Plate 5: Geologic Map of the City of Alexandria, Virginia and Vicinity, Showing Surficial Geology, Landforms, and Major Areas of Artificially Modified Land—Expanded Explanation

By Anthony H. Fleming, 2015

Introduction

The Alexandria landscape consists of what could be called an incompletely dissected *plateau*, ringed on three sides by deeply entrenched stream valleys (figure 5-1). The history of this landscape is closely entwined with that of the Potomac River, and includes multiple episodes of both deposition and erosion that began in the late *Tertiary* or earlier, and continue into the present. Incision of the landscape occurred in discrete episodes, punctuated by stable periods when the river deposited extensive alluvial plains. With each new pulse of downcutting, the river left behind a *terrace* marking the surface upon which it had recently flowed; forces of erosion would immediately begin acting on the terrace, triggering renewed transport of sediment from higher parts of the landscape down onto the newly steepened slopes. Sediment thus eroded would be recycled, or reworked, into the next terrace and into various slope deposits flanking it, in a cycle of geological cannibalism. This cycle may have repeated itself as many as 10 or 12 times since the late Tertiary, based on the number and positions of terrace remnants visible in the modern landscape.

Figure 5-1. Digital elevation model of the City of Alexandria. More elevated areas appear in progressively redder tones. Stream valleys and dissected areas appear in green and yellow tones. Source: http://www.alexandriava.gov/uploadedFiles/gis/Topography2014.pdf

The most dramatic downcutting has taken place relatively recently, as the Potomac River and its tributaries have responded over the past one million years or so to episodes of major sea-level lowering during the *Ice Age*. All of the major drainages, and most of the smaller ravines in and adjacent to the city, owe their present forms to this period. The *Pleistocene* climate is also responsible for the origin and current location of the *Fall Zone*, the physiographic boundary that separates the *crystalline rocks* of the Appalachian *Piedmont* to the west from the softer sediments of the Atlantic *Coastal Plain* to the east, and is exemplified locally by Holmes Run Gorge. The result of all this stream activity is a landscape underlain by a complex mosaic of terraces, slope deposits, and modern *alluvium* that mantles the underlying *bedrock* and Coastal Plain sediments (figure 5-2). **Plate 5** shows the distribution of these deposits, and the landforms they occur within.

Definition and Significance of Surficial Deposits

Plate 5 is a map of the surficial geology of the city and adjacent areas. As the name implies, "surficial" refers to the materials present at and immediately below the modern land surface. By virtue of their proximity to the surface, these are the deposits initially encountered when people interact with the soil-geologic environment, whether for construction projects, horticulture, managing property, or simply enjoying nature.

The map units encompass a wide range of geologic materials, from solid rock to a variety of poorly consolidated and *unconsolidated sediments*. In the Holmes Run Gorge area, for example, several types of ancient *Paleozoic* crystalline bedrock of the Piedmont (and soils developed on them) crop out or are extremely close to the surface. In other places, the compact but otherwise poorly *lithified* deposits of the early *Cretaceous* *Potomac Formation* are present at the surface, most commonly in ravines and on other moderate to steep slopes where there is little surficial sediment accumulating. As detailed in **plate 4**, the Potomac Formation is up to 400 feet thick and consists of 6 major mappable *members* within the city, and several minor ones, each representing a somewhat different sedimentary environment characterized by a specific association of *lithologies*.

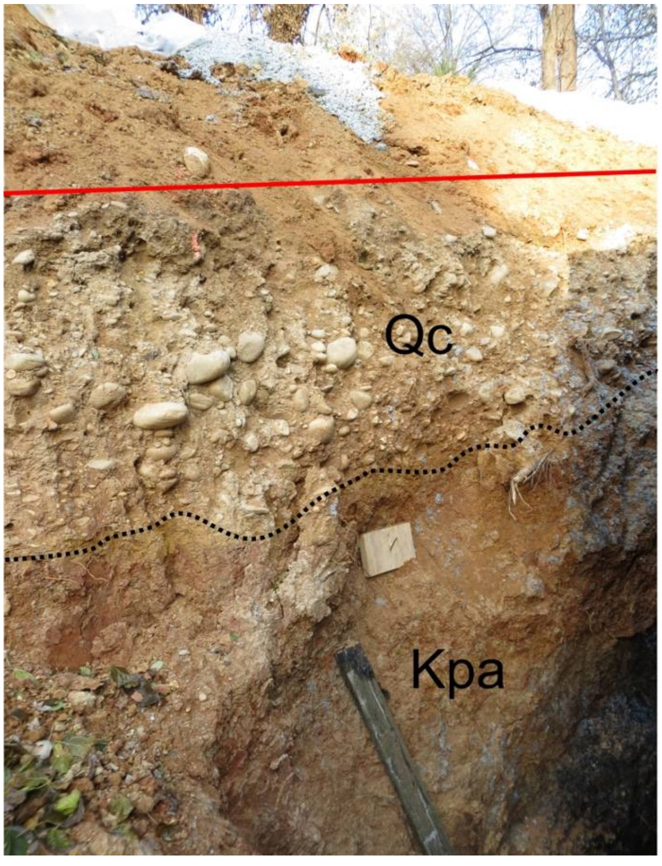

Figure 5-2. Many of the hillsides in the City are mantled by various kinds of slope deposits whose physical and chemical properties can differ substantially from those of the underlying Potomac Formation or bedrock. Here, about 30 inches of very coarse, cobbly, well drained Quaternary colluvium (map unit Qc) overlies deeply weathered, red-brown Arell clay (map unit Kpa). The clay is very poorly drained, hard, strongly fractured, and contains abundant expandable-lattice clay minerals that cause it to swell and shrink when wetted and dried, leading to a variety of stability issues for slopes and any structures built on them. On the other hand, the colluvium is loose and minimally weathered, but its stony character is problematic for landscaping, gardening, and other activities involving shallow hand excavations. The red line is the original soil surface prior to the excavation. Shooters Hill, above Taylor Run. Photograph by Tony Fleming.

Over large parts of the map area, however, the bedrock and Potomac Formation are concealed beneath a veneer of younger surficial deposits, which consist chiefly of alluvial terraces and slope deposits of widely varying ages, compositions, and position in the landscape. Many of the slope deposits are comparatively thin and transient (in geological terms), but they are nevertheless sufficiently thick at many places to dominate or have a major impact on the soil profile, and are thus of great importance to human and ecological affairs. Slope and stream deposits of one sort or another are present to at least a few inches depth on nearly every hillside and in every ravine in the city. Hence, the decision of where to show these units on the map (as opposed to highlighting the underlying bedrock or Potomac Formation units) was not always simple, but ultimately was based on the foregoing concept, which bears repeating: *slope deposits, such as colluvium, as well as alluvial deposits, are shown where they are generally of sufficient thickness to dominate or have a major influence on the soil profile*. In practical terms, this means that these deposits are more likely than not to affect the consistency, texture, profile development, strength and stability, and ecological properties of the soil within the areas where they are mapped, and thus have a major impact on the environmental qualities of the landscape. They are also the deposits people will actually see when they look at or excavate into the soil surface in these areas.

