Department of Natural Resources
Resource Assessment Service
MARYLAND GEOLOGICAL SURVEY
Richard A. Ortt, Jr., Director

REPORT OF INVESTIGATIONS NO. 89

ALLEGANY COUNTY HIGHWAY ROCK CUT INVENTORY AND SLOPE FAILURE POTENTIAL

by

David K. Brezinski
Rebecca Kavage Adams
Elizabeth R. Sylvia

DNR Publication Number DNR 12-041720-227

June 2023

EXECUTIVE SUMMARY

- One hundred ninety-five MDOT-maintained highway embankments in Allegany County, Maryland were catalogued in an effort to gain insight into the effects of climatic, vegetative, and geology factors on embankment slope stability.
- Information was collected in real-time in ArcGIS Survey123.
- In total, more than 7,000 data observations were made.
- Each exposure was categorized as to location, dimensions, weathering condition, and geologic structure.
- Based on these data, summary evaluations were made as to the potential for rockfall, rock roll, rockslide, or slumping and rotational failures.
- Rockfalls were considered to be most prone to occur in slopes of >60º, composed of massive sandstone or limestone lithologies, and exhibiting major levels of differential erosion.
- The rockfall failure type was identified for twenty-four percent of the slopes studied.
- The most common type of potential slope failure was rock roll, a type of potential failure that was assessed to be present for fifty-one percent of the studied exposures.
- Rock roll potential was typical of exposures comprised of interbedded lithologies, and for slopes of between 30º to 60º.
- Rockslide potential was identified for fourteen percent of the exposures studied, and this failure type was largely confined to strata that were inclined into the roadway.
- Slump or rotational dislocations were identified in eleven percent of the outcrops studied, and their potential tended to be present on highly weathered outcrops that were covered by vegetation.

Table of Contents

List of Figures

ABSTRACT

More than 7,000 data observations were made and catalogued at 195 MDOT-maintained highway embankments in Allegany County, Maryland. This effort was to gain insight into the effects of climatic, vegetative, and geology factors on embankment slope stability and to categorize potential types of embankment failure. Each embankment was identified by its GPS coordinates and was categorized by its dimensions, weathering condition, geologic structure and potential type of slope failure identified. All data was recorded in real time using ESRI Survey123.

Fifty-one percent of the studied exposures studied presented a potential slope failure by rock roll. Rock roll potential was typical of exposures comprised of interbedded lithologies, and for slopes of between 30º to 60º. This type of potential failure that was the leading type of failure identified. Rockfalls were identified for twenty-four percent of the slopes studied and were considered to be most prone to occur in slopes of >60º. This type of failure was mainly found in embankments composed of massive sandstone or limestone lithologies, or exhibiting major levels of differential erosion. Rockslide potential was identified for fourteen percent of the exposures studied. This method of failure was largely confined to interbedded strata that were inclined into the roadway. Slump or rotational dislocations were identified in eleven percent of the outcrops studied, and their potential tended to be present on highly weathered outcrops that were covered by vegetation.

INTRODUCTION

Slope failure represents an important form of geologic hazard. Identification of such features on a regional scale has been accelerated, in recent years, by the study of aerial LiDAR (Light detection and ranging) imagery (Schulz, 2004, 2007; Burns and Madin, 2009). However, small-scale slope and bedrock failures, too small for aerial LiDAR identification, present a different level for hazard study. Slopes present along roadways present a substantial hazard to drivers and expense and liability to roadway agencies. Such failures are dictated by a combination of factors such as bedrock character, steepness of slope, and climatic conditions. Because the state of Maryland transects parts of five physiographic provinces, there is no single set of stratigraphic, structural, or topographic conditions that can be applied statewide to coherently summarize potential slope failure regimes. Thus, it is necessary to evaluate roadway exposures in each physiographic province under a different set of observed and measured characteristics and constraints. In Allegany County, the bedrock consists of layered sedimentary rocks of differing erodibility. The shale, siltstone, limestone, and sandstone vary in thickness and geographic distribution. These changes in competency, along with the presence of pervasive planes of discontinuity, weather at different rates, and coupled with water infiltration and frost action, produce unstable masses of rock that, through the force of gravity, can result in slope failure. Furthermore, the compression and tension experienced by the bending of these rocks during the formation of the Appalachian Mountains produced fractures of varying orientations and attitudes that can expedite weathering, frost heaving, and water transmission. These processes serve to hasten detachment and release of clasts, boulders, and blocks that can fall, roll, or slide into the roadway.

Purpose

The initial objective of this project was to catalogue the surficial character, current conditions and rockfall potential for rock exposures along state-maintained roadways within Allegany County, Maryland. This effort was initiated to record a snapshot in time for each outcrop risk for rockfalls into roadways maintained by the Maryland Department of Transportation. Additionally, it was thought that the diverse data acquired from this effort might delineate certain rock types, structural features, or outcrop profiles that, when observed in certain combinations, produce a recognizable recurrence of slope failure types and their potential for failing. The compilation of such a recognizable suite of controlling factors may be used in production of a statewide categorization of existing and potential slope failure characters.

Location and Physiography

Maryland presents a broad range of bedrock types and characters across five physiographic provinces. Understanding slope failure within each physiographic region of the state requires detailed knowledge of each province's bedrock, climatic, and erosional histories. The current study area lies within Maryland's portion of the eastern Appalachian Plateaus and western Ridge and Valley physiographic provinces of Allegany County, Maryland (Reger and Cleaves, 2008) (Figure 1). In general, the Ridge and Valley Physiographic Province consist of highly folded and eroded sedimentary rocks of early to middle Paleozoic age. To the east of the study area, these strata consist of early Paleozoic carbonate rocks that underlie the Great Valley Section (Hagerstown Valley, eastern Washington County), as well as middle Paleozoic limestones that underlie some narrow linear valleys a little farther to the west. In Allegany County the greatest preponderance of the Ridge and Valley Province is underlain by middle Paleozoic sandstone, siltstone, and shale. It is the combination of several factors such as lithologic variations in steeply dipping strata along with the ease of decoupling within and between individual units of differing competence that provides the greatest concern for slope instability within this physiographic province. Elevations within the Ridge and Valley Physiographic Province of Maryland range from 600 to 1,800 feet above sea level.

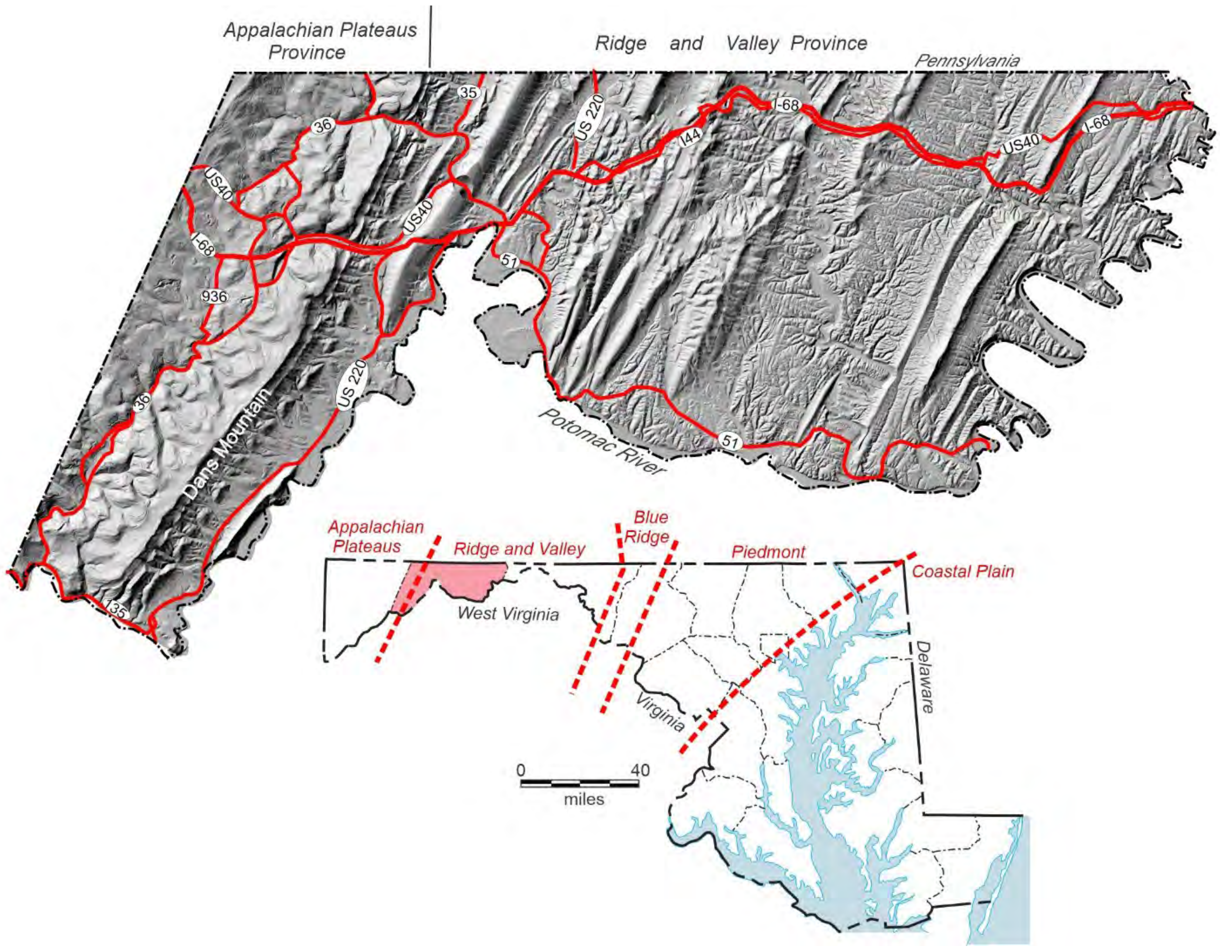


Figure 1. Light detecting and ranging (LiDAR) image of Allegany County, Maryland, illustrating state-maintained highways along which rock slope failure data were collected for this study. Image from https://geodata.md.gov/topoviewer. Inset map of location of Allegany County (pink).

The dividing line between the Ridge and Valley and Appalachian Plateaus physiographic provinces has been considered historically to coincide with Dans Mountain (Figure 1). This ridge demarcates what is known as the Allegheny Structural Front, and the change from highly folded rocks (Ridge and Valley Province to more gently folded rocks (Appalachian Plateaus Province) (Figure 2). The Appalachian Plateaus Province of western Allegany County presents a completely different suite of rocks, climate, and hazard factors. Within this area, gently inclined, thick-bedded intervals of erosion-resistant sandstone alternate with more easily weathered and eroded shales and coals. These substantial differences in bedrock erodibility create large topographic relief and steep, unstable slopes that are prone to failure. The Appalachian Plateaus Province of Allegany and Garrett counties, ranges in elevation from 1,200 to 3,000 feet above sea level.

Previous Study

Study of the bedrock geology of Allegany County, Maryland has concentrated mainly on detailed geologic mapping of bedrock units (Berryhill et al., 1956; Dennison, 1963; De Witt and Colton, 1964; Glaser, 1994a-e; Glaser and

Brezinski, 1994, 1996; Brezinski and Conkwright, 2013). In contrast, studies attempting to understand aspects of slope failure or rockfall hazard systems within Allegany County are extremely sparse (Southworth and Schultz, 1986; Pomeroy, 1988). Previous rock failure studies in Maryland have focused on the poorly indurated strata and high-relief areas adjacent to the Chesapeake Bay (Leatherman 1986; Pomeroy, 1988).

In the Ridge and Valley Province areas slope failure studies are well-known (Schultz and Southworth, 1989). In Maryland, three previous slope failure sites have been documented. Ancient rockslides on the west slope of Wills Mountain were thought to be caused by the undercutting of the Juniata and Tuscarora formations by Wills Creek (Southworth and Schultz, 1986). Slope failures on MD Route 48 in the Rose Hill Formation west of Cumberland, and on MD Route 51 in the Oriskany Formation south of Cumberland were attributed to a combination of dip slope, shale beds, and presence of water (Pomeroy, 1988). In the Appalachian Plateaus Province portion of the study area, Pomeroy (1988) identified the potential for rockfalls near Westernport from thick Pottsville and Allegheny sandstone overhangs and postulated that slope movements along MD Route 36 were due in part to water from abandoned strip mines in the Conemaugh and Monongahela formations. Pomeroy’s work represents early attempts to display mapped landslides and areas vulnerable to slope failure in Maryland. His generalized effort was presented at a scale of 1:500,000 and thus provided limited site-specific insight for understanding and predicting rock slope failures. Beyond Pomeroy’s work to identify isolated landslide areas, there have been few geologic maps (Brezinski, 2019; Brezinski and Glaser, 2014) that have attempted to display areas of potential slope failure or interpreted landslides within Maryland.

BEDROCK GEOLOGY

The physiographic provinces transecting the state of Maryland are distinguished by their topography, bedrock composition, and structure. These variables are the result of a complex history of sedimentation and mountain-building that is recorded in the geologic framework of the State. In western Maryland, the stratigraphic history is preserved in an exposed rock succession composed of highly variable lithologies.

Juniata Formation

The oldest exposed unit in the study area is the Juniata Formation. This formation is exposed only along the axis of Wills and Evitts Mountain anticlines near Cumberland (Figs. 2A, 2B). Oxidized clays give the Juniata Formation a reddish-brown to red color. The formation consists of interbedded sandstones, siltstones and shales (Figure 3A). Sandstones consist of sheetlike cross-bedded sandstones (lower and upper), mudstones (middle), and contain vertical Skolithos burrows (DeWitt and Colton, 1964). Estimated at up to 1600 feet in thickness, but only about 300 feet are exposed (Diecchio, 1985).

No slope failure characteristics were identified for the Juniata Formation in this study, but it was previously identified as a possible failure plane for an ancient slide on the west side of Wills Mountain (Pomeroy, 1988).

Tuscarora Formation

The main ridge-forming unit of the Ridge and Valley Province is the Tuscarora Sandstone. The Tuscarora is a white to gray, relatively pure, medium-bedded to massive, cross-bedded quartzitic sandstone, with a few thin shale layers in the upper part (Figure 2A). It is exposed along the axis of the Wills, Evitts, and Tussey mountains in western Allegany County (Figs. 2A, 2B, 3B). The Tuscarora sandstone is estimated to be 400 feet thick in the study area (DeWitt and Colton, 1964).

The Tuscarora sandstone weathers to large erosion-resistant blocks and boulders (colluvium) that mantle slopes below its outcroppings, and vertical cliffs along the narrows at Cumberland. Along Wills Mountain, some slides are formed along shaly beds where they are dipping steeply.

Rose Hill Formation

The Rose Hill Formation underlies slopes near the base of Wills, Evitts, and Tussey Mountain anticlines west of Flintstone (Figs. 2A, 2B, 3B). Thin-bedded, red shales and siltstones comprise most of the formation. A 1-3 foot hematite cemented sandstone (Cresaptown Ironstone) occurs in the lower third of the formation and a 10-30 foot thick quartz sandstone (Keefer Sandstone) occurs at the top. Trace fossils, bioturbation, and slickensides are common. In the study area, the thickness is approximately 550 feet (Swartz et al., 1923; DeWitt and Colton, 1964). Rock roll of cobble-size shale and siltstone is the dominant slope failure type in the Rose Hill Formation. Rockslide along incompetent planes of shale occurs west of Cumberland on Haystack Mountain.

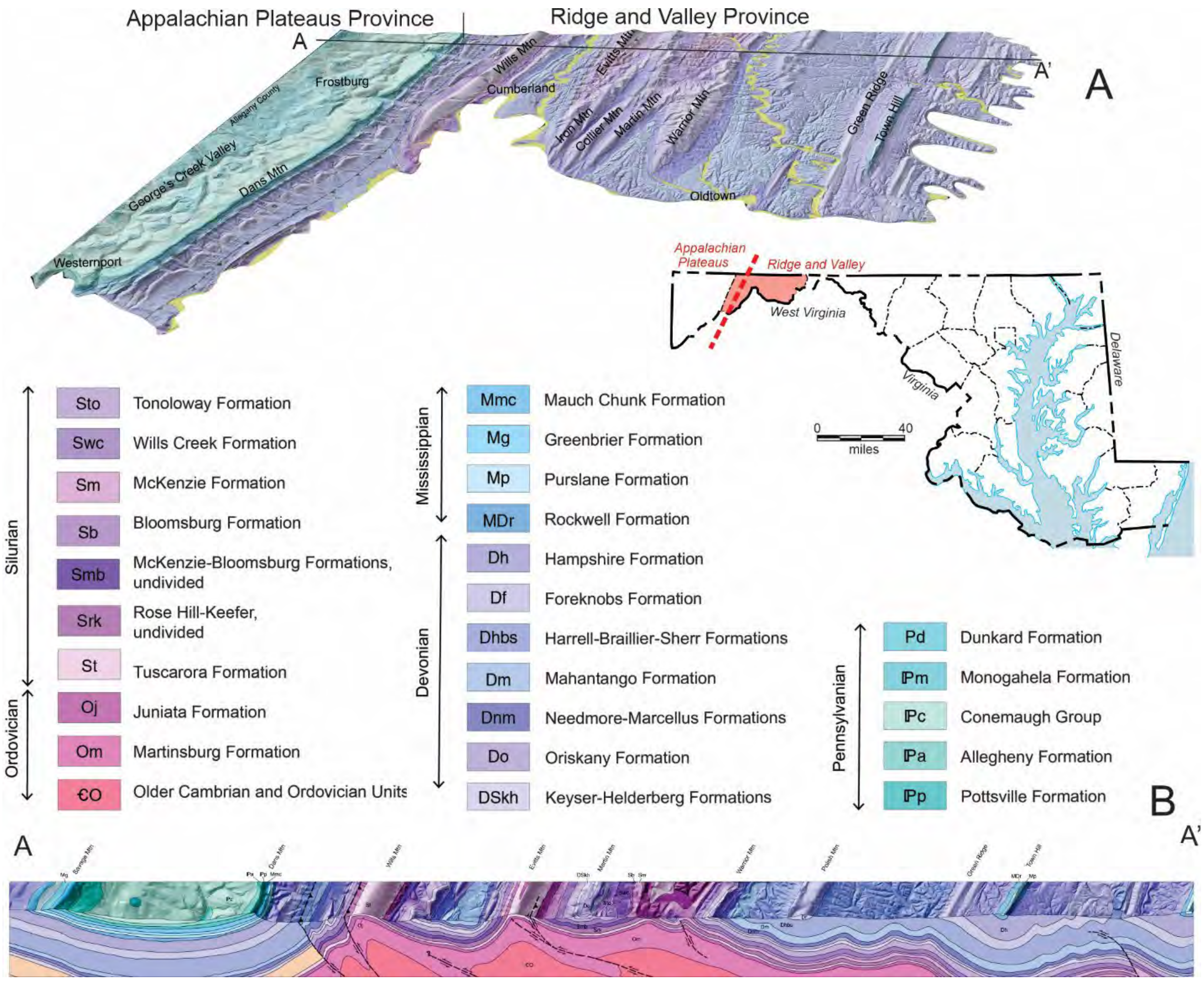


Figure 2. Bedrock geology and structure of Allegany County, Maryland, taken from Brezinski and Conkwright (2013). A, Geologic map of Allegany County overlaid on aerial imagery with major topographic features annotated. B, Idealized interpretive geologic cross section of bedrock units and structures for Allegany County. Abbreviated symbols correspond to those units identified in legend.

