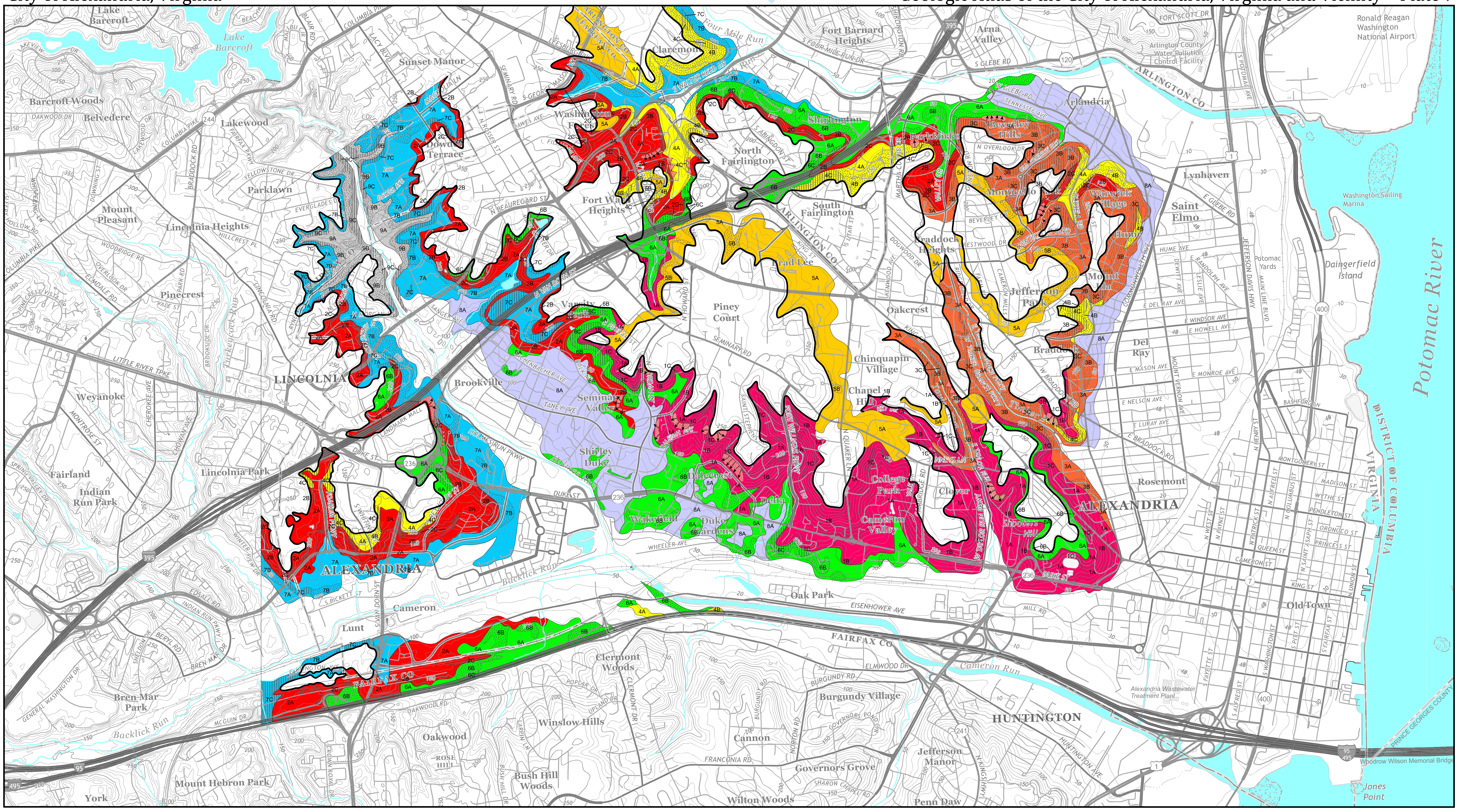
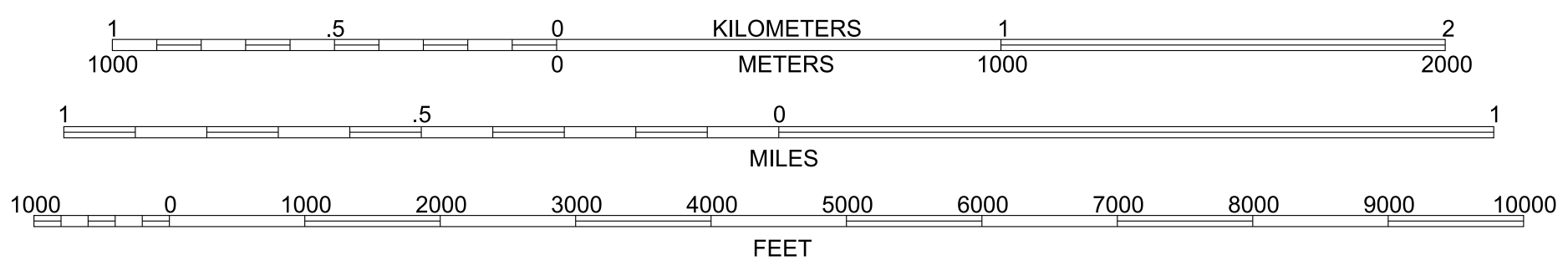
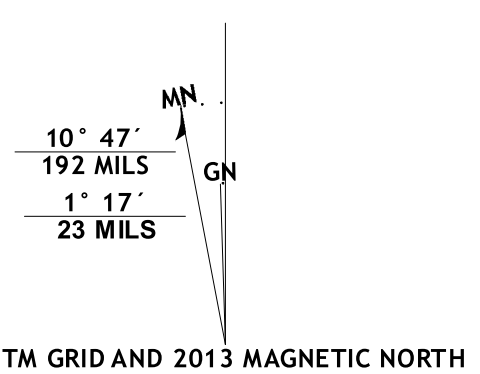