Previous Studies

For the most part, the surficial deposits within the city have received relatively little attention in past studies, and the sources of information bearing on their geology are the same as for the bedrock and Potomac Formation. The preliminary geologic map of Fairfax County (Drake and others, 1979), for example, shows several areas of *colluvium* overlying the Potomac Formation in parts of the present map area, but these deposits are not differentiated by age or origin. The geologic map of the Annandale Quadrangle (Drake and Froelich, 1986) shows a few small areas of colluvium, *lag gravel*, and *landslide* deposits, none of which lie within the city limits. It also shows extensive areas of terraces bordering modern streams, but all of these are grouped into one map unit without respect to age or position in the landscape. The surficial deposits shown on these maps are based on work done by Langer (1978) and Force (1975), which was incorporated into the "Simplified surficial materials map of the Coastal Plain" of Fairfax County presented in Froelich (1985).

North of Alexandria, the geologic map of the Washington West quadrangle (Fleming and others, 1994) distinguishes areas of Pleistocene and Tertiary colluvium, and breaks out the terraces bordering the Potomac River into five Pleistocene units based on their degree of weathering, position in the landscape, inferred age, and other features. Likewise, the Annandale, Falls Church, and Washington West geological maps also contain fairly detailed descriptions of the lithologies, weathering features, and landscape positions of each of the several late Tertiary river terraces, several of which are equivalent to the informally-named terraces that cap the Alexandria uplands. The late Tertiary river terraces (also called "upland gravels" or "upland river terraces") have probably received the most attention during previous studies, in no small part because their ages are a subject of debate and greatly affect our understanding of how and when the modern landscape evolved.

Data Sources and Methods

How the Map Was Made**:** The surficial geology map was made primarily from direct field observations, coupled with analysis of landforms using both modern and historical topographic maps along with the City's digital elevation model and orthophoto coverage. All of the major terrace surfaces, slopes, ravines, and stream valleys in the city were examined, usually in multiple places, in order to determine the kinds of geologic materials typically present in each, along with the predominant hydrologic aspects of each landform. The presence of specialized vegetation communities was also diagnostic of certain geologic conditions; for example, acidic gravel forests are very useful for indicating thick accumulations of colluvium on the slopes below the upland terraces. The locations of exposures are noted on the map of data points (**plate 1**), and the major observations are also recorded in the **database of Alexandria exposures** accompanying this study.

In addition, many large and small excavations were either observed directly during the course of fieldwork, or the tailings from closed sites were present in sufficient quantity to provide a good sense of the underlying materials. These observations were supplemented by subsurface data from many wells and geotechnical borings, which were useful for gauging the thickness and other properties of surficial deposits, as well as the nature of the formations underlying the landforms at depth (e.g., Potomac Formation, bedrock).

Artificial Fill and Modified Land: One of the biggest challenges for interpreting the surficial geology is the widespread disturbance of the landscape resulting from myriad urban activities. Emplacements of *fill* are ubiquitous in most parts of the city, and gravel derived from river terraces and colluvium is the most common type of fill material. Such gravelly fill can look misleadingly like native material, especially colluvium, unless the fill contains diagnostic anthropogenic materials (e.g., organic debris, cinders, demolition debris, exotic boulders, etc). It was not always possible to observe the soil profile in areas of suspected fill for *pedogenic* and geologic features, which is the most reliable way to determine whether material is native or artificial. Fortunately, the surroundings of most of these places gave a fairly reliable idea of whether fill was likely to be present. Beyond that, most major landforms in the city contain at least a modicum of undisturbed ground, some of it in native vegetation, which was usually sufficient to give a good sense of the geology.

Figure 5-3. Examples of artificial fill. Left: heterogeneous fill composed of a mix of native soil, concrete fragments, and granite boulders not native to the City. Right: Shirley Highway rides on a massive berm of fill derived mainly from local geologic materials. The example on the left is readily recognizable as artificial fill because of its exotic components; the one on the right might not be if the material was seen out of context. Photos by Tony Fleming.

Closely related to filling is the removal of parts of landforms, or even entire landforms, to make way for major buildings and infrastructure. Large parts of the landscape along Shirley Highway, for example, have been completely rearranged. The same is true of almost any large-scale development. This can be both good or bad for geology. Sometimes this work creates new exposures, and at other times, it can eliminate key geologic evidence. Large-scale disturbance and fill emplacements invariably alter the natural hydrology, making it very problematic to interpret water features, such as springs, ground-water flow patterns, and surface drainage for purposes such as slope stability assessments, water resource evaluations, ecological restoration, and similar activities.

The mapping of artificial fill and modified land poses a distinct challenge in a place like Alexandria, which has experienced centuries of European habitation. On the one hand, identifying areas of fill and modified land is of major importance to understanding the properties of the shallow subsurface for many activities, especially building projects and the design of other infrastructure. On the other hand, these areas are so ubiquitous in the urban landscape that they would obscure the underlying geology in many places if mapped at their full extent using a standard color on the map (figure 5-4).

