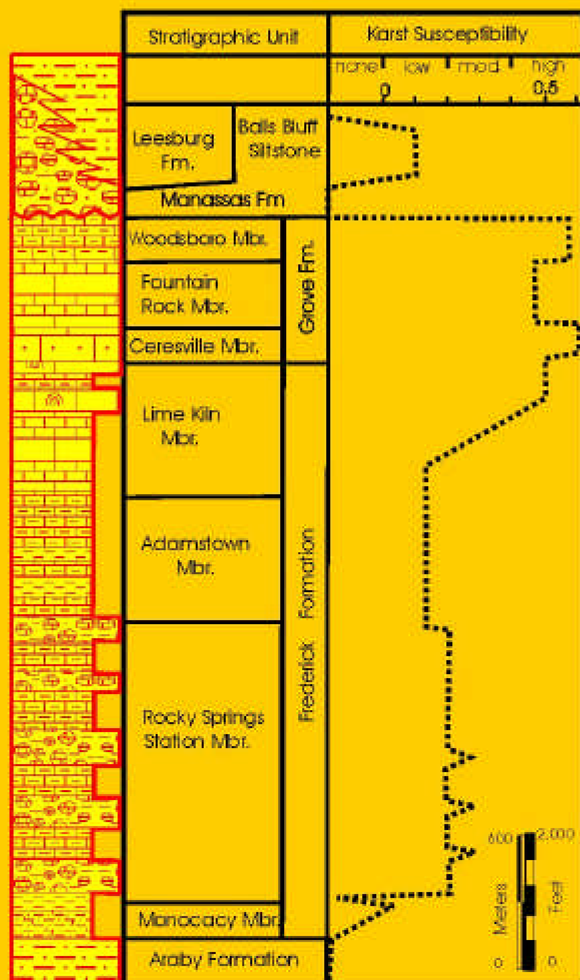
Report of Investigations No. 75
2004

Stratigraphy of the Frederick Valley and its Relationship to Karst Development

by
David K. Brezinski



Prepared in cooperation with the
Maryland State
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Department of Natural Resources
Resource Assessment Service
Maryland Geological Survey
Emery T. Cleaves, Director

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STRATIGRAPHY OF THE FREDERICK VALLEY AND ITS RELATIONSHIP TO KARST DEVELOPMENT

EXECUTIVE SUMMARY

* One thousand and eight hundred and sixteen karst features were identified and located with a global positioning system in the Frederick Valley of Frederick County.
* Active sinkholes make up approximately 34 percent of all identified karst features.
* Depressions are the most abundant karst features identified, and are most frequent in the Rocky Springs Station Member of the Frederick Formation and the Triassic Leesburg Formation. However, these units have few active sinkholes.
* Rock composition (lithology), fracturing, and ancestral drainage patterns are principal geologic factors contributing to sinkhole activity.
* A karst susceptibility index is proposed (SI), based on the ratio of the number of active sinkholes to total karst features per square mile. High index numbers were obtained for the Lime Kiln Member of the Frederick Formation, and all three members of the Grove Formation.
* In addition to geologic factors, sinkhole activation is strongly influenced by human activities. Storm-water management areas, stream re-routing, unlined drainage ditches, quarrying, and extensive overburden removal contribute greatly to the initiation of sinkhole activity.

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by

David K. Brezinski

ABSTRACT

The Frederick Valley of Maryland is a tightly folded overturned syncline that exposes easily soluble carbonate rocks that range in age from Early Cambrian to Early Ordovician. The valley is bordered on the west by Early Triassic alluvial deposits and on the east by metamorphosed rocks of the Westminster terrane. The Cambrian Frederick Formation was mapped utilizing a four-member subdivision that includes the Monocacy (new name), Rocky Springs Station, Adamstown, and Lime Kiln members. The Ordovician Grove Formation is herein subdivided into the Ceresville (new name), Fountain Rock (new name), and Woodsboro (new name) members, in ascending stratigraphic order. The older units in this study were formed in deep water at oceanic depths. As the rocks of the Frederick Formation accumulated, they steadily aggraded upward towards sea level so that the top of the formation was deposited in shallow water at the edge of the North American continent. The Grove Formation was deposited in sand shoals and algal reefs that were ultimately drowned during an Early Ordovician submergence. The Triassic Leesburg Formation was deposited in large alluvial fans at the margin of fault basins during extension and rifting that formed the Atlantic Ocean.

From these data, a relative scale of karst susceptibility was developed to assist land-use planners, developers, and the public in recognizing areas of high karst susceptibility. The Ceresville, Woodsboro, and Fountain Rock members of the Grove Formation and the Lime Kiln Member of the Frederick Formation have very high karst susceptibility. When unlined drainage, storm-water management areas, drainage diversions, or quarries are placed in proximity to these units, soil-cover collapses are likely to occur. A slightly lesser karst susceptibility is recognized for the Rocky Springs Station Member of the Frederick Formation. The Triassic Leesburg Formation, and the Monocacy and Adamstown members of the Frederick Formation have comparatively low karst susceptibility.

INTRODUCTION

The term ***sinkhole*** is a generic term for any number of geomorphic features that characterize the surface topography in areas underlain by soluble bedrock such as limestone and dolomite. Sinkholes are typically the surface manifestations of subsurface networks of dissolution features that have formed over millions of years, resulting in anastomosing networks of voids such as caverns or sediment-filled passageways. The topographic landforms produced by such an underground network are typically categorized as ***karst topography*** or ***karst terrane***. Therefore, it is the presence, abundance, and prominence of sinkholes that are typically used to determine the degree of development of karst terranes. Because such topography is the result of hydrologic processes, the study of sinkholes has been typically relegated to the discipline of hydrology. Consequently, the distribution of sinkholes has commonly been framed with respect to the distribution of hydrogeologic properties. As a result, few studies have tried to relate the abundance of sinkholes to either the stratigraphy or structure of the bedrock. Notwithstanding the importance of the hydrogeologic factors in sinkhole development, the working hypothesis of this study is that the abundance and distribution of sinkholes have strong affinities to the character of the underlying bedrock.

Several areas in Maryland are characterized by karst terranes. It is in these areas where property, water quality, and other valued cultural items are at risk from the catastrophic collapse of these subterranean features. Maryland has two main areas and a number of smaller areas of karst development. The largest is located in eastern Washington County and is known as the Hagerstown Valley. Also known as the Great, Shenandoah, or Cumberland valleys in adjacent West Virginia and Pennsylvania, this region is underlain largely by Cambrian and Ordovician limestones and dolomites, extends from Georgia to Vermont, and is bordered to the east in Maryland by the Blue Ridge Province. A second, somewhat smaller region of karst development found east of the Blue Ridge is locally known as the Frederick Valley. This lowland region stretches from the Potomac River northward to Woodsboro in Frederick County and in current physiographic terminology is considered the Frederick Valley District of the Piedmont Lowland Section (Reger and Cleaves, 2004). Farther east in the Maryland Piedmont Province linear zones of karst development are found in areas underlain by the Wakefield and Cockeysville marbles. In Carroll, Baltimore, and Howard Counties, the Wakefield, Worthington, and Green Spring valleys are underlain by these marbles. In the Ridge and Valley Province of western Washington and Allegany Counties, karst features are present along narrow valleys underlain by Silurian limestones such as the Tonoloway and Keyser formations.

This study focuses on the Frederick Valley. This area of lowlands east of the Maryland Blue Ridge is underlain by Cambrian and Ordovician limestone and dolostone of the Frederick and Grove formations. The Frederick Valley District, because of its soluble bedrock, has been known for some time to be susceptible to the development of karst features and, periodically, catastrophic collapse. Along the eastern margin of Catoctin Mountain is an outcrop belt underlain by detrital limestone of the Triassic Leesburg Formation. This area, previously regarded as little affected by solution, exhibits considerable karst surface features. Furthermore, northwest of the City of Frederick, a region previously mapped as being underlain by clastics of the Triassic New Oxford Formation exhibit topographic landforms compatible with a karst terrane. These three areas of the southern Western Piedmont Lowland are the focal point of this study, and although they represent several different districts within the Piedmont Lowland Section, they will be termed, for simplicity's sake, the *Frederick Valley* (Figure 1).

Recent extensive urban development in these regions and the accompanying drainage re-routing commonly destroy a tenuous equilibrium between surface and subsurface drainage systems. Concurrently, collapses that would not normally have occurred are precipitated. Predicting where catastrophic collapses will occur is virtually impossible. However, by inventorying all recognizable karst features and relating them to specific stratigraphic levels it is believed that one can reasonably determine where catastrophic sinkholes will likely occur. This delineation provides a valuable tool for developers, homeowners, and government decision-makers.

The purpose of this report is to describe the geology of the Frederick Valley with emphasis on detailed stratigraphic analysis to determine the relationship between the proclivity toward sinkhole development and the type and character of the underlying bedrock (Figure 1).

History of Study

The earliest geologic map of the Frederick Valley, published by Bassler (1919), portrayed the valley as a contorted syncline and underlain by two formations.

The lower of these two formations was interpreted by Bassler to be a massive, bluish limestone he termed the Beekmantown Limestone after a similar-appearing Ordovician unit found in the Ridge and Valley Province of Pennsylvania. Bassler's interpreted upper unit, composed of thinly bedded, shaly limestone, he named the Frederick Limestone for outcrops in the vicinity of the City of Frederick. Jonas and Stose (1938) showed that Bassler's stratigraphy was reversed, and that the Frederick Limestone actually is stratigraphically beneath the massive limestone, which they in turn named the Grove Limestone. Interestingly, Jonas and Stose (1938) envisioned the Frederick Valley as a highly contorted sequence, especially on the western limb of the syncline where large bands of the massive limestone, interpreted as Grove, interfingers with the shaly limestone of the Frederick. Rasetti (1959; 1961), in his study of Frederick and Grove trilobites, furthered Jonas and Stose's interfingering interpretation. In a detailed sedimentologic study of the Frederick Formation, Reinhardt (1974) demonstrated that these supposed Grove interfingers were actually allocthonous (i.e., transported) masses of limestone redeposited within the shaly limestone of the Frederick. Reinhardt (1974) also subdivided the Frederick Formation into three members: in ascending order, the Rocky Springs Station, Adamstown, and Lime Kiln members. While these three members were distinguishable along the western side of the Frederick Valley, Edwards (1988) found them inseparable along the eastern side of the valley and could not distinguish the members sufficiently to map them. In the first study of the Grove Formation, Taylor and others (1996) discussed the implications of age disparities between the northern and southern outcrop belts of this formation. Nutter (1973; 1975) studied the hydrogeology of the limestone areas of the Hagerstown and Frederick Valleys and the Triassic basins, respectively, and Duigon and Dine (1987) assessed the water resources of Frederick County.

Stratigraphic study and mapping of the Triassic strata of what is herein considered part of the Frederick Valley were published by Lee (1977; 1979). Lee interpreted the units in the northern part of the Culpeper Basin as belonging to the Culpeper Group. Furthermore, Lee subdivided the group into the Manassas, Balls Bluff, and Bull Run formations, in ascending order.

Regional Geology

The Frederick Valley lies near the western edge of the Piedmont Physiographic Province of Maryland (Figure 2). The Piedmont, which translates from Italian as 'foot of mountain,' is characterized by metamorphosed phyllites, schists, basalts, marbles, and granites that were created by intense deformational processes during the formation of the Appalachian Mountains. The Piedmont is subdivided into western and eastern regions. The eastern region extends from the highly deformed gneiss domes that surround Baltimore City westward to a northeast-oriented zone of highly sheared phyllites, approximately 1 mile across, termed the Pleasant Grove Zone. This zone of sheared rocks is interpreted as a large fault that juxtaposes the intensely deformed and high-grade metamorphic rocks of the eastern Piedmont with much lower-grade metamorphics of the western region (Muller *et al*., 1989; Valentino *et al*., 1994). West of the Pleasant Grove Zone, the Piedmont rocks consist largely of phyllites, quartzites, marbles, and metabasalts that are of markedly lower metamorphic grade than are those rocks east of the fault zone. Throughout this western region rocks are generally greenschist-grade meta-morphics. This low level of metamorphism and the clay mineral chlorite that pervades these rocks give most of the phyllites a greenish tone. The western Piedmont is bounded on the west by Catoctin Mountain, the eastern ridge of the Blue Ridge Province. While the western Piedmont encompasses this entire area, a number of geologic subdivisions of this region can be recognized. The first of these subdivisions is the Frederick Valley. This lowland was created by the erosion of Cambrian and Ordovician limestones that, beyond their intense folding, exhibit very little metamorphism. The eastern boundary of the Frederick Valley has generally been in dispute. While the boundary is commonly placed at the contact between the limestones of the Frederick Valley and the subjacent Araby Formation, it seems more appropriate to place it at the Martic Fault. Because the underlying Araby Formation is of similar metamorphic disposition as the Frederick Valley limestones, it seems logical to include it with rocks of similar geologic origin and deformation. The Martic Fault, which can be traced from Pennsylvania to Virginia, places the greenschist facies rocks of the western Piedmont against the virtually unmetamorphosed rocks of the Conestoga Valley in Pennsylvania and the Frederick Valley in Maryland (Southworth, 1996).

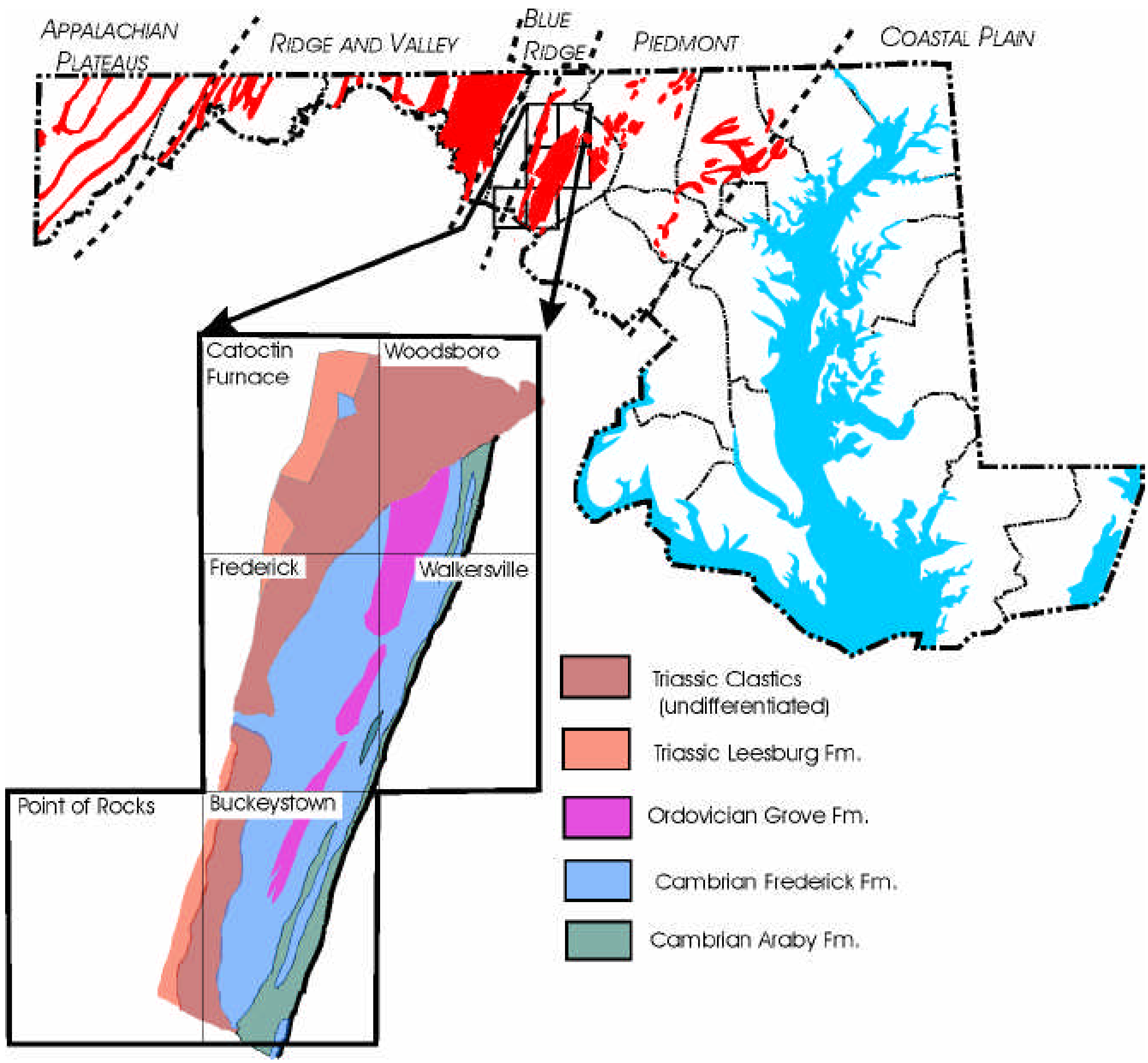

Figure 1. – Location map of the karst regions of Maryland (red areas) and the distribution of the six quadrangles studied.

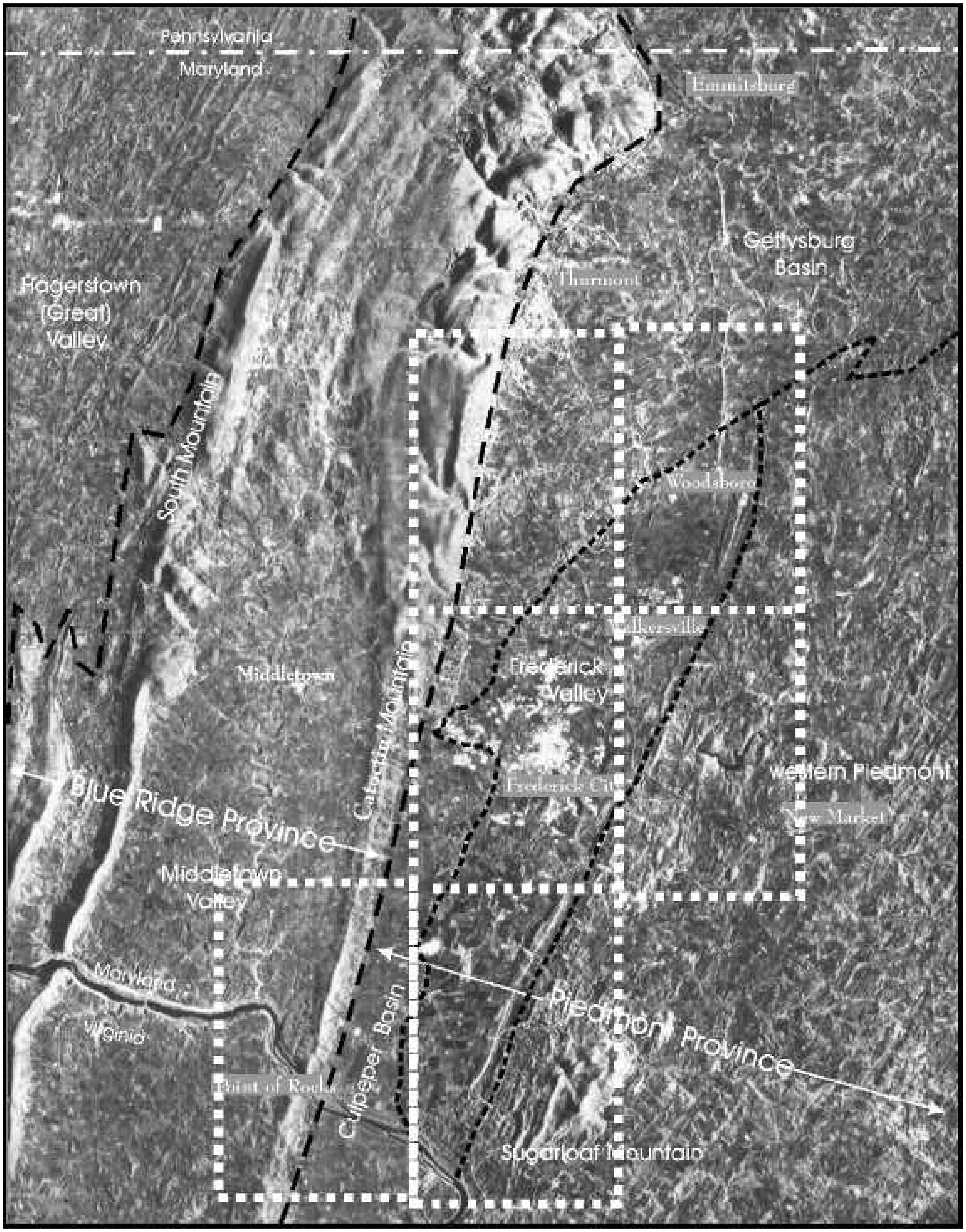

Figure 2. – Side-looking airborne radar image of the Western Piedmont and Blue Ridge Provinces of Maryland. The Frederick Valley is outlined by short black dashes.

Bassler, 1919	Jonas and Stose, 1946	Reinhardt, 1974		This Study	
Triassic undifferentiated	Triassic undifferentiated	Triassic undifferentiated		Leesburg Fm.; Balls Bluff Siltstone; Manassas Fm.	
Beekmantown Limestone	Grove Limestone	Grove Formation		Grove Fm.	Woodsboro Mbr.
					Fountain Rock Mbr.
					Ceresville Mbr.
Frederick Limestone	Frederick Limestone	Frederick Formation	Lime Kiln Member	Frederick Formation	Lime Kiln Mbr.
			Adamstown Member		Adamstown Mbr.
			Rocky Springs Station Member		Rocky Springs Station Mbr.
					Monocacy Mbr.
Antietam Sandstone	Antietam Quartzite	Araby Formation		Araby Formation	

Figure 3. – Nomenclatural revisions of the strata of the Frederick Valley and terminology used in this study.

The Frederick Valley is bounded on the south by the Potomac River and is overlapped to the west and north by Triassic rocks. These Triassic strata are the least deformed rocks of the Maryland Piedmont, the only deformation being a westward tilting. The Triassic rocks were deposited within localized fault basins that stretch from Massachusetts to North Carolina and were created by tensional forces coincident with the formation of the current Atlantic Ocean. In Maryland, parts of two separate Triassic basins are present. From the Potomac River north to U.S. Route 40, Triassic rocks were deposited in the Culpeper Basin. From just north of the northern terminus of the Culpeper Basin at U.S. 40 northward to the Pennsylvania State Line and beyond, the Triassic sediments were deposited in the Gettysburg Basin. While the rocks of the separate basins are not dramatically different in character, they do carry separate stratigraphic terminology. Because there is very little difference in topographic relief between the Frederick Valley and the Triassic sediments, discerning between the two separate subdivisions of the western Piedmont can be difficult. Moreover, because extensive areas underlain by Triassic strata are detrital carbonate and therefore prone to similar types of dissolution and erosion as the limestones of the Frederick Valley, the Triassic sediments are included within the current study. The western limit of the Triassic rocks is observed along a linear fault that is presumably Triassic in age. This presumed Triassic fault trace is nearly straight, indicating it has a steep dip. The strata along the western side of this fault belong to the Cambrian Harpers Formation at the foot of Catoctin Mountain; that is the easternmost unit of the Blue Ridge Province.

STRATIGRAPHY

The Frederick Valley is underlain by Cambrian and Ordovician limestones, and the adjacent Triassic strata that are primarily clastic in character. A significant part of the Triassic strata is composed of detrital carbonate rocks, and therefore susceptible to sinkhole development. The ability to recognize and map individual geologic units was paramount in the study of karst for this region.

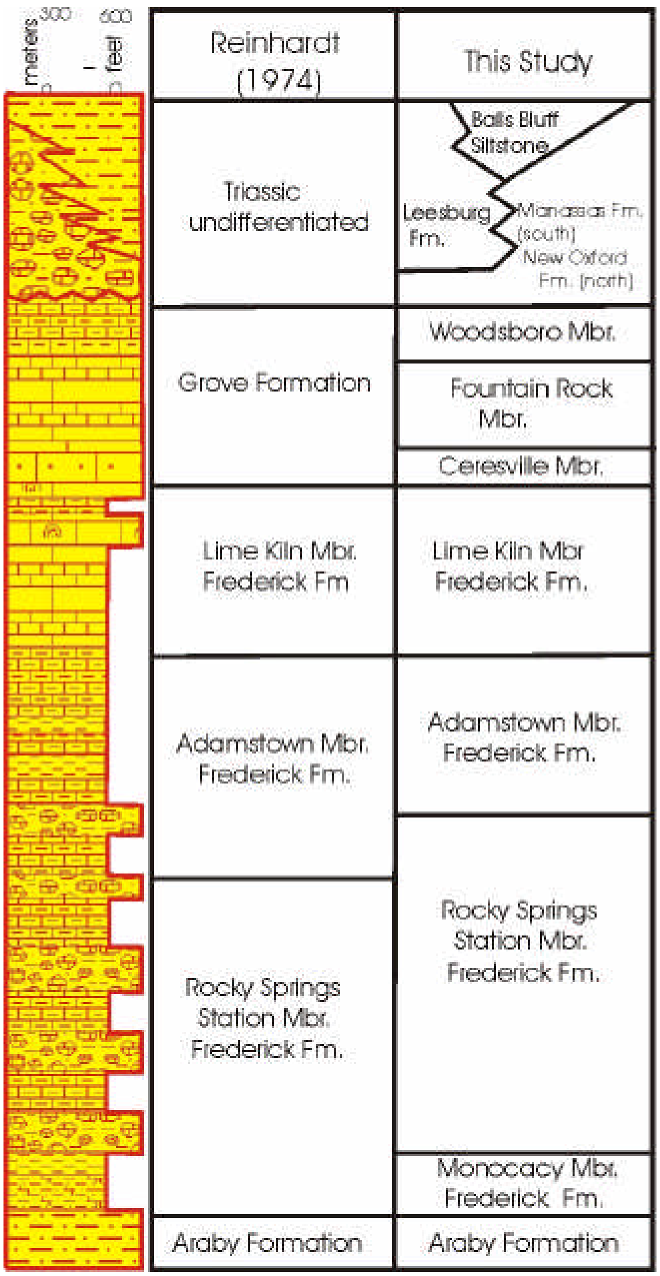

Figure 4. – Stratigraphic column of the Frederick Valley.

Tomstown Formation

Stratigraphic History. – The Tomstown Formation crops out along the eastern edge of the Blue Ridge in Maryland. Although it technically does not crop out within the Frederick Valley, it is susceptible to karst development and therefore is included here.

Named for a village in southern Franklin County, Pennsylvania, the Tomstown Formation in Maryland has been subdivided into four members by Brezinski (1992). On the eastern limb of the Blue Ridge, no such subdivision is possible.

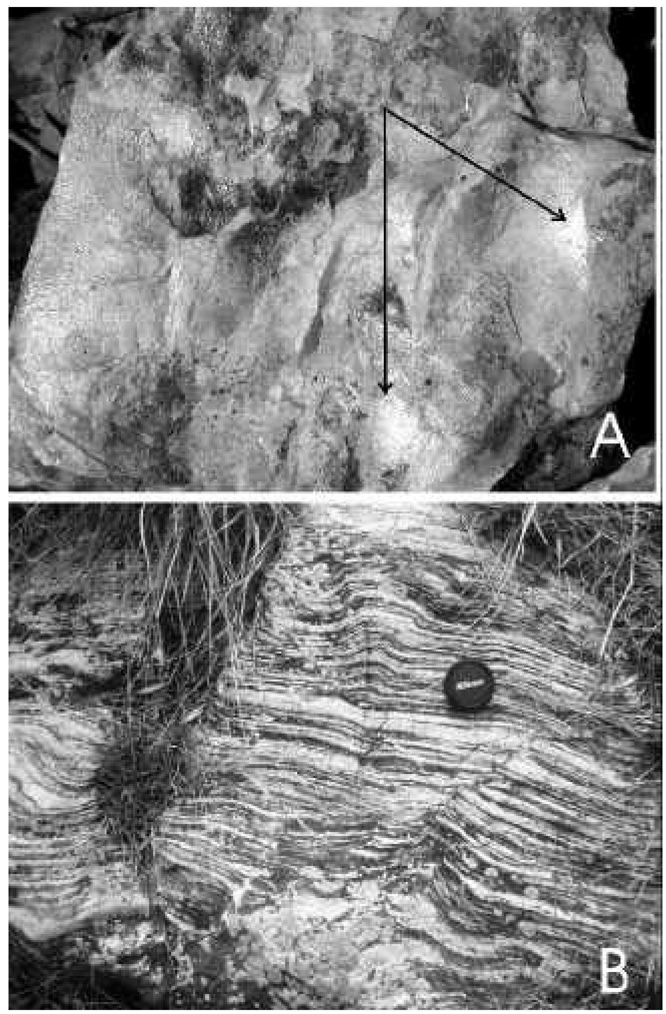

Figure 5. – A, Irregular foliation plane within the Tomstown Formation north of Point of Rocks. Irregular surface allows the sheen of micas to be seen (arrows). B, Foliated Tomstown dolomite from the southern shore of the Potomac, just south of Point of Rocks.

Character and Distribution. – Where the Tomstown Formation is exposed east of the Blue Ridge, it consists of a light gray to light medium gray, highly foliated, micaceous, saccharoidal dolomite. Foliation is defined by wavy planes that are covered by thin sheets of an unidentified mica. Stratification of this unit has been obliterated so the foliation is the dominant, if not only, discernable layering in outcrop.

The Tomstown Formation forms a narrow outcrop band that extends from the northern bank of the Potomac River to the northwestern section of the Frederick quadrangle, including a small segment of the Buckeystown quadrangle. The best exposures of this unit on the eastern side of the Blue Ridge are in northern Virginia near the bank of the Potomac River and in numerous isolated outcrops from Point of Rocks northward to U.S. Route 340.

Thickness. – Because of the poor exposure, it is difficult to determine the thickness of the Tomstown Formation, as it occurs in the footwall of the Triassic border fault along the eastern Blue Ridge. However, based upon outcrop width and dip angle, the thickness can be estimated at between 200 and 300 feet.

Araby Formation

Stratigraphic History. – Reinhardt (1974) named the Araby Formation for a fine-grained sandstone and sandy siltstone that crops out east of Frederick Junction along the CSXT Railroad tracks and northeast of Araby Church (Locality 1, Appendix I) (Figure 6). Reinhardt erected the name Araby Formation because he believed that this basal Cambrian unit that forms low ridges along the eastern margin of the Frederick Valley was dissimilar to the sandstone unit that occupied the same stratigraphic position in the Maryland Blue Ridge (Brezinski, 1992). While Reinhardt believed that the Araby Formation is coeval with the Antietam Sandstone, he recognized that it is lithologically distinct. Through the recovery of scattered fragments of the trilobite *Olenellus*, Reinhardt (1974, fig. 5) proposed that the age of the Araby is Lower Cambrian (Figure 6A). This age was verified by Edwards (1988) by the recovery of both *Olenellus* and the problematic Lower Cambrian index fossil *Salterella* from a black shale within the formation.

Character and Distribution. – The Araby Formation consists of thickly bedded, medium gray to dark greenish gray, fine-grained sandstone and sandy siltstone with numerous interbeds of greenish gray to dark gray, slaty shale. In fresh outcrop, the sandstone intervals commonly exhibit an anastomosing network of burrows; in some intervals this so pervades the strata that all indications of bedding have been obliterated. Furthermore, because of the fine-grained character of the Araby Formation, secondary cleavage further penetrates the rocks, making recognition of stratification extremely difficult.

The Araby Formation, by virtue of its modest resistance to erosion, forms a number of short ridges bordering the east side of the Frederick Valley. These ridges include Laurel Ridge east of Woodsboro and the two ridges that run southwestward and northeastward from Frederick Junction. These two ridges are doubly-plunging anticlines that are overturned to the northwest. The tightly packed axial planar cleavage related to the formation of these folds is a major reason for the poorly discernable stratification, which is characteristic of the Araby Formation. Where streams cut these ridges, stratigraphic sections of the Araby Formation can be observed. The Araby Formation is well exposed at numerous locations in the Buckeystown and Frederick quadrangles. In addition to the type section, one of the better exposures is Locality 3 (Appendix I), where more than 250 feet (80 m) of fine-grained sandstone and interbedded, greenish gray, silty shale are exposed. Strata of the Araby Formation are also well exposed in the Buckeystown quadrangle along Michaels Mill Road and the Monocacy River, east of Buckeystown. At this location, one can observe the folded character of the strata. To the east, the Araby Formation dips about 45 degrees to the southeast, but as one progresses to the west, the strata become flat-lying and then steeply overturned to the southeast. This relationship can likewise be seen along Reichs Ford Road in the Frederick quadrangle, immediately east of the Monocacy River and west of the road to Monocacy Pine Cliff County Park.

Because the type section of the Araby Formation is not well exposed and no other reference sections were proposed by Reinhardt (1974), confusion has arisen about the specific lithologies that are represented within the formation. While exposures along the abandoned westbound lane of Interstate 70 at the Monocacy River indicate that a significant portion of the Araby Formation is composed of intervals of interbedded, grayish green, slaty shale, it is generally believed that only silty, greenish, fine-grained sandstone comprises the formation (Edwards, 1988). This factor has led to both mapping and nomenclatural errors. A number of these shaly intervals can be recognized within the formation. For example, within

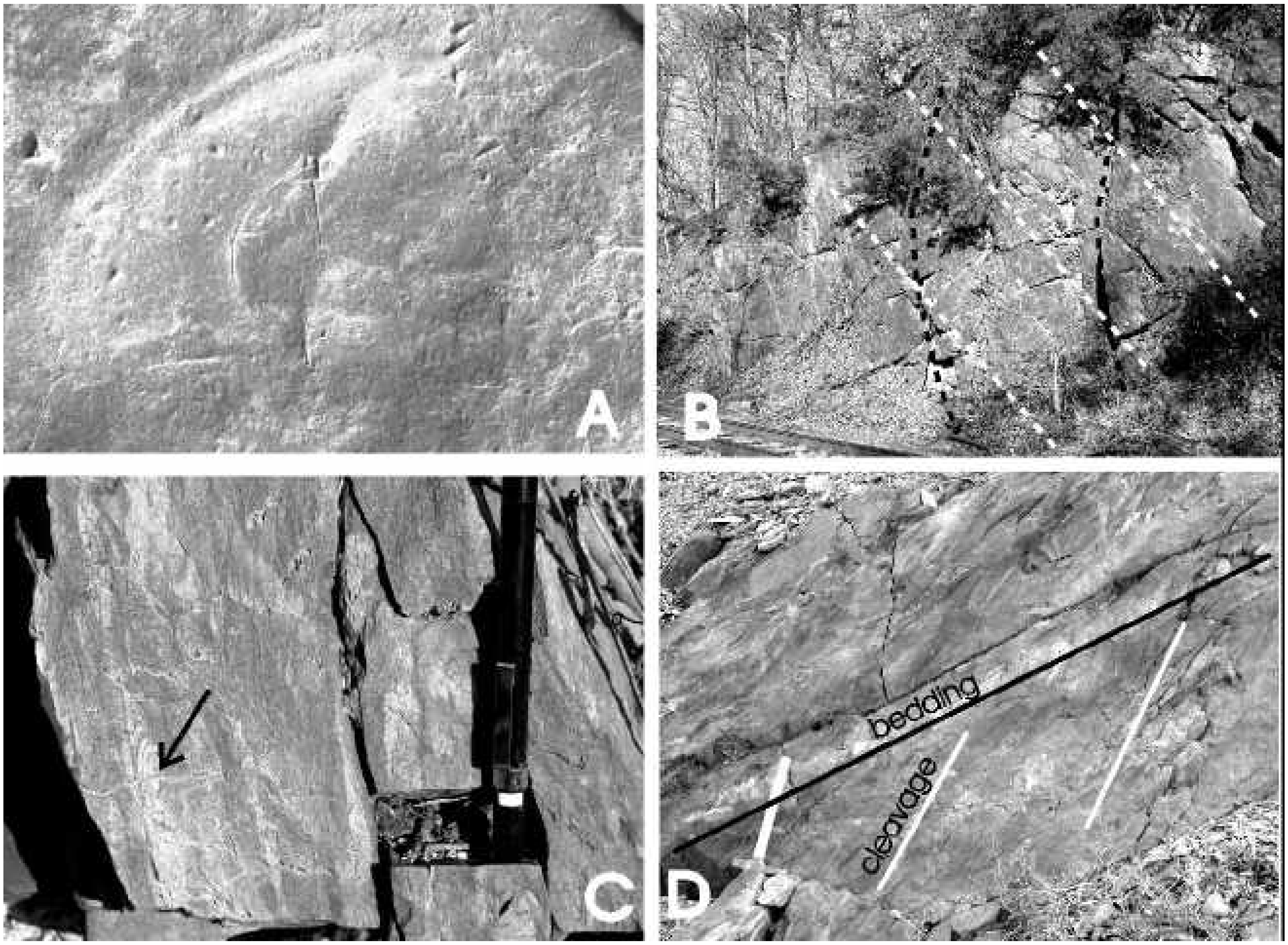

Figure 6. – Araby Formation. A, Incomplete cephalon of the trilobite *Olenellus* from the Cash Smith shale interval, Carnegie Museum 53211. B, Silty, fine-grained sandstones of the Araby Formation at the type section. White dashes=cleavage, black lines=stratification C, Close-up of silty sandstone of the Araby Formation. Faint cross-laminations are visible at arrow. D, Bedding and cleavage relationships within the Araby Formation along Interstate 70 at Linganore Road.

the Park Mill Road Section (Locality 3) at least two separate greenish gray shale intervals can be observed. Edwards (1988) recognized one of these shaly units, and believed that it was actually a separate unit stratigraphically above the Araby Formation and not within it. He erected a new formation, the Cash Smith Formation, for this unit and identified the type section along Cash Smith Road, west of Woodsboro. The type section has all but been removed and concealed, but it clearly lies within the Araby Formation, as outcrops to the west indicate, and is not stratigraphically above it. A second shaly unit, similar in appearance, believed by Edwards (1988) to be the same Cash Smith Shale, is present somewhat stratigraphically higher within the lower Frederick Formation. It was this second shale that Edwards mapped as the Cash Smith Formation, even though the type locality is within the Lower Cambrian Araby Formation. Because of the inconsistencies between the type locality, age, and stratigraphic position of the type Cash Smith Formation versus the mapped Cash Smith Formation, it is herein recommended that the term Cash Smith Formation be abandoned. Inasmuch as the shale at the type locality cannot be traced laterally, and the shale mapped by Edwards (1988) is not the same as at the type locality, a stratigraphic revision of this interval is warranted.

Thickness. – At no known location is the entire Araby Formation exposed. Consequently, only partial sections and estimates can be used to determine the thickness of the formation. Reinhardt (1974) estimated the thickness at 330 feet (100 m), but based on the exposures noted above, this estimate appears to be slightly low. Consequently, a thickness of 500 feet (152 m) is not unreasonable.

Araby-Frederick Contact. – There has been considerable confusion resulting from a poor understanding of the character and stratigraphic relationships between the Araby Formation and overlying Frederick Formation. Bassler (1919) interpreted the Araby-Frederick contact as a fault contact. Reinhardt (1974) believed that the contact was stratigraphic and not structural in nature. While Reinhardt stated that the contact between the Araby and Frederick formations was nowhere exposed, he believed that he could narrow the contact interval to less than 9 feet at several exposures. From Figure 3 of his paper the contact was interpreted to be relatively sharp, with sandstone of the upper Araby Formation overlain by thin-bedded limestone and dolomite of the basal Frederick Formation. Edwards (1988) believed that shales of the Cash Smith Formation intervened between the two formations and that the contact interval was, in most places, modified by late Paleozoic faulting.

Through field-work for this study, one locality (Locality 2, Appendix I) was found where the contact was relatively well exposed and could be measured. At this location, the upper 94 feet (29 m) of the Araby is exposed as a medium to dark grayish green, medium-bedded, bioturbated, argillaceous, silty sandstone. The overlying 122 feet (37 m) of the basal Frederick Formation consists of an unusual rock type made up of gray, knotty-looking, nodular limestone that characterizes a condensed stratigraphic section, and lime mudstone in which angular carbonate clasts are surrounded by dark gray, calcareous, siliceous shale. No indications of erosion are evident in the upper beds of the Araby Formation.

Frederick Formation

Stratigraphic History. – The Frederick Limestone was named by Bassler (1919) for the thin-bedded, bluish gray limestone that crops out in the vicinity of City of Frederick, Maryland. Bassler believed that the thickess of the Frederick Limestone was approximately 200 feet (61 m). Reinhardt (1974) characterized the different lithologies within the Frederick Limestone and subdivided the formation into the Rocky Springs Station, Adamstown, and Lime Kiln members. Reinhardt's depositional model notwithstanding, many of the lithologies used to characterize the individual members occur within the different units. This has produced considerable confusion among subsequent workers, so much so that named members were all but abandoned by Edwards (1988).

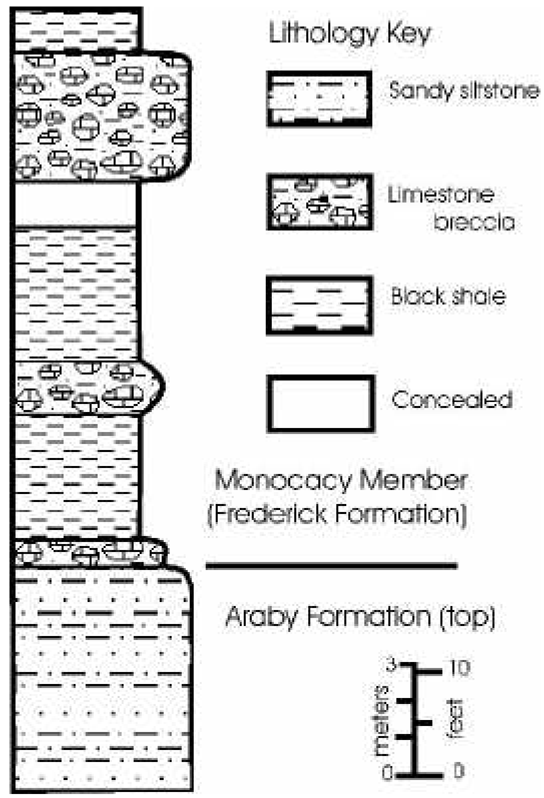

Figure 7. – Measured section through the Frederick-Araby contact at Locality 3.

When work was begun for the current study, the need to revise the characterizations of the individual members was quickly recognized. Mapping initiated in the Buckeystown quadrangle initially focused on the recognition of the three members of the Frederick Formation as defined by Reinhardt (1974) and the precise placement of the contacts between these members. Measured sections along the Monocacy River and in the Essroc Quarry illustrate the complex relationships between these units and their nebulous characterization as put forth by Reinhardt (1974). The confusion centers around several lithologies that are found in more than one member. Table 1 illustrates the main lithologies found in the Frederick Formation and which members display these lithologies.

Lithology	Monocacy	Rocky Springs Station	Adamstown	Lime Kiln
breccia	common	dominant	-----	-----
sandy limestone	-----	common	-----	common
rhythmite	-----	common	dominant	common
flaggy limestone	-----	common	-----	-----
algal limestone	-----	-----	-----	common
bioturbation	-----	-----	-----	common
shale	dominant	common	common	-----

Table 1. – Distribution of lithologies within each member of the Frederick Formation.

Monocacy Member (new name)

Stratigraphic History. – Along the eastern margin of the Frederick Valley, an enigmatic stratigraphic interval near the base of the Frederick Formation has for many years been troublesome to mappers and stratigraphers. Jonas and Stose (1938) recognized this interval and traced it as an isolated shale bed within the lower Frederick Formation. Reinhardt (1974, p. 11) interpreted this black shale as tectonic in origin, apparently forming from the pressure solution of argillaceous strata at the base of Frederick Formation. Edwards (1988) included this interval within the Cash Smith Formation even though, as discussed previously, it is part of the Frederick Formation. Because of past confusion and uncertainty about the origin, character, and stratigraphic position of these shaly strata, this unit will be herein separated from the Rocky Springs Station Member of the Frederick Formation and be informally termed the Monocacy Member. The type section chosen for the member is along the eastern bank of the Monocacy River (Locality 5, Appendix I) approximately 0.5 mile north of the Interstate 70 bridge. The Monocacy Member was treated as a shaly unit within the Rocky Springs Station Member by Southworth and Brezinski (2003), and termed the *Unnamed Member* by Brezinski and Southworth (2003).

Although trilobites have been recovered from the Monocacy Member, they are very rare and have been recovered from only two locations. These small trilobites, which are deformed and not well preserved, belong to a group known as agnostids. The best preserved specimen is tentatively assigned to the genus *Acmarhachis.* This genus is known from other early Late Cambrian deposits in the Appalachian Basin (Rasetti, 1961; Figure 8A).

Character and Distribution. – The Monocacy Member of the Frederick Formation is exposed at a number of locations in the Frederick, Buckeystown, Walkersville, and Woodsboro quadrangles. The most complete exposure of the Monocacy Member is the type section. Although the base of the member is covered, 232 feet (71 m) of section can be assigned to it. At this locality, the knotty and brecciated limestones that comprise this member are interbedded with intervals of dark gray, calcareous shale. The shale interval at the top of this member is well exposed. The upper black shale has a thickness of more than 100 feet (30 m). This shale represents an excellent marker bed, and, as Jonas and Stose (1938) and Edwards (1988) have shown, can be readily traced and mapped. Because of its character, soils overlying outcrops of this unit are typically thin and commonly contain large amounts of light gray weathering, black shale chips.

As discussed above, the basal strata of the Frederick Formation are partially exposed along a small stream adjacent to Greenfield Road (Locality 3, Appendix I) (Figure 7). The basal 122 feet (37 m) of the Monocacy Member consist of a nodular, lime mudstone with angular, carbonate clasts surrounded by a dark gray, dolomitic shale. The carbonate clasts within this knotty lithology have a tendency to weather more rapidly than does the surrounding siliciclastic matrix. This uneven weathering produces a pock-marked appearance on exposed surfaces (Figure 8B).

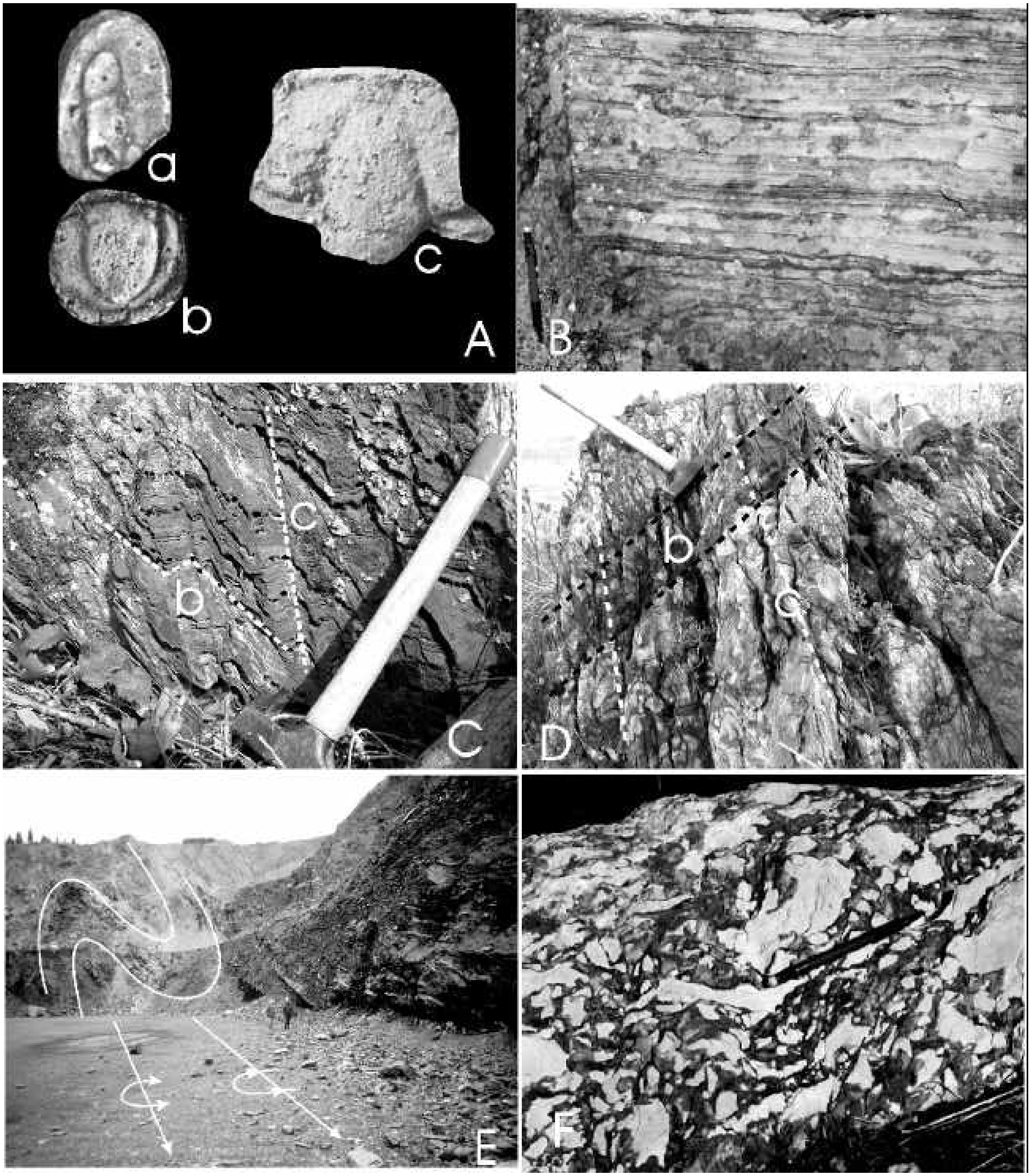

Figure 8. – Monocacy Member of the Frederick Formation. A, Trilobites from the upper Monocacy black shale. Aa, Ab, Internal molds of cranidium and pygidium of *Acmarhachis*, Carnegie Museum 53212, 53213. Ac, Unidentified trilobite cranidium, Carnegie Museum 53214. B, Thinly laminated shaly limestone. C, Bedding (black) and cleavage (white) relationship within upper shale bed. D, Rubbly weathering nodular limestone (black = bedding, white= cleavage). E, Isoclinally folded, shaly limestone of the Monocacy Member in the Lehigh Quarry east of Woodsboro. F, Characteristic nodular bedding of the middle part of the Monocacy Member.

Interbedded with this knotty lithology are intervals of very dark gray to black, platy, calcareous shale ranging from 3 feet (1 m) to 24 feet (8 m) thick. It is this shaly lithology that Edwards (1988) perceived as the true representation of the Cash Smith Formation.

A second location that reflects the character of this member is found along the north shore of Bennett Creek just west of its confluence with the Monocacy River and north of Lilypons. Although the strata are not as well exposed as at Locality 3, a similar relationship with the Araby Formation is evident and the same lithologic character as seen along Greenfield Road is expressed. At this location, the strata assignable to the Monocacy Member are exposed in the core of a sharp anticline and are repeated along both the east and west flanks. Just as at Locality 3, the basal Frederick lithology is a shaly, dark gray limestone with interbeds of black, calcareous shale. Because of poor exposure, it was not possible to precisely measure this outcrop, but the top of this member is placed at the top of a thick (>50 foot, 15 m) black, platy, calcareous shale. This appears to be the shale traced by Jonas and Stose (1938).

Another reference section for the Monocacy Member is Locality 5 (Appendix I). The base of the member is not exposed here, but measuring down section from the black shale seen elsewhere indicates that as much as 200 feet (60 m) of the Monocacy Member are present. Smaller, less complete, sections are present along the south bank of the Monocacy River, both at and west of the U.S. Route 355 bridge. The scattered exposures here display both the knotty, dark gray limestone and the black, platy shale at the top of the member.

Thickness. – Because the Monocacy Member of the Frederick Formation is so intensely folded along the eastern side of the Frederick Valley, it is difficult to precisely determine its thickness. Outcrop width suggests that this member is more than 600 feet (183 m) thick, but an incomplete measured section (Locality 5, Appendix I) suggests the unit is probably not much more then 300 feet (91 m) in thickness.

Monocacy-Rocky Springs Station Contact. – The contact between the Monocacy Member of the Frederick Formation and the overlying Rocky Springs Station Member is well exposed at Locality 5 near Frederick Junction. At this location, the contact is clearly gradational, with the shale at the top of the Monocacy Member interfingering with thin (0.5 inch, 1.0 cm), dark gray, lime mudstone strata of the overlying Rocky Springs Station Member. The contact can be placed at the point where the limestone strata become more than 50 percent of the section.

Rocky Springs Station Member (revised)

Stratigraphic History. – The basal member of the Frederick Formation was named the Rocky Springs Station Member by Reinhardt (1974) for approximately 1,000 feet (~300 m) of interbedded, very thinly bedded, dark gray, shaly limestone; medium-bedded, sandy, gray limestone; and thick-bedded, medium gray, polymictic (multiple lithologies) limestone breccias that occur near the base of the formation. The type section of the Rocky Springs Station Member is located in the northwest suburbs of the City of Frederick. The type locality is actually a number of disjunct sections, some separated by up to a mile, that Reinhardt (1974) combined to form a single stratigraphic section. While this technique of section assembly leaves room for significant errors owing to omissions by faulting and misalignment of stratigraphic units, Reinhardt's section characterizes this stratigraphic interval sufficiently well to be retained as a recognizable subdivision of the Frederick Formation. Unfortunately, Reinhardt (1974) failed to recognize that the rocks that crop out along the western flank of the Frederick Valley Synclinorium were markedly different from those that crop out along the eastern flank. This oversight has led to the current revision of the Frederick members and the addition of the Monocacy Member to the base of the formation.

The Rocky Springs Station Member of the Frederick Formation is Late Cambrian in age. Trilobites from the lower part of the member are tentatively assignable to the *Dunderbergia Zone* (Rassetti, 1961; Figure 9A), while a collection from the top of the member suggests that it is assignable to the *Keithia schuchteri* Fauna. This fauna characterizes the latest Cambrian in the Appalachians (Rassetti, 1959; Taylor *et al*., 1996).

