

Abandonment of the Upper Devonian Greenland Gap Group and Scherr Formation and revision of the Upper Devonian Brallier and Foreknobs Formations in the central Valley and Ridge Province

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ABSTRACT: This study revises the lithostratigraphic framework of the Upper Devonian interval traditionally assigned to the Greenland Gap Group across the central Appalachian Valley and Ridge Province. The work aims to modernize and standardize lithostratigraphic nomenclature, establish a new reference section and demonstrate how the revised stratigraphy improves edge-matching of 1:24,000 scale geologic maps and supports compilation mapping at scales of 1:100,000 and larger. The revision eliminates the names Greenland Gap Group, Scherr Formation and the Minnehaha Springs Member of the Scherr Formation; reassigns all strata previously designated as Scherr Formation by Dennison (1970) to the upper Brallier Formation; and abandons the basal Mallow Member of the Foreknobs Formation, placing its strata within the upper Brallier as originally defined by Butts (1918).

The contact between the Brallier and Foreknobs formations is placed at the base of the first mappable, ridge-forming package of fine- to coarse-grained, cross-bedded, sandstone beds, often containing rounded quartz pebbles with minor interbeds of shale and siltstone. This contact may be gradational in places but, even in absence of good exposure, can usually be distinguished topographically in recently produced lidar-derived imagery as having elevated relief due to the presence of more resistant, compositionally mature coarse-grained sandstone-rich strata. Applying this criterion for mapping the contact between the Brallier and Foreknobs formations has resulted in reconciliation of mismatches of geologic contacts along several 7.5-minute quadrangle boundaries in the states of Virginia, West Virginia, Maryland and Pennsylvania. A new reference section at Baker, West Virginia showcases the contacts between the Harrell Shale, Brallier Formation, Foreknobs Formation and Hampshire Formation. A digital outcrop model of the reference section is provided for future preservation.

INTRODUCTION

This work presents revisions to Upper Devonian lithostratigraphy to support seamless bedrock geologic mapping of siliciclastic strata of the Valley and Ridge Province throughout the north-central Appalachian region. Challenges to the mappability of bedrock units often originate with the unit's initial definition and the ability of geologists to recognize the key characteristics of the unit in the field based on the original descriptions (Raymond et al. 2012; Webb et al. 2008). The challenge to field geologists working in the Devonian siliciclastic strata of the central Appalachians is complicated by a high degree of lithologic variability, a general lack of continuous exposures due to dense vegetation in the eastern United States region and sometimes extensive interval deformation. The challenges to mappability have created a need to provide improved lithostratigraphic reconciliation and revision of units across both state and quadrangle boundaries.

Lithostratigraphic revision involves revisiting the original type and reference sections for comparisons to correlative strata in adjacent areas. However, many historic reference sections and geologic map products produced without the aid of modern lidar base imagery may have issues with accuracy and often need revision. Additionally, if the type sections were established several decades ago, they may have weathered to the point the critical features needed for future comparative studies are no longer visible (e.g. Self-Trail et al. 2023). Supplementary reference sections are often needed to record lithologic diversity, otherwise reference sections distant from their comparative sites should be relied on only for general comparison to account for lateral facies variation

(Raymond et al. 2012). The lithostratigraphic unit of primary interest for this study is the Upper Devonian Greenland Gap Group (Dennison 1970) comprised of (in ascending order) the Scherr and Foreknobs formations (text-fig. 1) and their contacts with the underlying Brallier Formation (Butts 1918) and overlying Hampshire Formation (Darton 1892).

Based on a review of existing geologic maps, the Scherr and Foreknobs formations, as they are currently defined, represent a challenge to 1:24,000 and smaller scale seamless geologic mapping. Evidence of mappability issues in these units is often expressed as non-contiguous lithostratigraphic unit contacts across state and quadrangle boundaries, or mapped units organized according to lithostratigraphic nomenclature (group, formation, member) that are incompatible with mapping conducted in adjacent areas (text-fig. 2). Additionally, vague definitions of the contacts between the Scherr and Foreknobs formations (Ryder et al. 2009; Haynes et al. 2019), as well as between the Scherr and Brallier formations, have resulted in numerous map boundary inconsistencies between adjacent 7.5-minute quadrangles. These issues are not new, and have persisted over several decades in areas within and surrounding the Winchester 30×60 minute quadrangle (e.g., Schultz 1997) extending from the type section at Scherr, West Virginia eastward across the Virginia state line (text-fig. 2- see geologic map unit boundary inconsistencies along lettered quads).

New geologic mapping (Doctor and Pitts 2023) combined with lidar imagery derived from the recently acquired 1 m elevation

Woodward (1943)		Dennison (1970)/ McGhee and Dennison (1976)/ Lyke (1986)		This Study	
NE	SW	NE	SW	NE	SW
Hampshire Formation		Hampshire Formation		Hampshire Formation	
Chemung Formation		Foreknobs Fm.		Foreknobs Fm.	
		Red Lick Member *		Red Lick Member	
		Pound Ss. Member		Pound Ss. Member	
		Blizzard Member.		Blizzard Member	
		Briery Gap Ss. Mbr.		Briery Gap Ss. Mbr.	
		Mallow Member			
		Scherr Formation		Brallier Formation (upper part)	
		** Minnehaha Springs Member			
Brallier Formation		Brallier Formation		Brallier Formation (lower part)	
Harrell Shale		Harrell Shale		Harrell Shale	

TEXT-FIGURE 1
Stratigraphic nomenclature changes to the Upper Devonian siliclastic units of the central Appalachians from Woodward (1943), Dennison (1970), McGhee and Dennison (1976) (Red Lick Member), Lyke (1986) (Minnehaha Springs Member), and this study. Fm. = Formation, Mbr. = Member, Ss. = Sandstone.

dataset produced through the U.S. Geological Survey 3D Elevation Program (3DEP) has helped to resolve the stratigraphic issues that were the primary obstructions to seamless mapping between quadrangle and state boundaries in the study area. Here, we demonstrate that our lithostratigraphic revisions allow for consistent geologic mapping between previously mapped 7.5-minute quadrangles in the eastern West Virginia panhandle and across the Virginia-West Virginia state line, while preserving the lithologic variability used for defining the original units (text-fig. 3).

The goals of this work are: i) to revise the lithostratigraphic nomenclature for the Upper Devonian Greenland Gap Group through the central portion of the Appalachian Valley and Ridge Province, ii) to provide a supporting reference section through a near-complete exposure of the relevant lithostratigraphic units, and iii) to demonstrate the utility of this lithostratigraphic revision as a solution for edge-matching 1:24,000-scale maps for compilation at scales of 1:100,000 and smaller.

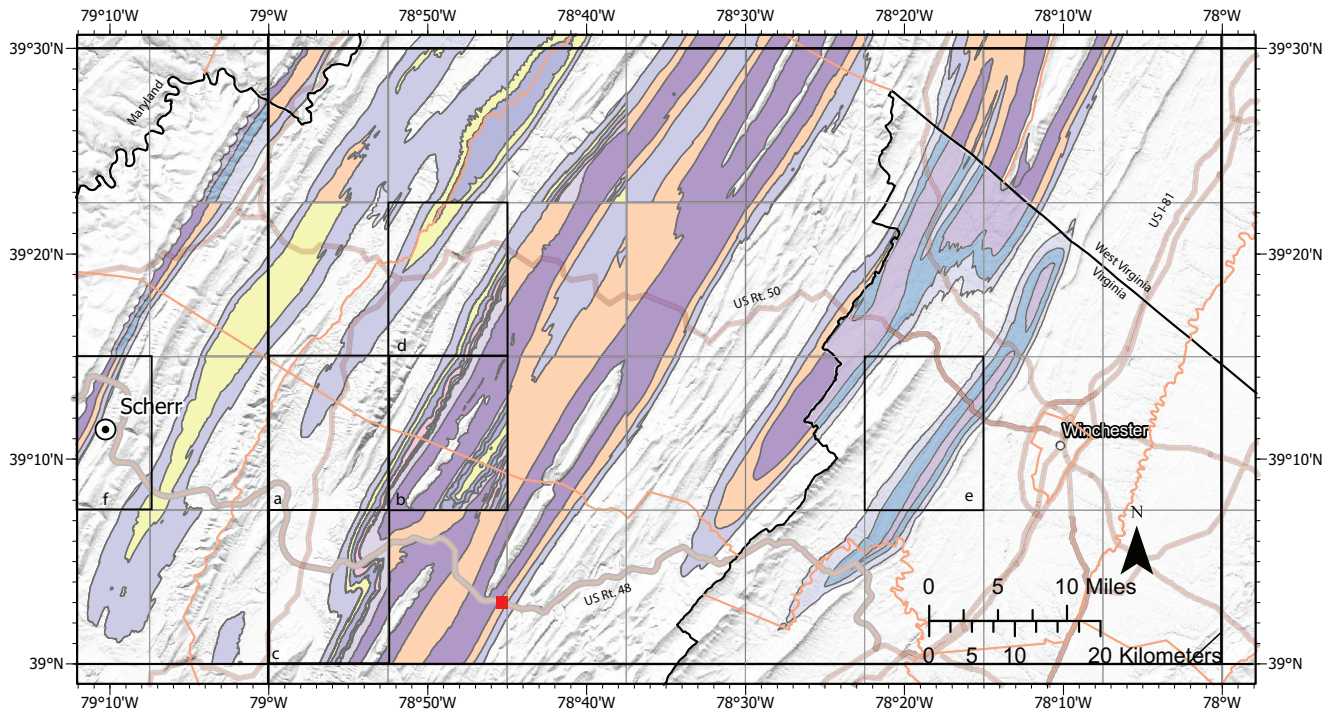
BACKGROUND AND GEOLOGY

The units in this study are part of a clastic wedge of Middle to Upper Devonian sediments deposited in association with the

Acadian Orogeny (Woodrow and Fletcher 1967; Boswell and Donaldson 1988; Quinlan and Beaumont 1984; Tankard 1986). The strata represent the gradual west to east transition from marine to terrestrial depositional environments in the central Appalachian Basin. Foundational work on this interval at a regional scale was conducted by James Hall (1839) who designated these units as the Chemung Series [“Series” is now recognized only as a chronostratigraphic terminology; North American Commission on Stratigraphic Nomenclature (2021)], named after the Chemung Narrows in south-central New York. The Chemung Series was mapped based on its sedimentological character, interpreted marine depositional environment, and the abundance of a distinct brachiopod fossil *Cyrtospirifer chemungensis*. Using these criteria, White (1881) extended the use of Chemung (Chemung Series) into West Virginia, where it was applied to rocks at the same approximate stratigraphic level. Later reorganizations of New York’s Upper Devonian stratigraphic nomenclature to recognize the need to base lithostratigraphy solely on lithologic grounds (ACSN 1961) led to the abandonment of the name “Chemung” at its type section in favor of several smaller formational divisions (Rickard 1964; Oliver et al. 1967; 1969). The loss of Chemung as a formal lithostratigraphic name in its original type locality led to its demotion (not always recognized) to informal status everywhere.