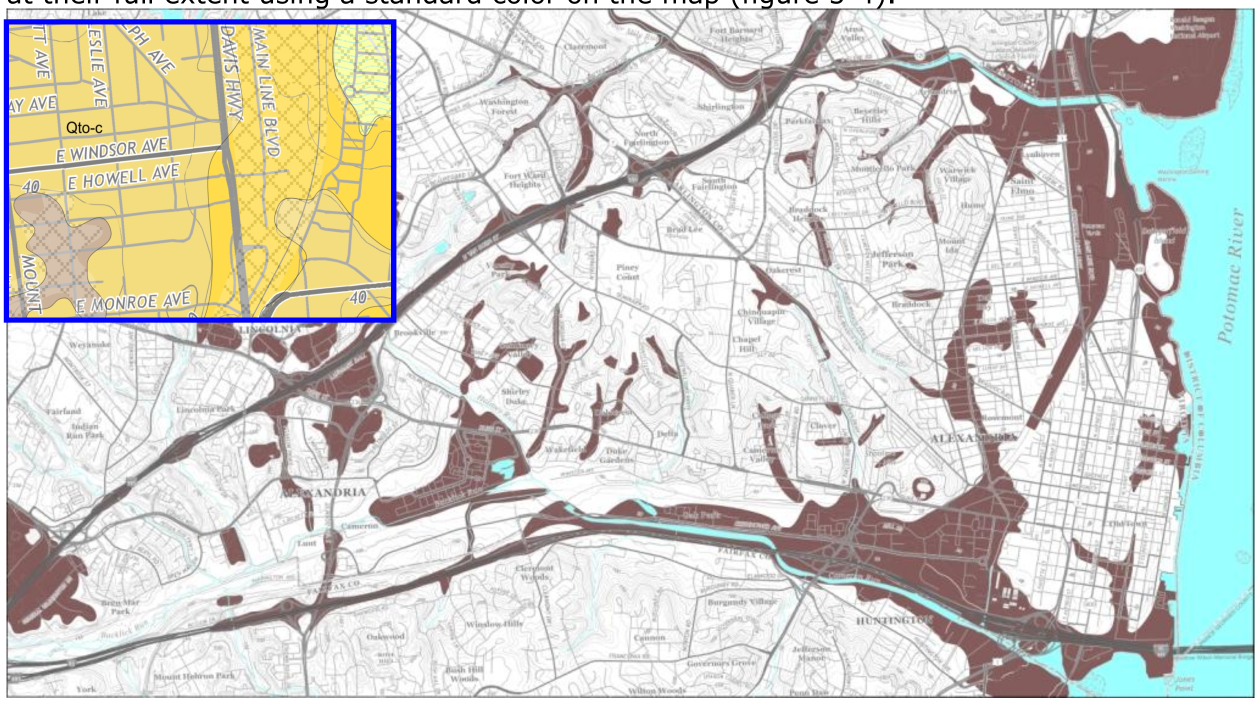

Figure 5-4. Major areas of artificial fill and modified land (brown) in Alexandria and vicinity. Many other minor areas are not shown on this map, but their collective extent is substantial—potentially greater than the area in brown. The inset contains examples of the transparent mesh pattern used on plate 5 to indicate major areas of fill and modified land.

Plate 5 strikes a balance between these two competing needs by using a transparent mesh overlay that preserves the visibility of the underlying geology, and by applying the overlay only to the *major* areas of fill and modified land. These areas are commonly defined by widespread fill thicknesses of at least a few feet and locally (and often unpredictably) much more, or widespread disturbance of the natural soil profile over at least several acres, or both. The fill pattern is readily visible but not dominant when viewing the map at the published scale of 1:12,000 (figure 5-4, inset); at smaller scales, it appears as a faint gray tone over the other colors and patterns.

<u>Depicting Colluvium and Other Transient or Spatially Variable Deposits</u>: A final challenge, as alluded to earlier, involves the mapping process itself, specifically how extensively to show relatively thin and variable surficial deposits on hillsides and in ravines, relative to the underlying bedrock and the Potomac Formation. In many locations, the surface of a given hillside will consist of some of both; on moderately steep hillsides developed on Potomac Formation clays, for example, fairly thick colluvium is commonly present in concave places, while the Potomac Formation crops out or is within inches of the surface on steep, convex parts of the hillside. Such variation frequently occurs at a scale finer than what can be easily shown at the current map scale. For the most part, the issue of variation in thickness of colluvium, alluvium, and other surficial materials, and the presence of multiple kinds of materials within a map unit, are handled in the explanation of the map unit. And, as

mentioned before, the impact on the soil profile is the guiding principle used to decide where and how extensively to map a specific surficial material in a particular area. If anything, plate 5 errs on the side of showing a greater proportion of surficial deposits than in a typical geologic map, the idea being that other maps in this atlas (e.g., **plates 3** and **4**) are available to give a more complete picture of the underlying bedrock and Potomac Formation. That said, the map is a bit of a compromise, and tries to strike a balance between the need to show as wide a variety of surficial units as possible, in the places they characteristically occupy, while also providing a reasonable indication of the distributions of the underlying bedrock and Coastal Plain units.

Tertiary Upland Terrace Deposits and Remnant Escarpments

Distribution and General Characteristics: Upland terraces are among the largest and most recognizable of the surficial deposits in the map area. Four upland terraces were recognized in the city during this study, and scattered remnants of a fifth terrace occur in the far western part of the map area, near Mount Pleasant in Fairfax County (figure 5-5). Although they are variously dissected, the four terraces within the city are prominent physiographic features, and all five can be readily distinguished from one another and from lower-lying Pleistocene terraces on the basis of their consistent surface elevations, geographic distributions, surface morphologies, and intensity of weathering.

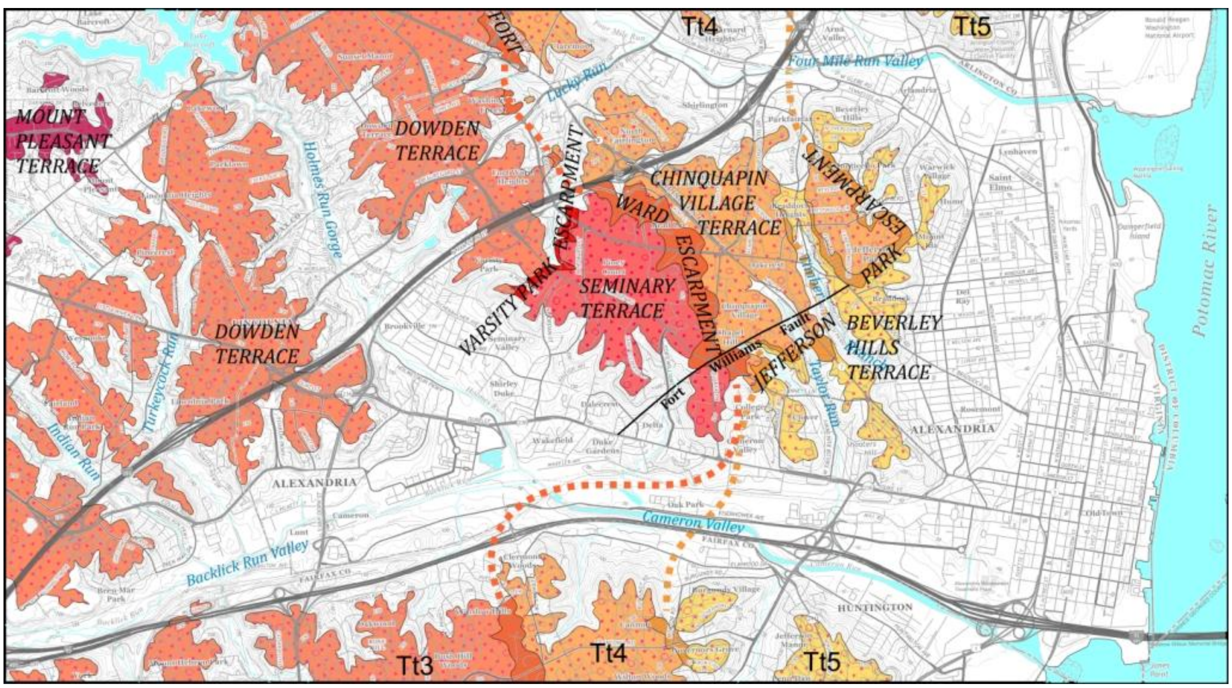

Figure 5-5. Distributions of the upland terraces and remnant escarpments named in the map area. Dotted orange lines indicate the general locations of the Fort Ward and Jefferson Park escarpments prior to Pleistocene incision of the landscape. Tt3, Tt4, and Tt5 are the identifiers applied to corresponding terraces in adjacent areas by Drake and others (1979).