Character and Distribution. – In the type area west and north of the City of Frederick, the Rocky Springs Station lithologies are characterized by dark gray, very thinly bedded, lime mudstone interbedded and interlaminated with black, calcareous shale (Figure 9B). This lithology, which is pervasive throughout the Frederick Formation, is interbedded with intervals, 30 to 50 feet (10-15 m) thick, of very thick to massively bedded limestone breccia that includes various limestone lithologies and sandy limestone. These polymictic breccia beds are diagnostic of the Rocky Springs Station Member and are key characteristics

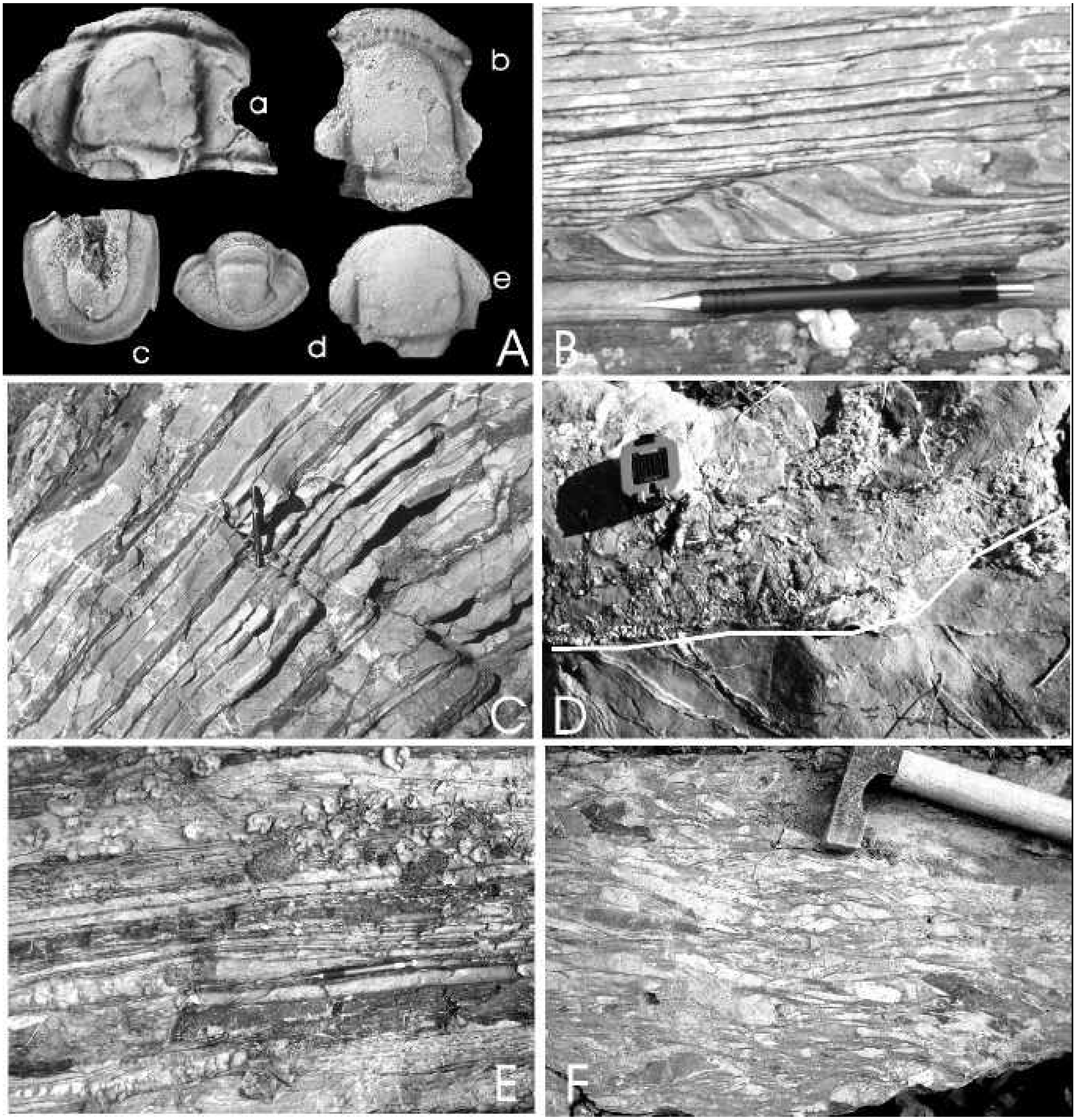

Figure 9. – **Rocky Springs Station Member of the Frederick Formation. A, Trilobites from the Rocky Springs Station Member. Aa, *Quebecaspis marylandica*, Carnegie Museum 53215, Rasetti (1961) locality ccm/3. Ab, *Levisella* sp., middle part of member, Carnegie Museum 53216. Ac, Unidentified agnostid, Carnegie Museum 53217. Ad, *Plethopeltis* sp., Rasetti (1959) locality ccb/3, Carnegie Museum 53218. Ae, *Theodenisia* sp., same location as Ad. Carnegie Museum 53219. B, Imbricated thin-bedded limestone. C, Flaggy limestone. D, Convex-down base of polymictic breccia bed eroded into underlying sandy limestone. E, Interbedded, shaly limestones that occur in intervals between polymictic breccia beds and flaggy strata. F, Polymictic breccia stratum with pebbles exhibiting faint indications of flow.**

for its origin and recognition (Figure 10). In Reinhardt's subdivision of the Frederick Formation, intervals containing these breccia deposits extended upsection into the Adamstown Member; however, under the current revision, such lithologies are considered endemic to the Rocky Springs Station Member only.

Another lithology that is characteristic of the Rocky Springs Station Member interval is flaggy limestone (Figure 9C). This lithology, which consists of regularly bedded, dark gray, lime mudstone strata, 0.5 to 1.0 inch (1.0 - 2.0 cm) thick and separated by thin layers of dolomitic shale, was not observed in any other member of the Frederick Formation. In his original definition of the members of the Frederick Formation, Reinhardt (1974) included both the polymictic breccia and the flaggy limestone in the Rocky Springs Station and Adamstown members. This presented a problem in distinguishing these two members, inasmuch as all lithologies found in the Rocky Springs Station Member were found in the overlying Adamstown Member. Moreover, the lack of clarity surrounding the separation of Rocky Springs Station and Adamstown members created inconsistencies in contact placement for both stratigraphers and mappers. Because of the blurred stratigraphic relationship created by the original designations, it was deemed necessary during the course of this study to redefine the lithologic attributes of both the Rocky Springs Station and Adamstown members.

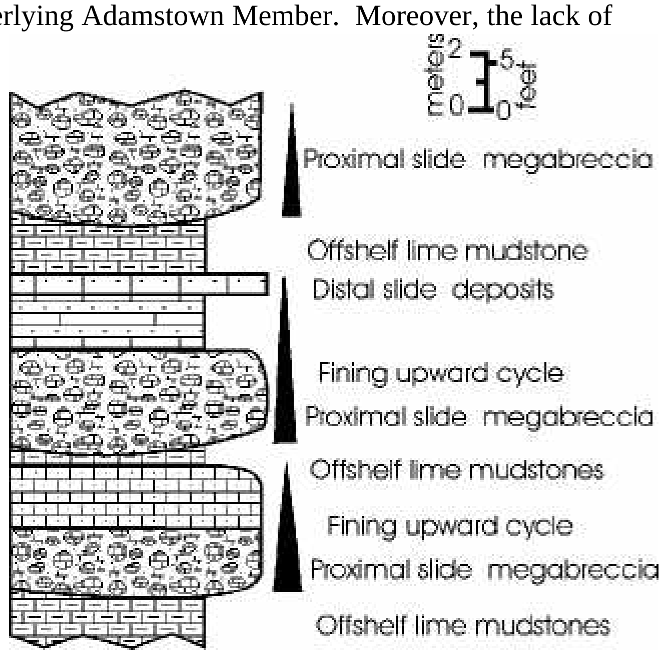

Figure 10. – Stratigraphic column of sequentially deposited polymictic breccia beds within the lower Rocky Springs Station Member of the Frederick Formation along the Monocacy River near Interstate 70 (Locality 5). Shaly strata represent *in situ* deposits repeatedly buried beneath polymictic slide masses that fine up stratigraphic section.

Thickness. – With the proposed redefinition of the members, the Rocky Springs Station Member not only loses approximately 300 feet (90 m) at its base with the erection of the Monocacy Member, but gains about the same thickness at the top of the member with the addition of the interval containing the breccia. Consequently, the thickness of the Rocky Springs Station Member along the western flank of the synclinorium, according to Reinhardt (1974), is approximately 900 feet (275 m). Keeping in mind that the base of the Frederick Formation is nowhere exposed along the western flank of the synclinorium, the thickness could be considerably more than Reinhardt's measurements. Furthermore, the outcrop belt along the western flank is much wider than one would expect from a unit less than 1,000 feet (305 m) thick. Consequently, the thickness of the Rocky Springs Station Member was estimated from the width of the outcrop belt. The area chosen for this estimation was nearly parallel to U.S. Route 40, through the City of Frederick to the western edge of the outcrop belt. This section, which parallels West Patrick Street, is the broadest part of the western Rocky Springs Station outcrop belt. The outcrop belt was measured as approximately 13,000 feet (~ 4,000 m) wide. The dip of these strata is southeast at between 20 and 50 degrees, with an average of approximately 35 degrees. Although dips locally vary significantly from this range, they generally fall within it. By graphical means, it was determined that the thickness of a unit with an outcrop belt 13,000 feet wide and a dip between 20 and 50 degrees is 4,446 to 9,958 feet (i.e., thickness = sine of 20E to 50EH 13,000 feet). If the average dip is 35 degrees, the estimated thickness is 7,456 feet (2,270 m). The thickness determined herein is not only significantly larger than the thickness determined by Reinhardt (1974), but differs by up to an order of magnitude. Even if one takes into consideration the minor dip reversals, the thickness is substantially greater than that proposed by Reinhardt (1974). Consequently, it is herein believed that the thickness of the Rocky Springs Station Member in the western outcrop belt is approximately 7,500 feet (2,300 m).

Along the eastern flank of the synclinorium, evaluating the thickness of the Rocky Springs Station Member is considerably easier and less prone to error. This is because along the eastern flank the strata have less dip variability, are dipping steeply (75 – 85 degrees) to nearly vertical, and also because numerous nearly complete measured sections were studied in that area. At Locality 5 (see Appendix I), strata assignable to the Rocky Springs Station Member were measured at 1,547 feet (472 m). From outcrop belt width, the thickness of the Rocky Springs Station Member appears to vary from about 750 to 1,500 feet (230-460 m), a range that appears to be consistent with actual outcrop width measurements.

The assumed thickness of around 1,000 feet (~300 m) for the eastern outcrop belt is considerably different than the estimated thickness of 7,500 feet (2,300 m) for the western outcrop belt. Indeed, the thickness difference of more than 6,000 feet (1,830 m) in less than 7 miles lateral distance is, at least on the surface, a conundrum more difficult to explain away than simply by tectonic thinning as Reinhardt (1974, p. 23) attempted. However, when put into its depositional context, the rapid eastward thinning of the Rocky Springs Station Member becomes more lucid. Reinhardt (1977) interpreted the Rocky Springs Station Member as being deposited in an outer slope to basinal depositional setting. The thick polymictic breccias common to this member in the western outcrop belt represent submarine slides that accumulated at the base of a steep continental slope. That these thick slide deposits are not found in the eastern outcrop belt is an indication of the rapidity in depositional slope change from west to east. In the east, the breccias of the Rocky Springs Station Member are typically less than three feet (1 m) thick and represent deposition at the distal edge of a large submarine fan that accumulated at the break in slope at the toe of the continental margin.

Rocky Springs Station-Adamstown Contact. – Reinhardt (1974, p. 24, and Plate 2) placed the top of the Rocky Springs Station Member at the stratigraphically highest sandy, thick-bedded limestone. This criterion, while utilitarian in his measured sections, ignored the stratigraphic distribution of the polymictic breccias and flaggy strata that pervade the Rocky Springs Station Member. While sandy limestones are present in both the Rocky Springs Station and Lime Kiln members, the breccias are restricted to the lower half of the formation. Consequently, the breccias represent a unique depositional lithology restricted to a confined stratigraphic interval and thus can be used as a criterion for member definition. Reinhardt (1974, p. 24) also noted that the flaggy strata are present in the lower Adamstown Member. However, with the currently recommended revisions, not only do all the breccias fall within the Rocky Springs Station Member, but so do the intervals of flaggy lime mudstones. As such, the Adamstown Member is characterized by thinly bedded, shaly lime mudstone. With the current redefinition of the Rocky Springs Station and the Adamstown members, the contact between them is placed at the stratigraphically highest polymictic breccia bed, which generally corresponds to the highest flaggy stratum. With this current revision, the contact would be placed approximately 300 feet (91 m) higher within the Adamstown Member (Reinhardt, 1974, plate 2,) so that this member would lose nearly a third of Reinhardt's interpreted thickness.

Adamstown Member (revised)

Stratigraphic History. – The exclusion of polymictic breccias from the Adamstown Member as suggested above sharply limits the type of lithologies that characterize this unit, but also more narrowly constrains the member for mapping and karst study purposes. The revision suggested herein is not only expedient to mappers, but confines the member both lithologically and genetically. This is because the origin of the polymictic breccia beds is related to the genesis of the ancient shelf edge. Therefore, the lithologic terminology and genetic depositional packages become one and the same.

No fossils were recovered from the Adamstown Member during this study. Consequently, no direct age determination is possible for this member. However, the uppermost strata of the Rocky Springs Station Member at one location along the Monocacy River produced a small collection of specimens (Figure 11A). These specimens suggest that the lowest strata of the Adamstown Member are *Keithia* Fauna from Newfoundland and Quebec (Ludvigsen *et al.*, 1989). These faunas are equivalent to the *Saukia* Zone deposited in shallow water environments to the west (Hagerstown Valley).

Character and Distribution. — Overlying the Rocky Springs Station Member is an interval characterized mainly by dark gray, very thinly bedded, lime mudstone with shaly partings (Figure 11B). Reinhardt (1974) named this interval the Adamstown

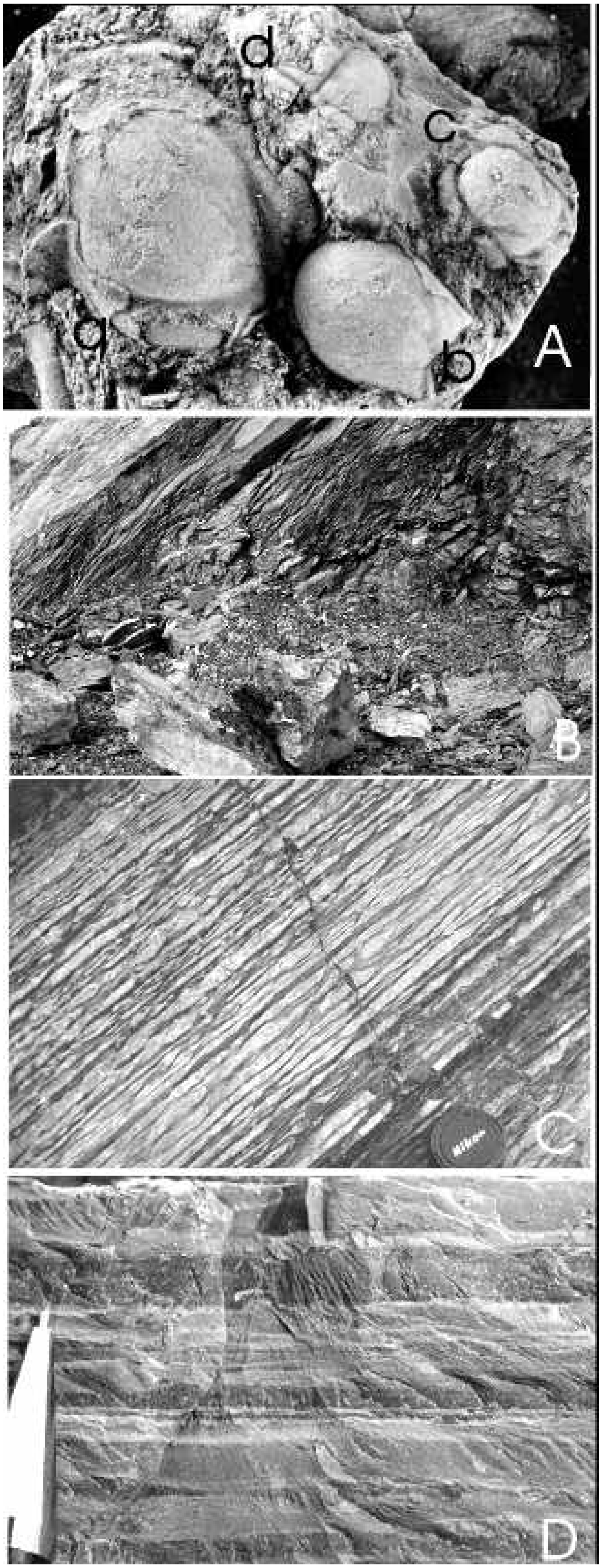

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Figure 11. – Adamstown Member of the Frederick Formation. A, Trilobites from the uppermost Rocky Springs Station Member at contact with Adamstown Member. Aa, *Onchonotus* sp. Ab, *Stenopilus angustus*?. Ac, *Keithiella* sp. Ad, Unidentified cranidium, Carnegie Museum 53220. B, Dark gray, shaly limestone of the Adamstown Member near the type section within the Essroc quarry at Lime Kiln (Locality 9). C, Weathering character of very thinly bedded limestone and calcareous, dolomitic, shaly limestone of the Adamstown Member. D, Close-up of layering on fresh surface. Light-colored layers are argillaceous dolomite; dark layers are lime mudstone.

Member for field and quarry exposures northeast of the town of Adamstown. The numerous intervals of polymictic breccia assigned to this member by Reinhardt (1974) are reassigned to the Rocky Springs Station Member. Consequently, the newly defined Adamstown Member is markedly thinner than originally proposed. Lithologies no longer assignable to the Adamstown Member are flaggy, peloidal limestones and, more importantly, the polymictic breccias.

The Adamstown Member is easily recognized and mappable in the type area. However, north of the City of Frederick, this unit appears to thin and becomes lithologically indistinct from the adjacent units. These thickness and compositional changes appear to be related to depositional topography. In the southern part of the valley basinal deposits were formed. However, in the northern part of the valley shallow water deposits are more prominent. Thus, the thinning of the Adamstown Member corresponds to a thickening of the overlying Grove Formation.

Thickness. – Reinhardt (1974, p. 24) estimated the thickness of the Adamstown at nearly 1,000 feet (300 m). Based on Reinhardt's Plate 2, the reassignment of a substantial part of the Adamstown to the Rocky Springs Station Member reduces the thickness to an estimated 600 feet (200 m). Based on a number of factors, a thickness of 600 feet appears to be too little for the Adamstown Member. Along the western outcrop belt, the outcrop width of the Adamstown Member ranges from 2,000 to 3,000 feet (650-1,000 m). In the Frederick and Buckeystown quadrangles bedding dip ranges from 25 to 59 degrees, with an average of approximately 40 degrees. Based on these variables, the thickness of the Adamstown Member could vary from about 1,270 to 2,570 feet (387-784 m) for an outcrop width of 3,000 feet (915 m) and 845 to 1,714 feet (258-523 m) for an outcrop width of 2,000 feet (610 m)(i.e., thickness = sine of 25 degrees to 59 degrees X 2,000 or 3,000 feet). With an average dip of 40 degrees, the thickness varies from 1,285 to 1,930 feet (390- 590 m)(i.e., thickness = sine of 40 degrees H 2,000 or 3,000 feet). A partial section of the Adamstown Member, exposed in the quarry operated by Essroc Corporation at Lime Kiln (Locality 7, Appendix I), was measured at 691 feet (210 m). This partial section represents approximately half of the outcrop belt in that area. Therefore, one can assume that the thickness of the Adamstown Member in that area is approximately 1,200 feet (365 m). This thickness would be consistent with the thickness calculated for a 40 degree dip and an outcrop belt 2,000 feet (610 m) wide. From these estimates, it appears that the Adamstown Member, even after being redefined, has a thickness that averages around 1,200 feet (365 m).

Along the eastern outcrop belt, where the Adamstown dip is nearly vertical, the outcrop belt ranges from 500 to 1,500 feet (150 - 460 m) in width with an average of 1,000 feet (300 m). This would suggest that the Adamstown Member, like the Rocky Springs Station Member below it, thins rapidly to the east.

Adamstown-Lime Kiln Contact. – The contact between the Adamstown Member and the overlying Lime Kiln Member of the Frederick Formation is placed at the first (i.e., stratigraphically lowest) medium-bedded, lime wackestone to packstone (Figure 6B). This lowest medium bed marks the first of many medium to thick beds that characterize the overlying unit.

Lime Kiln Member

Stratigraphic History. – The youngest, and stratigraphically highest, member of the Frederick Formation was named the Lime Kiln Member by Reinhardt (1974) for an exposure within what is now the Essroc Materials quarry near Buckeystown.

The Lime Kiln Member, especially in its upper part, is the most fossiliferous member of the Frederick Formation. Rasetti (1959) noted numerous occurrences of trilobites and brachiopods from these upper strata. The top of the Lime Kiln is the youngest Cambrian *Eurekia apopsis* Zone (J. F. Taylor, written communication, 1/04) (Figure 12A).

Character and Distribution. – The Lime Kiln Member consists of thinly interbedded, dark gray, thinly bedded, lime mudstone and black, calcareous shale with a few thicker layers (up to 1 foot (30 cm) in thickness) in the lower part of the member (Figure 12A). The scattered thicker layers become more prominent and abundant up-section, at the expense of the thinly interbedded limestone and shale intervals (Figure 12B). Also appearing and becoming common near the middle and top of the member are lenticular, medium gray, sandy, lime grainstone and packstone, that exhibit sharp, presumably erosional bases, and gradational upper contacts. These sandy intervals are up to 30 feet (10 m) thick. The upper 200 feet (60 m) of the member is marked by thick intervals of medium to dark gray, crudely bedded, algal thrombolitic, lime mudstone interbedded with thinly bedded, lime mudstone (Figure 12C).

Because of the mixture of carbonate textures, abundant sandy intervals, and gradation in lithologies exhibited by this member, there has been a considerable amount of confusion regarding the identification of this member and its contact with the overlying Grove Formation. While the appearance of abundant quartz sand in the stratigraphic section has long been used to mark the contact between the upper Frederick Formation and the Grove Formation (Jonas and Stose, 1938; Reinhardt, 1974), numerous stratigraphic sections measured for this study contain abundant quartz sand intervals through much of the Lime Kiln Member. Consequently, this characteristic is useless in formation separation.

Furthermore, some of the lithologies that appear in the middle and upper Lime Kiln Member, such as algal thrombolites, are also present in the Grove Formation. Fortunately, a measured section through the upper Lime Kiln Member and lower Grove Formation near the Lefarge Frederick quarry demonstrates the lithologic changes through this transitional interval and allows refined definition of the contact (Figure 13; Locality 11, Appendix I). Figure 14A also illustrates the marked change at the contact. The underlying medium to dark gray, thrombolitic, lime mudstones of the Lime Kiln Member are sharply overlain by the highly fractured, sandy dolomite of the basal Grove. This contact is also exposed, albeit more poorly, in the type section of the Lime Kiln Member in the old pit at the Essroc Materials Quarry near Buckeystown. At this location, the gray lime mudstone of the Lime Kiln Member is overlain by tan-weathering, cross-bedded, sandy dolomite of the basal Grove Formation.

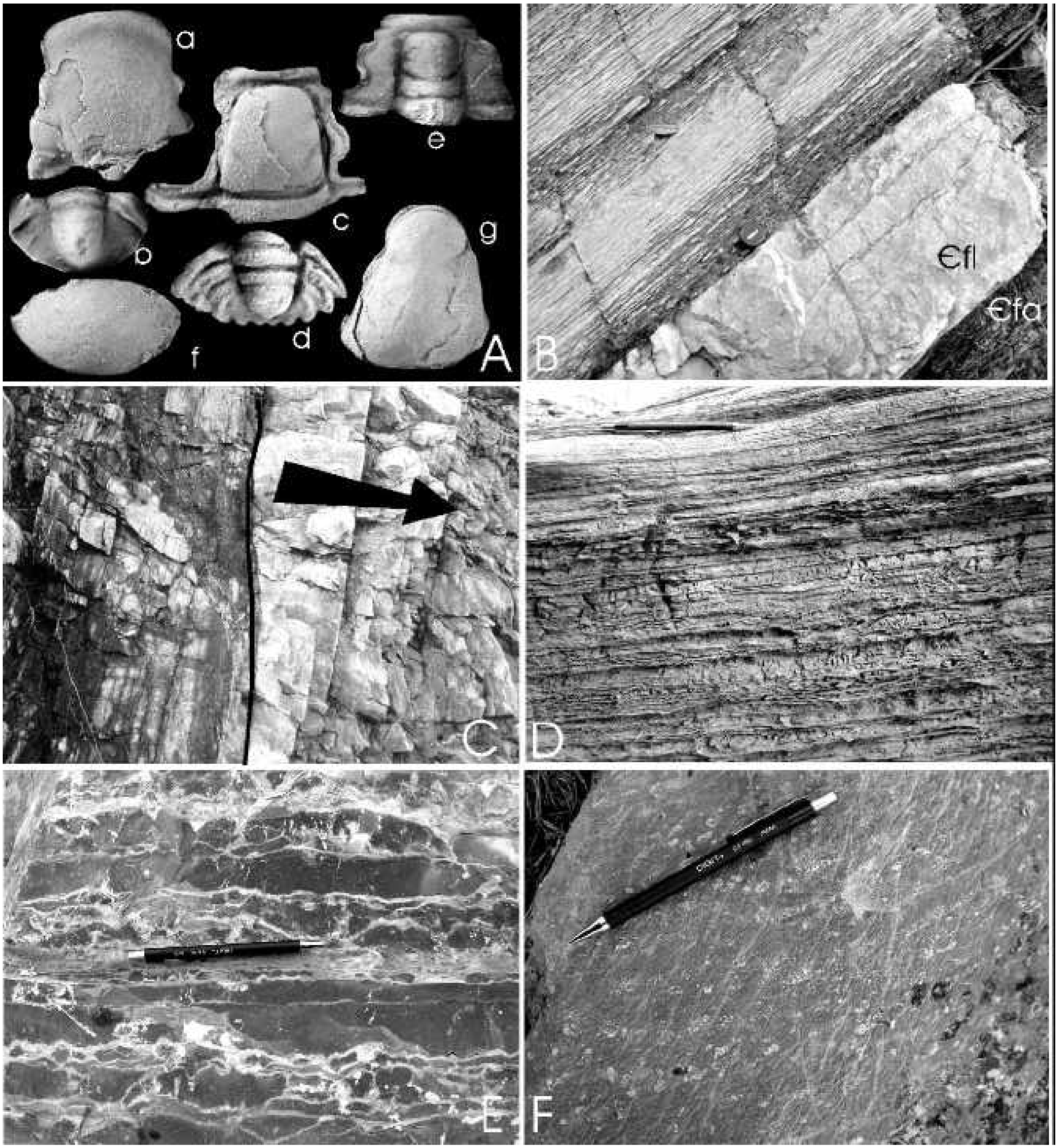

Figure 12. – Lime Kiln Member of the Frederick Formation. A, Trilobites. All specimens housed at Carnegie Museum (CM). Aa, Ab, *Plethopeltis concavus.* Aa, Ab, Locality 9, CM 53221, 53222 (Ab photograph by J.F. Taylor). Ac, Ad, *Eurekia apopsis,* Locality 9, CM 53223, 53224 (Ad photograph by J.F. Taylor). Ae, *Calvinella prethoparia,* CM 53225 (photo by J.F. Taylor). Af, *Leiocorphye* sp., CM 53226. Ag, *Stenopilus* sp. pygidium, CM 53227. B, Base of the member at type section marked by change from ribbony to medium-bedding (Locality 9). C, Concave-down channel in sandy limestone, (Locality 10). Stratigraphic top to the right (arrow). D, Thin-bedded, lime mudstone of the lower Lime Kiln Member. E, Burrow-mottled strata of the upper Lime Kiln Member. F, Unbedded algal thrombolitic beds within uppermost Lime Kiln Member.

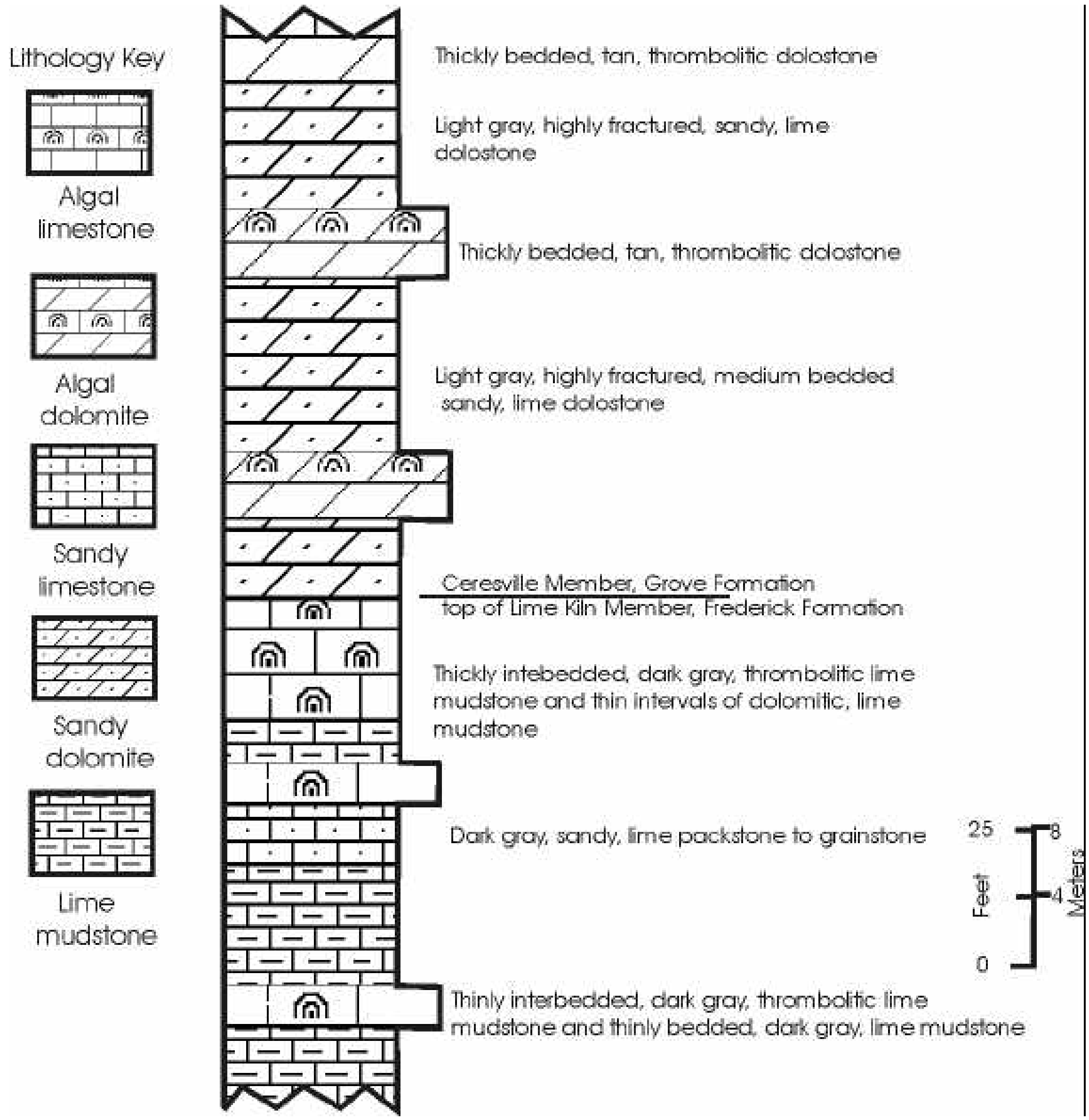

Figure 13. – Stratigraphic column of a measured section of the Lime Kiln-Grove contact in field south of the Lafarge Frederick quarry (Locality 11).

Thickness. – Reinhardt (1974) measured the thickness of the Lime Kiln Member of the Frederick Formation at 540 feet (165 m). This same section (Locality 9, Appendix I) was measured during this study at 806 feet (250 m). The 266-foot discrepancy between the two measured sections, while considerable, may be the result of Reinhardt's placement of the Frederick-Grove formation contact. If he placed the contact at the stratigraphic interval of the first cross-bedded, sandy grainstone, as mentioned above, then this horizon would have been well down within the Lime Kiln Member as defined in this study. Thus, the thickness discrepancy is explained by Reinhardt's placement of the contact. The greater thickness of the Lime Kiln Member is supported by another measured section in the study area (Locality 10, Appendix I). Along the south face of the Lafarge's Frederick quarry, an incomplete section of the Lime Kiln Member is measured at 868 feet (265 m) thick.

Lime Kiln-Grove Formation Contact. – The contact between the Frederick and Grove formations has long been a conundrum. Stose and Stose (1946) placed the base of the Grove Formation at the bottom of the lowest quartzose sand interval within the stratigraphic sequence. As discussed above, some of these sandy intervals are present well down in the Frederick Formation; therefore, basing the contact on such sandy intervals creates inaccuracy. In fact, Reinhardt (1974) suggested that the sandy intervals assigned to the Grove Formation by Jonas and Stose (1938) were actually Triassic in age and not related to the deposition of the Frederick or Grove formations at all. This interpretation by Reinhardt (1974) is assuredly incorrect, since numerous exposures of the upper Frederick and lower Grove formations contain abundant quartz sand that is consistently contained within the carbonate rocks and, in places, exhibits herringbone (bi-polar-directional) cross-bedding. The Frederick-Grove formational contact, as defined in this study, is placed at the base of the stratigraphically lowest, thickly bedded, sandy dolomite that marks the basal Grove Formation. This relationship is best observed at Locality 11 (Figure 13), where the actual contact is exposed (Figure 14A). It is also exposed, albeit more poorly, at Locality 18.

Grove Formation

The ostensibly youngest Paleozoic formation of Maryland's western Piedmont is the Grove Formation. This unit occupies the trough of the Frederick Valley Synclinorium and thus is the highest stratigraphically. Taylor and others (1996) have shown through faunal evidence that the Grove Formation spans the Cambrian-Ordovician boundary, but that most of the Grove Formation lies within the Lower Ordovician. Current detailed mapping of the Frederick, Buckeystown, Woodsboro, and Walkersville quadrangles indicate that three mappable members comprise the Grove Formation in the Frederick Valley. The lowest member consists of light gray, sandy dolomite, and is herein named the Ceresville Member. The middle member makes up the bulk of the formation in the northern part of the valley, but only forms a narrow outcrop belt in the Frederick and Buckeystown quadrangles. This member consists of thickly interbedded, algal limestones, known as thrombolites, and tan dolomite. In this report this member is named the Fountain Rock Member of the Grove Formation. The upper member of the Grove Formation is only recognized in the Woodsboro and Walkersville areas and consists of dark gray, thin-bedded, lime mudstone, and is named the Woodsboro Member.

Taylor and others (1996) have shown that the Grove Formation in the northern part of the Frederick Valley may be well over 2,000 feet (610 m) in thickness. However, to the south in the Buckeystown and Frederick quadrangles, the narrowness of the outcrop belt and observations of outcrops suggest that no more than 300 aggregate feet for the formation are present in these areas.

Ceresville Member (new name)

Stratigraphic History. – Jonas and Stose (1938) recognized and mapped a quartzose dolomitic unit at the base of the Grove Formation. Although Reinhardt (1974) failed to recognize this unit, geologic mapping conducted during this study verifies Jonas and Stose's interpretations. Southworth and Brezinski (2003) and Brezinski and Southworth (2003) informally termed this unit the *lower member* of the Grove Formation. This unit, which makes up the basal 150 to 200 feet (30- 60 m) of the Grove Formation, is herein termed the Ceresville Member of the Grove Formation. The type section designated for this member is along the western bank of the Monocacy River immediately south of the Maryland Route 26 bridge at Ceresville. Here only 79 feet (24 m) of the member are exposed (Locality 13), but this exposure precisely characterizes the lithology of the member as seen elsewhere. Fauna recovered from the Ceresville Member suggest that it is assignable to the Lower Ordovician *Symphysurina* Zone (Figure 14B).

Character and Distribution. – The Ceresville Member of the Grove Formation is characterized by light to medium light gray, cross-bedded, sandy dolomite and fractured, light gray dolomite (Figure 14). One of the more complete sections outside of the type area is within the pasture south and west of the Frederick Quarry (previously Grove Quarry) near the formational type area (Locality 9). At this location, the exposed lowest 100 feet (30 m) of the member consist of light gray, fractured, sandy dolomite that is interbedded with intervals of very light gray, fractured, fine-grained dolomite. At least one of these non-sandy interbeds is interpreted as a dolomitized algal thrombolite. The characteristic sand grains within the dolomite of this member vary from fine-grained to very coarse-grained and make up between 5 to 45 percent of the rock. Most of the larger sand grains are well rounded. Some sandy layers exhibit abundant cross-bedding, some of which are herringbone.

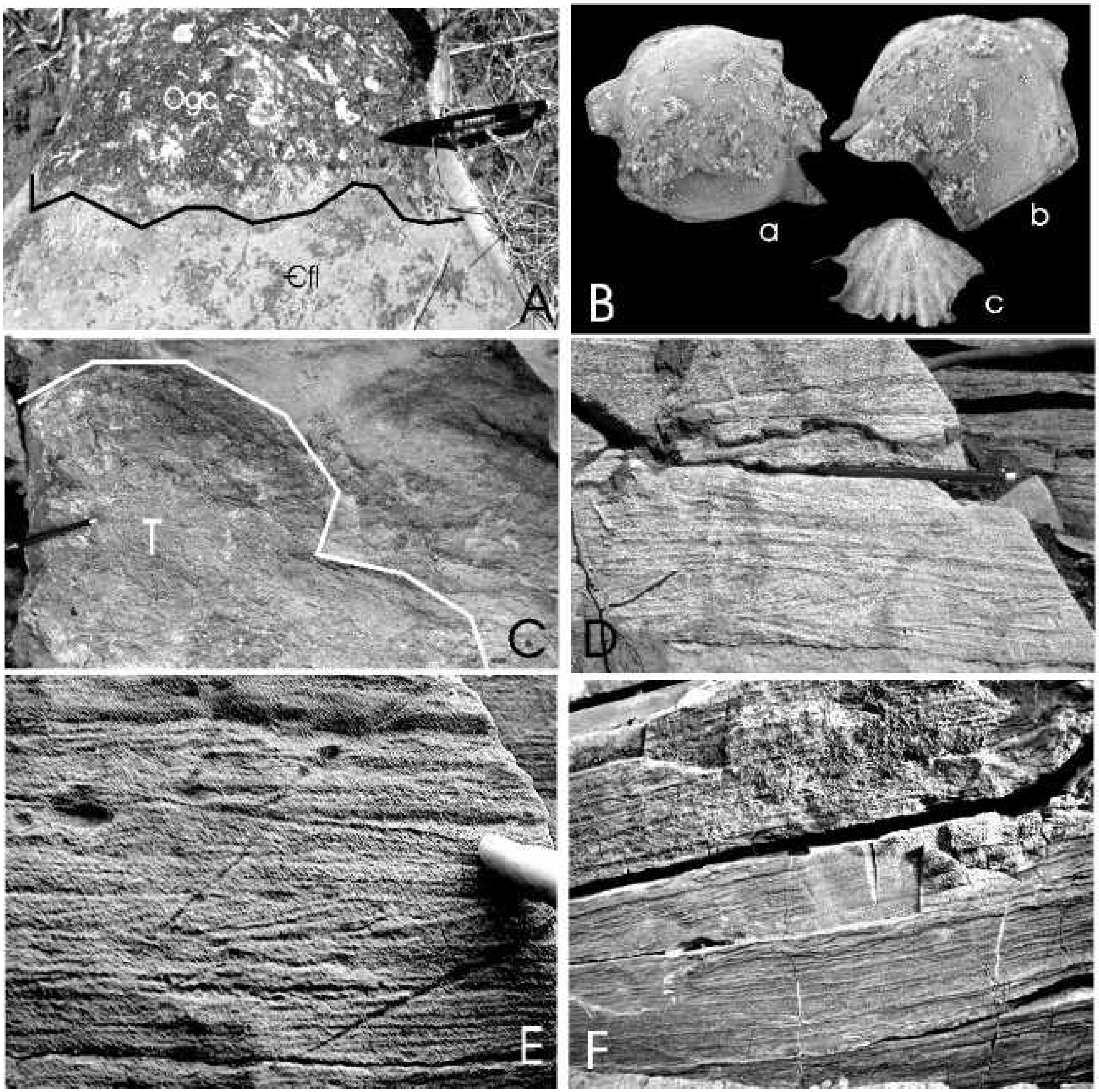

Figure 14. – **Ceresville Member of the Grove Formation. A, Thrombolitic algal limestone of the Lime Kiln Member of the Frederick Formation and dolomite of the basal Ceresville Member of the Grove Formation at Locality 11 (Ogc = Ceresville Member, Cfl = Lime Kiln Member). B, Fauna of the Ceresville Member at Locality 12. Ba, Bb, Cranidium of *Symphysurina* sp., Carnegie Museum 53228. Bc, Indeterminate brachiopod, Carnegie Museum 53229. C, Dolomitized thrombolite within the Ceresville Member. D, E, Cross-bedded, sandy dolomite of the Ceresville Member. F, Planar-bedded, sandy limestone.**

Another characteristic exposure of the Ceresville Member is present along Business Drive near the border between the Frederick and Buckeystown quadrangles. At this unmeasured exposure, a thick (70 feet (22 m)) section of very light gray, sandy dolomite of this member is exposed. The uppermost 15 feet of section consists of highly fractured, light gray, fine-grained dolomite. This same lithology is present at many other exposures (Localities 12, 18) and should be considered one of the characteristic lithologies of the Ceresville Member. This same lithology is present as pavement exposures within the confines of the Frederick County Fairgrounds, and along the Monocacy River at the crossing of Gashouse Pike. This interval is 22 feet (7 m) thick, as measured in the Grove Quarry section mentioned above.

Thickness. – A complete thickness for this member was not measured at any single stratigraphic section. However, based on nearly complete outcrops (Locality 18) and composites of exposures within the type area (Localities 12 and 13) the thickness of the Ceresville Member is estimated at between 150 to 200 feet (50 - 65 m).

Ceresville-Fountain Rock Members Contact. – The contact between the Ceresville Member and the overlying Fountain Rock Member of the Grove Formation is exposed at Locality 12. At this location the contact is placed at the top of the highest cross-bedded, sandy, dolomitic limestone. This interval coincides with the base of the lowest thrombolitic limestone interval in the overlying part of the Grove.

Fountain Rock Member (new name)

Stratigraphic History. – Overlying the distinctive Ceresville Member and making up the bulk of the Grove Formation's thickness is an interval of questionable thickness, herein termed the Fountain Rock Member of the Grove Formation for the exposure at Fountain Rock Quarry near Walkersville (Locality 17, Appendix I). This member was termed the *middle Grove member* by Brezinski and Reger (2002) and the *upper member* of the Grove Formation by Brezinski and Southworth (2003), and Southworth and Brezinski (2003).

Character and Distribution. – The Fountain Rock Member is composed of thick-bedded, thrombolitic, lime mudstone; tan, laminated, dolomitic, lime mudstone to dolostone; and light gray, sandy, intraclastic, lime packstone to grainstone (Figure 15). Near its northern extent several cross-bedded sandstone units were mapped within the middle of the member (Edwards, 1988). These sandstone strata were misidentified as being Triassic in age by Reinhardt (1974). The presence of herringbone cross-beds attests to the marine origin of these units, thus excluding them from the Triassic.

The Fountain Rock Member is exposed in three geographically separate outcrop areas, a southern, central, and northern. The southern outcrop belt, which is about half a mile wide in the vicinity of Buckeystown, lies within the core of the Frederick Valley Synclinorium and extends from east of Adamstown to north of the Frederick Quarry and Interstate 70. In the Buckeystown and Frederick quadrangles the outcrop pattern of this member is narrow, suggesting that it is thin in these areas. South of the town of Buckeystown and west of Maryland Route 85, pasture outcrops of the thickly interbedded, thrombolitic limestone and intervening laminated strata are exposed. Exposures are also present in small quarries east of the CSXT Railroad tracks east of Buckeystown (Locality 14). These abandoned quarries once supplied the local lime for the kilns located along the tracks and are comprised of the pure lime mudstone of the thick-bedded, algal thrombolites.

The central belt originates in the area around the Frederick County Fairgrounds and extends to immediately north of Ceresville. No good sections were observed for this member in this region.

The northern outcrop belt extends from Walkersville northward to the Triassic overlap north and west of Woodsboro where this member forms an outcrop belt more than 2 miles wide. In this area, the Fountain Rock Member typically forms isolated exposures that rarely are complete enough to measure. One of the better exposures is the type section at Fountain Rock Quarry (Locality 17). Here, 144 feet (44 m) of the massive thrombolites that characterize this member are exposed in the quarry wall. Two thicker, but more structurally deformed exposures were measured in the LeGore and Barrick quarries north of Woodsboro (Localities 15 and 16). Unfortunately, the well-exposed sections in these quarries are separated by a Jurassic diabase dike, and they have been heavily altered by the baking and deformation of the diabase intrusive. Perhaps the most substantial pasture section of this member is exposed straddling Dublin Road, south of Links Bridge Road (Taylor *et al.*, 1996; Locality 18). The stratigraphic section pieced together from the pasture exposures provides an incomplete composite thickness of more than 1,700 feet (520 m) for the Fountain Rock Member. Since the outcrop area

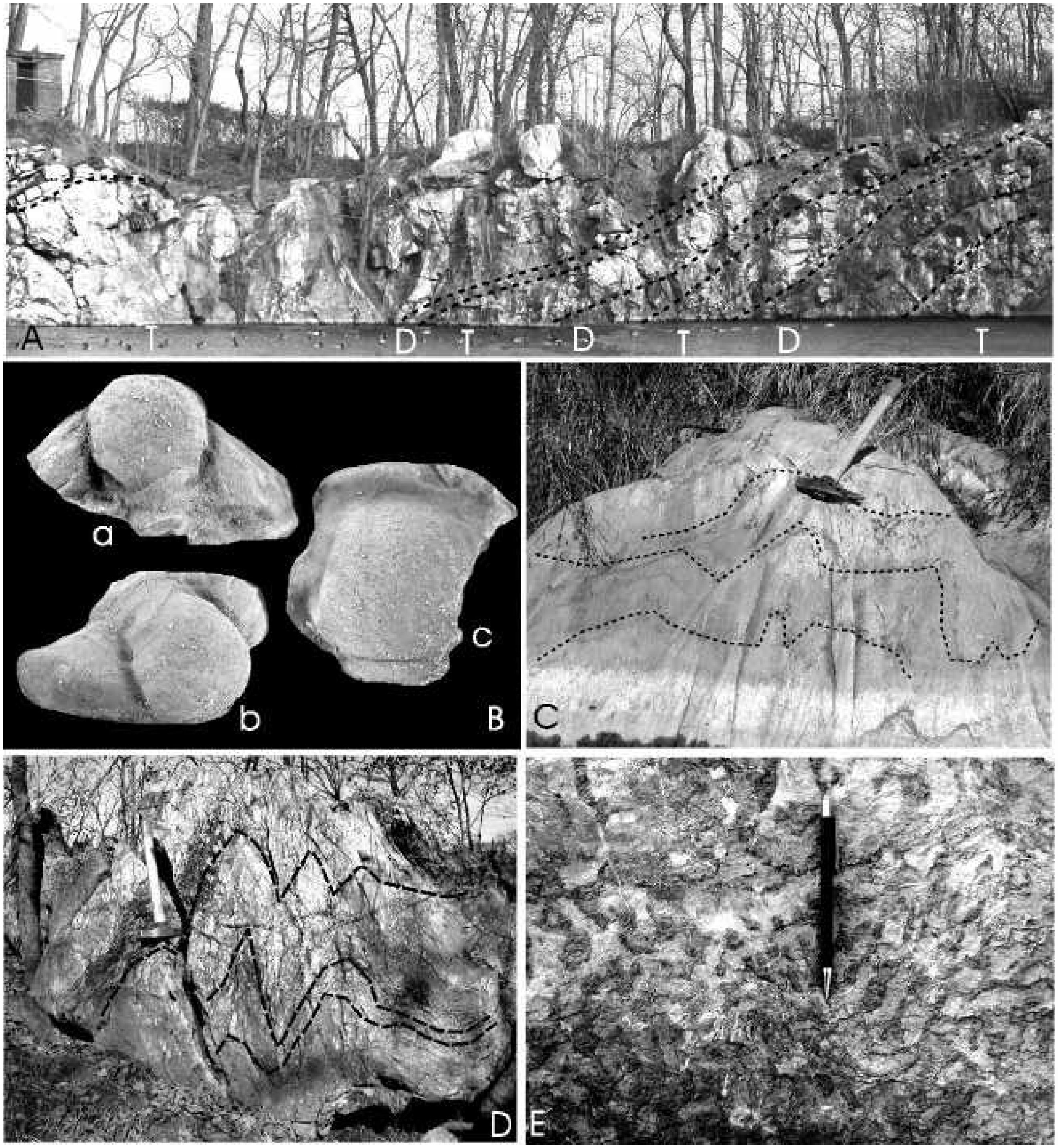

Figure 15. – **Fountain Rock Member of the Grove Formation. A, Type section of the Fountain Rock Member of the Grove Formation (Locality 17), exhibiting the alternation of thrombolitic (T) and dolomitic (D) strata. B, Trilobites from the Fountain Rock Member. Ba, Bb, *Keithia schucherti*, dorsal and oblique views, Carnegie Museum 35120. Bc, *Lecanopyge prolifica*, Carnegie Museum 35121. C, D, Large thrombolites of the Fountain Rock Member of the Grove Formation. Crude layering is shown by dashed lines. E, Characteristic textures of thrombolitic intervals of the Fountain Rock Member.**

of this member extends much farther east from the highest measured unit, one can surmise that the unit is nearly twice the thickness of that measured. The partially dolomitized thrombolites that pervade the Fountain Rock Member can be traced both south and north of the measured section, as they form prominent ledges in the fields and along Dublin Road.

Thickness. – No continuous sections of this member are know to exist, but its character can be determined by the examination of several incomplete sections. In the southern part of the Frederick Valley (Buckeystown and Frederick quadrangles), the Fountain Rock Member occupies a relatively narrow outcrop belt (Brezinski and Southworth, 2003; Brezinski, 2004). This suggests that the member in this part of the study area is much thinner than it is to the north. In the northern part of the valley and west of Woodsboro, Taylor *et al.* (1996) estimate the thickness of the entire Grove Formation was more than 5,000 feet (1,500 m). Based upon incomplete measured sections and outcrop belt width, the Fountain Rock Member is certainly 2,500 to 3,000 feet (760-915 m) thick in the northern outcrop belt.

Fountain Rock-Woodsboro Member Contact. – The contact between the Fountain Rock and the overlying Woodsboro Member of the Grove Formation is exposed in the Barrick Quarry of Laurel Sand and Gravel near Woodsboro (Locality 16, Appendix I). At this location the thick-bedded, light gray thrombolitic strata that characterize the Fountain Rock Member are replaced up section by the dark gray, bioturbated beds of the Woodsboro Member. This gradation takes place over as much as 100 feet, (30 m) and the contact is generally placed where the bioturbated lithologies become more dominant in the section.

Woodsboro Member (new name)

Stratigraphic History. – From Walkersville northeastward to the west of Woodsboro is an area mapped by Reinhardt (1974) as being underlain by the Lime Kiln Member of the Frederick Formation. The outcrop pattern created by the supposed inlier suggests a small anticlinal fold. However, no such changes of dip are apparent, and more importantly, no repetition of the Ceresville Member is observed. This suggests that the lithology believed to be Lime Kiln by Reinhardt is actually contained within the Grove Formation. Fossils recovered from this interval indicate a late Early Ordovician age and not of late Cambrian age, as would be consistent with the Lime Kiln (Taylor *et al.*, 1996). This unit not only marks the youngest early Paleozoic strata present in the Frederick Valley, but also the trough of the synclinorium. This interval is herein named the Woodsboro Member of the Grove Formation. The type section of this member is chosen along the western side of the Barrick Quarry northwest of Woodsboro (Locality 16, Appendix I).

Character and Distribution. – The Woodsboro Member consists of thinly interbedded, dark gray, thin-bedded, highly bioturbated, lime mudstone and thin-bedded, medium gray, lime mudstone. The bioturbated strata consist of knotty-weathering, gray lime mudstone, interstratified with tan-weathering, argillaceous dolomite. The somewhat thicker-bedded strata serve to define stratification and are less highly cleaved. Scattered throughout the member and much less common than the characteristic lithologies are thin beds of thrombolitic lime mudstone that range in thickness from 6 to 12 inches (15-30 cm). Also, scattered lime mudstone layers ranging in thickness between 1 and 6 inches (0.5-15 cm) are present. The upper 100 feet (30 m) of the member at the type section are marked by thick intervals of crudely bedded mudstone that tends to lack the bioturbated character of the member.

Because the lithologies exhibited by this member are identical to those that characterize the Lime Kiln Member of the Frederick Formation, it is understandable why Reinhardt (1974), in the absence of biostratigraphic evidence, believed that the outcrop belt of the Woodsboro Member of the Grove Formation was indeed the Lime Kiln Member.

The Woodsboro Member is distributed in an outcrop band that is broadest and best exposed at the type section and in the southern part of the Legore Quarry. To the north, the unit is buried beneath the Triassic New Oxford Formation overlap. The outcrop belt is relatively straight, but narrows to the south so that it terminates near Glade Elementary School in Walkersville. South of the type section, an excellent exposure of this member is found in an abandoned small quarry on the Stup property. This location is at the core of the Frederick Valley Synclinorium, and as such the rock exposure is penetrated by an extensive axial planar cleavage that makes discerning the stratification very difficult (Figure 16D). South from the Stup Quarry, the outcrop belt terminates. Consequently, the outcrop belt ends within the northern environs of Walkersville. Other exposures can be seen throughout the Walkersville Heritage Park.

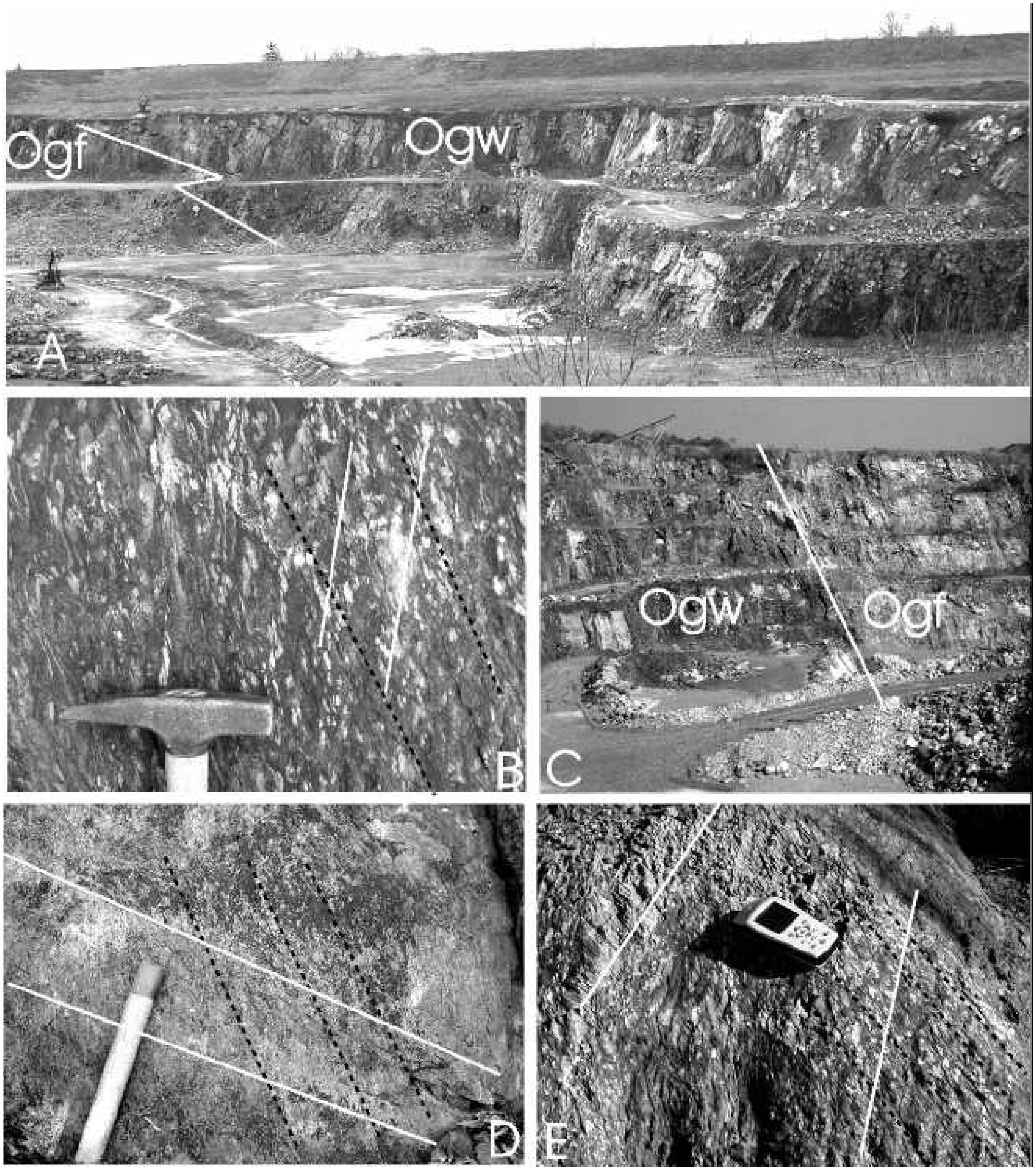

Figure 16. – **Woodsboro Member of the Grove Formation. A, Type section of the Woodsboro Member at the Barrick Brothers quarry west of Woodsboro (Locality 16). Ogf=Fountain Rock Member, Ogw=Woodsboro Member. B, E, Characteristic burrow-mottling of the Woodsboro Member. White lines indicate stratification, black dashed lines are cleavage. C, Contact between the Fountain Rock (Ogf) and Woodsboro (Ogw) members of the Grove Formation at the Legore quarry (Locality 15). D, Indistinct relationship between bedding (white lines) and cleavage (black dashed) in a partially filled quarry on the Stup farm, southwest of Woodsboro. This outcrop lies very near the axis of the Frederick Valley Synclinorium.**

Thickness. – Because the Woodsboro Member occupies the central trough of the Frederick Valley Synclinorium, it is impossible to determine the thickness of the member graphically. Moreover, the intense axial planar cleavage that is developed within the unit makes recognition of bedding difficult, and therefore, measurement of its thickness can be suspect. Inasmuch as this unit is the stratigraphically highest unit in the synclinorium, measured sections of this member are all incomplete. Based on partial stratigraphic section at the type section (Locality 16) and at the Legore Quarry (Locality 15), the unit is more than 320 feet (100 m) thick. It is likely that the Woodsboro Member was originally more than 500 feet (150 m) thick, but much of the Woodsboro Member is now buried beneath the Triassic onlap.