Dennison (1970) emphasized the need to revise the Chemung in West Virginia as the name was no longer valid as a formal lithostratigraphic name in New York where it was first named. As Chemung was previously used throughout West Virginia (Woodward 1943), the abandonment of the name brought the opportunity to provide a new lithostratigraphic nomenclature for the hundreds of feet of strata comprising the formerly mapped Chemung that Dennison (1970) later named the Greenland Gap Group.

The Greenland Gap Group, consisting of the basal Scherr Formation and overlying Foreknobs Formation, was originally defined by Dennison (1970) based on a composite of several measured sections along the Allegheny Front in Virginia, West Virginia and Maryland (text-fig. 1). Later, the basal part of the Scherr Formation was separately defined as the Minnehaha Springs Member by Lyke (1986). The Foreknobs Formation was ultimately subdivided into five named members (in ascending order, Mallow, Briery Gap Sandstone, Blizzard, Pound Sandstone and Red Lick) by Dennison (1970) and McGhee and Dennison (1976). Subsequent workers selectively applied these formational and member divisions for mapping and academic studies throughout the outcrop belt (McGhee 1977; Dennison 1985; van Tassell 1987; Warne et al. 1991; Rothwell et al. 1989; Brame 1999; Dean et al. 1992; Brezinski and Conkwright 2013) and subsurface (Boswell et al. 1987; Filer 2002), leading to an inconsistent application of nomenclature to intervals of similar lithology at different localities, further confounding the existing problem with field recognition and mappability of these contacts. Dennison (1970) published eleven reference sections for the Greenland Gap Group as plane table drawings and measured sections. However, the application of nomenclature among those plane table sections was inconsistent and occasionally erroneous. Due to weathering and anthropomorphic change, most of these sections no longer provide meaningful outcrop exposures for recognizing the



Explanation

- Scherr type section
- Baker reference section
- Major roads
- County borders
- State borders

7.5 minute quadrangles

- a: Old Fields
- b: Sector
- c: Moorefield
- d: Romney
- e: Hayfield
- f: Greenland Gap



Mapping Convention 1

- Dh: Hampshire Formation
- Dggrl: Foreknobs Formation - Red Lick Member
- Dggrf: Foreknobs Formation - Pound Sandstone Member
- Dggrb: Foreknobs Formation - Blizzard Member
- Dggrbg: Foreknobs Formation - Briery Gap Sandstone Member
- Dggrm: Foreknobs Formation - Mallow Member
- Dggs: Scherr Formation - Greenland Gap Group
- Dggsms: Scherr Formation - Minnehaha Springs Member
- Db: Brallier Formation
- Dhs: Harrell Shale

Mapping Convention 2

- Dh: Hampshire Formation
- Df: Foreknobs Formation
- Ds: Scherr Formation
- Db: Brallier Formation
- Dbh: Brallier / Harrell Formation Undifferentiated

Mapping Convention 3

- Dh: Hampshire Formation
- Dgg: Greenland Gap Group
- Db: Brallier - Harrell Formations
- Dhs: Harrell Shale

TEXT-FIGURE 2

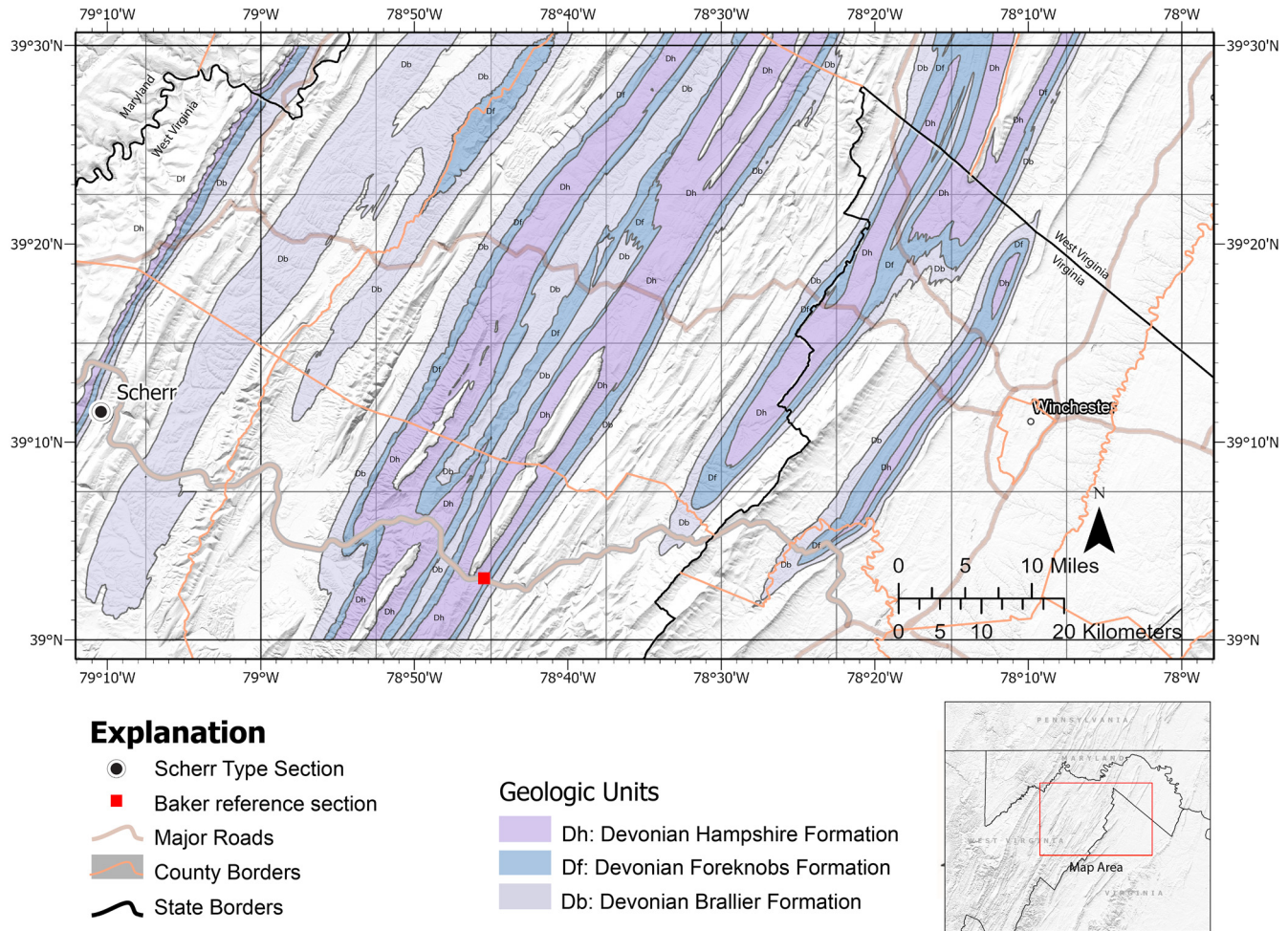
Index map showing the area of study and the lack of consistent mapping across 7.5-minute quadrangle boundaries within the Upper Devonian clastic units.

original named units. Here, we present a new, complete reference section of the Brallier Formation, Foreknobs Formation and minor intervals of the underlying Harrell Formation and overlying Hampshire Formation in a near-continuous roadcut that is captured through digital photography and a digital outcrop model for future reference and preservation. In addition, we use high-resolution lidar-derived topographic imagery and new roadcut exposures parallel to the original type section to demonstrate that the original type section of Dennison (1970) at Scherr, West Virginia was erroneously delineated with respect to the criteria used to describe the formational contacts and member designations.

Our revisions described herein reconcile these discrepancies and provide clarity for the divisions of units at the new reference section.

THE BRALLIER FORMATION (REVISED)

The Brallier Formation was initially defined by Butts (1918) and named after a railway station located six miles northeast of Everett, Bedford County, Pennsylvania. At the type section, the Brallier Formation was characterized as a 1,350-1,800-ft-thick (411-548 m) succession of fissile-weathering, fine-grained



TEXT-FIGURE 3
Index map showing the area of study, locations discussed in the text and seamless mapping of the units according to the mapping conventions proposed in this study.

siliceous shale in thin layers with overall consistent thickness. The formation also contains minor thin layers of fine-grained sandstone with rare small fossils (Butts 1918, 1940).

At the Baker, West Virginia reference section, the Brallier Formation is exposed along a recent road cut (ca. 2002) starting .25 miles west of the Baker exit along US Rte. 48 (also known as Corridor-H) that provides a near-complete section of the formation, including its lower and upper contact with the Harrell Shale and Foreknobs Formation, respectively. The Brallier Formation, as revised, is now informally divided into a lower shale and siltstone and an upper sandstone and siltstone (text-fig. 1). The lower part consists of the shale-rich lithologies included in the original description of the Brallier Formation by Butts (1918). The upper part includes strata previously described and mapped as the overlying Scherr Formation and the Mallow Member of the Foreknobs Formation, which typically contains a slightly higher proportion of coarser-grained units. The lithologies previously placed in the Brallier Formation include gray to dark gray shales and thin- to medium-bedded sharp-based siltstones with weakly graded bedding, hummocky cross-stratification, basal scour structures and sharp bounding

surfaces. Siltstone often occurs as 3-5 m thick packages of 5-10 discrete beds that, in outcrop, stand out in positive relief after weathering and are often laterally continuous over tens of meters.

The characteristic lithologies previously placed in the Scherr Formation, which are here incorporated into the informal upper unit of the Brallier Formation, are (lowest to highest):

- i) gray, dark-gray, brown and reddish-brown shale and fine grained, planar-bedded sandstone
- ii) thin- to medium-bedded sharp-based siltstones that show weak graded bedding, basal scour structures and sharp upper bounding surfaces,
- iii) massive to weakly normal-graded, medium- to thick-bedded sandstones occurring, in some cases, as beds that are >1-m-thick
- iv) fossiliferous zones principally containing brachiopods and crinoid pieces that typically form along the bases of sandstones and coarser siltstones.