For convenience in mapping and discussion, they are given informal local names based on prominent places where the terraces are well displayed. From highest to lowest, they are: 1) **Mount Pleasant terrace** (map unit Tmg), which forms three highly dissected remnants up to 30 feet thick with surface elevations ranging from 350-400 feet (Drake and Froelich, 1986); 2) **Seminary terrace** (Tsg, Tsm), with a typical surface elevation between 265 and 275 feet. The observed thickness is commonly around 30-35 feet; 3) **Dowden terrace** (Tdg, Tdm), with a surface elevation that is mostly between 240 and 250 feet. Although it is mostly about 30 feet thick, Dowden Terrace has the greatest observed thicknesses of any upland terrace, ranging up to 60 feet or more near Shirley Highway and Seminary Road; 4) **Chinquapin Village terrace** (Tcg, Tcs, Tcm), whose surface typically stands at 180-200 feet, with thicknesses commonly 25-30 feet; and 5) **Beverley Hills terrace** (Tbg, Tbm), with an average elevation of 145-150 feet and a typical thickness of less than 25 feet. Table 5-1 correlates the named terraces in the map area with the numbered terraces mapped in adjacent parts of Fairfax County and Washington, D.C.

Table 5-1. Nomenclature of the upland terraces in the Potomac Valley

Alexandria (this atlas)	Fairfax County (Drake and others, 1979)	Washington, D.C. (Fleming and others, 1994)
Not present	Tt1	Not present
Mount Pleasant terrace	Tt2	T4
Seminary terrace	Tt3	Not present
Dowden terrace	Tt3	T3
Chinquapin Village terrace	Tt4	T2
Beverley Hills terrace	Tt5	T1

Seminary terrace appears to be restricted to the City of Alexandria: no terraces of comparable elevation are identified on geologic maps of any surrounding jurisdictions. On the preliminary geologic map of Fairfax County (Drake and others, 1979), Seminary terrace is not distinguished from Dowden terrace (both are called "Tt3" on that map), but there is strong evidence in the city that they are distinct terraces. The boundary between them is particularly prominent along Seminary Road between Pegram and Howard Streets, where it forms a short, sharp, colluvium-covered *escarpment* about 25-30 feet high, across which the bases of the two terraces appear to differ by between a few feet and 25 feet. While it is theoretically possible that the scarp might be the result of a *fault*, this seems unlikely because there is no other line of evidence indicating a fault at this location, unlike the Fort Williams fault which cuts the southeast end of the Seminary terrace. The Seminary terrace also is pervasively capped by a robust thickness (locally >10 feet) of heavy silt loam, which creates a widespread, swampy landscape over the western part of the Episcopal Seminary. Silt loam also caps portions of the Dowden terrace, but it has a much patchier distribution and is typically less than 5 feet thick. Only a modest difference in weathering was observed between the two terraces, but this may be a function of substantial differences in hydrology and parent materials: large parts of the Seminary terrace are characterized by silty, dull colored *ultisols* with a prominent *fragipan* that impedes drainage, whereas coarse, well drained, brightly-colored ultisols on gravel are more typical of the Dowden terrace.

Lithology and Weathering: Outside of any fine-grained capping sediment, all of the upland terraces are composed predominantly of quartz-rich gravel in a brightly oxidized matrix of well-weathered sandy loam (table 5-2, figure 5-6). The loam is derived from chemical breakdown of feldspars, rock fragments, and other non-resistant *clasts*. Within the city, matrix colors tend to be brightest (strong yellow-red to red-brown) in well-drained parts of the two highest terraces (Seminary and Dowden), indicating a longer period of weathering than the lower terraces (Chinquapin Village, Beverley Hills), which are typified by brownish-yellow to yellow-orange matrix colors (figure 5-7). Soil profiles with prominent fragipans were observed on level parts of all four terraces.

Although it was not studied in detail, the Mount Pleasant terrace appears to be the most deeply weathered of all: a nearly complete soil profile observed in an excavation along Old Columbia Pike consisted of deep red clayey *sand* overlying a massive argillic horizon (figure 5-7A). Most of the pebbles were "ghosts", crumbling readily when handled.

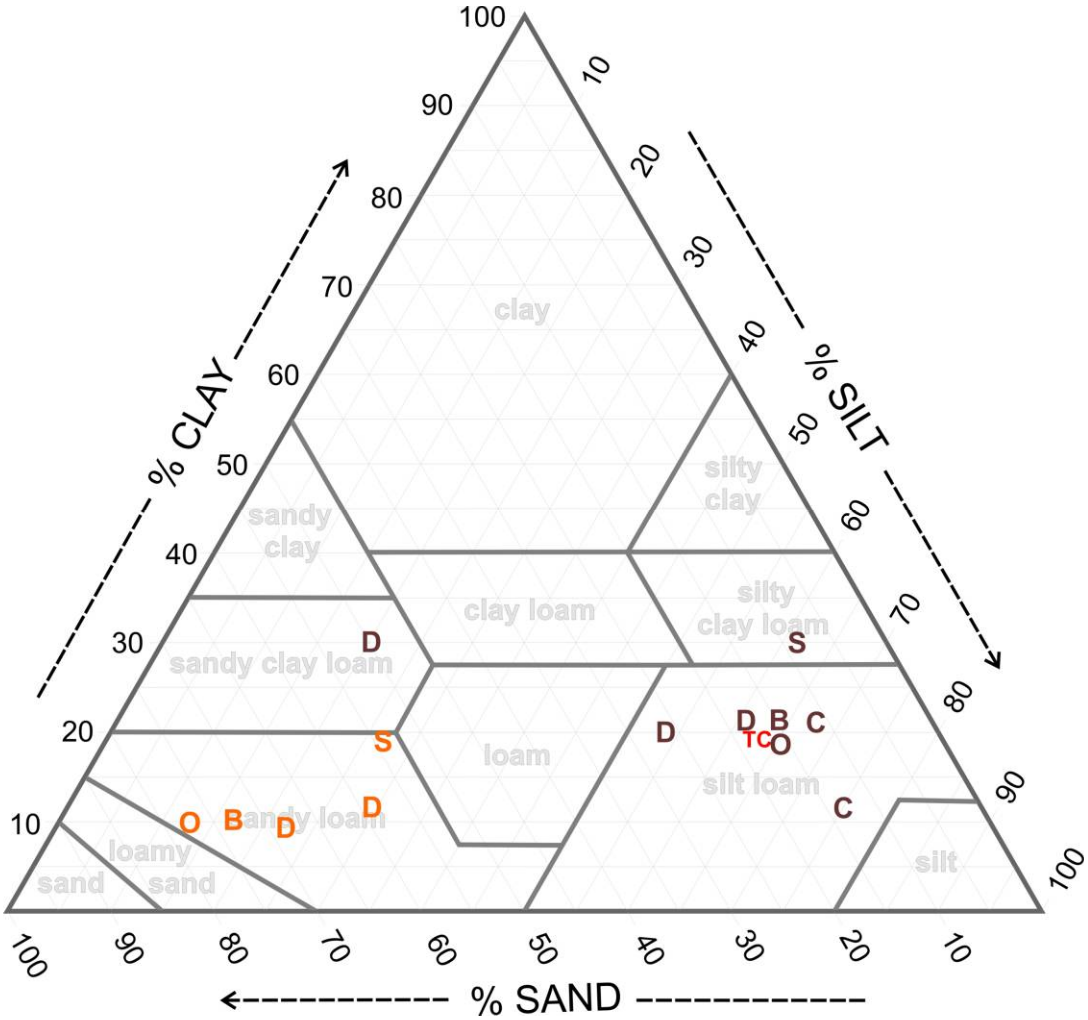

Figure 5-6 (above) and Table 5-2 (below). Particle size distributions of the major terraces in the City of Alexandria: B-Beverley Hills; C-Chinquapin Village; D-Dowden; O-Old Town; S-Seminary. Orange letters in the triangle represent the matrix texture of gravel units. Brown letters represent fine-grained capping sediment. TC (in red) is a sample of Tertiary colluvium from adjacent to the Dowden Terrace.