Genesis of the Frederick Valley Units

The Frederick Valley sequence represents a continuous depositional package that aggraded toward sea level throughout the late Proterozoic or Early Cambrian and continued, relatively uninterrupted, throughout the Cambrian and Early Ordovician. Deposition likely began in the late Proterozoic when continental rifting produced an ocean basin in which the fine-grained, bioturbated sandstones of the Araby Formation were deposited. This deep-water, sediment-starved deposition continued throughout the Early and Middle Cambrian into the early Late Cambrian with the slow accumulation of black shales of the upper Araby Formation, and the Monocacy Member of the Frederick Formation. At this time the Antietam, Tomstown, and Elbrook formations were being deposited on the shelf environments of the Hagerstown area.

During the early Late Cambrian, the development of an over-steepened bank or platform edge is suggested by the appearance of the first of many polymictic breccias representing submarine slide deposits (Reinhardt, 1974; 1977; Demicco, 1988) (Figure 17A). These deposits formed at the toe of the ancient continental slope and accumulated rapidly to form a wedge-shaped apron of slide masses that interfinger with the thinly laminated, shaly limestone of the in-place deep-water deposits. The steepness of inclination of these strata is suggested by the pervasive distribution of imbricated limestone slabs that formed by the down-slope sliding of some layers. While these slide masses continuously accumulated at the bottom of the slope, only a short distance into the oceanic basin these deposits thinned to a feather edge. This resulted in the creation of a unit, the Rocky Springs Station Member, that is well over a mile and a half in thickness on the western side of the Frederick Valley, while barely reaching 1,000 feet less than 5 miles to the east.

At the time these slides occurred in the Frederick area, shallow-water limestones of the Conococheague Formation were forming in the Hagerstown area. The accumulation of this wedge of sediment served to reduce the steepness of the platform edge so that through time thinner slide masses were deposited. Deposition ultimately changed character to the slower accumulation of the thinly bedded, shaly limestones of a deep-water ramp (Figure 17B) during the creation of the Adamstown Member. During this depositional episode, the entire Frederick Valley was submerged by water depths not nearly as great as during the creation of the Rocky Springs Station Member, but still well below depths that were hospitable to animal and plant life.

Accumulation of the Adamstown Member over the thick deposits of the Rocky Springs Station Member continued to produce an aggradation towards sea level. The first indications of bioturbation or deposition of algal limestone heralded the beginning of the Lime Kiln Member episode of deposition (Figure 18A). As this shallowing towards sea level continued, the incidence of bioturbation and deposition of algal strata increased. This resulted in fewer layers of thinly bedded, shaly limestone being deposited, while more massive, bioturbated and algal beds occurred.

The ultimate result was the filling of the oceanic basin in the Frederick region so that deposition within shallow water was initiated. Contemporaneously, strata of the upper Conococheague and Stonehenge formations were being deposited in the Hagerstown Valley. By Early Ordovician, shallow-water deposition dominated by the formation of cross-bedded, sandy limestone of the Ceresville Member of the Grove Formation covered the Frederick area (Figure 18B).

These sandy deposits were overwhelmed by the growth of large reefs composed of algae known as thrombolites (Fountain Rock Member of the Grove Formation). These reefs were created during repeated episodes of minor sea level change, thus giving the unit the characteristic alternations of reef and dolomite. By the late Early Ordovician, these reefs were inundated when sea level rose (Woodsboro Member) and submerged the platform edge deeply enough to return to the depositional style seen previously in the Lime Kiln Member of the Frederick Formation.

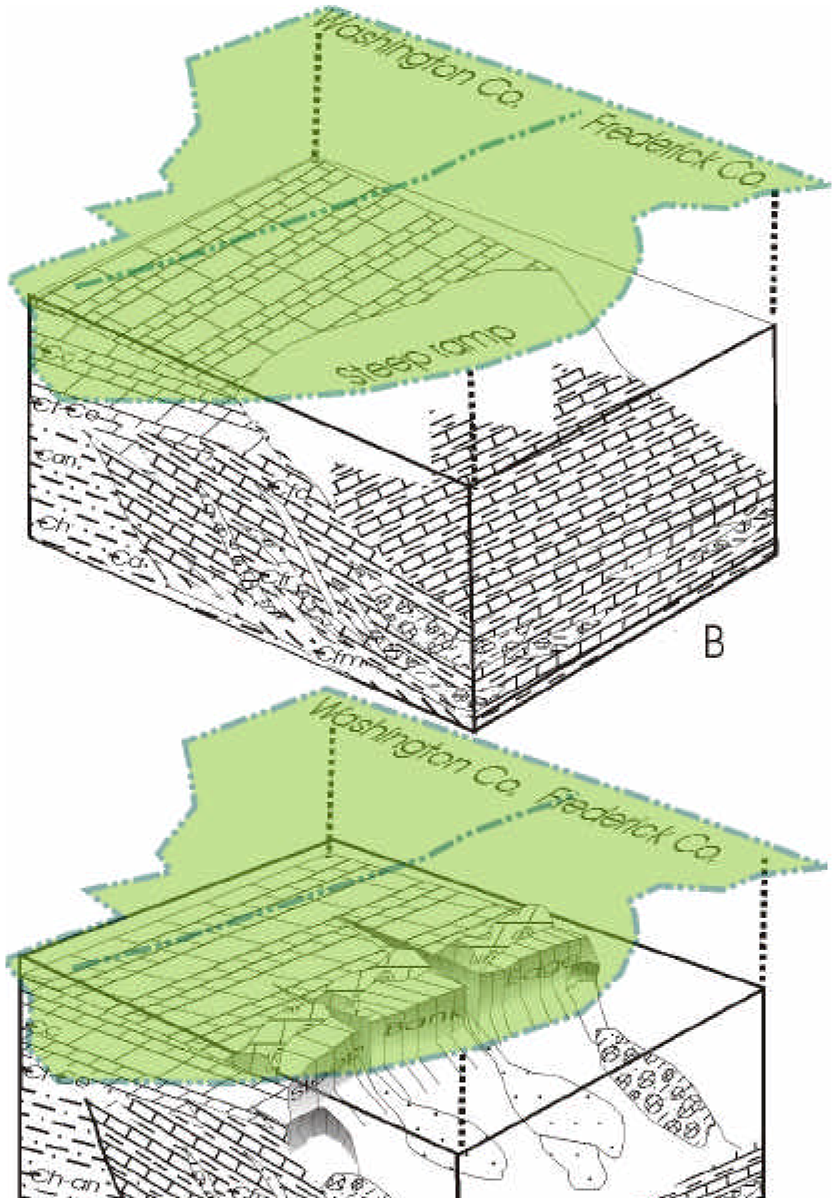

Figure 17. – **Idealized three-dimensional block diagrams illustrating lateral and vertical relationships of the Monocacy through Adamstown members of the Frederick Valley sequence. A, Early deposition was controlled by a high-relief platform edge that was created either during the Late Proterozoic or Early Cambrian. The Araby Formation and Monocacy Member of the Frederick Formation were deposited on the floor of this ocean basin. The platform that was present to the west periodically produced submarine landslides that moved downslope and came to rest at the foot of the continental slope. These slides, today preserved as the polymictic breccias of the Rocky Springs Station Member (Cfr) of the Frederick Formation, covered the ocean basin sediments that were forming *in situ*, now represented by the Monocacy Member (Cfm). B, Slide masses at toe-of-slope create a steep carbonate ramp on which the overlying Adamstown Member (Cfa) is deposited.**

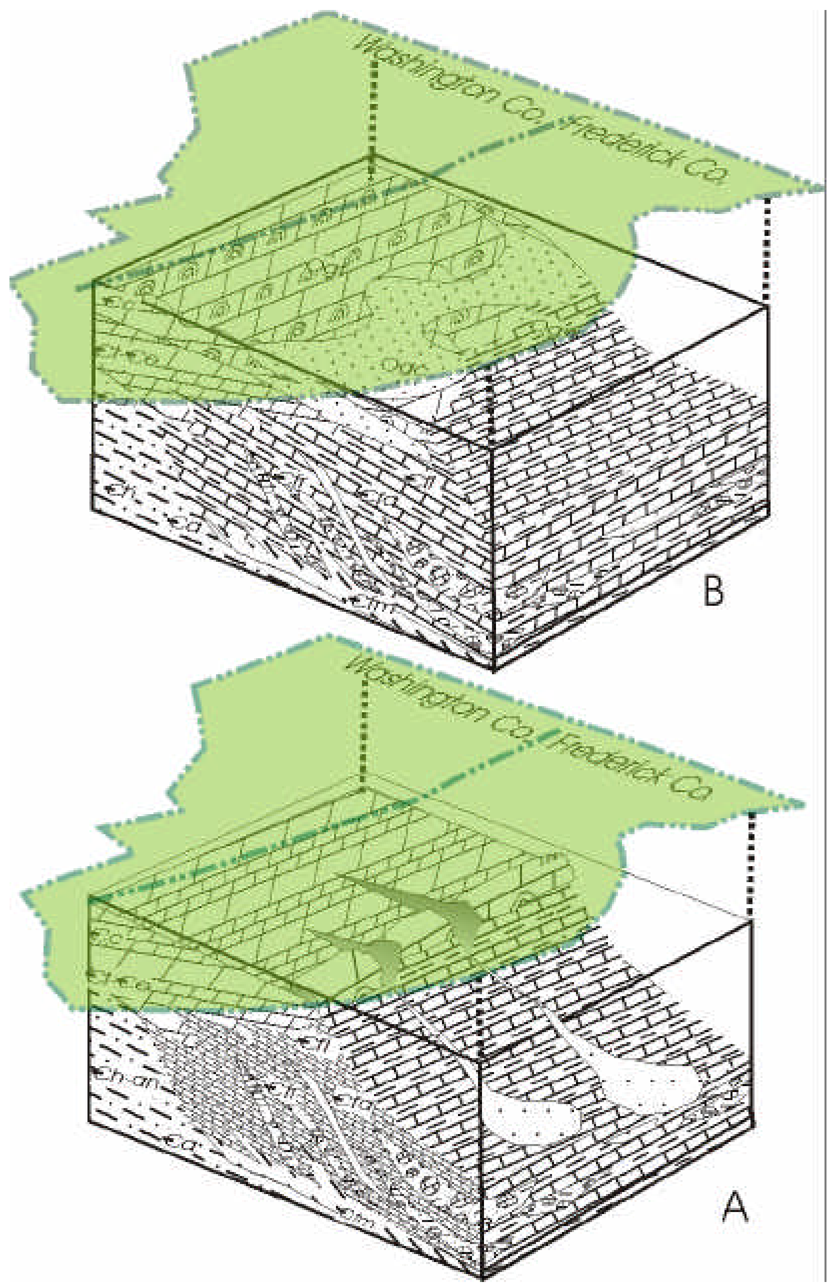

Figure 18. – Idealized three-dimensional block diagrams illustrating lateral and vertical relationships of the Lime Kiln through Woodsboro members of the Frederick Valley sequence. A, Accretion and aggradation on the Adamstown (Cfa) ramp created a shallowing sequence in the Lime Kiln Member (Cfl) so that the lower Lime Kiln strata were deposited in deep water, while upper strata of the member were deposited in shallow waters at the edge of the platform. B, Platform-edge sands of the Ceresville Member (Ogc) of the Grove Formation interfinger with algal thrombolitic reef facies of the Fountain Rock Member (Ogf). A late early Ordovician deepening episode again submerged the platform edge environments to produce ramp mudstones of the Woodsboro Member (Ogw).

Culpeper Basin Units

Triassic strata of Maryland have long been thought to occur within two separate depositional basins. In southern Frederick and western Montgomery counties, Triassic rocks were deposited in the northern part of the Culpeper Basin. This basin extends to the south into northern Virginia, but pinches out just west of the City of Frederick in the vicinity of U.S. Alternate 40. Just to the north of this basin termination, Triassic rocks are once again present. This outcrop belt broadens to the north into Pennsylvania and represents the southernmost extension of the Gettysburg Basin. Consequently, the U.S. Route 40 corridor along West Patrick Street in Frederick appears to represent a structural high point that separates the two basins. While these two separate depositional basins carry two individual nomenclatural packages, the lithologies contained within each are, as one would expect, similar. Both basins contain conglomerate units along the margins and fine-grained clastic units within the basin centers. Drilling conducted by the Maryland State Highway Administration in conjunction with this study in the vicinity of the supposed structural high that separates the two Triassic basins yielded limestone conglomerates with red siltstone matrix. These red, carbonate conglomerates are almost certainly Triassic in age. Consequently, the Triassic strata in Maryland's western Piedmont, once thought to be assignable to two separate basins, are actually continuous.

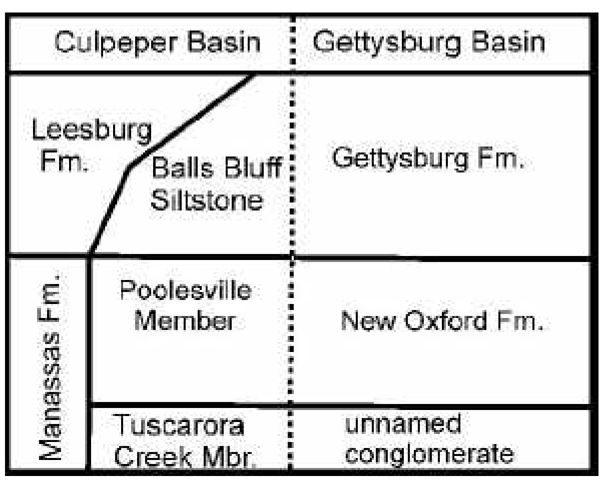

Figure 19. – Inferred relationships of stratigraphy between the Culpeper and Gettysburg Basins (Weems and Olsen 1997).

The stratigraphy employed herein follows Weems and Olson (1997) in its correlations. Because much stratigraphic confusion and disagreement surrounds the usage of the Bull Run Formation, ranking of the composite members varies among authors.

Sub-Triassic Contact

Based upon map relationships, the Triassic sediments overlap the Frederick Valley carbonates. Although not observed at any location, this relationship should have significant angular discordance. The map pattern in the Buckeystown, Frederick, and Woodsboro quadrangles indicate that the carbonate units are sequentially overlapped by the red clastics of the Triassic. At outcrop scale, no angular discordance was observed, but the stratigraphic relationship can be viewed (Localities 19 and 22, Appendix I). At Locality 22, fine-grained, thin-bedded limestone of the Rocky Springs Station Member of the Frederick Formation is overlain by 25 feet of dolomitic conglomerate that marks the base of the Triassic in the Culpeper Basin of Maryland. At Locality 19, 12 feet of reddish mudstone and then more than 50 feet of limestone conglomerate overlie a slide breccia of the Rocky Springs Station Member. This conglomerate is an unmapped unit within the New Oxford Formation, and has a similar stratigraphic position as the Tuscarora Creek Member of the Manassas Formation. As will be shown in subsequent sections, a recognizable karstification episode occurred within the Frederick Valley units prior to the deposition of the Triassic sediments. This is indicated by several interpreted Triassic age collapse breccias that have been identified and mapped.

Leesburg Formation

Stratigraphic History. – Considered a member of the Bull Run Formation by Lee (1979) and Weems and Olson (1997) and a member of the Balls Bluff Siltstone by Lee and Froelich (1989), the reddish, carbonate conglomerates that form a wide outcrop belt at the eastern base of Catoctin Mountain have long been a nomenclatural point of contention. Locally termed 'calico rock,' this easily recognizable unit was quarried in the Point of Rocks area for use as decorative columns within the United States Capitol building.

The conglomerate lithology that characterizes this unit is very extensive both in thickness and areal distribution, as it marks the western margin of the Culpeper Basin in Maryland. The lithologic distinctness of this unit in conjunction with the nomenclatural confusion that surrounds it, necessitated its elevation to formational status.

Character and Distribution. – Named for exposures near the town of Leesburg in Loudon County, Virginia by Lee (1979), conglomerates of the Leesburg mark the western edge of Triassic deposition in Maryland. It is characterized by a light reddish gray, cobble to boulder, limestone and dolomite conglomerate. Locally, thin layers of reddish brown, sandy siltstone partings are interbedded with the conglomerate. Most of the clasts are rounded to subangular and poorly sorted. Clasts vary in composition from light gray, lime mudstone to tan dolomite, and more rarely, reddish brown, sandy siltstone. The average size of the clasts that make up the conglomerate varies widely, from pebbles less than 0.5 inch (1cm) in diameter to cobbles more than 1 foot (30 cm) across (Figure 20C). The clasts are cemented by a light reddish brown to reddish gray, silty, carbonate cement. Although no detailed size analysis was conducted for this study, there appears to be a relative decrease in cobble size from the western edge of the outcrop belt toward the east.

Excellent exposures of this unit can be observed along the C&O Canal Historical Park east of Kanawha Spring, in the wooded areas north of that location, and along the adjacent CSXT Railroad tracks (Figure 20A). Other excellent exposures occur along the roadside and in pastures along Ballenger Pike north of Point of Rocks and near the Allegheny Power transmission station. Characteristic field exposures are present throughout the outcrop belt. The northernmost exposure of this unit is along the westbound lanes of Interstate 70 immediately east of its ascent of Catoctin Mountain.

Compositionally, the light gray limestone and tan dolomite clasts appear to be more similar to Cambrian and Ordovician rocks of the Great Valley rather than to the thinly bedded, dark gray, early Paleozoic rocks of the Frederick Valley. From this it is surmised that the provenance for the Leesburg Formation is from the west rather than the east.

Bedding in this formation is very coarse and rarely is apparent at outcrop scale (Figure 20A, B). Bedding, where present, is defined by slight changes in average clast size or presence of thin layers of reddish siltstone. Where evident, bedding consistently is inclined from 25 to 35 degrees to the west and northwest.

The conglomerates of the Leesburg Formation crop out in a belt nearly 1 mile wide extending from the Potomac River northward to Interstate 70. This formation underlies the low-lying area that occurs east of and parallel to U.S. Highway 15 from Point of Rocks to its intersection with U.S. Route 340. The western limit of the Leesburg is a fault, which places it in contact with the Cambrian Tomstown and Antietam formations. In most places, this western margin is generally concealed by a covering of Quaternary colluvium that has moved downslope from Catoctin Mountain. Eastern limits of the Leesburg Formation are mapped at the gentle rise along the eastern margin of its outcrop belt. This slope marks the transition into the facies equivalent Balls Bluff Siltstone.

Thickness. – Lee (1977; 1979) estimated that the thickness of the Leesburg Conglomerate ranged from 630 feet (190 m) to 3,500 feet (1,070 m). Judging from the width of the outcrop belt and the relatively consistent dip angle of the formation in the Point of Rocks vicinity, graphical estimates of the thickness of the Leesburg Formation range from 2,000 to 2,500 feet (610 to 760 m). These thickness estimates would only be applicable along the western border of the Triassic depositional basin. The Leesburg Conglomerate has been interpreted to be an alluvial fan deposit formed along the western escarpment created by Triassic age extension faulting. The formation is theorized to thin rapidly eastward as it interfingers with finer grained units deposited in more distal environments of the fan complex. In its more eastern exposures, a thickness of 100 feet (30m) or less would be expected.

Balls Bluff Siltstone

Stratigraphic History. – Lee (1977, 1979) interpreted the Balls Bluff Siltstone to be a fine-grained lateral equivalent to the conglomerates that comprise the Leesburg Formation. Lithologies that make up the Balls Bluff Siltstone, as mapped here, crop out along the eastern margin of the Leesburg Formation. Although Weems and Olsen (1997) demoted this unit to member rank, the original designation at formational status is retained in this study (Lee and Froelich, 1989).

Character and Distribution. – The Balls Bluff Siltstone is poorly exposed in Maryland, but it can be characterized based on a number of small exposures. The Balls Bluff Siltstone consists of reddish brown to brownish red, thin- to medium-bedded, argillaceous, sandy siltstone to silty mudstone. Locally, thin beds of argillaceous, silty, micaceous sandstone are present. Many of the mudstone intervals are characterized by intervals that are pervaded by carbonate nodules and blebs. The extensive bioturbation and abundance of carbonate nodules suggest that these layers are caliche horizons (Figure 20E).

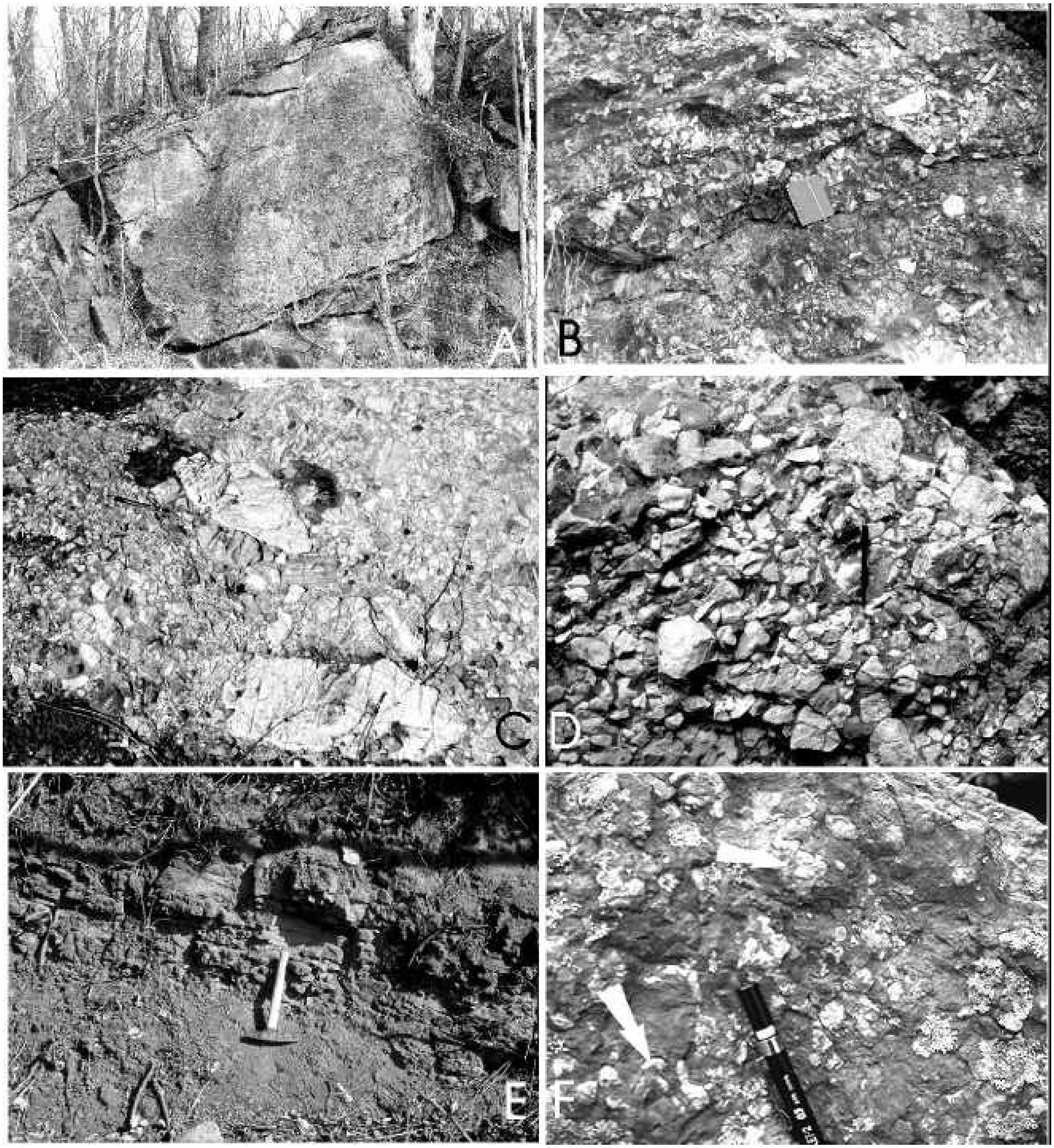

Figure 20. – Leesburg Formation and Balls Bluff Siltstone. A, Very thick bed of conglomerate along C & O Canal National Historical Park east of Point of Rocks. B, Color and textural changes suggesting bedding (at notebook). C, Large dolomite clasts within finer gravel matrix. D, Weathering character of the Leesburg Formation. E, Balls Bluff Siltstone typical lithology. F, Caliche soil horizon (at arrow) within the Balls Bluff Siltstone.

The Balls Bluff Siltstone forms a region of gently inclined upland and low hills along the eastern margin of the low-relief area created by the Leesburg Formation. Several small exposures are noteworthy. In the southern part of the Frederick quadrangle, the Balls Bluff Siltstone is exposed along the Jefferson Pike south of Feagaville. At this exposure, approximately 6 feet (2 m) of siltstone and micaceous siltstone are present along the west side of the highway. More than 45 feet (15 m) are also exposed along the westbound lanes of Interstate 70 just east of the ascent of Catoctin Mountain. At this exposure, the micaceous siltstone of the Balls Bluff Siltstone is interbedded with thin, silty, medium-grained sandstone beds.

Based on differences in geologic mapping between Lee (1979) and that conducted for this study, there appears to be a difference in interpretation in what lithologies constitute the Balls Bluff Siltstone in Maryland. While Lee (1979) contended that the Balls Bluff was composed primarily of siltstone, the areas he mapped as this unit contain several thick, coarse-grained sandstone units. These sandstones are more consistent with the Manassas Formation (Lee, 1979) and are herein considered part of that formation. Thus, the outcrop width of the Balls Bluff Siltstone is markedly narrower on maps produced for this study than those published by Lee (1979).

Thickness. – Lee (1979) estimated the thickness of the Balls Bluff Siltstone to range from 230-5,000 feet (70-1,525 m). Because the unit has a considerably narrower outcrop width in this study than that proposed by Lee (1979), the maximum thickness of the member is likely to be much lower than he proposed. Even so, an estimate of 3,000 feet (915 m) is quite likely.

Manassas Formation

Stratigraphic History. – Originally named as the Manassas Sandstone by Roberts (1928), the Manassas Formation was revised to consist of four members, the Rapidan, Reston, Poolesville, and Tuscarora Creek (Lee, 1977, 1979; Lee and Froelich, 1989). Only the Poolesville and Tuscarora Creek members extend into Frederick County, Maryland.

Poolesville Member

Stratigraphic History. – Named by Lee (1979) and Lee and Froelich (1989), the Poolesville Member makes up the greatest area of outcrop of the Manassas Formation in Maryland.

Character and Distribution. – The Poolesville Member is comprised of alternating red sandstone and siltstone to mudstone. The sandstone intervals consist of reddish-brown, reddish-gray weathering, trough cross-bedded, micaceous, medium- to coarse-grained sandstone, with shale-pebble conglomerates common at the base. These sandstones fine upward into fine-grained, platy micaceous, silty sandstone to sandy siltstone and exhibit sharp, convex-down bases that suggest an erosional origin. These abundant sandstone intervals are interbedded with reddish brown and brownish red mudstone and siltstone units that pinch out laterally between the sandstone units. The mudstone and siltstone units display abundant and pervasive root casts and carbonate nodules and blebs.

The outcrop belt of the Poolesville Member forms a gentle upland just east of the karst lowland created by the soluble Leesburg Formation. Exposures of the Poolesville Member of the Manassas Formation are generally small and scattered. The character of the member can be determined from two exposures. At Locality 21, nearly 1,200 feet (365 m) of the Poolesville Member were measured. The member at this location consists of the characteristic interbedded, rooted mudstone and siltstone and red-brown and grayish brown sandstone. The second measured section, Locality 20, exposes more than 550 feet (170 m) of the member, but along discontinuous exposure (Figure 21A). The rooted intervals with carbonate nodules are well exposed, and their relationship with the overlying and underlying sandstone intervals can be observed (Figure 21C-D).

Thickness. – Lee (1979) estimated the maximum thickness of the Poolesville Member to be 3,270 feet (1,060 m). Judging from the relative width of the outcrop belt and the thickness of the partial section measured along Interstate 70, it would appear that this estimate is reasonable.

Tuscarora Creek Member

Stratigraphic History. – A thin carbonate conglomerate is present long the eastern margin of the Triassic outcrop belt, and presumably at the base of the Manassas Formation,. Lee (1979) termed this thin conglomeratic unit the Tuscarora Creek Member for exposures along Tuscarora Creek in the southwestern part of the Buckeystown quadrangle. The base of this discontinuous member marks the unconformity between the underlying Cambrian strata of the Frederick Formation and the overlying Triassic rocks

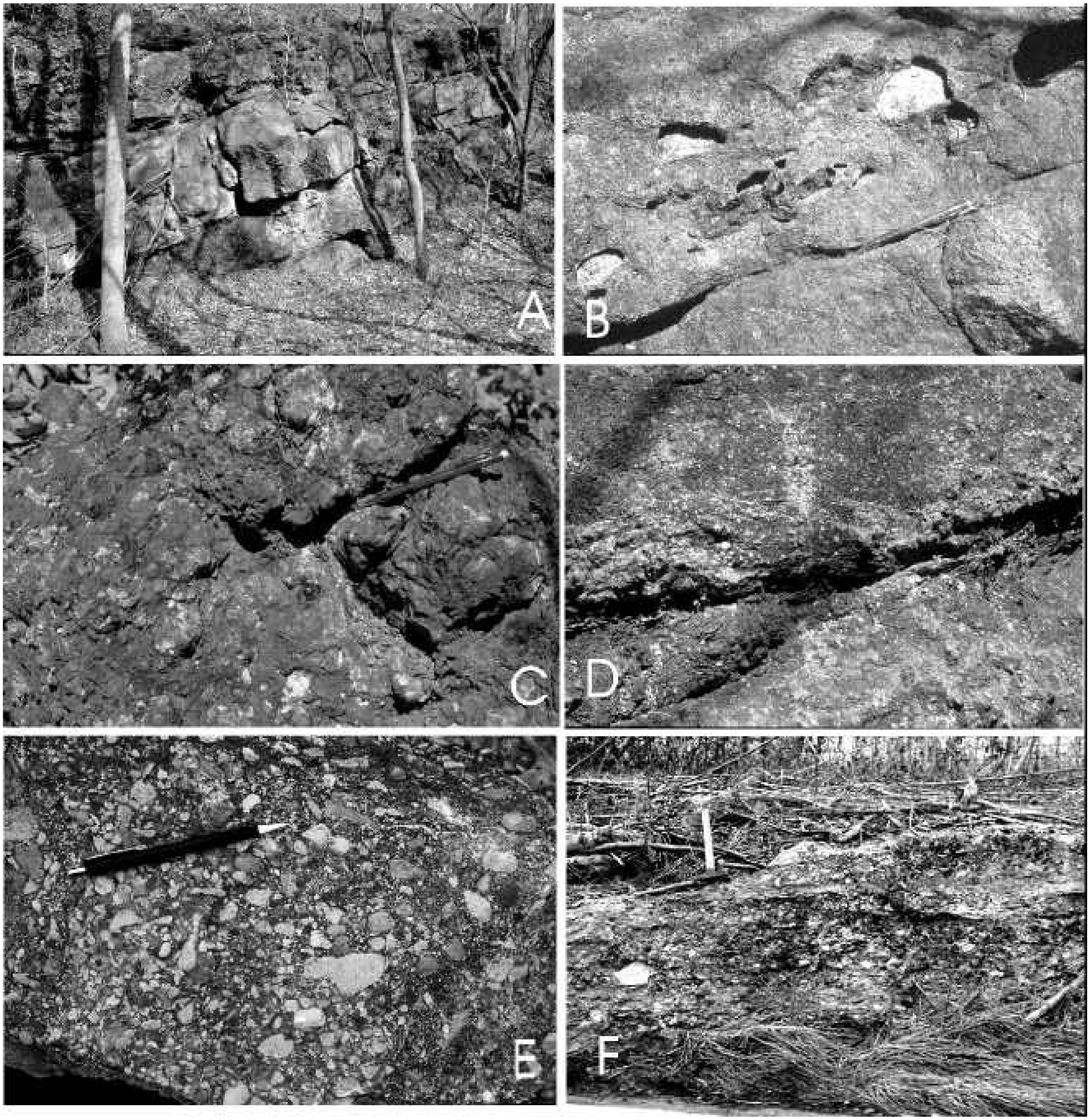

Figure 21. – Manassas Formation. A, Alternating coarse-grained, reddish brown sandstone with red mudstone that characterizes the Poolesville Member of the Manassas Formation (Locality 20). B, Basal lag conglomerate within coarse-grained sandstone unit of fluvial channel origin. C, D, Caliche nodules (light) within rooted, red mudstone unit. E, F, Dolomite pebble conglomerate of the Tuscarora Creek Member of the Manassas Formation.

that comprise the Culpeper depositional basin. Although this unit is discontinuous in outcrop, it serves as an excellent marker horizon.

Character and Distribution. – The Tuscarora Creek Member consists of thickly bedded, light gray-weathering, carbonate conglomerate to breccia. The clasts range in size from 0.5 inch (1.0 cm) to 4.0 inches (10 cm) in diameter and are typically well-rounded. Although the conglomerates of the Leesburg Formation are predominately limestone clasts and, to a lesser degree, dolomite clasts, the Tuscarora Creek Member is composed primarily of tan dolomite clasts with only minor numbers of limestone and red sandstone and siltstone clasts (Figure 21E-F). Moreover, the texture of the Tuscarora Creek Member is notably finer than the Leesburg Formation conglomerates that are present nearer the western basin margin. Average clast size in the Tuscarora Creek Member is approximately 1 inch (2.0 cm) in diameter, as compared to the clasts in the Leesburg that can exceed 12 inches (30 cm) in diameter.

Thickness. – The Tuscarora Creek Member of the Manassas Formation ranges in thickness from 0 to more than 200 feet (60 m) (Lee, 1979). An excellent exposure of this member is present along Maryland Route 28 just west of the intersection with New Design Road (Locality 13) in southern Buckeystown quadrangle. This location is very near the type area along Tuscarora Creek.

Gettysburg Basin Units

New Oxford Formation

Stratigraphic History. – Originally named by Jonas (1928), the New Oxford Formation is named for exposures in southern Pennsylvania. This unit appears to be correlative in time and lithology to the Manassas Formation of the Culpeper Basin (Weems and Olsen, 1997).

Character and Distribution. – The New Oxford Formation consists of thickly interbedded, dark reddish brown, trough cross-bedded, micaceous, medium- to coarse-grained sandstone; red to reddish brown, platy, sandy siltstone; and red-brown, rooted, silty mudstone. The sandstone intervals range from as little as 6 feet (2 m) to more than 30 feet (10 m) in thickness. Indeed, several of the more prominent sandstones are probably much thicker and can be traced and mapped. Most sandstone intervals exhibit an upsection fining, erosional bases, and shale-pebble or quartz-pebble conglomerates at the base, especially in the thicker units. The tops of these sandstone units typically grade into platy, micaceous, sandy siltstone to silty, fine-grained sandstone intervals and then into the rooted mudstone layers. The mudstone intervals contain abundant root-casts and locally light gray caliche nodules.

Perhaps the best exposure of the New Oxford Formation is in Carroll County along the Maryland Midland Railroad tracks at Detour (Locality 23, Appendix I). Here the section is dominated by intervals of medium-grained sandstone (Figure 22C) that exhibit the characteristic interbedding that makes up the preponderance of this unit. The New Oxford Formation extends from a narrow outcrop belt just to the north of Alternate U.S Route 40 in the western part of the City of Frederick northeastward to the Maryland-Pennsylvania State Line, to the type area at New Oxford in southern Adams County, Pennsylvania. Throughout most of Frederick County, the New Oxford Formation forms low hills that are dissected by the Monocacy River. Many of the linear hills of the New Oxford outcrop belt are underlain by some of the more prominent sandstone intervals that comprise the formation. Perhaps the most prominent and wide-spread of these sandstone units underlies the ridge on which Creagerstown is located. This sandstone ridge can be traced for more than three miles from southwest of Creagerstown northeastward to Rocky Ridge.

Thickness. – Because of lack of exposure, the total thickness of the New Oxford Formation could not be measured, but based upon the outcrop width a thickness in excess of 10,000 feet (3,050 m) is suggested.

New Oxford - Gettysburg Contact.

At no place is the contact between the New Oxford and Gettysburg formations exposed. The transition between the two formations can be recognized topographically by identifying the change from the low sandstone ridges of the New Oxford Formation to the flatlands of the Gettysburg Formation. This coincides with the Creagerstown sandstone bed. Since the stratigraphic section above this sandstone tends to lack the prominent sandstone units that characterize the New Oxford Formation, and because the topography manifests a different character due to a change in the bedrock, the Creagerstown sandstone bed is mapped as the top of the formation.

Gettysburg Formation

Stratigraphic History. — Originally named the Gettysburg Shale by Stose and Bascom (1929), this unit is now considered a formation. The Gettysburg Formation appears to be correlative to the Balls Bluff Siltstone of the Culpeper Basin (Weems and Olsen, 1997).

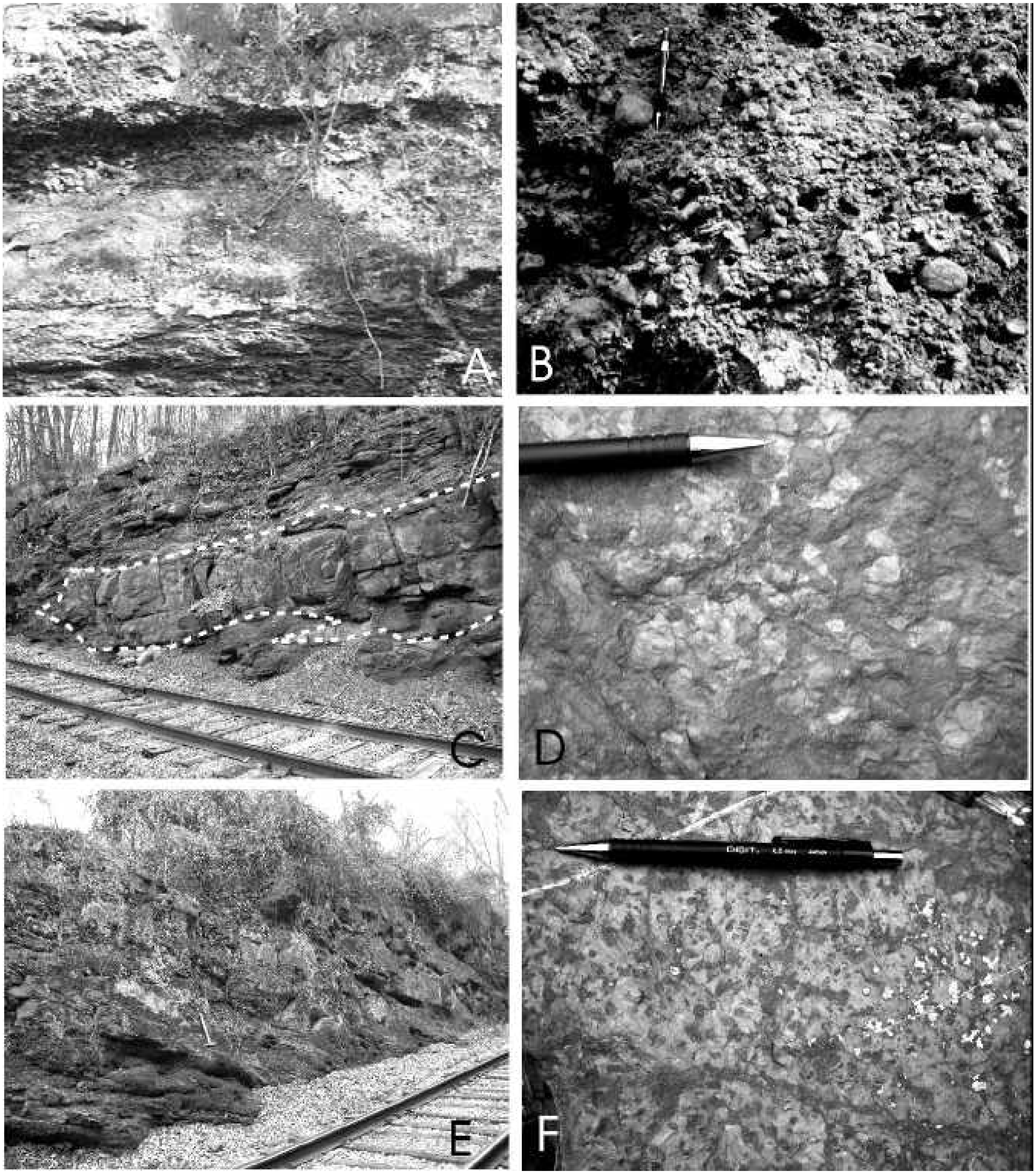

Figure 22. – New Oxford and Gettysburg formations. A, B, Basal quartz pebble conglomerate of the New Oxford Formation. C, Interbedded, coarse-grained, reddish brown sandstone channel (white dash) within reddish, rooted mudstone overbank deposits of the New Oxford Formation at Detour (Locality 23). D, Channel sandstone of the New Oxford Formation at Locality 23. E, Reddish brown, medium-bedded mudstones of the Gettysburg Formation at Locality 24. F, Root-casts within the mudstone layers of the Gettysburg Formation.

Character and Distribution. – The Gettysburg Formation is very poorly exposed in Maryland, but can be characterized based on a small number of exposures. The Gettysburg Formation consists of reddish brown to brownish red, thin- to medium-bedded, argillaceous, sandy siltstone to silty mudstone. Thin beds of argillaceous, silty, micaceous sandstone are locally present, but uncommon. The mudstone intervals are characterized by sections that show pervasive development of caliche carbonate nodules and root-casts.

The Gettysburg Formation forms a region of low hills along the western outcrop belt of the New Oxford Formation. Because it lacks the abundant sandstone intervals characteristic of the New Oxford, the topography created by this unit is lower in elevation and local relief. Consequently, exposures within the outcrop belt of the Gettysburg Formation are much rarer than those of the New Oxford Formation. Perhaps the best exposure of this unit in Frederick County is along the Maryland Midland Railroad tracks west of the brick plant at Rocky Ridge (Locality 24) and within the brick plant excavations south of the railroad tracks. At this exposure, more than 300 feet (91 m) of interbedded siltstone and mudstone are exposed (Figure 22E). The Gettysburg Formation occupies a wide outcrop belt from Lewistown northward to the Maryland-Pennsylvania State line. Even with this large outcrop area, exposures are sparse.

Thickness. – Like the New Oxford Formation, it is impossible to measure the total thickness of the Gettysburg Formation, but based upon outcrop width and dip angle, the unit is in excess of 8,000 feet (2,400 m) thick.

KARST FEATURE DISTRIBUTION

The refined stratigraphy described and illustrated in the preceding section provides a solid foundation for delineating the distribution and determining the possible origins of karst features. Without such a well-defined foundation, the distribution of karst features could not be evaluated precisely. Consequently, evaluation of whether the distribution of karst features is related to bedrock units would be tenuous. The second part of this report deals with the identification and precise location of karst features, and the evaluation of whether their distribution, density, and dimensions are related to bedrock geology or some other factor.

The three types of karst features identified are depressions, active sinkholes, and karst springs (Figure 23). Otherwise known as dolines, closed depressions were by far the most common feature recognized. These features are recognizable topographic lows towards which the surrounding area is inclined. These depressions can be elongate, or oblong, but typically are displayed as circular or bowl-shaped indentations. Because depression shapes vary greatly, one could potentially subdivide them into a number of narrowly defined categories based on their ostensible origin. For instance, a category could be erected to include broad, shallow depressions, some more than 100 yards across, that appear to represent areas created by the slow dissolution of the underlying bedrock and a very slow *letting-down* of the soil surface because of bedrock dissolution or the coalescence of smaller depressions

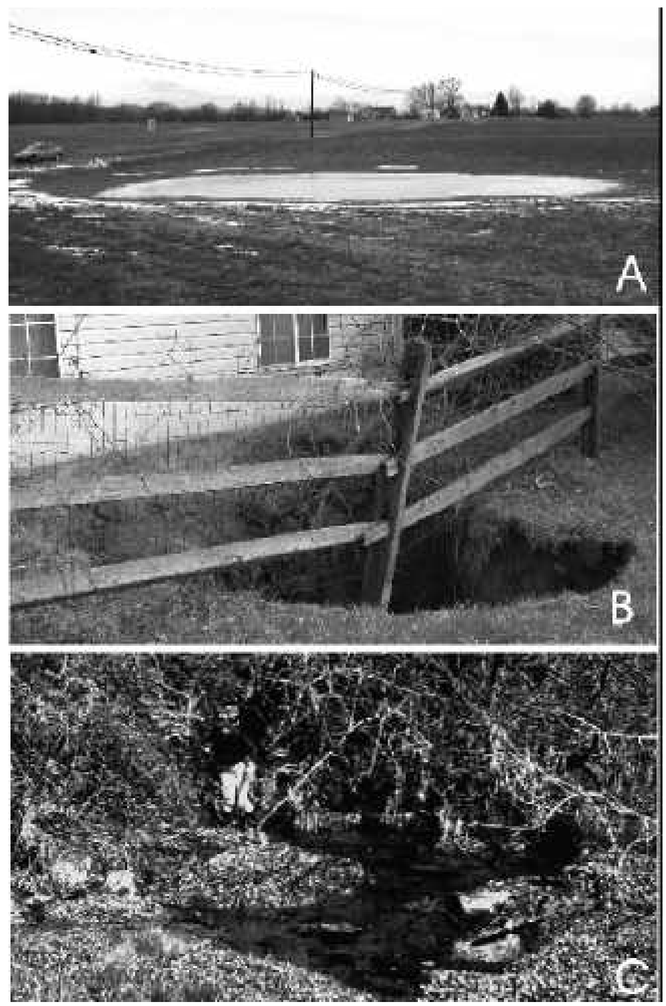

Figure 23. – Karst feature types examined in this study. A, Broad depressions in field. B, Active sinkhole collapse next to a house. C, Karst spring.

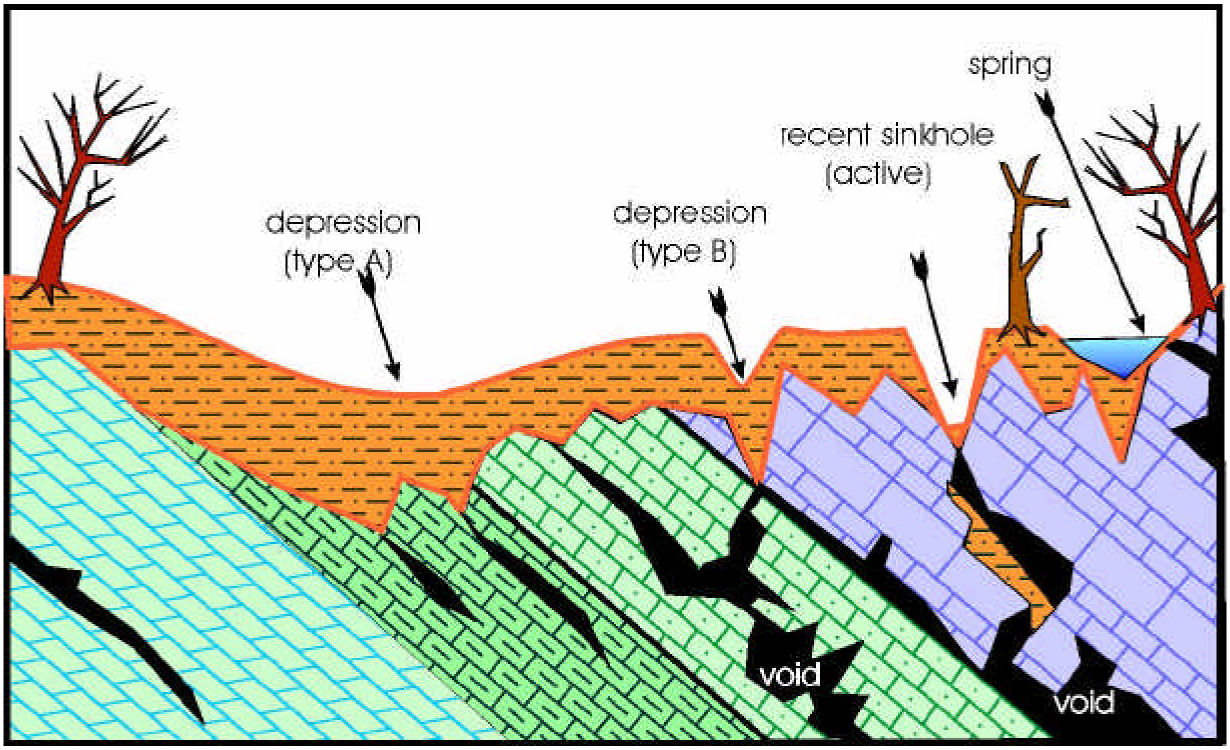

Figure 24. – Idealized karst illustrating interpreted form of karst features utilized in this study and their interpreted relationship to underlying bedrock.

that through time form one large depression (depression-type A in Figure 24). A second category could include narrow depressions ranging in width from 3 to 10 yards and in depth from 3 to 10 feet that appear to have their origins as partially filled active sinkholes (depression-type B in Figure 24). Since most depressions with no visible throat form a gradation in shape and size between these two types, all such depressions were lumped together as a single feature category for this study.

The second category of karst features recognized is active collapse sinkholes. Like depressions, active sinkholes do not have a single distinguishing characteristic, but constitute a wide range of different features. The most common and widely recognized type of active sinkhole in the Frederick Valley are those that expose an open throat and are clearly open holes. The active category also includes narrow, steep-sided depressions that lack an open throat, but have unvegetated sides that suggest recent activity. Soil cover-collapses are created by the collapse of soil that covered an open or partially open subterranean void (Figure 25). Lastly, collapses that are known to have occurred in recent years and have been repaired are also included in this category. These remediated collapses are included only if their locations could be ascertained. This was done where renewed subsidence was visible, surface patches could be seen, or eyewitnesses could precisely locate the repaired collapse.

The third category of karst features is karst springs. While these are the least common karst feature examined, they nonetheless represent a significant characteristic that sheds light on movements of subterranean water. Caves are an important category of karst features that were not included as part of the study, inasmuch as there are only two known caves in the Frederick Valley. This is an insufficient number for statistical purposes.

Karst features are distributed primarily in the Cambrian and Ordovician carbonate rocks of the Frederick Valley. However, two karst regions outside of the Frederick Valley proper, and previously not recognized or not considered important, were identified and included in this study. The most prominent of these belts is underlain by the Leesburg Formation along the eastern base of Catoctin Mountain from the Potomac River at Point of Rocks to the western part of the City of Frederick. The second belt is also found along the eastern base of Catoctin Mountain and extends from Yellow Springs northeastward to Lewistown. This area lies primarily within the Catoctin Furnace quadrangle, and although current

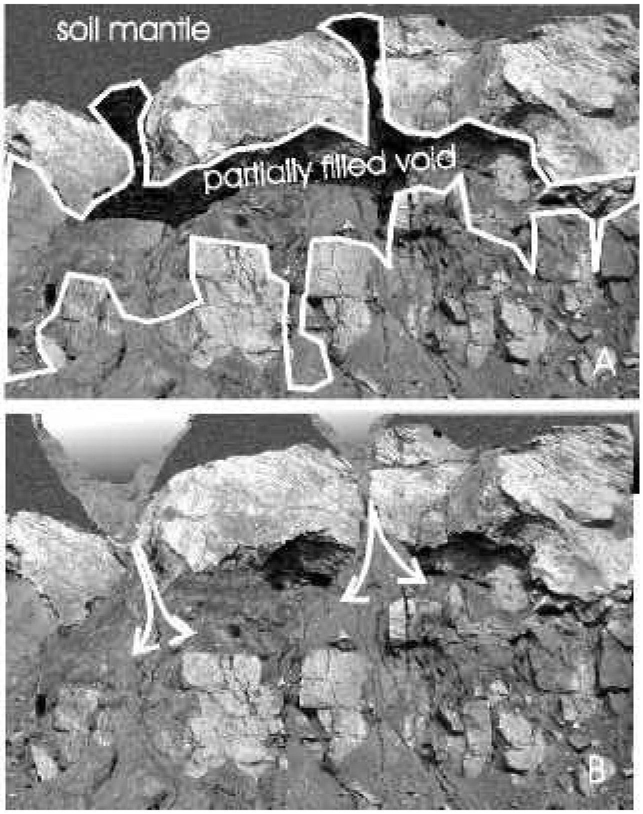

Figure 25. – Idealized creation of a soil cover-collapse sinkhole. Exposure of a partially filled void within the Grove Formation allows observation of mechanisms responsible for collapses. A, Subterranean void beneath the surface represents an area for future possible collapse of overlying soil layers. B, Collapse of soil cover into void allows soil movement into open parts of void, leaving depressions at surface.

mapping portrays this belt as an extension of the Lewistown inlier, previous mapping identified the bedrock in this area as Triassic clastics (Jonas and Stose, 1938; Reinhardt, 1974, Plate 1). Recent drilling by the Maryland State Highway Administration in conjunction with this study demon-strates that the underlying bedrock is assignable to the Rocky Springs Station Member of the Frederick Formation. Because most of this area is covered by colluvium, no bedrock outcroppings are visible.

Methods

Karst features were identified as part of a geologic mapping field study of the Point of Rocks, Buckeystown, Frederick, Walkersville, Woodsboro, and Catoctin Furnace 7.5-minute quadrangles. As these geographic areas were canvassed during geologic field mapping, identifiable and definable karst features were precisely located utilizing a Trimble GeoExplorer II® or GeoExplorer III® Global Positioning System (GPS) receiver. Most features were located by placing the GPS unit within the feature while a satisfactory number of satellites were in the constellation. The minimum number was usually four and optimally seven satellites. In some circumstances, features that could not be entered because of property permission constraints were located by offsetting to another location where the azimuth back to the feature could be determined, and the distance could be delineated by utilizing a laser range finder.

Once data were collected in the field, all GPS files were post-processed. Post-processing is an office procedure whereby the locations identified by the field receiver are differentially corrected by comparing the exact position of the satellites in the constellation as recorded by the field receiver with the position of the satellites as recorded by a base station. The primary base station used in this study is the U.S. Geodetic Survey receiver at Gaithersburg, Maryland. When that base station was not operating, the secondary station was Greenbelt, Maryland or Richmond, Virginia. These *corrected* GPS files and their locations typically gave a precision of less than 1 meter. While this level of precision is insufficient for most surveying purposes, it is more than sufficient for this study, considering that some of the larger depressions measured more than 200 feet diameter. The locations were stored in the State Plane Coordinate System with a North American Datum (NAD) of 1983.

In addition to the geographic coordinates, data acquired at each location were: karst feature identification; bedrock unit identification; presence or absence of Quaternary deposits that might cover the feature; bedrock orientation (strike-dip); any joint or fracture orientation; and other possibly significant characteristics, such as location in a drainage lowland, drainage ditch, or storm-water management reservoir.

In areas that were identified as troublesome, detailed geologic sketch maps were produced by precisely locating geographic features and sinkholes utilizing a global positioning system. Many of these troublesome areas are provided as figures in the remainder of this report.

Karst Feature Summary

Over 1,800 karst features were located in the six quadrangles studied. Table 2 and Figure 26 give a percentage breakdown of the three types of features. Depressions are by far the most common feature recorded, making up nearly sixty-five percent of all the readings. Active sinkholes comprised nearly 34 percent of the features, springs were a distant third at 1.7 percent of all karst features. Karst features were not distributed evenly throughout the Frederick Valley carbonate units, even though all carbonate units contained at least one type of karst feature. Some geologic units appear to have greater numbers of features than others just as some geologic intervals tend to develop specific types of karst features. This premise is key to the initiation of this study, and the basic distribution of karst features tends to validate this *a priori* interpretation.