We propose the revision of the Brallier Formation to incorporate the facies previously included in the light olive gray siltstone and fine sandstones of the overlying Scherr Formation on

the basis that the contact between them is not mappable at regional scale (1:100,000 or smaller), and that the original definition of the Scherr Formation included an arbitrary cutoff of its occurrence at the state line between Virginia and West Virginia.

The lack of mappability of the contact between the Scherr and Brallier formations is perhaps most clearly demonstrated at the type locality of Scherr, West Virginia within the Greenland Gap 7.5-minute quadrangle. A plane-table section along Route 42 published by Dennison (1970) was overlain and compared to the subsequent geologic map of the Greenland Gap quadrangle by Dean et al. (2011), and the discrepancy between the placement of the contact between the Brallier and Scherr formations by these authors is approximately 940 ft (280 m) (text-fig. 4). Moreover, Dean et al. (2011) did not distinguish the Foreknobs Formation from the Scherr Formation on their geological map and instead lumped them together into a single unit of the Greenland Gap Group. As noted in the description of map units for the Greenland Gap Group, Dean et al. (2011) wrote that the unit was “undifferentiated west of Wills Mountain anticline because individual units of the Greenland Gap Group could not be identified.” This is a remarkable statement, because the map by Dean et al. (2011) contains the type section of both the Foreknobs and Scherr formations along Rte. 42 at Scherr.

Previously published maps at 1:24,000 scale east of the Wills Mountain anticline (e.g., Dennison 1963; Dean and Kulander 2003, 2008) within the Winchester 30×60-minute quadrangle show inconsistencies and erroneous placement of the contact between the Brallier and Scherr formations (text-fig. 2). The contact crosses stratigraphic units in numerous places, especially when compared to high-resolution lidar-derived topographic imagery (Burke and Doctor 2021). For these reasons, we maintain that the contact between the Brallier and Scherr formations does not meet the standard of “tested mappability” required by Article 24(d) of the North American Stratigraphic Code (NACSN 2021).

THE SCHERR FORMATION (ABANDONED)

The Scherr Formation was designated by Dennison (1970) and named after the village of Scherr, Grant County, West Virginia. The type section for the Scherr Formation and the overlying Foreknobs Formation is along West Virginia Route 42, about 0.5 km northwest of the village of Scherr.

The key distinguishing features were initially reported as “chiefly siltstone, with considerable fine sandstone and shale that weathers to light olive gray.” The basal contact was originally defined as “an abrupt introduction of beds containing a small percentage of sandstone,” which was interpreted as distinct from the massive siltstone and general lack of sand in the underlying Brallier Formation (Dennison 1970). The lower portion of the Scherr was described in terms of its general lithology as abundant sandstone that decreases both up section and laterally southwest of its type section. The upper beds of the Scherr Formation were characterized by a general lack of sandstone facies and “essentially a repetition of Brallier lithology but with *Cyrtospirifer chemungensis* present in the coarsest beds” (Dennison 1970). According to Dennison (1970), the lower and upper parts of the Scherr Formation were only found suitable for use along the Allegheny Front, as facies changes were such that the Scherr Formation *sensu strictu* was not distinguishable in eastern outcrop belts. Similarly, Dennison (1970)

noted that the Scherr Formation graded laterally westward into the finer-grained lithologies of the Brallier Formation.

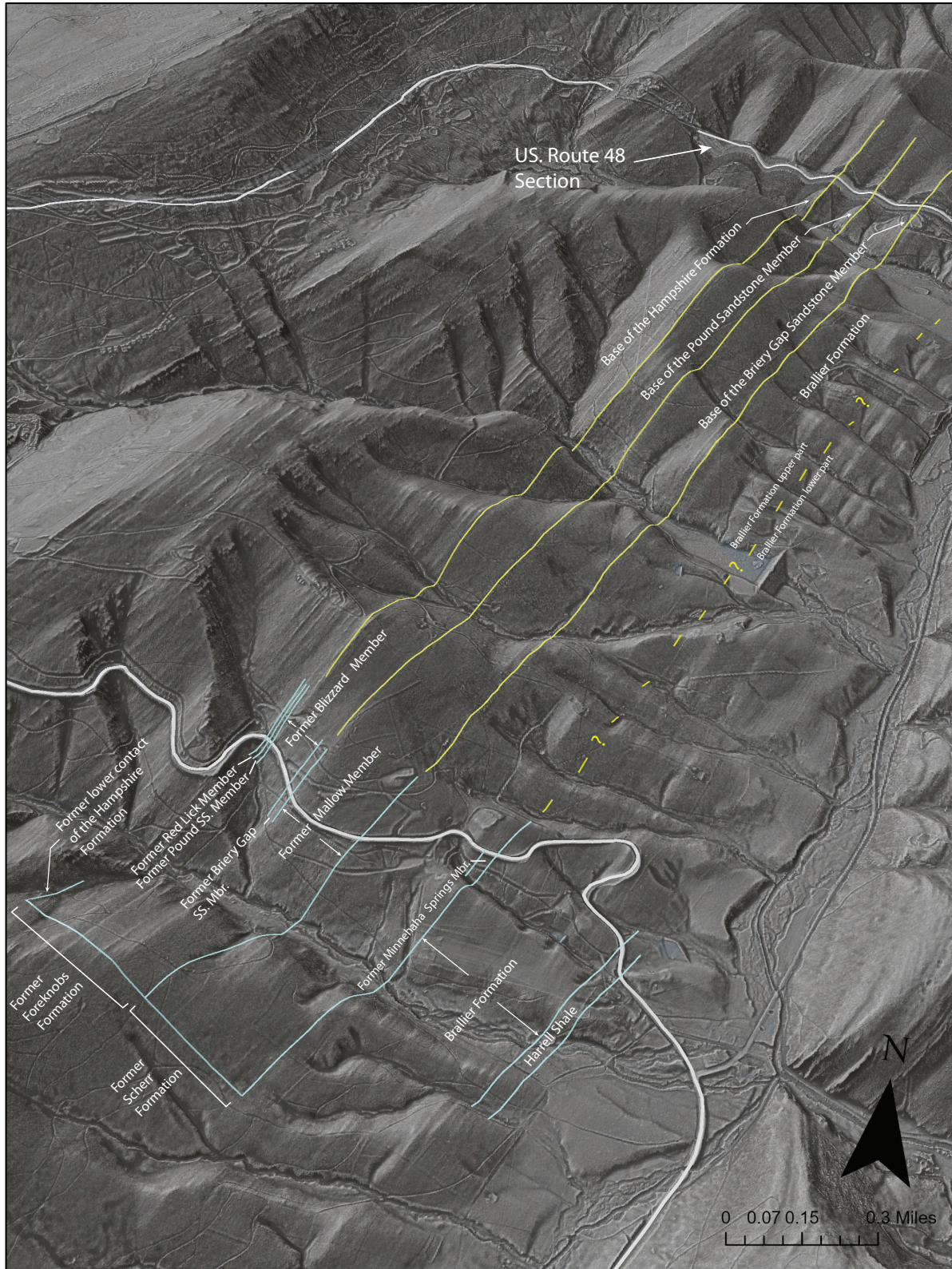
We propose abandonment of the Scherr Formation on the basis that both the upper and lower contacts have not been mapped consistently at 1:24,000 scale within multiple 7.5-minute quadrangles in West Virginia, even adjacent to the type locality (text-figure 2). Further, the original description discusses the fact that many of the members are unrecognizable in outcrop and were only constructed through years of work on subsurface data sets (Dennison 1970). Based on experience in regional mapping in the subsequent five decades, we consider the original establishment of the Scherr Formation as being contrary to Article 24(d) of the stratigraphic code (NACSN 2021), which states that named formations must be based on “tested mappability”.

Lyke (1986) formally defined the Minnehaha Springs Member to be the base of the Scherr Formation. In spite of the claim that this member is, “a distinct, laterally persistent base of coarser-grained clastic sequences which mark the lower part of the Scherr Formation” (Lyke 1986, p.176), we have not found this to be a mappable criterion on which to define the base of the unit. The member was defined as, “a zone of interbedded siltstones, shales, and some sandstones that is in part coarser-grained than the Brallier Formation” (Lyke 1986, p. 176). We contend that this lithologic description is insufficient to enable unambiguous identification of the base of this member in the field and has resulted in numerous inconsistencies among adjacent geologic maps at this contact (text-fig. 2).