BASE MAP ADAPTED FROM U.S. GEOLOGICAL SURVEY NATIONAL MAP, 2013: TOPOGRAPHIC MAPS OF THE ALEXANDRIA, VA-DC-MD AND ANNANDALE, VA 7.5-MINUTE QUADRANGLES, NAD 1983

SCALE 1:12,000



CONTOUR INTERVAL 10 FEET
NORTH AMERICAN VERTICAL DATUM OF 1988



UTM GRID AND 2013 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

DESCRIPTION OF THE MAP

Several kinds of mass wasting and related processes are documented in the map area, including slumps, slides, enhanced hillside creep, and high shrink-swell soils. The majority of these are associated with places where high-plasticity silts and clays of the Potomac Formation are at or close to the surface. Geotechnical problems stemming from these processes are commonly manifested on slopes, hence the title of the map. Although sloping terrain tends to amplify these issues, it is important to note that level terrain is not entirely immune: for example, high shrink-swell soils can effect foundation integrity regardless of slope, while relatively gentle terrain immediately below major escarpments is often the repository for debris shed from those same escarpments, including landslides and mudflows. And the presence of poorly documented, uncontrolled fill can create instability virtually anywhere.

It should also be emphasized that all of these mass wasting processes are naturally occurring over long geologic timescales, and have undoubtedly played a major role in the evolution of slopes in the map area. This is especially true of the major escarpments and steep ravine walls underlain by plastic silty clays. The massive Hospital escarpment is the quintessential example: with its many oversteepened, scarp-like, upper slopes and the massive debris fan at its base, it is not hard to imagine landsliding as the dominant geomorphic process shaping the escarpment. Likewise, the Mt. Ida escarpment probably derived its extremely steep profile from undercutting by the Potomac River during the late Pleistocene, when the river flowed on the Old Town terrace at the base of the escarpment.