Exposure No.	Terrace Name	Map Unit	Description	% Gravel	% Sand	% Silt	% Clay
Upland Terraces: Sand and Gravel							
55-B	Beverley Hills	Tbg	yellow brown pebbly sand	9	73	17	10
82	Dowden	Tdg	orange brown clayey sand and gravel	68	59	26	15
279	Dowden	Tdg	light brown sand and gravel	74	69	22	9
162-B	Seminary	Tsg	reddish loamy gravel	59	54	27	19
Terrace Surfaces: Fine Grained Capping Sediment							
55-A	Beverley Hills	Tbm	brown silt loam	-	15	64	21
121	Chinquapin Village	Tcm	gray-brown silt loam, heavily mottled	-	15	68	21
275	Chinquapin Village	Tcm	gray silt loam, mottled	-	14	75	11
83	Dowden	Tdm	gray-brown silt loam, weakly mottled	-	18	61	21
188-A	Dowden	Tdm*	brown silty sand with strong fragipan	-	59	30	11
188-B	Dowden	Tdm	brown-gray silt loam with fragipan	-	27	53	20
162-A	Seminary	Tsm	heavy silt loam, strongly mottled	-	9	61	30
High Level Colluvium							
82-A	Dowden	Tc	brown-gray gravelly silt loam	12	19	61	20

* site straddles contact between silt cap and underlying sand and gravel

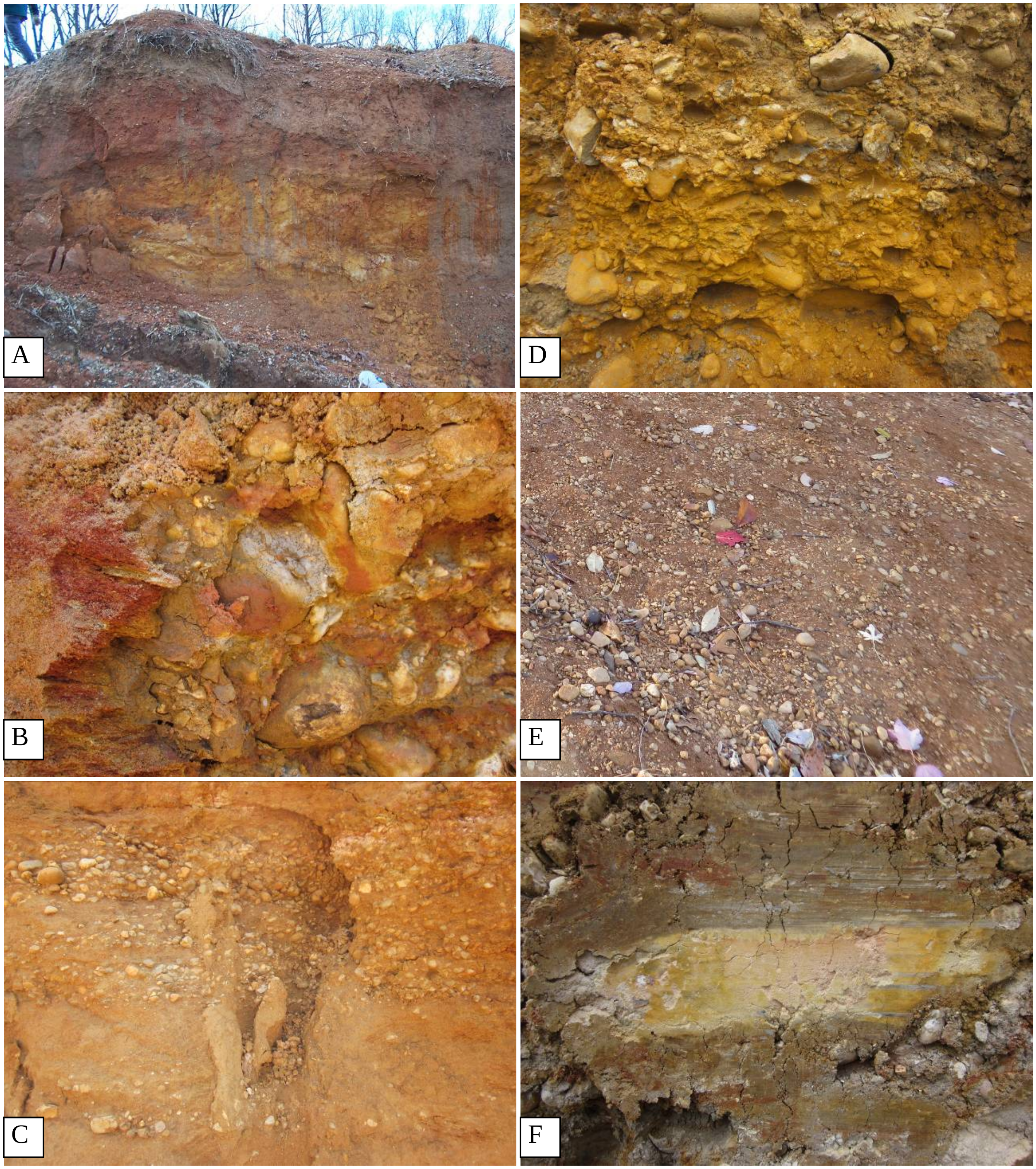

Figure 5-7. Characteristic appearance of the upland terrace gravels. A) deep red colors and thoroughly weathered "ghost pebbles" are the hallmark of the Mt. Pleasant terrace; B) red-brown colors dominate the Seminary terrace; C) bright orange-brown gravel interbedded with pebbly sand of the Dowden terrace; D) brownish-yellow, disorganized cobble gravel of the Chinquapin Village terrace; E) brown, medium gravel of the Beverley Hills terrace; F) clayey matrix (brown) and completely weathered "ghost pebble" (light object) in the Chinquapin Village terrace. Photos B-C-D-F by Rod Simmons, A-E by Tony Fleming.

