nature of the Lincolnshire-New Market contact suggests that the uppermost bedding surface of the New Market Limestone was exposed subaerially for some time before being flooded during the sea level rise that resulted in accumulation of the sediments of the Lincolnshire Limestone. This interpretation is consistent with previous studies, which have interpreted the contact as a paleo-epikarst and(or) a wave-cut platform surface (Kay, 1956; Read and Grover, 1977).

Lincolnshire Limestone

The New Market Limestone is overlain by the Lincolnshire Limestone, which has its type section in Tazewell County, Virginia (Cooper and Prouty, 1943). The Lincolnshire Limestone is characteristically a dark gray bioclastic packstone to grainstone to patches of boundstone, with an abundant and diverse assemblage of marine fossils including brachiopods, bryozoans, echinoderms including crinoids and cystoids, trilobites, corals, sponges, cephalopods, and pelecypods (Butts, 1941; Woodward, 1951; Kay, 1956). At some outcrops in the Arc Hollow section, small 4-6 cm high domal stromatolites are present in the basal bed of the Lincolnshire Limestone, immediately above the contact with the underlying New Market Limestone (Fig. 3).

In the Arc Hollow section, black chert lenses and nodules are present in two beds of the Big Valley Formation, and in one bed of the Nealmont Limestone. Common to abundant lenses, nodules, and discontinuous beds of hackly and variably fractured black chert are typical in the Lincolnshire Limestone throughout its extent from southwest Virginia to this region, although Kay (1956) noted, and we have confirmed, that the exposures in Germany Valley are far less cherty than elsewhere. Also of stratigraphic importance is that the presence of black chert is not unique to the Lincolnshire Limestone in the Ordovician sequence of this region, and in fact Kay (1956) described up to six intervals with black chert in the Ordovician limestones that he studied.

Figure 2.—Rick Lambert on the upper beds of the New Market Limestone in a tributary to the main stream valley in Arc Hollow, near Stop 4. Photo by J.T. Haynes.

Figure 3.—Eroded tops of several domal stromatolites on the upper bedding plane of the lowest bed in the Lincolnshire Limestone, which directly overlies the New Market Limestone. Exposure in stream valley in Arc Hollow, near Stop 4. Photo by J.T. Haynes.

In the Arc Hollow section, the bed of small domal stromatolites (Fig. 3) is interpreted as a short-lived(?) microbial community that developed in the initially very shallow waters that transgressed across the now-inundated disconformity (i.e., the regionally extensive paleo-epikarstic surface, immediately following initial flooding of that surface during the sea-level rise that initiated deposition of the more open-marine sediments of the Lincolnshire Limestone). This interpretation of the stromatolites is consistent with previous interpretations of the Lincolnshire Limestone as the initial unit in a deepening-upward sequence that accumulated in an open shallow shelf to ramp setting during initial stages of a regionally widespread transgression (Read, 1980).

Big Valley Formation

The Lincolnshire Limestone is overlain by the Big Valley Formation, named by Bick (1962, p. 11-14). Because Bick did not designate a specific type section for the Big Valley

Formation, but instead described three reference sections, we herein designate the Big Valley section of Bick (1962, p. 12) in southern Highland County, Virginia, to be the type section of the Big Valley Formation.

In Germany Valley the Big Valley Formation is a heterogeneous unit of shaly weathering, argillaceous, nodular bedded lime mudstone, sparsely to moderately fossiliferous wackestone and packstone, and less common grainstone, with a very few lenses and nodules of black chert (Fig. 4). At the Arc Hollow section in particular, the Big Valley Formation has common to abundant thin, argillaceous partings. Some or all of these might be bentonitic, and possibly correlative with potassium bentonites (K-bentonites) of the "Tumbling Run complex" (Fetzer, 1973, p. 101) of the lower Edinburg Limestone in the Shenandoah Valley to the east, a zone of altered tephra layers that is well-exposed along Tumbling Run in Shenandoah County (Haynes et al., 1998) where it will be seen on the post-meeting field trip. These argillaceous partings in the Arc Hollow section are at approximately the same stratigraphic interval as the "Tumbling Run complex" in the lower Edinburg Limestone, although the total thickness of the section in Arc Hollow is greater than at Tumbling Run.

Although no biohermal or biostromal layers have been observed to date in exposures of the Big Valley Formation in Germany Valley, Kay (1956) and Cuffey et al. (2000) described thickets or small buildups consisting of bryozoans, sponges, corals, and other organisms in correlative exposures of the Ward Cove and Benbolt Limestones to the south in Virginia.

In Arc Hollow, the Big Valley Formation is interpreted as shallow peritidal to open shelf carbonates, an interpretation that fits in with the observed sequence both downsection stratigraphically (the New Market and Lincolnshire Limestones) and upsection stratigraphically (the McGlone and McGraw Limestones) from the Big Valley Formation. Furthermore, this interpretation is consistent with regional interpretations of the correlative Benbolt Limestone as having accumulated in a relatively deeper (yet still shallow enough to be in the photic zone) slope or ramp environment that developed during the middle and late Ordovician along the margin of the Taconic foredeep, during the time of maximum inundation associated with a regionally extensive transgression of the Laurentian margin (Read, 1980). And following the ideas of Cecil (2004, 2012), the lenses of chert might be interpreted as eolian dust that accumulated in a marine environment.

The Big Valley Formation (Bick, 1962) was proposed and named because of difficulties that Bick encountered with attempts at stratigraphic correlations from southwestern Virginia to Bath and Highland Counties. The Big Valley Formation includes strata that are equivalent to the Ward Cove Limestone, Peery Limestone, and Benbolt Limestone as mapped in southwestern Virginia (Cooper and Prouty (1943; Kay, 1956).) Kay (1956) had likewise encountered problems using these three names in Germany Valley, and he suggested (Kay, 1956, p. 82) that the name Hatter Formation (Kay, 1944) from Pennsylvania might be used instead, but he did not use the name. Bick (1962) also had difficulties applying stratigraphic names from southwestern Virginia to Highland County, just south of Germany Valley, and he opted for the new name Big Valley Formation. Perry (1972) also used Big Valley Formation rather than Ward Cove

Limestone, Peery Limestone, and Benbolt Limestone, but Perry (1972) also included the thin Lincolnshire Limestone in his definition of the Big Valley Formation as well. In descriptions of the United Fuel No. 8800-T Sponaugle well in Pendleton County, Ryder (1992) used the terms Ward Cove Limestone, Peery Limestone, and Benbolt Limestone, but in subsequent descriptions of this well, Ryder et al. (2008) simply used the name Black River Group for all of the strata described in this paper as New Market Limestone through McGraw Limestone. Most of the Big Valley Formation in Germany Valley is what Kay (1956) recognized and described as the Benbolt Limestone, and indeed Martin et al. (2014) mapped most of this same stratigraphic interval of shaly and nodular-bedded limestone as the Benbolt Limestone, and did not recognize either the older Ward Cove or Peery Limestones. Use of the name Big Valley Formation, however, seems warranted because of the same uncertainties that were encountered by others in this area.

Figure 4.—Rick Lambert at a low bluff of the Big Valley Formation in Arc Hollow near Stop 4 pointing to black chert nodules along a bedding plane (inset, upper left). Del Martin (left) and Rick Diecchio are in the stream bed. Photo by J.T. Haynes.

McGlone Limestone

The Big Valley Formation is overlain by the McGlone Limestone, which has its type section in Alleghany County, Virginia (Kay, 1956, p. 66; 82-83). The McGlone Limestone is a heterogeneous unit of light gray fenestral lime mudstone, darker gray peloidal and bioclastic grainstone and packstone, and laminated lime mudstone that in places is burrowed and exhibits possible desiccation(?) cracks; some wackestone is also present (Fig. 5). Following Kay (1956) and Bick (1962), the contact between the Big Valley Formation and the overlying McGlone Limestone is placed at the change from a regionally extensive 3-4 m thick interval of cross-laminated silty to fine-sandy to dolomitic packstone and wackestone in the uppermost Big Valley Formation (Benbolt Limestone of Kay, 1956), to interbedded fenestral and laminated lime mudstone and peloidal and bioclastic grainstone of the lower part of the McGlone Limestone. At the North Fork quarry (Fig. 5; part of Stop 4), the Big Valley – McGlone contact is located at

Figure 5.—Rick Lambert in the North Fork quarry looking at shallowing upward cycles in the McGlone Limestone, which will be seen at Stop 4. Photo by J.T. Haynes.

the eastern end of the quarry, approximately 49 -50 m above the base of the Arc Hollow section, as marked by the tags in the quarry wall.

The McGlone Limestone and its stratigraphic equivalents in sections farther south and southwest (Gratton, Wardell, Bowen, and lower Witten Limestones of Cooper and Prouty, 1943) are part of an overall shallowing-upward sequence that accompanied a regionally extensive regression (Read, 1980) associated with the Blountian phase of the Taconic orogeny in the southern Appalachians. The McGlone Limestone, with its interbedded peloidal grainstone and fenestral and laminated lime mudstone, likely represents alternation of higher energy skeletal shoal and channel deposits and lower energy, peritidal mudflats that at times were overlain by rippled peloidal sands transported from shallow subtidal or intertidal environments. Deposition of the more massive fenestral lime mudstone also occurred in lower energy peritidal mudflats subsequent to shallowing of channeled sand flats (Read, 1980).

McGraw Limestone

The McGlone Limestone is overlain by the McGraw Limestone, which has its type section in Alleghany County, Virginia (Kay, 1956, p. 66; 83-84). The McGraw Limestone is a thick-bedded massive black lime mudstone with abundant tubular burrows that were identified by Kay (1956) as *Camarocladia* sp., and which are commonly filled with less resistant sediment that weathers more readily, leaving behind burrow moldic porosity (Fig. 6). Even in the walls of the North Fork quarry (Stop 4), where the surface of the rock is relatively unweathered, the compositional difference between the burrows and the sediment that fills them, and the surrounding black micrite, is readily seen on close inspection. Other than these burrows, the McGraw Limestone is sparsely fossiliferous. The comment about the regional character of the McGraw Formation by Kay (1956, p. 83), that the "...uniformity of lithology is paralleled by a persistence of small thickness" seems more true today based on observations of similar lithologies at this approximate stratigraphic interval in exposures from Alabama to Pennsylvania.