McKenzie Formation

The McKenzie Formation is exposed in narrow, low-lying bands at the base of Wills, Evitts, and Tussey Mountains between Flintstone and Cumberland (Figs. 2A, 2B). The formation contains thinly bedded, gray shale and limestone, gray calcareous shale with dark gray argillaceous limestone interbeds, and beds of highly fossiliferous coquina. A tan color becomes dominant upon weathering. The McKenzie Formation is approximately 285-380 feet thick (DeWitt and Colton, 1964).

Slope failure type in the McKenzie Formation is mostly limited to rock roll, but rockslide potential exists at one location east of Evitts Mountain where beds are steeply dipping into the roadway. Slump earthflow in the McKenzie and Bloomsburg formations was found along MD-48 west of Cumberland in a prior study (Pomeroy, 1988).

Bloomsburg Formation

The Bloomsburg Formation creates thin, low ridges between the less resistant McKenzie and Wills Creek formations (Figs. 2A, 2B, 3B). It is present irregularly, and therefore sometimes mapped undivided with the underlying McKenzie Formation (Brezinski and Conkwright, 2015) or the overlying Wills Creek Formation (Swartz et al., 1923). The Bloomsburg is comprised of thin- to medium-bedded red shale and sandstone with a 1-foot bed of limestone (Cedar Cliff Limestone) occurring near the middle. Calcareous nodules and deep vertical burrows are present at some exposures. It ranges from 25-50 feet thick in the study area (DeWitt and Colton, 1964).

Due to its limited exposure, only two Bloomsburg slope failure locations were observed; one showed potential for rock roll, while rockslide was identified where beds dip steeply into the roadway.

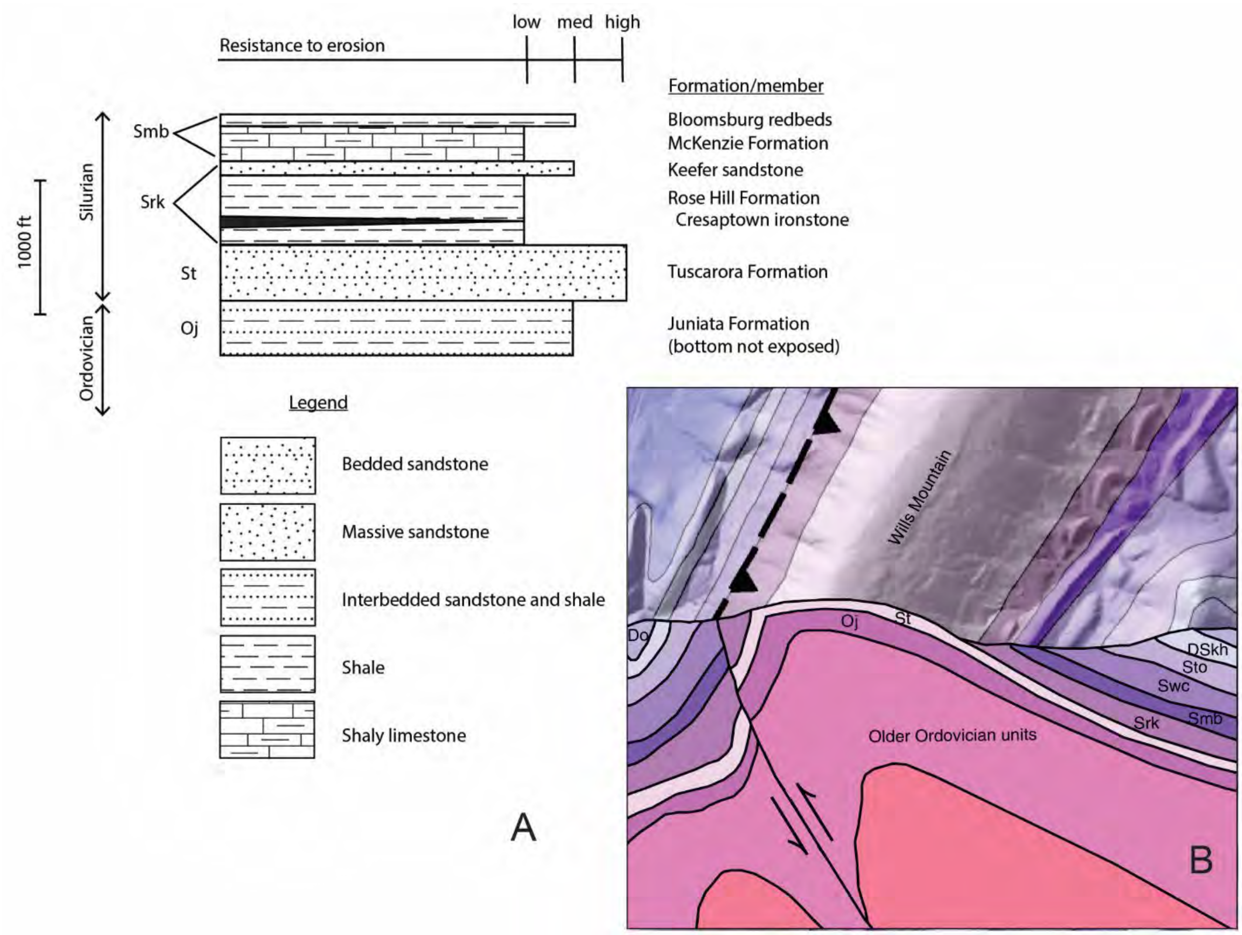


Figure 3. Upper Ordovician to Silurian stratigraphy and geologic structure of Wills Mountain. A, Stratigraphic column of Wills Mountain showing lithology and relative resistance to erosion for each rock unit. B, Block diagram of Wills Mountain showing anticlinal ridge formed by the resistant Tuscarora sandstone. Adapted from Brezinski and Conkwright (2013). See Figure 2 for the symbology key.

Wills Creek Formation

The Wills Creek Formation underlies large portions of the valleys from Flintstone and Cumberland, between ridges formed by the Tuscarora and Oriskany sandstones (Figs. 2A, 2B, 4B, 4C). It is primarily thin-bedded dark gray mudstone and shale, calcareous shale, and limestone (Figure 4A). Resistant, calcite-cemented sandstone beds are present in the upper and lower part of the formation, and desiccation cracks, halite and gypsum casts are common. Shales weather yellowish-green. The formation is 500 feet thick in the study area (DeWitt and Colton, 1964).

Slope failures in the Wills Creek Formation are commonly rock roll, with one rockslide failure plane found just west of Rocky Gap where shale beds erode from under more resistant limestone beds.

Tonoloway Formation

The Tonoloway Formation forms the base of slopes below ridges of the Keyser-Helderberg and Oriskany formations, with prominent exposures on Warrior and Martin mountains west of Flintstone (Figs. 4B, 4C). The bottom and top of the formation are laminated, dark gray, shaly limestone, with intervening dolostone beds that weather brown and contain desiccation cracks and halite casts (Figure 3A). The middle 100 feet of the Tonoloway is relatively pure dark gray limestone. The thickness is estimated at 550-600 feet (DeWitt and Colton, 1964).

Slope failure potential in the Tonoloway Formation exists predominantly as rock roll and rockfall. On Martin Mountain, rockfall is possible where the bedding angle is low and differential erosion of dolostone under massive limestone beds is prominent. As bedding steepens and dips into the roadway, rockslide potential is also present.

Keyser-Helderberg Formation

The Keyser-Helderberg Formation underlies a portion of the steep side slopes and ridges of Warrior and Martin mountains west of Flintstone (Figs. 4B, 4C). Other prominent exposures occur on the east slope of Fort Hill and the west slope of Wills Mountain near Cumberland. The Keyser Limestone is considered the basal member of the Helderberg Formation in Maryland (DeWitt and Colton, 1964; Brezinski and Conkwright, 2015). In the study area, the Keyser is a massive, dark gray, nodular limestone with abundant coral and stromatoporoid fossils (Figure 4A). It is approximately 300 feet thick. Overlying (in ascending order) are three members of the Helderberg Formation; the New Creek Limestone, Corriganville Limestone, and Mandata Shale. The New Creek Limestone (Coeymans Limestone of earlier reports) is medium gray, thick-bedded to massive, crinoidal, coarse-grained limestone with a thickness of 7 to 10.5 feet (DeWitt and Colton, 1964). The Corriganville Limestone (New Scotland Limestone of earlier reports) is light to medium gray, fossiliferous limestone interbedded with chert. Its thickness is 20 to 30 feet. The Mandata Shale is dark brown to black, thin-bedded shale interbedded with black chert. It weathers to dusky yellow clay and is approximately 20 feet thick. The total thickness of the Keyser-Helderberg Formation is 350 feet (DeWitt and Colton, 1964).

Rockfall is the dominant form of slope failure in the Keyser-Helderburg Formation and occurs mainly where erodible shales of the Tonoloway Formation have weathered from underneath massive limestones in the Keyser Limestone. Rockslide potential was seen at one location on Martins Mountain in the Keyser Limestone, due to beds dipping steeply into the roadway. Rock roll and slump were present but infrequent.

Oriskany Formation

The Oriskany Formation is a prominent ridge-former in the Ridge and Valley Physiographic Province, secondary to the Tuscarora Sandstone. In the areas stretching from Flintstone to Cumberland, the Tuscarora underlies the crests of Warrior, Martin, Collier, and Iron mountains as well as Fort Hill. Two members, the Shriver Chert and Ridgely Sandstone, are recognized in Maryland (Figure 4A). The Shriver Chert is dark gray, calcareous, and siliceous siltstone with nodules and beds of dark gray chert. It weathers yellow to brown, sometimes developing a banded appearance. It is estimated to be 160 feet thick. The overlying Ridgely Sandstone is gray, calcareous to arenaceous, medium- to thick-bedded, fossiliferous sandstone. In the upper portion, abundant silicified shells occur along bedding planes and a high proportion of calcareous material is present. Where calcite cemented, the Ridgeley is friable and weathers to sand; where silica cemented, it weathers to large resistant blocks. The thickness of the Ridgely Sandstone is approximately 150 feet. The total thickness of the Oriskany Formation is estimated at 300-350 ft (DeWitt and Colton, 1964). Numerous slope failure sites were found in the Oriskany Sandstone with the potential for rock roll, rockfall, and rockslide. At most of these sites, differential erosion of calcareous beds from underneath resistant sandstones creates large overhangs and loose blocks susceptible to failure.

Needmore and Marcellus Shales

The Needmore and Marcellus shales underlie the outer slopes of synclinal Oriskany ridges from Oldtown to Cumberland. Due to much infolding and poor exposure in the study area, the Needmore and Marcellus are mapped undivided (Brezinski and Conkwright; 2015). The Needmore shale consists of brownish- to greenish-gray shale and dark gray to black calcareous shale (Figure 4A). Some beds of resistant argillaceous limestone and large nodules and concretions are present. Brachiopods and trilobites are abundant in calcareous rocks. The thickness of the Needmore is estimated to be 150 feet. The Marcellus shale is mostly fissile black shale with sparse fauna. The middle third of the Marcellus is a calcareous shale resembling the Needmore shale, sometimes with a zone containing distinctive golf ball-size nodules recognized as Purcell limestone (Cate, 1963). The Marcellus shale is approximately 250 feet, and the total thickness of both units is approximately 400 feet (DeWitt and Colton, 1964).

Abundant joints in the Needmore and Marcellus shales create loose blocks with the potential for rockfall, rock roll, and rockslide along MD-51 and MD-220 near the Potomac River. Rockfall potential occurs where joints parallel the road, while rockslide occurs where joints dip into the road. Large concretions are also susceptible to rockfall where they weather out of surrounding shale.

Mahantango Formation

The Mahantango Formation comprises low-lying, synclinal valleys that widen toward the southwest along the Potomac River from Oldtown to Keyser, West Virginia. Most of the formation is dark gray siltstone and massive shale (Figure 4A). Resistant, fossiliferous siltstones occur near the middle and top of the formation (Cate, 1963), and form minor ridges. The massive shale weathers into spheroidal slopes of small chips that contrast with visible bedding in the resistant siltstones. Thickness is estimated at 1350 feet but is difficult to determine because of much intraformational folding and faulting (DeWitt and Colton, 1964).

Potential slope failure in the Mahantango Formation exists near the Potomac River on MD-51 and MD-220, and north of Cumberland on MD-220. Rock roll is the dominant slope failure type, but the potential for rockfall exists where bedding is less than 45 degrees and ledges of resistant siltstone develop above eroded shale. Rockslide occurs where bedded siltstones dip steeply into the roadway and bedding acts as a failure plane.

Harrell/Brallier/Sherr Formations

The Harrell Shale, Brallier, and Sherr formations underlie the axial portion of broad synclinal valleys throughout Alleghany County. Due to poor exposure, the three formations are difficult to differentiate and therefore mapped undivided (Brezinski and Conkwright, 2015). The Harrell Shale is a platy, laminated, dark gray shale estimated at 100 feet thick (DeWitt and Colton, 1964). It contains up to 50 feet of black, very fissile shale of the Burket Member at its base (Figure 4A). When present, the gray, fossiliferous Tully Limestone marks the base of the Harrell Shale. The overlying Brallier Formation is interbedded, medium- gray siltstone and shale. Siltstones are sharply bounded with cross laminations and convoluted bedding. Its thickness is approximately 2000 feet. The Scherr Formation is distinguished from the underlying Brallier Formation by an interval of brownish-gray redbeds near its base and is 1000 feet thick (Dennison et al., 1972) in western Allegany County. The total estimated thickness of the Harrell-Brallier-Sherr Formation is 2000-3000 feet.

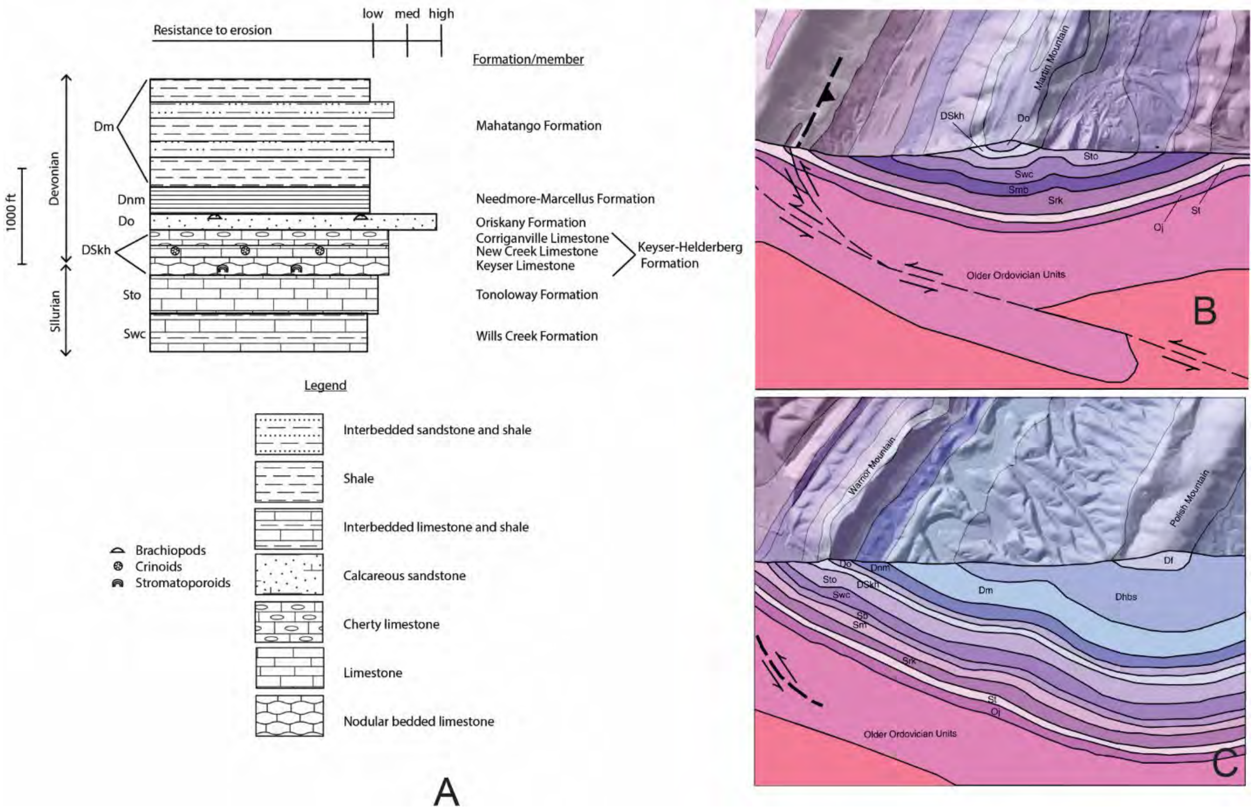


Figure 4. Middle Silurian to Devonian stratigraphy and geologic structure of Martin and Warrior Mountains. A, Stratigraphic column showing lithology and relative resistance to erosion for each rock unit. B, Block diagram of Martin Mountain showing synclinal ridge formed by the Oriskany Formation. C, Block diagram of Warrior Mountain, formed by the Oriskany and Keyser-Helderberg formations in the west limb of a syncline. Adapted from Brezinski and Conkwright (2013). See Figure 2 for the symbology key.

More slope failure sites (41) were cataloged in the Harrell-Brallier-Sherr than in any other formation in the study area. All four types of slope failure exist, with rock roll occurring at a majority of the sites. Rockslide potential was found at sites where bedding is inclined into the roadway, while sites with differential erosion have the potential for rockfall. Rock slump was evident in a variety of conditions.

Foreknobs Formation

The Foreknobs Formation forms low ridges within broad synclinal valleys in eastern Allegany County and a line of knobs below the high ridge of Pennsylvanian sandstone along the Allegheny Front. The formation contains mainly greenish- to brownish-gray interbedded sandstone, siltstone and shale (Figure 5A). Two thick- to massive-bedded, conglomeratic sandstones are recognizable in the study area: the fossiliferous Briery Gap Sandstone Member and the cross-bedded Pound Sandstone Member. The total thickness of the Foreknobs Formation is 1500 feet (Dennison et al., 1972).

Rock roll is the most common slope failure type in the Foreknobs Formation. Sites with potential rockfall and rockslide were found where massive sandstones are undercut by differential erosion and dip into the roadway.

Hampshire Formation

The Hampshire Formation underlies the broad slopes of Town Hill in eastern Allegany County and is exposed in western Allegany County along a narrow band east of the Allegheny Front (Figs. 5B, 6B). It is comprised of grayish-red to greenish-gray shale, siltstone, and sandstone (Figure 5A). The shale is typically thin-bedded, hackly, with root casts, and the siltstone and sandstone are cross-bedded, blocky weathering, and sometimes olive-gray in color (Woodward, 1943). Thickness ranges from 2000 to 3000 feet from eastern to western Allegany County (Brezinski and Conkwright, 2015).