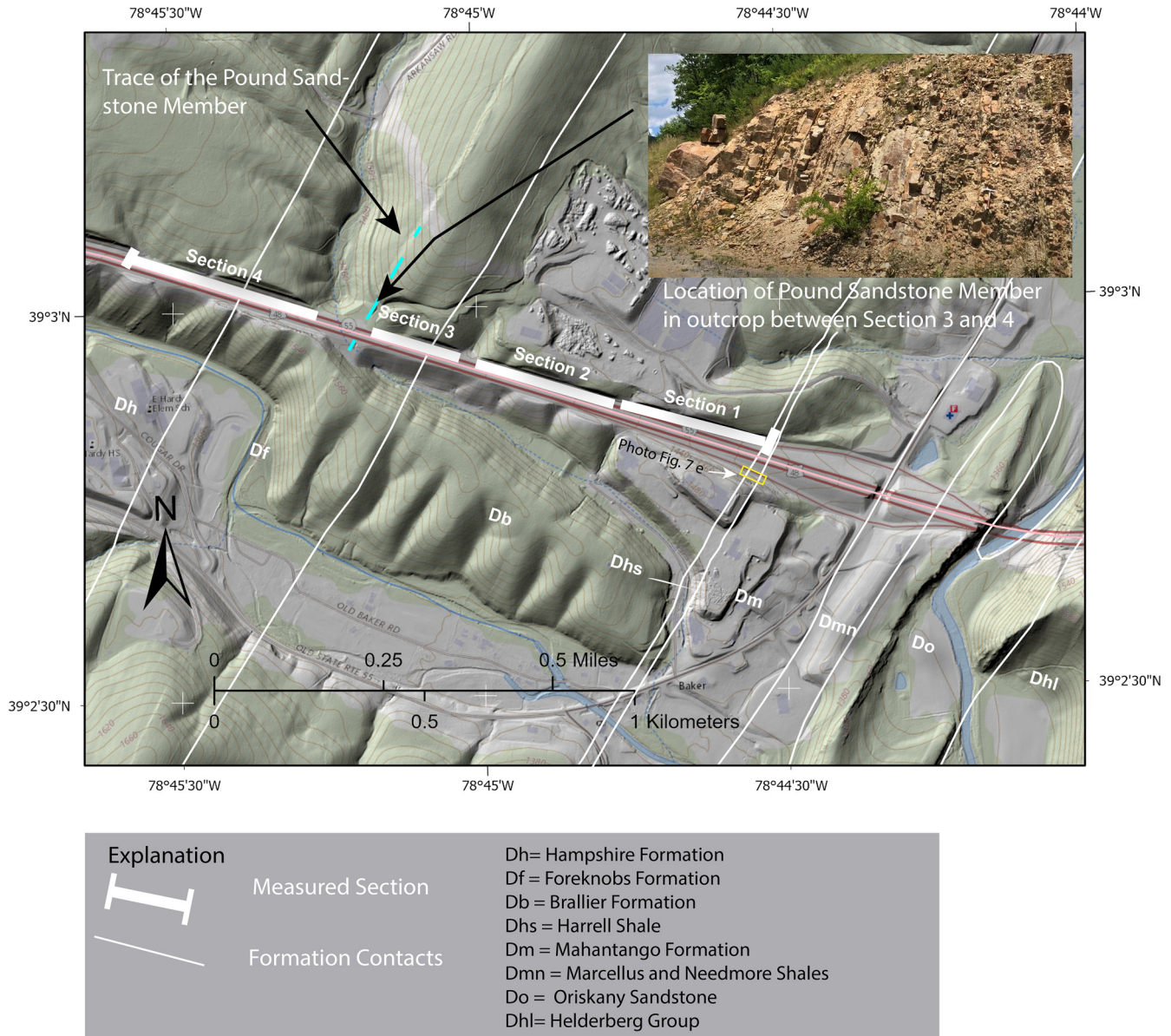
Therefore, the Minnehaha Springs Member of Lyke (1986) is also abandoned and these strata are placed along with the overlying remainder of the former Scherr Formation in the upper part of the Brallier Formation. We recognize that the strata of the Minnehaha Springs Member as mapped on the Moorefield (Dean et al. 2004; text-fig. 2c), Old Fields (Dean and Kulander 2003, text-fig. 2a), Sector (Dean et al. 2000; text-fig. 2b), and Petersburg (Dean et al. 2001) 7.5-minute quadrangles reflect the lowest limit of the upper part of the Brallier Formation in those localities. This convention is consistent with recent work by Rossbach (2020) and Doctor and Parker (2018).

THE FOREKNOBS FORMATION (REVISED)

The original unit description of the Foreknobs Formation by Dennison (1970) notes “abundant sandstone, massive sandstone, considerable siltstone, substantial red beds of brownish gray sandstone, siltstone and shale containing scattered marine fossils and occasional quartz-pebble conglomerate or conglomeratic sandstone beds”. Dennison (1970) established that the base of the Foreknobs Formation is “marked by a massive sandstone and west of the Mouth of Seneca is associated with conglomerate”. Later he notes the base is identified by “an abrupt upward increase in percentage, thickness, and massiveness of sandstone beds, and northeast of Mouth of Seneca the base generally is marked by conglomeratic strata.”; the upper contact is defined by the highest occurrence of marine fossils. Dennison (1970; 1971) defined four named members, and McGhee and Dennison (1976) added a fifth. From oldest (i) to youngest (v) they are:



TEXT-FIGURE 4
 Original plane table mapped section of the Foreknobs Formation at Scherr, West Virginia, by Dennison (1970) shown in blue. The section is rectified and draped over a lidar-derived, shaded relief raster image visualized in 3D. Careful matching of the plane table mapped lithologic contacts to lidar-derived terrain features reveals that the basal contact of the Foreknobs Formation has been misplaced. This image also traces the lithologic contacts from the Scherr section to the new roadcut section along Rt 48, located ~2.2 mi to the north-northeast shown in yellow. Mbr = Member, SS = Sandstone.



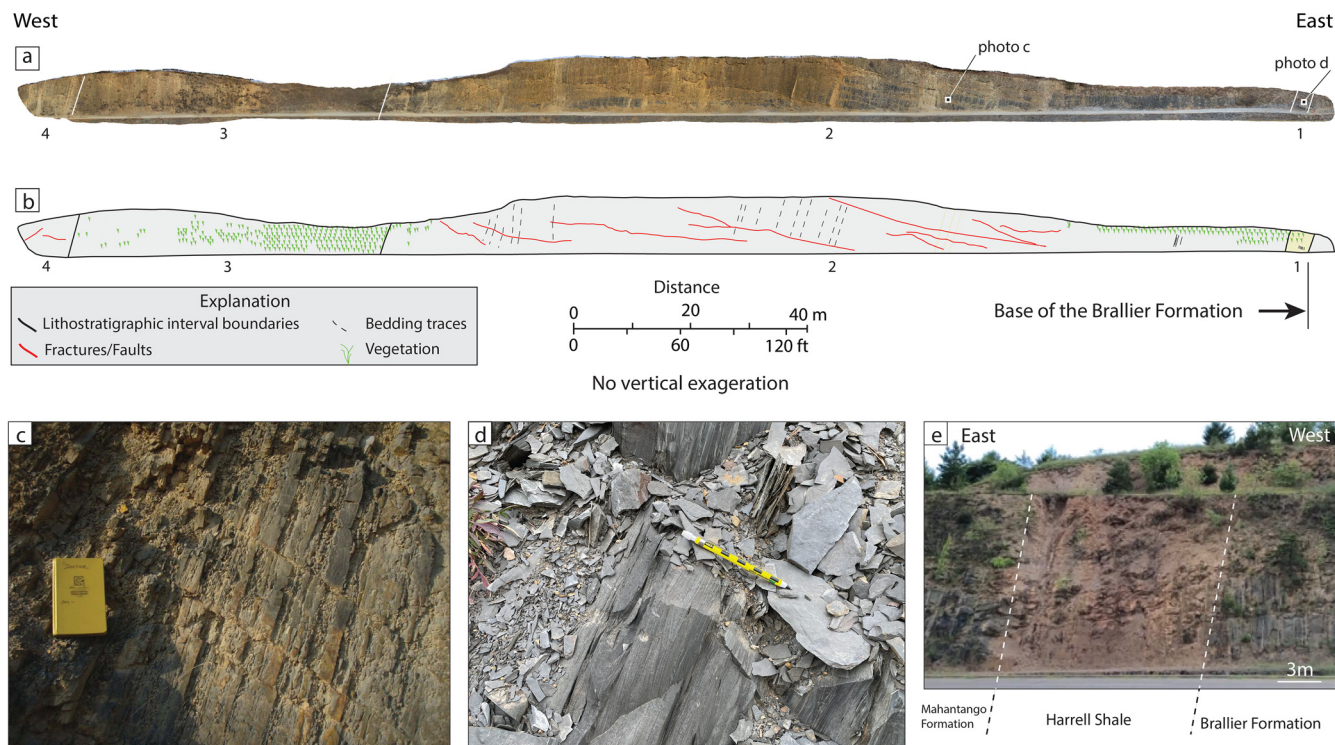
TEXT-FIGURE 5

Hybrid, lidar-derived shaded relief imagery draped with U.S. Geological Survey 20 ft contour interval topographic map showing location of the Baker reference section along the north side of US Rt. 48, west of the town of Baker, West Virginia. Text-figs. 6-9 correspond to the sections 1-4. Photo by Daniel H. Doctor.

- i) Mallow Member: brown and gray shale, siltstone and minor sandstone
- ii) Briery Gap Sandstone Member: massive, medium-grained to conglomeratic, cross-bedded, and well-sorted sandstones,
- iii) Blizzard Member: greenish gray or light olive gray heterogeneous interbedded sandstone and siltstone
- iv) Pound Sandstone Member: fine- to medium-grained, cross-bedded, and conglomeratic, well-sorted sandstones
- v) Red Lick Member: olive gray marine sandstones and siltstones with some brownish gray “redbeds”

Our revision of the Foreknobs Formation is based on a careful examination of the original type and reference sections together

with new lidar topographic data. This examination reveals that some of the existing mapped contacts are misplaced according to Dennison’s original lithological description. The Foreknobs Formation, as here redefined, includes all the lithofacies present within the Briery Gap Sandstone, Blizzard, Pound Sandstone and Red Lick Members of Dennison (1970). According to the NACSN (2021), members are not required to be mappable. However, the criteria used to define both the base of the Foreknobs Formation and the base of the Mallow Member lack clear characteristics to distinguish them from lithologies present in the adjacent upper part of the Brallier. The Mallow Member, as defined by Dennison (1970) includes exclusively marine strata consisting of olive gray-weathering siltstone, some shale and prominent sandstone packages up to 1-m-thick, with