The McGraw Limestone is interpreted as having accumulated in a muddy, restricted marine environment and (or) shallow peritidal environment where few shelly organisms were living, but evidently there was an abundance of soft-bodied organisms that were burrowing into the lime mud. The McGraw Limestone of Germany Valley is the uppermost unit of a shallowing upward sequence that began with the upper Big Valley Formation, and so the lack of a diverse fauna in the carbonate sediments of the McGraw is perhaps expected, as deeper water conditions did not return until the sediments that accumulated above the transgressive surface that separates the lime mudstone of the McGraw Limestone from the overlying fossiliferous beds of the Nealmont Limestone.

The contact of the McGlone Limestone and the McGraw Limestone is one of the key discussion topics at Stop 4 on the field trip. Kay (1956) used the presence of *Cryptophragmus antiquatuus* Raymond in the uppermost beds of the McGlone to guide his placement of the contact, and he stated "The basal contact of the McGraw with the McGlone is invariably sharp, as the McGlone commonly has *Cryptophragmus*-bearing calcarenite, particularly in more southerly sections, or plane-bedded calcilutite." The use of a fossil appearance or disappearance is no longer considered acceptable for determining a stratigraphic contact as per the North

American Stratigraphic Code and its restrictions on the use of "biological sequence" in setting lithostratigraphic formation boundaries vs. biozones (North American Commission on Stratigraphic Nomenclature, 2005), and so an obvious alternate criterion for identifying the top of the McGlone Limestone is the "invariably sharp" basal contact mentioned above by Kay (1956, p. 83). In the quarry wall at the southwest end of the exposure, there are two possible such sharp contacts (Fig. 7), and this site would be an appropriate place for thoughts and discussion on which contact might best be chosen as the McGlone – McGraw boundary.

Nealmont Limestone

The McGraw Limestone is overlain by the Nealmont Limestone, which has its type section in Huntingdon County, Pennsylvania (Kay, 1941, 1943). The Nealmont Limestone consists of shaly and thinner-bedded limestone that Kay (1956) noted is correlative with the upper part of the "*Camarocladia*" zone of Cooper and Prouty (1943). Indeed, several of the limestone beds in the Nealmont at the Arc Hollow section contain abundant burrows of "*Camarocladia.*" Otherwise, the presence of these burrows in both the McGraw and the Nealmont is one of the

Figure 6.—Rick Lambert pointing out recessively weathered burrows in the McGraw Limestone, in Arc Hollow, near Stop 4. These trace fossils are "*Camarocladia*" of Kay (1956). Photo by J.T. Haynes.

few characteristics shared by these two stratigraphic units.

The McGraw – Nealmont contact is identified by an increase in partings and thin beds of shale that occur upsection with increasing frequency, and by the relatively abrupt appearance of abundant brachiopods in thin beds and on bedding planes. The contrast in both bedding thickness and the limestone:shale ratio between the underlying McGraw and the overlying Nealmont is striking, even though the contact is transitional over a 2-3 m interval. Kay (1956) noted that the McGraw to Nealmont transition is characterized in particular by the presence of argillaceous limestone that have abundant *Pionodema* and *Doleroides*, and less common *Sowerbyella*, *Resserella*, and *Hesperorthis*, and that throughout the region, these beds of brachiopod grainstone and packstone are invariably within a meter of the base of the Nealmont.

Figure 7.—John Haynes pointing to beds of light gray laminated fenestral lime mudstone in the upper part of the McGlone Limestone, and the sharp contact with overlying beds of darker gray wavy laminated bioclastic wackestone and packstone. This contact, seen at Stop 4, is one of the two "candidates" for the McGlone – McGraw contact. Photo by R.C. Orndorff.

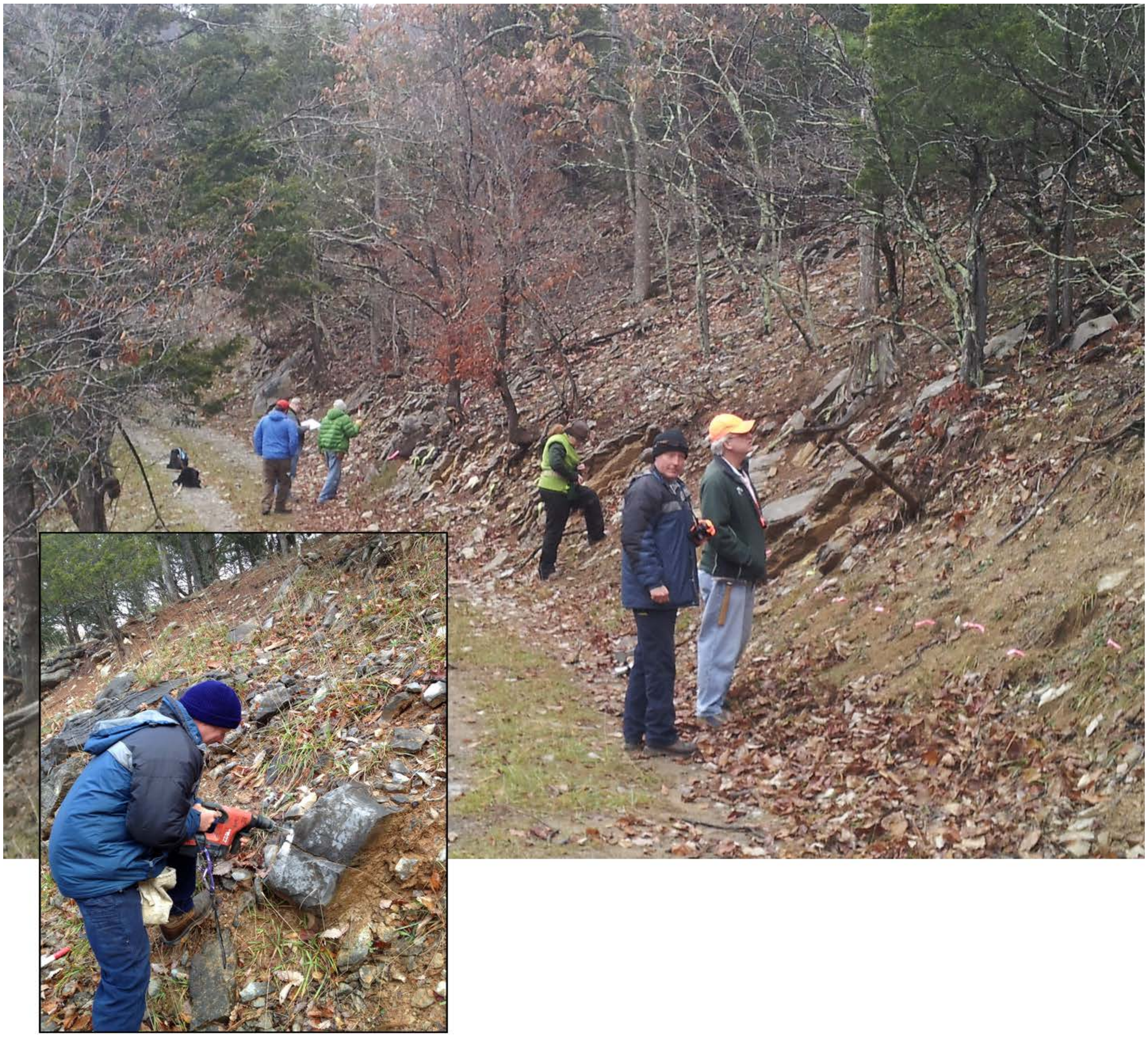

Figure 8—From right to left in main photo: John Haynes, Rick Lambert, Lisa Goggin, Rick Diecchio, Keith Goggin, and Alan Pitts collectively working to measure and describe the Nealmont Limestone at the Arc Hollow section, Stop 4. Subsequent to completion of the measurements and descriptions, Rick Lambert and John Haynes placed labels at regular intervals with the measurement in meters (inset at lower left). Photo by R.C. Orndorff, inset photo by J.T. Haynes.

This abrupt appearance of abundant shelly fossils is evident at the Arc Hollow section (Stop 4).

Of regional interest, this contact also records the classic “Trenton transgression” that is associated with the “Black River – Trenton” contact so familiar to workers in North America (e.g., Ryder et al., 2008). In Germany Valley, the fenestral lime mudstone of the McGlone Limestone is a classic “Black River Limestone” lithology, and the overlying bioclastic grainstone and packstone of the Nealmont Limestone are classic “Trenton Limestone” lithologies. The Katian – Sandbian contact is probably within the Nealmont Limestone as well, but detailed biostratigraphic work has not yet been done at the Arc Hollow section.

The medium to thin-bedded, light to medium gray limestone beds of the Nealmont Limestone include laminated lime mudstone, some of which are moderately to intensely bioturbated beds with "*Camarocladia*" burrows, and bioclastic wackestone and packstone, with less common grainstone. The grainstone lithology collectively includes beds with many intact or nearly intact fossils, especially gastropods and brachiopods, and beds of comminuted skeletal debris of varying sizes and shape (Fig. 8). Kay (1956) aptly described some of these fossiliferous beds as "coquina." Burrows are common only in some thin beds of the Nealmont Limestone, in contrast to the thick beds of extensively bioturbated limestone in the underlying McGraw Limestone. Other lithologies within the Nealmont Limestone include beds of light gray shale, a few chert nodules, and some beds of K-bentonite. These bentonite beds, however, have not yet been positively correlated with any regional extensive beds such as the Deicke or Millbrig K-bentonites of the widespread Hagan complex (Kolata et al., 1998).

The McGraw-Nealmont contact is interpreted as a transgressive surface, and the overlying Nealmont Limestone is interpreted as having been deposited in a higher-energy, open shelf setting, where mud entered at times, perhaps in association with storms (Carter et al., 1988). Burrows are less common in the Nealmont Limestone than in the underlying McGraw Limestone, perhaps as a result of more extensive predation during deposition of the Nealmont, or higher energy conditions that disrupted the previously quieter mud of the McGraw, or some other degree of restriction. Like the Lincolnshire Limestone downsection, the Nealmont Limestone is the oldest unit in a deepening-upward sequence that continues upsection through the entire Dolly Ridge Formation, and ends at the maximum flooding surface in the lower part of the Reedsville Shale.