Thirty-one potential slope failure sites occur within the Hampshire Formation in the study area, most of which are on roads that cut through Town Hill. As with the Foreknobs Formation and other Devonian shales, rock roll is the most common slope failure type. Rockfall potential is present where differential erosion creates overhanging sandstones. Rockslide potential is present where beds dip into roadways.

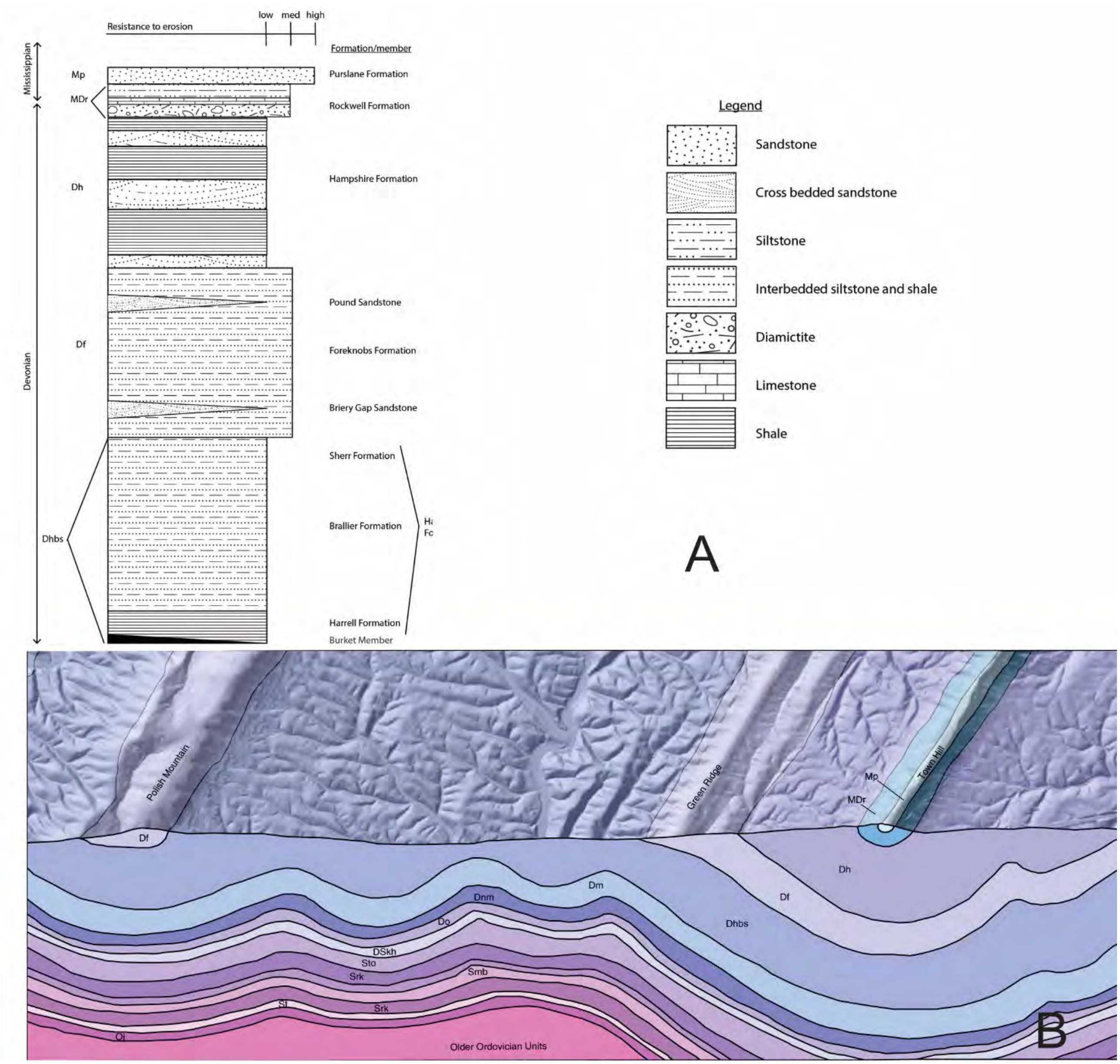


Figure 5. Middle Devonian to Mississippian stratigraphy and geologic structure of Town Hill, Green Ridge, and Polish Mountain. A, Stratigraphic column showing lithology and relative resistance to erosion for each rock unit. B, Block diagram of Town Hill, with synclinal ridge formed by the Purslane Formation. To the west, the Foreknobs Formation forms Green Ridge and Polish Mountain. Adapted from Brezinski and Conkwright (2013). See Figure 2 for symbology key.

Rockwell Formation

The Rockwell Formation forms the crest of Town Hill in eastern Allegany County and is exposed in a narrow band below the Allegheny Front (Figures. 5B, 6B). It is predominantly olive green to yellowish-gray siltstone and sandstone (Figure 5A). Two distinctive units are recognized in the study area: a polymictic diamictite near the base of the formation, and the overlying Riddlesburg Member, which grades from olive-gray to black, thin-bedded shale to cross-bedded, burrowed siltstone and sandstone from east to west. The thickness of the formation is 350-400 feet in Allegany County (Brezinski, 1989).

Due to its limited exposure, only 4 slope failure sites were observed in the Rockwell Formation. All of the slope failure types were present.

Purslane Formation

The Purslane Formation forms the ridge of Town Hill and a narrow ridge secondary to, and just east of the Pennsylvanian sandstones along the Allegheny Front (Figs. 5B, 6B). The formation contains olive gray, medium- to coarse-grained sandstone intervening layers of dark gray shale. Sandstones are tan to reddish-brown, cross-bedded, and sometimes conglomeratic. The Purslane Formation thins from 330 to 200 feet from eastern to western Allegany County (Brezinski, 1989). Four slope failure sites were observed in the Purslane Formation and failure types were limited to rock roll (3) and rockfall (1).

Greenbrier Formation

The Greenbrier Formation occurs in a poorly exposed, narrow band east of the Allegheny Front within the study area (Figure 6B). The formation consists of four members. The basal Loyalhanna Member is a reddish-gray to light gray, arenaceous, cross-bedded limestone (Figure 6A). Overlying in ascending order are: the Deer Valley Member, light olive gray, massive, crystalline limestone; the Savage Dam Member, predominantly clastic, variegated, reddish-gray to grayish-green, thin-bedded siltstone and shale; and the Wymps Gap Member, light olive gray to medium dark gray, argillaceous limestone with abundant brachiopod, bryozoan and crinoid fossils. The total thickness in the study area is approximately 250 feet (Brezinski, 1989).

The Greenbrier Formation had one site with slope failure potential, east of Westernport, in the form of rock roll and slump/rotation in shaly redbeds of the Savage Dam Member.

Mauch Chunk Formation

The Mauch Chunk Formation occurs narrow band east of the Allegheny Front on Dans Mountain and to the west on Savage Mountain (Figure 6B) where it is largely covered by resistant boulders of the overlying Pottsville Formation. It contains reddish-gray to olive-green shale that is typically thin-bedded and fissile (Figure 6A), with abundant root casts and weathers into reddish- gray soil. Also present are light olive gray, thin- to medium-bedded, siltstone and sandstone that are frequently cross-bedded in layers that outcrop as small ridges on hillsides. The total thickness is 550-600 ft in the study area (Brezinski, 1989).

Four slope failure sites occur east of Westernport on MD-135 in the Mauch Chunk Formation. Three of these are slumps, where no bedrock is present; rather, soils from the Mauch Chunk have rotated under Pottsville Formation boulders. One site has the potential for rockfall and rockslide, where differential weathering has created large sandstone overhangs that dip into the roadway.

Pottsville Formation

The Pottsville Formation forms dramatic ledges and cliffs on Dans Mountain and Savage Mountain (Figure 6B). It is only present in the western portion of the study area. Four thick, named sandstones comprise most of the formation with occasional interbedded shale, thin coal, and underclay layers (Figure 6A). From bottom to top: The Sharon sandstone is pale yellowish brown, massive, conglomeratic sandstone. The Lower and Upper Connoquenessing sandstones are olive green to yellowish brown, thin to massive, coarse sandstone, parting on layers, with plant fossils. The Homewood sandstone is white-gray, massive, conglomeratic sandstone with tabular cross-bedding and fossil plant fragments. The total thickness is 180-225 feet (Brezinski, 1988;

Glaser and Brezinski, 1998). Occasional shale, thin coal, and underclay layers are also present.

Five slope failure sites occur in the Pottsville Formation, distributed from Westernport on MD-135 to I-68 and MD-40 on Dans and Savage Mountain. Differential weathering of shale and clay from under massive sandstones creates a potential for rockfall at three of these sites. The potential for rock roll is present at all sites, and rockslide potential exists where bedding dips into the roadway at one site on MD-40.

Allegheny Formation

The Allegheny Formation forms steep sandstone ledges along the Potomac River near Westernport and on Savage Mountain. It is found only in the western portion of the study area. The formation contains sandstone, conglomerate, dark gray shale, coal and underclay (Figure 6A). Sandstone layers are very light to medium light gray, thick-bedded to massive and conglomeratic with tabular cross-bedding plant fossils, and iron staining common. Shale is medium gray to black, thinly bedded, and fissile. It is typically found in association with coal and clay layers, and all are capped by resistant sandstone ledges. Five minable coals (in ascending order) are present: Clarion; Lower, Middle, and Upper Kittanning; Upper Freeport. The total thickness of the Allegheny Formation is estimated to be 200-250 feet (Glaser and Brezinski, 1998).

The Allegheny Formation has 12 slope failure sites, with the steepest average slope of any formation in the study. Nine of the sites have rockfall potential and recent rockfall events. All of the rockfall sites occur near Westernport on MD-135 and MD-36 where massive sandstones overhang softer, recessed shale and coal layers. Two slump failure sites exist where the slope toe is cut by MD-135 and colluvial material has been destabilized. Two sites with potential rockslide occur where bedding dips into the roadway on MD-135 and I-68.

Conemaugh Group

The Conemaugh Croup underlies a large portion of low slopes in Georges Creek Valley, in western Allegany County and eastern Garrett County (Figure 6B). It is comprised mostly of medium gray to black, thinly bedded, fissile shale and coarse olive gray sandstone with some tabular cross-bedding (Figure 6A). Thin siltstone, limestone, and coal beds also occur. Two formations, the Glenshaw Formation and the Casselman Formation, are present. The Glenshaw Formation includes the Brush Creek, Lower and Upper Bakerstown, and Ames coalbeds as well as two shaly marine layers, the Brush Creek and Ames. The Casselman Formation includes the Franklin, Clarysville, Federal Hill, Barton, and Wellersburg coalbeds and numerous red-brown shales. The Conemaugh Group has an undivided thickness of 800-900 feet (Flint, N.K., 1965; Brezinski, 1988; Glaser and Brezinski, 1998).

Of the 10 slope failure sites in the Conemaugh Formation, 7 occur on MD-36 between Westernport and Lonaconing while 3 are located on MD-40 and MD-36 near Frostburg. Rock roll and slump/rotation are the dominant slope failure types due to the preponderance of erodible shales in the formation. At two sites, sandstone overhangs create rockfall potential.

Monongahela Formation

The Monongahela Formation underlies the synclinal axis of Georges Creek Valley in western Allegany County and eastern Garrett County. The Monongahela is herein considered a formation. It consists of dark gray shale, light gray sandstone and siltstone, limestone, and coal. Sandstones overlie coals in the bottom half of the formation, whereas the upper half is predominantly dark gray shale and siltstone. Coal beds in ascending order are the: Pittsburgh, Redstone, Lower and Upper Sewickley, and Waynesburg. Thickness is approximately 225-250 feet. (Brezinski, 1988; Glaser and Brezinski, 1998).

Four slope failure sites were found in the Monongahela Formation, on MD-40 and I-68 near Frostburg. Rock roll is the predominant failure type due to small siltstone and shale overhangs. One site on I-68 has the potential for rockfall where sandstone and limestone overhangs a recessive coal layer.

Dunkard Formation

The Dunkard Formation is the youngest unit in the study area. It caps several hills in Georges Creek Valley in and around Frostburg. The formation is comprised of gray shale, light gray sandstone and siltstone, limestone, and thick coal. Two coals, the Waynesboro and Washington, are minable. The thickness of the Dunkard Formation is estimated at less than 200 to 300 feet (Brezinski, 1988; Glaser and Brezinski, 1998).

No slope failure characteristics were identified in the Dunkard Formation in this study.

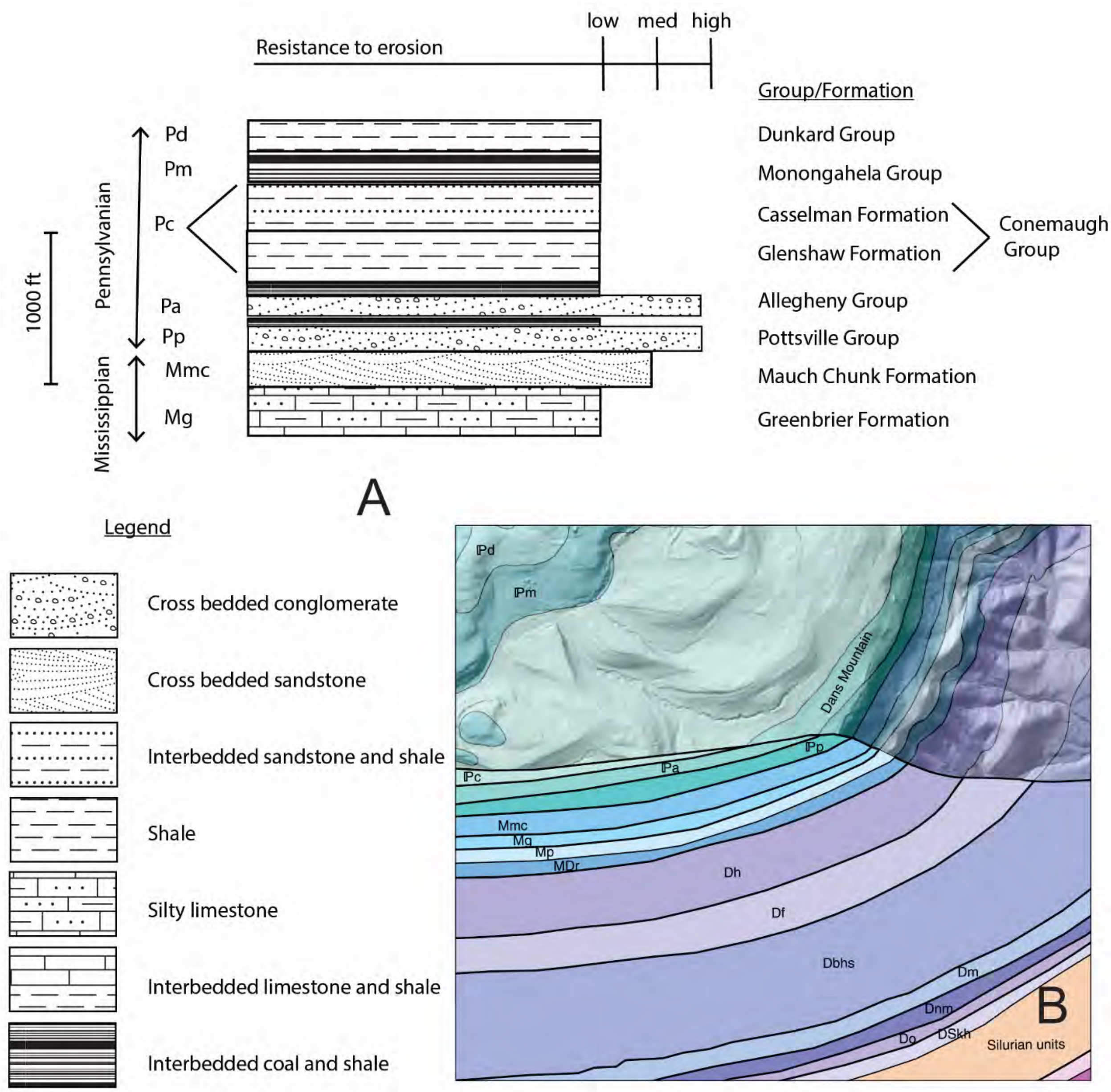


Figure 6. Middle Mississippian to Pennsylvanian stratigraphy and geologic structure of Dans Mountain. A, Stratigraphic column showing lithology and relative resistance to erosion for each rock unit. B, Block diagram of Dans Mountain, with gently folded rock layers typical of the Appalachian Plateaus. Resistant, conglomeratic sandstones of the Pottsville and Allegheny formations underlies Dans Mountain and form the steep escarpment of the Allegheny Front. Adapted from Brezinski and Conkwright (2013). See Figure 2 for the symbology key.

ROADWAY ROCK CUT INVENTORY SURVEY

Methods

This field investigation was tasked to characterize rock cuts along roadways maintained by the Maryland Department of Transportation's (MDOT) State Highway Administration throughout Allegany County, Maryland. A digital catalog was created for these exposures, to detail their character. These data were collected using ESRI's Survey123 application on an electronic tablet (Figure 3). Because Survey123 was already utilized by MDOT for slope inventories, that data collection format was appropriately modified to meet the focus of the current study.

It was initially estimated that this study would collect data for approximately 155 rock cuts. However, during the course of the study, additional exposures were identified on which data were collected. The final number of exposures examined was 195 (Figure 20). Additionally, several exposures that had long been recognized for their rockfall and slope failure potential were examined, characterized, and three-dimensionally imaged utilizing drone photography. The drone photography was meant to augment Survey123 examination and create a representational mosaic of these exposures to help in understanding these troublesome outcrops.

Survey123 Data Collection

The Survey123 data collection form constructed for this study (Figure 7) contains two broad categories of data: general and geologic. General data characteristics were so termed because they represent extrinsic factors affecting rock slope quality. General data include route number, topographic quadrangle, coordinates, slope dimensions (width, height, angle of inclination), orientation, presence of elevated benches, the character of the roadside catchment, and the presence of potential launching factors. Lastly, climate was described by the amount of regional precipitation and freezing, the presence and character of water on the outcrop, and vegetation type.

Geologic factors, largely intrinsic in nature, also control slope, shape, and failure potential. Geologic data include lithology, differential erosion, and typical block size, as well as failure plane (s). Failure planes were assessed for their orientation, continuity, and surface roughness (rock friction). Differential erosion was characterized by its abundance, distribution, and magnitude. Representative digital images of each exposure were taken to record its condition at that point in time.