Urbanization commonly accelerates the natural processes leading to slope instability, either by changing the stress field within a slope, or the natural hydrology, or both. Most of the specific examples of landslides shown on the map can be attributed to changes in the urban landscape, often made decades before and without guidance from a geotechnical engineer or engineering geologist. Indeed, loading of the tops of bluffs with inappropriately placed fill material intended to expand the area of level land at the top of the slope is directly responsible for several modern landslides observed or reported in the map area. Removal of material from the toes of slopes is another common cause of instability: the loss of supporting material changes the stress field above the cut and can turn a relatively stable slope into an ongoing landslide for years or decades. Likewise, removal of vegetation—particularly large, mature trees—from a steep slope (or the drainage area above it) can abruptly alter the hydrology of the slope, often with unintended consequences: in addition to helping stabilize the slope with their extensive root systems, trees and other vegetation remove the majority of water that falls during the growing season, slow down overland runoff, and promote ground water recharge. The removal of vegetation usually leads to greatly increased volumes of storm water runoff that can quickly destabilize a slope by carving gullies and saturating fractures, sand seams, and other potential failure surfaces in a body of rock or sediment. Diverting urban runoff to outfalls at the heads of slopes has a similar effect.

The geologic factors affecting slope stability in northern Virginia are well understood and are thoroughly documented in the seminal publications of Obermeier (1979; 1984). All of the conditions and mechanisms described therein that lead to slope instability in both the Potomac Formation and weathered Piedmont bedrock also apply to the present map area (figure 1). Hence, plate 7 uses a slightly modified version of Obermeier's (1979) methodology to produce a series of geologic- and slope-based units to represent the range of slope-stability conditions found in the City. Specifically, three increasingly steep classes of slope pitch, represented on the map by the letters A, B, and C, are overlain on nine geologic units (map units 1-9) derived from plates 4 and 5. The resulting polygons represent the typical, or modal, condition found in each map unit. The geologic units are based primarily on the members of the Potomac Formation mapped in plates 4 and 5, but also include the bedrock walls of Holmes Run gorge and large debris fans associated with the Hospital and Mt. Ida escarpments. Slope pitch was derived from a map of "marine" clay areas (City of Alexandria, 1976) and modified where needed by field observation and direct measurement from the base map used for this atlas. Both maps are at a scale of 1:12,000, so the two methods produced reasonably consistent results that reflect the typical pitches of slopes of predominantly medium length. These polygons represent a minority of the map area within the City: the large swaths of the map with no color or pattern are characterized by geologic conditions unfavorable to the development of slope stability issues or high shrink-swell soils.

The map also indicates the locations of modern landslides, conspicuous scarps, and similar features observed during the fieldwork for this atlas and(or) reported at geotechnical boring sites. Unless relatively recent, individual landslides are often difficult to recognize in the field, because the physical evidence typically becomes quickly obscured by other slope processes (e.g., colluviation and running water), vegetation, and urbanization. Therefore, the examples shown on the map are undoubtedly incomplete, but their distribution relative to the map units is nonetheless illuminating.

This map has a number of limitations inherent to scale, methodology, and natural geologic variation, and is not intended as a substitute for detailed, site-specific geotechnical exploration. Instead, it may help serve as a guide to the design and interpretation of such investigations, while also calling attention to different kinds of slope conditions in the city for planning, management, and educational purposes. Readers interested in a detailed treatment of slope stability issues in northern Virginia and the specific geologic features and processes that lead to them, are strongly encouraged to review the comprehensive publications of Obermeier, cited below.

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Obermeier, S.F., 1979, Slope stability map of Fairfax County, Virginia: U.S. Geological Survey Miscellaneous Field Studies Map 1072, scale 1:48,000 http://pubs.usgs.gov/mf/1072/plate-1.pdf

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MAP EXPLANATION

Description of Map Units Map units 1 through 9 are listed in order of generally decreasing, but overlapping, susceptibility to slope stability problems (figure 2), with some exceptions noted in the individual explanations. Slope classes A-B-C likewise correlate with both the frequency and intensity of slope stability problems, with the vast majority of observed problems in the map area occurring on steeper slopes (class C and the upper range of class B)

1C
1B
1A

Massive, plastic, silty clay, heavily jointed and fractured, with few or no sand bodies, and a high proportion of expandable clay minerals except where deeply weathered. 1A: <10% slope; 1B: 10-25% slope; 1C: >25% slope. Typically produces long, broadly convex, oversteepened slopes that have probably evolved over long periods of time through natural mass wasting processes. Upper 5-20 feet is commonly softened by strong weathering and contains abundant slope parallel joints thought to act as failure surfaces, particularly adjacent to upland terraces. Unit 1C is associated with numerous modern slope failures and many relict scarps. Corresponds chiefly to the Arell clay member