Dolly Ridge Formation

The Nealmont Limestone is overlain by the Dolly Ridge Formation, the type section of which is in Pendleton County, West Virginia (Perry, 1972), and Perry's type section is in fact Stop 5 of the field trip. The lower Dolly Ridge Formation is a sequence of interbedded shale and cobbly weathering lime mudstone that is black on a fresh surface but weathers almost white, as compared to the lighter gray limestone of the Nealmont Limestone on both fresh and weathered surfaces. The contact of the Nealmont Limestone and the overlying Dolly Ridge Formation (Stops 4 and 5) is placed at the first prominent greenish gray shale between the ledges of light gray limestone that are of distinctly Nealmont character, and the ledges of black micrite (that weather almost white) that are of distinctly Dolly Ridge character (Fig. 9). This greenish gray shale of the Dolly Ridge Formation contrasts with the light gray shale downsection that is typical of shale in the Nealmont Limestone.

The interbedded shale and cobbly weathering lime mudstone that forms the basal part of the Dolly Ridge Formation is overlain by the main part of the Dolly Ridge Formation, which consists primarily of interbedded argillaceous limestone, much of which is cobbly weathering (Fig. 10), dark gray to olive gray shale, and several K-bentonite beds (Perry, 1972). Perry (1972) reported scattered occurrences of *Cryptolithus* and *Isotelus* in the Dolly Ridge Formation, along with *Sowerbyella* and *Dalmanella*, as well as several thin beds of fossiliferous limestone containing fragments of unidentified brachiopods, crinoids, and other bioclasts. In the upper few meters of the Dolly Ridge Formation, the limestone beds abruptly become thinner and thinner, until the entire sequence becomes dark gray shale that is mapped as the basal beds of the Reedsville Shale, a transition that is regional in nature and is readily evident at sections from central Pennsylvania to northeastern Tennessee.

The Dolly Ridge Formation is interpreted as having accumulated on a deep shelf or ramp, with many of the limestone beds probably consisting of sediment that originally accumulated in shallower shelf settings but was later remobilized and transported down the ramp into deeper environments. This sediment may or may not have accumulated below the photic zone, but the setting was evidently deep enough for appreciable volumes of mud to accumulate in a quieter, low-energy setting. In a greater context, the Dolly Ridge Formation records continued relative deepening of the water column and a slowly but steadily increasing influx of mud into the depositional basin, as a result of increasing tectonic activity and uplift associated with the Taconic orogeny that was ongoing far to the east. So although carbonate sedimentation continued throughout the time that the Dolly Ridge Formation was accumulating, it became evermore disrupted by the increased influx of siliciclastic mud and volcanic ash into the depositional environment as evidenced by the increased volume of shale in the Dolly Ridge, and by the numerous tephra deposits (now altered to K-bentonite beds) that are present in the type section of the Dolly Ridge Formation (Perry, 1964, 1972), as will be seen at Stop 5.

Reedsville Shale

The Dolly Ridge Formation is overlain by the Reedsville Shale, which has its type section in Mifflin County, Pennsylvania (Ulrich, 1911; Keroher, 1966). The basal beds of the Reedsville Shale are visible at Stops 4 and 5, and the uppermost beds are visible at Stops 2 and 3. The Reedsville Shale is a heterogeneous formation, with beds of dark gray shale (many of which are calcareous) at its base that transition upward to repetitively interbedded shale, siltstone, fine-grained sandstone, and bioclastic grainstone and packstone.

Figure 9.—Steve Leslie at the Nealmont – Dolly Ridge contact in the Arc Hollow section, Stop 4. Steve Leslie is standing next to the uppermost ledges of bioclastic grainstone, packstone, and wackestone that are characteristic of the Nealmont Limestone. These ledges are overlain by greenish gray shale that is the basal bed of the Dolly Ridge Formation. Photo by R.C. Orndorff.

Figure 10.—Del Martin looking at cobbly weathering lime mudstone beds in the Dolly Ridge Formation, a characteristic of these limestones in outcrop. At the Dolly Ridge type section, Stop 5. Photo by J.T. Haynes.

The uppermost several meters of the Reedsville Shale are widely known as the *Orthorhynchula* biozone, or more commonly just the *Orthorhynchula* zone (Butts, 1940; Woodward, 1951; Bretsky, 1969, 1970). This typically 3-4 m thick stratigraphic interval "consists of an irregularly bedded, lumpy, brown sandstone that is almost incredibly filled with fossils which break out and weather out in molds and casts. The rock is gray and solid when fresh, but turns brown and crumbles rapidly on surface exposures. A few zones have become slightly calcareous because of their fossils." (Woodward, 1951, p. 360). Large and numerous specimens of *Orthorhynchula* sp., notably *Orthorhynchula linneyi*, and other brachiopods including *Lingula*, can be found with little effort at most exposures of the *Orthorhynchula* zone, including the outcrop at Stop 2.

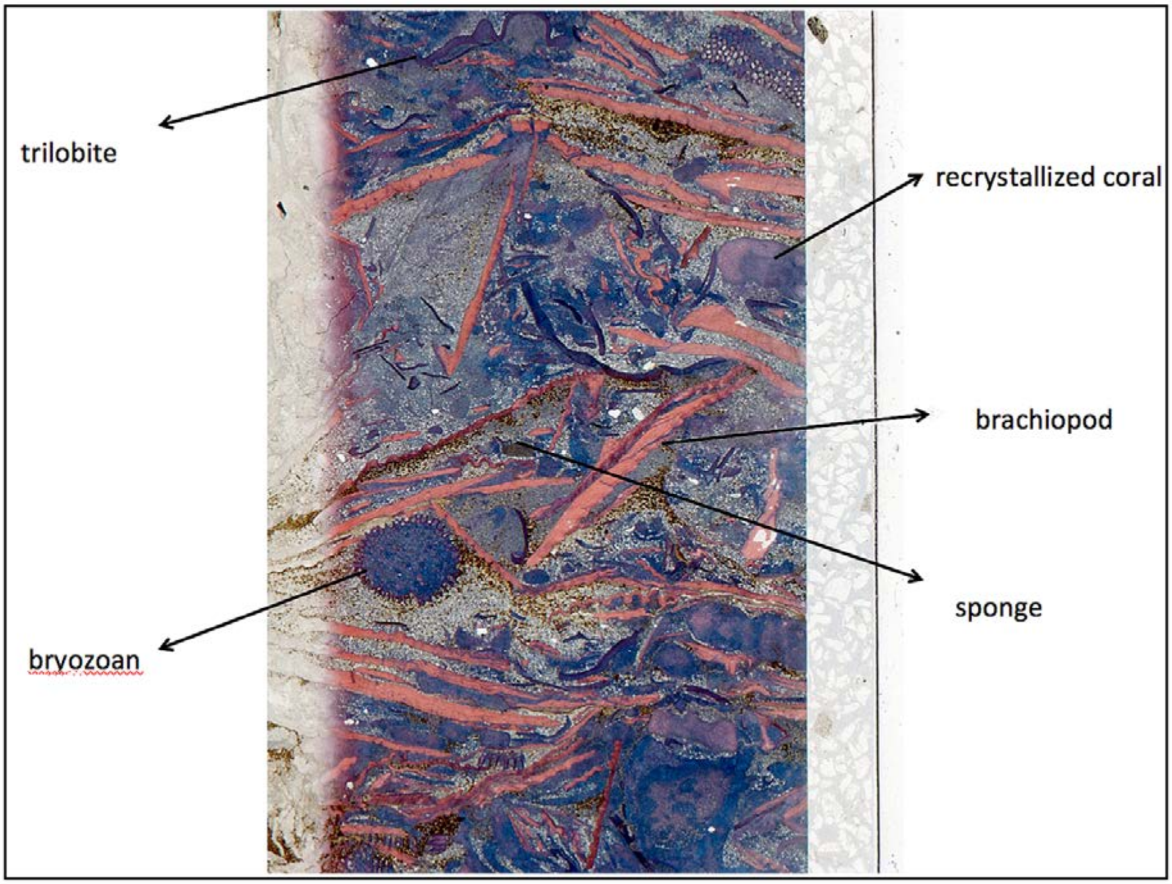

Figure 11. Stained thin section of a bioclastic packstone in the upper part of the Reedsville Shale, collected at Stop 3, with selected skeletal components identified. The packing arrangement of this shelly debris is typical of the storm beds in the Reedsville Shale throughout this area of the Appalachian region (Kreisa, 1981; Kreisa and Bambach, 1982). Staining with standard Dickson method by J.T. Haynes, with photo by JMU geology student H.M. Doherty.

Efforts to refine and improve our understanding of the conodont biostratigraphy of the upper part of the Reedsville from analysis of samples collected at Stop 2, have thus far met with limited success because the definitive conodont M element needed for identification of species in the genus *Oulodus* (thus far the only genus recovered), has not yet been recovered from any samples (S. Leslie, personal communication to JTH, 2015). As a result, the conodonts recovered from the Reedsville at Stop 2 (Fig. 12) are currently assigned only to *Oulodus* sp.

Maximum flooding of the shelf occurred in the lower part of the Reedsville Shale, when a sequence of dark mud accumulated and became the gray shale of the basal, lowermost Reedsville, which is mostly covered along the higher slopes of Germany Valley. This continued deepening of the water column was evidently a result of the combined eustatic sea-level rise (the "Trenton transgression;" Leslie and Bergström, 1995) that occurred during the Late Ordovician, and the buckling and downdropping of the Laurentian shelf edge that occurred as continent-microcontinent collision was producing the Taconic orogeny outboard of the Laurentian margin.

The middle and upper parts of the Reedsville Shale are the basal units of a second shallowing upward sequence, but unlike the older carbonate sequence (Big Valley Formation, McGlone Limestone, and McGraw Limestone), this younger sequence is characterized by a transition from mostly carbonate and less common mud, to mostly siliciclastic sediment, with a few shelly beds of grainstone and packstone. With gradual shallowing of the water column, storm-influenced and storm-generated sedimentary structures become more common, including hummocky cross-stratification, gutter casts, undulatory scoured-bases, and sandy whole-fossil packstone (Kreisa, 1981; Lehman and Pope, 1989). In thin section, storm-associated features include preferred shell orientation, various infiltration fabrics, abraded bioclasts of diverse types (Fig. 11), and shells with mud coatings (Kreisa and Bambach, 1982).