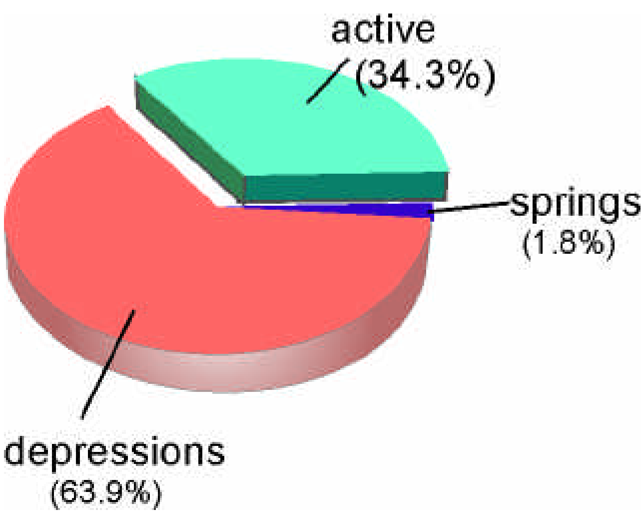

Figure 26. – Pie diagram illustrating the relative percentage of the three types of karst features identified in this study from more than 1,800 karst features of the Frederick Valley.

GEOLOGIC FACTORS INFLUENCING KARST DEVELOPMENT

Although a variety of natural and man-made factors contributes to the distribution, density, and type of karst features in any given area, this study concentrated mainly on those with geologic affinities.

Fractures

An important geologic factor governing the relative susceptibility of each unit to karstification is fractures. While fractures can include partings in stratification, the main fracture types are cleavage, joints, and faults. To assess the role of fractures in the development of karst features and to evaluate variations in fracture trends within the different lithologic units, the azimuths of more than 1,000 fractures were measured from three locations of the Grove Formation and two locations of the Leesburg Formation. A graphic summary of these data shows that there is a single main fracture pattern in the Grove Formation (Figure 27A-D). This pervasive joint system has a mean azimuth of 288 degrees (72 degrees west of north; Figure 27A). An ancillary fracture system has an azimuth of 20 degrees (20 degrees east of north). This secondary system coincides with the axial planar cleavage of the Frederick Valley fold.

Triassic fractures in the Leesburg Formation exhibit a completely different trend (Figure 27E-G). The main fracture trend has a mean of 87 degrees east of north, with a conjugate set having an azimuth of 315 degrees (45 degrees west of north). One can see that there is a considerable difference in the orientation of the joint directions between the Ordovician Grove and the Triassic Leesburg formations. The causes of these differences are the varying tectonic stresses that acted on these units during different geologic episodes. The fracture pattern of the Grove Formation can be interpreted as resulting from the compressional stresses created during the origination of the Frederick Valley in the Late Permian. The Leesburg Formation, which was deposited after the formation of the Frederick Valley, was influenced by tensional stresses that produced the Triassic basins concurrent with the initial opening of the Atlantic Ocean during the Late Triassic or Jurassic.

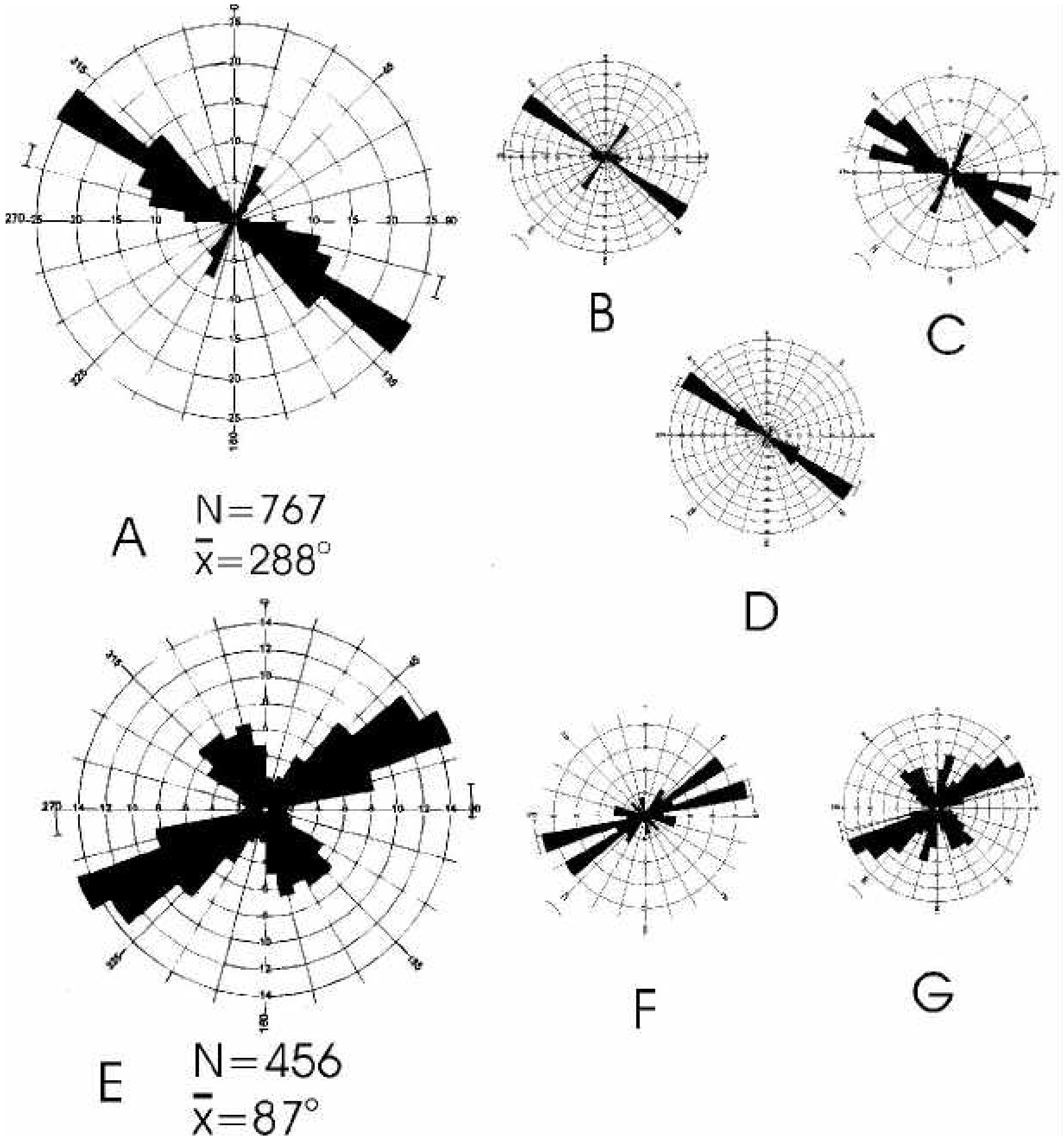

Figure 27. – Rose diagrams of 1,061 fracture surfaces. A, Compilation of 767 fracture planes measured in the Grove Formation at three locations. B, Executive Drive. C, South of Grove Road. D, Gashouse Pike at the Monocacy River. E, Compilation of 456 fracture planes measured at two locations of the Leesburg Formation. F, Kanawha Spring. G, North of Point of Rocks.

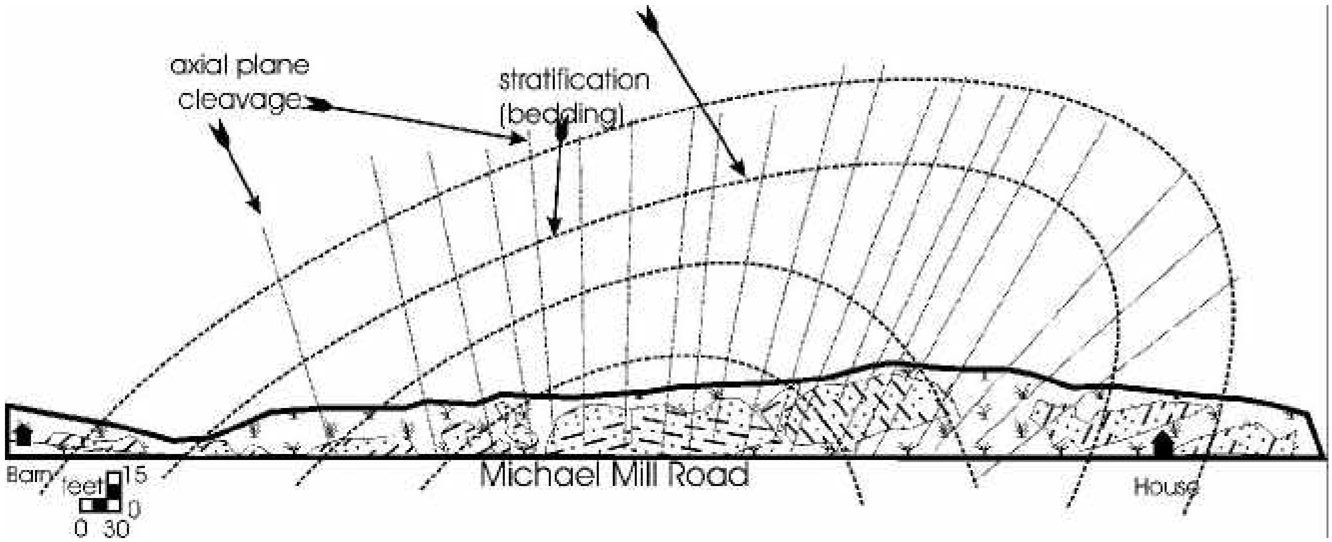

Figure 28. – Geologic sketch cross-section of the tightly folded Araby Formation along Michael Mill Road east of Buckeystown. The closely spaced fracturing is interpreted as axial planar cleavage to the fold within the Araby Formation. So intense is this fracturing that it has nearly masked the original stratification.

Cleavage

There is a system of northeast-trending, closely spaced fractures that pervades the limestone and dolomite units of the Frederick Valley. Although this system of fractures is common in shaly or dolomitic units, it is especially pronounced in units that occupy the center of the Frederick Valley Syncline (Figure 15D). This type of fracture can also be observed within outcrop-scale folds as illustrated in Figure 28. At this location along Michael Mill Road, the original stratification in the Araby Formation has been nearly completely obscured by this intense fracturing. The closely spaced fracture system that parallels the regional trend of stratification in the Frederick Valley units is interpreted as a foliation or cleavage. The relative intensity of this foliation varies both compositionally and, as shown in Figure 28, relative to the position on the fold.

Although cleavage surfaces allow abundant opportunities for water to permeate and dissolve the rocks within the Frederick Valley, they are most common in the lithology that is least prone to dissolution, shaly carbonate. That is why cleavage, if it is an important factor in sinkhole development, is a localized one. The most intense occurrence of cleavage seen over the course of this study was within the Woodsboro Member of the Frederick Formation. Not surprisingly, this unit contains shaly intervals and is located at the core of the Frederick Valley Synclinorium.

Joints

Joints, unlike cleavage, pervade all the rock types throughout the entire Frederick Valley. As shown above (Figure 27), joints in the Cambrian and Ordovician rocks of the Frederick Valley exhibit a completely different orientation from those present in the Triassic rocks. What appears to be much more important to karst development than the joint directions is the character of the joints. Within the Grove Formation, and to a lesser degree the Frederick Formation, the joints are closely spaced. This geologic factor provides greater surface area for dissolution (Figure 29A). Locally intense fracturing, especially within the dolomitic part of the Grove Formation, can result in the production of either a network of interconnected sinkholes or a linear alignment of sinkholes (Figure 29B, 30). Figure 30 illustrates how the former case is displayed in areas underlain by the Grove and Frederick formations. In this storm-water management area, sinkholes are produced in a network. This is interpreted to have resulted from dissolution along the many joint surfaces similar to that illustrated in Figure 29A.

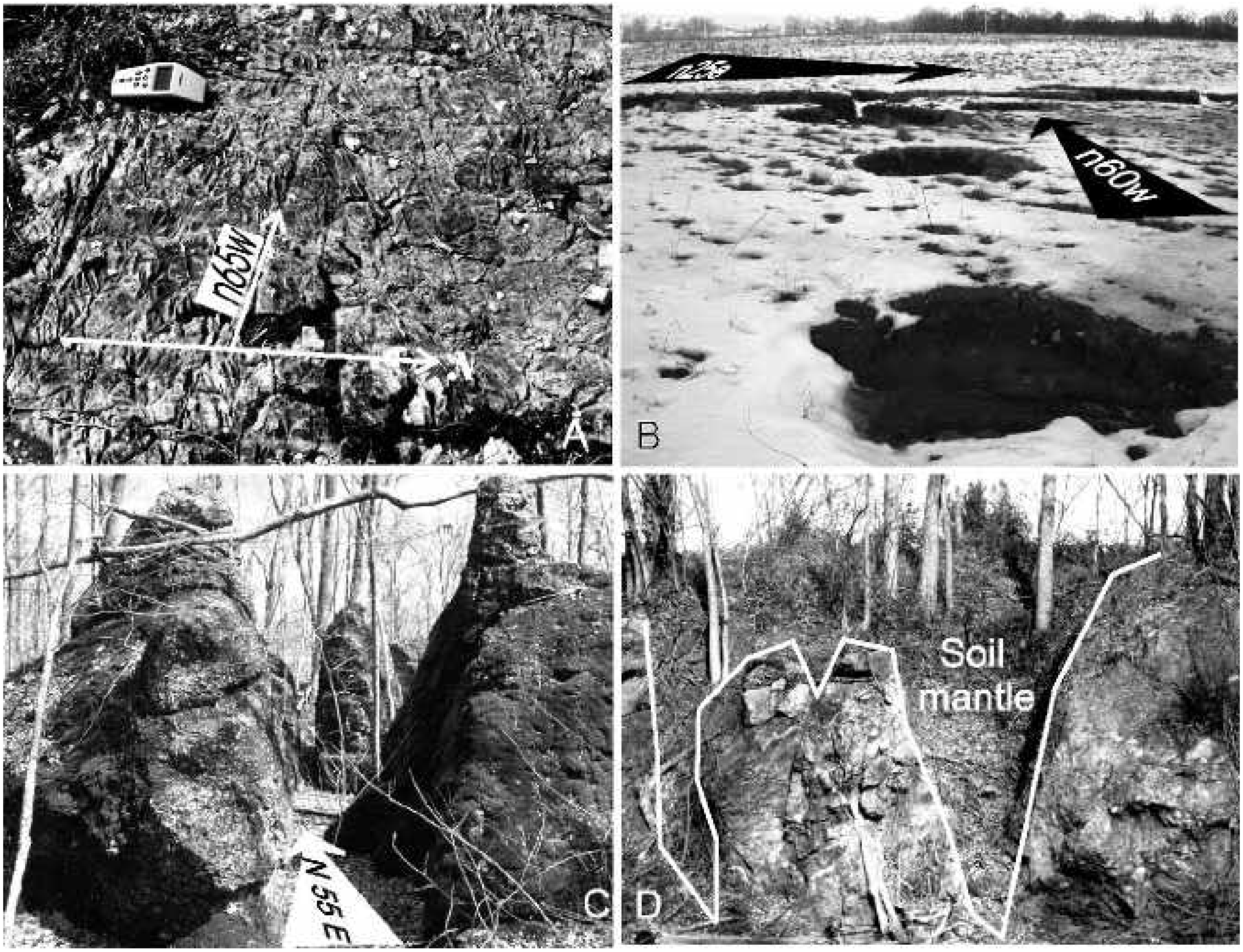

Figure 29. – A, Fracture pattern exhibited by the Ceresville Member of the Grove Formation. Main joint set marked by strike arrow is nearly N60W (azimuth of 60). B, Intersection of joint and cleavage planes as manifested by intersecting and coalescing sinkholes within the Lime Kiln Member of the Frederick Formation. Main joint and cleavage directions (illustrated by arrows) compare favorably with those illustrated in Figure 27A. C, Solution-widened joints characteristic of the Triassic Leesburg Formation. D, Buried and filled joint surfaces within the Leesburg Formation showing the solution-widened fractures.

Joints in the Leesburg Formation differ in both orientation and spacing. The Leesburg joints occur at regularly spaced intervals ranging from 3 -10 feet (1-3 m) (Figure 29 C, D). Solution has widened many of these fractures along straight surfaces. Even though the Leesburg Formation is composed of detrital limestones of varying compositions, it does not possess the thin bedding seen in the Frederick Formation and Woodsboro Member of the Grove Formation. Thus, it appears to act as a homogeneous unit with the spaced joints only rarely interconnected with other fractures. This allows dissolution to widen the joints without producing the honeycomb of collapsed sinkholes characteristic of the Frederick and Grove formations.

The relationship and importance of the spaced jointing in the Leesburg Formation can be seen through a ancillary study conducted in an area underlain by the formation near the Potomac River in the Point of Rocks quadrangle (Figure 31). The purpose of this minor study was to determine what relationship exists between the orientation of fractures and the distribution of surface streams. Three hundred eighty-two joints were measured in this area; their combined orientation is shown in the rose diagram at the top of the figure. Furthermore, surface drainages (dashed lines) and were also located using a global positioning system. One can see that sinkholes (solid circles) tend to develop along surface drainage transects. More importantly, the orientation of these drainage lows appears to follow the primary fracture sets that are present in the Leesburg Formation. This suggests that the surface drainage is, in large part, controlled by the distribution and direction of the joints and that the sinkhole distribution is controlled by the surface drainage and joints.

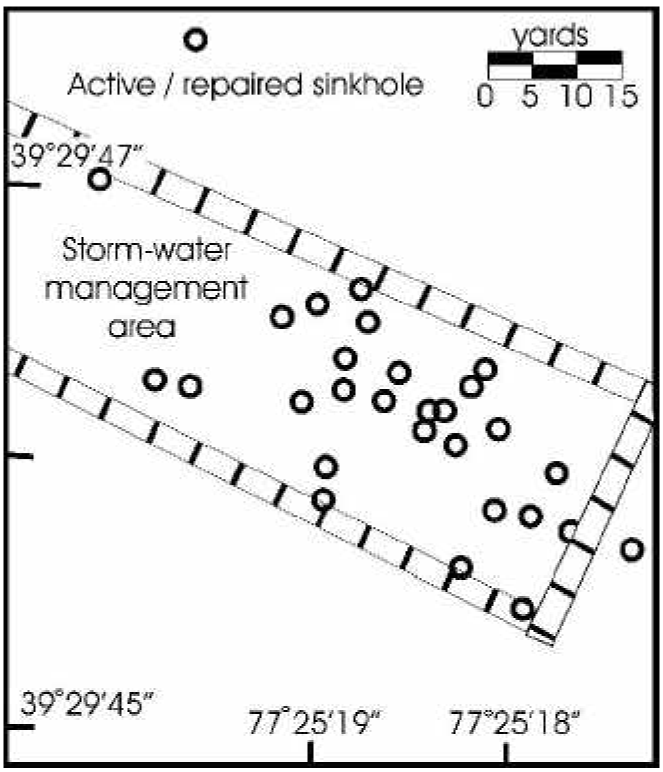

Figure 30. – Dense concentration of active sinkholes (open circles) related to dissolution of network of fractures within the Fountain Rock Member of the Grove Formation. Sinkholes are exposed in a storm-water management area north of Buckeystown and are precisely located with a global positioning system. Sinkholes show little to no preferred orientation paralleling the dominant joint directions within the Grove Formation.

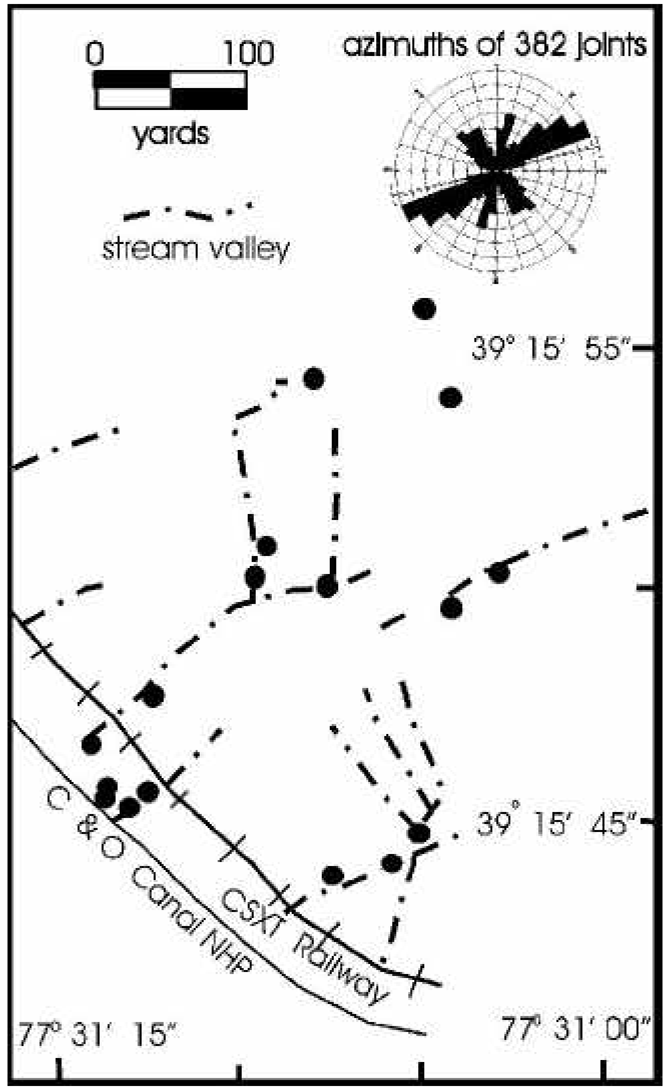

Figure 31. – Global positioning system sketch map of stream drainages and sinkhole development in the Leesburg Formation east of Kanawha Spring. Streams and sinkholes were precisely located utilizing a global positioning system and show a preferred trend that parallels the dominant joint directions as indicated by the rose diagram. Sinkholes are largely restricted to the drainage lows created along the inferred solution-widened joints.

Faults

Faults have rarely been recognized within the Frederick Valley sequence. Because outcrops are so poor in the Frederick Valley, identification of faults based on stratigraphic offset or missing units is nearly impossible. However, several small faults have been recognized in the main quarries of the valley. One of the more prominent is the offset within the Lime Kiln Member of the Frederick Formation in the Frederick Quarry (Figure 32). At this location, the normal fault has dropped overturned beds of the Lime Kiln Member against normal beds of the same member. Because this fault is totally within the Lime Kiln Member, it normally would not have been recognized in field exposures, since it lacked missing units. From close inspection, very little dissolution has occurred within this fracture zone, and it does not appear to be a major conduit for dissolution waters.

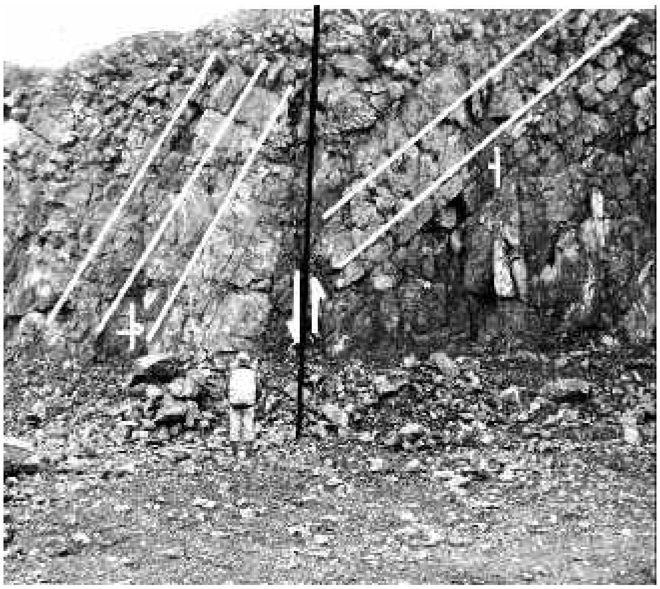

Figure 32. – Fault and associated fracturing within the Lime Kiln Member of the Frederick Formation within the Frederick Quarry. Down-dropped block on the southeast (left) places overturned Lime Kiln against right-side-up, southeast-dipping Lime Kiln in the foot-wall (right). Fracturing to the right of the fault is a combination of both axial planar cleavage and tension fractures associated with the fault.

A series of en echelon normal faults can be recognized in the Legore and Barrick quarries north of Woodsboro (Brezinski and Edwards, 2004). The best exposure of these faults is within the Legore quarry where members within the Grove Formation are offset or omitted. The throw on these faults ranges from several to dozens of yards. Left to field exposures, these faults would never have been identified. At the Legore Quarry the faults appear to be major conduits for incoming water. Furthermore, at least two of them exhibit noticeable dissolution. In these cases the fractures are active components of the local karst system.

Surface Drainage Patterns

As is typical of most karst terranes, the surface drainage of most of the Frederick Valley lacks perennial streams outside of the major trunk streams. The result is a dendritic drainage pattern reflected by the topography rather than by surface streams. In most cases, this pattern manifests itself as a series of swales, or ephemeral drainage ways, that only become submerged during heavy rainfall. Under normal conditions, surface runoff quickly finds its way to subterranean courses that transfer the waters to the local base level. Notwithstanding the lack of surface streams, these drainage ways reflect areas of increased water movement. Consequently, the underlying bedrock can exhibit indications of increased dissolution. The extra dissolution that is inferred to take place in these swales makes them prime areas for sinkhole development.

Boyer (1997, Fig. 8) demonstrated a positive relationship between surface drainage patterns and sinkhole development in an area of the southern Frederick quadrangle near the junction of Interstate 270 and Maryland Route 85. He showed that a large number of recently active sinkholes were found within the drainage lowlands.

The relationship between drainage ways and sinkhole development was verified at numerous locations in the Frederick Valley during this study (Figure 33). This relationship was illustrated in Figure 31 where surface drainage was related to the joint patterns of the underlying bedrock in the outcrop area of the Triassic Leesburg Formation. More importantly, active sinkholes commonly appear in these stream channels. A similar relationship can be documented in areas underlain by the upper Frederick and Grove formations.

West of Buckeystown, in the area around Manor Woods, the drainage courses have a high incidence of sinkhole activity and other types of karst features (Figure 34). In this area the karst features located by global positioning system are distributed within the swale areas as extracted from the 7.5-minute quadrangle base. As a whole, this area has high karst susceptibility with most of the features being found within the swales produced by the drainage pattern. In fact, in one area east of New Design Road, the drainage lowland is replete with active sinkholes.

A second noteworthy area lies north of Manor Woods, in an area north of English Muffin Way and west of Maryland Route 85. This area has a large concentration of karst features, many that occur in a linear pattern (Figure 35). When the sinkhole locations

Figure 33. – Some examples of drainage lowlands acting as sites of sinkhole activity. A, Parking lot present in the Ceresville Member of the Grove Formation in northeast City of Frederick collapsed along prehistoric drainage area. B, Coalescing sinkholes in the Lime Kiln Member of the Frederick Formation created along drainage lowland in southeast City of Frederick.

are overlain on a topographic map, the majority of the sinkholes is found to occur within the drainage way of an unnamed tributary to Ballenger Creek. A concentration of sinkholes that lies outside of the drainage way can be attributed to a storm-water management areas as illustrated in Figure 30. This area shows a high correlation between active karst development and relict drainage channels.

A third area of high sinkhole activity is in the southern part of the City of Frederick (Figure 36). This area has long been a trouble spot for active sinkhole formation. A significant issue for this area is whether the sinkholes are the consequence of some geologic factor, or whether they are related to local man-made features such as the highway or the quarry. The geology for the area was mapped, in detail, utilizing an enlarged version of the U.S Geological Survey 7.5-minute Frederick quadrangle. The Frederick and Grove formations were divided following the nomenclature proposed herein. The Grove Formation in this area consists of the Ceresville and Fountain Rock members. Based upon the new geologic mapping, there

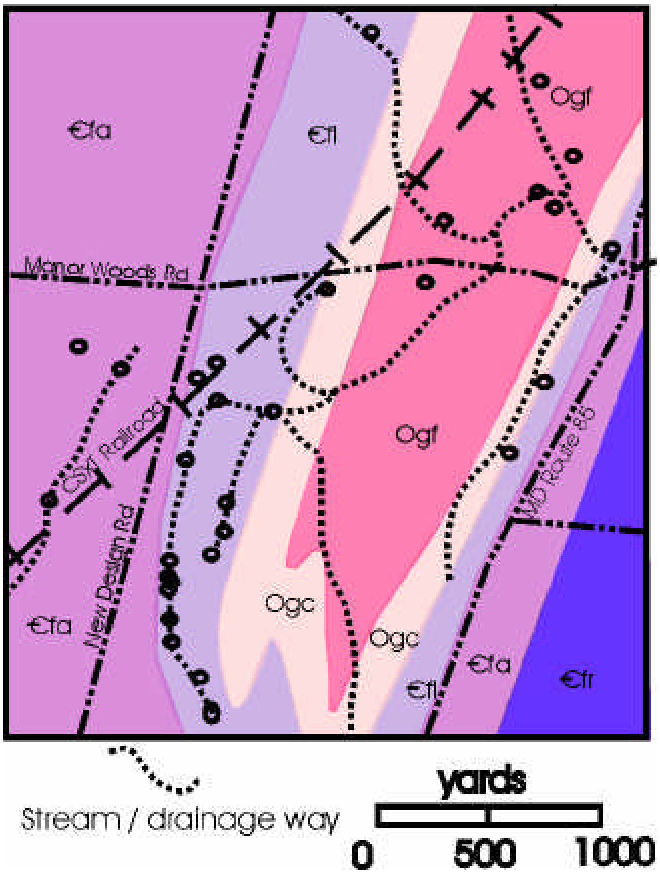

Figure 34. – Geologic map of the Manor Woods part of the Buckeystown quadrangle illustrating relationship of sinkholes and drainage patterns. Karst features are located utilizing a global positioning system. Geologic symbols: Frederick Formation, Cfa = Adamstown Member, Cfl = Lime Kiln Member; Grove Formation, Ogc = Ceresville Member.

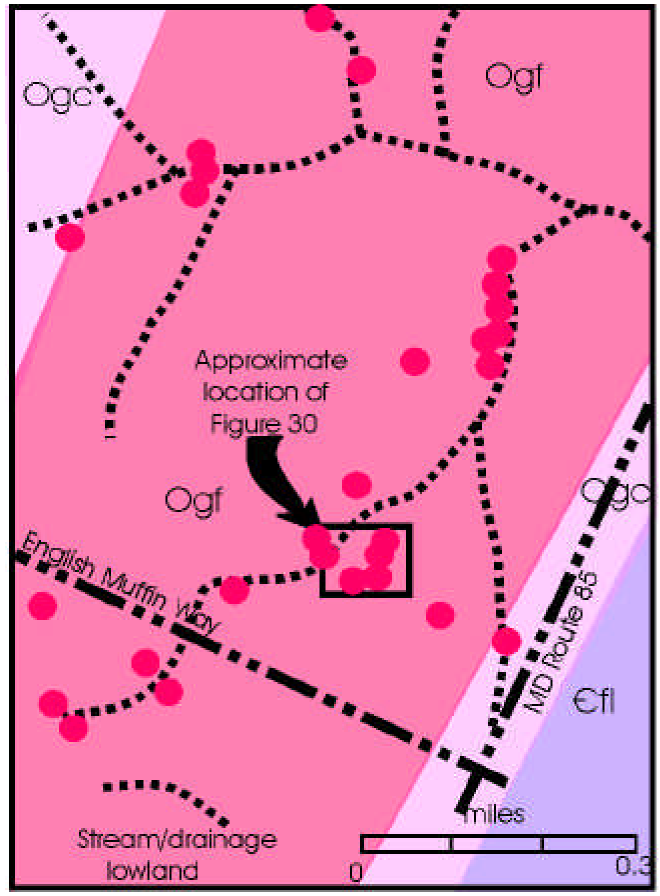

Figure 35. – Geologic map of an area of the northern Buckeystown quadrangle. Sink-holes were located using a global positioning system. Drainage pattern was enlarged from the U.S. Geological Survey digital line graph base map of the Buckeystown quadrangle. Detailed inset map of sinkhole clusters is illustrated in Figure 30. Geologic symbols: Frederick Formation, Cfl = Lime Kiln Member; Grove Formation, Ogc = Ceresville Member, Ogf = Fountain Rock Member.

is a modest correlation between rock unit and prominence of sinkhole development. Most sinkholes lie within the outcrop belts of the Lime Kiln Member of the Frederick Formation and the two lower members of the Grove Formation. A picture begins to emerge when the surface drainage patterns (dashed lines) are added to the map. These drainage channels were located by making transits with a global positioning system and walking the topographic lows of the inferred lowlands. The greatest percentage of active or filled sinkholes in this area falls near or within these drainage lowlands. The greatest percentage of active or filled sinkholes in this area falls near or within these drainage channels. If the entire low area of the former flood-plain deposits is included (shaded areas) an even greater correlation can be observed.

The three examples discussed above demonstrate that there is a strong correlation between relict drainage patterns and sinkhole activity. Another commonality with these three examples is that all the highly active drainage lowland areas fall within the outcrop belts of either the Lime Kiln Member of the Frederick Formation or the Ceresville or Fountain Rock

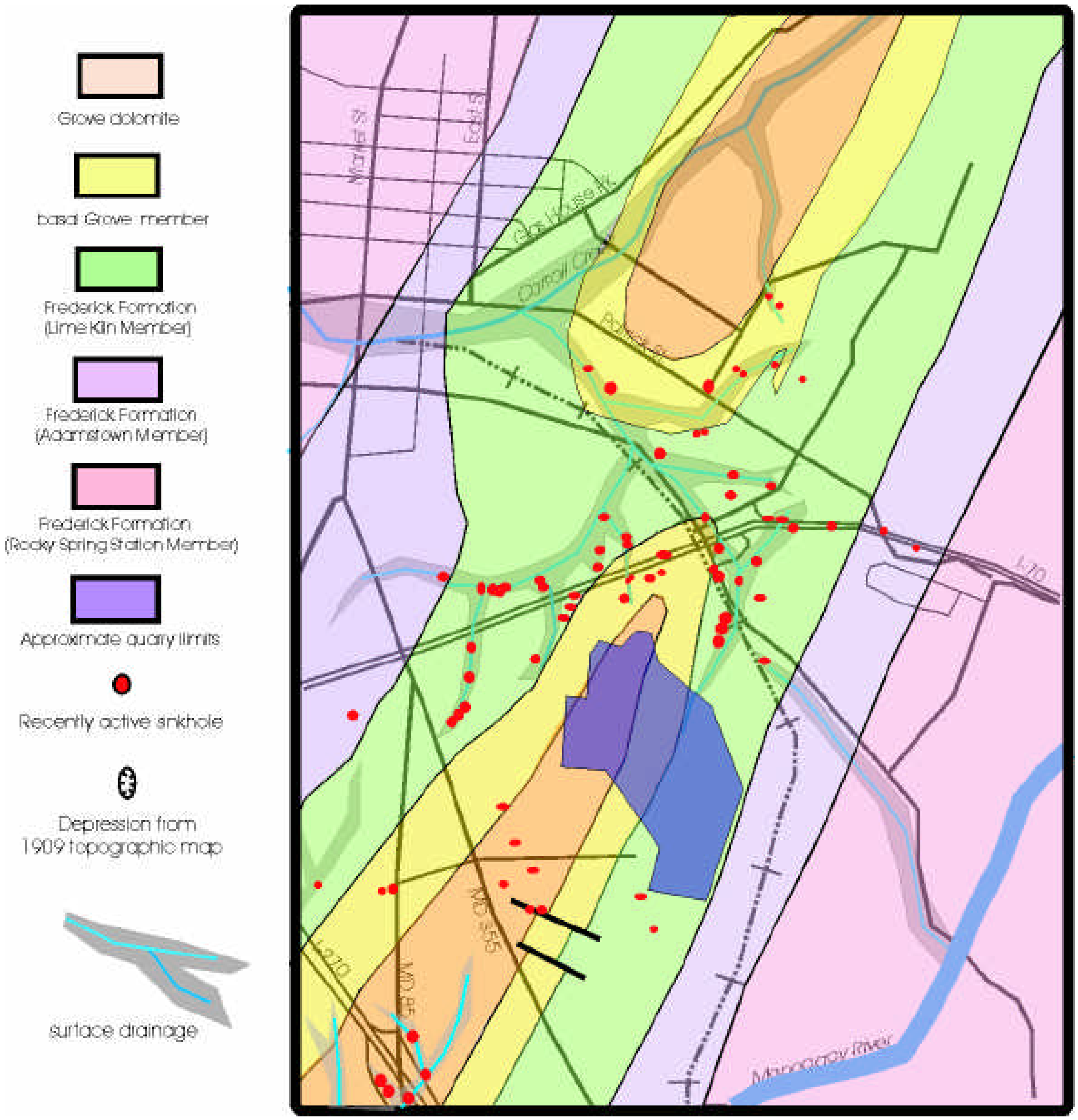

Figure 36. – Geologic map of a part of the Frederick quadrangle illustrating the relationship between geology, surface drainage pattern, and sinkhole development. Drainage network and sinkhole location were determined using a global positioning system.

members of the Grove Formation. This relationship might be especially important to know in developing areas where the surface drainage pattern has been changed or obliterated.

Paleokarst

There are indications that the karst features seen in the Frederick Valley today are the result of only the most recent of several episodes of karst development. At least one episode of karstification can be demonstrated to pre-date the deposition of the Triassic rocks. Therefore, that particular episode must be on the order of 220 million years old. Evidence of this earlier episode of karstification includes widespread occurrences of joint planes and other fractures within the Frederick and Grove formations that are filled with red, fine-grained clastics that are Triassic in age. These

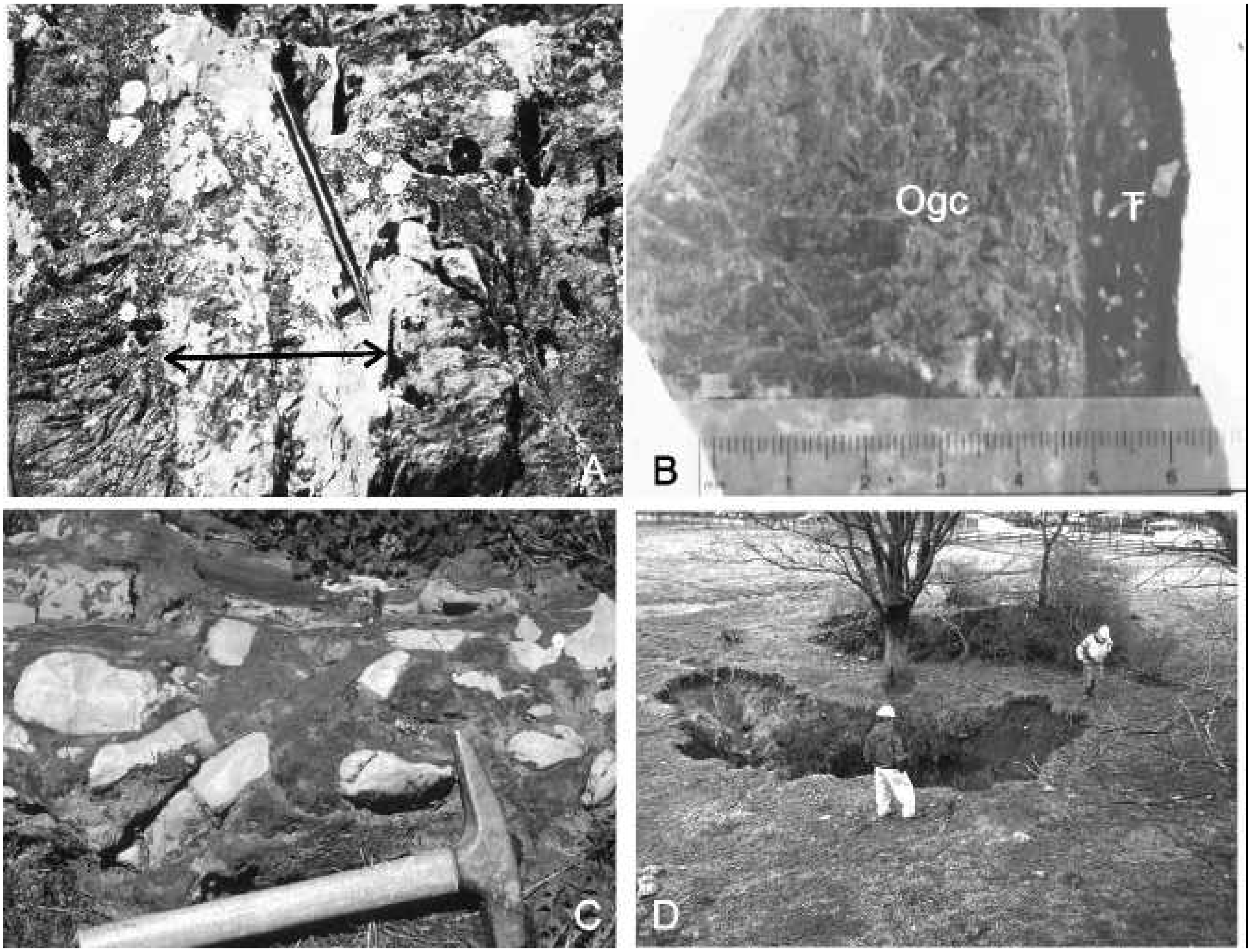

Figure 37. – Examples of paleokarst. A, Triassic red clastics filling a solution-widened joint within the Ceresville Member of the Grove Formation. B, Polished slab of the same joint surface within the Ceresville Member. C, Collapse-breccia of Ceresville Member (light) surrounded by Triassic age red clastics (dark) filling pre-Triassic sinkhole. D, Interpreted pre-Triassic sinkhole exhibiting recent reactivation.

joints can range from hairline to 6 inches (15 cm) in width. Some of these fractures appear to have been widened by solution prior to their filling with red muds (Figures 37A and B). Locally, the red muds have so thoroughly penetrated the fractures of the bedrock that the Frederick and Grove formations have taken on the red coloration.

In addition to the widespread, red-mud-filled, solution-enlarged fractures, there are a number of locations where breccia intervals can be mapped within the outcrop belts of the Frederick and Grove formations. These breccia intervals contain angular limestone pieces measuring 6-24 inches (15-60 cm) in a red mudstone to siltstone matrix (Figure 37C). Blocks from one of these breccias are used as lawn ornaments at the Hampton Inn at Maryland Route 85 and Interstate 270.

These highly localized lithologies are interpreted to represent collapse breccias formed by the collapse of ancient sinkholes or caverns. The red matrix appears to be Triassic muds that subsequently filled these collapse features and cemented the broken limestone pieces. Because the lithologies contained in these ancient sinkhole fillings have a high percentage of clastic material that does not weather or dissolve as readily as the surrounding carbonates, they tend to form topographic highs. Thus, all mapped Triassic collapse fillings form topographic inversions.

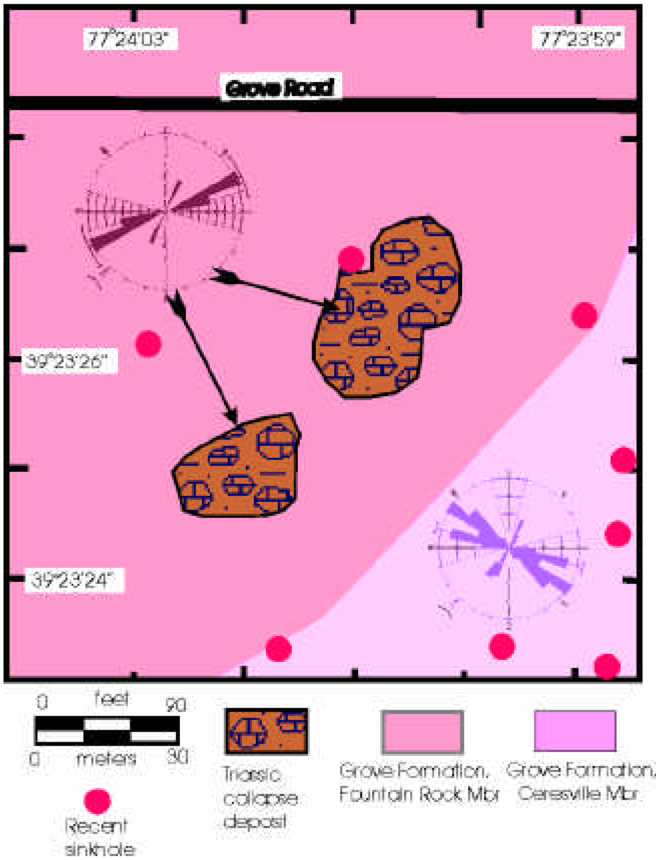

Figure 38. – Global positioning system sketch map of two areas underlain by interpreted collapse breccia units. Joint orientations within the inferred collapses parallel those seen within the main Triassic outcrop belt, while joint orientations within the surrounding Grove Formation are consistent with azimuths measured elsewhere for the Grove.

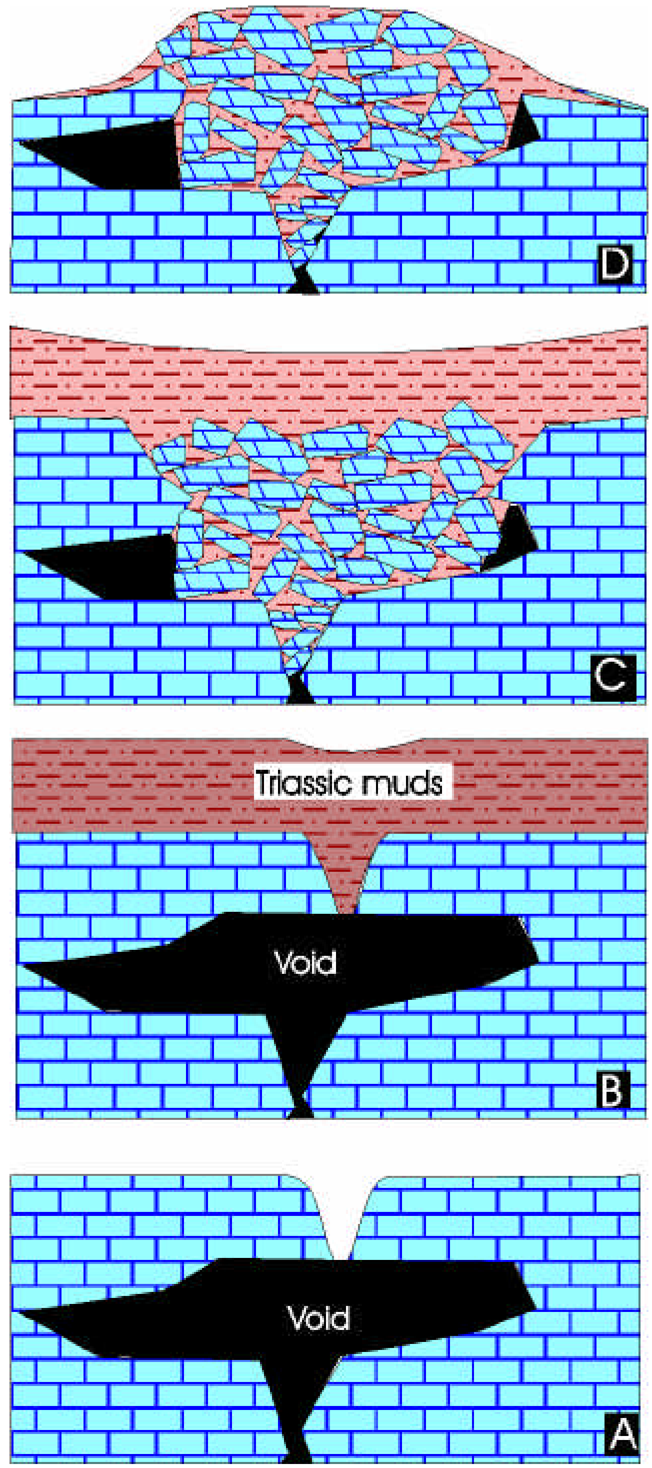

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Figure 39. – Diagram illustrating the origin of inverted topography created by paleokarst collapse filling of presumable Triassic age. A, Void within Frederick Valley carbonate units exists prior to deposition of Triassic muds. B, Triassic muds cover void. C, Collapsed void is filled with a combination of limestone clasts cemented by Triassic clastic muds. D, Surrounding limestone dissolves more easily than Triassic clastics, allowing sinkhole filling to produce a topographically positive area.

In at least one case, a pre-Triassic collapse has become a site of recent sinkhole activity indicating that even these ancient sinkholes are sites of weakness for later solution (Figure 37D). Two such pre-Triassic collapse features were identified in the southern Frederick quadrangle, south of Grove Road (Figure 38). At this location, the ancient sinkholes are less than 100 yards apart and form two topographic highs. Joint orientations taken from the rocks within the collapses exhibit the identical direction as those measured within the Leesburg Formation to the west, that is, 60 degrees east of north. This contrasts with the joint measurements taken from the surrounding Ceresville Member. These azimuths coincide with those taken elsewhere within the Grove Formation and are 55 degrees west of north (Figure 38). The rocks in these two features are interpreted as having experienced and recorded the same stress fields as those that occurred within the main outcrop belt of the Triassic, whereas the surrounding units record those stresses that were present in the remainder of the Frederick Valley. Figure 39 is an idealized sequence of events interpreting how such breccias may have formed.

Stratigraphic Controls

Lithology

The main goal in the early stages of this study was to test the hypothesis that lithology (rock composition) was a significant controlling factor in sinkhole distribution. It was postulated that precise mapping of rock units could be the basis for predicting sinkhole distribution if it could be demonstrated that particular karst features showed a pattern that paralleled rock type. Paramount to such a mapping project would be the identification of workable stratigraphic subdivisions of the geologic units that were consistent, repeatable, and resulted in easy identification of traceable subunits. The utility of this approach is illustrated in Figure 40. This illustration plots the same sinkhole locations on three separate versions of a geologic map. In mapping from Jonas and Stose (1938) (Figure 40A), the Frederick and Grove formational nomenclature is used. Since approximately equal numbers of sinkholes are present in both units, no distinction can be made between the two units regarding sinkhole formation and lithology. Utilizing the more refined stratigraphic nomenclature and mapping of Reinhardt (1974), sinkholes appear to occur in approximately equal numbers within the Grove Formation and Lime Kiln Member of the Frederick Formation (Figure 40B). When employing the even finer stratigraphic subdivisions proposed herein (Brezinski, 2004; Figure 40C), it is shown that the Lime Kiln Member of the Frederick Formation contains many more sinkholes in this area than any other unit. Consequently, for this area, an approach that utilized precise stratigraphic subdivisions could demonstrate a particular unit's overwhelming karst susceptibility over the adjacent units. It is this approach that was employed during the course of this study.

Map Author	Unit	Sinkhole No.s
Jonas and Stose (1938)	Og	27
	Cf	34
Reinhardt (1974)	Og	31
	Cfl	26
	Cfa	4
This Study	Ogf	5
	Ogc	13
	Cfl	40
	Cfa	3

Table 2. – Comparison of sinkhole numbers within each stratigraphic unit from three generations of geologic mapping in southern City of Frederick. Symbols are the same as in Figure 40.

More than 1,800 karst features were identified and located within the six quadrangles studied. The *a priori* assumption that karst features occur in differing densities within the different stratigraphic units appears valid. Although some units like the Tomstown Formation and Monocacy Member of the Frederick Formation had less than five karst features, most units had sufficient numbers to be included in a statistical analysis.

As might be expected, not all carbonate units in the Frederick Valley exhibit an equal susceptibility to karst development (Figures 41 and 42). Figure 41 is a stacked bar chart that summarizes the relative number of karst features with respect to the carbonate rock units. The data on karst features are also summarized in pie diagrams in Figure 42.

From these two illustrations, it can be seen that the Triassic Leesburg Formation has the greatest number of depressions (374 or 32.3% of all depressions), while having one of the fewest occurrences of active sinkholes (39 or 6.4% of all active sinkholes). This is a similar relationship to that shown by the Rocky Springs Station Member of the Frederick Formation. This unit contained the second highest number of

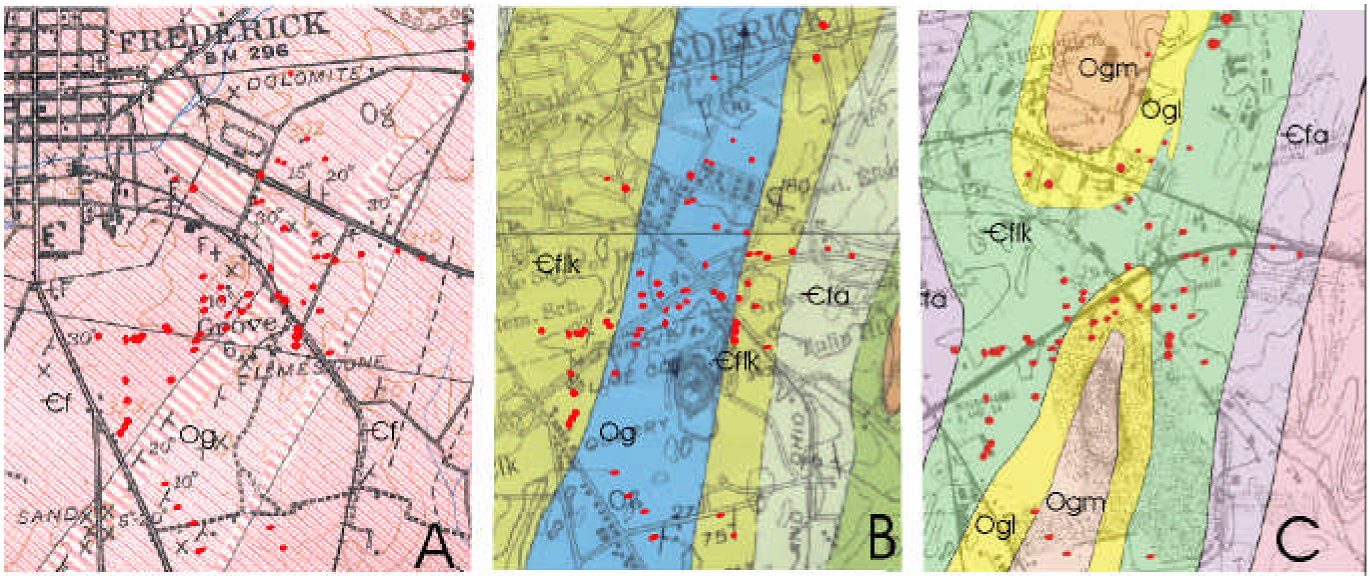

Figure 40. – Comparison of geologic mapping and relationship to sinkhole distribution. A, Mapping of Jonas and Stose (1938) shows no difference in sinkhole numbers between the two units. B, Mapping of Reinhardt (1974) suggests that sinkholes are more likely in the Lime Kiln Member of the Frederick Formation and the Grove Formation. C, Mapping by Brezinski (2004) utilizing stratigraphy outlined herein demonstrates that sinkholes are most likely in the Lime Kiln Member, and to a lesser degree the Ceresville Member of the Grove Formation. Thus, the troublesome geologic unit can be identified. Symbols: Og=Grove Formation (undivided), Cf= Frederick Formation (undivided), Cfa=Adamstown Member of the Frederick Formation, Cfl=Lime Kiln Member of the Frederick Formation, Ogc=Ceresville Member of the Grove Formation, Ogf=Fountain Rock Member of the Grove Formation.

Unit	Depressions	Active	Springs	Total
Trl	374	39	4	417
Ogw	35	45	0	80
Ogf	172	167	10	349
Ogc	54	84	0	138
Cfl	195	209	3	407
Cfa	73	13	7	93
Cfr	251	63	9	323
Cfm	2	2	0	4
Ct	3	0	0	3
Total	**1159**	**622**	**33**	**1814**

Table 3. – Summary table of karst feature distribution with respect to stratigraphic unit. Abbreviations: Ct = Tomstown Formation, Cfm = Monocacy Member, Cfr = Rocky Springs Station Member, Cfa = Adamstown Member, Cfl = Lime Kiln Member, Ogc = Ceresville Member, Ogf = Fountain Rock Member, Ogw = Woodsboro Member, Trl = Leesburg Formation.

depressions (251 or 21.6% of all depressions), but one of the fewest numbers of active sinkholes (63 or 10.1% of all active sinkholes). The Adamstown Member of the Frederick Formation and Woodsboro Member of the Grove Formation displayed low totals in both categories, even though the latter unit had a very high ratio of active sinkholes to depressions (1.29). This ratio of active sinkholes was by far the highest seen for any unit. The low total number of features in the Woodsboro Member may be misleading since this unit underlies a rather small area in the Woodsboro and adjacent Walkersville quadrangles. Consequently, the Woodsboro Member appears to be quite susceptible to the development of karst features. In the case of the Adamstown Member, the low number of depressions (73) and active sinkholes (13), and a low ratio of active sinkholes to depressions (0.18) are offset by the second highest number of springs (7).