General Survey Elements

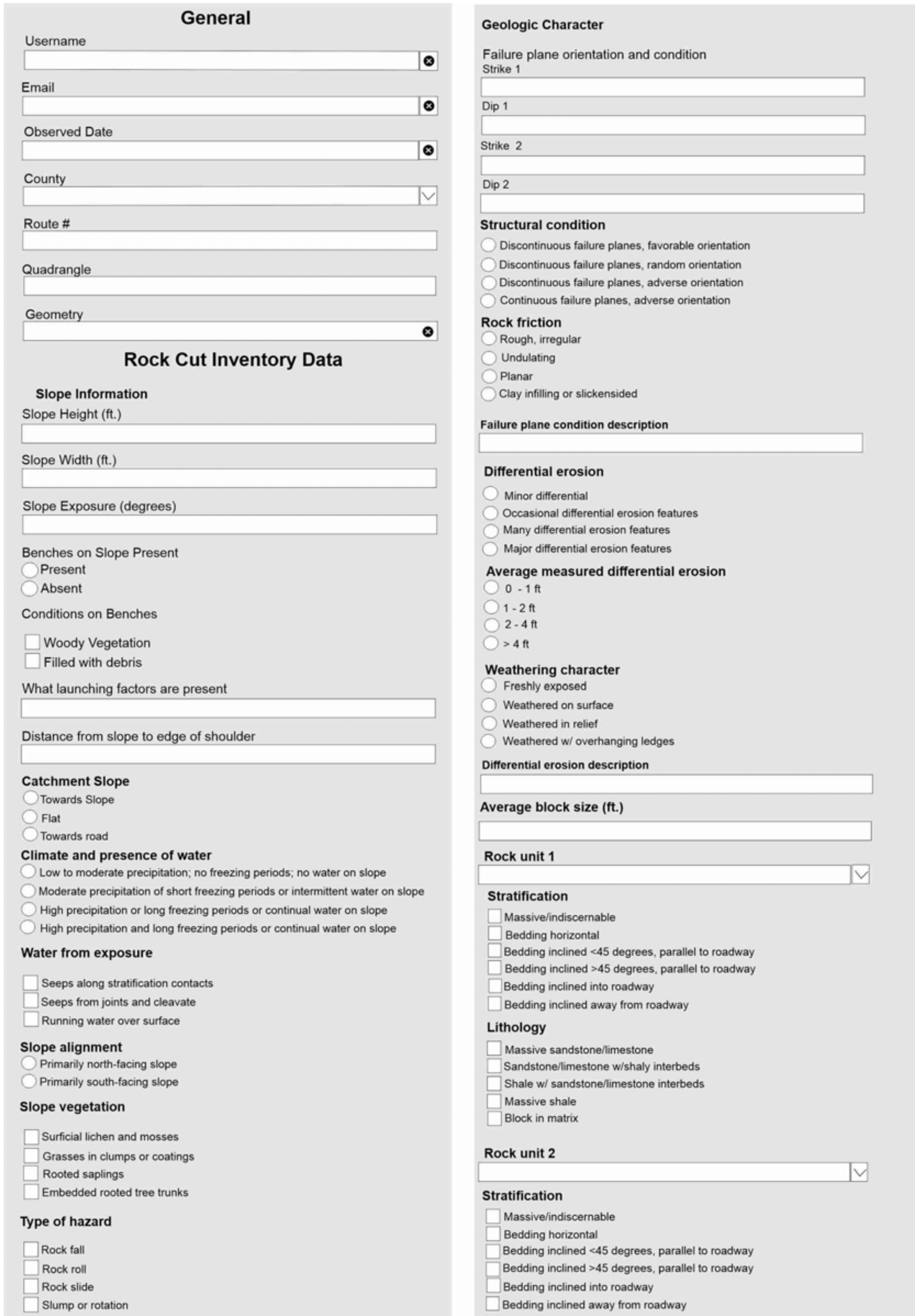
As mentioned previously, the first type of data collected for this study was general information. Besides location data, this includes information about the physical appearance of the roadside, such as slope and climate, and vegetation characteristics.

Slope Information

Each roadway exposure was initially characterized by its size and shape. Height was measured by laser rangefinder, from the bottom of the rock cut to the top of the slope (Figure 8A). At some outcrops, the top of the slope was marked at the base of the first or second bench if the portion of the cut above this point did not appear to be contributing material to the slope below. Slope width also was measured by laser rangefinder from one end of the cut to the other, parallel to the road. Slope exposure was measured with a compass clinometer as the average angle in degrees of the slope face. Beds of rock protruding from the slope were noted as potential launching factors, since they present the possibility of loose material rolling down the slope and being discharged onto the roadway (Figure 8B).

Benches and Catchment Character

The presence of a catchment area adjacent to the roadway provides space where fallen debris can come to rest rather than enter the roadway. Benches represent catchment areas that are elevated above the roadway. When empty, these features can be horizontal or inclined away from the roadway. However, they can become inclined toward the roadway when filled (Figures 9A-C). Measurements were taken to determine the distance from the slope to the edge of the shoulder. The interval measured was from the edge of the hard road surface to the base of the slope.



General

Username

Email

Observed Date

County

Route #

Quadrangle

Geometry

Rock Cut Inventory Data

Slope Information

Slope Height (ft.)

Slope Width (ft.)

Slope Exposure (degrees)

Benches on Slope Present
- Present
- Absent

Conditions on Benches
- Woody Vegetation
- Filled with debris

What launching factors are present

Distance from slope to edge of shoulder

Catchment Slope
- Towards Slope
- Flat
- Towards road

Climate and presence of water
- Low to moderate precipitation; no freezing periods; no water on slope
- Moderate precipitation of short freezing periods or intermittent water on slope
- High precipitation or long freezing periods or continual water on slope
- High precipitation and long freezing periods or continual water on slope

Water from exposure
- Seeps along stratification contacts
- Seeps from joints and cleavate
- Running water over surface

Slope alignment
- Primarily north-facing slope
- Primarily south-facing slope

Slope vegetation
- Surficial lichen and mosses
- Grasses in clumps or coatings
- Rooted saplings
- Embedded rooted tree trunks

Type of hazard
- Rock fall
- Rock roll
- Rock slide
- Slump or rotation

Geologic Character

Failure plane orientation and condition

Strike 1

Dip 1

Strike 2

Dip 2

Structural condition
- Discontinuous failure planes, favorable orientation
- Discontinuous failure planes, random orientation
- Discontinuous failure planes, adverse orientation
- Continuous failure planes, adverse orientation

Rock friction
- Rough, irregular
- Undulating
- Planar
- Clay infilling or slickensided

Failure plane condition description

Differential erosion
- Minor differential
- Occasional differential erosion features
- Many differential erosion features
- Major differential erosion features

Average measured differential erosion
- 0 - 1 ft
- 1 - 2 ft
- 2 - 4 ft
- > 4 ft

Weathering character
- Freshly exposed
- Weathered on surface
- Weathered in relief
- Weathered w/ overhanging ledges

Differential erosion description

Average block size (ft.)

Rock unit 1

Stratification
- Massive/indiscernable
- Bedding horizontal
- Bedding inclined <45 degrees, parallel to roadway
- Bedding inclined >45 degrees, parallel to roadway
- Bedding inclined into roadway
- Bedding inclined away from roadway

Lithology
- Massive sandstone/limestone
- Sandstone/limestone w/shaly interbeds
- Shale w/ sandstone/limestone interbeds
- Massive shale
- Block in matrix

Rock unit 2

Stratification
- Massive/indiscernable
- Bedding horizontal
- Bedding inclined <45 degrees, parallel to roadway
- Bedding inclined >45 degrees, parallel to roadway
- Bedding inclined into roadway
- Bedding inclined away from roadway

Figure 7. ESRI Survey123 form constructed for the study of roadside slope characterization of Allegany County, Maryland.

Figure 8. Embankment characterization. A, Slope dimensions. B, Launching factors.

The presence or absence of benches is generally dictated by the height of the exposure. Those exposures less than twenty feet in height rarely have benches. Those greater than forty feet in height typically possessed at least one level of the elevated bench (Figure 9D). Although benches represent elevated catchment areas, when they become filled with debris they can themselves become a launching factor, propelling rolling debris onto the roadway, and beyond roadside catchment (Figure 9E). Thus, filled benches switch from a safety factor to a hazard. When benches become filled, they also tend to spawn vegetation growth (Figure 9F).

Climate

The climate of a region dictates the amount and type of weathering that affects the rock outcrops in the area. Four categories were created to encompass climate variations, but only two effectively summarize these factors in Allegany County. The first was moderate precipitation with short freezing periods. This category was used for most outcrops within the Ridge and Valley Province of central and eastern Allegany County. The second category used was high precipitation and long freezing periods or continual water on the slope. This entry was used for outcrops along highways within the Appalachian Plateaus Province of western Allegany County.

These climate zones were directly correlated to the physiography of the region. Dans Mountain serves to divide the Appalachian Plateaus Province from the Ridge and Valley Province (Figure 21,2). Westward from Dans Mountain areas of higher elevation, some greater than 3,000 feet, are subject to increased levels of precipitation and longer periods of frost and/or freezing (Figure 10). Some areas of Allegany County have diurnal freezing and thawing for more than 220 days out of the year (Figure 10B). Lienhart (1988) considered the freeze-thaw intervals and the demonstrable durability of rock as important factors in the evaluation and understanding of engineering materials.

At higher elevations, the increased precipitation and prolonged freezing and thawing periods tend to produce higher rates of physical weathering resulting in greater levels of differential erosion. To the east, the lower elevations of the Ridge and Valley Province experience a less intense and shorter frost and freeze period. Furthermore, the elevation of Allegheny Structural Front (e.g., Dans Mountain), which exceeds 2,800 feet in elevation, creates an orographic effect, resulting in a rain shadow within the adjacent Valley and

Figure 9. Benches and catchments styles and character. A, Catchment shoulder sloping away from the roadway. B, Flat catchment shoulder. C, Shoulder inclined towards the roadway. D, Elevated catchment bench clear of debris. E, Elevated bench nearly filled with debris. F, Elevated bench with woody vegetation.

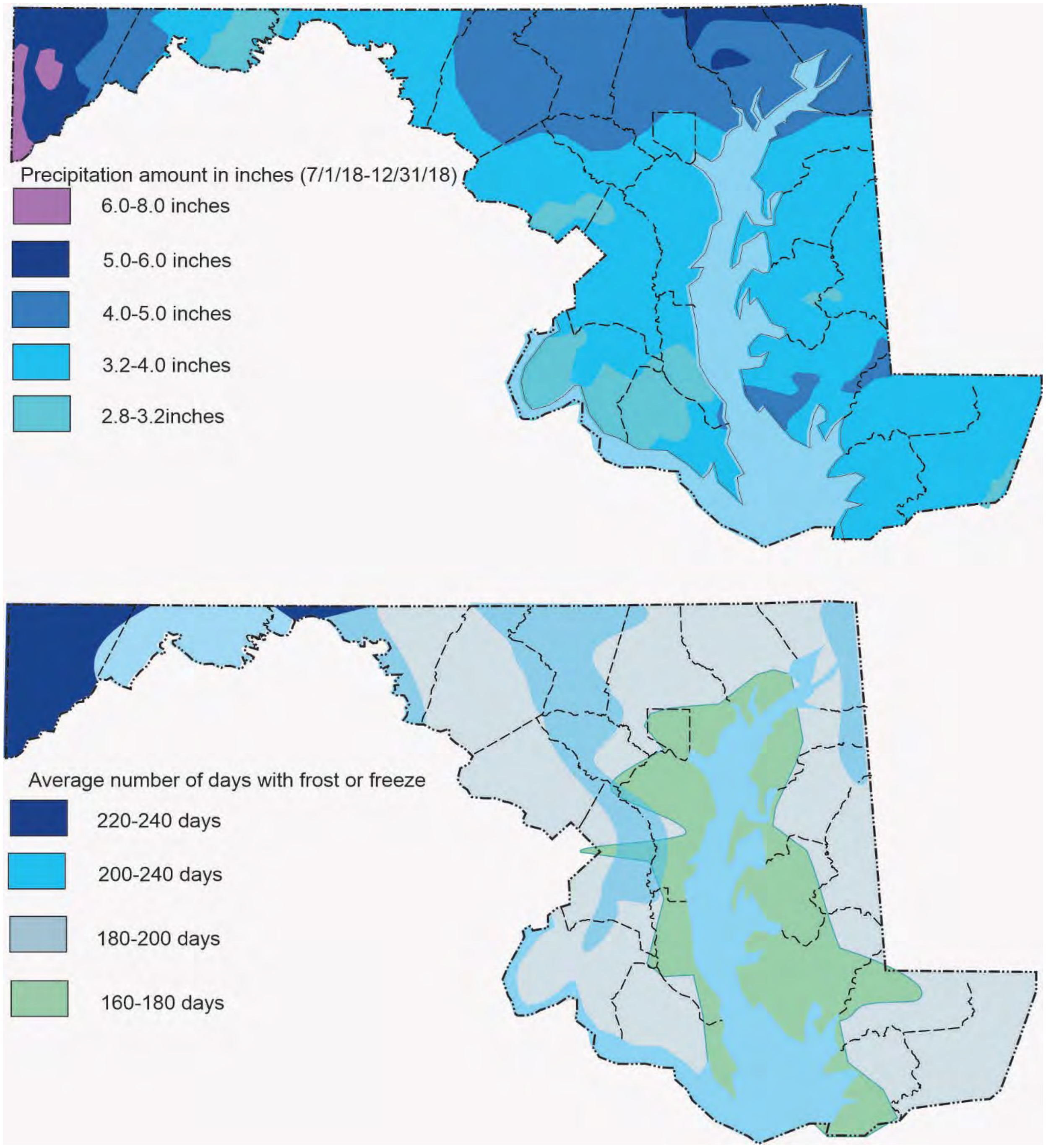


Figure 10. Variations in climate characteristics that are important in slope failure. A, Precipitation levels within the state of Maryland for the second 6 months in 2019 (data from http://prism.oregonstate.edu/). B, Generalized map of the number of days per year with potential frost or freeze. Data extracted from extension.umd.edu/hgic/topics/fall-frostfreeze-dates-maryland].

Figure 11. Degrees of variation in the amount and distribution of water on roadside slopes. A, Water seeps along stratification. B, Water seeping along joints and fractures. C, D, Water covering the surface of outcrops.

Ridge immediately to the east of this ridge. The drier climate and shorter freezing periods in eastern Allegany County produce a lower potential for physical weathering of the rock that translates into the reduced propensity for differential erosion. Moreover, these drier areas are known to promote a semiarid flora referred to as "shale barrens" (Platt, 1951). Areas with shale barren development have greatly reduced rooting and mechanical weathering from root penetration.

Water on/from Exposure

Water seeping from or running on rock slopes constitutes a significant secondary contributing factor to roadside slope failure potential for several reasons (Figure 11). Most importantly, water can serve as a lubricant that reduces friction between rock layers and along fractures and parting surfaces. This reduced friction, especially where failure planes are steeply inclined, can contribute to the triggering of slope failure events. Where subvertical, fractures can increase the conductivity of the water downward into subsurface stratification planes and reduce friction along those surfaces.

In areas where frost and freezing are prevalent, fractures containing water can freeze at night and thaw during the day, thus producing a mechanical process known as frost wedging. North-facing slopes preferentially preserve water at the surface that can remain frozen for extended periods of time. Where episodes of repeated freezing and thawing are a factor, frost wedging can force apart and widen openings in the rock. Frost-wedging is a highly effective way to break apart large rock masses (Oilier, 1969).

Slope Vegetation

The prominence and type of vegetation can play a significant role in roadway slope failure. Rooting by grassy and woody vegetation is an important component of the physical and chemical weathering of outcrops in temperate biomes. In these climate zones, ice fragments the bedrock by repeatedly freezing and thawing. Consequently, biotic elements are not only attracted to these locations, but their rooting can further fragment rocks and their rootlets can propagate along fractures to loosen blocks and boulders.

As a general observation, vegetation of all types tends to be better developed where water is present on the outcrop. North-facing slopes maintain moisture that allows increased vegetation development (Figure 12A). Branson and Shown (1989) proposed that north-facing highway slopes tended to contain shrubby vegetation, while south-facing slopes more often

Figure 12. Differences in vegetation between north-facing and south-facing slopes. A, Rooted tree saplings and grasses developed on a north-facing slope of sandstones of the Oriskany Formation. B, South-facing slope from the same road cut as A. This face contains grasses and few shrubs. C, Highly vegetated north-facing slope on shales of the Brallier Formation. Vegetation includes rooted trees, saplings, shrubs, and grasses. D, South-facing slope corresponding to the location shown in C. This slope exhibits only sparse grasses.

Figure 13. Types of vegetation on roadside slopes. A, Lichens and mosses. B, Grasses in clumps or coatings. C, Rooted saplings. D, Embedded and rooted tree trunks.

displayed grassy and herbaceous flora (Figure 12B). These authors opined that the cause for these vegetation differences was related to the differing levels of solar radiation. They maintained that south-facing slopes were associated with increased levels of sunlight that resulted in elevated temperatures, reduced moisture, and a reduced potential for plant colonization and growth. Furthermore, these authors suggested that increased duration of freeze-thaw potential on north-facing slopes led to greater moisture availability in those locations. It is in this position that most lichens and mosses were observed during the current study (Figure 13A). In contrast, the presence of grassy vegetation on south-facing slopes tended to be present where water was preserved in fractures and partings of the bedrock units (Figure 9B). Saplings and rooted trees were generally found to verify Branson and Shown's (1989) findings in that they tended to be better established on the north-facing exposures at road cuts (Figures 13C, D).

Type of Hazard

Four generalized categories of slope failure were utilized for this study. The first of these hazards is rockfalls, which encompass rock topples of other authors (Hungr et al., 2013). This type of failure requires a precipitously steep slope at the outcrop, often in excess of 70 degrees. Moreover, adverse failure planes frequently create greater potential for this type of failure (Figure 14A). The second category of slope failure is termed rock roll (Figure 14B). This most common type of failure varies in prominence based upon the inclination of the slope. Commonly, slope angles between 50 and 70 degrees yield rock rolls. Lithologies that typically are associated with rock rolls are interbedded sandstone/limestone and shale where differential weathering is prominently identified. Rockslides are a failure type that tends to occur where stratification is inclined towards the highway (Russell et al., 2008) (Figure 14C). This category includes detachments that are parallel to subparallel to bedding surfaces. Slide type failures tend to be intricately associated with the presence of intersecting groups of joints that can be oriented sub-perpendicular to the direction of the slide. The jointing, whether discontinuous or continuous, provides areas that allow detachment of rock slabs near the head of the slide. These types of slope failures are much more common in the highly folded strata of the Ridge and Valley Province. The last category of hazard considered was slump or rotational slides (Figure 1D). This type of hazard tended to be observed in outcrops that were highly weathered and vegetated, or where thick soil intervals had developed on steep slopes.

Geology Survey Elements

The second type of data collected for this study is geologic factors. These data include information on lithology, stratification, differential erosion, and the character of failure planes in the rock. Vanderwater et al. (2005) attempted to classify and correlate dependence of slope failure mode on geologic variables. Their study indicates that lithologic variations and the number of discontinuities (i.e. failure planes) are significant predictors of rockfall type in the Tennessee Rockfall Hazard Rating System.