The uppermost several meters of the Reedsville Shale represent shallowing of the basin to nearshore conditions that were favorable for communities of large brachiopods, and the *Orthorhynchula* zone also represents essentially the last occurrence of marine shelly faunas of this region during the Ordovician. The overlying Oswego Sandstone and Juniata Formation are non-marine to marginal marine deposits, with a few trace fossils including *Skolithos*. The next marine flooding surface and regional transgression that was accompanied by radiation and colonization of marine organisms into newly marine habitat over a widespread area did not occur until deposition of the Silurian (Telychian) Rose Hill Formation (Woodward, 1941).

Oswego Sandstone

The *Orthorhynchula* zone of the Reedsville Shale is overlain by the Oswego Sandstone, which was named for outcrops in Oswego County, New York, although a type section was not specified (Prosser, 1888). The Oswego Sandstone in Germany Valley is a light brown to gray, medium to fine-grained sandstone (sublitharenite and less common lithic wacke), with interbedded siltstone and shale (Fig. 13). The Oswego is almost devoid of fossils, other than

Figure 12.—Steve Leslie on interbedded shale, siltstone, and bioclastic limestone in the upper part of the Reedsville Shale at Stop 2. Photo by J.T. Haynes.

Figure 13.—Rick Lambert at the exposure of the Oswego Sandstone at Stop 2 along US 33 on the east side of Germany Valley. Photo by J.T. Haynes.

eurypterid impressions about 145 km NNE of Germany Valley in Berkeley County, West Virginia (Diecchio, 1985). Yellow orange flecks of limonite are common in some of the Oswego sandstone beds, and these flecks are the weathering product of iron-bearing lithic framework grains and of ankerite cement that occurs in minor amounts throughout both the Oswego Sandstone and the overlying Juniata Formation (Horowitz, 1971).

The Oswego Sandstone is interpreted as the culmination of the shallowing upward sequence that was initiated with the maximum flooding surface in the lower part of the Reedsville Shale (Diecchio, 1985; 1986). The sand and mud of the Oswego Sandstone were derived from weathering and erosion of the Taconic highlands to the east, and dispersal of these siliciclastic sediments toward the west was facilitated by transport in rivers and streams into a shallow nearshore deltaic complex (Bretsky, 1970; Diecchio, 1985), but one that was evidently almost inhospitable to life in much of the region.

Juniata Formation

The Oswego Sandstone is overlain by the Juniata Formation, which was named for the

Juniata River in central Pennsylvania (Darton and Taff, 1896). The Juniata Formation consists of red shale, siltstone, and sandstone arranged in a very cyclic order. The Juniata Formation has a low diversity assemblage of trace fossils, including *Skolithos, Cruziana,* and *Rusophycus*. . The transition from the Oswego Sandstone to the overlying Juniata Formation is first and foremost one of color, as the Juniata Formation is characterized by red shale, siltstone, and sandstone (Fig. 14), in contrast to the greenish gray siliciclastic strata of the Oswego Sandstone. To a far lesser extent, the transition is also one of overall grain size, as the Oswego Sandstone usually contains more sandstone and less mudrock overall than the Juniata Formation (Diecchio, 1985). However, the green-to-red transition does not correlate with any lithologic grain size boundaries related to primary depositional settings (Thompson, 1970). The Juniata Formation is capped by an unconformity, above which lies the Silurian Tuscarora Sandstone.

The Juniata Formation is interpreted as a tidally-influenced deposit on a prograding delta platform that was intermittently inundated with sea water, but the lack of desiccation cracks or other evidence of subaerial exposure suggests that the Juniata Formation here in Germany Valley was not exposed in an intertidal or supratidal environment. The cyclic arrangement of shale, siltstone, and sandstone beds is interpreted in terms of parasequences, in which the base of each cycle is thought to be a transgressive surface above which regressive tidal parasequences accumulated. The red-to-green transition from the Oswego Sandstone to the overlying Juniata Formation is the result of diagenetic rather than depositional changes, specifically from variation in the vertical chemical gradient caused by change in oxidation potential as reducing fluids expelled from the underlying dark organic marine mud of the Reedsville Shale migrated through the overlying sand and mud of the Oswego Sandstone and Juniata Formation (Thompson, 1970; Horowitz, 1971).

Figure 14.—Rick Lambert looking at the cyclic arrangement of shale, siltstone, and sandstone beds of the Juniata Formation along US 33 on the east side of Germany Valley. Photo by J.T. Haynes.

DESCRIPTION OF STOPS

Stop 1: US 33, North Fork Mountain - east, Pendleton County, WV
38.698350 N, 79.403169 W; Circleville 7½ minute quadrangle

At this stop, we will examine the upper several meters of the Juniata Formation, which in this region is the youngest Ordovician unit. We will also discuss the Ordovician – Silurian boundary, which is an unconformity that occurs between the red mudrock and sandstone of the Ordovician Juniata Formation, and the silica-cemented white sandstone of the overlying Silurian Tuscarora Sandstone (Diecchio, 1985).

The upper part of the Juniata Formation at this stop consists of about 48 m of interbedded grayish-red sandstone (quartz arenite to sublitharenite) interbedded with grayish-red mudstone and mud-shale. For most of this interval, these strata are organized into cycles (Fig. 15) that are interpreted as regressive tidal parasequences. Spectral analysis of the thicknesses of the sandstone-mudstone couplets suggests that these meter-scale parasequences have Milankovich periods, and are probably associated with either orbital obliquity or precession (Hinnov and

Diecchio, 2015, abstract for this symposium). Further analyses of cyclicity in the Juniata are in progress.

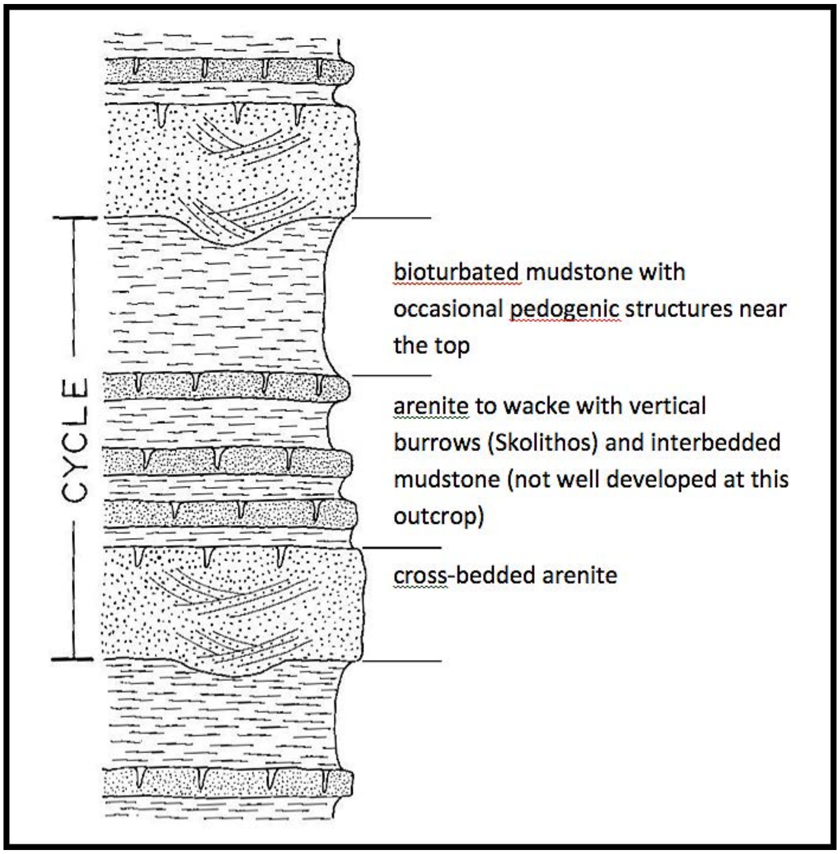

Figure 15.—Generalized cycle in the Juniata Formation (Diecchio, 1985).

The Juniata Formation is overlain by the Tuscarora Sandstone (Fig. 16), which is primarily a white to light gray sandstone (quartz arenite). The lower 2.5 m of the Tuscarora is light olive gray, brown weathering sandstone that is capped by a 0.3 m-thick bed of very fine, red sandstone with vertical burrows (*Skolithos*). This bed corresponds to the "Lower Tuscarora Sandstone" of Dorsch et al. (1994).

Above the red sandstone, the majority of the Tuscarora Sandstone at this stop is 50 m of very light gray sandstone (quartz arenite), which corresponds to the "Upper Tuscarora Sandstone" of Dorsch et al. (1994). The lower 20 m of the "Upper Tuscarora Sandstone" is medium- to very coarse-grained, well-indurated, and cross-bedded, with some interbeds of friable sandstone. The upper 30 m is very fine- to medium-grained, with some cross-bedding, horizontal burrows (*Arthrophycus*), and beds of dark gray shale, especially in the upper portion.

The Tuscarora Sandstone is interpreted as sands that were deposited in a mosaic of terrestrial to shallow marine environments. These environments include fluvial systems, braided alluvial fan and fan delta systems, high-energy foreshore and shoreface zones of a beach or barrier island system, and sand-wave complexes on a shallow marine shelf (Folk, 1960; Yeakel, 1962; Cotter, 1983).

Figure 16.—John Haynes at Stop 1 along US 33 at the approximate position of the Ordovician – Silurian boundary, which is placed at the contact of the Juniata Formation (redbeds to left) and the Tuscarora Sandstone (quartz arenites to the right). Inset at lower left shows Rick Lambert at the reddish sandstone that has numerous *Skolithos*, and which is either the uppermost Juniata Formation or the lowest Tuscarora Sandstone. Photo by R.A. Lambert, inset photo by J.T. Haynes.