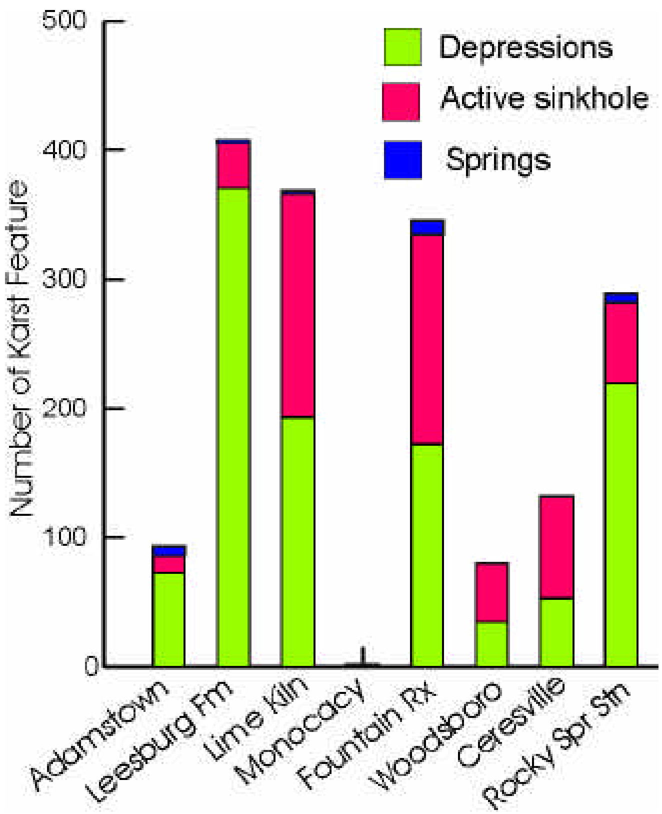

Figure 41. – Stacked bar chart of numbers of karst features identified within each main carbonate rock unit of the Frederick Valley.

In contrast to the Leesburg Formation and Rocky Springs Station and Adamstown members, both the Lime Kiln Member of the Frederick Formation and the Fountain Rock Member of the Grove Formation have comparatively high numbers of both active sinkholes and depressions. The Lime Kiln Member had 195 depressions (16.8% of all depressions) and 209 active sinkholes (33.6 % of all active sinkholes) while the Fountain Rock Member exhibited 172 depressions (14.9% of all depressions) and 172 active sinkholes (26.9% of all active sinkholes). Consequently, these two units appear to be the most highly prone to karst development of the units defined in this study.

The reasons for differences in the overall numbers of karst features within each unit may be the result of both lithologic and structural factors. For instance, the high number of depressions and low number of active sinkholes in the Leesburg Formation is interpreted to be the result of the massive, dolomitic conglomerate lithology and the regularly spaced, solution-enlarged joints (structure). Because the massive breccias of the Leesburg act as a homogeneous unit, solution waters act relatively slowly on the predominately dolomitic composition, and these waters are restricted to channels

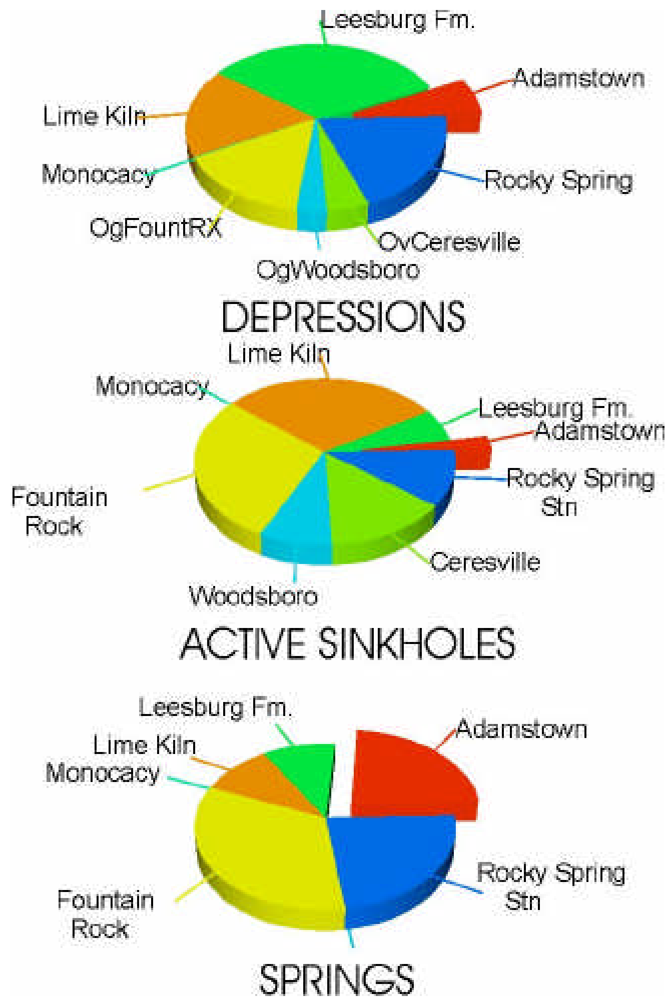

Figure 42. – Pie diagrams of the relative abundance of the three types of karst features within the rock unit subdivisions utilized in this study.

resulting from joint widening. Similarly, the low numbers of active sinkholes within the Rocky Springs Station and Adamstown members of the Frederick Formation are also probably the result of lithology and structure. The thin-bedded, shaly limestones that characterize the bulk of both of these units exhibit few joints, yet abundant argillaceous layers. These layers absorbed strain during the folding of the unit and thus are less likely to exhibit the brittle fractures seen in more massive units. These argillaceous layers also produce clay that when dissolved which impedes further water movement. In contrast, the Ceresville Member of the Grove Formation is predominately thick-bedded, highly fractured dolomite with few clayey intervals. This unit had few depressions identified within its outcrop belt and has a high ratio of active sinkholes to depressions.

The high karst susceptibility exhibited by both the Lime Kiln and Fountain Rock members is interpreted to be caused by composition. In spite of the overall number of depressions and active sinkholes within the Lime Kiln Member outcrop belt, most of these karst features appear to be concentrated in the stratigraphically highest part of the member. Figure 43 demonstrates this interpretation in a global positioning system sketch map. In this area along the Lime Kiln-Ceresville members contact near Locality 11 (Appendix I), most of the karst features are stratigraphically concentrated in the upper Lime Kiln Member. Because the lower Lime Kiln Member is characterized by thin-bedded, shaly and dolomitic, lime mudstones, they tend to have a disposition to karstification similar to that of the Rocky Springs Station and Adamstown members. In contrast, the upper part of the Lime Kiln Member is characterized by algal thrombolitic, lime mudstone and sandy, lime grainstone. Both of these lithologies represent purer carbonates that lack the high clay content of the lower strata of the member. These purer lithologies of the upper Lime Kiln Member make this stratigraphic interval much more susceptible to karstification. This interpretation can be extended to the other highly susceptible unit, the Fountain Rock Member of the Grove Formation. This member, like the upper Lime Kiln Member, is composed of thick intervals of pure carbonate, in the form of thrombolitic lime mudstone and lime grainstone. The purity of this unit is the reason that it has been quarried at Localities 11, 14, 15, and 17. Thus, the pure thrombolite intervals in both of these members appear to be a significant factor in the abundance of karst features and especially the number of active sinkholes found within them.

Karst Susceptibility

Although the raw karst feature data (Table 3) ostensibly demonstrate the relative karst susceptibility of each stratigraphic unit, other statistics show a somewhat different picture. For example, when the total number of karst features is compared to the number of features per square mile, some units that have a high number of features (e.g., Rocky Springs Station Member) have a relatively low number per square mile (Table 4). This is because some units have large outcrop areas and therefore have more area in which to develop karst features. This contrasts with some units that may have small outcrop areas (e.g., Woodsboro Member) and moderately low numbers of karst features, but a very high number of features per square mile. Clearly, a high number of features per unit area is a more important indication of karst susceptibility than the raw number of features contained within that unit. With this in mind, the Woodsboro Member is much more susceptible to karst development than the Rocky Springs Station Member, even though the latter has many more karst features displayed within its outcrop belt. Likewise, knowing the number of active sinkholes per unit area or the ratio of active sinkholes to depressions is much more illuminating than simply totaling the numbers of features per stratigraphic unit.

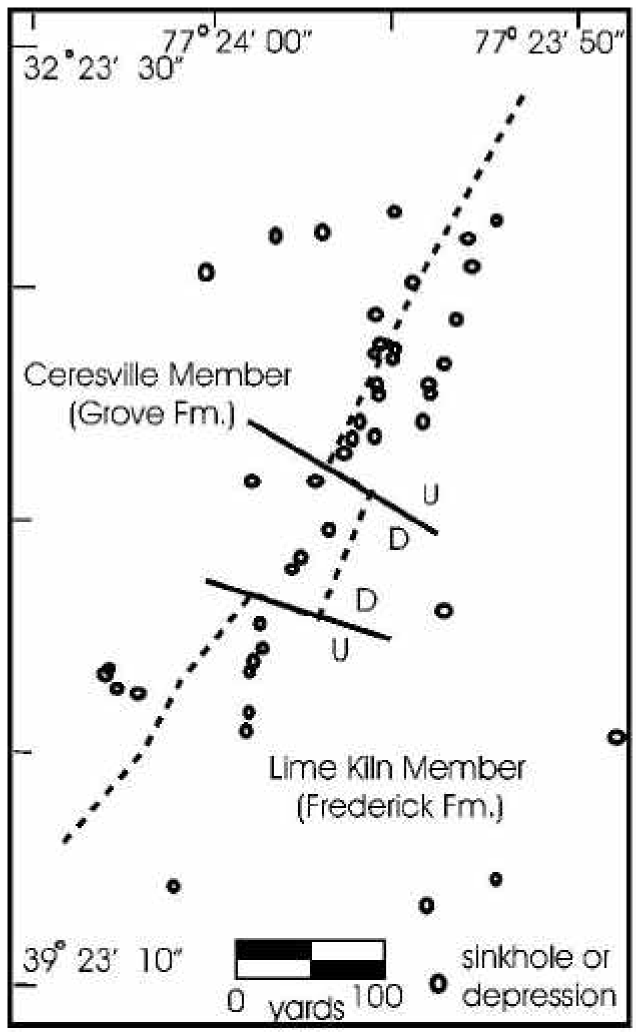

Figure 43. – Global positioning system sketch map of the Frederick-Grove contact and the distribution of karst features relative to it at Locality 11. Map demonstrates that the upper Lime Kiln Member has abundant sinkholes within it.

Unit	Area ($mi.^2$)	Feats./ $mi.^2$	Active/ $mi.^2$	Act./Dep. Ratio	SI
Trl	8.72	42.89	4.47	0.09	0.1
Ogw	1.28	62.5	35.16	1.29	0.56
Ogf	9.77	35.62	17.09	0.97	0.48
Ofc	3.52	39.21	23.86	1.56	0.61
Cfl	9.98	40.78	20.94	1.07	0.51
Cfa	12.14	7.66	1.07	0.18	0.14
Cfr	31.6	10.22	1.99	0.25	0.20
Cfm	7.18	0.56	0.28	1.00	0.54
Ct	0.97	3.09	0.0	0.00	0.00

Table 4. – Summary table of area underlain by each unit and ratio of karst features per unit area. Abbreviations: Ct = Tomstown Formation, Cfm = Monocacy Member, Cfr = Rocky Springs Station Member, Cfa = Adamstown Member, Cfl = Lime Kiln Member, Ogc = Ceresville Member, Ogf = Fountain Rock Member, Ogw = Woodsboro Member, Trl = Leesburg Formation.

Ratios, like the number of active sinkholes to depressions for a particular stratigraphic unit, are valuable, but one must have a statistically significant number of features in order for ratios to be meaningful. Otherwise, misleadingly high or low values can give a false impression as to the susceptibility of a unit. This is demonstrated by the Monocacy Member, which has only four karst features recognized within its outcrop belt. However, it has a relatively high ratio of 1.0 (active sinkholes to depressions) since two active sinkholes and two depressions were identified in the study area. By applying all of these statistics, one can obtain a fairly clear understanding of the relative susceptibility of each stratigraphic unit to the development of karst features. Based on this premise, a generalized susceptibility index was developed for the stratigraphic units in this study. The karst susceptibility index (SI) is a simple ratio of the number of active sinkholes per square mile to the total number of karst features per square mile of exposure for each stratigraphic unit.

$$SI=(\text{active/mile}^2)/(\text{number of features/mile}^2),$$

or more simply

$$SI=(\text{no. active sinkholes})/(\text{total no. features})$$

This index gives a relative value of the sensitivity of a particular rock unit to the development of karst features that is somewhat more quantitative than the raw data presented in Table 3.

When the SI is compared to the raw numbers of karst features (Table 3), a different picture of susceptibility appears. Some units with large numbers of karst features (Rocky Springs Station Member and Leesburg Formation) have comparatively low SI's, while others with modest totals of features (Ceresville and Woodsboro members) have high SI's. This is because the SI emphasizes the active sinkholes. Weighting the active sinkholes was done because they pose the greatest risk for economic loss and personal injury than do depressions or springs. Critical to this was the recognition that large areas, both developed and undeveloped, are underlain by both the Rocky Springs Station Member of the Frederick Formation and the Leesburg Formation, and only rarely have catastrophic collapses been identified within these areas. Conversely, the Woodsboro Member of the Grove Formation has little development in areas underlain by it, yet relatively high numbers of catastrophic collapses were recognized where this member occurs. Of course, calculation of the SI requires statistically significant numbers of features; otherwise spurious calculations arise. This is exemplified by the SI of 0.54 for the Monocacy Member of the Frederick Formation. While this index value would normally indicate a strong susceptibility to the development of active sinkholes, in this case the index is based on only four karst features.

The values of the SI for each unit were plotted against the stratigraphic section of the Frederick Valley in Figure 44. In places on the section, the relative SI was modified to correspond to implicit changes in lithology that were observed to have varying susceptibilities. For example, thicker breccia beds are interpreted to be purer carbonate that is more easily dissolved than the surrounding strata of the Rocky Springs Station Member, and as such are given a higher SI. Likewise, the lower Lime Kiln Member is given an SI equal to the Adamstown Member, because it is known that the lower part of the Lime Kiln Member is lithologically similar to the Adamstown Member.

The graphic portrayal of the SI values (Figure 44) can be used to illustrate how karst features, and especially active sinkholes, vary with stratigraphic level. From this diagram, it is clear that the upper Lime Kiln Member of the Frederick Formation and the three members of the Grove Formation are the units most highly susceptible to the development of karst features in the Frederick Valley. Furthermore, the Ceresville and Woodsboro members of the Grove

Formation are the most sinkhole-prone units in the valley. Clearly, the *a priori* assumption that sinkholes

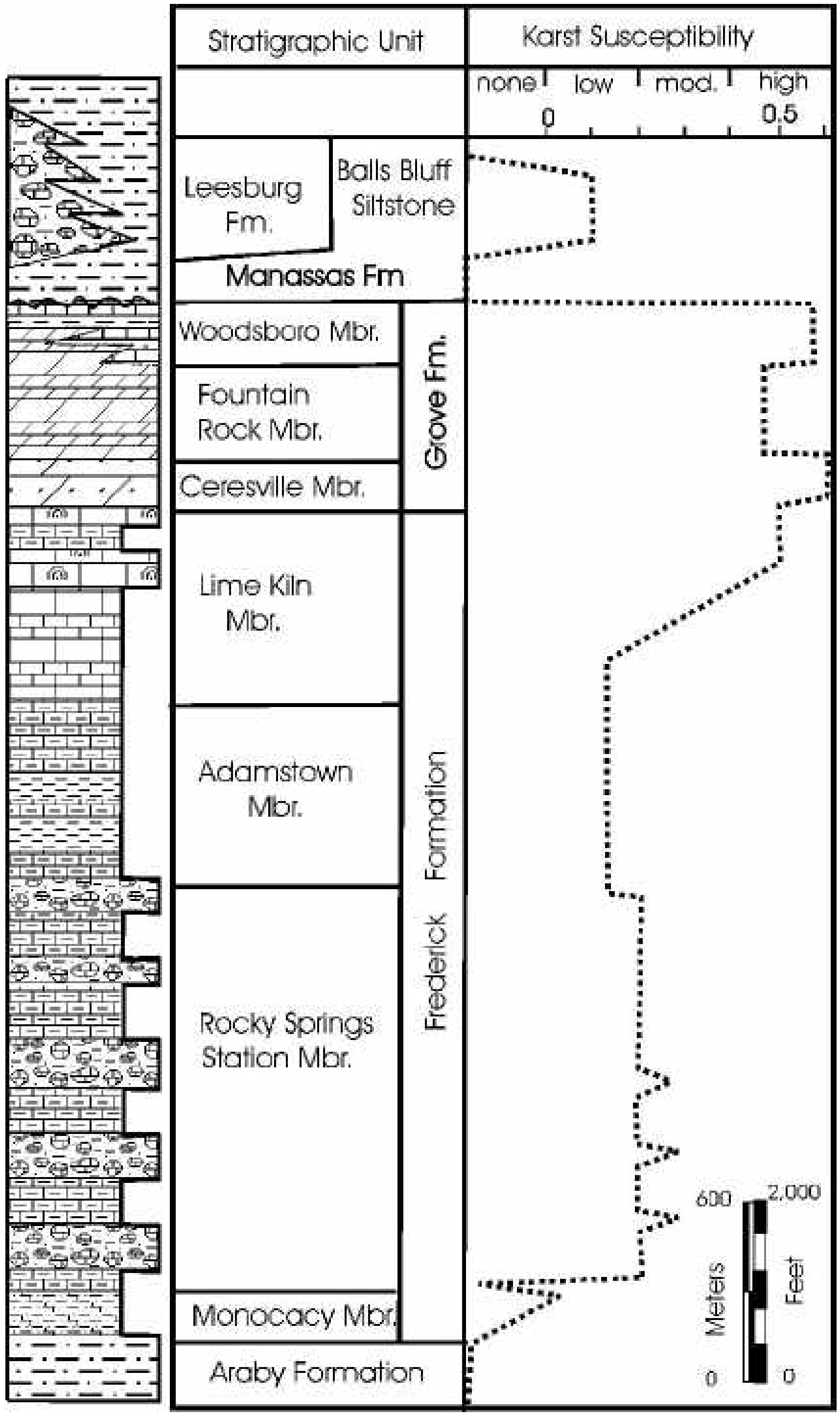

Figure 44. – Stratigraphic variations in relative karst susceptibility within units of the Frederick Valley. Susceptibility Index plotted against empirical values of low, moderate, and high susceptibility. Minor lithologic changes may impact the relative susceptibility on a local scale.

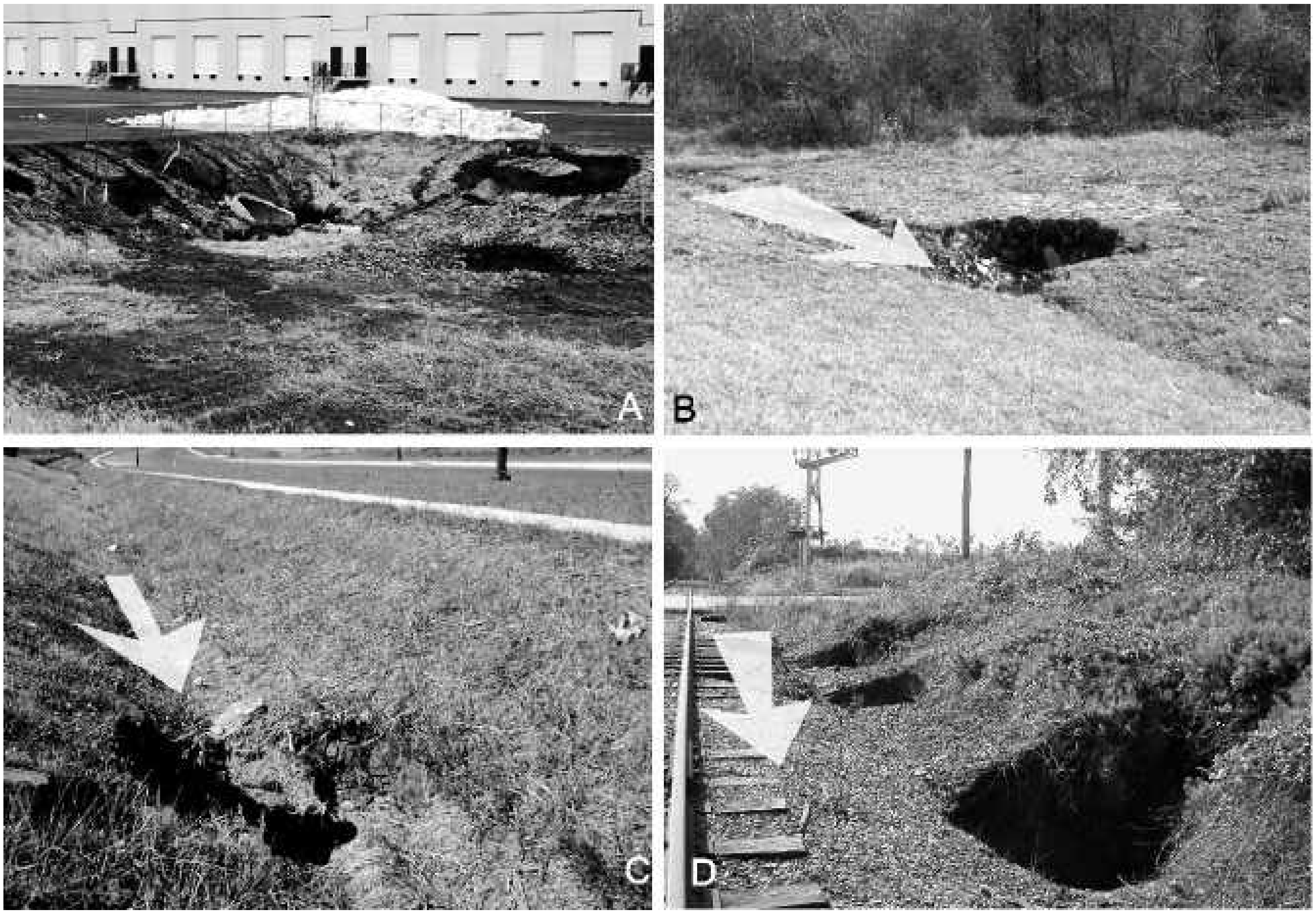

Figure 45. – Sinkhole activation and drainage. A, Storm-water management area north of Buckeystown. B, C, Unlined road drainage, with direction of flow indicated by arrows. D, Unlined drainage adjacent to railroad.

in the Frederick Valley are concentrated at certain stratigraphic levels is validated.

HUMAN-INDUCED FACTORS INFLUENCING KARST DEVELOPMENT

In addition to the geologic factors cited above that influence the abundance and distribution of active sinkholes, there are numerous ways that human activities can contribute to the creation or activation of sinkholes in a karst area. Factors such as urban development, quarrying, and highway construction can upset the soil-bedrock equilibrium that may have existed over long periods of time.

Storm-Water Management Areas

A common site for active sinkhole development is within the plethora of storm-water basins or ponds constructed in the vicinity of business parks or housing developments (Kochanov, 1999). During the construction of such features, the soil is stripped away, commonly exposing the underlying bedrock and often soil-filled voids and inactive sinkholes. When these ponds become filled during periods of rainfall, the plugged sinkholes are flushed by the deluge. Additionally, these catch basins are often constructed along existing drainage lowlands, areas that are already susceptible to sinkhole activation. Figure 45A is an example of such an area that has become riddled by active sinkhole formation. This same area is illustrated in a global positioning system sketch map in the Buckeystown area (Figure 30). A second example can be found in Walkersville (Figure 46).

The most troublesome of the storm-water management areas observed during the course of this study were located within the outcrop belts of the Lime Kiln, Ceresville, and Fountain Rock members. Consequently, even though active sinkholes in catch basins may be triggered by development activity, stratigraphy plays an important part in their distribution.

Unlined Drainage

Another common location for active sinkhole occurrence is within unlined road drainage ways (Figure 45). Like storm-water management areas, road drainages are excavations that remove soil cover from inactive or filled sinkholes so that during subsequent periods of rainfall these features become activated. An example of this is shown in the sketch map illustrated in Figure 47. Unlike storm-water management ponds, sinkholes activated along roadside drainage ditches were observed in nearly all lithologic units. The example illustrated in Figure 47 lies mainly in the outcrop belt of the Adamstown Member of the Frederick Formation. In this example, the number of sinkholes identified represents nearly 54 percent of all the active sinkholes seen in the Adamstown Member. Moreover, this area does not represent a pre-existing drainage lowland. This suggests that even those units that are not normally susceptible to active sinkhole formation can, under suitable conditions, be areas of high collapse density.

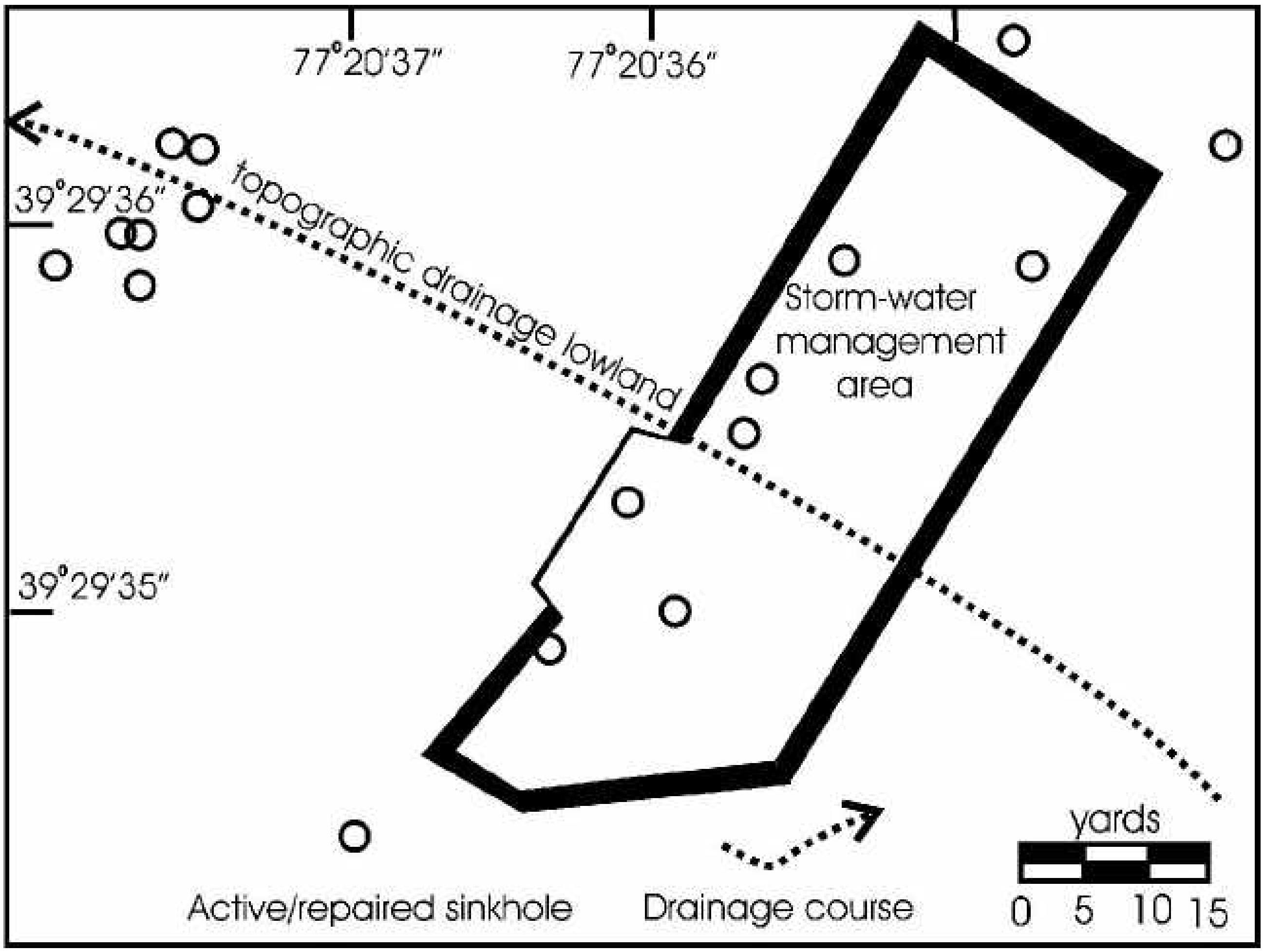

Figure 46. – Distribution of active sinkholes and their relationship to a storm-water management area and predevelopment surface drainage in Walkersville. Nearly all active sinkholes occur either directly within the storm-water catch basin or the relict drainage. Geologic unit is the Fountain Rock Member of the Grove Formation.

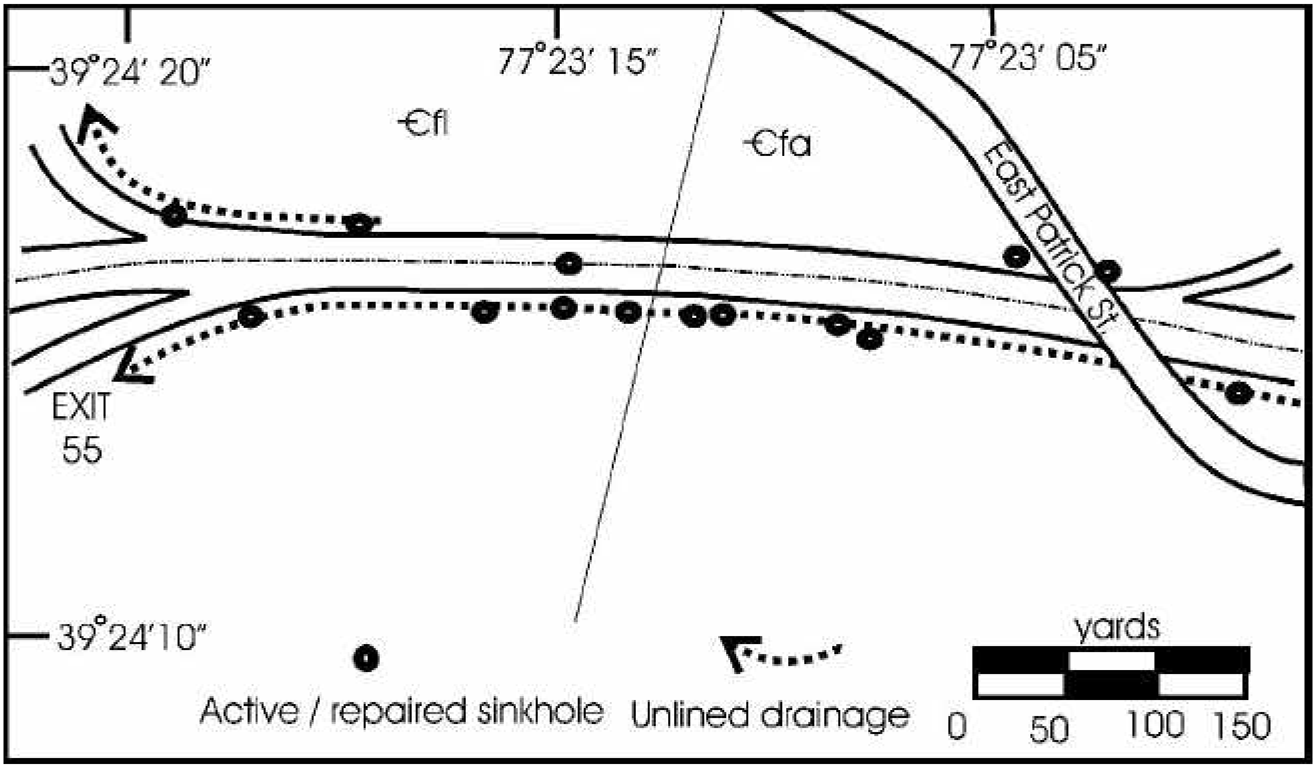

Figure 47. – Global positioning system sketch map of the distribution of active sinkholes and their relationship to roadside drainage ways along Interstate 70 in southeastern City of Frederick. Location is on the eastern limb of the Frederick Valley Synclinorium, so that units are steeply inclined to the southeast (lower right). Most of the active sinkholes were identified in the outcrop belt of the Adamstown Member of the Frederick Formation. Note that the area of lined drainage on the north side of the highway has no active sinkholes while the corresponding unlined area to the south does. Geologic symbols: Frederick Formation, Cfr = Rocky Springs Station Member, Cfa = Adamstown Member, Cfl = Lime Kiln Member.

Sinkhole activation in areas of unlined drainage is not restricted to roads or highways. At several locations, numerous sinkholes were identified along railroad rights-of-way (Figure 45D). Figure 48 illustrates the clustering of active sinkholes along the Maryland Midland Railroad tracks at Devilbiss Bridge Road in the Walkersville quadrangle. The map area is within the Woodsboro Member of the Grove Formation, and most active sinkholes are concentrated along the railroad tracks in shallow drainage ditches. The surficial cover (overburden) in this area is quite thick (Brezinski *et al*., 2004). Consequently, the railroad has removed a thick soil cover from the underlying Woodsboro bedrock. Because this railroad cut is relatively old, the sinkhole activity cannot be blamed on the cut itself, but must be the result of the unlined drainage that parallels the tracks.

Rerouted Stream Drainages

In many areas throughout the Frederick Valley, housing and business development and road construction have changed the courses of the surface drainage systems. This was mentioned briefly in the section dealing with surface drainage patterns, but this common practice in the Frederick area may be a significant culprit in the creation of zones of high karst activation. One particular example that demonstrates the results of this practice merits illustration. East of Legore Quarry, construction of a concrete mixing plant necessitated the rerouting of Israel Creek and the partial filling of a portion of its natural channel (Figure 49). In order to bypass the plant, a new channel was created for Israel Creek and a section of the original channel was abandoned. The exposed section of the abandoned channel has been the site of frequent sinkhole activity ever since. Compounding the problem is the fact that the rerouted section lies within the outcrop belt of the Lime Kiln Member of the Frederick Formation, one of the most troublesome stratigraphic units in the valley. In this case, the static relationship between soil cover and water content near the channel

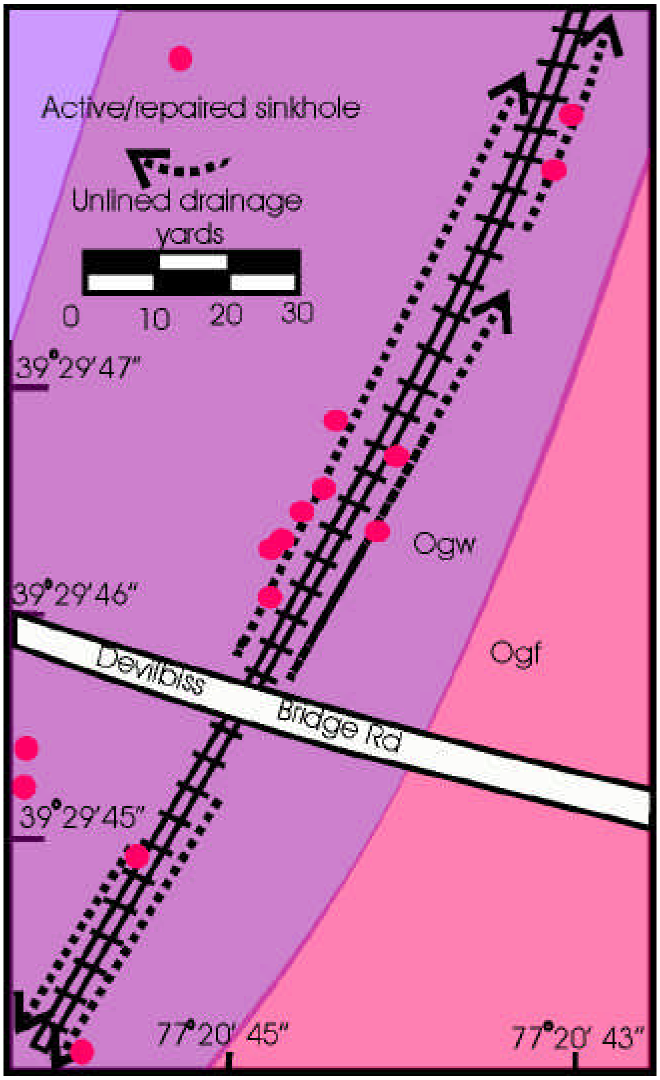

Figure 48. – Global positioning system sketch map of the distribution of active sinkholes and their relationship to railroad drainage ways at Devilbiss Bridge Road in Walkersville. Abundant active sinkholes are within the Woodsboro Member of the Grove Formation. Geologic symbols: Grove Formation, Ogf = Fountain Rock Member, Ogw = Woodsboro Member.

was destroyed during channel rerouting, and this resulted in a very high incidence rate of sinkhole formation.

Quarry Activity

Quarry activity has long been recognized as a trigger for creation of active sinkholes. In areas surrounding active quarries, the water table is usually depressed because of pumping of inflowing water from the quarry floor. This localized base level for the water table is usually lower than it would be under normal conditions. The new hydrologic gradient allows subterranean voids that normally would be filled with sediment, to be flushed out by water moving along the steepened gradient. Increased karst activity was observed around every quarry in the Frederick Valley. However, the incidence rate of active sinkholes varies greatly. For instance, surrounding the Essroc quarry

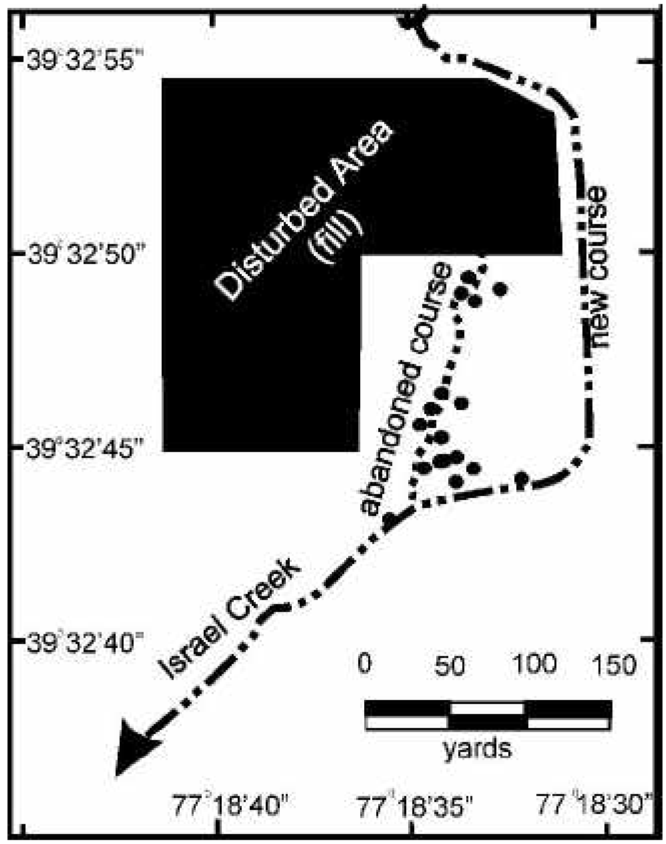

Figure 49. – Global positioning system sketch map of the distribution of active sinkholes and their relationship to an abandoned stream channel course in an area of rerouted drainage northeast of Woodsboro.

near Buckeystown, sinkhole activity is very low along the western and southern sides of the quarry within the outcrop belt of the Adamstown Member, but increases markedly along the eastern side of the quarry where the outcrop belt of the Ceresville Member of the Grove Formation is located. A similar pattern can be shown around the Lefarge Quarry in Frederick. Sinkhole activity in the Lime Kiln and Adamstown members' outcrop belts east of the quarry is moderately low. In contrast, activity within the Lime Kiln and Ceresville members' outcrop areas north of the quarry is very high (Figure 36). In this case, the area north of the quarry is also the site of numerous rerouted drainage patterns and unlined drainage ways. Consequently, it appears that stratigraphy, rerouted drainages, unlined drainage, and quarry activity may all play contributing roles to the sinkhole propensity at this location.

Overburden Disturbance

In areas undergoing housing or business development, large expanses of soil cover are typically rearranged. This disrupts the static situation among soil cover, surface drainage, and subterranean flow. In most cases, the disrupted area is immediately covered by either asphalt or structures. In these instances, no recognizable increase in sinkhole activity was observed during the course of this study. However, in some instances, the removal of the overburden was followed by prolonged periods of exposure of the disrupted area. In such cases, increased sinkhole activity was noticeable, especially if the rock units that underlie the disturbed area are one of the geologic units more susceptible to karst feature development.

An example from one area in particular deserves discussion because it was evaluated for karst features both before and after the surficial deposits were disturbed. On a meander bend of the Monocacy River, at the border between the Frederick and Walkersville quadrangles, recent business park development necessitated the removal of thick accumulations of terrace deposits (Figure 50). In some places, more than 20 feet (6.0 m) of terrace gravels were excavated to the top of bedrock and moved to other locations on the meander bend. Bedrocks units include the Rocky Springs Station through Lime Kiln members of the Frederick Formation, and the Ceresville Member of the Grove Formation. Geologic and karst mapping prior to excavation revealed a small number of sinkholes within the Frederick-Grove contact interval on the north side of the meander bend along the banks of the Monocacy River and primarily outside of the terrace deposits. A single sinkhole was identified within the terrace cover. Following removal of terrace deposits, a large number of sinkholes developed, both within the Lime Kiln Member of the Frederick Formation and the Ceresville Member of the Grove Formation. While a few of these active sinkholes formed in a storm-water management area, most formed where the bedrock had been laid bare and left uncovered and unvegetated. Also noteworthy is that no sinkholes were identified within the Rocky Springs Station or Adamstown members of the Frederick Formation either prior to or after excavation.

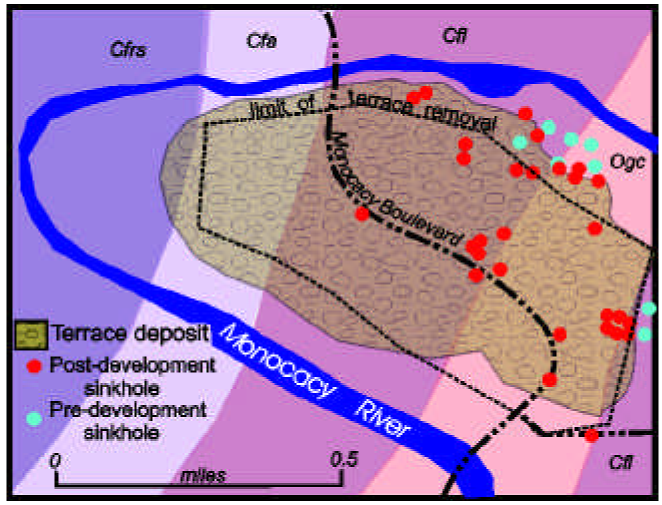

Figure 50. – Geologic map of an area at the border of the Frederick and Walkersville quadrangles that illustrates the relationship between the timing of sinkhole development and the removal of surficial deposits (river terrace). Note how sinkholes were confined to the banks of the Monocacy River prior to excavation, but became widespread in the Lime Kiln and Ceresville members after terrace gravels were removed. Geologic symbols: Frederick Formation, Cfr = Rocky Springs Station Member, Cfa = Adamstown Member, Cfl = Lime Kiln Member; Grove Formation, Ogc = Ceresville Member.

CONCLUSIONS

Geologic factors play an important part in the distribution of karst features in the Frederick Valley. A redefined, precise stratigraphy helps delineate the stratigraphic intervals most susceptible to karstification. The Lime Kiln Member of the Frederick Formation, and the Fountain Rock, Ceresville, and Woodsboro members of the Grove Formation are intervals of especially high active sinkhole formation. An elevated risk of sinkhole development is likely where altered surface stream drainage, unlined road drainage, storm-water management areas, active quarrying, and soil mantle removal are in proximity to these stratigraphic units.

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APPENDIX I

Measured stratigraphic sections referred to in the text of this report.

Locality 1

Section of the Araby Formation approximately 1 mile east of Frederick Junction, along the CSXT railroad tracks. Section starts in discontinuously exposed strata dipping eastward and continues to the east. 39°22'08"N, 77°22'53"W, Walkersville Quadrangle.

Thickness (feet)
unit total

Araby Formation

unit	total	
12.0	546.0	Greenish gray, medium-bedded, bioturbated, fine-grained sandstone.
11.0	534.0	Covered
6.0	523.0	Greenish gray, thin-bedded, shaly, fine-grained sandstone.
7.0	517.0	Covered.
11.0	510.0	Grayish green to dusky green, medium-bedded, argillaceous, fine-grained sandstone with shaly partings.
5.5	499.0	Covered.
26.0	493.5	Greenish gray to grayish green, massive, fine-grained sandstone.
21.0	467.5	Interbedded, greenish gray, argillaceous, medium-bedded, fine-grained sandstone and greenish gray, sandy siltstone.
36.0	446.5	Covered.
11.0	410.5	Thinly interbedded, greenish gray, argillaceous, fine-grained sandstone and platy, grayish green, sandy shale.
24.0	399.5	Covered.
9.0	375.5	Interbedded, greenish gray, fine-grained, argillaceous sandstone, and thin-bedded, platy, silty shale.
1 9.0	366.5	Covered.
15.5	347.5	Greenish gray, silty shale. Resembles Cash Smith Formation.
31.0	332.0	Interbedded, greenish gray, medium-bedded, argillaceous, fine-grained sandstone, and greenish gray, silty shale.
7.0	301.0	Covered.
41.0	294.0	Interbedded, greenish gray to grayish green, argillaceous, thin-bedded, fine-grained sandstone and greenish gray, silty, sandy shale.
15.0	253.0	Covered.
70.0	238.0	Greenish gray to grayish green, medium-bedded, bioturbated, argillaceous, fine-grained sandstone, with greenish gray, shaly partings and interbeds.
72.0	168.0	Grayish green to dark greenish gray, massive, bioturbated, argillaceous, fine-grained sandstone.
96.0	96.0	Interbedded, greenish gray, argillaceous, fine-grained sandstone, and greenish gray, silty shale with burrows common.

Locality 2

Section in the Araby Formation along the Monocacy River at Park Mill Road Bridge and across the Monocacy River from Greenfield Mills. Section starts along abandoned road grade, near center of anticline where bedding is nearly horizontal and cleavage is vertical, and progresses eastward toward Park Mill Road. 39°15'46"N, 77°26'01"W, Buckeystown Quadrangle.

Thickness (feet)
unit total

Araby Formation

unit	total	
12.0	251.5	Medium gray, thin-bedded, shaly, fine-grained sandstone, with thin, light gray sandstone interbeds.
13.0	239.5	Light gray, thick-bedded, fine-grained, silty sandstone.
47.0	226.5	Light greenish gray, silty shale, with wispy, fine-grained sandstone layers.
24.0	179.5	Light greenish gray, thin-bedded, silty, fine-grained sandstone.
3.0	155.5	Covered.
15.0	152.5	Medium greenish gray, laminated, silty, sandy shale.
22.0	137.5	Light greenish gray, thin-bedded, laminated, silty, fine-grained sandstone.
23.0	115.5	Light greenish gray to light gray, cross-laminated, shaly, fine-grained sandstone with shaly partings.
27.0	92.5	Light greenish gray to light gray, sandy siltstone to silty, fine-grained sandstone.
6.5	65.5	Greenish gray, rubbly, sandy siltstone.
22.0	59.0	Medium-bedded, fine-grained sandstone. Mostly covered.
37.0	37.0	Medium grayish green to light grayish green, medium-bedded, cross-laminated, fine-grained sandstone with shaly partings.

Locality 3

Section along stream that parallels Greenfield Road. Section exposes contact interval between the Araby Formation and the Cash Smith Shale. 39°15'32"N, 77°26'45"W, Buckeystown Quadrangle.

Thickness (feet)

unit	total	
		Frederick Formation
		Monocacy Member
11.0	121.0	Mostly covered. Dark gray, platy shale.
14.5	110.0	Dark gray, knotty, lime mudstone with thin, platy, lime mudstone clasts and thin, sandy and breccia rudstone layers.
5.5	95.5	Dark gray, knotty, lime mudstone with thin layers of platy lime mudstone clasts, and sandy, lime grainstone.
7.0	90.0	Dark gray, knotty, lime mudstone with abundant lime mudstone clasts.
9.5	83.0	Covered.
27.0	73,5	Dark gray, thinly laminated, calcareous shale, with a number of contorted layers
14.5	46.5	Dark gray shale with a few dark gray, argillaceous, lime mudstone nodules.
25.0	32.0	Dark gray, calcareous shale, with crinkled laminations and a few thin (<0.5 inch) dark gray, lime mudstone layers.
1.5	7.0	Medium to dark gray, calcareous shale, with thin, limey laminations.
0.5	5.5	Medium greenish gray, very argillaceous, lime mudstone.
2.0	5.0	Light greenish gray shale with green-gray carbonate clasts.
3.0	3.0	Mostly covered. Dark gray, knotty, calcareous shale, with carbonate clasts, 0.2-1.0 inch in diameter.
		Araby Formation
2.0	94 .0	Dark gray, thin-bedded, fine-grained sandstone.
33.0	92.0	Dark gray green, thin-bedded, very fine grained, bioturbated, silty sandstone.
5.0	59.0	Medium to dark gray green, thin-bedded, very fine grained, shaly sandstone with shale interbeds.
32.0	59.0	Medium to dark grayish green, thin-bedded, very fine grained, silty sandstone.
22.0	22.0	Medium gray green, medium-bedded, fine-grained, bioturbated, silty sandstone.

Locality 4

Section in the Monocacy Member of the Frederick Formation exposed along road south of Lehigh's Woodsboro Quarry. 39°29'27"N, 77°19'07"W, Walkersville Quadrangle.

Thickness (feet)

unit	total	
		Frederick Formation
		Monocacy Member
7.0	26.0	Dark gray, rubbly limestone with black, dolomitic matrix.
1.5	19.0	Dark gray, lime mudstone.
2.0	17.5	Dark gray, rubbly, lime mudstone breccia with black, dolomitic shale partings.
1.0	15.5	Dark gray, lime mudstone.
5.0	14.5	Dark gray, rubbly, lime mudstone breccia with dark gray, shaly partings.
0.5	9.5	Dark gray, lime mudstone.
1.0	9.0	Dark gray, rubbly, lime mudstone breccia with dark gray, shaly partings
0.5	8.0	Dark gray, lime mudstone.
3.5	7.5	Dark gray, rubbly, lime mudstone breccia with dark gray, shaly partings.
0.5	4.0	Dark gray, lime mudstone.
3.5	3.5	Dark gray, rubbly, lime mudstone breccia with dark gray shaly partings.

Locality 5

Section along east bank of the Monocacy River east of Frederick Airport and north of Interstate 70. Bottom of section is approximately 500 yards north of Interstate 70. This is the type section of the Monocacy Member of the Frederick Formation. The top of the section is in the Lime Kiln Member near Clustered Spires Golf Course. 39°24'52"N, 77°21'46"W, Walkersville Quadrangle.

Thickness (feet)

unit	total	
		Frederick Formation
		Lime Kiln Member
11.0	397.0	Dark gray, very thin-bedded, shaly, lime mudstone.
5.0	386.0	Medium gray, sandy, lime packstone.
27.0	381.0	Interbedded, dark gray, thin-bedded, shaly, lime mudstone and black, calcareous shale.
23.0	3540	Covered.
37.0	331.0	Medium gray, cross-bedded, sandy, lime packstone-grainstone.
21.0	294.0	Dark gray, shaly, flaggy to very thin

		bedded, lime mudstone.
12.0	273.0	Covered.
11.0	261.0	Medium gray, medium-bedded, sandy, lime packstone.
7.0	250.0	Dark gray, shaly, thin-bedded, lime mudstone.
16.0	243.0	Medium gray, cross-bedded, sandy, lime grainstone.
12.0	227.0	Covered.
6.0	215.0	Medium gray, sandy, lime grainstone.
2.0	209.0	Dark gray, platy, thin-bedded, shaly lime mudstone.
32.0	207.0	Medium gray, cross-bedded, sandy, lime packstone.
23.0	175.0	Covered.
25.0	152.0	Medium gray, flaggy, lime mudstone.
3.0	127.0	Covered.
15.0	124.0	Dark gray, medium-bedded, argillaceous, lime mudstone.
10.0	109.0	Covered.
15.0	99.0	Dark gray, platy, very thin bedded, lime mudstone with black shale partings.
2.0	84.0	Dark gray, sandy, lime packstone.
35.0	82.0	Medium to dark gray, medium- to thin-bedded, lime mudstone.
27.0	47.0	Medium to dark gray, thin-bedded, lime mudstone with shaly partings.
20.0	20.0	Medium gray, cross-bedded, sandy, lime packstone.

Frederick Formation
Adamstown Member

20.0	483.0	Covered. stream valley.
11.0	463.0	Dark gray, shaly, very thin bedded, lime mudstone.
80.0	452.0	Covered.
60.0	372.0	Dark gray, shaly, thin-bedded, lime mudstone.
20.0	312.0	Dark gray, shaly, platy-bedded, lime mudstone.
205.0	292.0	Dark gray, shaly, thin-bedded, lime mudstone, highly folded.
7.0	87.0	Dark gray, very thin-bedded, shaly, lime mudstone with contorted bedding
80.0	80.0	Medium to dark gray, shaly, very thin-bedded, lime mudstone.

Frederick Formation
Rocky Springs Station Member

12.0	934.0	Medium gray, medium-bedded, sandy, lime rudstone with shaly interbeds.
20.0	922.0	Dark gray, platy, shaly, lime mudstone.
18.0	902.0	Medium gray, lime rudstone breccia with contorted bedding and sharp, concave base.
15.0	886.0	Covered.
12.5	871.0	Dark gray, calcareous shale to shaly, lime mudstone.
5.0	858.5	Covered.
8.0	853.5	Dark gray, flaggy, lime mudstone.
27.0	845.5	Covered.
20.0	818.5	Interbedded, medium to dark gray, shaly, platy, lime mudstone and thin (1.0 foot), lime rudstone breccias.
10.5	798.5	Medium gray, platy, lime mudstone with shaly partings.
6.0	788.0	Medium gray, sandy, packstone to grainstone with imbricated, lime mudstone slabs.
2.0	782.0	Dark gray, shaly, thin-bedded, lime mudstone.
6.0	780.0	Dark gray, sandy grainstone to packstone.
18.0	774.0	Dark gray, shaly, flaggy, lime mudstone.
8.0	756.0	Dark gray, platy, shaly, lime rudstone breccia with sandy interbeds.
20.0	748.0	Covered. Spring house at top of interval.
32.0	728.0	Interbedded, dark gray, thin-bedded, shaly, lime mudstone and flaggy, lime mudstone with shaly partings.
5.0	696.0	Covered.
3.0	691.0	Medium gray, sandy, lime rudstone breccia.
10.0	689.0	Dark gray, very thin-bedded, shaly, lime mudstone with shaly partings.
6.5	679.0	Medium gray, lime wackestone with sharp base.
23.0	672.5	Medium gray, flaggy, lime mudstone.
2.5	649.5	Dark gray, medium-bedded, lime rudstone breccia with imbricated, lime mudstone slabs.
7.0	647.0	Dark gray, flaggy, lime mudstone with calcareous shale partings.
4.0	640.0	Medium gray, lime rudstone breccia.
11.0	636.0	Black, calcareous shale.
17.0	625.0	Dark gray, platy, very thin-bedded, lime mudstone with shaly partings.
2.0	608.0	Covered.
30.0	606.0	Dark gray, very thin-bedded, shaly, lime mudstone with imbricated slabs of lime mudstone.
4.0	576.0	Dark gray, shaly, lime mudstone.
6.5	572.0	Dark gray, shaly, lime rudstone breccia.
6.0	565.5	Dark gray, shaly, lime mudstone.
12.0	559.5	Dark gray, platy, lime mudstone with thin (<0.5 foot), lime rudstone breccia beds.
3.0	547.5	Dark gray, shaly, lime rudstone breccia.
10.0	544.5	Dark gray, shaly, lime mudstone.
65.0	534.5	Covered. Valley trending northeastward. South of Rosenstock archeological site.
3.5	469.5	Dark gray, lime rudstone breccia.
10.0	466.0	Covered.
15.0	456.0	Interbedded, thin-bedded to flaggy mudstone with shaly partings.
3.5	441.0	Dark gray, lime rudstone breccia.