TEXT-FIGURE 6

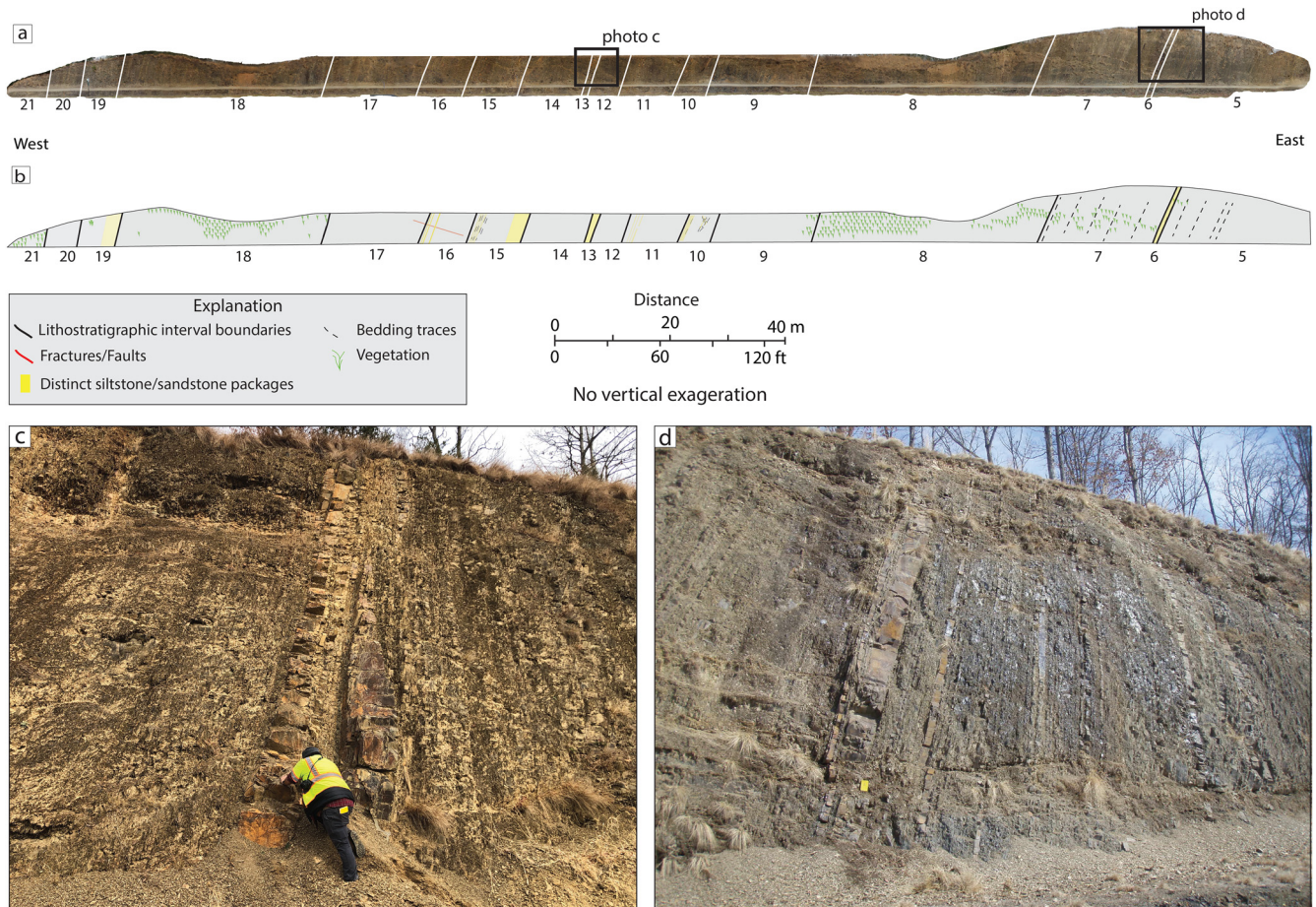
Structure from Motion (SfM)-derived orthomosaic images with line work indicating gross lithostratigraphic intervals and outcrop line-drawing below of section 1. Location of sections shown in text-fig. 5. Numbered intervals correspond to Table 1 with lithologic descriptions. a) Baker section 1 showing the base of the Brallier Formation in contact with the uppermost portions of the Harrell Shale (image left) and gray to dark gray shale and siltstone facies. b) Baker section 2 covering the Brallier Formation. c) Outcrop photo showing typical lithofacies of the Brallier Formation dominated by interbedded thin siltstones and shales. d) Hummocky and cross stratified siltstones at the base of the Brallier Formation. e) Dark gray to black shales of the Harrell Shale exposure location at Burlington, WV. Photos by Daniel H. Doctor

some “brackish water siltstones” and a few quartz-pebble conglomerates up to 30-cm-thick. Dennison (1970), in his original designation of these members of the Foreknobs Formation, states that “very few of the stratigraphic divisions outlined in this paper were evident in field examination. Only after having the complete bed-by-bed stratigraphic sections in field notes and plotting the relations at various scales in stratigraphic cross-sections was it possible to correlate details of lithologic timelines. The results were much more successful than anticipated and stratigraphic character can be predicted at new localities.” Thus, the definition of the contact between the Scherr Formation and the Foreknobs Formation in this way is contrary to Article 24(a-d) of the stratigraphic code (NACSN 2021), which establishes that formations must be mappable as a body of rock identified solely by lithic characteristics and stratigraphic position.

Revisiting sections described in detail by Dennison (1970) revealed a lack of correspondence between the placement of designated formation/member contacts and the stratigraphy observed by us in the field. Using georeferenced plane-table sections produced by Dennison (1970), we attempted to identify each member. Identifying prominent packages of sandstones like those described as being indicative of the base of the Scherr and Foreknobs formations was achieved; however, numerous additional, equally prominent sandstone units were also

observed, which were either not recorded in the described section or lumped within one of the named members (text-fig. 4).

We propose a revision of the Foreknobs Formation, including adjustment of its basal contact with the underlying Brallier Formation on the basis that it is not mappable in its current definition at 1:24,000 scale and smaller (text-fig. 4). The strata previously designated as the Mallow Member at the base of the Foreknobs Formation are revised to be included in the upper part of the Brallier Formation. The revised contact of the base of the Foreknobs Formation is therefore defined at the base of the stratigraphically lowest quartz-pebble conglomerate found in close association with a quartz-rich, ridge-forming package of medium- to coarse-grained sandstone often occurring as cross bedded or lenticular bodies at the scale of the outcrop. Over the scale of several kilometers, the conglomeratic facies pinch and swell. In the absence of quartz pebbles, a ridge-forming sandstone is traceable. This occurrence in most places corresponds to the Briery Gap Sandstone Member of Dennison (1970) and, more importantly, a mappable ridge-forming package that is traceable in lidar-derived imagery (text-fig. 4) and outcrop for several hundred kilometers. Previous workers have noted the pervasive nature of pebble conglomerates within the more dominant fine-grained nature of the Foreknobs (McClung et al. 2013). While these pebble conglomerate intervals appear throughout the formation, their first presence is often paired



TEXT-FIGURE 7

Structure from Motion (SfM)-derived orthomosaic images with line work indicating gross lithostratigraphic intervals (panel a) and outcrop line-drawing (panel b) of section 2. Location of sections is shown in text-fig. 5. Numbered intervals correspond to Table 1 with lithologic descriptions. a) Baker section 2 showing the lower and middle portion of the Brallier Formation. b) Baker Section 2, line drawing covering the lower and middle portion of the Brallier Formation. c) Close photo of interval 13 showing a 1.5 m thick sandstone unit. d) Outcrop photo of a notable .75 m thick sandstone containing disarticulated brachiopod and crinoid fossils. Photos by Daniel H. Doctor.

with a prominent topographic ridge visible in the lidar imagery in inclined sections. The upper contact with the overlying Hampshire Formation is here placed at the base of the first thick-bedded maroon to gray sandstone bed containing abundant plant fragments and lacking marine fossils.

GREENLAND GAP GROUP (ABANDONED)

The Greenland Gap Group is abandoned on the basis that one of the two formations (the Scherr Formation) is herein abandoned, thereby obviating group status.

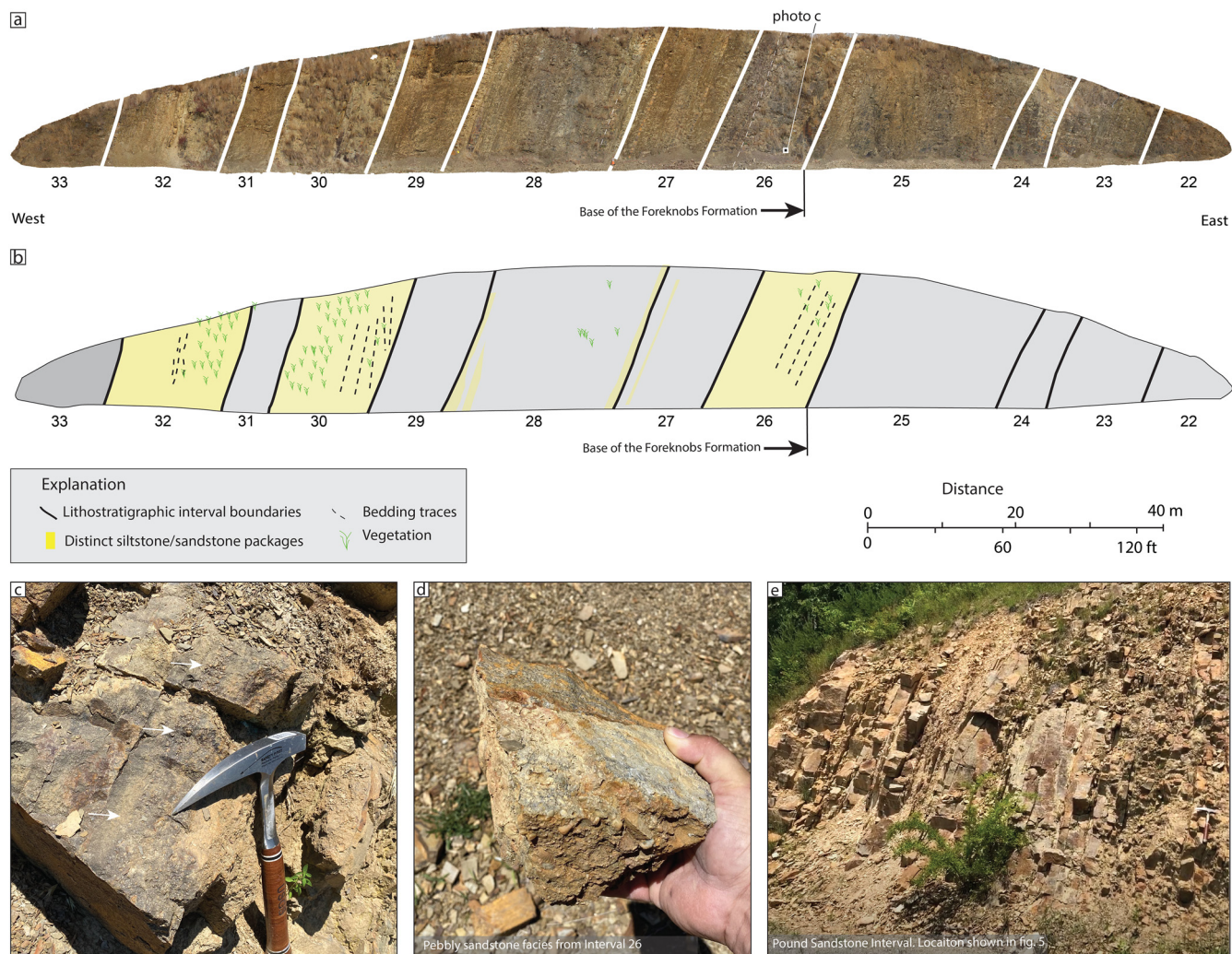
NEW REFERENCE SECTION AT BAKER, WEST VIRGINIA

The Baker, West Virginia reference section includes four individual measured road-cut sections that are interrupted by covered intervals, starting .25 miles west of the Baker exit along US Rte. 48 (also known as Corridor-H) (text-fig. 5). This site was chosen for the quality of the exposure which features several formational contacts that are often not exposed along strike, the lack of intense structural deformation complicating

the stratigraphy, and its relative central location with respect to the east-west extent of the distribution of map units.