Owing to the lack of fossils, the Ordovician-Silurian boundary in the central Appalachians is not known with certainty. Traditionally, this boundary has been placed at the Juniata-Tuscarora contact (Butts, 1940; Woodward, 1941, 1951; Diecchio 1985), based on an extensive regional unconformity that corresponds to the global Ordovician-Silurian unconformity. Dorsch et al. (1994) placed this unconformity at the "Lower Tuscarora" – "Upper Tuscarora" boundary, and related it to post-Taconic orogeny basin-rebound uplift. The exact position of, and the basis for determining, the Ordovician-Silurian boundary in these strata are still a matter of debate, and will be discussed at this stop. One hypothesis is that the ~2.5 m of the lower part of the Tuscarora, including the reddish bed with abundant *Skolithos,* might represent the Hirnantian Stage in this section.

Figure 17.—Steve Leslie (left) and Randall Orndorff at Stop 2 along US 33 on the east side of Germany Valley. This stop shows fossiliferous beds in an outcrop of the *Orthorhynchula* biozone. Photo by J.T. Haynes.

Stop 2: US 33, North Fork Mountain - west, Pendleton County, WV
38.708090 N, 79.410665 W; Circleville 7½ minute quadrangle

At this stop we will scrutinize the regionally extensive *Orthorhynchula* zone, an assemblage biozone described by Bretsky (1969, 1970) at the contact of the Reedsville Shale and the overlying Oswego Sandstone (Fig. 17). This zone, which participants on the pre-meeting southern Appalachian trip saw at Dug Gap near Dalton, Georgia and at Hagan in southwestern Virginia, is a useful stratigraphic marker from Pennsylvania south to Georgia. At this stop, the zone consists of about 10 m of gray to olive-gray mudstone that weathers into distinctive blocky shale, with beds of siltstones and thin beds of sandstone exhibiting abundant *Orthorhynchula* molds, and less abundant *Lingula* within discrete beds. Above the *Orthorhynchula* biozone are 20 meters of the Oswego Sandstone, which is a fine- to very fine-grained, cross-bedded sandstone (sublitharenite to quartz arenite), usually greenish gray and with common limonite flecks. Below the *Orthorhynchula* biozone is the Reedsville Shale. At this stop, about 25 m of the upper part of the Reedsville Shale is exposed and it has a heterogeneous lithology of siliciclastic mudrock, fine-grained sandstone, and fossiliferous grainstone to wackestone, including a limestone bed that was processed for conodonts (Figs. 11, 12) and a siltstone bed from which a large *Isotelus* was obtained (Fig. 18).

Stop 3: US 33, Germany Valley overlook, Pendleton County, WV
38.708133 N, 79.413188 W; Circleville 7½ minute quadrangle

At this stop, we will present an overview of the stratigraphic (Fig. 19) and structural (Fig. 20) setting of Germany Valley, which is an anticlinal valley that developed as erosion cut into the Wills Mountain anticline, a culmination on the more regionally extensive Nittany anticlinorium. A cross-section through this region (Fig. 20) shows that the Wills Mountain anticline is the westernmost major fold of the Valley and Ridge province in this region of the Appalachian Mountains. Detailed bedrock mapping by Del Martin and Rick Lambert has resulted in a new geologic map and cross-sections of Germany Valley (Martin et al., 2014), included herein as a scaled-down version (Fig. 21) and as an overlay on the GoogleEarth™ landscape (Fig. 22). As a result of that mapping, in combination with the newly generated and still ongoing measurements of the section in Arc Hollow (Plates 1, 2, and 3, included herein as scaled-down versions) that is the focus of Stop 4, a far more detailed understanding has emerged of the stratigraphy of the Ordovician carbonate sequence from the New Market Limestone upsection to the Reedsville Shale.

Stop 4: North Fork quarry area and Arc Hollow, at the Germany Valley Karst Survey (GVKS) Fieldhouse, Riverton, WV, *38.742399 N, 79.423907 W; Circleville 7½ minute quadrangle*

At this stop, the principal stop of the field trip, we will examine in detail the Ordovician limestone sequence from the upper part of the Big Valley Formation upsection to the lower part of the Dolly Ridge Formation. The oldest strata that outcrop in this part of the Arc Hollow section are the upper part of a regionally widespread shallowing upward sequence, from the middle of the Big Valley Formation through the McGlone Limestone and into the McGraw Limestone. This sequence is followed by a regionally widespread deepening upward sequence that goes from the base of the Nealmont Limestone to the base of the Dolly Ridge Formation


Figure 18.—*Isotelus* sp. in a siltstone bed of the Reedsville Shale at Stop 2. Photos by R.C. Orndorff.

(seen at Stop 5). These sea-level changes are inferred from interpretations of depositional environments.

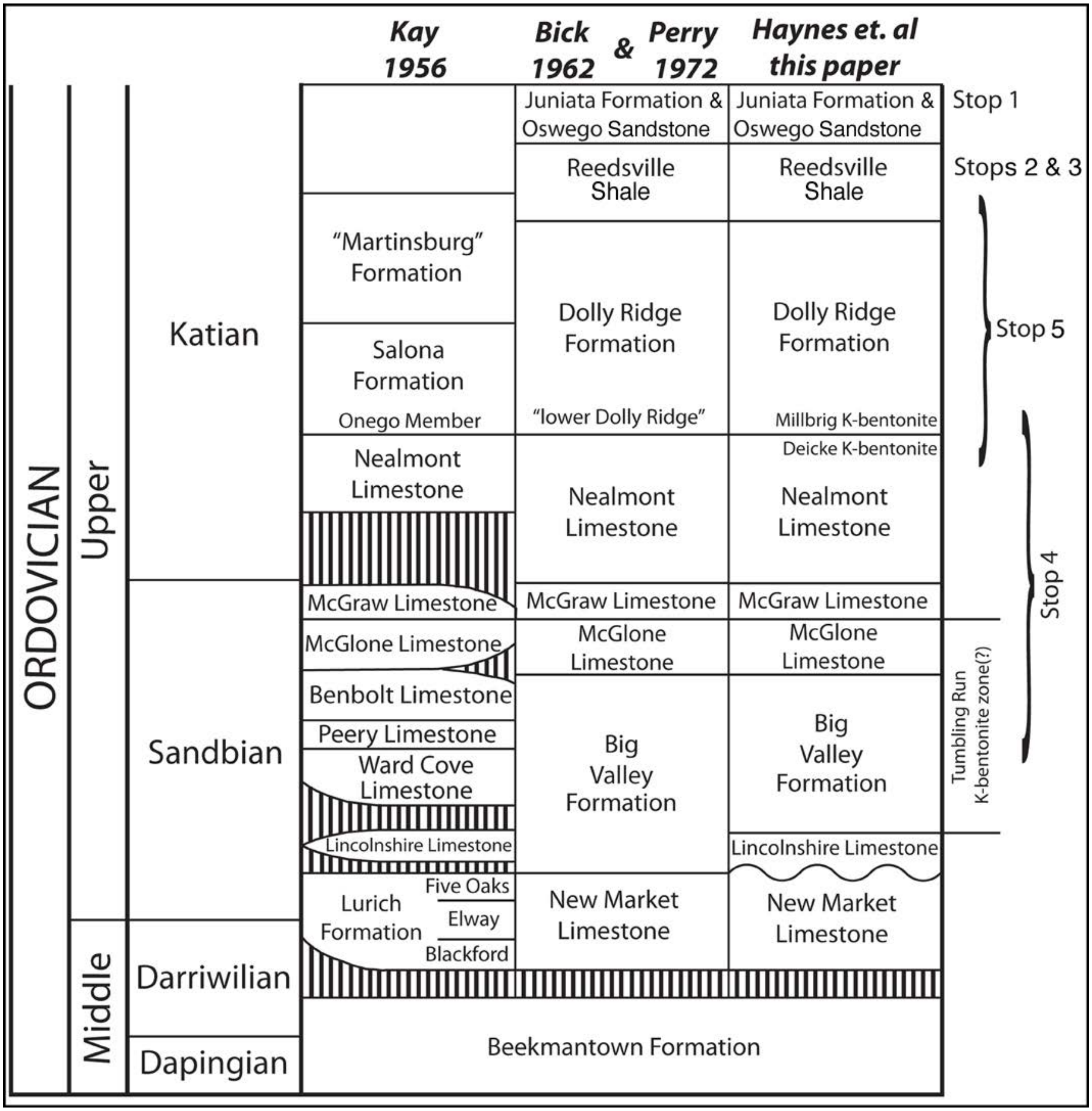

Figure 19.—Comparison of stratigraphic names used by geologists who have worked in the Germany Valley area.

From the Field House to the old North Fork Quarry, the section has been marked with aluminum tags at approximately 2 m intervals, and these measurements correspond to the measured section that comprises Plates 1, 2, and 3.

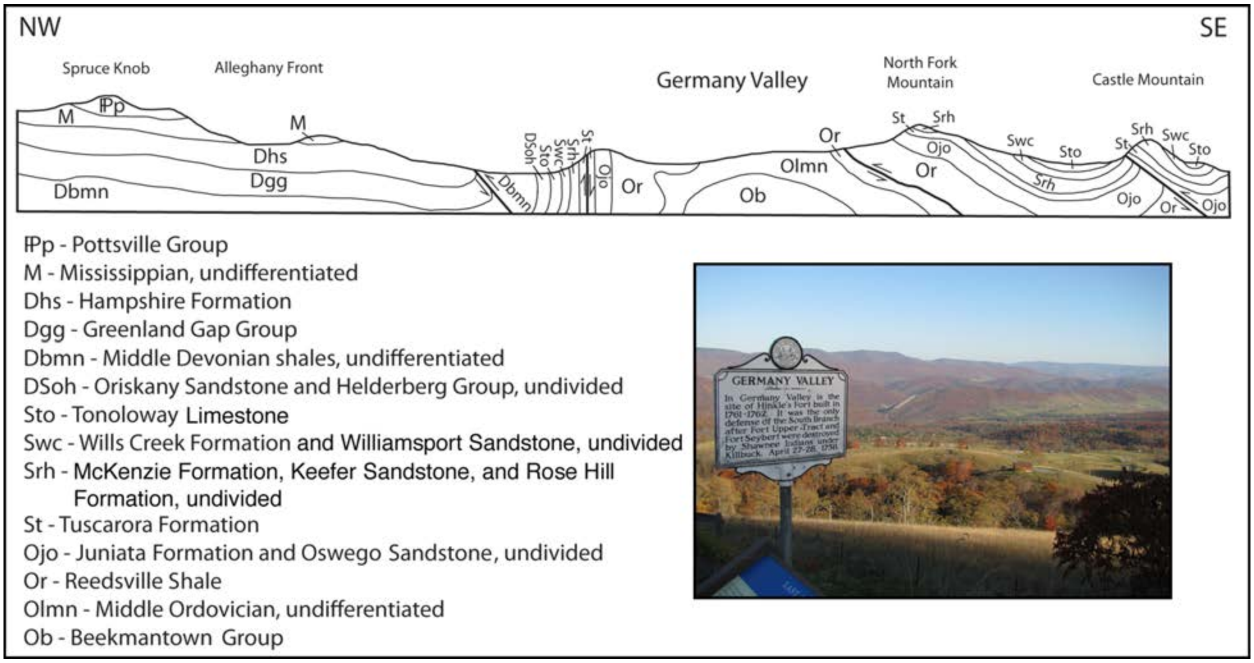

Figure 20.—Structural cross section across the Germany Valley area (Modified from Goggin, 1989).