2C
2B
2A

Mostly elastic silt and plastic clay, heavily jointed and fractured, with sparse to moderately common tabular sand bodies of mostly local extent. Contains a high proportion of expandable clay minerals except where deeply weathered. 2A: <10% slope; 2B: 10-25% slope; 2C: >25% slope. Typically forms medium to long, concave to convex slopes with oversteepened crowns. Landslides are probably an important natural process on these slopes. Upper 5-25 feet is commonly softened by weathering and contains numerous, closely spaced joints and slickensided fissures that probably serve as the main types of failure surfaces; thin sand seams may act as another when pore pressures are high. Units 2B and 2C contain a significant number of modern slope failures and relict scarps, especially adjacent to upland terraces. Corresponds chiefly to the Lincolnia silty clay member and map-scale silty clay bodies in the Chinquapin Hollow member

3C
3B
3A

Thin to thick beds of sandy plastic clay, elastic silt, and clayey sand complexly interbedded at fine to coarse scales. Contains scattered, poorly defined, but apparently map-scale bodies of both sand and plastic clay. Very high in expandable clay minerals. 3A: <10% slope; 3B: 10-25% slope; 3C: >25% slope. Typically forms short to long, concave to convex slopes with many localized oversteepened areas that may mark the locations of currently undocumented clay bodies. Landslides are probably a moderately important natural process on these slopes. The upper 5-15 feet is commonly softened by weathering, but the comparatively high sand content gives large parts of the unit a relatively stiff, rigid consistency, even where weathered. The larger silty clay bodies are well jointed and fractured, but the rest of the unit generally is not. Typically better drained than units 1 and 2, but may locally host complex perched ground water systems at multiple horizons, resulting in seasonally high pore pressures that can propagate into adjacent fractured clays and wedge loose planar glide blocks, similar to the process described by Sterrett and Edil (1982) in bluffs of interbedded clayey and sandy glacial deposits. Units 3B and 3C commonly exhibit sharply leaning trees, rippled pavement, cracked foundations and walls, and other evidence of strong creep and instability; several prominent slope failures are associated with the larger clay bodies. Corresponds to the Chinquapin Hollow member

4C
4B
4A

Bodies of medium sand, elastic silt, and plastic clay interbedded on a medium to large scale. Fine-grained units contain a high proportion of expandable clay minerals. 4A: <10% slope; 4B: 10-25% slope; 4C: >25% slope. Typically forms short, steep, convex to concave slope segments at the tops of longer slopes developed on units 2, 6, and 7. Landslides are probably a moderately important natural process on these slopes. Most of this unit is sand, but the proportion of interbedded silt and clay bodies can often vary abruptly and unpredictably between sites. The upper 5-30 feet is commonly softened by weathering, although iron-cemented horizons are common in sands. Silty clay bodies typically contain large joints and fractures that can act as failure surfaces. High pore pressures in sands underlying and interbedded with silty clays may also contribute to instability. Two small landslide scars were noted to head in unit 4C at Parkfairfax; otherwise, modern slope failures appear to be sparse. Corresponds to marginal portions of the Winkler sand, transitional zones between the Cameron Valley sand and Lincolnia silty clay, and sand bodies of uncertain extent within the Chinquapin Hollow member

5B
5A

Gravelly colluvium of laterally variable thickness over silty clay of the Potomac Formation. Typically exhibits a deep Tertiary weathering profile, resulting in a relatively low proportion of expandable clay minerals in the upper 5-15 feet of the profile. 5A: <10% slope; 5B: 10-25% slope. Slope seldom exceeds 15%. Forms gently sloping escarpments between upland terraces, steepest adjacent to the heads of modern ravines. Landslides do not appear to be an important natural process now on these slopes, which show little evidence of modern slope failures and generally appear stable. Instability could result from disturbances in the most steeply sloping areas adjacent to modern ravines, however; the same areas may have greater shrink-swell potential because less weathered material with a higher proportion of expandable clay is closer to the surface