Failure Plane Character

It was an a priori assumption of this study that the type, orientation, and character of the dominant fracture system in the bedrock, whether joints, faults, or stratification, represented a prevailing factor in roadside slope failures. These fracture systems were noted during observations made throughout the course of this study and are recognized as potential failure planes. This assumption is based on previous studies of roadside rock slope failures (Russell et al., 2008). Joints are planar to subplanar brittle fractures of the bedrock along which no perceptible movement has taken place. They tend to form by shear or extensional stresses. Joints generally occur as semi-rectilinear patterns that are genetically related (Hobbs et al., 1976). These fractures are generally discontinuous where they are displayed within interbedded lithologies, but are more continuous where they pass through massive interbedded lithologies (Figure 15). The number, spacing, and orientations of joint sets vary with respect to the bedrock composition and their position on fold limbs. Road excavation through massive rock types can lead to the formation of extensional joints that form parallel to the roadway. In such cases, extensional joints form from the release of confining pressure. These extensional joints are especially common within sandstone units of the Ridge and Valley Province. Another type of fracture forms subparallel to fold axes. These closely spaced fractures are termed cleavage.

The orientation of joints or other fracture systems with respect to the roadway is important to note, because such failure planes dictate a propensity and direction of slope failure. For the current study, joints and fractures that dipped away from the roadway were considered adverse, while those dipping toward the highway were recognized as favorable (Figure 15). Although this may seem contrary to general reasoning, it was theorized that the adverse orientations were more likely to produce rockfalls and favorably more likely to yield rockslides and rock rolls. Vanderwater et al. (2005) noted that using the terms favorable and adverse for rockfall hazard was “ambiguous.” This is because the term favorable when used for fracture plane characterization implies favorable as stable and did not necessarily represent favorability for failure.

Figure 14. Type of slope failures and resulting hazards identified during this study. A, Rockfall. B, Rock roll. C, Rockslide. D, Slump (rotation) scar.

Rock Friction

While the orientation of the fracture planes is important in regard to the type of failure, the intrinsic character of the fracture provides insight into its origin and potential for movement. This character is herein termed rock friction. Rock friction, where observable, was cataloged only for the primary fracture system (Figure 16). At some exposures, this was the dominant joint set, while at others it is represented by partings along stratification or faults. Identifying this character is considered important because it provides insight into the potential for further movement along the observed discontinuity. Rough surfaces have a rough and irregular texture to the touch (Figure 16A). Undulating surfaces suggest a level of shearing and movement along the surface (Figure 16B). These surfaces tend to be rounded rather than smooth and planar. Planar surfaces typically display smooth surfaces that may be parallel to one another (Figure 16C). Lastly, slickenside surfaces are tectonically smoothed fractures and suggest that movement parallel to the fracture surface has taken place (Figure 12D).

Differential Erosion

There are considerable differences in the rates of weathering and erosion, when one considers lithology, slope angle, outcrop compass orientation, and physiographic province. These variations in erosional susceptibility can produce a range of rock overhang characteristics that can result in an increased likelihood of rock failure

(Figure 17). The rock types least affected by such erosion are massive lithologies such as sandstone, limestone, siltstone, and to a lesser degree, shale (Figure 17A). Because of their homogeneity, these lithologies typically have fewer bedding discontinuities along which weathering and erosion can occur. These lithologies tend to form a subvertical wall with little overhang. In contrast, interbedded lithologies provide varying levels of both weathering and erosion. This variation is known as differential erosion (= differential weathering of Vanderwater et al., 2005). The pervasiveness of interbedding is also a key component in the potential for the number and prominence of differential erosion features (Figures 17B, C). With greater differential erosion there is an increased likelihood for the formation of overhanging ledges (Figure 17D), which therefore present greater potential for both rockfall and rock roll events.

Figure 15. Failure plane character. A, Discontinuous and favorable orientation. B, Discontinuous and random orientation. C, Discontinuous and adverse orientation. D, Continuous and adverse orientation.

Figure 16. Rock friction. A, Rough and irregular. B, Undulating. C, Planar. D, Slickensides.

Weathering Character

Weathering character is closely related to differential erosion (Figure 18). While Vanderwater et al. (2005) considered these to be the same factor, they will be treated separately herein. Newly created exposures generally present no substantial weathering characteristics. However, with age, rock exposures develop features as a result of weathering. No study outcrop in Allegany County was considered freshly exposed. Massive rock exposures that are susceptible to chemical and physical weathering have been exposed for a considerable time, or are oriented so that weathering is more effective, and tend to display irregular surfaces (Figure 18B). Many more outcrops were categorized as being weathered in relief. These are especially common within limestone strata where the solution has removed shaly or more soluble layers along stratification (Figure 18C). The final category, weathered with overhanging ledges, is considered typical of thick interbedded lithologies, where more massive intervals of rock are interbedded or underlain by more easily removed lithologies (Figure 18D). In this case, weathering produces overhanging ledges created by major differential weathering and erosion. Overhanging ledges appear to be more prevalent where higher levels of freeze-thaw cycles and precipitation are present. Thus, rock exposures of the Appalachian Plateaus Province show greater levels of differential weathering.

Stratification

Because all of the rocks in Allegany County are sedimentary in origin, all bear some level of layering, otherwise known as stratification, or more commonly, bedding (Figure 19). The type, character, and orientation of stratification are critical to the understanding of the type of potential slope failure. Massive strata, because of their internal structure, tend to have fewer numbers of failure planes and differential erosion surfaces (Figure 19A). This character, especially common when the rocks are nearly horizontal, tends to present steep roadside slopes and often an elevated launching potential. Strata whose dips are oriented parallel to the roadway present greater thickness of strata available for weathering and exposure, although there is a reduced potential for strata decoupling and sliding into the roadway (Figure 19C-D). Strata dipping into the roadway tends to present greater potential for slides, glides, or detached rock masses where rock can be displaced into the highway right-of-way (Figure 19E). Likewise, this orientation of stratification provides abundant potential for rock roll events where weathered and decoupled blocks can roll down the inclined slope and into the roadway. By contrast, strata dipping away from the roadway can present steep slopes, but a reduced potential for either slides, falls, and rolls (Figure 19F).

Figure 17. Differential erosion. A, Minor differential erosion within massive siltstone. B, Occasional differential erosion along sandstone interbeds. C, Many differential erosion surfaces within interbedded sandstone and shale. D, Major differential erosion at the contact between the Pottsville and Mauch Chunk formations.

Figure 18. Weathering of outcrops. A, B, Weathered on surface. C, Weathered in relief. D, Weathered with overhanging ledges.

Lithology

The composition, or lithology, of the rocks through which a road cut passes is a fundamental geologic aspect that affects the potential for slope failures (Figure 20). Massive sandstone and limestone tend to create steep slopes adjacent to the roadway and based upon the type and the prominence of failure plane within these rock types, may create the potential for rockfalls and rock rolls (Figure 16A). Lithologies that are pervasively interbedded present the greatest potential for differential weathering (Figure 16B, C). Within these lithologies, failure planes may create an increased potential for rockfall and rock roll. If such interbedded lithologies are oriented with dips into the roadway, especially when water is concentrated along bedding planes, they present the greatest potential for massive rockslides. Subhorizontal intervals of massive shale rarely are capable of creating steep slopes. These units tend to weather to slopes of small chips and thick soil. These slopes are readily vegetated, and where abundant water is available, can produce slumps and rotations into the roadway. Lastly, irregular sandstone blocks in existing or preexisting landslides can form incoherent masses of loose blocks (Figure 16E). These blocks can roll or slide into the roadway under the influence of frost action or gravity.

Figure 19. Stratification. A, Massive with stratification poorly discernible. B, Stratification horizontal. C, Stratification inclined parallel to road at <45 degrees. D, Stratification inclined parallel to road, >45 degree angle. E, Stratification inclined into roadway. F, Stratification inclined away from roadway.

Figure 20. Lithology. A, Massive sandstone/limestone. B, Sandstone/limestone with shaly interbeds. C, Shale with sandstone/limestone interbeds. D, Massive shale. E, Block in matrix.

SITE ANALYSIS EXAMPLES

General

The categories illustrated above play varying roles in the development of the different types of slope failure. The following section will attempt to illustrate how individual slope failure locations can be evaluated and how geologic character plays differing roles in the development of failures.

Rockslide (Glide)

A well-known example of roadway rockslide is present along the north side of Interstate 68 on Haystack Mountain. Slides have intermittently occurred at this location nearly since the highway was constructed in the 1970s. The slides are located along the eastern flank of Haystack Mountain near the core of the Wills Mountain anticline. They appear to be confined to shales and thinly interbedded shales and sandstone of the lower Rose Hill Formation very near the contact with the resistant and competent quartzose sandstones of the underlying Tuscarora Formation (Figure 21A).

The main unit involved with the sliding is the Rose Hill Formation (Srh on Fig 21B). This unit consists of interbedded reddish to reddish-gray shale with thin (4-30 cm) interbeds of argillaceous, bioturbated sandstone. In this location, the Rose Hill dips 25-35 degrees eastward, toward the interstate. It is underlain by dense, medium beds of quartz-rich sandstone of the Tuscarora Formation (St in Figure 21B). The relatively incompetent shale of the Rose Hill lying upon the stable and competent sandstone of the Tuscarora appears to have created numerous planes of discontinuity or detachment sub-parallel to the Rose Hill bedding. The current slide mass is a lobate body of rock resembling a rotational slump (Figure 21C), but movement appears to be bedding-parallel and therefore it should be considered a translational slide (Hungr et al., 2013).

The head of the detachment appears to be a series of prominent east-northeast trending joints that separate the headwall from the slides (Figure 21B-D). A second joint set, orthogonal to the first, is evident in the rectilinear pattern formed by the areas of separation (Figure 21D). At least two older scarps are interpreted from the LiDAR image. These features are upslope from the current scarp, but suggest that the detachment has a relatively long history. The basal slide surface was not viewed but is envisioned to have occurred along a shaly detachment zone that is inclined steeply to the southeast (Figure 21A).

Rockfall

The most prominent cases of highway rockfall in Maryland occur along state and county roads along the North Branch of the Potomac River and its tributary the Savage River in western Allegany and eastern Garrett counties. The steep slopes of this area mark the boundary between the Ridge and Valley and Appalachian Plateau physiographic provinces, and river incision has eroded deeply into Pennsylvanian age strata. An incised meander in the Potomac River has created steepened slopes that stretch for three miles from east of Westernport to west of Luke. Along this section of the river, several different types of slope failure including rockfalls and landslides can be observed and studied.

The most prominent area of rockfall susceptibility is located along Maryland Route 135 at the border of Allegany and Garrett counties and the confluence of the Savage River and Potomac River (Figure 22A). The combination of precipitous slopes, differential erosion of alternating lithologies, and joint orientation produce an area of perpetual slope instability and failure. This area is so prone to failure that MDOT attempted to conduct a partial remediation of this location through rock bolting and surface grouting (Figure 22E).

The predominant factor in rockfall at this location is the steep slope formed by flat-lying Pennsylvanian strata. Subvertical cliffs with slope angles up to 86 degrees occur along a southwest facing slope next to MD Route 135. The stratigraphy, which consists of interbedded lithologies of varying competence, contributes substantially to the potential for rockfall. Intervals of fine-grained strata that are easily eroded (shale, siltstone, and coal), alternate with thick-bedded to massive, well-cemented sandstones. The sandstones are undercut at their base by the easily eroded shales, and overhanging ledges of massive sandstone result (Figure 22C).

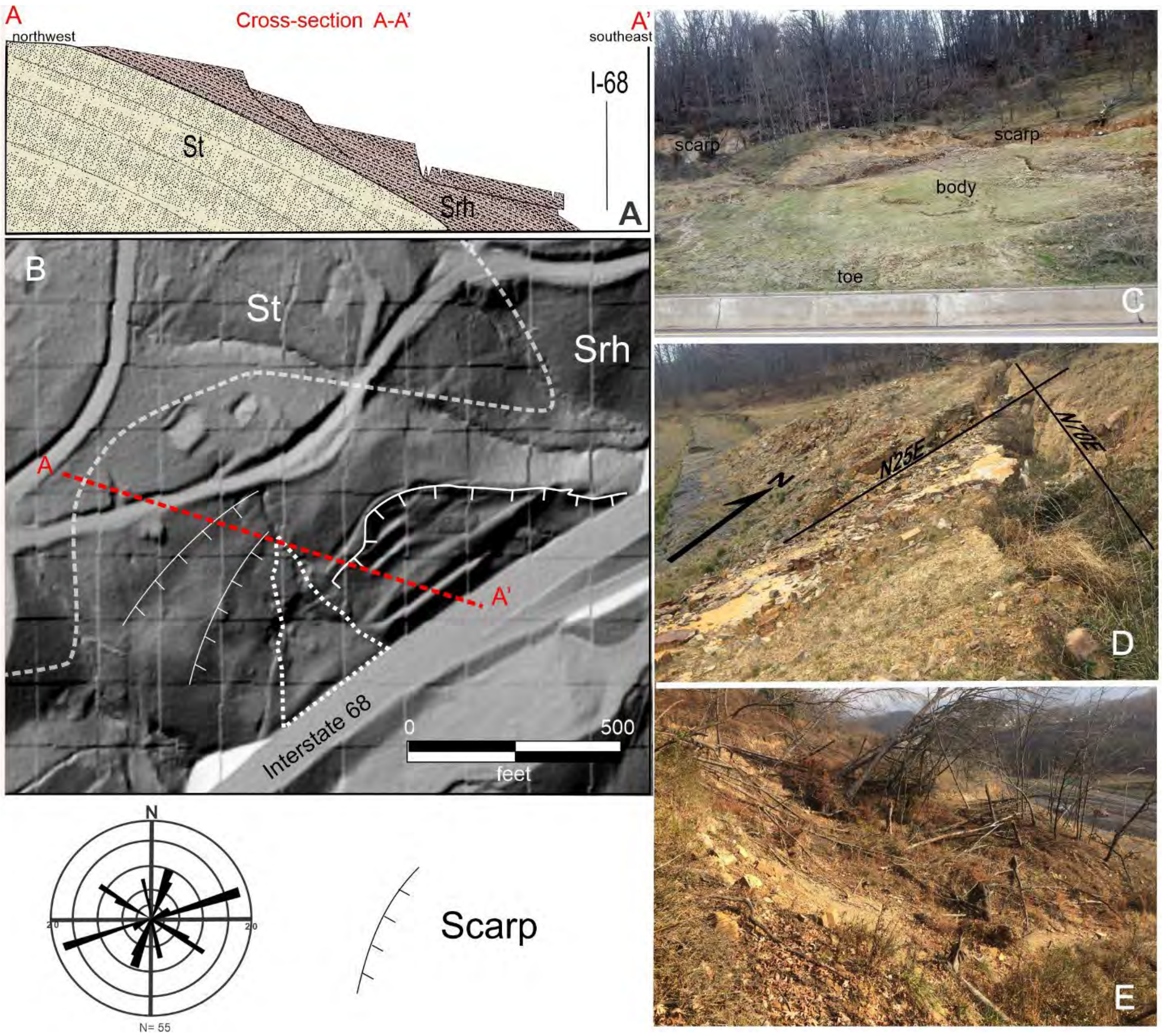


Figure 21. Overview of the Haystack Mountain rockslide area. A, Cross-section of the slide mass along section line A-A'. B, LiDAR image of slide area showing existing and earlier slide scarps (MD iMAP, 2018). Rose diagram illustrates dominant and ancillary joint fracture orientations. C, View of slide area from the east-bound lanes of Interstate 68. D, Rupture fissure illustrating recent detachment. E, Undulating upper surface of the body of the slide mass with disturbed vegetation.

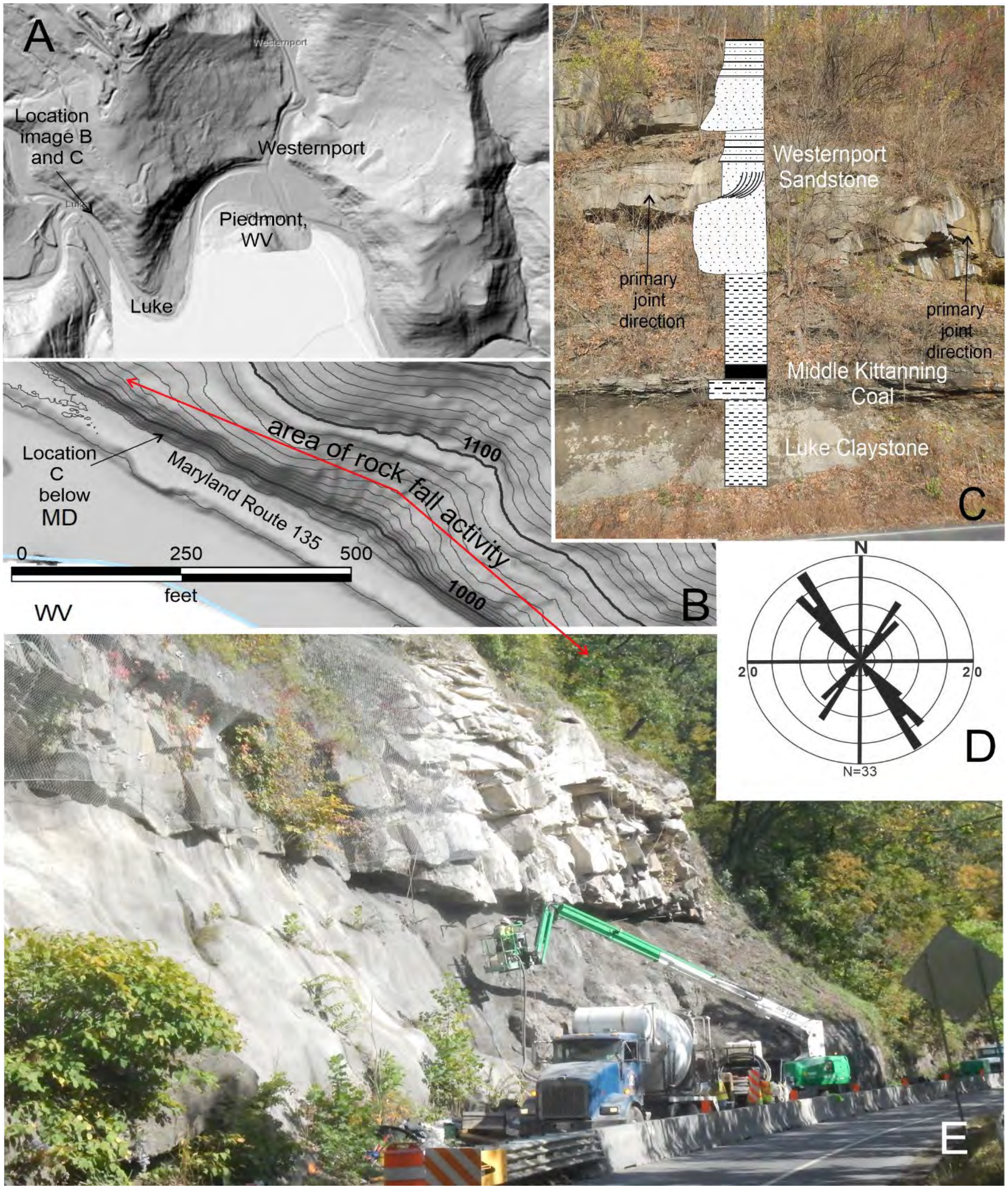


Figure 22. Overview of the rockfall at Bloomington. A, B, LiDAR images of the area along MD Route 135 near the mouth of the Savage River (MD iMAP, 2018). C, Stratigraphy of the rock strata at the study site. D, Rose diagram of joint orientations measured along MD 135 within the lower Allegheny Formation. Notice how the main joint set is subparallel to the Potomac River and state route. E, Grouting and fencing retainment mitigation conducted during 2021.