Discussion of the Measured Sections for Stop 4 (Plates 1 – 3):

The measured section shown in Plates 1 – 3 represents a preliminary version of an ongoing project that will compare the depositional environments, facies thicknesses, and other geologic data from Germany Valley (this stop) with similar data from the Tumbling Run section in the northern Shenandoah Valley of Virginia, as from the transitional section located in the Bolar anticline first described by Kay (1956). The key elements of these sections are the cm-scale descriptions of the rocks and the identification of K-bentonite beds, which allow exact correlations in time. Other ongoing analyses include thin sections, x-ray diffraction, x-ray fluorescence, and inductively coupled plasma-mass spectrometry.

The measured section included in this publication depicts the uppermost beds of the New Market Limestone through the basal portion of the Dolly Ridge Formation. The remainder of the Dolly Ridge Formation will be measured at its type section, and then tied to the Arc Hollow section using marker beds, including the thicker shales and the K-bentonite beds.

The sections were measured using a metric Jacob's Staff, and in the few covered intervals a metric tape, Brunton compass, and a calculator were used to determine the true stratigraphic thicknesses. Each interval was described in as much detail as possible including rock name, color (using a standard Munsel Color Chart), sedimentary structures and features, fossil types, trace fossils, and other features. The standard format for the field descriptions is a graphical form modified from Boyles et al. (1986). The advantage of the graphical method is that the description is a sketch of the data that present the spatial relations of sedimentary features present in the core. The graphical form can be understood by most geologists, and can be plotted with core gamma-log data to allow correlation of core descriptions with geophysical well log data. Where possible, specific descriptive information includes sedimentary structures (both physical and biogenic), constituents (mineralogy, fossil types, etc.), texture (grain size and sorting), type and degree of cementation, and macroporosity.

The field gamma log represents data recorded using a Berkeley Nucleonics Corporation Model SAM Eagle radionuclide identifier, which was calibrated before and after each trip to the outcrop using cesium and potassium standards. Background radiation measurements were performed approximately 1.2 m (4 ft) above the ground at the beginning of each day. Radionuclide measurements were taken at approximately every stratigraphic meter where possible. Clean or freshly exposed rock surfaces were preferentially chosen for each sample point, and measurements were recorded for most sample stations on the measured section. A 30-second analysis was performed at each sample point, and repeat analysis was performed on occasion to confirm reliability of measurements. The probe was placed squarely on each rock surface and held in place for the duration of each analysis. Where elevated values were observed, or if there was any question about the origin of an elevated signal, a series of evenly spaced sample points (usually several cm apart) were taken starting below and moving up beyond the original observed elevated value until a maximum elevated value was defined. Composite measurements within a single bed (an average value for a series of closely spaced measurements with minimal differences in radionuclide response) were reported for some thick, visually homogeneous beds on the measured section. Measurements in covered intervals were typically measured on a roughly 1 m (stratigraphic) separation to determine whether soil profiles contained any measurable variability in radionuclide response.

Regional Significance Discussion:

As described above, the rocks exposed at the Arc Hollow and Dolly Ridge sections are interpreted as deposits on a stable continental shelf (New Market Limestone) followed by the initial deepening of the basin as a result of the earliest pulses of the Taconic orogeny (Lincolnshire Limestone and Big Valley Formation) possibly coupled with a relative sea level rise, which in turn was followed by a relative shallowing of sea level (McGlone and McGraw Limestones) and another, much more extensive, deepening of the basin with increased siliciclastic sediment input (Nealmont Limestone, Dolly Ridge Formation, and Reedsville Shale).

Regionally, this sequence can be contrasted to the rocks exposed at the classic Tumbling Run exposure at the eastern geographic extreme of the Ordovician exposure belt near Strasburg, Virginia, where the post-New Market supratidal sediments consist of ever-deepening facies from the Lincolnshire (shallow to mid-shelf) to predominately nodular bedded to shaly Edinburg

Formation (deeper slope) through the Stickley Run Member of the Martinsburg Formation (deeper, more distal slope) and ultimately to the basinal, slightly calcareous siliciclastic shale of the Martinsburg Formation (deep basin), which was derived predominately from the uplifted Taconic highlands to the east.

At the Tumbling Run exposure, the stratigraphic thickness from the New Market/Lincolnshire contact to the K-bentonite zone known as the “Tumbling Run complex” (Fetzer, 1973, p. 101, within the lowermost Edinburg Formation), and to the younger Deicke, Millbrig and associated K-bentonites (within the Stickley Run Member) appears to be much thinner, presumably due to slower depositional rates in those deeper water sediments. It should be noted that the St. Luke Member of the Edinburg Formation is poorly exposed at Tumbling Run, and may represent a shallowing at that part of the section that could be correlative with the McGlone and(or) McGraw Limestones of Germany Valley. Owing to the poor exposure and the possibility of an adjacent fault of unknown displacement, however, further work will be required to ascertain the true depositional environment of the St. Luke Member and its relationship to the stratigraphic units of Germany Valley.

Stop 5 (optional): Dolly Ridge Formation type section, Riverton, WV
38.738466 N, 79.424618 W; Circleville 7½ minute quadrangle

For those who are interested, there will be an opportunity in mid-afternoon to walk over to the Dolly Ridge road and examine the type section of the Dolly Ridge Formation (Fig. 22) of Perry (1972). The Arc Hollow section and the Dolly Ridge type section are correlated at the ~ 3 m thick olive gray shale that is the lowest bed in the Dolly Ridge Formation. This shale is located at the top of the Arc Hollow section, and near the base of the Dolly Ridge type section. Using the shale bed to tie both sections together, it is possible to construct a composite stratigraphic section from the New Market Limestone to the base of the Reedsville Shale.

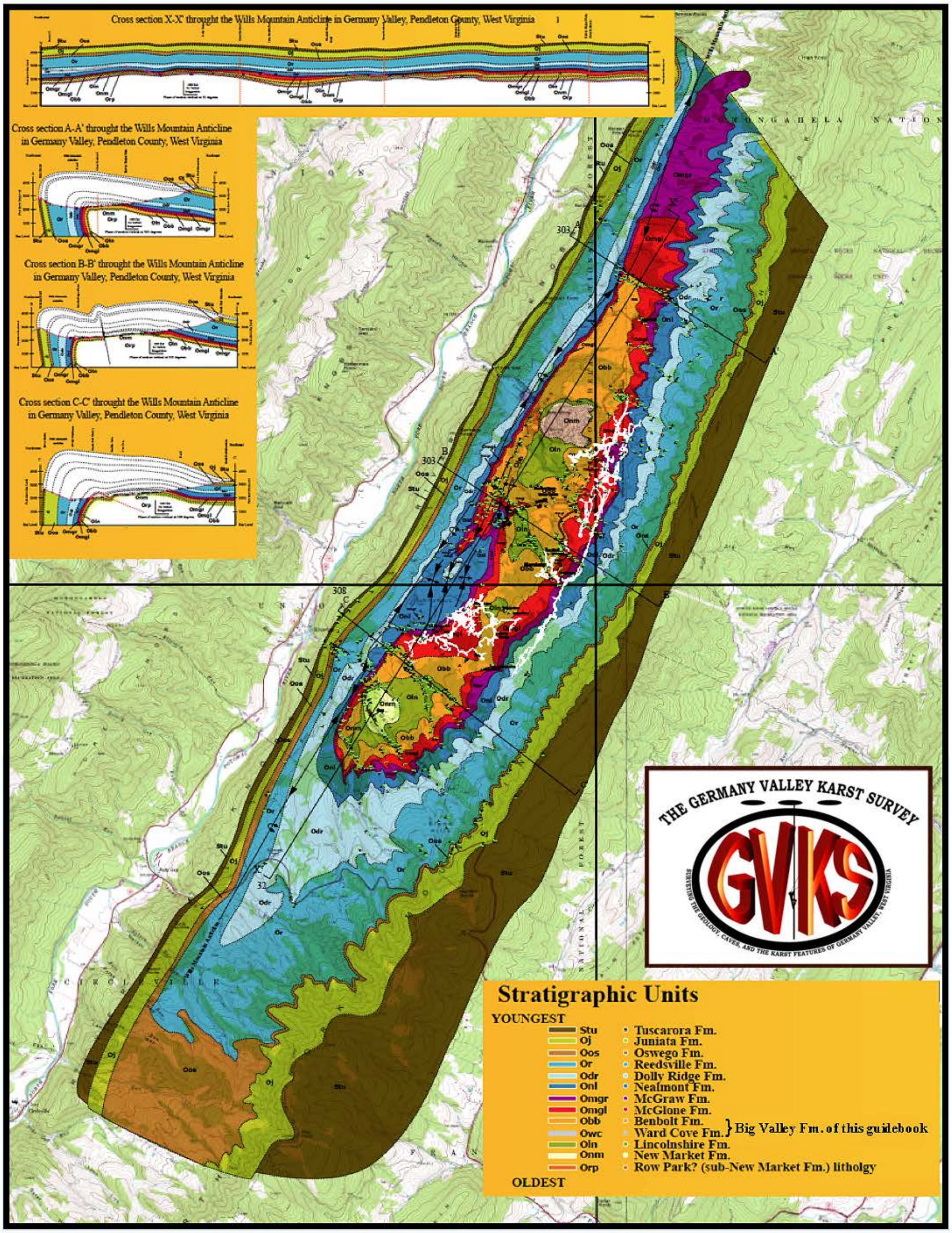

Figure 21.—Bedrock geologic map of Germany Valley from field mapping by Del Martin and Rick Lambert of the Germany Valley Karst Survey (Martin et al., 2014). Ordovician carbonate strata were folded under brittle conditions across the northwest verging, overturned Wills Mountain anticline, with the carbonate strata experiencing only minor additional flexing. Tighter folds are recognized above the carbonate strata,

especially in the Reedsville Shale. These folds, along with the overall fissile nature of the Reedsville Shale, suggest that significant shearing occurred across the entire thickness of the strata. Thus, it is hypothesized that the Reedsville Shale absorbed the majority of the regional deformation, and may even have acted as a decollement between the underlying carbonate strata and the overlying sandstone units.