The gravel in the upland terrace deposits consists almost entirely of resistant, siliceous types, chiefly vein quartz, quartzite, and quartz sandstone (figure 5-8). Most large clasts are moderately to well rounded, polished, and stained with iron oxides. Pitting of the surfaces of some pebbles was observed in exposures of the Dowden terrace, suggesting intense weathering. Although bright colors and other weathering effects are most pronounced in the upper 10-15 feet of the terraces, *weathering profiles* in all of these terraces appear to extend through the entire thickness of the deposits at many places. Exposures of relatively unweathered terrace gravel are rare, and limited to a few deep excavations in the thickest parts of Dowden terrace (figure 5-8).

Figure 5-8. Left: Vein quartz, quartzite, and other quartz-rich clasts resistant to chemical weathering dominate the terrace gravels. Exposure #82, Dowden terrace, Stevenson Park, photo by Rod Simmons. Right: Rare exposure of relatively unweathered terrace gravel, evidenced by the lack of bright colors, low clay content (table 5-2), and presence of granite pebbles. Exposure 279, Dowden terrace, old headwall of the former Van Dorn St. gravel pit. This face is estimated to lie 40+ feet below the original soil surface. Photo by Tony Fleming.

Figure 5-9. The gravel is very poorly organized, and may exhibit a crude layering or imbrication of clasts. Faint cross bedding, such as that visible to the right of the person at about waist level, is rarely seen outside of excavations. Chinquapin Village terrace, exposure 312. Photo by Rod Simmons.

The majority of clasts are in the coarse *gravel* fraction; however, *cobbles* are common, and *boulders* up to several feet long were observed in all four terraces or in *colluvium* and *alluvium* derived from them (figure 5-10). Boulders in the 3-4-foot range are fairly common and can be seen along the edges of most of the terraces. The coarseness of the gravel indicates that most of it is bed load dragged along the bottoms of channels during floods and deposited in bars. Much of it was probably open framework cobble gravel in which finer pebbles and sand transported by less energetic currents filled in around the larger clasts. Occasional beds and short intervals of *sand* are reported to be interbedded with the gravel in a number of geotechnical borings, and relatively thin layers of trough cross-bedded coarse pebbly sand were observed in several excavations (figure 5-7C).

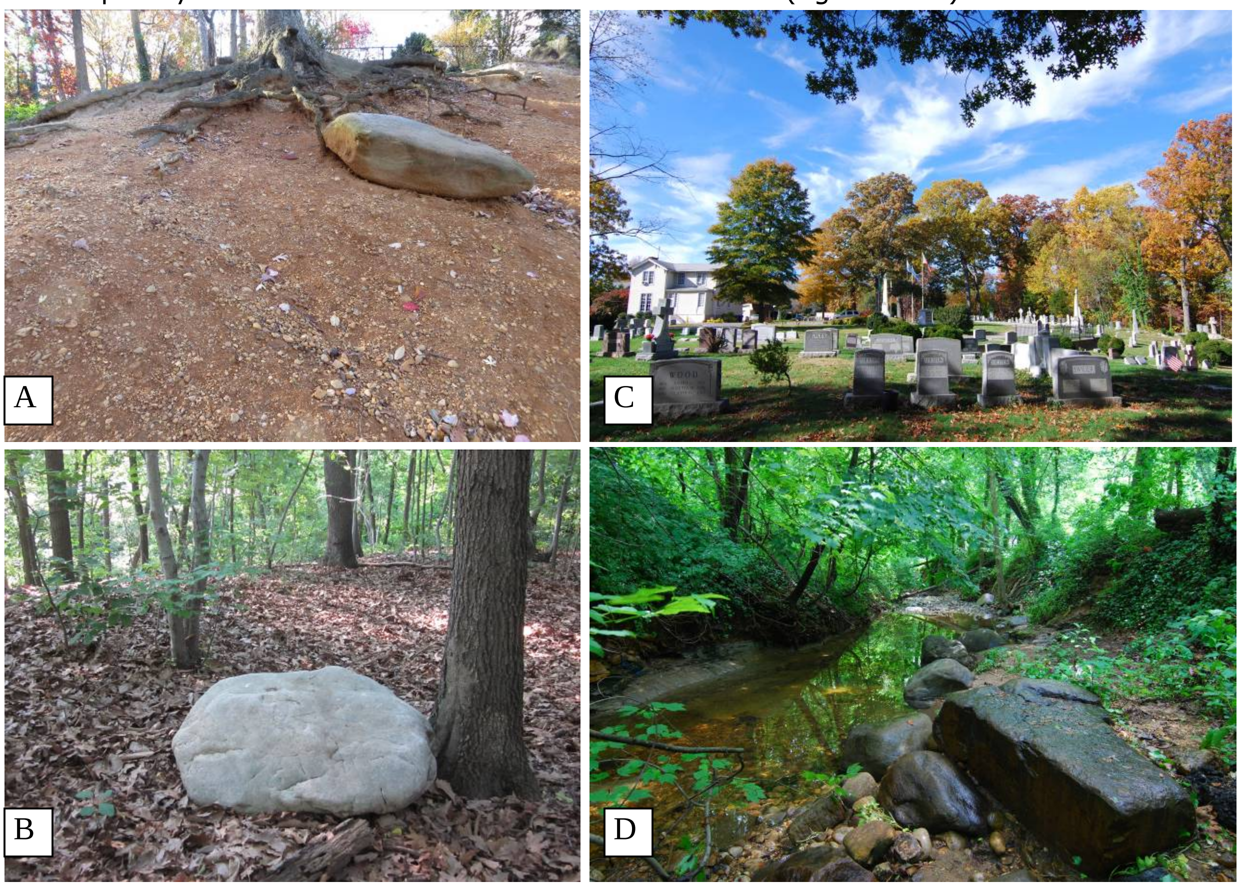

Figure 5-10. Large boulders are present in all of the terraces and are most commonly seen on hillsides where the base of a terrace deposit is exposed to erosion. Most boulders are quartzite (A) or vein quartz (B). The largest concentration of such boulders observed during this project are along the hillside and adjacent parts of Timber Branch below the Beverley Hills terrace at Ivy Hill Cemetery (C), where some boulders of Antietam Quartzite are as much as 6 feet long (D) and probably weight close to a ton. How such massive boulders were transported down-river from their source areas in the Blue Ridge is an enigma. Photo A by Tony Fleming, photos B-C-D by Rod Simmons.

Distinct from the gravels are a series of fine-grained sediments found in association with all of the upland terraces (figure 5-11). This material is mostly clayey silt, silt loam, and/or loam in composition (figure 5-6, table 5-2), and in most cases, it occurs on the surfaces of the terraces, sometimes over wide areas. These sediments have a massive, unstratified appearance in excavations and are usually devoid of gravel except where mixed with underlying gravel by tree throws or burrowing animals. They commonly contain a small proportion of fine to very fine sand. The origin of this material is unclear: the most likely possibility is that it was deposited at the same time or shortly after the gravel that makes up the bulk of the terrace, presumably as alluvial overbank sediment and possibly as swamp deposits in swales and oxbows. Some of it could be windblown silt, however. The lack of stratification, near-total dominance of silt sized grains (now partly weathered to clay), and association with large alluvial plains are all consistent with loess (windblown silt).