42.0	437.5	Interbedded, dark gray, thin-bedded to flaggy, lime mudstone with a few thin lime rudstone breccia beds (< 1.0 foot thick) (Pinnacle).
3.0	395.5	Medium gray, platy, lime mudstone breccia.
3.0	392.5	Dark gray, very thin-bedded, shaly, lime mudstone.
2.0	389.5	Medium gray, lime rudstone breccia.
12.0	387.5	Dark gray, very thin-bedded, shaly, lime mudstone.
2.0	375.5	Medium gray, sandy, lime rudstone breccia.
45.0	373.5	Dark gray, very thin-bedded, lime mudstone with shaly partings.
14.0	328.5	Dark gray, flaggy, lime mudstone with silty partings.
5.0	314.5	Covered.
19.0	309.5	Dark gray, flaggy, lime mudstone with shaly partings.
47.0	290.5	Dark gray, platy, calcareous shale to shaly, lime mudstone, becoming more calcareous at top.
1.0	243.5	Light gray, lime rudstone breccia.
14.0	242.5	Dark gray, thin-bedded, shaly, lime mudstone.
2.0	228.5	Dark gray, lime rudstone breccia.
30.0	226.5	Dark gray, very thin-bedded to platy, lime mudstone with shaly partings.
2.0	196.5	Medium gray, lime rudstone breccia.
2.0	194.5	Covered.
2.0	192.5	Medium gray, cross-bedded, sandy, lime packstone.
3.5	190.5	Medium gray, medium-bedded, lime rudstone breccia.
2.0	187.0	Dark gray, platy, lime mudstone.
3.0	185.0	Medium gray, cross laminated, sandy, lime packstone.
35.0	182.0	Dark gray, thin-bedded to platy, lime mudstone with calcareous shale partings, and thin (<0.5 foot), lime rudstone breccia.
60.0	147.0	Covered. Stream valley trending northeastward.
15.0	87.0	Dark gray, platy, lime mudstone.
72.0	72.0	Covered. Valley trending eastward.

Frederick Formation
Monocacy Member (Type Section)

22.0	322.0	Black, platy shale.
18.5	300.0	Dark gray, platy, lime mudstone with black, calcareous shale partings.
6.5	281.5	Black, calcareous, platy shale.
6.0	275.0	Covered.
24.0	269.0	Black, platy shale.
10.0	255.0	Covered.
7.0	245.0	Dark gray, thin-bedded, lime wackestone with shale partings.
23.0	238.0	Black, platy, shale with strong cleavage.
24.0	215.0	Interbedded, black shale and lime wackestone with few flaggy beds.
6.0	191.0	Covered.
50.0	185.0	Interbedded, dark gray, platy, lime mudstone and black calcareous shale, with thin (>1.0 foot) rudstone breccia.
6.0	135.0	Black, calcareous shale with lime mudstone clasts.
30.0	129.0	Interbedded, black shale, with dark gray, shaly, lime mudstone.
10.0	99.0	Interbedded, dark gray shale with lime mud-stone clasts.
32.0	89.0	Covered.
22.0	57.0	Dark gray, platy, lime mudstone with shaly partings.
3.0	35.0	Dark gray, lime rudstone breccia.
11.0	32.0	Interbedded, black shale with lime mudstone clasts and thin-bedded lime mudstone.
1.0	21.0	Dark gray, lime rudstone breccia in black shale.
19.0	20.0	Black, shaly, lime mudstone with dark gray, calcareous shale interbeds.
1.0	1.0	Dark gray, lime rudstone breccia in black shale.

Locality 6

Section along south bank of Monocacy River southwest of Interstate 270 overpass. Section is within the Monocacy Battlefield Historic Park. 39°21'49"N, 77°24'04"W, Buckeystown Quadrangle.

Thickness (feet)
unit total

Frederick Formation
Adamstown Member?

unit	total	
35.0	105.0	Dark gray, thin-bedded, lime mudstone with tan, dolomitic partings.
5.0	70.0	Dark gray, wavy-bedded, thickly laminated, lime mudstone.
7.0	65.0	Dark gray, thickly laminated, lime mudstone.
6.0	58.0	Dark gray, thin-bedded, shaly, lime mudstone.
15.0	52.0	Dark gray, thickly laminated, platy, lime mudstone, especially shaly at base.
16.0	37.0	Medium dark gray, platy, mottled, calcareous shale.
21.0	21.0	Dark gray, thickly laminated, platy, shaly, lime mudstone to calcareous shale with shale interbeds.

Frederick Formation

Rocky Springs Station Member

12.0	425.0	Dark gray, thickly laminated, flaggy, lime mudstone.
7.0	413.0	Dark gray, massive, lime packstone.
65.0	406.0	Interbedded, medium- to thick-bedded, dark gray, locally cross-laminated, lime grain-stone with platy, thickly laminated, dark gray, shaly, lime mudstone. Few thin (<3 feet), megaclastic breccia beds, and possibly soft sediment deformation features.
16.0	341.0	Medium dark grayish brown, calcareous shale.
1.5	325.0	Dark gray, fractured, lime mudstone.
37.0	323.5	Dark gray, thickly laminated, lime mudstone with interbeds of flaggy, lime packstone.
5.0	286.5	Covered.
6.0	281.5	Dark gray, thickly laminated, shaly, lime mudstone.
7.5	275.5	Covered.
10.0	268.0	Dark gray, medium-bedded, lime mudstone.
25.0	258.0	Dark gray, thickly laminated to flaggy, lime mudstone with dark gray, shaly partings.
36.0	233.0	Covered. Valley west of I-270.
12.0	197.0	Dark gray, thin- to medium-bedded, lime mudstone.
50.0	185.0	Covered.
22.0	135.0	Dark gray, thickly laminated to platy, lime mudstone, with a few interbeds of sandy, lime packstone.
20.0	113.0	Covered.
3.0	93.0	Dark gray, flaggy, lime mudstone.
35.0	90.0	Covered.
7.0	55.0	Dark gray, sandy, lime packstone.
8.0	48.0	Covered.
10.0	40.0	Interbedded, dark gray, intraclastic, lime grainstone, and dark gray, flaggy, lime mudstone with shaly partings.
30.0	30.0	Interbedded, dark gray, thickly laminated, lime mudstone, and black, calcareous shale (beneath I-270).

Locality 7

Section in the lower Frederick Formation along west bank of the Monocacy River, 300 yards north of Frederick Junction. Section starts near axis of anticlinal fold. 39°22'27" N, 77°23'27"W, Frederick Quadrangle.

Thickness (feet)
unit total

Frederick Formation

Rocky Springs Station Member

10.0	1547.5	Dark gray, flaggy, lime mudstone with thin, shaly interbeds and partings.
149.0	1537.5	Interbedded, dark gray, shaly, lime mud-stone and dark gray, calcareous shale.
39.0	1388.5	Covered.
107.0	1349.5	Interbedded, dark gray, shaly, lime mud-stone and dark gray, calcareous shale.
10.0	1242.5	Covered.
25.0	1232.5	Thinly interbedded, dark gray, argillaceous, lime mudstone and dark gray, calcareous shale.
48.0	1207.5	Covered.
64.0	1159.5	Thinly interbedded, dark gray, very thin-bedded, lime mudstone, and dark gray, calcareous shale.
73.0	1095.5	Covered.
33.0	1022.5	Dark gray, flaggy, lime mudstone and dark gray, calcareous shale.
25.0	989.5	Thinly interbedded, dark gray, lime mudstone and dark gray, calcareous shale.
65.0	964.5	Dark gray, flaggy, lime mudstone with thin, shale interbeds.
10.0	899.5	Thinly interbedded, dark gray, lime mudstone and dark gray, calcareous shale.
110.0	889.5	Interbedded, dark gray, flaggy, lime mudstone, medium-bedded, lime mudstone and thin, dark gray, calcareous shale.
45.0	779.5	Interbedded, dark gray, flaggy lime mudstone and dark gray, calcareous shale.
12.0	734.5	Thinly interbedded, dark gray, lime mud-stone and dark gray, calcareous shale.
3.5	722.5	Thick-bedded, dark gray, lime mudstone.
15.0	719.0	Thinly interbedded, dark gray, thickly-laminated, lime mudstone and dark gray, calcareous shale.
20.0	704.0	Covered.
12.0	684.0	Thinly interbedded, dark gray, thin-bedded, lime mudstone and dark gray shale.
22.0	672.0	Covered.
65.0	650.0	Interbedded, dark gray, thin-bedded, lime mudstone and dark gray, calcareous shale.
30.0	585.0	Covered.
43.0	555.0	Thinly interbedded, dark gray, lime mudstone and black, calcareous shale.
70.0	512.0	Covered.
15.0	442.0	Dark gray, thickly laminated, platy, lime mudstone with black shale partings.
220.0	427.0	Interbedded, dark gray, thin-bedded, flaggy and shaly, lime mudstone. Poorly exposed.
60.0	207.0	Covered.
10.0	147.0	Dark gray, thickly laminated, lime mudstone and dark gray calcareous shale.
27.0	137.0	Covered.

45.0	110.0	Dark gray, thickly laminated to very thin-bedded, lime mudstone.
43.0	65.0	Covered.
22.0	22.0	Dark gray, platy, lime mudstone, with shaly interbeds.

Locality 8

Section of the Frederick Formation, Rocky Springs Station Member, along the west and south bank of the Monocacy River next to the sewage treatment plant for Fort Detrick. 39°26'28"N, 77°23'40" W, Frederick Quadrangle.

Thickness (feet)
unit total

Frederick Formation
Rocky Springs Station Member

6.0	779.0	Dark gray, thick-bedded, lime rudstone-packstone breccia. Contains clasts up to 2.0 inches in length and made up of sandy, lime packstone.
4.0	773.0	Covered.
5.0	769.0	Medium gray, sandy, lime packstone.
26.0	764.0	Dark gray, flaggy, lime mudstone with dark gray, dolomitic partings.
1.0	738.0	Dark gray, shaly, lime rudstone-packstone breccia.
6.0	737.0	Thinly interbedded, medium gray, flaggy, lime mudstone and very thin bedded, sandy, lime packstone.
7.0	731.0	Medium gray, lime rudstone-packstone breccia.
24.0	724.0	Dark gray, flaggy, lime mudstone with thin interbeds of sandy, lime packstone.
6.0	700.0	Dark gray, lime rudstone breccia.
65.0	694.0	Dark gray, flaggy, lime mudstone with dark gray, shaly, dolomitic partings. Many strata are contorted and folded.
5.0	629.0	Dark gray, sandy, lime packstone.
16.0	624.0	Dark gray, medium-bedded, lime rudstone breccia, sandy at top (slide mass?).
5.0	608.0	Dark gray, laminated lime mudstone.
12.0	603.0	Medium gray, sandy, lime packstone.
40.0	591.0	Covered, stream valley.
26.0	551.0	Medium gray, medium-bedded, lime pack-stone breccia with thin layers of shaly, lime mudstone (slide mass?).
5.0	525.0	Dark gray, thin-bedded, lime packstone with imbricated layers and thin, shaly partings.
2.0	520.0	Medium gray, lime rudstone breccia.
2.0	518.0	Dark gray, flaggy, lime mudstone.
3.0	516.0	Medium gray, thin-bedded, lime wacke-stone.
6.0	513.0	Covered.
9.0	507.0	Medium gray, sandy, lime packstone.
85.0	498.0	Medium gray, thick-bedded, sandy, lime packstone.
14.0	413.0	Dark gray, very thin-bedded, platy, lime mudstone.
17.0	399.0	Covered.
55.0	382.0	Light to medium gray, sandy, lime packstone with thin (1-2 inch) intervals of dolomitic, rudstone breccia. Base of unit is sharp, suggesting erosional origin.
3.0	327.0	Dark gray, very thin bedded, platy, lime mudstone.
43.0	324.0	Covered.
14.0	281.0	Dark gray, very thin bedded lime mudstone.
2.0	267.0	Dark gray, lime packstone-grainstone, with clasts up to 0.5 inch diameter.
29.0	265.0	Dark gray, flaggy, lime mudstone with contorted beds common.
26.0	236.0	Dark gray, very thin bedded, shaly, lime mudstone with lenses of sandstone and breccia. Probable submarine slide mass.
24.0	210.0	Covered.
4.0	186.0	Dark gray, flaggy to thin-bedded, lime mud-stone.
5.0	182.0	Fold hinge; exact thickness obscure.
24.0	177.0	Dark gray, flaggy, lime mudstone.
4.5	153.0	Dark gray, flaggy, lime mudstone with abundant bedding folds.
5.0	148.5	Dark gray, flaggy, lime mudstone.
1.0	143.5	Medium to dark gray, lime rudstone breccia with imbricated clasts.
11.0	142.5	Dark gray, flaggy, lime mudstone.
5.5	131.5	Covered.
22.0	126.0	Dark gray, flaggy, lime mudstone with dark gray, dolomitic partings.
60.0	104.0	Covered. Bend in river to the east.
27.0	44.0	Medium gray, medium-bedded, lime mudstone.
7.0	17.0	Medium to dark gray, lime rudstone breccia.
10.0	10.0	Dark gray, flaggy, lime mudstone with dolomitic partings and abundant bedding-plane folds.

Locality 9

Section in south face, along haul road, and in abandoned pit Number 3 in the Essroc Quarry northwest of Buckeystown, Maryland. Strata dip southeast at between 30 and 35 degrees. 39°21'05" N, 77°26'41" W, Buckeystown Quadrangle.

Thickness (feet)
unit total

Grove Formation
Ceresville Member

6.0	53.5	Light gray, medium-bedded, sandy dolomite.
5.0	47.5	Covered.
19.0	42.5	Light gray, sandy dolomite. Exhibits herringbone crossbedding.
5.0	23.5	Covered.
4.0	18.5	Medium gray, medium-bedded dolomite, with coarse sand abundant.
1.5	14.5	Medium gray, mottled, dolomitic limestone.
13.0	13.0	Tan-weathering, cross-bedded, sandy dolo-mite.

Frederick Formation
Lime Kiln Member

2.5	806.0	Covered.
8.0	803.5	Medium gray, medium-bedded, thrombo-litic, lime mudstone and bioturbated, lime mudstone, with tan, ribbony laminations and partings.
14.0	795.5	Medium gray, medium-bedded, lime mud-stone, with black, shaly, dolomitic interbeds and laminations.
11.5	781.5	Medium light gray, medium-bedded, sandy, lime grainstone with local cross-bedding.
13.0	770.0	Covered.
24.0	757.0	Medium dark gray, thin- to medium-bedded, sandy lime mudstone to intraclastic lime packstone, with tan, shaly, dolomitic inter-beds and partings.
27.0	694.0	Light gray, medium-bedded, sandy, lime grainstone, locally cross-bedded.
95.0	667.0	Covered. North end of old Pit No. 3.
7.0	572.0	Interbedded, medium dark gray, medium-bedded, thrombolitic, lime mudstone, bioturbated, lime mudstone, and tan-weathering, shaly dolomite.
20.0	565.0	Covered. Section moved to haul road.
15.0	545.0	Medium dark gray, medium-bedded, bio-turbated lime mudstone.
11.0	530.0	Dark gray, medium- to thick-bedded, lime mudstone.
15.0	519.0	Dark gray, thickly laminated, shaly, lime mudstone.
21.0	504.0	Covered.
55.0	483.0	Dark gray, tan-weathering, shaly, lime mudstone.
44.0	428.0	Dark gray, thinly laminated to medium-bedded, lime mudstone. Mostly covered.
15.0	384.0	Medium gray, thick-bedded, lime mudstone.
35.0	369.0	Interbedded, dark gray to black, thickly laminated, shaly lime mudstone, and dark gray, bioturbated, thin-bedded, lime mudstone.
7.0	334.0	Dark gray, thin-bedded, bioturbated lime-stone.
6.0	327.0	Dark gray, thinly interbedded, lime mudstone and calcareous shale.
15.0	321.0	Covered.
65.0	306.0	Thinly interbedded, dark gray, thickly laminated, lime mudstone, and black, calcareous shale.
56.0	241.0	Interbedded, medium gray, bioturbated, lime mudstone, and black, calcareous shale.
1.5	185.0	Medium gray, bioturbated lime mudstone.
11.5	183.5	Medium dark gray, thickly laminated, shaly, lime mudstone.
27.0	172.0	Dark gray, thickly laminated, shaly, lime mudstone.
4.0	145.0	Medium dark gray, medium-bedded, lime mudstone.
36.0	141.0	Dark gray, very thin-bedded, shaly, lime mudstone, with tan, shaly, dolomitic partings.
1.0	105.0	Medium dark gray, bioturbated, lime mudstone.
36.0	104.0	Dark gray, thickly laminated, shaly, lime mudstone with black, shaly calcareous shale partings.
2.0	68.0	Medium gray, lime mudstone.
49.0	66.0	Interbedded, very dark gray, thickly laminated, shaly, lime mudstone and black, calcareous shale.
17.0	17.0	Dark gray, medium-bedded, bioturbated, lime mudstone, thin-bedded to shaly at its top.

Frederick Formation
Adamstown Member

6.0	691.0	Very dark gray, thickly laminated, shaly, lime mudstone.
2.0	685.0	Black, platy, shaly, lime mudstone.
17.0	683.0	Very dark gray, thickly laminated, lime mudstone with black, shaly partings.
6.0	666.0	Dark gray, laminated, shaly, lime mudstone.
77.0	660.0	Very dark gray, laminated, shaly, lime mudstone with abundant shaly partings.
15.0	583.0	Dark gray, thickly laminated to very thin-bedded, shaly, lime mudstone.
57.0	568.0	Dark gray, laminated, lime mudstone with black, calcareous shale partings.
5.0	511.0	Black, laminated, lime mudstone with black shale partings.
42.0	506.0	Dark gray, laminated, lime mudstone with black, calcareous shale partings.
11.0	464.0	Dark gray, laminated, lime mudstone with platy partings.
9.0	453.0	Black, shaly, lime mudstone with

		calcareous shale partings.
12.0	444.0	Dark gray, thin-bedded, lime mudstone, with dark gray, shaly partings.
3.0	432.0	Black, calcareous shale.
10.0	429.0	Dark gray, laminated, lime mudstone, contorted.
5.0	419.0	Covered, sinkhole.
10.0	414.0	Dark gray, laminated, lime mudstone with dark gray, calcareous shale partings.
35.0	404.0	Dark gray, thinly to thickly laminated, lime mudstone with dark gray, dolomitic, shaly partings.
26.0	369.0	Dark gray, thin-bedded, lime mudstone with beds up to 1 inch thick, and dark gray, shaly partings and interbeds.
22.0	343.0	Dark gray, thin-bedded, lime mudstone with interbeds and partings of black calcareous shale.
23.0	321.0	Black, thickly laminated to very thin-bedded, lime mudstone with black, carbona-ceous shale partings and interbeds.
47.0	298.0	Medium dark gray, laminated, lime mud-stone with black, carbonaceous shale inter-beds and partings.
17.0	251.0	Dark gray, thinly interbedded, lime mud-stone and black, calcareous shale. Highly fractured and sheared.
12.0	234.0	Black, shaly, lime mudstone.
42.0	222.0	Black, very thin-bedded, lime mudstone (0.25-0.50 inch thick) with black, carbonaceous shale partings and interbeds.
105.0	180.0	Very dark gray, laminated to very thin bedded, lime mudstone with black, carbo-naceous shale interbeds. Highly fractured and sheared.
75.0	75.0	Very dark gray, platy, shaly, lime mudstone.

Locality 10

Section in the Lime Kiln Member of the Frederick Formation exposed along the south face of the Lafarge Quarry, Frederick, Maryland. Section begins in southeast corner of the quarry and proceeds west-northwest. 39°23'26"N, 77°23'34"W, Frederick Quadrangle.

Thickness (feet)
unit total

Frederick Formation
Lime Kiln Member

unit	total	
20.0	868.5	Dark gray, tan-weathering, lime mudstone, with abundant chevron folds.
10.0	848.5	Covered.
21.0	838.5	Very dark gray, very thin bedded, lime mudstone, highly folded and contorted.
41.0	817.5	Very dark gray, very thin bedded, lime mudstone with a few beds of contorted, laminated strata (west end of lift).
122.0	776.5	Very dark gray, thin-bedded, lime mudstone with tan-weathering, black shale partings.
6.0	654.5	Medium dark gray, sandy, lime grainstone with erosional base that is convex down.
48.0	648.5	Very dark gray, thickly laminated, lime mudstone with tan-weathering, black, carbonaceous, shale partings.
23.0	600.5	Dark gray, very thin bedded, lime mudstone with black, calcareous shale partings.
18.0	577.0	Dark gray, thickly laminated, lime mudstone with a few faint burrows.
15.0	559.5	Dark gray, laminated, lime mudstone, with dark gray, shaly partings that weather tan.
6.0	544.5	Dark gray, medium-bedded, lime wacke-stone.
21.0	538.5	Medium gray, medium-bedded, lime wacke-stone to lime mudstone.
22.0	517.0	Medium dark gray, sandy, lime grainstone with sharp, erosional base, less sandy at top.
94.0	495.5	Interbedded, dark gray, very thin bedded to thickly laminated, lime mudstone, with dark gray shale.
12.0	401.0	Black, shaly, lime mudstone, platy at the top.
2.5	389.5.	Medium gray, sandy, lime grainstone.
12.5	377.0	Thinly interbedded, dark gray, very thin bedded, lime mudstone with black shale that weathers tan.
24.0	365.0	Medium gray, medium-bedded, sandy, lime grainstone to limey sandstone. Base is sharp, probably erosional.
7.0	341.0	Thinly interbedded, dark gray, very thin bedded, lime mudstone and black, calcar-eous shale.
29.0	334.0	Medium gray, thin- to medium-bedded, sandy, lime wackestone to packstone, becoming sandy at the top, with an erosional base.
27.0	307.0	Thinly interbedded, dark gray, very thin bedded, lime mudstone with tan weathering, black shale. Few burrows near top.
18.0	280.0	Medium dark gray, medium-bedded, sandy, lime packstone to grainstone, becoming very thin-bedded at the top.
3.5	262.5	Dark gray, thin-bedded, lime mudstone.
3.0	258.5	Black, thickly laminated, lime mudstone with black shale interbeds.
16.0	255.5	Medium gray, medium-bedded, laminated, sandy, lime wackestone, less sandy and more mud at the top.

8.0	239.5	Thinly interbedded, dark gray, thin-bedded, lime mudstone with black shale interbeds and partings.
41.5	231.5	Medium gray, medium-bedded, sandy, lime grainstone with sharp, convex-down base, becoming less sandy at the top.
3.0	190.0	Black, shaly, lime mudstone.
12.0	187.0	Medium dark gray, cross-bedded, lime grainstone with sharp (erosional?) base. Grades up into overlying unit.
11.0	175.0	Medium dark gray, very thin bedded, lime mudstone.
28.0	164.0	Medium gray, thick-bedded, cross-bedded, sandy, lime grainstone to calcareous sandstone.
48.0	136.0	Thinly interbedded, dark gray, lime mudstone and black, calcareous shale.
27.0	88.0	Dark gray, sandy, lime packstone grading upwards into a black, massive, lime mud-stone.
1.5	61.0	Black, calcareous shale.
13.5	59.5	Thinly interbedded, dark gray, very thin bedded, lime mudstone and black shale.
11.0	46.0	Dark gray, sandy, lime packstone.
18.0	35.0	Very thinly interbedded, dark gray, lime mudstone and dark gray, calcareous shale.
14.0	17.0	Dark gray, sandy, lime packstone to wackestone.
3.0	3.0	Dark gray, very thin-bedded, lime mudstone with black, shaly partings.

Frederick Formation
Adamstown Member?

30.0	30.0	Very thinly interbedded, dark gray, argilla-ceous, lime mudstone and black, calcareous shale.

Locality 11

Section in the upper Lime Kiln Member of the Frederick Formation and its contact with the Grove Formation on the Lefarge Frederick Quarry property, southwest of the main quarry, and south of the Kline paving plant. 39°23'21"N, 77°23'59"W, Frederick Quadrangle.

Thickness (feet)
unit total

Grove Formation
Ceresville Member

9.5	102.0	Light gray, coarse-grained, sandy, fractured dolomite with faint cross-bedding.
3.0	92.5	Light gray, sandy, fractured dolomite.
4.5	89.5	Covered.
15.0	85.0	Light to medium gray, fine-grained, sandy fractured dolomite.
3.0	70.0	Medium gray, dolomite (thrombolitic?).
11.0	67.0	Light gray, fractured, sandy dolomite.
5.5	56.0	Light gray, coarse-grained, sandy dolomite.
22.0	50.5	Light gray, saccharoidal dolomite, highly fractured.
12.0	28.5	Light gray, sandy dolomite. Quartz sand is rounded and fine-grained.
15.0	16.5	Medium light gray, cross-bedded, sandy, fractured dolomite. Sand is medium- to coarse-grained. (Move section 150 yards to the south.)
1.5	1.5	Light gray, fine-grained dolomite.

Frederick Formation
Lime Kiln Member

9.0	182.0	Medium to dark gray, thrombolitic, lime mudstone with tan, dolomitic, wispy layers.
5.0	173.0	Tan, fractured dolomite.
19.0	168.0	Medium gray, medium-bedded, cross-laminated, sandy, lime wackestone-packstone.
3.0	149.0	Covered.
6.0	146.0	Dark gray, thin-bedded, sandy, lime wacke-stone.
11.0	140.0	Covered.
6.0	129.0	Dark gray, thin-bedded, lime mudstone.
4.5	123.0	Dark gray, sandy, thrombolitic, lime mud-stone.
5.0	118.5	Dark gray, sandy, lime packstone.
4.0	113.5	Dark gray, thrombolitic, lime mudstone.
4.5	109.5	Dark gray, thin- to medium-bedded, sandy, lime wackestone.
22.0	105.0	Dark gray, thin-bedded, lime mudstone.
4.0	83.0	Medium gray, sandy, thrombolitic, lime wackestone.
15.0	79.0	Covered.
3.0	64.0	Dark gray, thin- to medium-bedded, lime mudstone.
7.0	61.0	Dark gray, thrombolitic, lime mudstone.
4.0	54.0	Dark gray, sandy, cross-bedded, lime pack-stone.
27.0	50.0	Covered.
23.0	23.0	Dark gray, ribbony to very thin bedded, lime mudstone with tan, dolomitic partings.

Locality 12

Section along south bank of the Monocacy River approximately 0.5 mile southwest of Ceresville. Section starts at top of patchy outcrops of dark gray, ribbony limestone of the upper Lime Kiln Member of the Frederick Formation and proceeds into the Ceresville Member of the

Grove Formation. 39°26'30"N, 77°22'11"W, Walkersville Quadrangle.

Thickness (feet)

Grove Formation
Ceresville Member

unit	total	
5.0	83.0	Medium light gray, thrombolitic, lime mudstone with a wackestone and packstone caprock.
3.0	78.0	Very light gray, highly fractured, slightly sandy dolomite.
12.0	75.0	Medium light gray, thinly cross-laminated, sandy, dolomitic, lime packstone.
5.0	63.0	Covered.
3.0	58.0	Light gray, sandy, dolomitic, lime pack-stone.
2.0	55.0	Very light gray, highly fractured dolomite.
5.0	53.0	Light gray, thin-bedded, sandy dolomite with platy, tan, dolomite clasts.
8.0	48.0	Covered.
19.0	40.0	Very light gray, thinly cross-laminated to cross-bedded, sandy, dolomitic, lime grain-stone.
17.0	21.0	Covered.
4.0	4.0	Very light gray, highly fractured, medium-bedded dolomite.

Frederick Formation
Lime Kiln Member

unit	total	
9.0	9.0	Light gray, fractured, cross-laminated, sandy dolomite to dolomitic, lime packstone.

Locality 13

Section in the upper Lime Kiln Member of the Frederick Formation and Ceresville Member of the Grove Formation. Section is on the west bank of the Monocacy River, and starts 130 feet south of the Maryland Route 26 bridge over the Monocacy. This is the type section of the Ceresville Member. 39°27'05"N, 77°22'15"W, Walkersville Quadrangle.

Thickness (feet)

Grove Formation
Ceresville Member (type section)

unit	total	
12.0	79.0	Medium light gray, cross-bedded, sandy, fractured dolomite. Bedding horizontal at center of Frederick Valley Syncline.
15.0	67.0	Medium light gray, cross-bedded, sandy, dolomitic lime packstone.
12.0	52.0	Interbedded, medium light gray, cross-bedded, sandy, dolomitic, lime packstone, and thrombolitic dolomite.
5.0	40.0	Covered.
5.0	35.0	Medium light gray, fractured, thrombolitic, lime mudstone.
10.0	30.0	Medium light gray, cross-bedded, sandy, dolomitic, lime packstone.
5.0	20.0	Covered.
15.0	15.0	Medium light gray, cross-bedded, sandy, dolomitic, lime packstone.

Frederick Formation
Lime Kiln Member

unit	total	
5.0	174.0	Covered.
9.0	169.0	Medium gray, massive, thrombolitic, lime mudstone.
7.0	160.0	Covered.
13.0	153.0	Medium gray, massive, thrombolitic, lime mudstone.
18.0	140.0	Medium light gray, ribbony, sandy, lime packstone.
2.0	122.0	Covered.
1.0	120.0	Medium gray, laminated, lime mudstone.
15.0	119.0	Medium gray, ribbony, cross-laminated, sandy, lime packstone.
24.0	104.0	Covered.
11.0	80.0	Medium gray, sandy, lime packstone.
15.0	69.0	Medium to dark gray, ribbony, thrombolitic (?), lime mudstone.
7.0	54.0	Dark gray, thin-bedded, lime mudstone.
6.0	47.0	Dark gray, ribbony, lime mudstone.
11.0	41.0	Covered.
2.0	30.0	Medium gray, thrombolitic, lime mudstone.
15.0	28.0	Dark gray, thin-bedded, shaly, lime mud-stone.
7.0	13.0	Medium gray, thick-bedded, thrombolitic, lime mudstone.
3.0	6.0	Covered.
3.0	3.0	Dark gray, thin-bedded, shaly, lime mud-stone.

Locality 14

Section in the Fountain Rock Member of the Grove Formation exposed in small, abandoned quarry along the CSXT Railway tracks 0.5 mile west of Buckeystown. Section starts in the southeast corner of the quarry and proceeds northeastward along the northern face. 39°20'14"N, 77°26'24"W, Buckeys-town Quadrangle.

Thickness (feet)
unit total

Grove Formation

Fountain Rock Member

3.0	73.0	Light gray, tan-weathering, fractured dolomite.
17.0	70.0	Medium gray, massive, algal, lime mudstone.
15.0	53.0	Medium gray, medium-bedded, locally cross-bedded, lime packstone to grainstone, slightly dolomitic at top.
32.0	38.0	Medium gray, massive, lime mudstone-boundstone, made up of algal thrombolites 3.0-9.0 feet thick. Interfingers with medium light gray, lime packstone.
6.0	6.0	Medium light gray, medium-bedded, lime packstone to grainstone, grading upwards into algal, lime mudstone.

Locality 15

Section in the Fountain Rock and Woodsboro Members of the Grove Formation exposed along the north face of the Legore Quarry. Section begins in the northeast corner of the quarry immediately west of fracture zone that omits the Ceresville Member of the Frederick Formation. Section measured with tape measure. 39°33'05"N, 77°18'32"W, Woodsboro Quad-rangle.

Thickness (feet)
unit total

Grove Formation
Woodsboro Member

78.0	238.0	Dark gray to very dark gray, shaly, lime mudstone with a few interbeds of medium gray, lime mudstone.
120.0	160.0	Interbedded, dark gray, ribbony to bioturbated, lime mudstone and medium gray, medium-bedded, lime mudstone.
40.0	40.0	Dark gray, bioturbated, thin-bedded, shaly, lime mudstone.

Grove Formation
Fountain Rock Member

30.0	328.0	Interbedded, medium light gray, tan-weathering, laminated, dolomitic mudstone and medium- to thick-bedded, thrombolitic, lime mudstone. Most beds are marblized.
278.0	298.0	Light gray, medium- to thick-bedded, fractured, dolomitic limestone and marble. Some beds contain light gray, thrombolitic dolomite and intraclastic, lime grainstone. Increasingly sandy in upper strata.
20.0	20.0	Interbedded, medium gray, thick-bedded, lime mudstone and tan dolomite.

Locality 16

Section in the Fountain Rock and Woodsboro Members of the Grove Formation exposed in the Barrick Brothers Quarry, Woodsboro. This is the type section of the Woodsboro Member of the Grove Formation. 39°32'56" N, 77°18'55" W, Woodsboro Quadrangle.

Thickness (feet)
unit total

Grove Formation
Woodsboro Member

40.0	310.0	Medium dark gray, ribbony, lime mudstone.
7.0	270.0	Tan, fractured dolomite
63.0	263.0	Very dark gray, platy to ribbony, lime mudstone.
100.0	200.0	Medium dark gray, laminated to ribbony, lime mudstone, and dark gray, shaly, lime mudstone.
95.0	100.0	Dark gray to black, thin-bedded to ribbony, lime mudstone with shaly partings, and interbeds of medium-bedded, dolomitic, lime mudstone.
5.0	5.0	Black, ribbony, shaly, lime mudstone.

Grove Formation
Fountain Rock Member

48.0	269.0	Medium gray, medium-bedded, lime mudstone.
53.0	210.0	Interbedded, medium to light gray, medium-bedded, lime mudstone, and tan, thrombolitic, lime mudstone.
1.0	168.0	Tan, thrombolitic, lime mudstone.
47.0	167.0	Light gray, medium-bedded, thrombolitic, lime mudstone.
10.0	120.0	Light gray, to tan-weathering, fractured, dolomitic, lime mudstone.
110.0	110.0	Interbedded, light gray, medium-bedded, lime mudstone, and tan, thick-bedded dolomite.

Locality 17

Section along the northern wall of the Fountain Rock Quarry in Walkersville. This is the type section of the Fountain Rock Member of the Grove Formation. 39°28'32" N, 77°22'03" W, Walkersville Quadrangle.

Thickness (feet)
unit total

8.0	144.0	Medium gray, medium-bedded, lime mudstone (along NW corner of quarry wall).
15.0	136.0	Medium gray, thick-bedded to massive, thrombolitic, lime mudstone.

2.0	121.0	Tan-weathering, medium-bedded, dolomitic, lime mudstone.
6.5	119.0	Medium gray, thick-bedded to massive, thrombolitic, lime mudstone.
5.0	112.5	Tan-weathering, medium-bedded, dolomitic, lime mudstone.
11.0	107.5	Medium gray, thick-bedded to massive, thrombolitic, lime mudstone.
1.0	96.5	Tan, dolomitic, lime mudstone.
5.0	95.5	Tan, fractured dolomite.
15.0	90.5	Medium gray, thick-bedded to massive, thrombolitic, lime mudstone.
2.0	75.5	Medium gray, thin-bedded, lime mudstone.
11.0	73.5	Medium gray, thick-bedded to massive, thrombolitic, lime mudstone.
1.0	62.5	Medium gray, thin-bedded, lime mudstone.
6.0	61.5	Medium gray, thick-bedded to massive, thrombolitic, lime mudstone.
5.0	55.5	Tan dolomite.
25.0	50.5	Covered.
10.0	25.5	Medium gray, thick-bedded to massive, thrombolitic, lime mudstone.
3.0	15.5	Medium gray, thin-bedded, lime mudstone.
9.0	12.5	Medium gray, thick-bedded to massive, thrombolitic, lime mudstone.
3.5	3.5	Tan, fractured, thrombolitic dolomite (along eastern wall of quarry).

Locality 18

Section through the upper Lime Kiln Member of the Frederick Formation to the Fountain Rock Member of the Grove Formation in separate farm fields along Dublin Road. Section is taken from Taylor *et al*. (1996), field checked, and modified (especially in lower part) to fit the current format. Section begins on the west side of Dublin Road in the pasture of the Trout Farm and continues northeastward into the Roderick farm. Top of the section is at the crest of the ridge paralleling the farm buildings. 39°30'53" N, 77°21'54" W, Woodsboro Quadrangle.

Thickness (feet)
unit total

Grove Formation
Fountain Rock Member

33.0	1771.0	Medium-gray, thick-bedded to massive, thrombolitic, lime mudstone with interbeds of lime grainstone.
92.0	1738.0	Covered. Scattered exposures of thrombolites.
12.0	1646.0	Medium light gray, massive, thrombolitic, lime mudstone.
69.0	1634.0	Covered.
11.0	1565.0	Medium light gray, thin- to medium-bedded, cross-bedded lime grainstone.
28.0	1554.0	Medium light gray, thick-bedded, thrombo-litic, dolomitic, lime mudstone.
44.0	1526.0	Covered.
25.0	1482.0	Massive, thrombolitic, lime mudstone.
21.0	1457.0	Covered.
10.0	1436.0	Medium light gray, massive, thrombolitic, lime mudstone.
17.0	1426.0	Covered.
15.0	1409.0	Brownish gray, tan-weathering, fine- to medium-grained, cross-bedded, calcareous sandstone (forms crest of ridge).
28.0	1394.0	Covered.
22.0	1365.0	Medium gray to medium light gray, thick-bedded, thrombolitic, lime mudstone.
15.0	1343.0	Covered.
15.0	1327.0	Medium light gray, thin-bedded, bioturbated, lime mudstone.
10.0	1312.0	Covered.
7.0	1301.0	Medium light gray, thin-bedded, dolomitic, lime mudstone.
7.0	1293.0	Medium light gray, thick-bedded, lime grainstone.
96.0	1286.0	Covered.
4.0	1190.0	Light gray, thin-bedded, lime mudstone.
44.0	1186.0	Covered.
4.0	1142.0	Medium gray, thick-bedded, thrombolitic, lime mudstone.
36.0	1138.0	Covered.
5.0	1102.0	Medium-light gray, thin-bedded, lime mud-stone.
15.0	1097.0	Covered.
5.0	1081.0	Medium light gray, medium-bedded, lime grainstone.
12.0	1076.0	Covered.
10.0	1063.0	Light gray, thick-bedded, thrombolitic, lime mudstone.
25.0	1053.0	Covered.
3.0	1028.0	Light gray, thin-bedded, lime mudstone.
115.0	1025.0	Covered.
5.0	910.0	Medium light gray, thin-bedded, lime mud-stone.
274.0	904.0	Covered.
8.0	630.0	Light gray, medium-bedded, lime grainstone.
3.0	622.0	Light gray, thin-bedded, lime mudstone.
10.0	619.0	Covered.
9.0	609.0	Light gray, medium-bedded, sandy, lime packstone.
271.0	600.0	Covered.
12.0	329.0	Light gray, thick-bedded, thrombolitic, lime mudstone.
25.0	315.0	Covered.
5.0	289.0	Medium light gray, thick-bedded, dolomitic, thrombolitic, lime mudstone.
4.0	282.0	Medium light gray, thin-bedded, bioturbated, lime mudstone.

61.0	278.0	Covered.
34.0	217.0	Light gray, thin-bedded, bioturbated, lime mudstone.
61.0	183.0	Light gray, thin-bedded, lime mudstone.
54.0	122.0	Covered.
68.0	68.0	Medium light gray, tan weathering, dolomitic, thrombolitic, lime mudstone.

Grove Formation
Ceresville Member

34.0	171.0	Covered.
18.0	138.0	Medium light gray, medium-bedded, cross-bedded, sandy, lime grainstone.
30.0?	120.0	Covered.
15.0	91.0	Light gray, fractured, thrombolitic (?) dolo-mite.
50.0	76.0	Covered.
16.0	26.0	Light gray, thick-bedded to massive, fractured dolomite.
10.0	10.0	Light gray, thick-bedded to massive, fractured, thrombolitic (?) dolomite.

Frederick Formation
Lime Kiln Member

10.0	43.0	Medium gray, thick-bedded, thrombolitic, lime mudstone.
3.0	41.0	Medium gray, stromatolitic, lime mudstone.
10.0	39.0	Medium gray, thick-bedded to massive, stromatolitic to thrombolitic, lime mudstone.
3.0	26.0	Medium gray, cross-bedded, sandy, lime grainstone.
9.0	23.0	Medium gray, medium-bedded, stromatolitic and thrombolitic, lime mudstone.
10.0	14.0	Interbedded, medium gray, medium-bedded, sandy lime grainstone and stromatolitic lime mudstone.

Locality 19

Section through the contact of the Frederick Formation, Rocky Springs Station Member and the Triassic New Oxford Formation. Location is on the west bank of the Monocacy River, 200 yards east of the Old Pull off of U.S. Route 15, north of Resthaven Cemetery, at the northern end of the Frederick Valley. 39°29'44"N, 77°23'49"W, Frederick Quadrangle.

Thickness (feet)
unit total

New Oxford Formation

5.5	267.5	Brownish red, medium-bedded, medium-grained sandstone.
6.0	262.0	Covered.
2.0	256.0	Brownish red, argillaceous, fine-grained sandstone.
3.0	254.0	Brownish red mudstone.
8.0	251.0	Brownish red, medium-grained, medium-bedded, argillaceous sandstone.
5.0	243.0	Brownish red siltstone.
52.0	238.0	Brownish red mudstone.
4.5	186.5	Brownish red, blocky claystone.
35.0	182.0	Brownish red, silty mudstone.
3.5	147.0	Brownish red conglomerate of lime mudstone pebbles and reddish, mudstone matrix.
7.5	143.5	Brownish red mudstone.
5.0	136.0	Covered.
7.0	131.0	Brownish red, sandy mudstone.
24.0	124.0	Covered.
16.5	100.0	Brownish red mudstone, sandy at top.
11.0	83.5	Interbedded, brownish red mudstone, and rubbly, mudstone conglomerate.
4.0	72.5	Brownish red conglomerate with abundant lime mudstone clasts, and red, argillaceous cement.
3.5	68.5	Brownish red, conglomerate with lime mudstone pebbles and mudstone matrix.
15.0	65.0	Brownish red, conglomerate with cobbles and pebbles of reddish sandstone, reddish siltstone, and lime mudstone in a red, calcareous, mudstone matrix.
14.0	50.0	Covered.
6.5	36.0	Brownish red, limestone conglomerate.
17.5	29.5	Covered.
12.0	12.0	Reddish brown, silty mudstone.

Frederick Formation
Rocky Springs Station Member

7.0	21.0	Dark gray, thin-bedded, lime mudstone with black, shaly partings.
14.0	14.0	Medium gray, sandy, lime packstone, with zones of imbricated breccia.

Locality 20

Section in Manassas Formation along abandoned B &O railroad grade east of Kanawha Spring. Rocks dip westward at about 30 degrees. Section begins on north side of grade and progresses westward. 39°15'45"N, 77°30'38"W, Point of Rocks Quadrangle.

Thickness (feet)
unit total

Manassas Formation

Poolesville Member

3.0	522.0	Brownish red, silty mudstone.
1.0	519.0	Medium brownish red, cross-bedded, medium-grained sandstone, with erosional base and shale-pebble conglomerates in lower strata.
9.0	508.0	Brownish red, medium-bedded, silty, argil-laceous sandstone.
4.5	499.0	Brownish red, coarse-grained, cross-bedded sandstone with erosional base.
6.0	494.5	Brownish red, sandy siltstone.
21.0	488.5	Covered.
16.0	467.5	Light brownish red, coarse-grained, cross-bedded sandstone, with erosional base.
11.5	451.5	Brownish red siltstone, with thin, fine-grained sandstone interbeds.
5.0	440.0	Covered.
19.0	435.0	Brownish red, argillaceous, coarse-grained sandstone.
16.5	416.0	Brownish red, silty mudstone with a few layers of carbonate nodules.
5.5	399.5	Brownish red, sandy siltstone.
7.0	394.0	Light brownish red, coarse-grained, friable, cross-bedded sandstone.
65.0	387.0	Covered. Stream valley.
11.0	322.0	Brownish red siltstone with root casts and abundant carbonate nodules, and a few, thin interbeds of fine-grained sandstone.
3.5	311.0	Brownish red mudstone with abundant carbonate nodules.
6.5	307.5	Brownish red siltstone with a few, thin, fine-grained sandstone interbeds.
1.5	301.0	Brownish red siltstone with abundant carbonate nodules.
9.5	299.5	Brownish red siltstone with abundant root casts.
6.0	290.0	Brownish red, coarse-grained sandstone with sharp base.
2.5	284.0	Reddish siltstone.
4.5	281.5	Interbedded, brownish red, fine-grained, silty sandstone and brownish red mudstone.
6.0	277.0	Brownish red, root casts siltstone with a few carbonate nodules.
2.0	271.0	Brownish red mudstone with carbonate nodules.
6.0	269.0	Brownish red mudstone with root casts.
3.0	263.0	Brownish red, medium-grained sandstone with claystone partings.
4.0	259.5	Brownish red claystone with root casts.
3.5	255.5	Brownish red, flaggy, medium-grained sandstone, pinches out laterally.
2.0	252.0	Covered.
5.0	250.0	Brownish red siltstone with abundant carbonate nodules.
4.0	245.0	Covered.
11.0	241.0	Brownish red, silty mudstone with abundant root casts and intervals of carbonate nodules.
14.5	230.0	Light brownish red, coarse-grained, cross-bedded, friable sandstone.
3.0	215.5	Covered.
6.0	212.5	Light brownish red, medium-grained, cross-bedded sandstone.
12.5	206.5	Covered.
3.5	194.0	Brownish red, medium-grained sandstone.
6.0	190.5	Brownish red siltstone with abundant carbonate nodules.
4.5	184.5	Covered.
17.0	180.0	Light brownish red, medium-grained, cross-bedded sandstone, grading upsection into reddish, fine-grained, sandy siltstone.
6.0	163.0	Brownish red, medium-grained sandstone with sharp base and root casts in upper strata.
9.0	157.0	Interbedded, brownish red siltstone and brownish red mudstone.
2.0	148.0	Brownish red mudstone.
3.0	146.0	Brownish red, fine-grained, silty sandstone.
12.0	143.0	Brownish red siltstone with abundant root casts.
6.5	131.0	Red mudstone with abundant root casts and carbonate nodules.
11.0	124.5	Reddish brown, medium-grained, cross-bedded sandstone.
7.0	113.5	Brownish red silty mudstone with fine-grained sandstone interbeds.
2.0	106.5	Brownish red mudstone with abundant carbonate nodules.
10.0	104.5	Brownish red mudstone with root casts.
19.0	94.5	Light brownish red, coarse-grained sandstone with shale-pebble, basal conglom-erate, grading upsection into red mudstone with root casts.
3.5	75.5	Brownish red siltstone.
6.0	72.0	Brownish red mudstone with a few, fine-grained sandstone interbeds.
11.0	66.0	Brownish red, medium grained sandstone.
3.5	55.0	Brownish red, silty, mudstone, grading up section into reddish, medium-grained sand-stone.
0.5	51.5	Light gray layer of carbonate nodules.
7.0	51.0	Brownish red mudstone with carbonate nodules.
12.0	44.0	Light brownish red, coarse-grained, cross-bedded sandstone with a few large (> 2.0 inches) clasts of limestone or dolomite.
6.0	32.0	Brownish red mudstone with tan, carbonate nodules.
26.0	26.0	Light brownish red, coarse-grained, cross-bedded, friable sandstone with shale-pebble conglomerates at the base.

Locality 21

Section in the Manassas Formation along Interstate 70 at its interchange with U.S. 340. Section starts along southwest ramp of interchange from I-70 east to US Route 340 south, and progresses westward. 39°23'52"N, 77°26'34"W, Frederick Quadrangle.

Thickness (feet)
unittotal

Manassas Formation
Poolesville Member

10.0	1270.5	Brownish red, silty mudstone with root casts and variegation at the top, and layers of light gray, calcareous nodules.
17.0	1260.5	Brown to light gray-brown, medium-grained, medium-bedded sandstone, reddish at top.
3.5	1243.0	Brownish red, silty sandstone.
11.0	1240.0	Brownish red, platy, root casts shale.
3.0	1229.0	Brownish red, silty, sandy mudstone with tan, calcareous blebs.
7.0	1226.0	Light gray to reddish, medium-grained, medium-bedded sandstone, soft, friable.
12.0	1219.0	Reddish mudstone, variegated, highly root casts. Incipient slide at top of outcrop.
5.0	1207.0	Brownish red mudstone with greenish areas, abundant root casts, tan carbonate nodules, and thin sandstone beds.
10.0	1202.0	Light gray to tan, medium- to coarse-grained, medium-bedded sandstone.
21.0	1192.0	Brownish red, silty, fine-grained, thin-bedded sandstone.
3.0	1171.0	Brownish red, mudstone with root casts.
67.0	1168.0	Brownish red mudstone with abundant root casts, and carbonate blebs and nodules.
21.0	1101.0	Tan to light gray-brown, medium- to coarse-grained, medium-bedded, friable sandstone.
3.0	1080.0	Reddish mudstone.
9.0	1077.0	Light grayish brown, medium-grained, medium-bedded sandstone.
38.0	1068.0	Brownish red siltstone with abundant root casts and thin, 1-3 foot, red, silty, fine-grained sandstone interbeds.
5.0	1030.0	Brownish red silty, argillaceous, fine-grained sandstone with root casts.
15.0	1025.0	Brownish red, silty mudstone.

Move section to westbound lane of Interstate 70

15.0	1010.0	Light grayish brown, medium-grained, medium-bedded sandstone.
115.0	995.0	Interbedded, brownish red mudstone with abundant root casts, calcite nodules, and thin (3.0 feet), medium- to fine-grained, silty sandstone.
7.0	880.0	Light grayish brown, medium-grained, medium-bedded sandstone.
62.0	873.0	Brownish red mudstone with abundant root casts.
4.0	811.0	Reddish, medium-grained, thin-bedded sandstone.
10.0	807.0	Reddish mudstone with abundant root casts and calcite nodules.
11.0	797.0	Covered.
17.0	786.0	Light grayish brown, medium grained, medium-bedded sandstone.
6.0	769.0	Red, sandy mudstone with abundant root casts.
15.0	763.0	Red argillaceous, fine-grained, thin-bedded sandstone, grading upsection into argilla-ceous, platy, sandy siltstone. Root casts common.
11.0	748.0	Red mudstone.
21.0	737.0	Covered.
3.5	716.0	Red siltstone with abundant root casts.
32.0	712.5	Red mudstone.
37.0	680.5	Light grayish red, medium-grained, cross-bedded sandstone.
95.0	643.5	Covered; Jefferson Pike overpass.
11.0	548.5	Red, micaceous, medium-grained, thin-bedded sandstone, grading up section into red, platy siltstone.
23.0	537.5	Red mudstone with abundant root casts and calcareous nodules.
11.0	514.5	Light grayish red, medium-grained, medium-bedded sandstone, becoming silty at top.
25.0	503.5	Brownish red siltstone to mudstone.
32.0	478.5	Light reddish gray, medium-grained, medium-bedded sandstone, becoming red, sandstone with root casts at top.
22.0	446.5	Red mudstone.
18.0	429.5	Red, argillaceous, fine-grained, thin-bedded sandstone with root casts at top.
23.0	406.5	Light reddish gray, medium-grained, cross-bedded sandstone, becoming variegated siltstone at top.
6.0	383.5	Covered.
45.0	377.5	Red, silty mudstone with abundant root casts and calcareous nodules.
16.0	332.5	Covered.
17.0	316.5	Brownish red, mudstone with tan, calcareous blebs.
15.0	299.5	Light reddish gray, fine-grained, thin-bedded sandstone.
6.0	284.5	Covered.
17.0	278.5	Light reddish gray, medium-grained, medium-bedded sandstone, red siltstone at top.

11.0	261.5	Covered.
21.0	250.5	Brownish red mudstone, with abundant root casts and tan, calcareous blebs.
23.0	229.5	Covered.
26.0	206.5	Brownish red mudstone with abundant root casts and few sandstone interbeds.
7.0	180.5	Covered.
12.0	173.5	Red mudstone with tan, calcareous nodules and root casts.
45.0	161.5	Covered.
18.0	116.5	Red siltstone.
6.0	98.5	Light reddish brown, medium-grained, medium-bedded sandstone, becoming thin-bedded and argillaceous at top.
34.0	92.5	Covered.
25.0	58.5	Light reddish gray, coarse-grained, cross-bedded, micaceous sandstone.
4.5	33.5	Brownish red, argillaceous, thin-bedded, fine-grained sandstone.
22.0	29.0	Brownish red, variegated mudstone with abundant interbeds of fine-grained sandstone.
7.0	7.0	Light reddish gray, medium-bedded, coarse-grained sandstone.

Locality 22

Section of the Tuscarora Creek and lower Poolesville Members of the Manassas Formation along Maryland Route 28, 0.3 mile west of its intersection with New Design Road. 39°15'47" N, 77°29'01" W, Buckeystown Quadrangle

Thickness (feet)
unit total

Manassas Formation
Poolesville Member

27.0	72.0	Reddish brown, silty, micaceous claystone to silty shale.
20.0	45.0	Reddish claystone, mostly covered.

Manassas Formation
Tuscarora Creek Member

6.0	25.0	Coarse-grained, carbonate conglomerate with red, hematitic, mudstone cement.
12.0	19.0	Covered.
7.0	7.0	Thick-bedded, tan to light gray, pebbly conglomerate. Clasts consist mainly of tan, rounded clasts of dolomite, ranging in size from 1.0 to 1.5 inch (2-3 cm) with very few clasts ranging up to 3 inches (8 cm) in diameter. Single bed coarsens upwards.

Locality 23

Section in the New Oxford Formation along the Maryland Midland Railroad tracks at Detour, Carroll County. Section begins just to the west of Keysville Road. 39°36'19"N, 77°16'17"W, Woodsboro Quadrangle.

Thickness (feet)
unit total

New Oxford Formation

15.0	574.0	Interbedded, reddish brown, shaly siltstone with fine-grained to medium-grained, sandy beds. Top of section near Monocacy River bridge.
11.0	559.0	Covered.
15.0	548.0	Reddish brown, silty mudstone.
4.0	533.0	Covered.
15.0	529.0	Reddish brown siltstone, with silty, fine-grained sandstone interbeds.
5.0	514.0	Reddish brown, silty, fine-grained sandstone.
12.0	509.0	Reddish brown, silty mudstone with fine-grained sandstone interbeds.
3.0	497.0	Reddish brown, medium-grained sandstone.
30.0	494.0	Covered; Stream valley.
3.0	464.0	Reddish brown, platy, fine-grained sandstone.
18.0	461.0	Covered.
3.0	443.0	Interbedded, reddish brown, medium-grained sandstone, and bioturbated siltstone.
5.0	440.0	Reddish brown, silty mudstone.
18.0	435.0	Interbedded, reddish brown, medium-grained, cross-bedded sandstone and platy siltstone.
12.0	417.0	Interbedded, reddish brown, fine-grained sandstone and platy siltstone.
16.0	405.0	Reddish brown, medium-grained sandstone.
5.0	389.0	Interbedded, reddish brown, fine-grained sandstone and platy siltstone.
20.0	384.0	Interbedded, reddish brown, platy siltstone, and fine-grained sandstone.
35.0	364.0	Covered.
11.0	329.0	Reddish brown to medium grayish brown siltstone.
5.0	318.0	Covered.
5.0	313.0	Reddish brown, medium-grained, punky sandstone.
5.0	308.0	Reddish brown siltstone.
5.0	303.0	Reddish brown, medium-grained sandstone, fining to platy siltstone.
18.0	298.0	Covered.