The base of the composite reference section starts just below the exposed contact between the Harrell Shale and overlying Brallier Formation (text-fig. 6). Westward from this point, the section continues to provide a nearly continuous exposure through the currently named units of the Brallier (text-fig. 7) and Foreknobs formations (text-fig. 8). The westernmost exposure in the section ends within the Hampshire Formation, ~120 m above the contact with the underlying Foreknobs Formation (text-fig. 9).

These individual sections are illustrated as four photo panel orthomosaics (text-figs. 6-9). Interval numbers annotated on the image correspond to the descriptive section (see Table 1). The full-resolution images in this work and the 3D point clouds from which they were derived are available as a USGS data release (Pitts and Doctor 2024). The numbered facies intervals are intentionally generalized to coincide with large-scale changes in lithologic character, notable stratigraphic surfaces and key faunal zones. The intervals reported from this section



TEXT-FIGURE 8
 Structure from Motion (SfM)-derived orthomosaic images with line work indicating gross lithostratigraphic intervals and outcrop line-drawing below of section 3. Location of sections shown in text-fig. 5. Numbered intervals correspond to Table 1 with lithologic descriptions. a) Baker section 3 showing the top of the Brallier Formation and the lower contact of the Foreknobs Formation indicated at the base interval 26. b) line drawing showing lithostratigraphic intervals c) outcrop photo showing the conglomeratic sandstones at the base of the Foreknobs Formation. D) Broken sample of conglomeratic sandstone interval showing rounded quartz pebbles. e) The Pound Sandstone Member. Photographs C & D by Daniel H. Doctor; Photograph B by Alan D. Pitts.

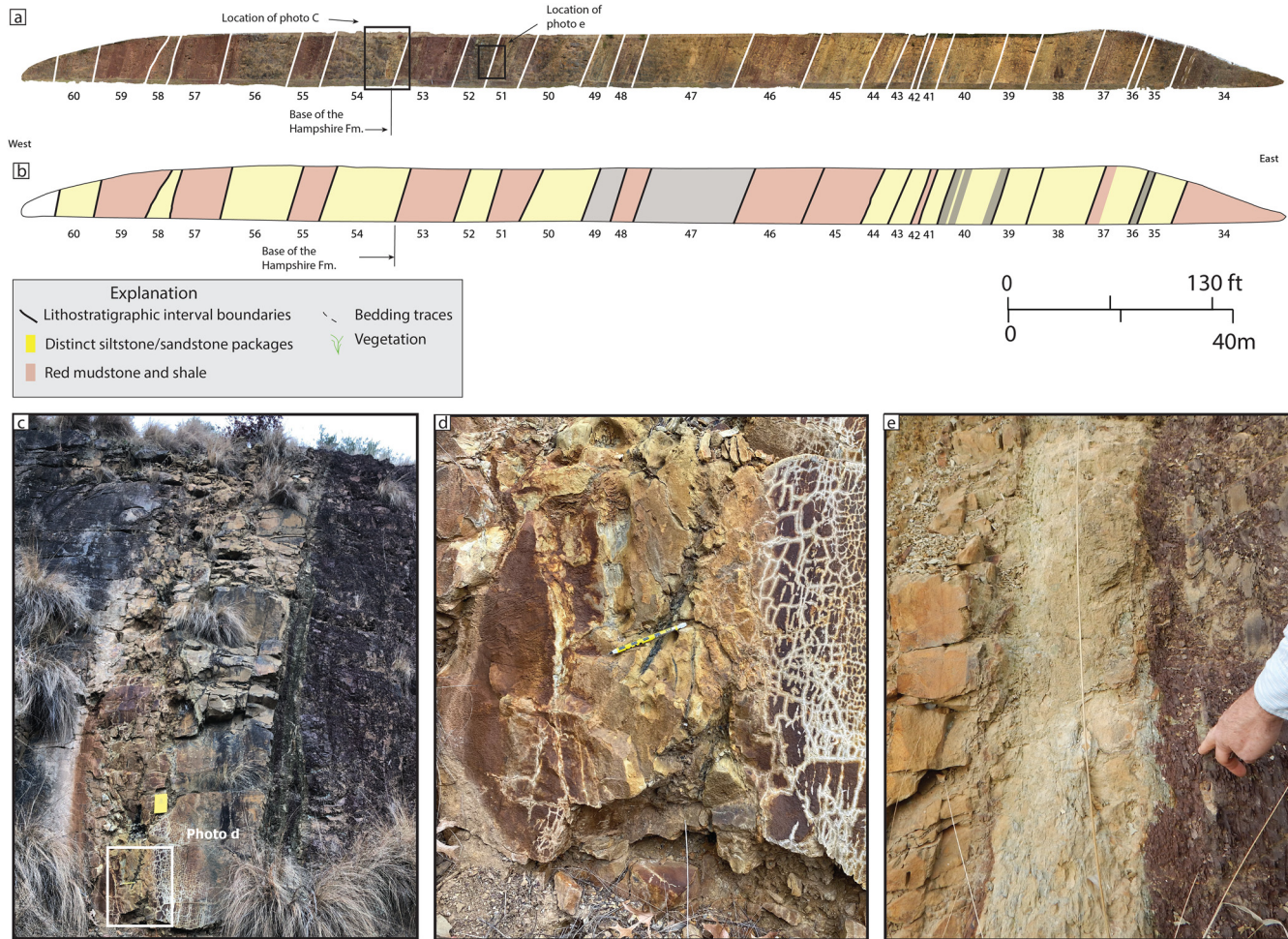
were created to record the gross lithostratigraphic framework, detailed facies descriptions and major environmental indicators and all other descriptive elements that may aid the future field geologist in locating features along this section. Our measured section includes notes where it was possible to recognize correspondence with the members of the Foreknobs Formation described by Dennison (1970) including the base of the Briery Gap Sandstone Member (text-fig. 8 interval #26) and the base of the Pound Sandstone Member.

SUMMARY AND CONCLUSIONS

According to the North American Code of Stratigraphic Nomenclature (2021), named formations on geologic maps must be mappable. The revisions to formational contacts and lithostratigraphic unit descriptions in this work reconcile the

lithostratigraphy of the Devonian Brallier and Foreknobs formations across state boundaries and avoid reliance on individual event beds or other depositional features that may have an irregular lateral distribution along and across strike. By abandoning the Scherr Formation (and therefore the Greenland Gap Group) and better defining the Brallier and Foreknobs formations with persistent lithologic units, we demonstrate the utility of these lithostratigraphic revisions as a solution to seamless mapping across 7.5-minute quadrangle boundaries that comprise the Winchester 30x60-minute quadrangle. This work represents a first step that may be used as a model for long-distance correlation of adjacent units throughout the region.

This work formalizes the following revisions to the lithostratigraphy in the study here summarized:



TEXT-FIGURE 9

A) Structure from Motion (SfM)-derived orthomosaic image with line work indicating gross lithostratigraphic intervals and outcrop line-drawing below B) of section 4. Location of sections shown in text-fig. 5. Numbered intervals correspond to Table 1 with lithologic descriptions. Baker section 4 showing the upper portion of the Foreknobs Formation and the lower contact of the Hampshire Formation at the base of interval 54. C) Sandstone package at the base of the Hampshire Formation. D) Plant fragments incised in sandstone beds. E) Paleosol horizon. Photos by Daniel H. Doctor

1) Abandonment of the names Greenland Gap Group, Scherr Formation, and the Minnehaha Springs Member of the Scherr Formation.

2) Inclusion of all strata previously designated Scherr Formation by Dennison (1970) within the upper Brallier Formation.

3) Abandonment of the basal Mallow Member of the Foreknobs Formation named by Dennison (1970), and strata comprising this interval are placed in the upper Brallier Formation of Butts (1918).

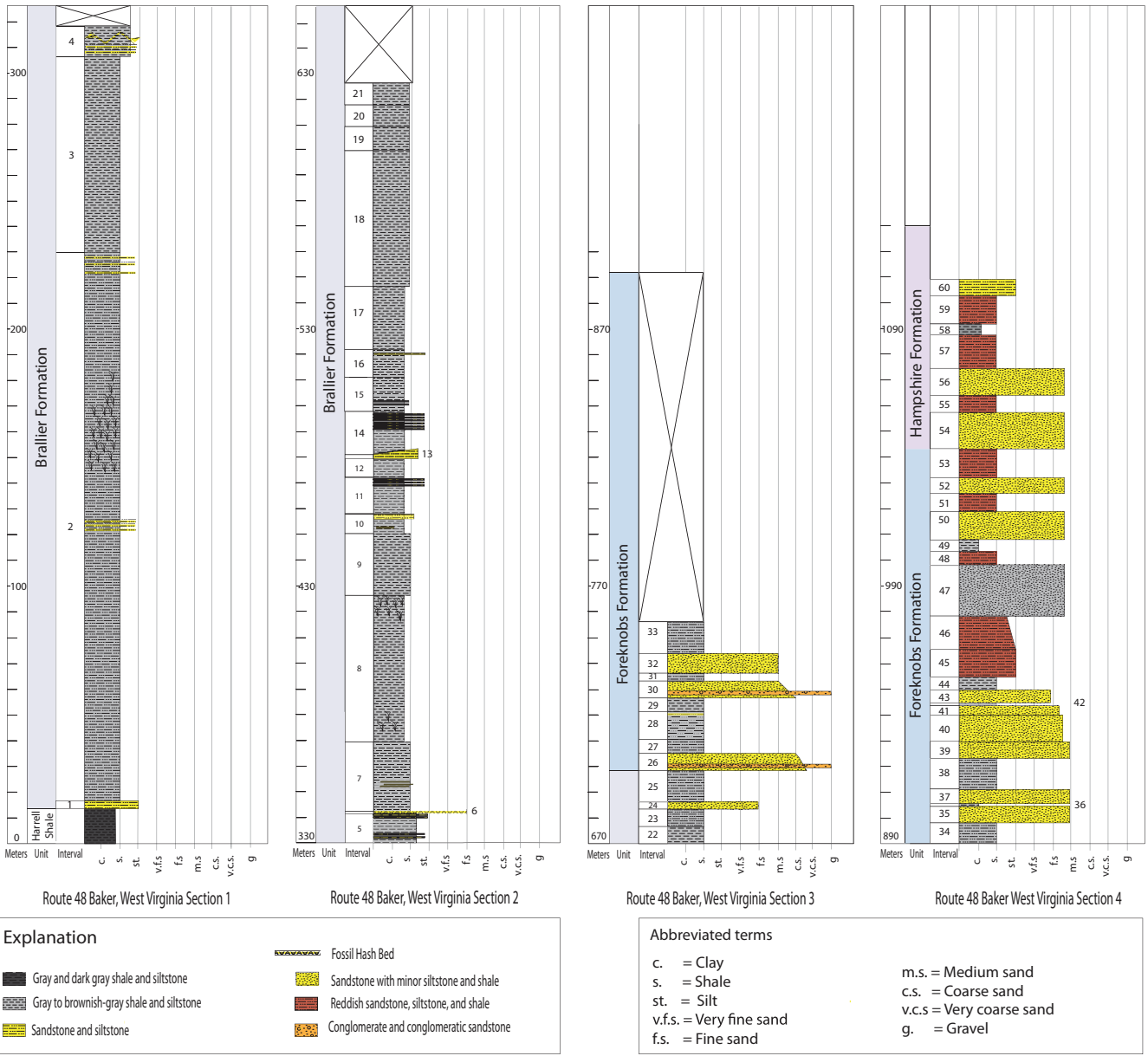
This work designates a new criterion to define the contact between the Brallier Formation and overlying Foreknobs Formation and follows the convention of Schultz (1997) used to map these units in the Broadtop Synclinorium. The base of the Foreknobs Formation is now recognized by the first definitive occurrence of a mappable ridge-forming sandstone package often containing rounded quartz pebble conglomeratic sandstone facies, cross-stratified sandstones with lesser shale and siltstone interbeds. The base of this oldest conglomeratic