A third mitigating factor is the pervasive, north-northwest trending, primary joint set in these rocks. The dominant jointing direction is subparallel to the Potomac River and MD Route 135, and speeds detachment of overhanging sandstone blocks.

Rock Roll

Rock roll is common where lithologies are interbedded and roadside embankments are steep. Where more competent layers (sandstone or limestone) weather in relief relative to intervening shaly intervals, loose cobbles and boulders can be dislodged and roll downslope in nearly every lithology except massive shales. Examples of this type of failure are widespread and occur at varying scales. One example of rock roll exists along Interstate 68 on Martin Mountain. At this location the thin-bedded limestones of the Tonoloway Formation are inclined toward the highway in the west-bound lanes and away from the interstate in the east-bound lanes (Figure 23 A, B). The slope on both sides of the roads is relatively steep at 65 degrees. Weathering of the thinly bedded limestone produces elongated slabs that slide downslope and produce a wedge of limestone debris along benches and at the base of the outcrop (Figure 23 C, D). The tabular shape of the debris at this location is not prone to rolling, but as the debris apron grows larger, slabs exhibit a greater likelihood of moving farther from the outcrop. This type of debris apron is common along steeply cut, non-vertical outcrops, and where little road shoulder is present, requires regular removal.

Slump/Rotation

Slumps and rotations occur over a broad range of scales and lithologies. Most are too small to be presented on quadrangle scale geologic maps, but even the smallest can present a nuisance for highway maintenance. At several locations in Allegany County, the strata and slope favor the development of large slumps and rotations. One such area is adjacent to the Potomac River at Luke, Maryland (Figure 24). At this location, flat-lying Pennsylvanian age strata consisting of alternating intervals of massive sandstone and erodible shales and coal create an irregular slope promoting slump, slide, and rotational slope failures (see Figure 24A). At least three prominent sandstone intervals can be identified from LiDAR images at this location by a steepening of the slope along the outcrop belt. These massive sandstone units appear to be the source of the rotational slumps. The stratigraphically highest sandstone is interpreted to be the Saltsburg Sandstone of the Glenshaw Formation of the Conemaugh Group (Figure 24B). The next lower is the Mahoning Sandstone at the base of the Conemaugh, and the third sandstone occurs near the base of the slope where it is largely covered by debris from above. This lower sandstone is interpreted to be the Worthington Sandstone of the Allegheny Formation which locally is termed the Westernport Sandstone. This lowest sandstone unit is well exposed along MD Route 135 just to the north of the image shown in Figure 24A.

Examination of the LiDAR hillshade of this area reveals numerous arcuate indentations into the hillside. These are interpreted as scarps created by slope rupture at the head of individual slumps (Figure 25A). Down slope, amalgamated masses of angular sandstone blocks and boulders represent the body of the slump (Figure 25B). These sandstone-block masses pass downslope into additional scarps that are created along lower sandstone strata (Figure 25A, B). Thus, the sandstone block and boulder fields tend to form semi-continuous fields of debris that extend down the entire slope. At the base of the slope, the toes of the lowest slumps coalesce and are exposed along MD Route 135 and areas adjacent to the town of Luke (Figure 25C).

This location illustrates that larger slump/rotation failures tend to occur where massive lithologies are interbedded with easily erodible lithologies. While this is characteristic of the Pennsylvanian strata in the Appalachian Plateau Physiographic Province, units with similar interbedded massive lithologies in the Valley and Ridge Physiographic Province (e.g. Foreknobs Formation) may also provide conditions prone to large slumps and rotations.

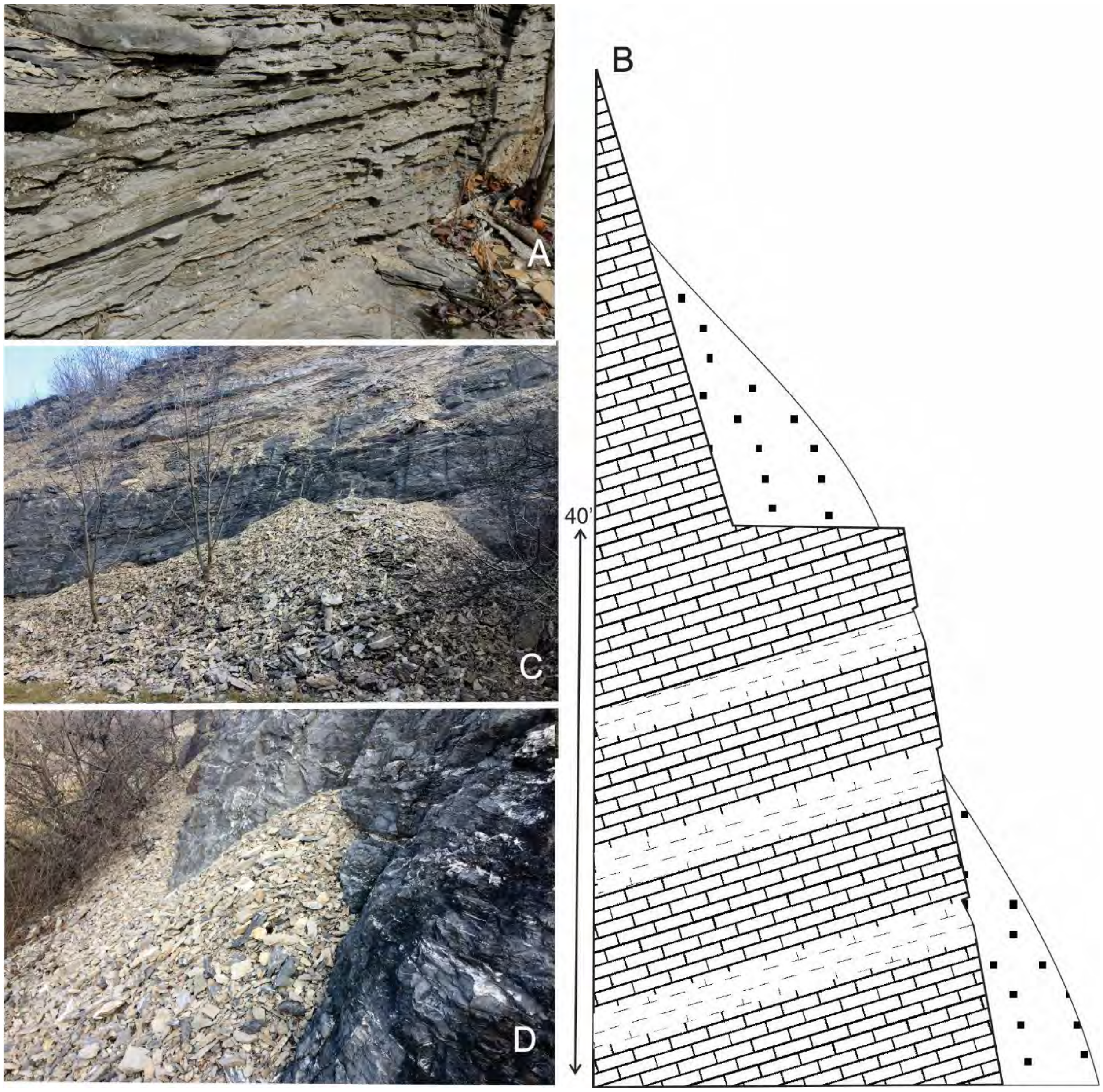


Figure 23. Example of extensive rock roll along Interstate 68 on Martin Mountain. A, Thinly bedded limestone of the Tonoloway Formation. B, Diagrammatic sketch of dipping limestone strata and debris cones along eastbound lane of I-68. C, Basal outcrop debris apron at the study location. D, View of coalescing debris aprons.

Outcrop Survey Utilizing Areal Drone Imagery

Methodology

Unmanned Aerial Vehicle (UAV) flights were used to capture images and videos in order to assess rockfall sites along MD 135 near Luke and Westernport in Allegany County. Both visible light and infrared imagery were collected with the UAV. MDOT SHA performed traffic control during the surveys; they closed one lane to ensure the safety of the researcher and UAV pilot. The UAV was flown no more than 100 feet in the air and was flown within the closed lane. A DJI Mavic 2Enterprise Dual drone with iPad running the DJI Pilot application was used.

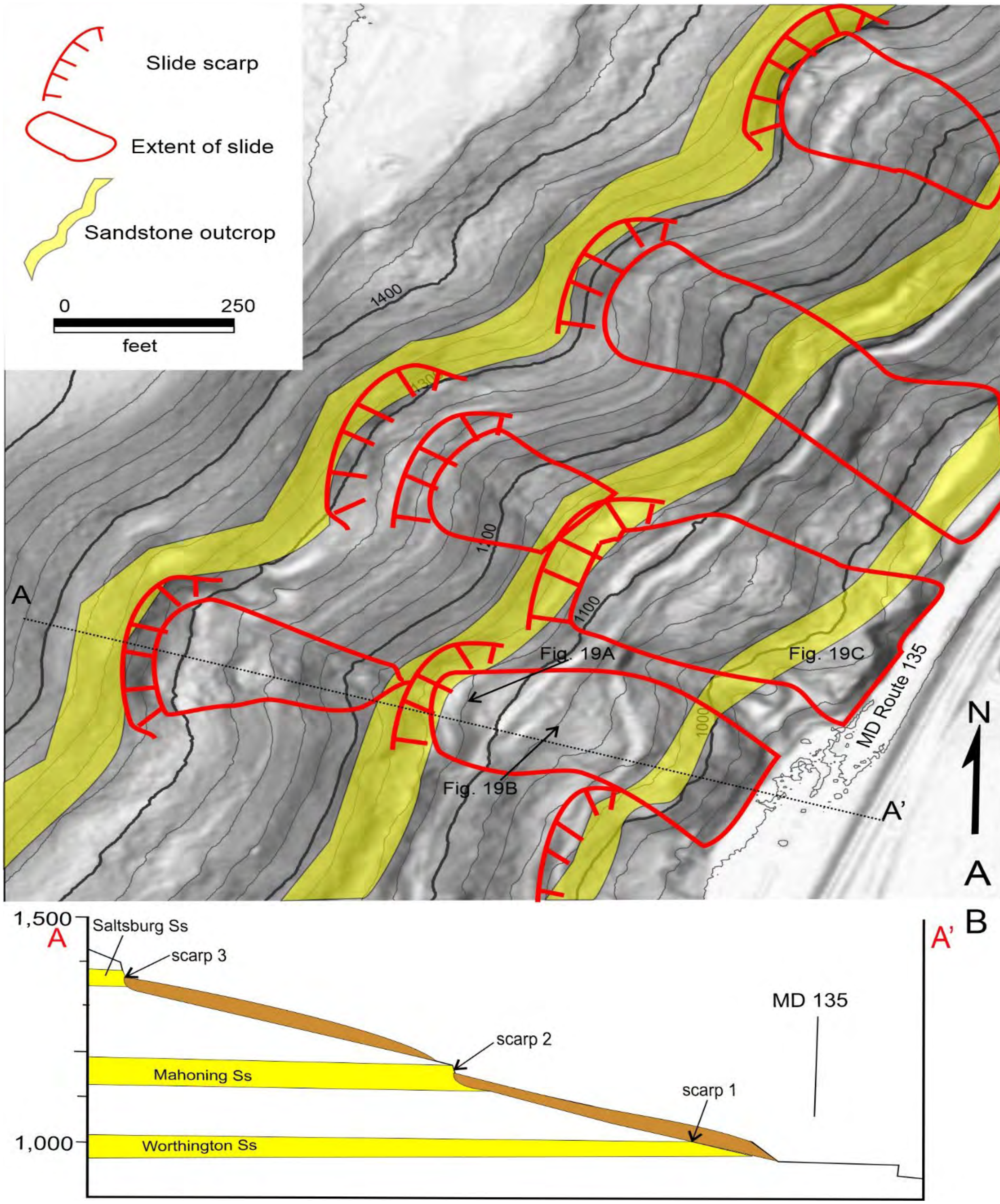


Figure 24. Example of slumps/slides at Luke, Maryland. A, LiDAR image of slopes along the Potomac River at Luke, Allegany County, Maryland. Yellow bands are approximate outcrop belts of significant sandstone beds. Slumps/slides appear to be controlled by an outcrop of the sandstone units. B, Specific sandstone units interpreted from nearby outcrops and unpublished geologic mapping (Brezinski, 2022).

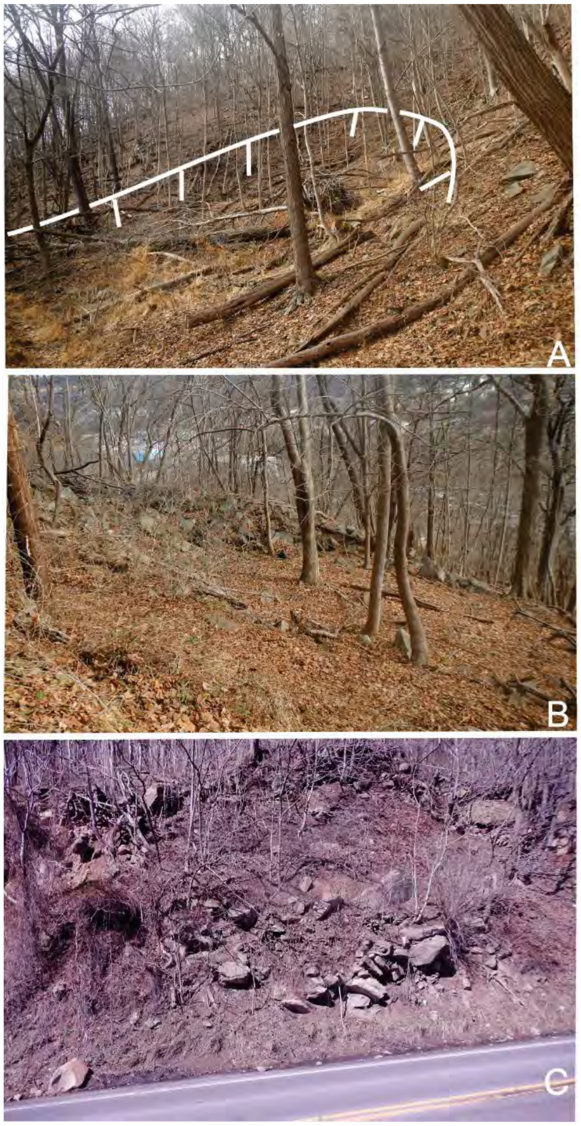


Figure 25. Segments of rotational slumps at Luke, Maryland. A, Arcuate scarp of a single rotational slump. See Figure 24A for location. Note disturbed vegetation from unstable slope. B, View of the nearly flat upper surface of an individual slump. C, Toe of an individual slump as seen along MD Route 135.

UAV video was collected by manual flight and collected in segments for longer outcrops. To collect video, the UAV lifted off the ground to about the height of the top of the outcrop, or to a nearby area of interest (i.e., a potential area of groundwater seepage above the outcrop) and maneuvered horizontally at roughly the same elevation across the outcrop. Each segment was approximately 250 feet long. Once the UAV reached the end of the segment, the pilot lowered the elevation of the UAV and continuously captured video as it flew back toward the crew. While the UAV pilot monitored the UAV in the air, a geologist monitored the iPad to ensure overlapping data collection. The UAV flight continued in a back-and-forth pattern until the ground-level video was captured.

Pix4D Mapper software was used to take the video from each section, break it into frames, and utilize the images to create a point cloud and a singular stitched image by utilizing structure from motion technology. The UAV is equipped with a global positioning system (GPS), and stored location coordinates in WGS 1984 UTM Zone 17N.

Advantages

Drone imagery had a few advantages for characterizing rockfall sites. First, it captured in-depth video, in both visible and infrared light, at heights and angles not visible from the road. This allowed the researchers to see failure planes, water sources, and loose blocks not captured in traditional data collection (Figure 17A). This video could be used to monitor sites over time. Second, viewing the infrared video side-by-side with the visible light video was helpful in correlating temperature variations for potential areas of groundwater seepage (Figures 17B, C). Third, drone data collection was relatively quick. Three road cut sections 200-300 feet long, west of Westernport, took approximately 2 hours to collect, including MDOT traffic control set-up.