19.0	280.0	Interbedded, reddish brown siltstone and thin-bedded, fine-grained sandstone.
3.0	261.0	Reddish brown siltstone.
3.0	258.0	Reddish brown, medium-grained sandstone.
10.0	255.0	Covered.
12.0	245.0	Reddish brown siltstone with a few stringers of fine-grained sandstone.
5.0	233.0	Reddish brown siltstone.
25.0	228.0	Reddish brown, medium-grained, medium-bedded sandstone, fining to platy, sandy siltstone.
5.0	203.0	Interbedded, reddish brown siltstone, and silty mudstone.
3.0	198.0	Covered.
7.0	195.0	Reddish brown, medium-grained sandstone.
3.0	188.0	Reddish brown, mudstone with root casts.
6.0	185.0	Reddish brown, medium-grained sandstone with shaly partings.
5.0	179.0	Reddish brown, shaly siltstone.
5.0	174.0	Red-brown, medium-grained sandstone.
6.0	169.0	Interbedded, reddish brown mudstone and siltstone.
2.0	163.0	Reddish brown, medium-grained sandstone.
8.0	161.0	Reddish brown, silty mudstone.
35.0	153.0	Covered.
5.0	118.0	Interbedded, brown, fine-grained sandstone and siltstone.
4.0	113.0	Reddish brown, mudstone with root casts.
3.0	109.0	Reddish brown, coarse-grained sandstone.
8.0	106.0	Covered.
13.0	98.0	Interbedded, reddish brown, silty mudstone and sandy siltstone.
2.0	85.0	Reddish brown mudstone.
20.0	83.0	Reddish brown, medium-grained, medium-bedded sandstone.
7.0	63.0	Interbedded, reddish brown, silty mudstone and siltstone.
6.0	56.0	Reddish brown, coarse-grained sandstone with sharp base.
10.0	50.0	Interbedded, reddish brown, sandy mudstone and siltstone.
5.0	40.0	Reddish brown mudstone.
9.0	35.0	Reddish brown, medium-grained sandstone.
3.0	26.0	Thinly interbedded, mudstone and siltstone.
2.0	23.0	Reddish brown mudstone.
5.0	21.0	Thinly interbedded, reddish brown, mudstone with root casts and siltstone.
3.0	16.0	Reddish brown, silty mudstone.
5.0	13.0	Covered.
3.0	8.0	Reddish brown mudstone.
1.0	5.0	Reddish brown siltstone.
2.0	4.0	Brown, platy siltstone.
2.0	2.0	Reddish brown, silty, fine-grained sandstone.

Locality 24

Section in the Gettysburg Formation along the Maryland Midland Railroad tracks west of the Redland Brick Plant at Rocky Ridge. 39°36'16"N, 77°19'55"W, Woodsboro Quadrangle.

Thickness (feet)		
unit	total	
Gettysburg Formation		
7.0	318.0	Reddish brown, platy, micaceous siltstone.
5.0	311.0	Reddish gray mudstone.
10.0	306.0	Reddish brown, sandy siltstone with shaly partings.
3.0	296.0	Reddish brown, mudstone with root casts.
6.0	293.0	Reddish brown, platy, sandy siltstone.
22.0	287.0	Red-brown, silty mudstone with a few, scattered siltstone beds.
33.0	265.0	Interbedded, reddish brown, platy siltstone and mudstone.
2.0	232.0	Red-brown, mudstone with root casts.
1.0	230.0	Red-brown siltstone.
7.0	229.0	Reddish brown, mudstone with root casts.
5.0	222.0	Reddish brown, platy siltstone.
28.0	217.0	Reddish brown, silty mudstone.
3.0	189.0	Reddish brown, platy siltstone.
37.0	186.0	Reddish brown, root casts, silty mudstone.
6.0	149.0	Reddish brown, thin-bedded siltstone.
5.0	143.0	Reddish brown, silty mudstone with scattered, platy, siltstone beds.
6.0	98.0	Interbedded, reddish brown siltstone and silty mudstone.
41.0	92.0	Reddish brown mudstone with few interbeds of platy, sandy siltstone.
5.0	51.0	Reddish brown, silty sandstone.
12.0	46.0	Reddish, mudstone with root casts.
24.0	34.0	Reddish brown, silty, mudstone with root casts with few interbeds of platy siltstone.
5.0	10.0	Reddish brown, cross-bedded, silty sandstone with conglomerate at base.
5.0	5.0	Reddish brown, silty, mudstone with root casts (base of section on north side of cut).

APPENDIX II

Table of karst features identified in each quadrangle and plotted on Plate 1. Feature types: ACT = Active sinkhole; Dep = depression; SPR = spring. Units: Tomstown = Tomstown Formation; Frederick Formation units- Monocacy = Monocacy Member; Rocky Spr. Stat. = Rocky Springs Station Member; Adamstown = Adamstown Member; Lime Kiln = Lime Kiln Member. Grove Formation units- Ceresville = Ceresville Member; Fountain Rx = Fountain Rock Member; Woodsboro = Woodsboro Member. Leesburg = Leesburg Formation. Easting and Northing = Coordinates of feature in State Plane, NAD 1983, meters.

BUCKEYSTOWN QUADRANGLE

Number	Type	Unit	Easting	Northing
1	DEP	Fountain Rx	362936.746	187274.6038
2	DEP	Fountain Rx	364459.836	189529.2924
3	ACT	Fountain Rx	363372.659	188103.7674
4	DEP	Fountain Rx	363324.169	188695.2913
5	DEP	Fountain Rx	363335.31	188728.4905
6	DEP	Fountain Rx	363551.612	188265.7778
7	ACT	Fountain Rx	363724.253	188548.8577
8	DEP	Fountain Rx	363715.262	188529.9955
9	DEP	Fountain Rx	363651.22	188446.6104
10	ACT	Fountain Rx	363733.362	188442.9873
11	DEP	Fountain Rx	363724.883	188488.4022
12	ACT	Fountain Rx	363730.825	188518.3563
13	DEP	Fountain Rx	363739.148	188586.2979
14	DEP	Fountain Rx	363766.607	188613.314
15	DEP	Fountain Rx	363500.897	188967.1632
16	ACT	Fountain Rx	363591.999	188865.6009
17	DEP	Fountain Rx	363519.932	189188.1302
18	DEP	Fountain Rx	363463.36	189201.8109
19	ACT	Fountain Rx	363523.286	189393.1885
20	DEP	Fountain Rx	363384.622	188888.3859
21	DEP	Fountain Rx	363328.163	188752.6267
22	DEP	Fountain Rx	363146.74	188599.6222
23	ACT	Ceresville	362690.284	187898.3602
24	ACT	Ceresville	362738.029	187804.1838
25	ACT	Fountain Rx	362922.595	187720.6383
26	DEP	Fountain Rx	362898.884	187617.2034
27	DEP	Fountain Rx	362893.197	187664.9241
28	DEP	Fountain Rx	362898.889	187717.2751
29	ACT	Fountain Rx	362891.239	187566.0339
30	DEP	Fountain Rx	362918.56	187543.7762
31	DEP	Fountain Rx	362928.283	187473.8311
32	DEP	Fountain Rx	362909.964	187349.0213
33	ACT	Lime Kiln	364614.649	189603.9109
34	DEP	Lime Kiln	364666.444	189152.5512
35	SPR	Adamstown	360924.882	185499.0506
36	DEP	Adamstown	361323.801	187142.2616
37	DEP	Adamstown	361360.045	187302.3191
38	SPR	Adamstown	361228.1	186929.0457
39	SPR	Adamstown	361183.475	186702.6116
40	ACT	Fountain Rx	361772.65	184885.814
41	ACT	Fountain Rx	361646.149	184802.1522
42	DEP	Fountain Rx	361802.579	185341.1817
43	DEP	Fountain Rx	361846.051	185327.9325
44	ACT	Fountain Rx	361926.052	185251.8808
45	DEP	Fountain Rx	361839.377	185403.9567
46	DEP	Fountain Rx	361849.232	185408.735
47	DEP	Fountain Rx	362024.182	185784.675
48	DEP	Fountain Rx	362400.094	185966.5393
49	DEP	Fountain Rx	362496.799	186228.2771
50	DEP	Fountain Rx	362584.893	186293.3781
51	DEP	Fountain Rx	362768.085	186418.6674
52	ACT	Fountain Rx	362751.519	186466.7604
53	DEP	Fountain Rx	362638.138	186446.7433
54	ACT	Fountain Rx	361747.141	185488.7573
55	ACT	Ceresville	361388.672	184845.1428
56	ACT	Ceresville	361451.793	184836.267
57	ACT	Ceresville	361468.9	184959.4933
58	DEP	Ceresville	361524.799	185058.4694
59	DEP	Ceresville	361497.023	185002.3852
60	ACT	Ceresville	361828.135	185009.4331
61	DEP	Lime Kiln	361468.466	185216.6459
62	ACT	Lime Kiln	361770.641	185994.444
63	DEP	Rocky Spr Stn	361551.672	187955.8303
64	DEP	Rocky Spr Stn	361184.938	187179.989
65	DEP	Rocky Spr Stn	361001.842	187412.8578
66	DEP	Rocky Spr Stn	361030.08	187427.7514
67	DEP	Rocky Spr Stn	361050.908	187424.1244
68	DEP	Rocky Spr Stn	360776.137	187472.3418
69	DEP	Rocky Spr Stn	360818.731	187550.3023
70	DEP	Rocky Spr Stn	360727.62	187639.895
71	DEP	Rocky Spr Stn	360742.053	187702.8602
72	DEP	Rocky Spr Stn	360031.872	187299.5257
73	DEP	Rocky Spr Stn	360238.752	186944.9617
74	ACT	Rocky Spr Stn	360499.474	187022.6861
75	DEP	Rocky Spr Stn	360574.986	187070.381
76	DEP	Rocky Spr Stn	360671.978	187175.8926

77	DEP	Lime Kiln	362509.968	188421.8936
78	DEP	Lime Kiln	362734.871	188652.0142
79	DEP	Lime Kiln	360598.681	183595.5761
80	DEP	Lime Kiln	360649.099	183595.2717
81	DEP	Lime Kiln	360884.109	183576.9022
82	DEP	Lime Kiln	360951.179	183585.1067
83	DEP	Lime Kiln	360937.745	183506.8316
84	DEP	Lime Kiln	360897.775	183504.0813
85	DEP	Lime Kiln	360830.987	183498.4038
86	DEP	Lime Kiln	360986.39	183487.3461
87	DEP	Lime Kiln	360923.981	183319.3116
88	DEP	Lime Kiln	360874.624	183300.1593
89	DEP	Lime Kiln	360918.334	183260.9817
90	DEP	Lime Kiln	360950.649	183233.2405
91	DEP	Lime Kiln	360882.05	183182.9579
92	DEP	Lime Kiln	360843.379	183154.2559
93	DEP	Lime Kiln	360778.378	183156.1282
94	DEP	Lime Kiln	360850.273	183259.8011
95	DEP	Lime Kiln	360828.526	183216.6457
96	DEP	Lime Kiln	360760.964	183265.0407
97	DEP	Lime Kiln	360809.849	183283.25
98	DEP	Lime Kiln	360810.096	183338.9522
99	DEP	Lime Kiln	360830.3	183409.4153
100	ACT	Lime Kiln	360788.65	183353.7415
1	DEP	Lime Kiln	360754.34	183379.0953
2	DEP	Lime Kiln	360732.949	183407.0804
3	DEP	Lime Kiln	360689.671	183290.2351
4	ACT	Lime Kiln	360659.739	183466.6399
5	ACT	Lime Kiln	360657.997	183494.819
6	DEP	Lime Kiln	360653.771	183523.5068
7	ACT	Lime Kiln	360654.642	183555.0822
8	DEP	Fountain Rx	363253.918	187314.6904
9	DEP	Fountain Rx	363523.137	187699.748
110	DEP	Fountain Rx	363538.319	187770.7494
11	DEP	Ceresville	363599.866	187695.4924
12	DEP	Ceresville	363667.374	187792.9929
13	DEP	Ceresville	363595.208	187522.3377
14	ACT	Ceresville	363606.794	187566.1078
15	DEP	Fountain Rx	363264.354	187963.7419
16	DEP	Fountain Rx	363188.269	187807.6621
17	DEP	Fountain Rx	363107.855	187935.1344
18	DEP	Fountain Rx	363145.353	187903.3907
19	ACT	Fountain Rx	363235.417	188014.0423
120	ACT	Fountain Rx	363088.875	188089.1909
21	DEP	Ceresville	363480.747	187423.1229
22	DEP	Adamstown	362774.329	185386.9646
23	DEP	Lime Kiln	362452.174	188421.4853
24	DEP	Lime Kiln	362608.757	188731.1498
25	DEP	Lime Kiln	362567.632	188911.4612
26	DEP	Adamstown	362216.496	188732.3056
27	DEP	Adamstown	362333.407	188576.5803
28	DEP	Adamstown	362386.183	188610.3495
29	DEP	Adamstown	362402.777	188697.6879
130	DEP	Adamstown	362428.713	188578.5782
31	DEP	Lime Kiln	362587.394	188612.0201
32	ACT	Adamstown	362176	188928.2059
33	DEP	Rocky Spr Stn	361903.925	189152.1541
34	DEP	Rocky Spr Stn	362110.211	188773.169
35	DEP	Rocky Spr Stn	362081.728	188725.48
36	DEP	Rocky Spr Stn	362194.936	188825.2305
37	DEP	Rocky Spr Stn	361703.245	188403.301
38	DEP	Lime Kiln	361012.596	182870.0217
39	ACT	Lime Kiln	360880.972	183740.5069
140	ACT	Lime Kiln	360871.736	183774.5473
41	DEP	Lime Kiln	360923.926	183890.9087
42	DEP	Lime Kiln	360663.887	183661.1685
43	DEP	Lime Kiln	360621.042	183750.4514
44	DEP	Lime Kiln	360636.576	183769.5503
45	DEP	Lime Kiln	360633.011	183781.4207
46	ACT	Lime Kiln	360928.983	184028.5584
47	ACT	Lime Kiln	360937.047	184039.8658
48	ACT	Lime Kiln	360930.128	184107.806
49	SPR	Lime Kiln	361077.987	184388.879
150	DEP	Lime Kiln	360965.704	184381.9145
51	DEP	Lime Kiln	360969.711	184541.6982
52	ACT	Lime Kiln	360950.323	184621.4264
53	DEP	Lime Kiln	360803.294	184474.0119
54	DEP	Lime Kiln	360761.885	184433.2959
55	ACT	Lime Kiln	360729.728	184405.9696
56	DEP	Lime Kiln	360804.766	184353.9631
57	ACT	Lime Kiln	360694.261	184371.5903
58	DEP	Lime Kiln	360668.593	183843.7476
59	DEP	Lime Kiln	361006.256	182939.1112
160	DEP	Lime Kiln	361097.848	183035.4902
61	DEP	Lime Kiln	360953.498	183034.9569
62	ACT	Lime Kiln	360921.41	182961.8615
63	DEP	Lime Kiln	361038.276	182791.0323
64	DEP	Lime Kiln	361049.087	182880.9065
65	DEP	Lime Kiln	361098.887	182935.9529
66	DEP	Lime Kiln	360869.852	183652.7181
67	ACT	Lime Kiln	361132.819	183164.3766
68	DEP	Lime Kiln	361145.331	183085.669
69	DEP	Lime Kiln	361178.43	182904.7987
170	ACT	Ceresville	361228.008	182898.4816
71	DEP	Rocky Spr Stn	359706.585	185616.8813
72	DEP	Rocky Spr Stn	359814.224	184429.2719
73	DEP	Rocky Spr Stn	360044.23	184286.0241
74	DEP	Rocky Spr Stn	359617.859	186012.4061
75	DEP	Rocky Spr Stn	359680.432	186098.6565
76	DEP	Rocky Spr Stn	359729.94	186156.5528

77	DEP	Rocky Spr Stn	359748.852	186219.08
78	DEP	Rocky Spr Stn	359795.817	186259.093
79	DEP	Rocky Spr Stn	359828.778	186219.8196
180	DEP	Rocky Spr Stn	359868.482	186164.1273
81	DEP	Rocky Spr Stn	359825.45	186021.5132
82	DEP	Rocky Spr Stn	359917.114	186045.1774
83	DEP	Rocky Spr Stn	360058.1	186044.9002
84	DEP	Rocky Spr Stn	360024.089	186101.6572
85	DEP	Rocky Spr Stn	359963.103	186162.7594
86	DEP	Rocky Spr Stn	359919.574	186286.2349
87	DEP	Rocky Spr Stn	360078.924	186238.6149
88	DEP	Rocky Spr Stn	360078.702	186149.0338
89	DEP	Rocky Spr Stn	360141.982	186121.5716
190	DEP	Rocky Spr Stn	360216.177	186171.006
91	DEP	Rocky Spr Stn	360354.035	186557.2605
92	DEP	Rocky Spr Stn	360274.466	186644.6884
93	DEP	Rocky Spr Stn	360316.135	186690.389
94	DEP	Rocky Spr Stn	360181.381	186758.9917
95	DEP	Rocky Spr Stn	360146.196	186724.8752
96	DEP	Rocky Spr Stn	360151.371	186853.7242
97	DEP	Rocky Spr Stn	360112.626	186464.9381
98	DEP	Rocky Spr Stn	360181.754	186418.8704
99	DEP	Rocky Spr Stn	359709.647	185951.2368
200	DEP	Rocky Spr Stn	359789.797	185964.0484
1	DEP	Rocky Spr Stn	359894.761	185925.0216
2	DEP	Rocky Spr Stn	359953.18	185934.1599
3	DEP	Rocky Spr Stn	359975.873	185887.5475
4	DEP	Rocky Spr Stn	360043.71	185826.8548
5	DEP	Rocky Spr Stn	360110.018	185833.1176
6	DEP	Rocky Spr Stn	360028.034	185966.4596
7	DEP	Rocky Spr Stn	360214.414	185925.6606
8	DEP	Rocky Spr Stn	360256.883	185811.8955
9	DEP	Rocky Spr Stn	360024.264	185753.7805
210	DEP	Rocky Spr Stn	360045.941	185693.1215
11	DEP	Rocky Spr Stn	360042.3	185580.7741
12	DEP	Rocky Spr Stn	359992.469	185563.8911
13	DEP	Rocky Spr Stn	359715.406	185477.0758
14	DEP	Adamstown	360114.059	183836.6736
15	DEP	Adamstown	359604.649	183279.0192
16	DEP	Adamstown	359596.793	183108.9148
17	DEP	Adamstown	359839.531	183101.2536
18	DEP	Adamstown	359977.302	183109.5013
19	DEP	Adamstown	360002.72	183221.0223
220	DEP	Adamstown	360072.443	183215.3449
21	DEP	Adamstown	360035.361	183341.6415
22	DEP	Adamstown	359961.526	183328.5754
23	DEP	Adamstown	360439.212	183074.1469
24	DEP	Adamstown	359955.434	182820.9801
25	DEP	Adamstown	360462.625	184468.2751
26	ACT	Adamstown	360448.206	184591.0169

27	DEP	Adamstown	360478.534	184630.0405
28	DEP	Adamstown	360372.902	186045.9355
29	DEP	Adamstown	360288.639	185925.8808
230	DEP	Adamstown	360478.277	184089.9159
31	DEP	Leesburg Fm	358217.419	189424.9554
32	DEP	Leesburg Fm	356924.372	184834.199
33	DEP	Leesburg Fm	356987.252	184970.87
34	DEP	Leesburg Fm	356981.611	184824.75
35	DEP	Leesburg Fm	358368.61	180143.0763
36	DEP	Leesburg Fm	358333.661	189302.8489
37	DEP	Leesburg Fm	358412.477	189396.4936
38	DEP	Leesburg Fm	358476.08	189285.1849
39	DEP	Leesburg Fm	358368.401	189330.1165
240	DEP	Rocky Spr Stn	359737.061	184230.5245
41	DEP	Rocky Spr Stn	360193.158	185432.0992
42	DEP	Rocky Spr Stn	360081.108	185402.4911
43	DEP	Rocky Spr Stn	360122.202	185314.667
44	DEP	Rocky Spr Stn	360054.771	185269.921
45	DEP	Rocky Spr Stn	360127.541	185165.7704
46	DEP	Rocky Spr Stn	359714.255	185473.59
47	SPR	Rocky Spr Stn	359562.266	187206.706
48	DEP	Rocky Spr Stn	358511.622	180269.4082
49	SPR	Rocky Spr Stn	358976.35	182975.8645
250	DEP	Rocky Spr Stn	359482.382	183964.0754
51	DEP	Adamstown	360223.91	185224.0253
52	DEP	Adamstown	360796.841	185888.4532
53	DEP	Adamstown	360599.842	185004.9391
54	DEP	Adamstown	359511.463	180970.1856
55	DEP	Adamstown	359495.159	180905.5092
56	DEP	Adamstown	359720.571	180977.8594
57	DEP	Adamstown	359713.182	180469.4048
58	DEP	Adamstown	359804.261	180440.7137
59	DEP	Adamstown	360795.031	180420.1607
260	DEP	Adamstown	360789.368	180589.866
61	DEP	Lime Kiln	361099.313	185211.5385
62	DEP	Lime Kiln	361076.087	185204.86
63	ACT	Lime Kiln	361353.713	185329.804
64	DEP	Lime Kiln	361276.869	185419.4528
65	SPR	Lime Kiln	361076.695	185590.3794
66	DEP	Lime Kiln	361299.545	185822.5862
67	DEP	Lime Kiln	361565.192	185874.0906
68	DEP	Lime Kiln	361697.06	186173.3509
69	DEP	Lime Kiln	361623.383	186246.0104
170	ACT	Lime Kiln	362617.307	188225.0536
71	DEP	Lime Kiln	362530.937	187950.9725
72	DEP	Lime Kiln	360648.741	182072.6629
73	DEP	Fountain Rx	362730.625	187621.1172
74	DEP	Fountain Rx	362703.02	187551.9659
75	DEP	Fountain Rx	362753.228	187291.1266
76	DEP	Fountain Rx	362841.044	187311.0928

77	ACT	Fountain Rx	362850.166	187302.7009
78	ACT	Fountain Rx	362861.006	187297.7592
79	DEP	Fountain Rx	362977.165	186816.9898
280	ACT	Fountain Rx	362791.564	186679.1616
81	DEP	Fountain Rx	362860.742	186862.3112
82	DEP	Leesburg Fm	358394.119	180238.3353
83	DEP	Leesburg Fm	357335.126	186268.9596
84	DEP	Leesburg Fm	358409.21	189641.4926
85	DEP	Leesburg Fm	358393.771	189725.4631
86	DEP	Leesburg Fm	358345.261	189697.1692
87	DEP	Leesburg Fm	358369.407	189747.9853
88	DEP	Leesburg Fm	358330.638	189645.9097
89	DEP	Leesburg Fm	358317.082	189694.1632
290	DEP	Leesburg Fm	358251.203	189686.801
91	DEP	Leesburg Fm	358358.898	189491.8647
92	DEP	Leesburg Fm	358397.853	189461.3405
93	DEP	Leesburg Fm	358487.247	189489.2623
94	DEP	Leesburg Fm	358389.311	189542.389
95	DEP	Leesburg Fm	358483.586	189550.6328
96	DEP	Leesburg Fm	358594.786	189599.615
97	DEP	Leesburg Fm	358204.23	189536.6423
98	DEP	Leesburg Fm	358328.485	189753.5156
99	DEP	Leesburg Fm	357627.454	188200.4789
300	DEP	Leesburg Fm	357692.032	188363.3732
1	DEP	Leesburg Fm	357882.565	188555.4578
2	DEP	Leesburg Fm	357538.694	188670.275
3	DEP	Leesburg Fm	357605.295	188679.617
4	DEP	Leesburg Fm	357518.42	188692.146
5	DEP	Leesburg Fm	357602.252	189041.032
6	DEP	Leesburg Fm	358012.131	189092.8117
7	DEP	Leesburg Fm	358088.721	188902.5235
8	DEP	Leesburg Fm	357906.084	188931.5307
9	DEP	Leesburg Fm	358026.123	188760.946
310	DEP	Leesburg Fm	357968.142	188649.0562
11	DEP	Leesburg Fm	357918.788	188640.7746
12	DEP	Leesburg Fm	357986.439	188600.0708
13	DEP	Leesburg Fm	358014.154	188532.9985
14	DEP	Leesburg Fm	358043.082	188249.0675
15	DEP	Leesburg Fm	358022.258	188216.6401
16	DEP	Leesburg Fm	358161.167	188195.9905
17	DEP	Leesburg Fm	358181.874	188159.4129
18	DEP	Leesburg Fm	358200.9	188126.3071
19	DEP	Leesburg Fm	358236.415	188189.7343
320	DEP	Leesburg Fm	358263.555	188182.718
21	DEP	Leesburg Fm	358307.399	188246.5543
22	DEP	Leesburg Fm	358310.881	188048.7318
23	DEP	Leesburg Fm	358383.381	188042.9001
24	DEP	Leesburg Fm	358357.302	187976.79
25	DEP	Leesburg Fm	358639.029	189283.1285
26	DEP	Leesburg Fm	358294.847	189439.6969
27	DEP	Leesburg Fm	356945.191	185027.6521
28	DEP	Leesburg Fm	357033.826	185035.9617
29	SPR	Leesburg Fm	357100.891	185576.3473
330	DEP	Leesburg Fm	357271.064	186289.7618
31	DEP	Leesburg Fm	357299.577	186341.6829
32	DEP	Leesburg Fm	357255.751	186225.7843
33	DEP	Leesburg Fm	358462.377	189679.9742
34	DEP	Fountain Rx	362521.449	185588.7101
35	DEP	Lime Kiln	361989.386	184136.694
36	DEP	Lime Kiln	361308.653	182769.0125
37	DEP	Fountain Rx	363049.239	186578.9473
38	ACT	Fountain Rx	363103.204	186700.6667
39	DEP	Fountain Rx	363037.075	186691.7123
340	DEP	Fountain Rx	363062.38	186757.3205
41	DEP	Ceresville	363197.228	186692.9867
42	DEP	Lime Kiln	362854.248	185658.3013
43	DEP	Lime Kiln	362842.756	185682.9668
44	DEP	Lime Kiln	362884.267	185847.4321
45	DEP	Leesburg Fm	358085.848	188014.0628
46	DEP	Leesburg Fm	358186.241	187951.697
47	DEP	Leesburg Fm	357860.02	187996.4553
48	DEP	Leesburg Fm	357795.569	187922.8832
49	DEP	Leesburg Fm	357727.516	187840.799
350	DEP	Leesburg Fm	357765.15	187763.2776
51	DEP	Leesburg Fm	357747.327	187689.2427
52	DEP	Leesburg Fm	357741.718	187646.0896
53	DEP	Leesburg Fm	357672.169	187717.4555
54	DEP	Leesburg Fm	357647.17	187742.0193
55	DEP	Leesburg Fm	357721.11	187845.9493
56	DEP	Leesburg Fm	357651.196	187679.017
57	DEP	Leesburg Fm	357590.836	187701.6342
58	DEP	Leesburg Fm	357555.081	187726.776
59	DEP	Leesburg Fm	357609.859	187673.1545
360	DEP	Leesburg Fm	357614.879	187609.4073
61	DEP	Leesburg Fm	357531.029	187687.9481
62	DEP	Leesburg Fm	357626.402	187636.0894
63	DEP	Leesburg Fm	357657.228	187620.8233
64	DEP	Leesburg Fm	357604.503	187560.2115
65	DEP	Leesburg Fm	357567.493	187552.5995
66	DEP	Leesburg Fm	357709.842	187520.4461
67	DEP	Leesburg Fm	357653.994	187487.7229
68	DEP	Leesburg Fm	357558.013	187488.028
69	DEP	Leesburg Fm	357619.006	187466.8259
370	DEP	Leesburg Fm	357701.789	187412.4026
71	DEP	Leesburg Fm	357778.708	187396.9615
72	DEP	Leesburg Fm	357546.192	187001.2032
73	DEP	Leesburg Fm	357148.819	186737.9258
74	DEP	Leesburg Fm	357242.645	186586.5122
75	DEP	Leesburg Fm	357247.052	186764.9349
76	DEP	Leesburg Fm	357238.429	186828.453

77	DEP	Leesburg Fm	357204.274	186821.1203	**27**	ACT	Fountain Rx	363497.503	188175.5347
78	DEP	Leesburg Fm	357147.118	186784.2279	**28**	ACT	Fountain Rx	363583.849	188123.3617
79	DEP	Leesburg Fm	357234.754	186885.5594	**29**	ACT	Fountain Rx	363587.988	188122.683
380	DEP	Leesburg Fm	357124.923	186922.4302	**430**	ACT	Fountain Rx	363613.179	188093.0435
81	DEP	Leesburg Fm	357057.255	186950.3282	**31**	ACT	Fountain Rx	363773.804	188033.857
82	DEP	Leesburg Fm	357269.237	186980.6845	**32**	DEP	Lime Kiln	363008.35	186147.4436
83	DEP	Leesburg Fm	357248.583	187030.9176	**33**	SPR	Adamstown	359902.561	179031.8532
84	DEP	Leesburg Fm	357143.533	186950.2808	**34**	DEP	Rocky Spr Stn	358591.032	176388.294
85	DEP	Leesburg Fm	357147.371	187065.301	**35**	DEP	Rocky Spr Stn	358896.098	176939.631
86	DEP	Leesburg Fm	357204.128	187098.1322	**36**	DEP	Rocky Spr Stn	358894.008	176923.777
87	DEP	Leesburg Fm	357630.381	188452.1677	**37**	DEP	Rocky Spr Stn	358839.559	176643.038
88	DEP	Leesburg Fm	358201.174	188031.4748	**38**	DEP	Rocky Spr Stn	358835.774	176631.675
89	DEP	Rocky Spr Stn	366982.185	189403.4203	**39**	ACT	Ceresville	363669.009	188076.174
390	DEP	Rocky Spr Stn	361421.453	187614.8742	**440**	ACT	Ceresville	363676.735	188078.271
91	DEP	Lime Kiln	362247.941	184400.214	**41**	ACT	Fountain Rx	363655.998	188069.817
92	DEP	Lime Kiln	363091.126	186276.1306	**42**	ACT	Fountain Rx	363657.386	188077.863
93	DEP	Lime Kiln	363128.539	186261.4692	**43**	ACT	Fountain Rx	363554.903	188119.385
94	DEP	Lime Kiln	360672.247	182959.6739	**44**	ACT	Fountain Rx	363664.661	188076.337
95	ACT	Ceresville	361199.879	182256.21	**45**	ACT	Fountain Rx	363577.33	188129.582
96	DEP	Lime Kiln	361554.535	182295.0355	**46**	DEP	Fountain Rx	362759.601	187557.606
97	DEP	Lime Kiln	361518.729	182373.6907	**47**	ACT	Fountain Rx	362650.535	187230.761
98	DEP	Lime Kiln	361583.797	182403.0942	**48**	ACT	Fountain Rx	362858.235	187308.184
99	DEP	Lime Kiln	361624.473	182485.6926	**49**	ACT	Fountain Rx	363614.786	188086.774
400	DEP	Lime Kiln	361599.698	182854.4676	**450**	ACT	Fountain Rx	363497.735	188156.693
1	DEP	Lime Kiln	361583.644	182804.015	**51**	ACT	Fountain Rx	363512.398	188171.606
2	DEP	Lime Kiln	361689.701	182883.9569	**52**	DEP	Fountain Rx	363513.043	188171.348
3	DEP	Lime Kiln	361692.483	182836.6653	**53**	ACT	Fountain Rx	363508.366	188171.091
4	DEP	Lime Kiln	361817.56	182875.2335	**54**	DEP	Lime Kiln	363008.349	186147.444
5	DEP	Lime Kiln	361783.67	182786.0176	**55**	SPR	Adamstown	359902.561	179031.854
6	DEP	Lime Kiln	361762.805	182720.1839	**56**	DEP	Rocky Spr Stn	365417.42	189570.787
7	DEP	Lime Kiln	361735.292	182681.9001	**57**	DEP	Rocky Spr Stn	365228.486	189651.465
8	DEP	Lime Kiln	361694.495	182606.739	**58**	DEP	Lime Kiln	364682.51	189600.383
9	DEP	Lime Kiln	361650.713	182580.3372	**59**	ACT	Lime Kiln	364696.788	189645.142
410	DEP	Lime Kiln	361650.524	182549.8919	**460**	DEP	Fountain Rx	362104.714	185763.745
11	DEP	Lime Kiln	360707.369	182857.1321	**61**	ACT	Fountain Rx	363655.998	188069.817
12	DEP	Lime Kiln	360709.053	182857.8442	**62**	ACT	Fountain Rx	363657.386	188077.863
13	DEP	Adamstown	359797.37	182735.3828	**63**	ACT	Fountain Rx	363554.903	188119.385
14	DEP	Adamstown	361028.323	181367.1826	**64**	ACT	Fountain Rx	363664.661	188076.337
15	DEP	Adamstown	361135.621	181358.4223	**65**	ACT	Fountain Rx	363577.33	188129.582
16	DEP	Adamstown	361682.036	182328.062	**66**	SPR	Fountain Rx	364009.429	189962.823
17	DEP	Adamstown	361773.068	182337.4892	**67**	ACT	Fountain Rx	364019.057	189962.193
18	DEP	Adamstown	361827.336	182290.4853	**68**	ACT	Fountain Rx	363636.901	188111.215
19	DEP	Adamstown	359565.932	180183.5496	**69**	ACT	Fountain Rx	363637.724	188100.141
420	DEP	Leesburg Fm	357549.765	187449.3579	**470**	ACT	Fountain Rx	363630.861	188080.8
21	DEP	Leesburg Fm	358242.378	188094.4233	**71**	ACT	Fountain Rx	363633.745	188082.302
22	DEP	Leesburg Fm	358309.045	188088.9494	**72**	ACT	Fountain Rx	363640.226	188084.602
23	DEP	Fountain Rx	362907.167	186020.9625	**73**	ACT	Fountain Rx	363642.811	188084.683
24	ACT	Lime Kiln	360601.775	183579.6291	**74**	ACT	Fountain Rx	363646.875	188090.9
25	DEP	Lime Kiln	363058.968	186155.558	**75**	ACT	Fountain Rx	363649.7	188088.221
26	ACT	Fountain Rx	363581.853	188118.9755	**76**	ACT	Fountain Rx	363644.277	188084.025

77	ACT	Fountain Rx	363650.898	188089.864
78	ACT	Fountain Rx	363656.215	188078.556
79	ACT	Fountain Rx	363631.194	188111.165
480	ACT	Fountain Rx	363641.557	188099.474
81	ACT	Fountain Rx	363641.355	188106.365
82	ACT	Fountain Rx	363652.899	188094.909
83	ACT	Fountain Rx	363653.684	188093.554
84	DEP	Fountain Rx	361739.91	185493.066
85	DEP	Fountain Rx	361736.33	185497.432
86	DEP	Fountain Rx	362138.047	185215.181
87	DEP	Fountain Rx	362148.212	185261.122
88	SPR	Fountain Rx	362229.487	185407.559
89	SPR	Fountain Rx	362379.063	185290.8
490	DEP	Fountain Rx	363403.786	187551.644
91	DEP	Fountain Rx	362759.601	187557.606
92	ACT	Fountain Rx	362650.535	187230.761
93	ACT	Fountain Rx	362858.235	187308.184
94	ACT	Fountain Rx	363614.786	188086.774
95	ACT	Fountain Rx	363497.735	188156.693
96	ACT	Fountain Rx	363512.398	188171.606
97	ACT	Fountain Rx	363513.043	188171.348
98	ACT	Fountain Rx	363508.366	188171.091
99	DEP	Fountain Rx	362298.846	185446.852
500	ACT	Fountain Rx	362297.21	185526.077
1	DEP	Fountain Rx	361825.748	185754.318
2	DEP	Fountain Rx	361834.528	185610.438
3	DEP	Fountain Rx	361819.444	185599.865
4	ACT	Fountain Rx	363628.54	188125.813
5	ACT	Fountain Rx	363598.904	188178.111
6	ACT	Fountain Rx	361881.778	185341.201
7	SPR	Fountain Rx	364015.519	188608.787
8	DEP	Fountain Rx	361889.775	185372.328
9	DEP	Fountain Rx	361885.334	185362.7
510	DEP	Fountain Rx	361975.64	185302.305
11	DEP	Fountain Rx	362131.894	185561.672
12	ACT	Fountain Rx	362090.503	185741.753
13	ACT	Ceresville	363669.009	188076.174
14	ACT	Ceresville	363676.735	188078.271
15	ACT	Lime Kiln	363237.848	186718.438
16	DEP	Rocky Spr Stn	358896.098	176939.631
17	DEP	Rocky Spr Stn	358894.008	176923.777
18	DEP	Rocky Spr Stn	358839.559	176643.038
19	DEP	Rocky Spr Stn	358835.774	176631.675
520	DEP	Rocky Spr Stn	358591.032	176388.294
21	ACT	Lime Kiln	360853.005	184203.207
22	ACT	Fountain Rx	363652.766	188093.074
23	ACT	Fountain Rx	363647.35	188083.917
24	ACT	Fountain Rx	363647.923	188090.087
25	ACT	Fountain Rx	363642.544	188092.845
26	ACT	Fountain Rx	363641.75	188097.864
27	ACT	Fountain Rx	363646.292	188100.333
28	ACT	Fountain Rx	363647.616	188097.052
29	ACT	Fountain Rx	363638.055	188099.14
530	ACT	Fountain Rx	363640.574	188084.074
31	ACT	Fountain Rx	363665.148	188083.111
32	ACT	Fountain Rx	363652.552	188072.053
33	ACT	Fountain Rx	363653.878	188096.824
34	ACT	Fountain Rx	363646.81	188089.098

FREDERICK QUADRANGLE

1	DEP	Lime Kiln	365546.307	192849.454
2	ACT	Lime Kiln	366172.156	192558.352
3	ACT	Lime Kiln	365362.394	192818.851
4	ACT	Lime Kiln	365529.696	192802.73
5	ACT	Lime Kiln	365523.223	192811.76
6	ACT	Lime Kiln	365535.32	192824.715
7	ACT	Lime Kiln	365659.713	192909.915
8	DEP	Lime Kiln	365706.536	192913.043
9	ACT	Lime Kiln	365891.125	193076.356
10	ACT	Lime Kiln	366504.882	193610.795
11	ACT	Lime Kiln	366375.333	193630.056
12	ACT	Lime Kiln	366353.028	193638.298
13	ACT	Lime Kiln	366532.328	193651.097
14	DEP	Ceresville	364608.11	189861.41
15	DEP	Ceresville	364695.989	190097.131
16	DEP?	Fountain Rx	364701.021	190017.169
17	ACT	Fountain Rx	364632	190087.26
18	DEP	Fountain Rx	365470.22	191428.091
19	ACT	Fountain Rx	365515.364	191461.415
20	DEP	Fountain Rx	365150.794	191361.378
21	ACT	Ceresville	363903.975	190357.36
22	DEP	Ceresville	363875.544	190290.284
23	ACT	Ceresville	363863.646	190231.074
24	ACT	Lime Kiln	365769.958	191150.249
25	DEP	Lime Kiln	365698.74	191058.679
26	DEP	Lime Kiln	365727.366	191099.581
27	DEP	Lime Kiln	365612.586	191002.814
28	ACT	Lime Kiln	365832.439	191273.147
29	DEP	Rocky Spr Stn	363378.743	192739.439
30	DEP	Rocky Spr Stn	363261.178	192589.209
31	DEP	Rocky Spr Stn	363328.022	192592.51
32	DEP	Rocky Spr Stn	363351.991	192546.808
33	DEP	Rocky Spr Stn	363467.326	192575.38
34	DEP	Rocky Spr Stn	363441.645	192690.846
35	DEP	Rocky Spr Stn	363480.696	192620.727
36	DEP	Rocky Spr Stn	363422.314	192143.841
37	DEP	Adamstown	363664.827	191913.76
38	DEP	Adamstown	363696.263	191857.839
39	DEP	Adamstown	363618.901	191863.598
40	DEP	Lime Kiln	366420.679	193209.981

41	DEP	Lime Kiln	367406.129	199075.257
42	DEP	Lime Kiln	367342.959	199066.772
43	DEP	Lime Kiln	367295.984	199004.75
44	DEP	Lime Kiln	367272.239	199090.964
45	ACT	Lime Kiln	367542.327	197175.085
46	ACT	Lime Kiln	367578.754	197168.37
47	DEP	Lime Kiln	367616.638	197083.901
48	ACT	Lime Kiln	367511.276	197092.489
49	DEP	Lime Kiln	367362.779	197049.371
50	ACT	Lime Kiln	367374.516	197935.793
51	DEP	Lime Kiln	366216.939	193602.043
52	ACT	Lime Kiln	366101.533	193005.602
53	DEP	Lime Kiln	366312.651	192834.211
54	ACT	Lime Kiln	366234.539	193248.125
55	ACT	Lime Kiln	366416.519	193142.801
56	DEP	Rocky Spr Stn	366029.618	190511.9
57	DEP	Rocky Spr Stn	365808.902	190017.41
58	DEP	Rocky Spr Stn	361132.327	203119.545
59	DEP	Rocky Spr Stn	361872.313	202294.84
60	DEP	Rocky Spr Stn	361912.315	202311.49
61	DEP	Rocky Spr Stn	361892.311	202243.392
62	DEP	Rocky Spr Stn	361798.963	202241.86
63	DEP	Rocky Spr Stn	361770.253	202274.754
64	DEP	Rocky Spr Stn	361672.76	202317.41
65	DEP	Rocky Spr Stn	361764.008	202233.763
66	DEP	Rocky Spr Stn	361727.739	202315.652
67	DEP	Rocky Spr Stn	361730	202353.364
68	DEP	Rocky Spr Stn	361732.509	202408.898
69	DEP	Rocky Spr Stn	361838.101	202338.925
70	DEP	Rocky Spr Stn	361178.578	202095.955
71	DEP	Rocky Spr Stn	361101.277	201961.244
72	DEP	Rocky Spr Stn	361371.057	202121.891
73	DEP	Rocky Spr Stn	361485.203	202202.401
74	DEP	Rocky Spr Stn	361560.195	202278.697
75	SPR	Rocky Spr Stn	361186.521	203271
76	ACT	Ceresville	367729.755	197019.559
77	DEP	Ceresville	367712.405	197087.715
78	DEP	Ceresville	367670.046	197112.118
79	ACT	Ceresville	367615.082	197038.278
80	DEP	Ceresville	367682.684	196996.714
81	ACT	Ceresville	367711.299	196265.486
82	ACT	Ceresville	365730.139	193706.351
83	ACT	Ceresville	365778.59	193613.372
84	ACT	Ceresville	366151.888	193631.835
85	ACT	Ceresville	367706.658	196263.21
86	DEP	Ceresville	364576.561	191587.546
87	ACT	Ceresville	364853.74	191396.806
88	DEP	Lime Kiln	364420.853	191651.569
90	DEP	Adamstown	364115.483	191914.622
91	DEP	Adamstown	364520.428	192361.196

82	ACT	Lime Kiln	365180.99	192814.948
93	ACT	Lime Kiln	364974.43	192279.426
94	ACT	Lime Kiln	364953.471	192270.616
95	DEP	Lime Kiln	364988.729	192313.357
96	ACT	Lime Kiln	365002.901	192331.611
97	ACT	Lime Kiln	364982.432	192326.991
98	ACT	Lime Kiln	365047.795	192488.807
99	ACT	Lime Kiln	365042.655	192477.662
100	ACT	Lime Kiln	365382.867	192537.31
1	DEP	Lime Kiln	365128.992	192213.095
2	DEP	Lime Kiln	365137.053	192211.926
3	ACT	Lime Kiln	365125.256	192817.789
4	ACT	Lime Kiln	365148.192	192818.749
5	ACT	Lime Kiln	365150.95	192833.309
6	ACT	Lime Kiln	365142.438	192833.388
7	ACT	Lime Kiln	365120.489	192828.651
8	ACT	Lime Kiln	365198.454	192836.523
9	ACT	Lime Kiln	365225.264	192828.893
110	ACT	Lime Kiln	365226.491	192809.389
11	ACT	Lime Kiln	365215.229	192823.26
12	ACT	Lime Kiln	365208.498	192813.76
13	DEP	Rocky Spr Stn	361925.228	195110.833
14	ACT	Lime Kiln	365494.555	192695.737
15	ACT	Lime Kiln	365548.449	192701.939
16	ACT	Lime Kiln	365528.2	192668.915
17	DEP	Lime Kiln	365545.141	192699.51
18	DEP	Lime Kiln	365558.213	192703.298
19	ACT	Ceresville	365869.467	192818.943
120	ACT	Ceresville	365912.298	192890.057
21	ACT	Ceresville	365929.051	192842.606
22	DEP	Ceresville	365921.044	192823.105
23	DEP	Ceresville	365142.417	191932.994
24	DEP	Leesburg Fm	358304.657	190497.449
25	DEP	Leesburg Fm	358010.457	190152.269
26	DEP	Leesburg Fm	358087.819	190093.68
27	DEP	Leesburg Fm	358113.021	190209.376
28	DEP	Leesburg Fm	358176.371	190585.563
29	DEP	Leesburg Fm	358259.65	190599.872
130	ACT	Leesburg Fm	358390.704	190498.777
31	ACT	Fountain Rx	365282.575	191555.777
32	ACT	Fountain Rx	365287.366	191561.936
33	ACT	Fountain Rx	365281.987	191567.309
34	ACT	Fountain Rx	365292.371	191586.787
35	ACT	Fountain Rx	365207.775	191542.667
36	ACT	Fountain Rx	365218.3	191541.839
37	ACT	Ceresville	366141.156	192808.873
38	ACT	Lime Kiln	366156.681	192802.805
39	ACT	Lime Kiln	366119.921	192838.719
140	ACT	Ceresville	365213.744	191574.323
41	DEP	Adamstown	367037.752	193031.168

42	DEP	Adamstown	367157.639	193115.763
43	DEP	Adamstown	366759.536	192931.149
44	DEP	Adamstown	366664.72	192950.432
45	DEP	Adamstown	366632.961	192885.427
46	DEP	Adamstown	366573.411	192882.61
47	DEP	Adamstown	366549.702	191760.541
48	DEP	Adamstown	366564.473	191914.232
49	ACT	Adamstown	366984.509	192977.888
150	ACT	Adamstown	366876.903	193003.036
51	ACT	Adamstown	366790.768	192962.012
52	ACT	Adamstown	366793.147	192963.776
53	ACT	Adamstown	366803.312	192963.17
54	ACT	Adamstown	366833.865	192955.086
55	ACT	Lime Kiln	366423.193	192214.944
56	ACT	Lime Kiln	366156.965	192549.773
57	ACT	Lime Kiln	366435.513	192218.748
58	ACT	Lime Kiln	366593.6	193034.163
59	ACT	Lime Kiln	366513.382	193021.825
160	ACT	Lime Kiln	366408.999	193024.423
61	ACT	Lime Kiln	366569.197	192976.21
62	ACT	Lime Kiln	366624.439	193002.423
63	ACT	Lime Kiln	366625.253	192976.925
64	ACT	Lime Kiln	366651.766	192971.207
65	ACT	Lime Kiln	366659.54	192970.331
66	ACT	Lime Kiln	366166.094	192683.041
67	ACT	Lime Kiln	366175.582	192687.932
68	ACT?	Lime Kiln	366190.32	192686.398
69	ACT	Lime Kiln	366284.906	192691.59
170	DEP	Rocky Spr Stn	361860.834	190312.424
71	DEP	Rocky Spr Stn	361820.712	190242.216
72	DEP	Rocky Spr Stn	361906.215	190241.048
73	DEP	Rocky Spr Stn	362018.759	190300.476
74	DEP	Rocky Spr Stn	362288.041	190248.215
75	ACT	Rocky Spr Stn	367176.949	192867.712
76	DEP	Leesburg Fm	358443.685	191021.206
77	DEP	Leesburg Fm	358308.777	191252.082
78	DEP	Leesburg Fm	359127.545	193604.264
79	ACT	Leesburg Fm	359222.926	193596.128
180	DEP	Leesburg Fm	359292.956	193428.242
81	ACT	Leesburg Fm	359607.755	193439.969
82	DEP	Leesburg Fm	359562.568	193183.561
83	DEP	Leesburg Fm	359346.582	192364.138
84	DEP	Leesburg Fm	359299.383	192267.703
85	DEP	Leesburg Fm	360995.179	200872.07
86	DEP	Leesburg Fm	358201.296	191186.216
87	DEP	Rocky Spr Stn	361067.434	195508.818
88	DEP	Rocky Spr Stn	360914.236	195638.537
89	DEP	Rocky Spr Stn	360816.069	195635.875
190	DEP	Rocky Spr Stn	360772.214	195617.921
91	DEP	Rocky Spr Stn	360624.093	195425.593
92	DEP	Leesburg Fm	360520.576	195510.725
93	DEP	Leesburg Fm	360615.43	195529.239
94	DEP	Leesburg Fm	360671.839	195611.815
95	DEP	Leesburg Fm	360570.427	195583.846
96	DEP	Leesburg Fm	360464.374	195359.691
97	DEP	Leesburg Fm	360461.26	195566.182
98	DEP	Leesburg Fm	360465.338	195607.605
99	DEP	Leesburg Fm	360494.241	195465.636
200	DEP	Rocky Spr Stn	360527.291	195424.724
1	DEP	Leesburg Fm	360355.057	195680.056
2	DEP	Leesburg Fm	360236.323	195934.91
3	DEP	Rocky Spr Stn	360305.544	195958.797
4	DEP	Leesburg Fm	360376.389	195890.415
5	DEP	Leesburg Fm	360571.232	195675.103
6	DEP	Leesburg Fm	360584.089	195839.65
7	DEP	Leesburg Fm	360604.702	195792.035
8	DEP	Leesburg Fm	360785.141	195682.703
9	DEP	Leesburg Fm	360086.593	196084.088
210	DEP	Lime Kiln	366701.327	195562.453
11	ACT	Rocky Spr Stn	366993.414	192923.954
12	ACT	Adamstown	366037.133	195356.942
13	DEP	Adamstown	366242.623	195769.607
14	DEP	Adamstown	366288.271	195684.341
15	ACT	Ceresville	365883.903	192861.889
16	DEP	Leesburg Fm	361671.824	197430.654
17	DEP	Leesburg Fm	361726.077	197444.266
18	DEP	Leesburg Fm	361808.954	197416.816
19	ACT	Ceresville	367618.474	197018.547
220	ACT	Lime Kiln	367413.15	196703.401
21	DEP	Lime Kiln	366703.921	193744.021
22	DEP	Lime Kiln	366573.373	193779.742
23	ACT	Ceresville	367413	196701.951
24	ACT	Ceresville	367618.257	197017.599
25	DEP	Lime Kiln	367632.461	197054.374
26	DEP	Leesburg Fm	358744.788	191691.891
27	DEP	Leesburg Fm	358806.069	191706.77
28	DEP	Leesburg Fm	359029.952	191658.77
29	DEP	Leesburg Fm	359185.026	192019.872
230	DEP	Leesburg Fm	359185.312	192020.852
31	DEP	Leesburg Fm	359185.787	192020.713
32	DEP	Leesburg Fm	359039.42	193160.304
33	DEP	Leesburg Fm	358965.606	193136.021
34	DEP	Leesburg Fm	359047.816	193264.603
35	DEP	Leesburg Fm	359059.507	193309.47
36	DEP	Leesburg Fm	359075.764	193341.272
37	DEP	Leesburg Fm	359145.933	193311.791
38	DEP	Leesburg Fm	359109.691	193464.621
39	DEP	Leesburg Fm	359079.388	193582.532
240	DEP	Leesburg Fm	358635.949	191738.614
41	ACT	Rocky Spr Stn	362547.408	194478.489

42	DEP	Rocky Spr Stn	363230.277	192815.93
43	ACT	Rocky Spr Stn	363151.228	192926.136
44	DEP	Rocky Spr Stn	363310.897	193415.422
45	ACT	Rocky Spr Stn	362057.835	192453.158
46	ACT	Lime Kiln	364911.975	190253.134
47	ACT	Lime Kiln	364914.591	190258.207
48	ACT	Lime Kiln	365332.695	192532.37
49	ACT	Lime Kiln	366180.306	192572.096
250	ACT	Lime Kiln	366164.24	192639.919
51	ACT	Lime Kiln	366174.289	192649.8
52	ACT	Lime Kiln	366164.893	192667.39
53	ACT	Lime Kiln	366185.599	192656.188
54	ACT	Lime Kiln	366185.215	192670.457
55	ACT	Lime Kiln	366172.048	192673.194
56	ACT	Lime Kiln	366190.49	192675.703
57	DEP	Lime Kiln	366676.363	193985.798
58	DEP	Lime Kiln	366740.901	193778.587
59	DEP	Lime Kiln	366586.849	193797.808
260	DEP	Lime Kiln	366907.455	194173.294
61	ACT	Lime Kiln	366714.652	193010.793
62	DEP	Lime Kiln	365715.221	193074.407
63	ACT	Lime Kiln	365118.455	192833.078
64	ACT	Lime Kiln	364859.885	191752.242
65	ACT	Fountain Rx	364813.538	190520.897
66	ACT	Fountain Rx	364814.642	190515.969
67	ACT	Fountain Rx	364813.634	190525.246
68	ACT	Fountain Rx	364768.44	190611.068
69	DEP	Fountain Rx	364773.717	190315.267
270	DEP	Fountain Rx	364749.814	190314.626
71	DEP	Fountain Rx	364747.895	190296.418
72	ACT	Fountain Rx	364759.861	190515.273
73	DEP	Fountain Rx	364733.227	190517.939
74	ACT?	Fountain Rx	365104.52	191362.199
75	ACT	Ceresville	364919.925	190266.867
76	ACT	Ceresville	364928.345	190256.917
77	DEP	Ceresville	365904.223	193523.26
78	ACT	Ceresville	366150.242	193441.589
79	ACT	Ceresville	366169.254	193457.888
280	ACT	Ceresville	366492.97	194059.071
81	ACT	Ceresville	364416.482	191253.096
82	DEP	Adamstown	364943.979	193501.178
83	ACT	Monocacy	361439.21	190493.332
84	ACT	Leesburg Fm	362045.586	192430.288
85	DEP	Lime Kiln	366573.685	195893.34
86	ACT	Lime Kiln	366975.694	193423.563
87	DEP	Rocky Spr Stn	365728.872	197034.294
88	DEP	Rocky Spr Stn	365971.124	197284.439
89	DEP	Lime Kiln	367618.134	197082.458
290	ACT	Lime Kiln	367665.588	197105.006
91	ACT	Ceresville	367659.653	197103.026

92	ACT	Lime Kiln	367613.415	197124.693
93	ACT	Lime Kiln	367610.28	197130.984
94	ACT	Lime Kiln	367578.984	197154.291
95	DEP	Lime Kiln	367572.444	197129.883
96	DEP	Lime Kiln	367571.348	197122.006
97	DEP	Lime Kiln	367584.541	197111.395
98	DEP	Lime Kiln	367579.581	197115.725
99	ACT	Lime Kiln	367574.786	197169.941
300	DEP	Lime Kiln	367636.872	197170.336
1	DEP	Ceresville	367702.957	197099.824
2	DEP	Rocky Spr Stn	360924.537	200635.915
3	DEP	Rocky Spr Stn	363571.035	197885.53
4	DEP	Rocky Spr Stn	363568.209	197905.906
5	DEP	Rocky Spr Stn	363555.766	197928.172
6	ACT	Rocky Spr Stn	364598.523	196705.707
7	DEP	Rocky Spr Stn	365396.182	197880.521
8	DEP	Rocky Spr Stn	365372.199	197814.656
9	ACT	Rocky Spr Stn	365475.64	198990.566
310	ACT	Rocky Spr Stn	364809.09	196529.258
11	ACT	Rocky Spr Stn	364759.76	196567.249
12	ACT	Rocky Spr Stn	364163.422	199444.377
13	ACT	Rocky Spr Stn	363773.522	199299.075
14	ACT	Rocky Spr Stn	363567.446	199561.241
15	ACT	Rocky Spr Stn	363647.291	199713.282
16	DEP	Rocky Spr Stn	363297.116	199607.55
17	DEP	Rocky Spr Stn	365489.279	197630.249
18	DEP	Rocky Spr Stn	365594.648	198279.973
19	DEP	Rocky Spr Stn	366411.103	197702.366
320	DEP	Rocky Spr Stn	366950.04	200305.815
21	DEP	Rocky Spr Stn	366970.429	200357.46
22	DEP	Rocky Spr Stn	365817.577	198353.658
23	DEP	Rocky Spr Stn	365865.539	198425.095
24	DEP	Rocky Spr Stn	365848.386	198421.917
25	DEP	Rocky Spr Stn	361986.278	197554.983
26	ACT	Rocky Spr Stn	362122.769	197318.695
27	ACT	Rocky Spr Stn	362068.548	197632.284
28	ACT	Rocky Spr Stn	361960.113	198241.792
29	ACT	Rocky Spr Stn	361949.318	198281.883
330	DEP	Rocky Spr Stn	361947.121	198296.288
31	ACT	Rocky Spr Stn	361945.712	198300.133
32	ACT	Rocky Spr Stn	361965.998	198275.95
33	ACT	Rocky Spr Stn	362514.567	198352.666
34	DEP	Rocky Spr Stn	362348.615	198480.616
35	DEP	Rocky Spr Stn	362354.447	198326.053
36	ACT	Rocky Spr Stn	362353.566	195414.535
37	ACT	Rocky Spr Stn	362350.355	195416.715
38	ACT	Rocky Spr Stn	362433.148	196770.286
39	ACT	Rocky Spr Stn	362109.188	197293.459
340	ACT	Rocky Spr Stn	364210.411	200273.612
41	DEP	Rocky Spr Stn	364199.155	200247.315