6C
6B
6A

Mostly medium, silty and clayey sand, may locally be interbedded with plastic silty-clay bodies of various sizes that contain a moderately high proportion of expandable clay minerals. 6A: <10% slope; 6B: 10-25% slope; 6C: >25% slope. Occurs in a variety of slope positions. Most commonly forms long, concave toeslopes adjacent to the major drainages, and shorter, convex mid- to upper-slope segments in major escarpments and deeply incised ravines. In and of itself, this unit is not expected to be particularly prone to slope failures, but it commonly occurs above and(or) below more susceptible units on long slopes, and may be involved in slope failures that originate in these other units. Typically very well drained, but commonly contains a perched water table that may lead to softening and weakening of underlying silty clays. Corresponds to the upper Cameron Valley sand and Shooters Hill gravel members, and to thicker bodies of the Winkler sand member. Transitional between units 4 and 7

7C
7B
7A

Mostly medium, silty and clayey sand with occasional gravelly lenses and sparse, widely scattered, and mostly small bodies of elastic silt. The proportion of expandable clay minerals is uniformly low except in the silt bodies. 7A: <10% slope; 7B: 10-25% slope; 7C: >25% slope. Typically forms long, gentle to steep, mostly convex slopes adjacent to the major drainages, commonly with unit 2 at the head of the slope. No evidence of instability was observed in this unit, other than some minor slumps where steep banks are undercut by streams. Landslides do not appear to be an important natural process on these slopes, except at the crowns of slopes where steep sections of unit 2 are present, which is much more susceptible to slope failure. Debris from such crown failures in unit 2 will travel downslope and end up being deposited on unit 1. Corresponds to the lower Cameron Valley sand member and the thickest, most homogeneous parts of the Winkler sand member

8A

Heterogeneous debris fans of variable thickness overlying sands or sandy clays of the Potomac Formation. Slope seldom greater than 5% and invariably less than 10%. Typically forms long, gently undulating, concave slopes flanking the bases of the Hospital and Mt. Ida escarpments. Some of the debris is composed of landslide deposits derived from the adjacent escarpments, particularly in the upper portions of the fans. This unit is well drained and stable, and not expected to be susceptible to slope failures; however, the higher, upper parts of the unit are the repository for landslide debris and are potentially susceptible to slides and mudflows emanating from the adjacent escarpments. Soils with high shrink-swell potential may be possible at places where the debris contains appreciable material derived from Potomac Formation silty clays, or the depth to sandy clays is shallow adjacent to the Mt. Ida escarpment

9C
9B
9A

Crystalline bedrock of varied composition. 9A: <10% slope; 9B: 10-25% slope; 9C: >25% slope. Forms the inner walls of Holmes Run gorge. Typically very steep where fresh, unweathered to moderately weathered bedrock is present, gentler where weathered to saprolite. Small talus and rockfalls are fairly common below bold, near-vertical rock faces in the steeper areas, though no significant rockslides are noted. Saprolite is generally well drained and stable, and slope failures are exceedingly rare on slopes less than about 50%. As Obermeier (1979) notes, however, joints in saprolite are commonly clay coated where overlain by Potomac Formation deposits—a widespread condition in Holmes Run Gorge—and represent a potential source of instability and wall failure in excavations

Map Symbols

Boundary of geologic unit, approximately located

Outline of slope class unit. A - <10%; B - 10-25%; C - >25% Each class contains minor inclusions of greater or lesser slope pitch too small to be shown at the scale of mapping. Patterns appear together with geologic units 1-9

Narrow strip of sand and gravel along the feather edge of major terraces at the heads of slopes. Common location for the inception of landslides

Modern landslide or conspicuous scarp (probable failure surface) observed in field. Arrows indicate direction of movement. Most areas consist of multiple smaller slides or scarps

General area of landslide mentioned in geotechnical report. Exact size and location generally not known. Teeth point in inferred direction of motion