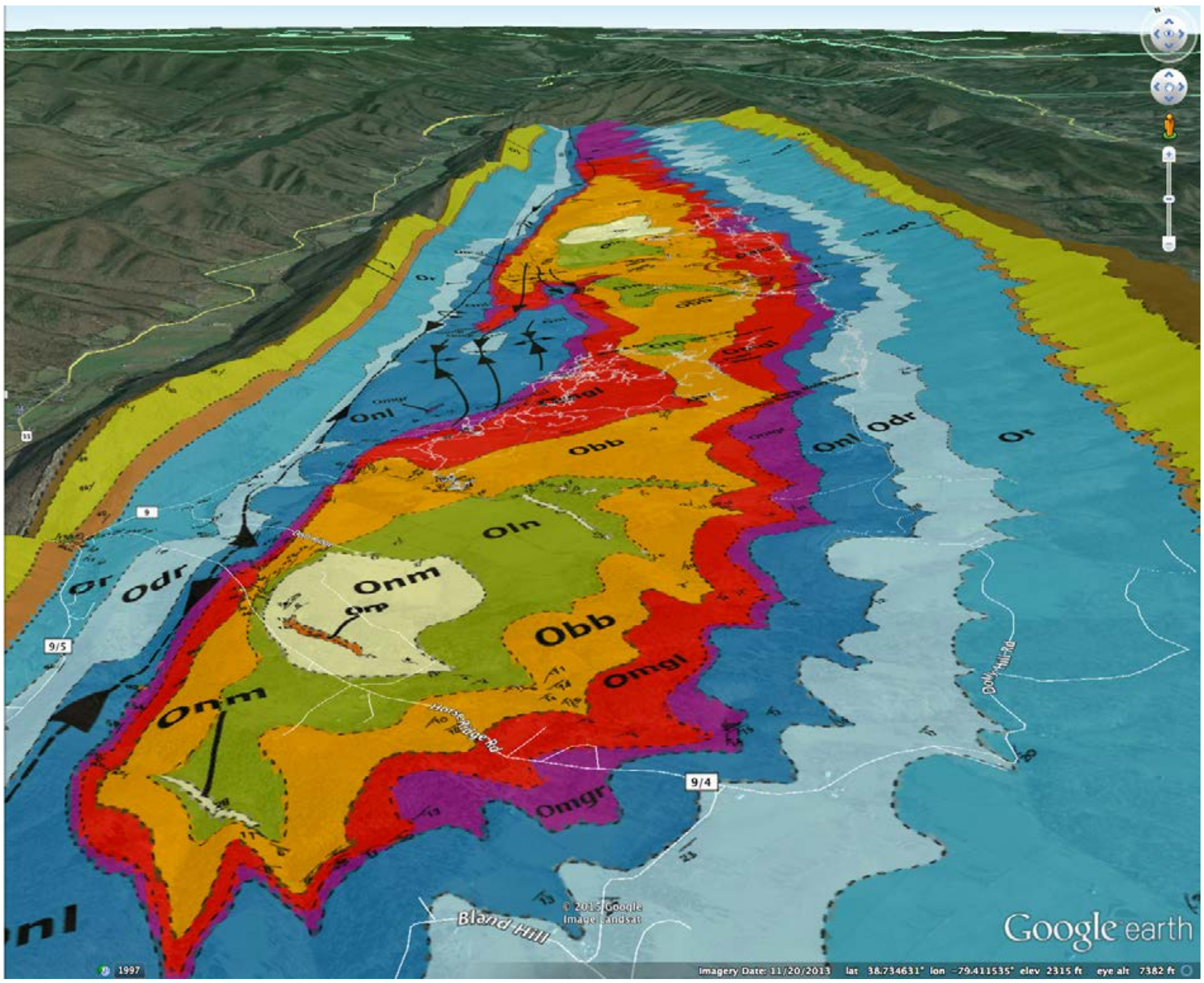

Figure 22.—Geologic map of Germany Valley (Martin et al., 2014) overlain on GoogleEarth terrain, which shows the breached anticlinal structure of the valley, with two structural culminations where the New Market Limestone (Onm) is exposed. This view is visible from the Germany Valley overlook at Stop 3. Geospatial processing done by S.J. Whitmeyer of JMU.

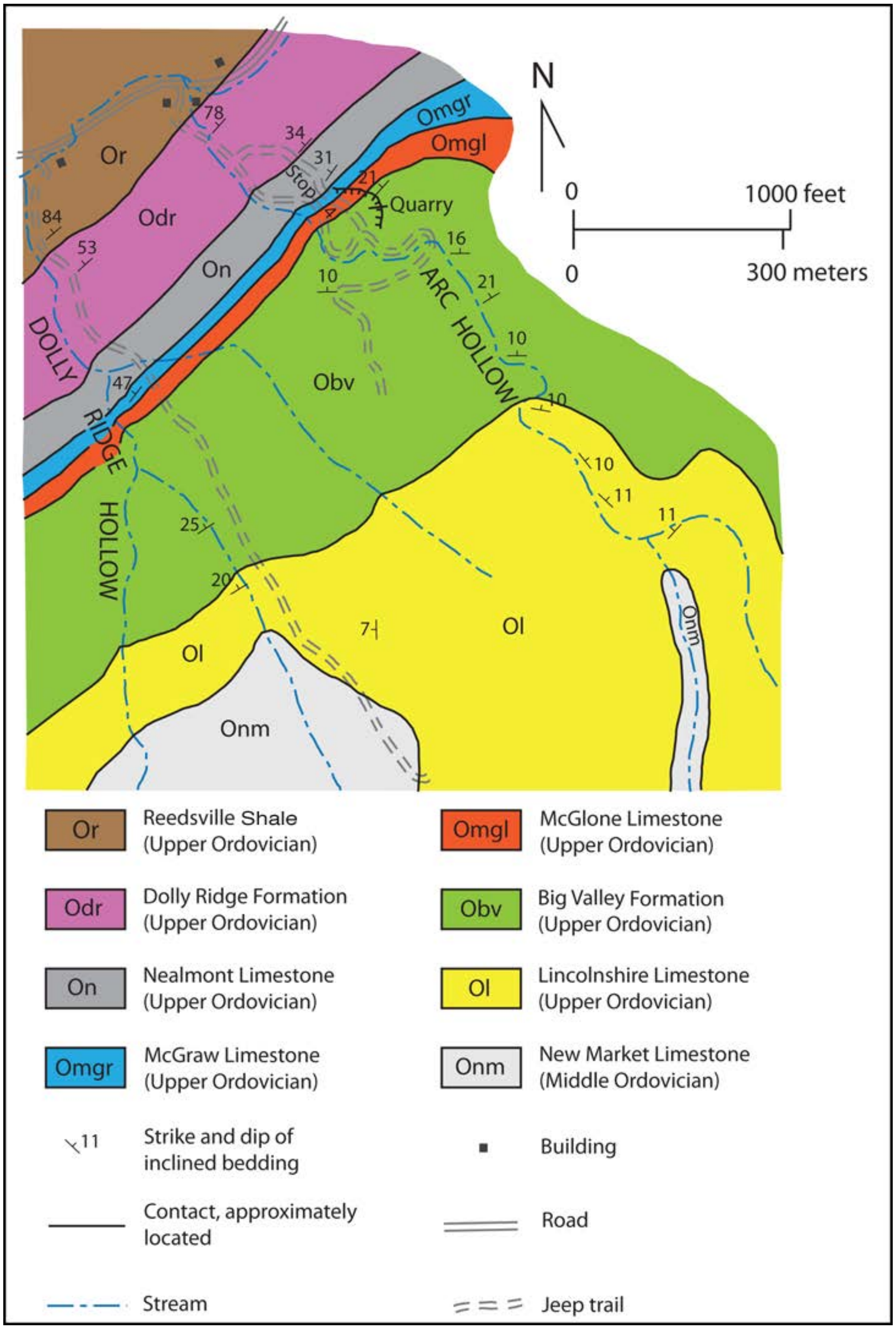

Figure 23.—Detailed geologic map of the Arc Hollow and Dolly Ridge areas that are the focus of Stops 4 and 5. Adapted and modified from the map of Martin et al. (2014).