sandstone marks a convenient, widespread, recognizable and readily mappable horizon upon which to establish the contact between the shale-rich Brallier below and the more sand-rich Foreknobs strata above.

The changes in geologic map units proposed here incorporate insights gained from modern geologic mapping practices and represent an attempt to update lithologic units according to parameters available to field geologists working in poorly exposed rocks in heavily vegetated terrains. Widespread availability of 1 m resolution lidar-derived imagery has cemented its use as a source for detailed base maps throughout the mapping community. This work reflects the impact of lidar imagery on field mapping and attempts to update unit definitions considering this new data.

Data Availability

The data used in this report are published at USGS Science-Base and available for download at: <https://doi.org/10.5066/P96A2ZWW>.



TEXT-FIGURE 10
Stratigraphic log of the entire reference section with interval numbers corresponding to the Table 1 descriptions. Each column corresponds to sections 1-4 on text-fig. 5 and text-figs. 6-9.

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TABLE 1
Stratigraphic descriptions and thickness which correspond to intervals shown in Figures 6-9.

Interval	Description	Thickness			
		Interval Feet	Interval Meters	Unit Cumulative (m)	Total Cumulative (m)
Hampshire Formation (lower part)					
60	Sandstone, moderate brown (5YR 3/4). Sandstone is thin- to medium-bedded with erosional basal bounding surfaces as well as scour and fill structures. Plane parallel laminations are abundant and locally cross-stratified.	22.2	6.8	65.9	1192.74
59	Shale, moderate red (5R 4/6) and dusky red (5R 3/4) siltstone and sandstones maroon to brown and reddish-brown. Alternating successions of red siltstone and red shale showing erosional scour and fill geometries.	35.4	10.8	59.14	1185.98
58	Shale, dusky red (5R 4/6) and thin- to medium-bedded sandstone dark reddish-brown (10R 3/4).	13.5	4.1	48.34	1175.18
57	Shale, dark reddish-brown (10R 3/4) and siltstone reddish-brown (10R 3/4).	42.7	13.0	44.24	1171.08
56	Sandstone, dark-yellowish-brown (10YR 2/2), and shale, dusky red (5R 3/4). Sandstone is fine- to medium-grained occurring in packages of medium- to thick-beds with erosional surfaces, scour and fill structures, planar parallel and wedge-shaped beds and bedsets transition upwards into thin-bedded sandstones and shale.	34.4	10.5	31.24	1158.08
55	Shale, dusky red (5R 4/6) along a sharp base with some small stringers of siltstone light yellowish-brown (2.5Y 6/4.)	21.8	6.6	20.74	1147.58
54	Sandstone, dark reddish-brown (10YR 3/4), dark-yellowish brown (10YR 4/4) and moderate brown (5YR 3/4). Medium- to thick-bedded, fine- to medium-grained moderately sorted sandstone with erosional surfaces, scour and fill structures, planar parallel and wedge-shaped beds, and bed sets. Abundant large plant fragments and organic material. Lack of marine fossils.	46.3	14.1	14.1	1140.94
Base of the Hampshire Formation / Top of the Foreknobs Formation					
53	Distinct package of shale, dusky red (5R 4/6) interspersed silt and shale, light yellowish brown (2.5Y 6/4) Interval contains two sharp zones ~ 1m thick that are greenish-gray in color.	20.3	6.2	336.49	1115.54
52	Sandstone, moderate brown (5YR 3/4) and grayish-brown (5Y 3/2), fine- to medium-grained, medium- to thick-bedded. The basal bedding surfaces show evidence of scour and fill. Bedding is planar parallel and locally cross-bedded. The strata of this interval are discordant with underlying units. A partial brachiopod mold was found in this sandstone and is the highest known marine fossil occurrence in the exposed section.	24.9	7.6	330.3	1109.35
51	Shale and siltstone, dusky red (5R 4/6) and sandstone, dark reddish-brown (10YR 3/4) sandstones. The lower portion of this interval is medium- to thick-bedded sandstones transitioning upward into shales and thin-bedded siltstones. Strata of this interval overlay a concave-up erosional channel form surface	35.8	10.9	322.7	1101.75

(continued)

Table 1 (Continued)

Interval	Description	Thickness			
		Interval Feet	Interval Meters	Unit Cumulative (m)	Total Cumulative (m)
50	Sandstone, dark reddish-brown (10 YR 3/4) and grayish-brown (5Y 3/2) locally erosive base. Medium- to thick-bedded with minor erosional surfaces, scour and fills. Plane parallel laminations and locally cross-bedded.	15.1	4.6	311.8	1090.85
49	Shale, yellowish gray (5Y 7/2) and light greenish gray (5GY 8/1) with minor thin- bedded siltstones.	17.1	5.2	307.2	1086.25
48	Shale, siltstone, and thin-bedded sandstones, grayish red (10R 4/2).	66.3	20.2	302	1081.05
47	Sandstone, moderate brown (5YR 4/4) and pale yellowish-brown (10 YR 6/2) siltstone and fine-grained sandstones.	42.7	13.0	281.8	1060.85
46	Heterolithic shale, dusky reddish-brown (10 YR 3/4) and red thin-bedded planar siltstone and sandstone.	36.1	11.0	268.8	1047.85
45	Shale, light olive gray (5Y 5/2) and light greenish-gray (5GY 8/1) with minor thin-bedded siltstone and fine-grained sandstone.	16.4	5.0	257.8	1036.85
44	Shale, dusky red (5R 3/4) and greenish-gray (5GY 6/1) and sandstone, pale yellowish brown (10YR 6/2); shale is interspersed with thin- to medium-bedded siltstone and fine-grained sandstone.	16.4	5.0	252.8	1031.85
43	Sandstone, dusky red (5R 2/4); erosional channel forms sharp base.	3.3	1.0	247.8	1026.85
42	Shale, dark red (5R 3/4) and dark reddish-brown (10R 3/4).	12.1	3.7	246.8	1025.85
41	Sandstone, pale yellowish-brown (10 YR 6/2); concave-up erosional surface forms a sharp base.	32.8	10.0	243.1	1022.15
40	Sandstone, pale yellowish-brown (10 YR 6/2) interbedded grayish-black (N2) and dark gray shales (N3) and thin-bedded siltstone pale yellowish-brown (10YR 6/2).	21.3	6.5	233.1	1012.15
39	Sandstone, pale yellowish brown (10 YR 6/2) medium- to thick-bedded; wedge-shaped beds alternating with planar bedded sandstones and shales.	39.4	12.0	226.6	1005.65
38	Sandstone, pale yellowish-brown (10 YR 6/2) beds alternating with planar bedded sandstones and shales. The upper portion consists of siltstone moderate brown (5YR 3/4) capped by a thin interval of light brownish gray (5GY 4/1) shale.	27.0	8.2	214.6	993.65
37	Sandstone, dusky red (5R 2/4) medium- to thick-bedded sandstone and shale dark reddish-brown (10R 3/4).	3.3	1.0	206.36	985.41
36	Shale moderate brown (5YR 3/4) to dark reddish-brown (10R 3/4).	21.3	6.5	205.36	984.41
35	Sandstone, grayish-red (10R 4/2) medium- to thick-bedded sandstone occur as blocky-weathering 20-60-cm-thick wedge-shaped beds that pinch out laterally.	26.2	8.0	198.86	977.91
34	Shale, dusky red (5R 2/4) interbedded with shale moderate brown (5YR 3/4) and very thin-bedded siltstones yellowish-gray (5Y 8/4). Red shale intervals have a mottled texture.	22.2	6.8	65.9	1192.74

(continued)

Table 1 (Continued)