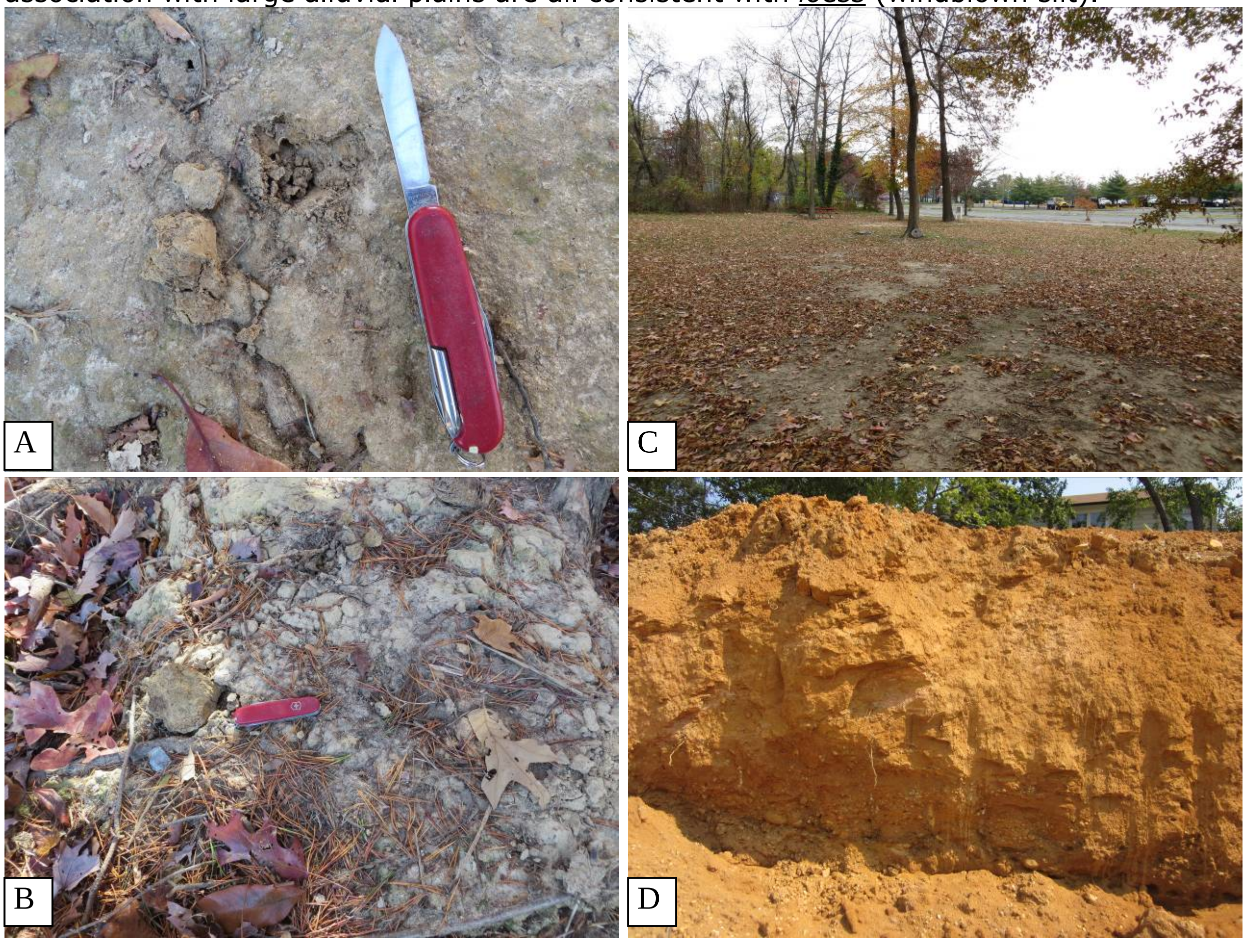

Figure 5-11. Fine-grained sediment composed mainly of silt occurs locally on the surfaces of all of the upland terraces. This material (A and B) tends to have a brown-gray, locally mottled and/or gleyed appearance regardless of what terrace it is on, and it often underlies broad, shallow swales as well as larger, poorly drained, almost perfectly level areas (C). Some bodies are somewhat sandier (D) and are characterized by faint stratification and well developed fragipans—a hard, prismatic soil horizon that impedes drainage and root penetration. The contact with the underlying gravel is visible near the bottom of the photo. Photos A-B-C by Tony Fleming, photo D by Rod Simmons.

Fine-grained sediment is particularly abundant on the surfaces of the Seminary and Chinquapin Village terraces. Silt loam, typically with a well-developed fragipan or clay pan, caps virtually all of the highest part of the Seminary terrace, which also is the highest place in the city; the associated landscape is very poorly drained and locally characterized by hummocky microtopography and distinct swales and subtle ridges—elements that could be inherited from an original floodplain. On the other hand, a sizable volume of the original terrace material has been lost to chemical weathering, and the resulting compaction has undoubtedly affected the appearance of the surface. In any case, this landscape is essentially undissected and retains relict swamp vegetation and wetland hydrology, and was probably an extensive, precipitation-fed upland swamp prior to settlement.

In contrast to the widespread silt distribution on the Seminary terrace, fine-grained sediments on the surface of the Chinquapin Village terrace occur in distinct belts near the original inner margin of the terrace, paralleling the base of the river-cut Fort Ward escarpment that separates the terrace from the adjacent Seminary terrace (figure 5-5). A belt of heavy, clayey silt follows the base of the scarp and probably represents a backwater swamp or floodplain terrace. The silt is more than ten feet thick at places and is commonly thicker than the underlying gravel close to the edge of the terrace. Relict swamp hydrology and vegetation is widespread on the silt, being well displayed in parts of Chinquapin Village, Chapel Hill, and along the eastern edge of Episcopal Seminary. A second belt, composed mostly of sandy loam and sandy silt, lies on the inboard side of the heavy silt. It was well exposed in a series of shallow excavations in South Fairlington and Oakcrest, where it typically consisted of light orange brown, massive, well-drained loam. The original deposit is inferred to have been silty, feldspathic sand, which has since weathered into loam. Plane laminations were observed in two shallow utility trenches in South Fairlington. The loam was probably deposited in a more proximal part of the same floodplain as the heavy silt.

Smaller areas of similar fine-grained sediment cap parts of the Dowden and Beverley Hills terraces. The surfaces of both of these terraces are significantly more dissected and deflated than the other two, hence it is thought that the present erosion surface of both terraces mostly lies below the original depositional surface. Known areas of fine-grained sediments tend to occur on the highest, flattest, and thus presumably least eroded sections. The best example is in the Dowden Terrace neighborhood, which is characterized by a gently undulating, somewhat poorly drained landscape that lacks any visible gravel on the surface and exhibits hydric vegetation in a few low swales (figure 5-12). Two nearby foundation excavations exposed several feet of very heavy silt loam. The soil profile exhibited strong mottling and a heavy clay pan, indicating a shallow seasonal water table.