Disadvantages

However, there were challenges to drone imagery collection. The safety of the drone survey crew and passing drivers was the first concern. Even with one lane of traffic control in place, the drone crew did not have abundant room to maneuver themselves and keep the UAV at a safe distance from passing vehicles. Second, there were obstructions to the drone's flight path,

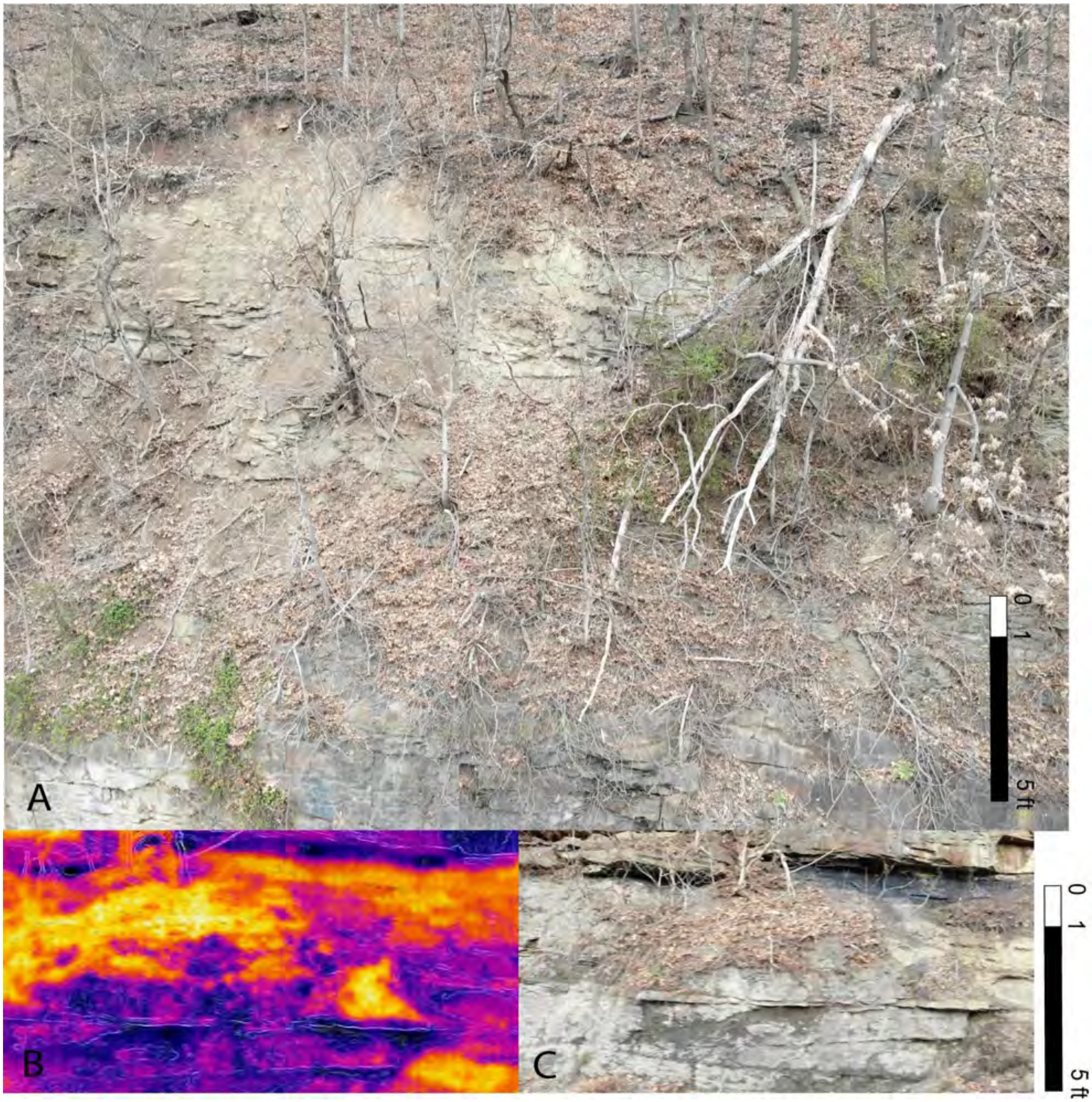


Figure 26. Drone imagery. See Figure 18A for location. A, Slide scarp approximately 50 feet above the road, on the hillside above two massive sandstone layers. Not visible from road level. B, Infrared drone imagery (orange/red = warm, purple/black = cold) of bedrock layers (purple) with water (black) exiting along stratification in the Allegheny Formation. C, Visible drone imagery, same area as B.

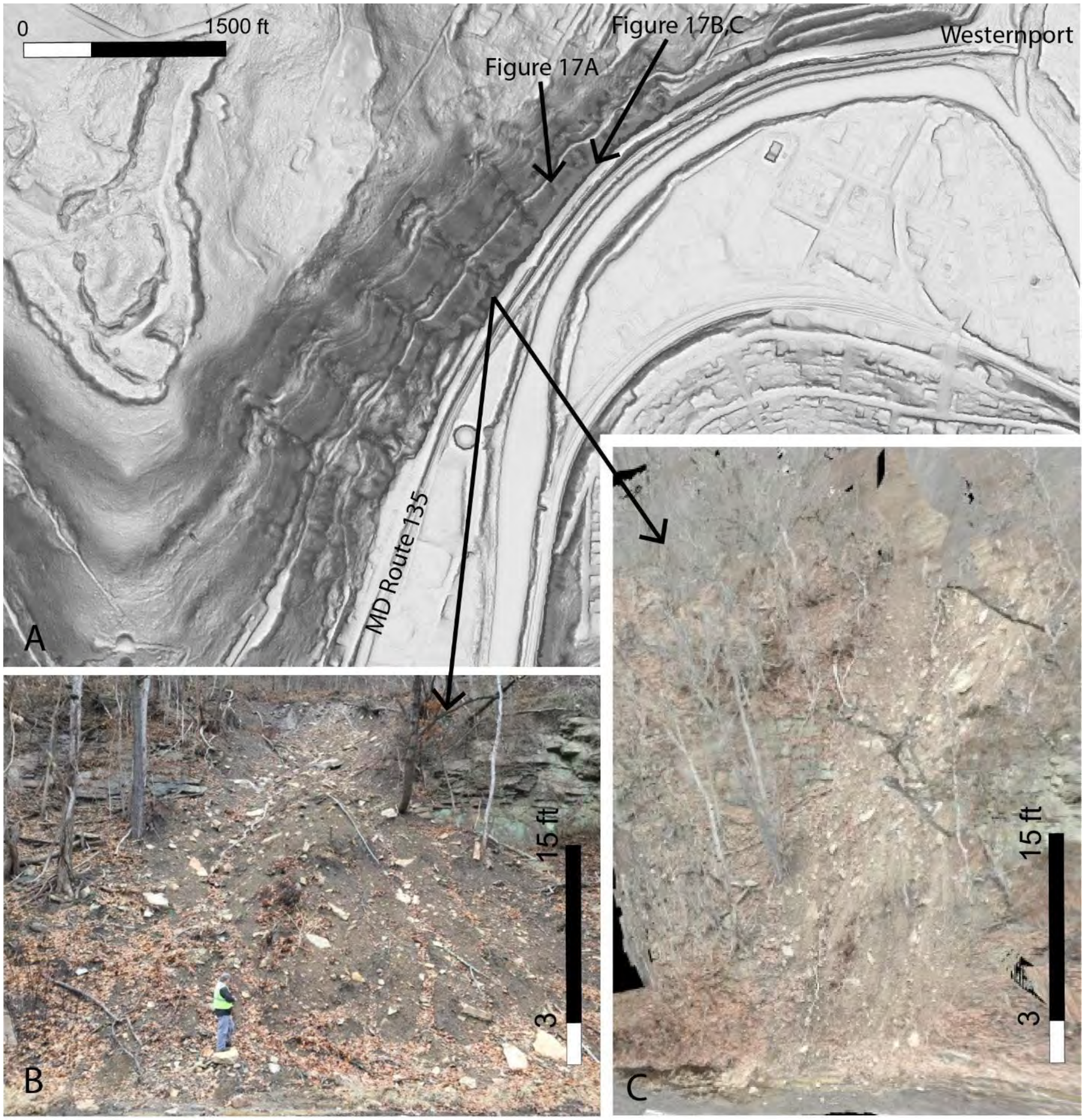


Figure 27. Slope failures. A, LiDAR image showing channel visible on hillslope above MD Route 135 that leads to slide area in photos B and C. Similar channels nearby are also visible. B, Standard photo of the slide area. C, Stitched image of drone photography, same location as B.

such as overhanging power lines and trees, and it was easy to lose sight of the drone when flying high enough (>100 feet) to capture images of the upper portion of the hillslope. Third, images produced by stitching drone photos together were somewhat distorted. Furthermore, processing was time-intensive without a super- computer or cloud processing features. For example, a stitched image of 850 photos for a 25-foot-wide slide area west of Westernport took approximately 15 hours to process (Figure 18C). Fourth, due to the low resolution of infrared video capture, infrared images did not produce a coherent stitched image. Additionally, when the UAV was not flown far enough away from the outcrop, or was rotated while flying, the resulting stitched image was distorted (Figures 18B, C).

Analysis

Examination of drone video footage, in visible light and side-by-side with infrared light, emphasizes the importance of groundwater exiting along bedrock stratification and delineates a slope failure above the height visible from the roadside on MD 135, both east and west of Westernport. The groundwater seepage and slope failure are likely related; both features may be exacerbated by drainage from mining in coal beds at and above the level at which water exits the hillside in the MD 135 road cut. Strip and deep mining in the Upper Freeport, Barton, and Pittsburgh coal beds are visible in recent Garrett County LiDAR hillshade imagery (MDiMap, 2015) and was documented in historic mine maps of Franklin Hill that forms the promontory above the study outcrops. Most of the visible channels on this hillslope initiate at the level of the Upper Freeport coal.

EVALUATION OF GEOLOGY ELEMENTS

The rock outcrop characteristics of 195 roadside slope exposures (Figure 19) were cataloged using the above-categorized features. For each of these locations, up to 36 outcrop qualities were recorded, and images of multiple perspectives of the outcrop also were taken. When evaluating the more than 7,000 data observations, it became difficult to sort out subtle relationships. Because of the voluminous nature of this data set geologic insights gathered from both the fieldwork and empirical data collection are summarized herein. Complete data analysis was viewed as beyond the goals of the current effort.

The geographic distribution of studied exposures gives a representative sampling of rock units, physiography, and structural qualities for the bedrock of Allegany County (Figure 19). Figure 20 illustrates the relative potential for the individual types of slope failure as inferred from observations taken from the 195 roadside sites. Rock roll was the most common type of potential slope failure and accounted for more than 51% of the locations. Nearly one-quarter of the locations had some level of rockfall potential (24%), while rockslides and slumps or rotations had a 14 % and 11% failure potential, respectively.

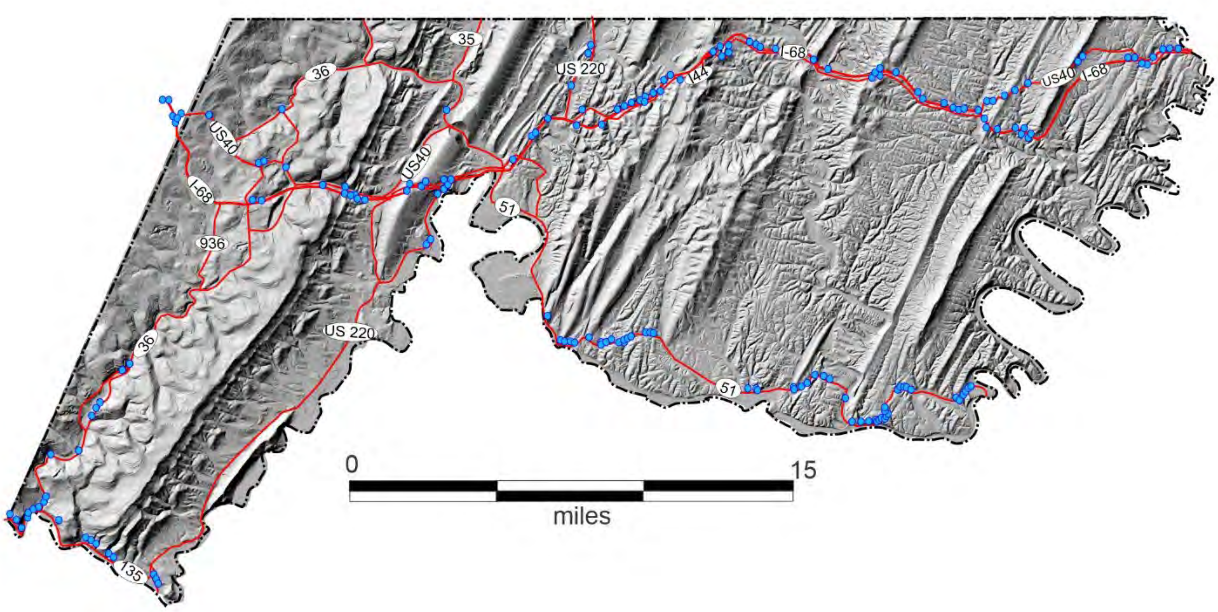


Figure 28. Summary map illustrating approximate locations of highway slopes evaluated during this study (blue dots).

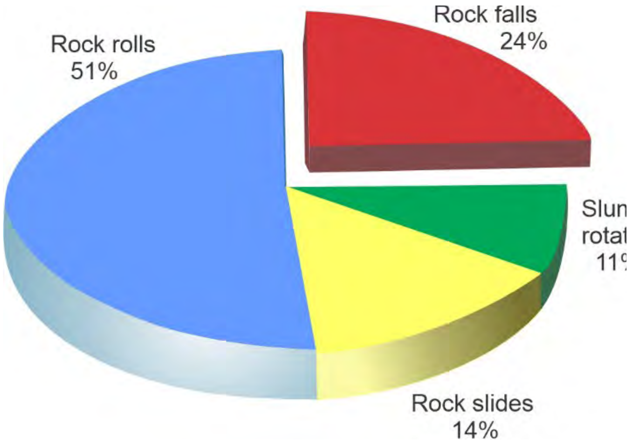


Figure 29. Pie diagram showing relative percentages of potential slope failures identified from roadside exposures in Allegany County, Maryland.

Perhaps one of the most fundamental relationships confirmed by this data set is that steeper slopes produce greater potential for slope failure incidence (Figure 21). Based upon these data, rockfall potential exists in slopes ranging from 40 to 90 degrees. Elevated prospects exist in slopes greater than 70 degrees (Figure 21A). Interpreted potential for rock roll ranged in slopes of between 20 to 70 degrees (Figure 21B). The greatest interpreted potential was for slopes of between 40 and 50 degrees. Surmised rockslide potential was found for slopes that ranged between 30 and 90 degrees (Figure 21C). Although the inferred potentials were on slopes between 50 to 60 degrees, these slope ranges are largely confined to strata that dip towards the roadway. The potential for slumps and rotations was found to be similar in slope steepness and rockslides (Figure 21D). The range for these potential failures was from 30 to 80 degrees, with an identified peak probability between 40 to 50 degrees.

Although slope steepness was one of many factors determined to contribute to the type of slope failure, subsequent discussion will concentrate on what are considered geologic factors. These intrinsic rock characteristics were deemed to play substantial roles in the type of slope failures (Figure 22). Based upon the review of these data, information on stratification, lithology, fracture character, and differential erosion were chosen for evaluation.

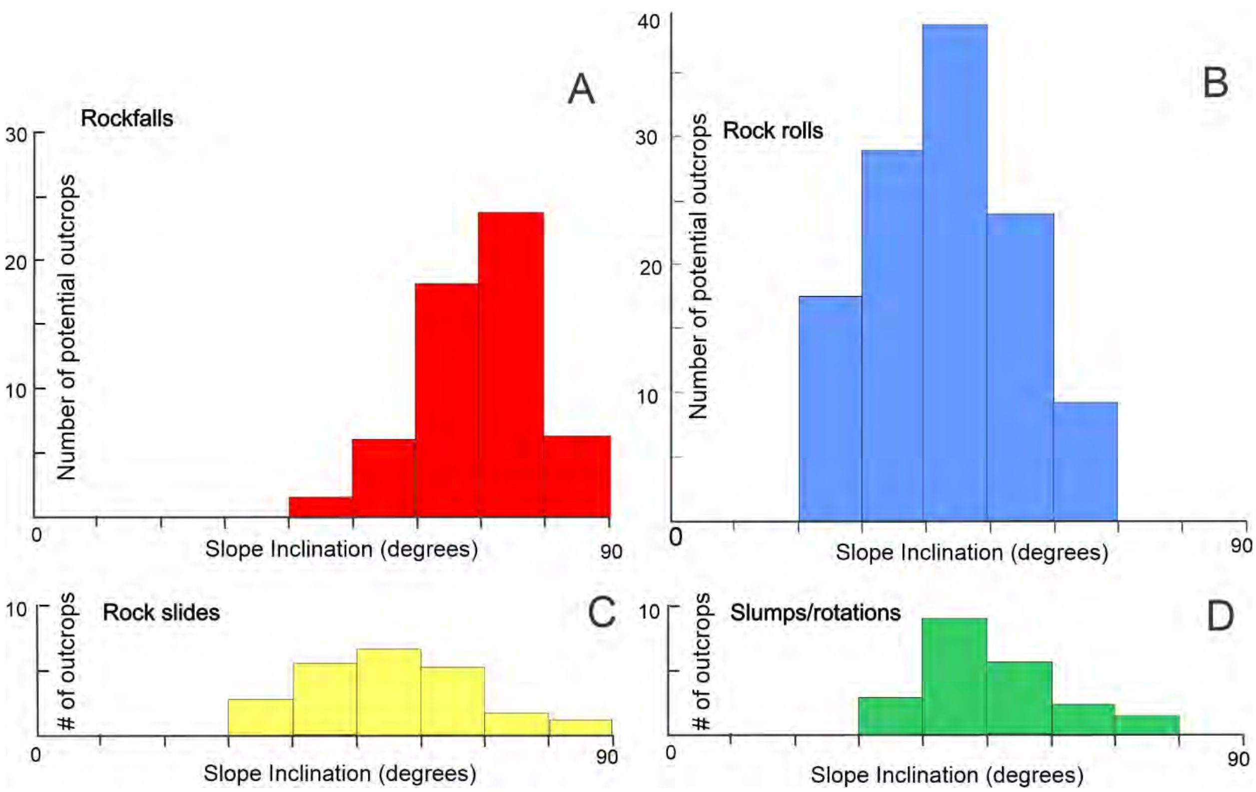


Figure 30. Embankment steepness and its relationship to slope failure type.

The orientation of stratification was judged to be a significant contributing factor in roadway slope failures (Figure 22A). Based upon inferences derived from these data, rockfall potential appears to be highest within strata that are either horizontal or are inclined parallel to the roadway, but at less than 45 degrees. The potential for rock roll is deduced to be relatively constant across the varying strata orientations. The only exception is a minor increase in the potential for cases where bedding is parallel to the roadway and inclined at less than 45 degrees. Rockslide probability is generally low, except where strata are inclined into the roadway. Slumps or rotations do not seem to be substantially related to stratification.

Based on outcrop numbers, lithology was considered a significant geologic factor contributing to potential slope failure (Figure 22B). Allegany County data demonstrate that rockfall potential is substantially higher within massive lithologies than within other rock types. This relationship is somewhat reduced within thick-bedded sandstone and/or limestone units that have interbedded shaly layers. Rockfalls are lower in potential where shale with interbeds of sandstone, massive shale, and block in matrix form the slope. The reason for this relationship may not be directly related to lithology, but it may be tied to road construction techniques. Outcroppings of massive sandstone, or thick intervals of sandstone with shaly interbeds are capable of forming steep-sided rock exposures. As such, excavations passing through these lithologies tend to be steeper than those that pass through rock types that are less resistant to weathering and erosion, like shale. The resulting steep road cuts, therefore, are more prone to rockfall incidence.

Rock roll was the most prevalent type of slope failure associated with diverse lithologic packages. This failure type makes up between 50% and 77% of the potential failures within interbedded lithologies, but typically makes up less than 50% of the inferred failure potential within massive lithologies. Rockslides and slumps and rotations appear to be little associated with lithology.

One geologic factor that appears to play a substantial role in the potential for roadway slope failure is the character of the fracture planes within the rock unit (Figure 22C). Fracture planes that are continuous and adverse to the roadway appear to be correlative to most types of failures. This type of fracture system was interpreted to be responsible for 57% of potential failures in the outcrops studied. No other joint or fracture characteristic was responsible for more than 20% of potential failures.