42	DEP	Rocky Spr Stn	365389.363	200463.767
43	DEP	Rocky Spr Stn	365351.001	200291.522
44	DEP	Rocky Spr Stn	365971.917	199243.364
45	DEP	Rocky Spr Stn	364732.149	201135.506
46	DEP	Rocky Spr Stn	365333.09	201070.616
47	DEP	Rocky Spr Stn	365495.136	201266.458
48	DEP	Rocky Spr Stn	365060.392	201651.134
49	DEP	Rocky Spr Stn	364991.512	201417.806
350	DEP	Rocky Spr Stn	365032.046	201367.624
51	DEP	Rocky Spr Stn	364843.769	201449.909
52	DEP	Rocky Spr Stn	365204.364	200534.327
53	ACT	Rocky Spr Stn	365326.661	200698.022
54	DEP	Rocky Spr Stn	366759.938	200145.608
55	DEP	Rocky Spr Stn	366799.074	200157.341
56	DEP	Rocky Spr Stn	366995.152	201128.723
57	DEP	Rocky Spr Stn	367003.258	201202.052
58	DEP	Rocky Spr Stn	365937.141	202135.249
59	ACT	Rocky Spr Stn	365425.169	197909.663
360	DEP	Rocky Spr Stn	362210.498	198274.449
61	DEP	Rocky Spr Stn	362293.393	198288.905
62	DEP	Rocky Spr Stn	362208.01	198204.793
63	DEP	Rocky Spr Stn	361127.349	200101.981
64	ACT	Rocky Spr Stn	362466.27	195989.929
65	ACT	Leesburg Fm	359372.955	193491.166
66	DEP	Leesburg Fm	360387.852	196452.813
67	ACT	Leesburg Fm	360329.458	196566.545
68	DEP	Leesburg Fm	360320.404	196574.953
69	DEP	Tomstown	360284.915	196675.414
370	DEP	Tomstown	360303.345	196771.674
71	DEP	Leesburg Fm	360575.624	196549.748
72	DEP	Leesburg Fm	360363.556	195962.12
73	DEP	Leesburg Fm	360415.199	196064.948
74	DEP	Leesburg Fm	360452.897	196094.843
75	DEP	Leesburg Fm	360437.582	196151.008
76	DEP	Leesburg Fm	360565.816	196144.602
77	DEP	Leesburg Fm	360487.429	196140.764
78	DEP	Leesburg Fm	360368.096	196134.15
79	DEP	Leesburg Fm	360313.881	196157.683
380	DEP	Leesburg Fm	360232.788	196294.779
81	DEP	Leesburg Fm	360276.957	196214.594
82	DEP	Leesburg Fm	360173.484	196302.136
83	DEP	Tomstown	360095.184	196261.067
84	DEP	Leesburg Fm	360161.657	196212.469
85	DEP	Leesburg Fm	360142.309	196179.269
86	DEP	Leesburg Fm	360192.806	196145.845
87	DEP	Leesburg Fm	360298.759	196100.465
88	DEP	Leesburg Fm	360228.478	196072.801
89	DEP	Leesburg Fm	360485.438	195978.296
390	DEP	Leesburg Fm	361870.073	198040.756
91	DEP	Leesburg Fm	361819.831	197765.745
92	DEP	Leesburg Fm	364439.643	201296.173
93	DEP	Leesburg Fm	360664.396	196939.729
94	DEP	Leesburg Fm	360818.07	197653.295
95	DEP	Leesburg Fm	361217.246	197650.553
96	DEP	Adamstown	367490.933	200380.27
97	DEP	Adamstown	367606.944	200530.876
98	DEP	Adamstown	365541.683	194710.237
99	ACT	Adamstown	365757.816	194928.393
400	DEP	Adamstown	367544.423	200283.21
1	DEP	Adamstown	367291.488	200328.918
2	DEP	Adamstown	367417.388	200314.664
3	DEP	Adamstown	367374.089	200289.862
4	ACT	Adamstown	366997.578	192923.056
5	DEP	Ceresville	366492.693	194144.502
6	DEP	Ceresville	367137.795	195028.955
7	DEP	Ceresville	367128.728	195277.068
8	ACT	Ceresville	366496.425	194023.103
9	ACT	Ceresville	366496.035	194028
410	ACT	Ceresville	366505.89	194026.227
11	DEP	Ceresville	364595.47	189741.9803
12	DEP	Ceresville	364576.03	189795.4996
13	DEP	Fountain Rx	364523.823	189792.1522
14	DEP	Ceresville	364500.722	189784.9389
15	DEP	Leesburg Fm	358365.56	189830.5556
16	DEP	Leesburg Fm	358257.265	189845.748
17	DEP	Leesburg Fm	358230.681	189814.1765
18	DEP	Leesburg Fm	358166.624	189862.6342
19	DEP	Leesburg Fm	358264.813	189844.4278
420	SPR	Fountain Rx	364009.429	189962.823
21	DEP	Fountain Rx	364019.057	189962.193
22	ACT	Ceresville	367460.408	196734.882
23	ACT	Ceresville	367588.893	196423.791
24	ACT	Rocky Spr Stn	366763.147	193251.018
25	DEP	Lime Kiln	365653.979	191205.284
26	DEPp	Lime Kiln	367537.584	201346.057
27	DEP	Lime Kiln	367710.855	201510.657
28	DEP	Lime Kiln	368085.032	196676.008
29	ACT	Lime Kiln	366496.425	194023.103
430	ACT	Lime Kiln	366496.035	194028
31	ACT	Lime Kiln	366505.89	194026.227
32	ACT	Lime Kiln	367460.408	196734.882
33	ACT	Lime Kiln	366933.614	194304.529
34	ACT	Lime Kiln	366944.455	194311.415
35	DEP	Lime Kiln	367632.443	195065.769
36	DEP	Lime Kiln	367609.738	195067.356
37	ACT	Lime Kiln	367593.499	195091.29
38	ACT	Lime Kiln	364928.208	192309.532
39	ACT	Lime Kiln	366406.125	192713.868
440	DEP	Lime Kiln	365663.117	191485.817
41	DEP	Lime Kiln	365644.973	191472.999

42	DEP	Lime Kiln	365648.883	191455.123
43	DEP	Lime Kiln	365643.347	191419.548
44	DEP	Lime Kiln	365637.655	191389.993
45	ACT	Lime Kiln	365606.476	191390.037
46	ACT	Lime Kiln	365604.772	191395.633
47	DEP	Lime Kiln	365604.085	191390.234
48	DEP	Lime Kiln	365596.915	191366.924
49	DEP	Lime Kiln	365629.569	191370.353
450	DEP	Lime Kiln	365626.788	191349.417
51	DEP	Lime Kiln	365595.963	191337.638
52	DEP	Lime Kiln	365586.153	191347.061
53	DEP	Lime Kiln	365577.387	191323.978
54	DEP	Lime Kiln	365535.11	191191.212
55	ACT	Lime Kiln	365772.9	191155.54
56	ACT	Lime Kiln	365197.338	192754.773
57	DEP	Lime Kiln	365195.239	192752.656
58	DEP	Lime Kiln	365224.738	192756.623
59	DEP	Lime Kiln	365531.852	191207.577
460	DEP	Lime Kiln	365530.143	191181.616
61	DEP	Lime Kiln	365528.525	191174.99
62	DEP	Lime Kiln	365530.302	191147.944
63	DEP	Lime Kiln	365529.928	191135.768
64	DEP	Lime Kiln	365490.104	191029.603
65	DEP	Lime Kiln	365607.999	191006.351
66	DEP	Lime Kiln	365658.009	191033.336
67	DEP	Lime Kiln	365702.376	191052.974
68	DEP	Rocky Spr Stn	363611.809	197773.176
69	DEP	Rocky Spr Stn	362964.833	197960.424
470	DEP	Rocky Spr Stn	363053.563	197903.444
71	DEP	Rocky Spr Stn	362654.781	197502.412
72	ACT	Rocky Spr Stn	362466.27	195989.929
73	DEP	Rocky Spr Stn	363571.035	197885.53
74	DEP	Rocky Spr Stn	363568.209	197905.906
75	DEP	Rocky Spr Stn	363555.766	197928.172
76	ACT	Rocky Spr Stn	364598.523	196705.707
77	DEP	Rocky Spr Stn	365396.182	197880.521
78	DEP	Rocky Spr Stn	365372.199	197814.656
79	ACT	Rocky Spr Stn	365475.64	198990.566
480	ACT	Rocky Spr Stn	364809.09	196529.258
81	ACT	Rocky Spr Stn	364759.76	196567.249
82	ACT	Rocky Spr Stn	364163.422	199444.377
83	ACT	Rocky Spr Stn	363773.522	199299.075
84	ACT	Rocky Spr Stn	363567.446	199561.241
85	ACT	Rocky Spr Stn	363647.291	199713.282
86	DEP	Rocky Spr Stn	363297.116	199607.55
87	DEP	Rocky Spr Stn	365489.279	197630.249
88	DEP	Rocky Spr Stn	365594.648	198279.973
89	DEP	Rocky Spr Stn	366411.103	197702.366
490	DEP	Rocky Spr Stn	361847.222	190322.008
91	DEP	Rocky Spr Stn	361879.29	190260.076
92	DEP	Rocky Spr Stn	361809.536	190199.297
93	DEP	Rocky Spr Stn	361880.213	190156.141
94	DEP	Rocky Spr Stn	365817.577	198353.658
95	DEP	Rocky Spr Stn	365865.539	198425.095
96	DEP	Rocky Spr Stn	365848.386	198421.917
97	DEP	Rocky Spr Stn	361986.278	197554.983
98	ACT	Rocky Spr Stn	362122.769	197318.695
99	ACT	Rocky Spr Stn	362068.548	197632.284
500	ACT	Rocky Spr Stn	361960.113	198241.792
1	ACT	Rocky Spr Stn	361949.318	198281.883
2	DEP	Rocky Spr Stn	361947.121	198296.288
3	ACT	Rocky Spr Stn	361945.712	198300.133
4	ACT	Rocky Spr Stn	361965.998	198275.95
5	ACT	Rocky Spr Stn	362514.567	198352.666
6	DEP	Rocky Spr Stn	362348.615	198480.616
7	DEP	Rocky Spr Stn	362354.447	198326.053
8	ACT	Rocky Spr Stn	362353.566	195414.535
9	ACT	Rocky Spr Stn	362350.355	195416.715
510	ACT	Rocky Spr Stn	362433.148	196770.286
11	ACT	Rocky Spr Stn	362109.188	197293.459
12	ACT	Rocky Spr Stn	364210.411	200273.612
13	ACT	Rocky Spr Stn	364199.155	200247.315
14	DEP	Rocky Spr Stn	365389.363	200463.767
15	DEP	Rocky Spr Stn	365351.001	200291.522
16	DEP	Rocky Spr Stn	365971.917	199243.364
17	DEP	Rocky Spr Stn	364732.149	201135.506
18	DEP	Rocky Spr Stn	365333.09	201070.616
19	DEP	Rocky Spr Stn	365495.136	201266.458
520	DEP	Rocky Spr Stn	364991.512	201417.806
21	DEP	Rocky Spr Stn	365032.046	201367.624
22	DEP	Rocky Spr Stn	364843.769	201449.909
23	DEP	Rocky Spr Stn	365204.364	200534.327
24	ACT	Rocky Spr Stn	365326.661	200698.022
25	DEP	Rocky Spr Stn	366759.938	200145.608
26	DEP	Rocky Spr Stn	366799.074	200157.341
27	DEP	Rocky Spr Stn	366995.152	201128.723
28	DEP	Rocky Spr Stn	367003.258	201202.052
28	DEP	Rocky Spr Stn	365937.141	202135.249
530	ACT	Rocky Spr Stn	365425.169	197909.663
31	DEP	Rocky Spr Stn	362210.498	198274.449
32	DEP	Rocky Spr Stn	362293.393	198288.905
33	DEP	Rocky Spr Stn	362208.01	198204.793
34	DEP	Rocky Spr Stn	361127.349	200101.981
35	DEP	Rocky Spr Stn	360924.537	200635.915
36	ACT	Rocky Spr Stn	366763.147	193251.018
37	DEP	Rocky Spr Stn	363500.1	197807.019
38	ACT	Leesburg Fm	359372.955	193491.166
39	DEP	Leesburg Fm	359307.243	193705.29
540	DEP	Leesburg Fm	360387.852	196452.813
41	ACT	Leesburg Fm	360329.458	196566.545

42	DEP	Leesburg Fm	360320.404	196574.953
43	DEP	Leesburg Fm	360284.915	196675.414
44	DEP	Leesburg Fm	360303.345	196771.674
45	DEP	Leesburg Fm	360575.624	196549.748
46	DEP	Leesburg Fm	360363.556	195962.12
47	DEP	Leesburg Fm	360415.199	196064.948
48	DEP	Leesburg Fm	360452.897	196094.843
49	DEP	Leesburg Fm	360437.582	196151.008
550	DEP	Leesburg Fm	360565.816	196144.602
51	DEP	Leesburg Fm	360487.429	196140.764
52	DEP	Leesburg Fm	360368.096	196134.15
53	DEP	Leesburg Fm	360313.881	196157.683
54	DEP	Leesburg Fm	360232.788	196294.779
55	DEP	Leesburg Fm	360276.957	196214.594
56	DEP	Leesburg Fm	360173.484	196302.136
57	DEP	Leesburg Fm	360095.184	196261.067
58	DEP	Leesburg Fm	360161.657	196212.469
59	DEP	Leesburg Fm	360142.309	196179.269
560	DEP	Leesburg Fm	360192.806	196145.845
61	DEP	Leesburg Fm	360298.759	196100.465
62	DEP	Leesburg Fm	360228.478	196072.801
63	DEP	Leesburg Fm	360485.438	195978.296
64	DEP	Leesburg Fm	361870.073	198040.756
65	DEP	Leesburg Fm	361819.831	197765.745
66	DEP	Leesburg Fm	364439.643	201296.173
67	DEP	Leesburg Fm	360664.396	196939.729
68	DEP	Leesburg Fm	360818.07	197653.295
69	DEP	Leesburg Fm	361217.246	197650.553
570	ACT	Ceresville	367890.05	196964.853
71	ACT	Ceresville	367895.742	196971.509
71	ACT	Ceresville	367826.512	196951.328
72	ACT	Ceresville	367840.232	196940.377
74	DEP	Ceresville	366492.693	194144.502
75	DEP	Ceresville	367137.795	195028.955
76	DEP	Ceresville	367128.728	195277.068
77	ACT	Ceresville	367588.893	196423.791
78	ACT	Ceresville	367894.432	196958.945
79	SPR	Ceresville	366823.032	195091.295
580	ACT	Ceresville	367735.671	196981.36
81	DEP	Ceresville	365595.069	191485.575
82	DEP	Ceresville	365548.547	191469.247
83	DEP	Ceresville	365589.203	191418.193
84	DEP	Ceresville	365612.216	191441.733
85	DEP	Ceresville	365598.239	191394.574
86	DEP	Ceresville	365595.499	191397.235
87	DEP	Ceresville	365592.099	191393.293
88	DEP	Ceresville	365594.948	191374.109
89	ACT	Ceresville	365629.446	191372.782
590	DEP	Ceresville	365581.311	191334.548
91	DEP	Ceresville	365560.408	191304.342
92	DEP	Ceresville	365517.979	191300.167
93	DEP	Ceresville	365572.39	191273.629
94	DEP	Ceresville	365554.569	191253.286
95	DEP	Ceresville	365550.624	191245.453
96	DEP	Ceresville	367817.762	196564.453
97	ACT	Ceresville	365455.469	191153.871
98	ACT	Ceresville	365434.166	191164.461
99	ACT	Ceresville	365434.402	191163.774
600	ACT	Ceresville	365441.868	191155.501
1	ACT	Ceresville	365436.12	191167.506
2	DEP	Adamstown	365541.683	194710.237
3	ACT	Adamstown	365757.816	194928.393
4	DEP	Adamstown	367544.423	200283.21
5	DEP	Adamstown	367291.488	200328.918
6	DEP	Adamstown	367417.388	200314.664
7	DEP	Adamstown	367374.089	200289.862
8	ACT	Adamstown	366997.578	192923.056
9	ACT	Fountain Rx	364669.991	190122.363
610	ACT	Fountain Rx	364667.364	190118.304
11	ACT	Fountain Rx	364675.034	190106.107
12	ACT	Fountain Rx	364679.582	190104.88
13	ACT	Fountain Rx	364682.088	190115.12
14	ACT	Fountain Rx	364300.129	190003.71
15	ACT	Fountain Rx	364902.919	191339.849
16	ACT	Fountain Rx	365517.443	191464.245
17	DEP	Fountain Rx	365475.182	191437.133
18	ACT	Lime Kiln	366574.373	192976.139
19	ACT	Lime Kiln	366172.363	193447.726
620	ACT	Lime Kiln	366939.253	194294.12
21	ACT	Lime Kiln	366941.455	194303.553
22	ACT	Lime Kiln	366943.605	194302.352
23	ACT	Lime Kiln	366944.114	194320.799
24	ACT	Lime Kiln	366580.979	192974.358
25	ACT	Ceresville	367611.823	196547.22
26	ACT	Ceresville	364677.421	190083.967
27	ACT	Rocky Spr Stn	365424.851	197910.328
28	SPR	Rocky Spr Stn	366238.867	199124.068
29	SPR	Rocky Spr Stn	365067.869	196765.959
630	SPR	Rocky Spr Stn	365132.973	196751.825
31	ACT	Lime Kiln	366134.08	192883.738
32	ACT	Lime Kiln	365193.067	192745.871
33	ACT	Lime Kiln	366140.561	192880.996
34	ACT	Lime Kiln	366226.058	193237.154
35	ACT	Ceresville	365813.394	192655.659
36	ACT	Ceresville	365816.332	192684.227
37	ACT	Ceresville	365839.247	192698.536
38	ACT	Ceresville	365845.239	192713.907
39	ACT	Ceresville	363727.676	190466.409
640	ACT	Ceresville	363717.812	190408.855
41	ACT	Ceresville	365162.096	191409.246

42	ACT	Ceresville	367903.925	196972.749
42	ACT	Ceresville	367524.45	196828.2
43	ACT	Ceresville	367475.69	196722.05
44	ACT	Lime Kiln	367479.06	196746.64
45	ACT	Lime Kiln	367473.44	196744.2
46	ACT	Lime Kiln	367469.69	196740.88
47	ACT	Lime Kiln	367472.67	196743.88
48	ACT	Lime Kiln	367467.09	196737.56
49	ACT	Lime Kiln	367470.1	196738.85
650	ACT	Lime Kiln	367467.63	196733.36
51	ACT	Lime Kiln	367471.81	196727.69
52	ACT	Lime Kiln	367475.62	196721.12
53	ACT	Lime Kiln	367460.52	196736.13
54	act	Lime Kiln	373362.51	209062.97
55	act	Lime Kiln	373361.52	209065.89
56	act	Lime Kiln	363743	190420.29
57	act	Lime Kiln	365408.46	190244.01
58	act	Lime Kiln	365403.39	190239.35
59	act	Lime Kiln	365401.19	190234.88
660	act	Lime Kiln	365392.22	190238.18
61	act	Lime Kiln	367304.88	196764.17
63	act	Fountain Rx	364751.07	190284.45
64	act	Fountain Rx	364248.7	189540.76
65	act	Fountain Rx	364224.15	189522.66
66	act	Lime Kiln	367414.7	197076.5
67	act	Lime Kiln	364659.6	189406.5
68	act	Lime Kiln	367425.3	197084.3
69	dep	Rocky Spr Stn	362821.4	197494
670	dep	Rocky Spr Stn	363104.8	197840

POINT OF ROCKS QUADRANGLE

1	ACT	Leesburg Fm	355258.782	177275.081
2	DEP	Leesburg Fm	354448.421	178353.137
3	DEP	Leesburg Fm	354531.666	178306.427
4	ACT	Leesburg Fm	354540.075	178338.201
5	DEP	Leesburg Fm	354534.448	178355.342
6	ACT	Leesburg Fm	354490.875	178373.867
7	ACT	Leesburg Fm	354418.592	178207.704
8	SPR	Leesburg Fm	354307.668	178171.413
9	DEP	Leesburg Fm	355235.504	177254.997
10	DEP	Leesburg Fm	355215.556	177261.057
11	DEP	Leesburg Fm	355243.164	177374.669
12	DEP	Leesburg Fm	355268.75	177447.545
13	ACT	Leesburg Fm	355319.994	177455.953
14	DEP	Leesburg Fm	356902.278	185034.63
15	DEP	Leesburg Fm	356889.224	184845.205
16	DEP	Leesburg Fm	355129.289	180291.931
17	DEP	Leesburg Fm	355255.564	177225.31
18	ACT	Leesburg Fm	355116.953	177405.498
19	DEP	Leesburg Fm	355237.16	177569.387
20	DEP	Leesburg Fm	355269.112	177599.034
21	DEP	Leesburg Fm	354641.701	178396.786
22	DEP	Leesburg Fm	355020.633	178481.941
23	DEP	Leesburg Fm	355294.693	178215.085
24	DEP	Leesburg Fm	355316.972	178240.924
25	DEP	Leesburg Fm	355312.433	178062.533
26	DEP	Leesburg Fm	354520.573	180227.847
27	DEP	Leesburg Fm	354647.537	180110.031
28	DEP	Leesburg Fm	354697.32	180278.174
29	DEP	Leesburg Fm	354859.376	180275.886
30	DEP	Leesburg Fm	355101.813	180409.366
31	ACT	Leesburg Fm	354459.348	178072.141
32	DEP	Leesburg Fm	355240.412	177975.565
33	DEP	Leesburg Fm	355108.863	177788.078
34	DEP	Leesburg Fm	355056.009	178090.232
35	ACT	Leesburg Fm	355172.12	177973.419
36	DEP	Leesburg Fm	355202.612	177757.855
37	ACT	Leesburg Fm	355077.609	177298.593
38	DEP	Leesburg Fm	355842.5	180571.281
39	DEP	Leesburg Fm	355912.084	180749.233
40	ACT	Leesburg Fm	355887.65	180739.232
41	DEP	Leesburg Fm	355884.784	180730.45
42	ACT	Leesburg Fm	355898.428	180711.442
43	ACT	Leesburg Fm	355969.83	180752.189
44	DEP	Leesburg Fm	355893.663	180665.684
45	DEP?	Leesburg Fm	356252.118	180972.653
46	DEP	Leesburg Fm	356260.22	181004.827
47	ACT	Leesburg Fm	356023.239	180680.255
48	DEP	Leesburg Fm	356126.46	180674.303
49	DEP	Leesburg Fm	356236.677	180656.225
50	ACT	Leesburg Fm	356222.31	180726.965
51	ACT	Leesburg Fm	356240.399	180740.285
52	DEP	Leesburg Fm	356322.906	180522.76
53	DEP	Leesburg Fm	356102.436	180478.905
54	DEP	Leesburg Fm	355960.104	180610.294
55	ACT	Leesburg Fm	355956.995	180582.648
56	ACT	Leesburg Fm	355939.582	180552.259
57	ACT	Leesburg Fm	355932.504	180531.583
58	ACT	Leesburg Fm	355979.341	180480.83
59	ACT	Leesburg Fm	355876.778	180522.536
60	ACT	Leesburg Fm	355860.932	180502.985
61	DEP	Leesburg Fm	355929.06	180830.634
62	DEP	Leesburg Fm	355843.305	180894.259
63	DEP	Leesburg Fm	355676.168	180628.753
64	DEP	Leesburg Fm	355721.819	180541.945
65	DEP	Leesburg Fm	355608.072	180433.613
66	ACT	Leesburg Fm	355461.089	180114.361
67	DEP	Leesburg Fm	355330.375	179867.23
68	DEP	Leesburg Fm	355299.189	179915.545

69	ACT	Leesburg Fm	355294.283	179794.349	**19**	DEP	Leesburg Fm	355876.604	182794.404
70	DEP	Leesburg Fm	355048.149	179521.77	**120**	DEP	Leesburg Fm	355913.176	182706.691
71	DEP	Leesburg Fm	354998.119	179392.824	**21**	DEP	Leesburg Fm	355951.502	182958.714
72	DEP	Leesburg Fm	355066.598	179319.305	**22**	DEP	Leesburg Fm	355888.554	183031.238
73	DEP	Leesburg Fm	354998.546	179121.896	**23**	DEP	Leesburg Fm	355863.991	183042.618
74	DEP	Leesburg Fm	354939.069	179041.622	**24**	DEP	Leesburg Fm	354434.73	179782.229
75	DEP	Leesburg Fm	355747.767	180460.476	**25**	DEP	Leesburg Fm	356215.52	183604.792
76	DEP	Leesburg Fm	355714.341	180667.38	**26**	DEP	Leesburg Fm	356040.532	182709.235
77	DEP	Leesburg Fm	355252.736	180538.789	**27**	DEP	Leesburg Fm	356227.306	182572.207
78	DEP	Leesburg Fm	355177.595	180568.327	**28**	DEP	Leesburg Fm	356239.615	182777.381
79	DEP	Leesburg Fm	355227.189	180623.68	**29**	DEP	Leesburg Fm	356303.899	182605.101
80	DEP	Leesburg Fm	355244.684	180582.716	**130**	DEP	Leesburg Fm	356528.734	182626.327
81	DEP	Leesburg Fm	355159.749	180705.223	**31**	DEP	Leesburg Fm	356283.363	183823.331
82	DEP	Leesburg Fm	355183.752	180848.649	**32**	DEP	Leesburg Fm	356272.5	183999.899
83	DEP	Leesburg Fm	355089.534	180900.357	**33**	DEP	Leesburg Fm	356342.859	183905.805
84	DEP	Leesburg Fm	355049.355	180891.39	**34**	DEP	Leesburg Fm	355961.528	182714.769
85	DEP	Leesburg Fm	355120.03	180973.768	**35**	DEP	Leesburg Fm	354451.324	179947.438
86	ACT	Leesburg Fm	355192.415	181435.967	**36**	DEP	Leesburg Fm	355151.515	177701.044
87	DEP	Leesburg Fm	355219.398	181409.743	**37**	DEP	Leesburg Fm	355243.883	177645.291
88	DEP	Leesburg Fm	355312.019	181354.661	**38**	DEP	Leesburg Fm	355318.971	177614.904
89	DEP	Leesburg Fm	355314.267	181255.135	**39**	ACT	Leesburg Fm	355074.479	177298.224
90	DEP	Leesburg Fm	355360.995	181122.215	**140**	DEP	Leesburg Fm	356899.4	184991.731
91	DEP	Leesburg Fm	355779.646	181147.216	**41**	DEP	Leesburg Fm	356902.278	185034.63
92	ACT	Leesburg Fm	355622.594	180598.84	**42**	DEP	Leesburg Fm	356889.224	184845.205
93	DEP	Leesburg Fm	355741.523	182938.343	**43**	DEP	Leesburg Fm	356740.318	185175.116
94	DEP	Leesburg Fm	354523.674	179716.512	**44**	DEP	Leesburg Fm	356205.368	182892.804
95	DEP	Leesburg Fm	354505.242	179679.56	**45**	DEP	Leesburg Fm	356422.11	184825.186
96	DEP	Leesburg Fm	354454.937	179729.549	**46**	DEP	Leesburg Fm	356717.239	184267.032
97	DEP	Leesburg Fm	354483.792	179523.739	**47**	DEP	Leesburg Fm	356587.535	184770.994
98	DEP	Leesburg Fm	354396.816	179656.531	**48**	DEP	Leesburg Fm	356546.613	184669.658
99	DEP	Leesburg Fm	355474.098	181485.768	**49**	DEP	Leesburg Fm	356602.47	184569.81
100	ACT	Leesburg Fm	355446.238	181696.121	**150**	DEP	Leesburg Fm	356770.729	184910.257
1	DEP	Leesburg Fm	355567.486	181647.891	**51**	DEP	Leesburg Fm	356817.386	184924.425
2	ACT	Leesburg Fm	355455.553	181735.946	**52**	DEP	Leesburg Fm	356740.879	184913.288
3	DEP	Leesburg Fm	355492.771	181761.276	**53**	DEP	Leesburg Fm	356743.135	184988.591
4	DEP	Leesburg Fm	355567.665	181725.389	**54**	DEP	Leesburg Fm	356611.903	185079.793
5	DEP	Leesburg Fm	355568.129	181788.652	**55**	DEP	Leesburg Fm	356613.151	185161.065
6	DEP	Leesburg Fm	355578.503	181689.442	**56**	DEP	Leesburg Fm	356700.958	185149.979
7	DEP	Leesburg Fm	355448.639	181867.73	**57**	DEP	Leesburg Fm	356596.155	185196.718
8	DEP	Leesburg Fm	355427.608	182046.799	**58**	DEP	Leesburg Fm	356634.376	185261.454
9	DEP	Leesburg Fm	355527.005	182171.167	**59**	DEP	Leesburg Fm	356656.201	185311.082
110	DEP	Leesburg Fm	355598.287	182036.965	**160**	DEP	Leesburg Fm	356692.306	185239.528
11	DEP	Leesburg Fm	355561.397	181942.855	**61**	DEP	Leesburg Fm	356290.398	183460.684
12	SPR	Leesburg Fm	355981.003	181160.742	**62**	DEP	Leesburg Fm	356917.708	185516.707
13	DEP	Leesburg Fm	355736.023	182534.453	**63**	DEP?	Leesburg Fm	356873.236	184702.062
14	DEP	Leesburg Fm	355762.136	182630.997	**64**	DEP	Leesburg Fm	356900.234	184928.581
15	DEP	Leesburg Fm	355688.072	182720.464	**65**	DEP	Leesburg Fm	356653.173	185888.134
16	DEP	Leesburg Fm	355763.227	182659.966	**66**	DEP	Leesburg Fm	356704.12	185932.229
17	DEP	Leesburg Fm	355683.804	182819.029	**67**	DEP	Leesburg Fm	356803.877	186058.317
18	DEP	Leesburg Fm	355793.368	182758.779	**68**	DEP	Leesburg Fm	356786.904	185942.854

69	DEP	Leesburg Fm	356724.185	185927.278
170	DEP	Leesburg Fm	356776.9	185823.859
71	DEP	Leesburg Fm	356731.741	185807.49
72	DEP	Leesburg Fm	356776.339	185784.979
73	DEP	Leesburg Fm	356740.992	185764.894
74	DEP	Leesburg Fm	356802.758	185727.956
75	DEP	Leesburg Fm	356736.717	185667.011
76	DEP	Leesburg Fm	356803.564	185602.836
77	DEP	Leesburg Fm	356827.098	185562.445
78	DEP	Leesburg Fm	356846.086	184806.677
79	DEP	Leesburg Fm	354446.346	179886.459
180	DEP	Leesburg Fm	354451.374	179935.154
81	DEP	Leesburg Fm	354516.652	179909.588
82	DEP	Leesburg Fm	354554.647	179883.187
83	DEP	Leesburg Fm	354540.869	179824.048
84	DEP	Leesburg Fm	354489.19	179803.042
85	DEP	Leesburg Fm	354510.516	179739.381
86	ACT	Leesburg Fm	354667.32	179621.242
87	DEP	Leesburg Fm	354713.658	179669.593
88	DEP	Leesburg Fm	354678.78	179319.629
89	DEP	Leesburg Fm	354603.548	179459.477
190	DEP	Leesburg Fm	354618.509	179513.175
91	DEP	Leesburg Fm	354571.363	179515.794
92	DEP	Leesburg Fm	354615.233	179563.953
93	DEP	Leesburg Fm	354541.794	179593.025
94	DEP	Leesburg Fm	354699.701	179893.667
95	DEP	Leesburg Fm	354446.346	179886.459
96	DEP	Leesburg Fm	355164.266	177741.221
97	ACT	Leesburg Fm	354901.39	177590.108
98	ACT	Leesburg Fm	354362.516	178131.067

WALKERSVILLE QUADRANGLE

1	DEP	Ceresville	367783.607	196716.298
2	ACT	Ceresville	367839.749	196965.322
3	ACT	Ceresville	367828.007	196954.901
4	DEP	Ceresville	367781.898	197043.059
5	ACT	Ceresville	367828.637	196954.325
6	ACT	Ceresville	367838.023	196966.206
7	DEP	Ceresville	367990.101	196987.595
8	DEP	Ceresville	368182.545	196874.582
9	DEP	Ceresville	368163.359	196870.22
10	ACT	Ceresville	367890.05	196964.853
11	ACT	Ceresville	367895.742	196971.509
12	ACT	Ceresville	367826.512	196951.328
13	ACT	Ceresville	367840.232	196940.377
14	ACT	Ceresville	367897.495	196910.732
15	DEP	Fountain Rx	368589.421	200654.743
16	DEP	Fountain Rx	368105.96	199882.157
17	DEP	Fountain Rx	368138.178	199781.199
18	DEP	Fountain Rx	368171.947	200026.716
19	DEP	Fountain Rx	368112.695	200398.257
20	ACT	Fountain Rx	367991.773	200679.386
21	DEP	Fountain Rx	368127.052	200315.186
22	DEP	Fountain Rx	368045.13	200150.903
23	DEP	Fountain Rx	369822.635	203554.676
24	DEP	Fountain Rx	368691.931	201374.202
25	DEP	Fountain Rx	368718.04	201404.616
26	DEP	Fountain Rx	368731.028	201408.537
27	DEP	Fountain Rx	368646.849	201392.815
28	SPR	Fountain Rx	368671.352	201385.106
29	SPR	Fountain Rx	368550.078	201285.859
30	DEP	Fountain Rx	368548.373	200948.01
31	DEP	Fountain Rx	368494.59	200926.335
32	ACT	Fountain Rx	368508.525	200893.72
33	DEP	Fountain Rx	368731.263	201099.72
34	DEP	Fountain Rx	368748.566	201151.893
35	DEP	Fountain Rx	368686.027	201385.6
36	DEP	Fountain Rx	370212.413	202333.261
37	DEP	Fountain Rx	368575.083	199708.597
38	DEP	Fountain Rx	370415.389	203054.471
39	DEP	Fountain Rx	370487.125	202912.83
40	ACT	Fountain Rx	370482.567	202906.874
41	DEP	Fountain Rx	370541.678	202952.453
42	DEP	Fountain Rx	370528.669	203260.828
43	DEP	Fountain Rx	370377.306	203329.154
44	DEP	Fountain Rx	369838.096	203409.435
45	DEP	Fountain Rx	369875.399	203351.202
46	DEP	Fountain Rx	369877.73	203334.926
47	ACT	Fountain Rx	369898.904	203314.796
48	DEP	Fountain Rx	369842.623	203335.65
49	DEP	Fountain Rx	369852.207	203253.572
50	DEP	Fountain Rx	369840.307	203208.024
51	DEP	Fountain Rx	369888.393	203254.963
52	DEP	Fountain Rx	369840.93	202708.68
53	DEP	Fountain Rx	368296.488	200805.171
54	SPR	Fountain Rx	368192.671	200887.819
55	DEP	Fountain Rx	368278.363	200990.775
56	DEP	Fountain Rx	369804.263	203592.442
57	DEP	Fountain Rx	369843.703	203561.225
58	ACT	Fountain Rx	368583.867	201462.267
59	DEP	Fountain Rx	368565.865	200799.895
60	DEP	Fountain Rx	368499.656	200825.034
61	DEP	Fountain Rx	368423.225	200797.272
62	DEP	Fountain Rx	368371.203	200794.419
63	DEP	Fountain Rx	368354.116	200785.261
64	ACT	Fountain Rx	368672.981	200717.707
65	ACT	Fountain Rx	368657.146	200692.614
66	ACT	Fountain Rx	368661.375	200693.317
67	ACT	Fountain Rx	368650.297	200685.075

68	DEP	Fountain Rx	368604.589	200632.064
69	DEP	Fountain Rx	368562.75	200637.883
70	DEP	Ceresville	367868.846	200071.099
71	DEP	Ceresville	367960.962	200160.696
72	ACT	Ceresville	370587.094	203133.47
73	DEP	Ceresville	367884.048	200037.596
74	DEP	Lime Kiln	367630.229	201348.341
75	ACT	Lime Kiln	368333.361	196296.997
76	DEP	Lime Kiln	368602.422	199188.748
77	DEP	Lime Kiln	368087.889	203536.532
78	DEP	Lime Kiln	369456.555	199985.874
79	DEP	Lime Kiln	369419.998	200057.977
80	DEP	Lime Kiln	369486.23	200095.429
81	DEP	Lime Kiln	370129.744	201451.7
82	DEP	Lime Kiln	370174.645	201511.228
83	DEP	Lime Kiln	369047.803	198449.557
84	DEP	Lime Kiln	369020.639	198588.949
85	DEP	Lime Kiln	368910.014	198652.545
86	DEP	Lime Kiln	368905.372	198378.83
87	DEP	Lime Kiln	368933.631	197388.854
88	ACT	Lime Kiln	370876.12	203046.057
89	DEP	Lime Kiln	368855.961	199249.918
90	DEP	Lime Kiln	368848.382	199223.459
91	ACT	Lime Kiln	368666.395	199297.37
92	SPR	Rocky Spr Stn	368556.718	195516.1
93	DEP	Rocky Spr Stn	370590.961	201376.935
94	DEP	Rocky Spr Stn	369525.379	196344.435
95	ACT	Woodsboro	370229.937	203077.592
96	ACT	Woodsboro	370212.742	203116.774
97	ACT	Woodsboro	370212.408	203114.936
98	ACT	Woodsboro	370207.201	203117.095
99	ACT	Woodsboro	370204.575	203119.816
100	ACT	Woodsboro	370210.225	203108.291
1	ACT	Woodsboro	369775.867	202632.09
2	DEP	Woodsboro	369918.792	202648.937
3	DEP	Woodsboro	369927.359	202661.137
4	ACT	Woodsboro	370353.051	203300.992
5	ACT	Woodsboro	370294.844	203197.497
6	DEP	Woodsboro	370275.082	203153.857
7	ACT	Woodsboro	370266.125	203152.295
8	ACT	Woodsboro	370258.248	203145.432
9	DEP	Adamstown	367722.438	202278.251
110	DEP	Adamstown	367760.915	202381.395
11	DEP	Adamstown	369708.34	198497.137
12	DEP	Rocky Spr Stn	367829.454	192236.657
13	ACT	Rocky Spr Stn	367846.812	192224.814
14	ACT	Rocky Spr Stn	368366.071	192984.286
15	SPR	Adamstown	368568.405	195707.028
16	ACT	Fountain Rx	369963.608	202410.874
17	DEP	Woodsboro	369926.665	202661.699

18	DEP	Woodsboro	369917.891	202647.429
19	ACT	Fountain Rx	370487.282	202829.563
120	ACT	Fountain Rx	370474.163	202818.552
21	ACT	Fountain Rx	370421.808	202827.844
22	ACT	Fountain Rx	370427.546	202834.084
23	ACT	Fountain Rx	370430.549	202831.375
24	ACT	Fountain Rx	370461.763	202802.54
25	DEP	Fountain Rx	370431.228	202570.179
26	DEP	Fountain Rx	370409.053	202560.48
27	ACT	Fountain Rx	370054.076	202813.419
28	DEP	Fountain Rx	370199.716	202800.965
29	DEP	Fountain Rx	370013.611	202642.224
130	ACT	Woodsboro	369992.477	203051.451
31	DEP	Fountain Rx	367780.793	197045.769
32	ACT	Fountain Rx	368186.191	196890.599
33	DEP	Fountain Rx	368165.571	196827.852
34	ACT	Fountain Rx	368149.202	196811.48
35	ACT	Fountain Rx	368152.259	196793.426
36	ACT	Fountain Rx	367857.264	196956.005
37	DEP	Fountain Rx	368469.274	197886.703
38	DEP	Lime Kilnk	368113.424	198187.142
39	DEP	Lime Kilnk	368109.792	198213.533
140	ACT	Lime Kilnk	368066.727	198071.241
41	SPR	Lime Kiln	367858.632	202375.005
42	ACT	Fountain Rx	370427.934	202832.431
43	ACT	Fountain Rx	370427.577	202832.838
44	ACT	Fountain Rx	370422.299	202833.148 dl
45	ACT	Fountain Rx	370426.046	202836.784
46	ACT	Fountain Rx	370429.223	202837.04
47	ACT	Fountain Rx	370422.991	202829.568
48	ACT	Fountain Rx	370423.173	202826.532
49	ACT	Fountain Rx	370416.494	202827.847
150	ACT	Fountain Rx	370492.054	202844.509
51	ACT	Fountain Rx	370509.521	202837.03
52	ACT	Woodsboro	369923.248	202844.336
53	ACT	Woodsboro	370299.621	203190.631
54	ACT	Woodsboro	370292.676	203187.641
55	ACT	Woodsboro	370255.3	203136.045
56	ACT	Woodsboro	370253.898	203138.878
57	ACT	Woodsboro	370236.158	203105.537
58	ACT	Monocacy	372660.898	202670.95
59	DEP	Lime Kiln	368429.82	196773.8
160	ACT	Lime Kiln	368067.34	196580.72
61	ACT	Lime Kiln	368056.86	196574.3
62	ACT	Lime Kiln	368055.74	196582.46
63	ACT	Lime Kiln	368050.43	196586.29
64	ACT	Lime Kiln	368054.45	196590.72
65	ACT	Lime Kiln	368048.69	196591.41
66	ACT	Lime Kiln	368038.25	196584.06
67	ACT	Lime Kiln	368038.35	196589.46

68	ACT	Lime Kiln	368037.58	196594.38
69	ACT	Lime Kiln	368018.17	196579.96
170	ACT	Lime Kiln	368022.06	196583.32
71	ACT	Lime Kiln	368019.11	196588.11
72	ACT	Lime Kiln	368012.77	196596.37
73	ACT	Lime Kiln	368005.23	196595.78
74	ACT	Lime Kiln	368005.49	196606.46
75	ACT	Lime Kiln	368001.04	196610.36
76	ACT	Lime Kiln	368043.51	196604.84
77	ACT	Lime Kiln	368283.39	196838.39
78	ACT	Lime Kiln	368298.59	196813.91
79	DEP	Lime Kiln	368465.17	196864.09

WOODSBORO QUADRANGLE

1	ACT	Lime Kiln	373384.226	208632.66
2	ACT	Lime Kiln	373365.18	208591.156
3	DEP	Lime Kiln	371421.322	204273.266
4	DEP	Lime Kiln	371301.183	204357.925
5	DEP	Lime Kiln	371472.692	204541.279
6	DEP	Lime Kiln	371695.582	204593.7
7	DEP	Lime Kiln	371669.413	204917.633
8	DEP	Lime Kiln	371686.027	204948.327
9	DEP	Lime Kiln	371832.554	205012.065
10	ACT	Lime Kiln	368078.898	204096.564
11	DEP	Lime Kiln	373144.635	208315.918
12	DEP	Lime Kiln	373161.818	208335.083
13	ACT	Lime Kiln	373431.662	208775.541
14	ACT	Lime Kiln	373409.442	208770.776
15	ACT	Lime Kiln	373419.484	208762.938
16	ACT	Lime Kiln	373412.969	208744.304
17	ACT	Lime Kiln	373381.315	208671.198
18	ACT	Lime Kiln	373402.835	208642.169
19	ACT	Lime Kiln	373410.465	208639.753
20	ACT	Lime Kiln	373410.144	208639.772
21	ACT	Lime Kiln	373413.599	208630.817
22	ACT	Lime Kiln	373405.067	208625.392
23	ACT	Lime Kiln	373396.509	208637.331
24	ACT	Lime Kiln	373384.449	208633.783
25	ACT	Lime Kiln	373385.035	208630.404
26	DEP	Lime Kiln	373195.039	208601.997
27	DEP	Lime Kiln	373179.955	208619.114
28	ACT	Lime Kiln	373151.915	208693.953
29	ACT	Lime Kiln	373819.713	209480.187
30	ACT	Lime Kiln	373386.135	208650.249
31	ACT	Lime Kiln	373389.179	208655.959
32	ACT	Lime Kiln	373389.386	208666.406
33	ACT	Lime Kiln	373381.547	208670.92
34	ACT	Lime Kiln	373388.584	208679.736
35	ACT	Lime Kiln	373395.619	208692.263
36	ACT	Lime Kiln	373407.852	208768.54
37	ACT	Lime Kiln	373412.329	208779.918
38	ACT	Lime Kiln	373431.506	208775.631
39	ACT	Lime Kiln	373418.493	208763.596
40	DEP	Lime Kiln	373407.597	208685.664
41	DEP	Lime Kiln	373394.853	208656.453
42	ACT	Lime Kiln	373404.762	208640.476
43	ACT	Lime Kiln	373410.531	208639.582
44	ACT	Lime Kiln	373413.369	208636.898
45	ACT	Lime Kiln	373412.538	208634.182
46	ACT	Lime Kiln	373412.315	208631.521
47	ACT	Lime Kiln	373412.324	208631.827
48	ACT	Lime Kiln	373414.267	208631.668
49	ACT	Lime Kiln	373403.398	208625.898
50	ACT	Lime Kiln	373399.728	208647.776
51	ACT	Lime Kiln	373394.991	208638.044
52	ACT	Lime Kiln	373382.932	208635.083
53	ACT	Lime Kiln	373211.252	208656.757
54	ACT	Adamstown	373442.997	208622.319
55	ACT	Fountain Rx	370488.514	204902.317
56	DEP	Fountain Rx	370486.892	204903.237
57	DEP	Fountain Rx	370644.175	204649.811
58	ACT	Fountain Rx	370647.615	204652.999
59	ACT	Fountain Rx	370719.864	203938.653
60	DEP	Fountain Rx	371384.029	204675.96
61	ACT	Fountain Rx	371465.069	204769.7
62	ACT	Fountain Rx	370551.451	203677.615
63	DEP	Fountain Rx	371294.33	204533.426
64	DEP	Fountain Rx	371619.853	204961.769
65	DEP	Fountain Rx	371684.678	205064.079
66	DEP	Fountain Rx	371347.142	204639.832
67	DEP	Fountain Rx	370912.111	204210.51
68	DEP	Fountain Rx	370660.746	204375.067
69	DEP	Woodsboro	370788.75	204532.021
70	DEP	Woodsboro	370776.233	204526.882
71	DEP	Woodsboro	370739.829	204510.612
72	ACT	Woodsboro	370766.867	204556.521
73	ACT	Woodsboro	370212.422	203574.661
74	DEP	Woodsboro	370233.279	203590.976
75	DEP	Woodsboro	370368.649	203528.51
76	ACT	Woodsboro	370387.807	203541.008
77	ACT	Woodsboro	370463.237	203577.777
78	DEP	Woodsboro	370530.629	203717.266
79	ACT	Woodsboro	370562.631	203761.631
80	ACT	Woodsboro	370573.57	203766.565
81	DEP	Woodsboro	370538.184	203840.983
82	DEP	Woodsboro	370582.128	203890.749
83	ACT	Woodsboro	370788.678	204014.625
84	ACT	Woodsboro	371383.029	204677.927
85	DEP	Woodsboro	370480.795	203606.182

86	ACT	Woodsboro	372540.526	209064.234
87	ACT	Woodsboro	372560.304	209044.453
88	DEP	Woodsboro	371045.2	204366.35
89	DEP	Woodsboro	370968.609	204472.026
90	DEP	Woodsboro	370889.129	204534.149
91	DEP	Woodsboro	370334.952	203609.501
92	DEP	Woodsboro	370336.947	203620.581
93	ACT	Woodsboro	370339.754	203756.969
94	ACT	Woodsboro	370359.264	203797.061
95	DEP	Woodsboro	370334.792	203777.612
96	DEP	Woodsboro	370319.065	203731.411
97	DEP	Woodsboro	370251.946	203751.567
98	DEP	Woodsboro	370265.396	203820.825
99	ACT	Woodsboro	370516.038	203981.073
100	ACT	Woodsboro	370510.806	203991.243
1	DEP	Woodsboro	370583.083	203891.366
2	ACT	Woodsboro	370406.826	203461.604
3	ACT	Woodsboro	370405.557	203461.054
4	DEP	Woodsboro	370479.667	203605.062
5	DEP	Woodsboro	370788.506	204308.401
6	DEP	Woodsboro	370713.505	204180.431
7	ACT	Woodsboro	370643.988	204116.382
8	ACT	Woodsboro	370649.666	204113.869
9	DEP	Woodsboro	370697.216	204055.913
110	DEP	Woodsboro	370601.719	203972.566
11	ACT	Woodsboro	373382.786	208636.722
12	ACT	Ceresville	373161.566	208743.822
13	DEP	Ceresville	373859.327	209837.476
14	ACT	Rocky Spr Stn	373597.911	207303.483
15	ACT	Rocky Spr Stn	373579.311	207429.121
16	ACT	Rocky Spr Stn	373541.818	207411.796
17	ACT	Rocky Spr Stn	373534.118	207404.099
18	DEP	Adamstown	371107.648	203114.227
19	DEP	Adamstown	371669.065	203444.423
120	DEP	Adamstown	371640.745	203374.129
21	SPR	Fountain Rx	369690.771	203335.686
22	DEP	Fountain Rx	369918.927	204692.673
23	ACT	Fountain Rx	369996.516	204784.91
24	SPR	Fountain Rx	371508.145	205675.789
25	ACT	Fountain Rx	370293.403	205251.08
26	ACT	Fountain Rx	370266.367	205227.435
27	DEP	Fountain Rx	370302.499	205255.485
28	DEP	Fountain Rx	372751.993	207663.68
29	ACT	Fountain Rx	372758.752	207730.714
130	DEP	Fountain Rx	372899.325	207412.064
31	ACT	Fountain Rx	372710.166	207345.888
32	DEP	Fountain Rx	372530.244	207472.08
33	DEP	Fountain Rx	372492.568	207576.365
34	DEP	Fountain Rx	372246.874	207599.549
35	DEP	Fountain Rx	371190.769	207614.582
36	SPR	Fountain Rx	369795.809	206222.262
37	DEP	Fountain Rx	370000.316	206331.935
38	DEP	Fountain Rx	370078.927	206146.985
39	DEP	Fountain Rx	370086.763	206095.114
140	ACT	Fountain Rx	369935.926	205836.029
41	DEP	Fountain Rx	370166.024	206238.069
42	DEP	Fountain Rx	370164.972	206383.826
43	DEP	Fountain Rx	370267.009	206004.828
44	ACT	Fountain Rx	370278.665	206030.43
45	DEP	Fountain Rx	370265.854	205884.834
46	DEP	Fountain Rx	370624.159	205832.062
47	DEP	Fountain Rx	370448.342	205850.868
48	DEP	Fountain Rx	369421.723	206248.771
49	DEP	Fountain Rx	369130.209	205528.053
150	DEP	Fountain Rx	369265.708	203679.246
51	DEP	Fountain Rx	369477.647	203670.474
52	DEP	Fountain Rx	369451.765	203497.036
53	DEP	Fountain Rx	369672.039	203369.388
54	DEP	Fountain Rx	369361.393	203708.514
55	DEP	Fountain Rx	371283.617	205484.99
56	ACT	Fountain Rx	371283.848	205485.068
57	DEP	Fountain Rx	370973.934	205485.594
58	DEP	Fountain Rx	372545.949	207122.741
59	ACT	Fountain Rx	372684.483	207039.772
160	DEP	Fountain Rx	372592.116	206757.209
61	DEP	Fountain Rx	372265.104	206515.973
62	DEP	Fountain Rx	372462.546	206472.332
63	ACT	Fountain Rx	372548.116	206347.849
64	DEP	Fountain Rx	372063.823	205664.176
65	DEP	Fountain Rx	372106.011	205893.238
66	SPR	Fountain Rx	370271.868	207274.312
67	DEP	Fountain Rx	372547.572	208032.429
68	ACT	Fountain Rx	372846.845	208496.936
69	ACT	Fountain Rx	372845.207	208508.34
170	DEP	Fountain Rx	372854.445	208536.071
71	DEP	Fountain Rx	372846.17	208444.233
72	ACT	Fountain Rx	372651.048	208456.084
73	ACT	Fountain Rx	372627.501	208465.379
74	ACT	Fountain Rx	372620.469	208432.977
75	ACT	Fountain Rx	372610.58	208409.102
76	ACT	Fountain Rx	372594.05	208379.811
77	ACT	Fountain Rx	372369.417	208435.948
78	ACT	Fountain Rx	372358.329	208426.785
79	ACT	Fountain Rx	372362.677	208401.164
180	ACT	Fountain Rx	372326.722	208258.153
81	ACT	Fountain Rx	372368.962	208240.791
82	ACT	Fountain Rx	372369.007	208240.348
83	ACT	Fountain Rx	372448.799	208099.519
84	DEP	Rocky Spr Stn	372375.354	205200.77
85	DEP	Rocky Spr Stn	372335.766	205554.489

86	ACT	Rocky Spr Stn	373540.284	207399.657
87	ACT	Rocky Spr Stn	373579.946	207444.225
88	ACT	Rocky Spr Stn	374251.922	210202.33
89	DEP	Lime Kiln	372711.155	207315.821
190	DEP	Lime Kiln	372124.301	205644.948
91	DEP	Ceresville	372740.636	207399.03
92	ACT	Ceresville	372708.16	207339.624
93	DEP	Ceresville	368574.372	205110.809
94	ACT	Ceresville	372793.912	208233.001
95	DEP	Woodsboro	372365.127	207612.542
96	DEP	Woodsboro	372295.055	207604.835
97	DEP	Woodsboro	372086.493	207590.037
98	DEP	Woodsboro	371262.467	207652.668
99	DEP	Woodsboro	371848.61	207654.699
200	ACT	Woodsboro	372372.356	208488.643
1	ACT	Woodsboro	372451.193	208439.275
2	ACT	Woodsboro	372468.196	208473.985
3	ACT	Woodsboro	372315.362	208319.479
4	ACT	Woodsboro	370013.688	202984.198
5	ACT	Woodsboro	370240.129	203104.175

CATOCTIN FURNACE QUADRANGLE

1	DEP	Rocky Spr Stn	363152.142	205926.472
2	DEP	Rocky Spr Stn	363221.404	205937.865
3	DEP	Rocky Spr Stn	364247.594	209942.995
4	DEP	Rocky Spr Stn	363525.351	205838.684
5	DEP	Rocky Spr Stn	363448.252	205880.272
6	DEP	Rocky Spr Stn	363397.878	205943.382
7	DEP	Rocky Spr Stn	363456.063	205872.895
8	DEP	Rocky Spr Stn	363467.154	205885.015
9	DEP	Rocky Spr Stn	363372.52	205850.707
10	DEP	Rocky Spr Stn	363506.096	205979.827
11	DEP	Rocky Spr Stn	363506.669	205918.193
12	DEP	Rocky Spr Stn	363422.404	205989.1
13	DEP	Rocky Spr Stn	363217.729	206050.173
14	DEP	Rocky Spr Stn	363175.447	205978.69
15	DEP	Rocky Spr Stn	362947.371	205905.332
16	DEP	Rocky Spr Stn	362627.261	205878.388
17	DEP	Rocky Spr Stn	362678.728	205871.835
18	DEP	Rocky Spr Stn	362416.877	205902.638
19	DEP	Rocky Spr Stn	361953.819	205620.136
20	DEP	Rocky Spr Stn	362151.936	205663.379
21	DEP	Rocky Spr Stn	363832.761	210122.266
22	DEP	Rocky Spr Stn	361606.9	204168.978
23	ACT	Rocky Spr Stn	363365.823	208819.498
24	DEP	Rocky Spr Stn	362686.821	209308.542
25	DEP	Rocky Spr Stn	362638.075	209732.82
26	DEP	Rocky Spr Stn	362523.321	209226.248
27	DEP	Rocky Spr Stn	363506.68	205918.883
28	DEP	Rocky Spr Stn	361444.72	203708.377
29	DEP	Rocky Spr Stn	361489.222	203712.042
30	DEP	Rocky Spr Stn	361453.489	203753.645
31	DEP	Leesburg	363479.61	215180.08
32	DEP	Leesburg	364019.01	214810.85
33	SPR	Leesburg	363663.76	213815.39
34	DEP	Leesburg	363781.68	215352.96
35	SPR	Rocky Spr Stn	362975.62	209506.53
36	SPR	Rocky Spr Stn	362799.68	210884.84