Interval	Description	Thickness			
		Interval Feet	Interval Meters	Unit Cumulative (m)	Total Cumulative (m)
Lower part of the Red Lick Member of the Foreknobs Formation (base not exposed)					
Pound Sandstone Member of the Foreknobs Formation (covered); see map on Fig. 5					
33	Shale, grayish-red (10R 4/2) and siltstone, light olive gray (5Y 5/2) moderate yellowish-brown (10YR 6/6). Siltstones occur as sharp-based beds of 5 - 15 cm in thickness. Shale is variegated as alternating .7-2m packages	33	20.5	6.3	55.86
Top of the Briery Gap Member / Base of the Blizzard Member of the Foreknobs Formation					
32	Sandstone, pale yellowish-brown (10YR 7/4) with siltstone and fine-grained sandstone occurring as planar and wedge-shaped beds that is interbedded with brown and gray shale. Siltstones and fine-grained sandstone beds occur as sharp-based packages ranging from 5-10 cm and up to ~40 cm in thickness	32	21.8	6.6	49.61
31	Shale, grayish-brown (5Y 3/2).	31	9.8	3.0	42.98
30	Sandstone, pale-yellowish brown (10YR 7/4) to light olive gray (5Y 5/2) that is medium- to thick-bedded with planar parallel laminations, cross-stratification, and wedge-shaped bedding. Large-scale cross-stratified beds.	30	22.1	6.8	39.98
29	Shale, moderate brown (5YR 4/4) to dark yellowish-brown (10YR 4/2).	29	16.4	5.0	33.23
28	Shale, dark yellowish-brown (10YR 4/2) to moderate brown (5YR 3/4), light olive brown (5Y 5/6) and dusky red (5R 3/4); interbedded sandstone pale yellowish-brown (10YRR 6/2) medium- to coarse-grained in 5- 50-cm-thick beds. Sandstones alternate with shale light brown to olive gray. Sandstone beds show large scale swaley cross-stratification.	28	35.8	10.9	28.23
27	Shale, moderate brown (5YR 4/4) and light olive brown (5Y 5/6) and thin-bedded siltstone	27	27.6	8.4	17.33
26	Sandstone and conglomeratic sandstone, dusky red (5R 3/4) to moderate brown (5YR 4/4) in beds .15 – 1-m-thick. Planar to gently inclined and wedge-shaped beds that pinch and swell laterally. Sand dominated interval with minor interbedded shale. The first presence of occasional rounded quartz pebbles is diagnostic of the base of the unit. The base of this interval is a sharp contact.	26	29.3	8.9	8.93
Top of the Brallier Formation/ Base of the Foreknobs Formation					
25	Shale, medium gray (N5) dark gray (N3) and interspersed siltstones.	25	54.5	16.6	779.35
24	Shale, yellowish-brown (10YR 4/2) and sandstone light olive gray (5Y 5/2) wedge shaped package is erosive at the base and bed thickness pinches and swells laterally.	24	9.0	2.8	762.75
23	Shale, moderate yellowish-brown (5YR 5/4) and thin- to medium-bedded siltstone and fine-grained sandstone moderate brown (5YR 4/4).	23	23.0	7.0	760
22	Shale, moderate yellowish-brown (5YR 4/4) and minor siltstone, yellowish-brown (10YR 4/2) Partially covered interval.	22	19.7	6.0	753
21	Covered Interval- Break in Section Covered	196.9	60.0	707	706.7

(continued)

Table 1 (Continued)

Interval	Description	Thickness			
		Interval Feet	Interval Meters	Unit Cumulative (m)	Total Cumulative (m)
20	Shale, moderate reddish-brown (10R 3/4) gray thin-bedded with siltstone and shale light olive gray (5Y 5/2).	27.1	8.3	647	646.7
19	Siltstone, dark yellowish-brown (10YR 4/2) light olive gray (5Y 5/2) thin- to medium-bedded and gray shale.	31.0	9.5	638.75	638.45
18	Semi-covered. Siltstone, dark reddish-brown (10R 3/4). At the base of this interval, a 44-cm-thick siltstone bed grades upward into shale, light olive gray (5Y 5/2) and dark yellowish-brown (10YR 4/2); thin- to medium- and thick-bedded siltstone occurs near the top of interval.	172.6	52.6	629.3	629
17	Siltstones and shales, dark yellowish-brown (10YR 4/2) in the lower portion passing upward into brown thin- to medium-bedded siltstones, light olive gray (5Y 5/2).	80.1	24.4	576.7	576.4
16	Shale, light olive gray (5Y 5/2) and dark yellowish brown (10YR 4/2) and minor siltstone, moderate brown (5YR 4/4) that weathers to dark yellowish orange (10YR 6/6) and thin- to medium-bedded brownish siltstones. Bedding thickness in this interval shows a general pattern of thickening upward trend, and the top of this interval is placed above a package of alternating thin- to medium-bedded siltstones and shales. Strata in this interval are deformed by a series of low angle faults which show little to no apparent offset.	34.4	10.5	552.3	552
15	Shale, moderate reddish-brown (10R 4/6) and moderate brown (5YR 4/4) and siltstone and fine-grained sandstone, light olive gray (5Y 5/2). The interval consists of amalgamated thin- and medium-bedded siltstones and fine-grained sands that are a prominent marker bed notable in its light color and blocky nature against the surrounding darker-colored shales. Bedding in the lower portion is swaley to dune cross-stratified.	44.0	13.4	541.8	541.5
14	Shale and minor siltstone, grayish-brown (5Y 3/2) and very dusky red (10R 2/2) and dark yellowish brown (10YR 4/2) on weathered surfaces.	53.5	16.3	528.4	528.1
13	Siltstone / fine sandstone, dark yellowish brown and moderate brown (5YR 2/1). This interval has a blocky texture and weathers in positive relief against the under/overlying shales. Bedding is characterized by low angle cross bedding and thin- to medium- and thick-bedded.	5.9	1.8	512.1	511.8
12	Shale and siltstone, grayish-brown (5Y 3/2) and brownish-black. Primarily shale with minor thin siltstone beds.	23.0	7.0	510.3	510
11	Shale, grayish-brown (5YR 3/2) and brownish-black (5YR 2/1) and siltstone moderate brown. The lower portion is shale dominated with minor thin beds of siltstone that transitions upward into medium- and thin-bedded siltstones and shales.	45.9	14.0	503.3	503

(continued)

Table 1 (Continued)

Interval	Description	Thickness			
		Interval Feet	Interval Meters	Unit Cumulative (m)	Total Cumulative (m)
10	Shale and siltstone, brownish-black (5YR 2/1) and olive black (5Y 2/2) and grayish-black (N2) that weathers to moderate brown (5YR 4/4) and dark yellowish-brown (10YR 4/2). The lower portion consists primarily of shale with minor siltstone occurring as discrete sharply bound beds and chaotically folded siltstone and shales forming an overall lens-shaped body. The upper portion is characterized by amalgamated thin- and medium-bedded sharply bound siltstone beds.	25.3	7.7	489.3	489
9	Shale and siltstone, Olive black (5Y 2/2) and brownish-black (5YR 2/1), and grayish-black (N2) that weathers to moderate brown and dark yellowish brown. Siltstone beds vary in thickness from common thin 1-3-cm-thick beds and medium 5-15-cm-thick beds. Shale color gradually transitions through this interval, from lighter colors at the base to darker at the top. Siltstone beds increase in thickness and coarsen upwards culminating with a ~.75-m-thick siltstone bed.	78.7	24.0	481.6	481.3
8	Semi covered interval. Shale and siltstone, grayish brown (5Y 3/2) that weathers to moderate brown (5YR 4/4) and moderate yellowish brown (5YR 5/4). This interval capped with a .75-m-thick package of thin- to medium-bedded siltstones.	187.0	57.0	457.6	457.3
7	Shale, moderate brown (5YR 4/4) to grayish-brown (5Y 3/2) that weather to light olive gray (5Y 5/2) and yellowish-gray (5Y 7/2). Lower portion of the interval consists of moderate brown shale. The top of this interval contains a ~50-cm-thick siltstone bed.	88.6	27.0	400.6	400.3
6	A prominent 45-cm-thick sharply bound sandstone bed brownish-gray (5YR 4/1) with abundant fossils. First appearance of disarticulated brachiopod and encrinoidal body fossils in the section.	147.6	45.0	373.6	373.3
Base of the Brallier Formation upper part/ top of the Brallier Formation lower part					
5	Shale and siltstone brownish-gray (5YR 4/1) and olive black (5Y 2/1) that weathers to light olive gray (5Y 5/2) and dusky yellowish-brown (10YR 2/2); siltstone beds which stand in positive relief from the outcrop as sharp based individual beds ranging from 1-10 cm in thickness and larger bed sets consisting of a series of generally evenly spaced siltstone and shale beds occurring over 3-5 m. Siltstone and shale pale yellowish-brown (10YR6/2) and medium light gray (N6), abundant thin beds of interbedded siltstone. Siltstone beds range from thin 1-3-cm-thick and some approaching 5-7-cm in thickness.	38.1	11.6	328.6	328.3
	Covered Interval – Break in Section	45.9	14.0	317	330.7
4	Shale and siltstone; grayish-brown (5Y 3/2) to and grayish-orange (10YR 7/4). Siltstone beds are thin, ranging from 1-3 cm in thickness.	39.4	12.0	303	316.7
3	Shale; dusky yellowish-brown (10 YR 2/2) and rare thin siltstone beds in the range of 1-3 cm	249.3	76.0	291	304.7

(continued)

Table 1 (Continued)

Interval	Description	Thickness			
		Interval Feet	Interval Meters	Unit Cumulative (m)	Total Cumulative (m)
2	in thickness. A mostly vegetated zone covers the lower portion of the interval. Shale and interspersed thin-bedded siltstones medium dark gray (N4) to olive gray (5Y 4/1) Siltstones weather to grayish-brown (5Y 3/2), moderate brown (5YR 4/4) and pale yellowish-brown (10YR 6/6). Siltstones occur as 1-5-cm-thick sharp-based beds with hummocky cross-stratification, planar parallel laminations, and minor basal scour structures. The strata in this interval are mildly deformed by a series of low angle fractures which show no to very minor apparent displacements.	695.5	212.0	215	228.7
1	Shale with interbedded siltstones, medium dark gray (N4). This basal facies of the Brallier Formation is marked by a ~2 m- thick - interval of tightly spaced and amalgamated thin siltstone beds. When present, and in inclined sections, this interval forms a minor ridge clearly visible in the lidar imagery.	9.8	3.0	3	16.7
	Base of the Brallier Formation/ Top of the Harrell Shale Shale, medium dark gray (N4).	45	13.7	13.7	13.7

TABLE 2

Starting and ending points of the 4 sections that make up the Baker reference section shown on the map in Figure 5.

Location	Start Lat./Long.	End Lat./Long.
Section 1	39.047063, -78.742252	39.047808, -78.745705
Section 2	39.047882, -78.746113	39.048879, -78.749998
Section 3	39.049041, -78.750533	39.049353, -78.751888
Section 4	39.050090, -78.754631	39.050724, -78.756970