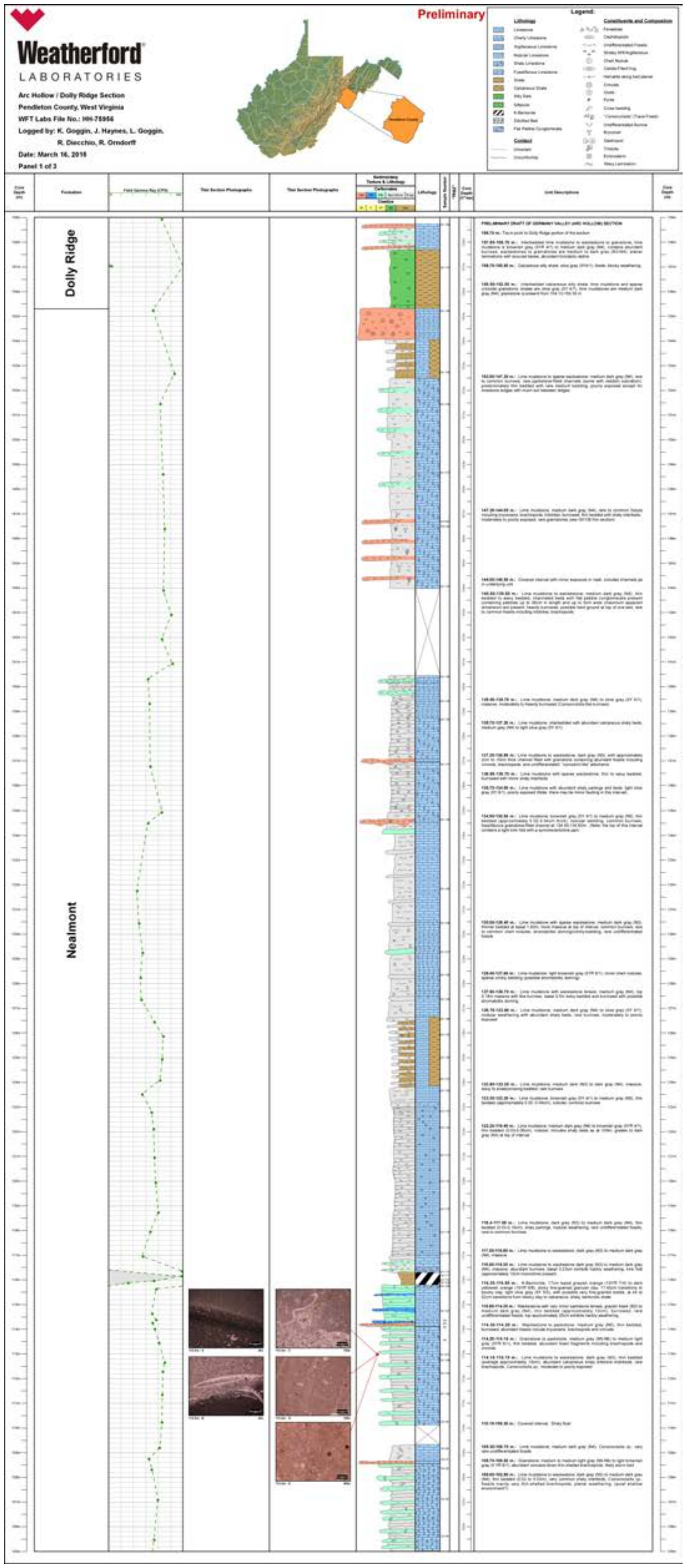

Plate 1.—Arc Hollow measured section of the Dolly Ridge Formation and Nealmont Limestone. Note that the counts-per-second (CPS) represent raw data and have not been normalized with respect to the ambient background readings.

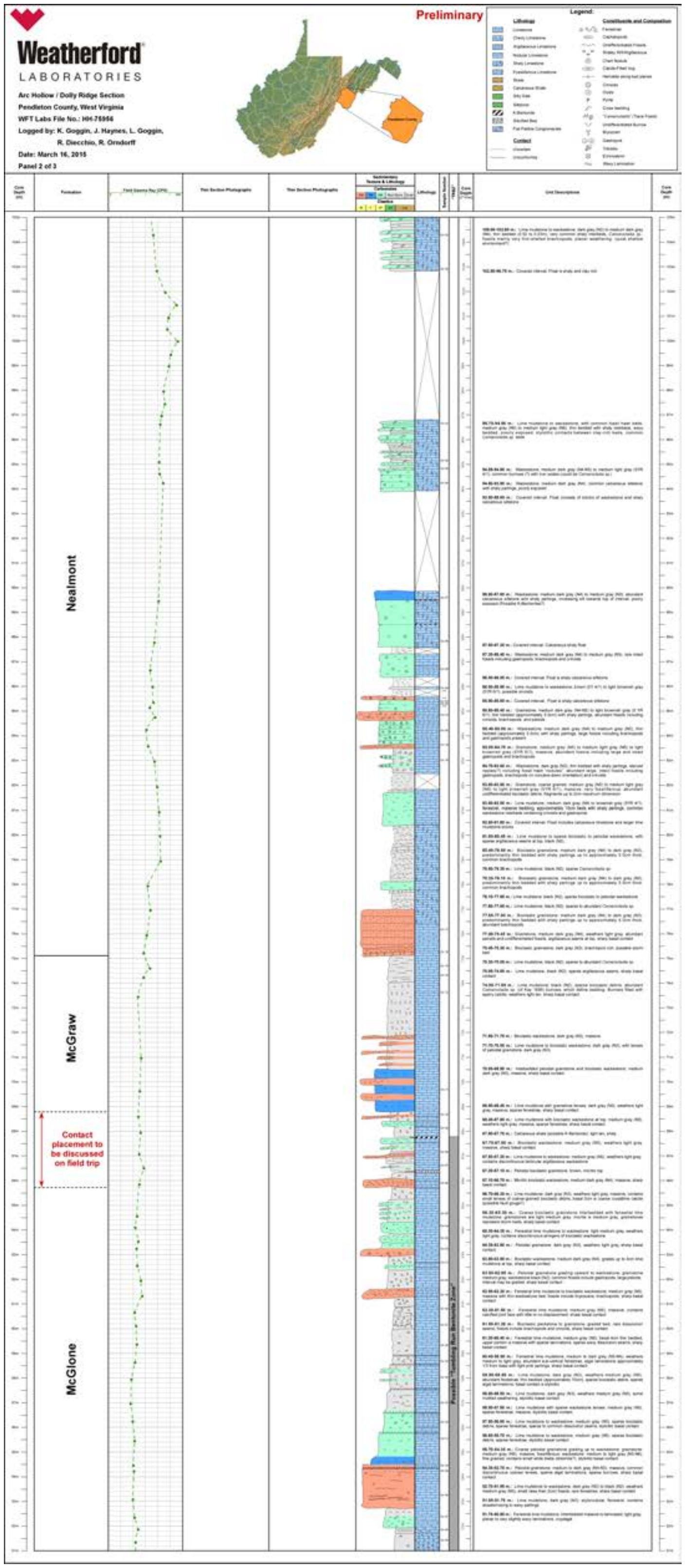

Plate 2.—Arc Hollow measured section of the Nealmont Limestone, McGraw Limestone, and McGlone Limestone.

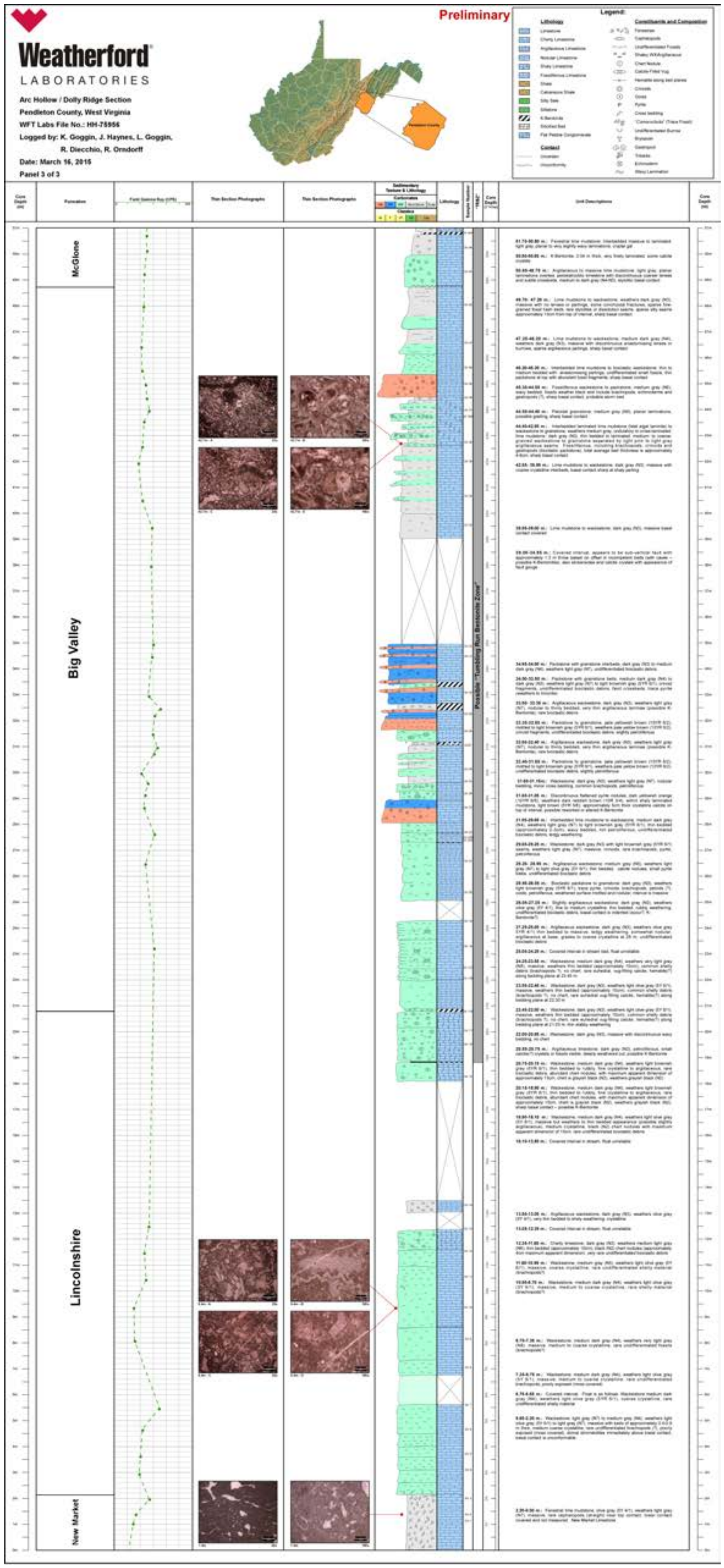

Plate 3. Arc Hollow measured section of the McGlone Limestone, Big Valley Formation, Lincolnshire Limestone, and New Market Limestone.

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