Another factor that impacts the likelihood, degree, and type of slope failure is the extent of differential erosion (Figure 22D). This figure illustrates the increased potential for rockfalls where major amounts of differential erosion are present. This is because significant amounts of differential erosion create over-steepening of slopes and lead to a greater likelihood of rockfalls. Also, rock roll can be shown to have an increased potential where many differential erosion surfaces exist. Differential erosion does not appear to play a significant role in the creation of rockslides or slumps and rotations. As discussed in the earlier section on differential erosion, this feature is related to both the weathering rate and lithology. Because differential erosion or differential weathering is more pronounced in interbedded lithologies, it would appear to have a greater tendency to produce loosened rock fragments within those lithologies. Figure 23 illustrates this relationship between differential erosion and lithology. Contrary to a priori notions, massive lithologies that are resistant to erosion, such as sandstone and limestone, as well as those resistant lithologies with thin interbeds of shale display a definite differential erosion potential. Meanwhile, shales with lesser amounts of interbedded sandstone and/or limestone and massive shales tend to produce lower levels of differential erosion potential.

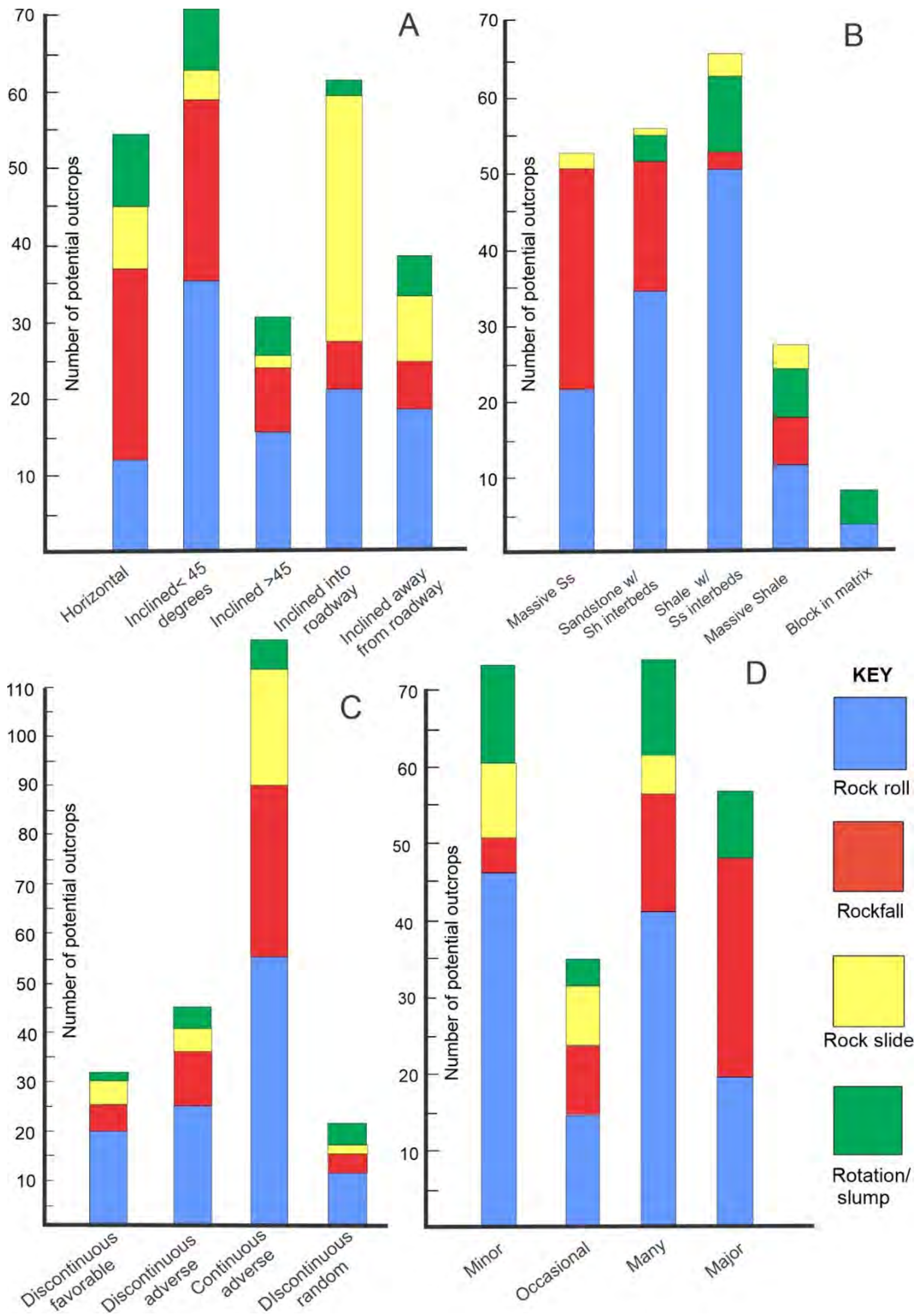


Figure 31. Geologic factors related to slope failure. A, Stratification and potential failure type. B, Lithology and its potential frequency in failures. C, Character of fracture planes and relations to slope failure type. D, Amount of differential weathering and its potential relationship to type of slope failure.

Failure type	Lithology	Stratification	Differential Erosion	Fracture Character	Slope Steepness
Rock fall	Major factor in massive to interbedded lithologies	Important factor when strata are horizontal to dipping @ <45°	Major factor	Major factor when fractures are continuous and adverse	Very important on slopes >60°
Rock roll	Especially important with interbedded lithologies	Greatest on beds inclined <45°	Varies from minor to many	Very Important factor when fractures are continuous and adverse	Greatest on slopes of 30 to 60°
Rock slides	Minor factor for interbedded and shaly lithologies	Major factor when strata dips into roadway	Minor factor in slide occurrences	Major factor when oriented normal to inclined bedding	Minor factor
Slump/ rotation	Not significant factor	Minor factor with inclined strata	Not significant factor	Not significant factor	Important factor

Table 1. Summary of factors contributing to potential roadway embankment failures in Allegany County, Maryland.

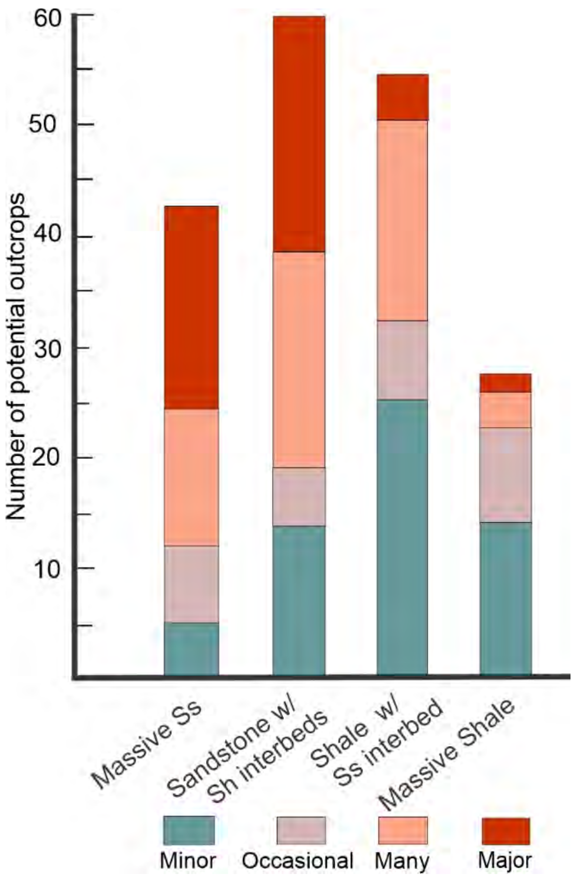


Figure 32. Lithology and its potential relationship to differential erosion.

Geologic Factor Summary

In Allegany County, Maryland, climate, topography, and geology all play varying roles in highway slope stability. Variations in precipitation, elevation, and climate are extrinsic factors that act on outcrops on a regional scale. In contrast, geologic factors such as bedrock composition, orientation, and structure are local factors that may vary from one outcrop to another. These outcrop's characteristics produce gradational variations that intrinsically control slope failure. Several key geologic factors are summarized in Table 1. Regional topographic and climatic, and local geologic factors provide contributing roles in slope failure. However, geologic factors provide a metric that allows empirical evaluation of potential failures.

ACKNOWLEDGEMENTS

We would like to thank Eric Dougherty (Maryland Environmental Service (MES), formerly of the Maryland Department of

Transportation State Highway Administration (MDOT SHA)) for suggesting this project. Nathan Moore, Nick Caviglia, and Ross Cutts (MDOT SHA, Office of Materials Technology (OMT)) provided helpful suggestions that facilitated this study's completion. We would also like to thank George Walker, Ryan Frankenberry, and their crew (MDOT SHA) for traffic control along MD Route 135. Helpful review suggestions were supplied by C.A. Kertis of the U.S. Geological Survey.

REFERENCES

Berryhill, H.L., Colton, G.W., DeWitt, W., and Johnston, J.E., 1956. Geologic Map of Allegany County. Maryland Geological Survey County Geologic Map, scale 1:62,500.

Branson, F.A., and Shown, L.M., 1989. Contrasts of vegetation, soils, microclimates, and geomorphic processes between north- and south-facing slopes on Green Mountain near Denver, Colorado. U.S. Geological Survey, Water-Resources Investigations Report 89-4094, 18 p.

Brezinski, D.K., 1988. Geologic map of the Avilton and Frostburg quadrangles, Allegany and Garrett counties, Maryland. Maryland Geological Survey Quadrangle Geologic Map, scale 1:24,000.

Brezinski, D.K., 1989. The Mississippian System in Maryland. Maryland Geological Survey Report of Investigations 52, 75 p.

Brezinski, D.K., 2019. Geologic map of the Accident and McHenry Quadrangles, Garrett County, Maryland. Maryland Geological Survey Digital Geologic Map ACCID-McHEN2019.1, scale 1:24,000.

Brezinski, D.K., 2022. Draft Geologic map of the Barton and Westernport Quadrangles, Garrett and Allegany Counties, Maryland. Scale 1:24,000.

Brezinski, D.K., and Conkwright, R.D., 2013. Geologic map of Garrett, Allegany, and western Washington Counties, Maryland. Maryland Geological Survey Geologic Map, version 1.1, scale 1:100,000.

Brezinski, D.K., and Glaser, J.D., 2014. Geologic map of the Clear Spring and Hedgesville quadrangles Washington County, Maryland. Maryland Geological Survey Digital Geological Map CL_HE2014.1, scale 1:24,000.

Burns, W.J., and Madin, I.P., 2009. Protocol for inventory mapping of landslide deposits form light detection and ranging (LIDAR) imagery. Oregon Department of Geology and Mineral Industries Special Paper 42, 30 p.

Cate, A.S., 1963. Lithostratigraphy of some Middle and Upper Devonian rocks in the subsurface of southwestern Pennsylvania, IN Shepps, V.C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Geological Survey General Geology Report, 4th series, no. 39, p. 229-240.

Dennison, J.M., 1963. Geology of the Keyser Quadrangle. West Virginia Geologic Quadrangle Maps, GM 1, scale 1:24,000.

Dennison, J. M., de Witt, Jr., W., Hasson, K. 0., Hoskins, D. M., and Head, J. W., 1972. Stratigraphy, sedimentology, and structure of Silurian and Devonian rocks along the Allegheny Front in Bedford County, Pennsylvania, Allegany County, Maryland, and Mineral and Grant Counties, West Virginia, Guidebook, 37th Annual Field Conference of Pennsylvania Geologists.

De Witt, W., and Colton, G.W., 1964. Bedrock geology of the Evitts Creek and Patterson Creek Quadrangles, Maryland, Pennsylvania, and West Virginia. U.S. Geological Survey Bulletin 1173, 90 p.

Diecchio, R.J., 1985. Post-Martinsburg Ordovician stratigraphy of Virginia and West Virginia: Virginia Division of Mineral Resources Publication 57, 77p.

Flint, N.K., 1965. Geology and mineral resources of southern Somerset County, Pennsylvania: Pennsylvania Geological

Survey County Report, 4th series, no. 56A, 267 p.

Glaser, J.D., 1994a. Geologic map of the Artemas Quadrangle, Allegany County, Maryland Maryland Geological Survey Open-File Geological Map, scale 1:24,000.

Glaser, J.D., 1994b. Geology of the Cresaptown Quadrangle, Allegany County, Maryland. Maryland Geological Survey Open-File Geological Map, scale 1:24,000.

Glaser, J.D., 1994c. Geologic map of the Oldtown Quadrangle, Allegany County, Maryland Maryland Geological Survey Open-File Geological Map, scale 1:24,000.

Glaser, J.D., 1994d. Geologic map of the Flintstone Quadrangle, Allegany County, Maryland Maryland Geological Survey Open-File Geological Map, scale 1:24,000.

Glaser, J.D., 1994e. Geologic map of the Paw Paw Quadrangle, Allegany County, Maryland Maryland Geological Survey Open-File Geological Map, scale 1:24,000.

Glaser, J.D., and Brezinski, D.K., 1994. Geologic map of the Cumberland Quadrangle, Allegany County, Maryland. Maryland Geological Survey Geologic Map, scale, 1:24,000.

Glaser, J.D., and Brezinski, D.K., 1998. Geology of the Lonaconing Quadrangle, Allegany and Garrett Counties, Maryland. Maryland Geological Survey Geologic Map, scale 1:24,000.

Hobbs, B.E., Means, W.D., and Williams, P.F., 1976. An outline of structural geology: John Wiley and Sons, New York, 571 p.

Hungr, O., Leroueil, S., and Picarelli, L., 2013. The Varnes classification of landslide types, an update. Landslides, 11:167-194.

Leatherman, S.P., 1986, Cliff stability along western Chesapeake Bay, Maryland: Marine Technology Society Journal, 20:28-36.

Lienhart, D.A., 1988. The geographic distribution and intensity of freeze-thaw cycles. Bulletin of the Association of Engineering Geologists, 25:65-469.

Oilier, C.D., 1969. Weathering. Elsevier, New York, 304 p.

MD iMap Data Catalog, 2018. Maryland LiDAR AlleganyCounty - DEM.

Platt, R.B., 1951. An ecological study of mid-Appalachian shale barrens and of the plants endemic to them. Ecologic Monographs 21, p. 269-300.

Pomeroy, J.S., 1988. Map showing landslide susceptibility in Maryland. U.S. Geological Survey MF-2048, 8 p.

Reger J.P., and Cleaves, E.T., 2008. Physiographic map of Maryland. Maryland Geological Survey, scale 1:250,000.

Russell, C.P., Santi, P., Higgins, J.D., 2008. Modification and statistical analysis of the Colorado rockfall hazard rating system. Colorado Department of Transportation Report CDOT-2008-7, 124 p.

Schultz, A.P., and Southworth, C.S., 1989. Large bedrock landslides of the Appalachian Valley and Ridge Province in eastern North America. Geological Society of America Special Paper 236, p. 57-74.

Schulz, W.H., 2004. Landslides mapped using LIDAR imagery, Seattle, Washington. U.S. Geological Survey Open File Report 2004-1396, 11 p.

Schulz, W.H., 2007. Landslide susceptibility revealed by LIDAR imagery and historical records, Seattle, Washington. Engineering Geology, 89:76-87.

Southworth, C.S., and Shultz, A.P., 1986. Characteristics of giant rockslides in the Appalachian Valley and Ridge, Virginia, West Virginia, Maryland, and Pennsylvania. U.S. Geological Survey Open-File Report 86-94, 5 p.

Swartz, C.K., Prouty, W.F., Ulrich, E.O., and Bassler, R.S., 1923. Silurian [deposits of Maryland]. Maryland Geological Survey Systematic Report, 794 p.

Vanderwater, C.J., Dunne, W.M,, Mauldon, M., Drumm, E.C., and Bateman, V., 2005. Classifying and Assessing the Geologic Contribution to Rockfall Hazard. Environmental and Engineering Geoscience, 11:141–154.

Woodward, H.P., 1943. Devonian System of West Virginia: West Virginia Geological Survey Volumes, v. 15, 655 p.

GLOSSARY

Anticline **–** A convex-upward bend in rock, the central part of which contains the oldest section of rock.

Argillaceous **–** Containing significant amounts of clay.

Bedding **–** Original or depositional layering in sedimentary rocks. Also called stratification.

Bedrock **–** Solid rock that underlies unconsolidated material, such as soil.

Limestone **–** A rock composed of calcium carbonate.

Cherty – Consisting, or being made up of high contents of microcrystalline SiO_2.

Cleavage **–** A dense set of subparallel stress fractures caused by the bending of strata within folded rocks.

Colluvium **–** A sedimentary deposit formed by the movement of unconsolidated material down steep slopes.

Cross-bedding **–** The arrangement of sedimentary beds tilted at different angles to each other, indicating that the beds were deposited by flowing water or wind.

Fault **–** A rock fracture in rock along which movement can be identified.

Fracture -– A crack or break in rock.

Joint **–** A fracture along which no movement has occurred.

Interbedded **–** Alternations of layers of rock with beds of a different kind of rock.

Landslide **–** Any group of mass movements characterized by downslope passage of rock or soil.

Lithology **–** Referring to the composition and character of a specific rock type.

Orographic effect **–**Change in climatic conditions that result from sharp variations in elevation.

Physiographic **–** The topographic character of a region based on its climate, bedrock, their orientation, and weathering.

Sandstone - A clastic sedimentary rock composed of sand-size particles. This size ranges in diameter from 1/16 millimeter to 2 millimeters.

Shale **–** A clastic sedimentary rock composed of clay particles.

Shale barren **–** Hill slope, generally south facing, where paucity of precipitation provides opportunity for colonization by arid to semiarid vegetation.

Slickensides**–** A polished rock surface created by frictional movement of rocks.

Slump **–** Downslope movement of water-saturated material such as rock and soil along a curved failure surface.

Strata **–** Layers of sedimentary rock.

Stratification **–** The layering in sedimentary rock.

Rockfall **–** Slope failure where loosened rock fragments fall ono the roadway. Includes rock topples.

Rock roll **–** Gravity induced failure created by downslope rolling of dislodged rock fragment.

Rockslide -Downslope movement of sheets of rock along planar sliding surface such as a bedding surface or fracture plane.

Rain shadow **–** Areas that experience reduced precipitation as a result of their presence on the leeward side of a topographic ridge or mountain range.

Weathering **–** The process of chemical and physical breakdown of rock into soil by water, ice, and atmospheric, and biologic means.

Wes Moore
Governor

Josh Kurtz
Secretary

Aruna Miller
Lt. Governor

A message to Maryland's citizens
The Maryland Department of Natural Resources (DNR) seeks to balance the preservation and enhancement of the living and physical resources of the state with prudent extraction and utilization policies that benefit the citizens of Maryland. This publication provides information that will increase your understanding of how DNR strives to reach that goal through the earth science assessments conducted by the Maryland Geological Survey.

MARYLAND DEPARTMENT OF NATURAL RESOURCES
Resource Assessment Service
Tawes State Office Building
580 Taylor Avenue
Annapolis, Maryland 21401
Toll free in Maryland: 877-620-8DNR
Out of State call: 410-260-8021
TTY users: Call via the Maryland Relay
Internet Address: dnr.Maryland.gov
MARYLAND GEOLOGICAL SURVEY
2300 St. Paul Street
Baltimore, Maryland 21218
Telephone Contact Information: 410-554-5500
Internet Address: mgs.md.gov
DNR Publication No. 12 DNR 12-041720-227
2020