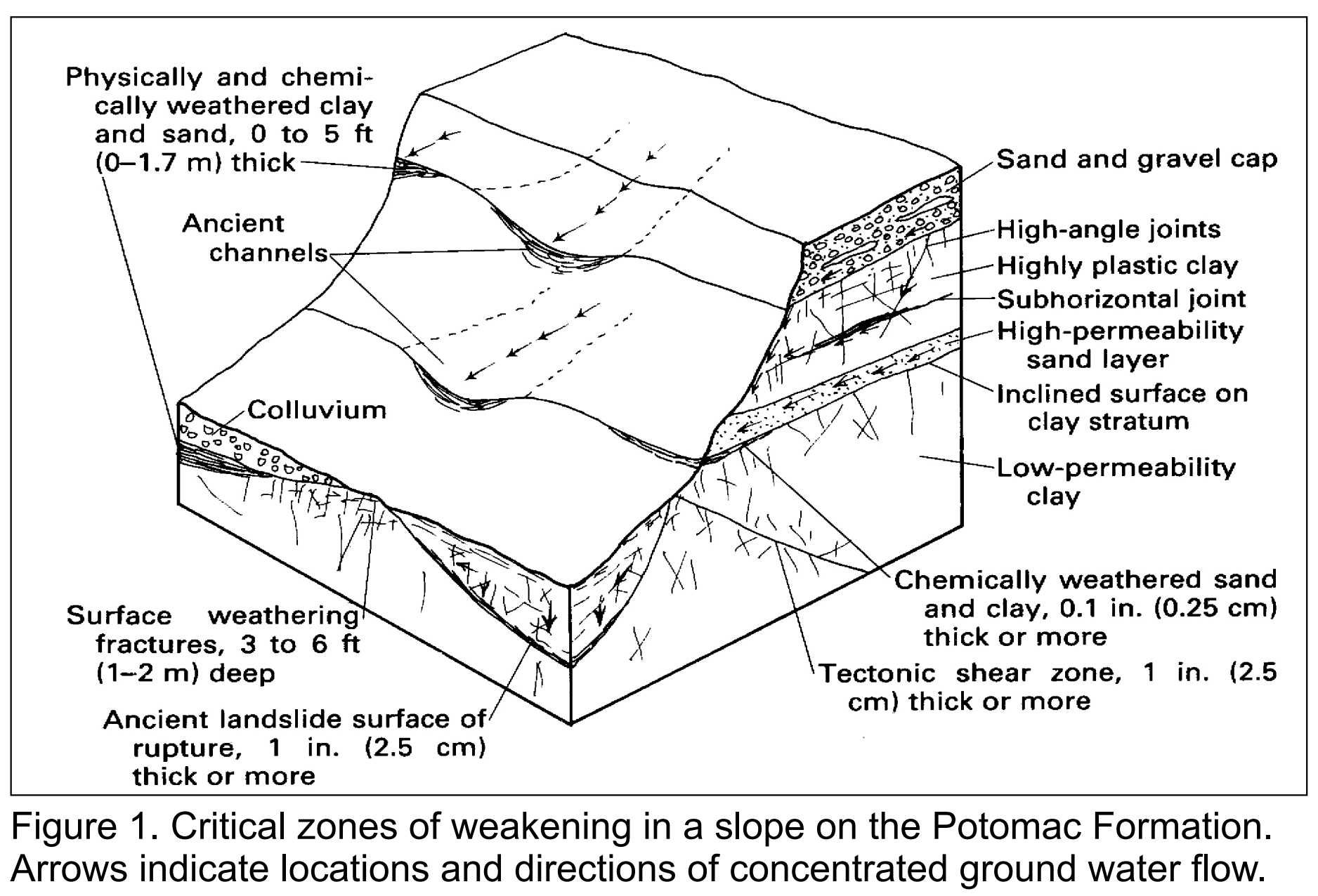
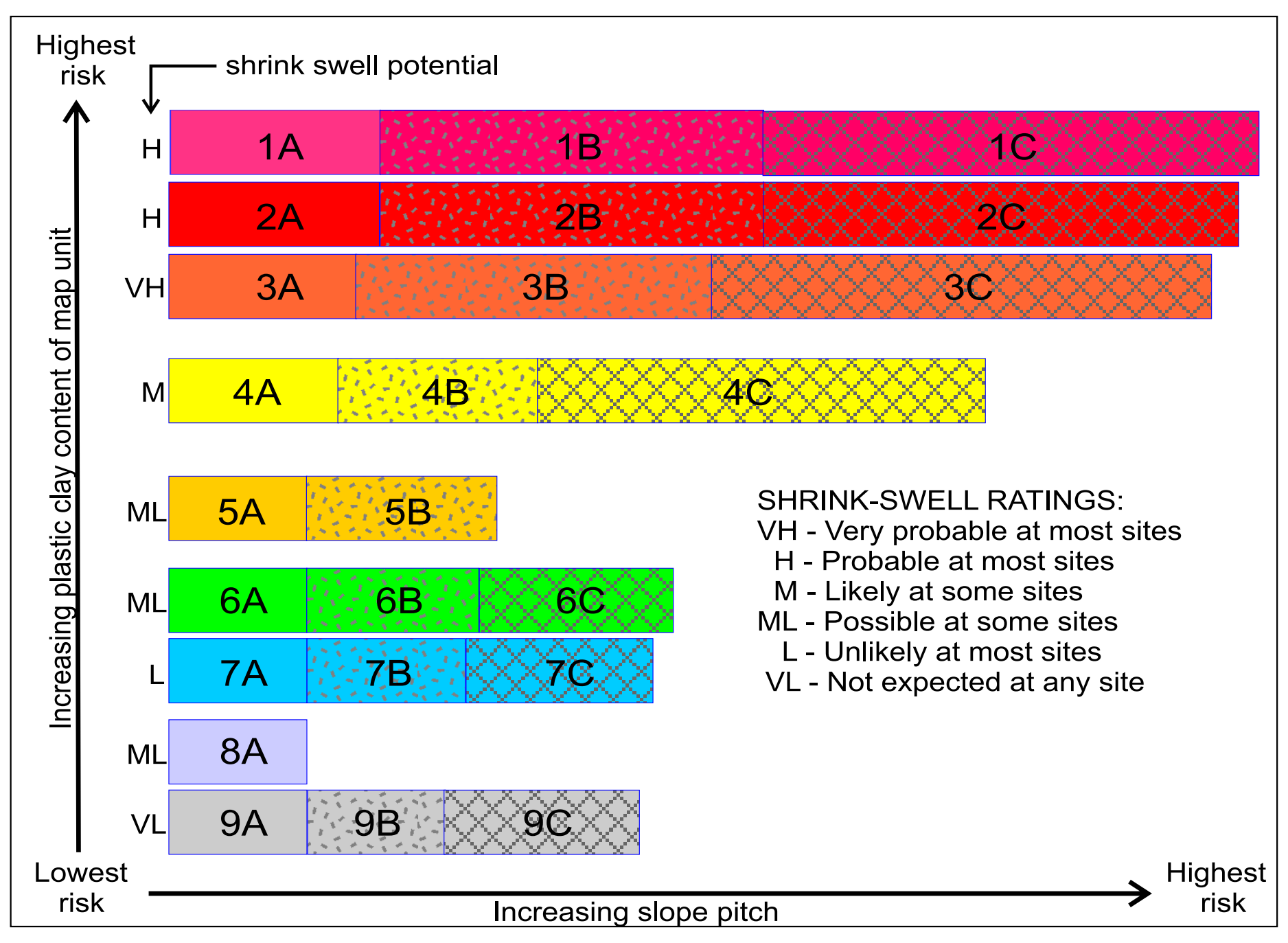


Figure 1. Critical zones of weakening in a slope on the Potomac Formation. Arrows indicate locations and directions of concentrated ground water flow. Source: Obermeier, 1984, figure 6, courtesy of the U.S. Geological Survey



SHRINK-SWELL RATINGS:
VH - Very probable at most sites
H - Probable at most sites
M - Likely at some sites
ML - Possible at some sites
L - Unlikely at most sites
VL - Not expected at any site

Figure 2. Generalized potential for slope stability problems relative to geologic unit and slope class, and probability of encountering high shrink-swell soils within a given map unit

SLOPE STABILITY MAP OF THE CITY OF ALEXANDRIA, VIRGINIA AND VICINITY

By Anthony H. Fleming, 2015