Figure 5-12. Upland depressional swamp, Dowden Terrace. Photo by Rod Simmons.

Almost all of the Beverley Hills terrace is strongly dissected, and most of its remaining surface is thought to be moderately stripped by erosion. Fine-grained material appears to be present only in small isolated patches, a good example being the clayey silt that underlies the upland along Janneys Lane, immediately east of Taylor Run. Although engineering borings on this terrace are sparse, the few that do exist suggest that some of the fine-grained sediment may be interbedded with the gravel. This is also true to an extent on the Chinquapin Village terrace.

Geotechnical borings on the upland terraces typically describe the fine-grained capping sediments as being of low plasticity, that is they lack the *expandable lattice clay minerals* that cause significant shrink-swell of the soil and can be so problematic for foundation conditions and slope stability. So-called "*fat clays*" and "elastic silts" are rarely reported in borings made in the upland terraces. Analyses conducted for this study (table 5-3) of both the terrace gravels and the silty capping sediments indicate they contain an insignificant proportion of expandable-lattice clay minerals (e.g., montmorillonite, smectites); the clay fractions of these deposits are instead dominated by illite, kaolinite and soil vermiculite, which are indicative of strong weathering.

Exposure No.	Terrace Name	Map Unit	Expandable Clays	Illite	Kaolinite	Chlorite	Vermiculite Index
Upland Terraces: Sand and Gravel							
55-B	Beverley Hills	Tbg	3%	49%	26%	22%	35
82	Dowden	Tdg	1%	10%	47%	43%	45.5
279	Dowden	Tdg	4%	24%	39%	34%	4
162-B	Seminary	Tsg	6%	21%	45%	28%	53
Terrace Surfaces: Fine Grained Capping Sediment							
55-A	Beverley Hills	Tbm	7%	33%	36%	23%	51
121	Chinquapin Village	Tcm	4%	27%	40%	29%	35
275	Chinquapin Village	Tcm	1%	17%	47%	34%	17
83	Dowden	Tdm	3%	17%	44%	36%	43
188-A	Dowden	Tdm	3%	26%	39%	32%	37
188-B	Dowden	Tdm	5%	45%	29%	21%	26
162-A	Seminary	Tsm	3%	27%	42%	28%	41
High-Level Colluvium							
82-A	Dowden	Tc	2%	25%	43%	31%	44

Table 5-3. Clay mineralogy of the upland terraces. The abundance of each clay mineral class is expressed as a percentage of the clay fraction contained in the sediment.

Age and Correlation: Early workers (c.f., Darton, 1947; Johnston, 1964) tended to regard most, if not all of the terraces that extend into Alexandria as being of *Pleistocene* age, with some of the higher, outlying upland gravels in Fairfax County (e.g., the Mount Pleasant terrace of this atlas) potentially being of late *Tertiary* age. These two broad subdivisions were referred to as the "Brandywine" and Bryn Mawr" gravels, respectively. In more recent work, all of the upland terraces in the city (or their equivalents in surrounding jurisdictions) have been interpreted to be late Tertiary, based in part on presumed correlations with fossiliferous formations of known late Tertiary age further east in the Coastal Plain (c.f., McCartan, 1989, and Fleming and others, 1994); a fossil cypress log recovered from the highest terrace in Fairfax County (Drake and Froelich, 1997) points toward a late Miocene age for that unit, but has little bearing on the ages of the terraces in Alexandria, which are much lower in elevation and clearly younger.

Based on the weight of the evidence, all of the upland terraces above about 130 feet in elevation are assigned to the late Tertiary in all of the published geological quadrangle maps produced by the USGS during the last 20 years or so. This assignment spawned a scheme of alpha-numeric designations to identify each terrace, for example T1, T2, T3, etc. This scheme has not been applied consistently, leading to considerable confusion over nomenclature. In Fairfax County, for example, the highest terrace (at Tysons Corner) is referred to as "T1" (c.f., Drake and Froelich, 1997), while the lowest of the upland terraces (the Beverley Hills terrace of this atlas) is called "T5" (c.f., Drake and others, 1979). But in the District of Columbia and Maryland, the exact opposite is true: the lowest of the upland terraces is referred to as "T1", with higher numbers assigned to progressively higher terraces (c.f., Fleming and others, 1994). This poses a distinct challenge for assigning identifiers to the terraces in the City of Alexandria, whose location is directly in the middle of these two conflicting systems of nomenclature. Rather than trying to resolve this regional problem here, the terraces in the map area are given a series of informal local names to facilitate recognition and discussion.

The work performed for this atlas turned up no new evidence bearing on the ages of the upland terraces, nor any that would refute the currently accepted late Tertiary age assignments. Therefore, **plate 5** retains the late Tertiary age assignments for all of the upland terraces. This question is of more than academic interest, however: a number of faults in the region cut these terraces, hence, the lack of definitive age assignments greatly hinders the assessment of the age of most recent fault motion and associated seismic hazards. **This link** provides additional details about the challenges associated with assigning ages to the upland terraces.

Tertiary-Early Pleistocene Escarpments: Erosional remnants of three, high-level, river-cut *escarpments* are preserved in the city and separate portions of the upland terraces (figure 5-5). These remnants preserve short segments of what formerly must have been longer and more continuous escarpments that were cut when the river migrated to successively lower levels; in essence, they are relict valley walls. Most of the original escarpments have been eroded away, leaving only a few remaining segments, most of which are somewhat dissected by the heads of modern ravines, but still retain their basic form. The escarpments are held up by fine- and medium-grained sediments of the *Potomac Formation*, chiefly the Arell clay and Lincolnia silty clay in the central and western part of the uplands, and the Chinquapin Hollow fine sandy clay in the northeast. They typically form gentle to moderately steep slopes with convex summits and concave toes. Old gravelly *colluvium* eroded off the superjacent terrace typically mantles the surface of each scarp, and ranges from a few inches to a couple of feet thick, exceptionally attaining thicknesses of several feet adjacent to ravines and hollows. Strongly developed *ultisols* are typical, with the upper part of the soil profile developed in gravelly colluvium and the lower part in the Potomac Formation. There is little evidence of recent movement of the colluvium on most of these scarps, except close to a few active, deep ravines. Each scarp is roughly the same age as the terrace at its base, and, as with the upland terraces, each is given an informal local name for reference purposes.

The **Varsity Park escarpment (Tev)** is the oldest of the three upland scarps. It forms a short, mostly gentle slope that trends north-south across Seminary Road and separates Seminary and Dowden terraces between Braddock Road and Varsity Park. Maximum relief is about 30-35 feet. The scarp is held up by the Arell clay, which is mantled at most places by moderately thick colluvial gravel that contributes to a well-drained landscape. No evidence of landslides was observed on the scarp, which appears fairly stable. The scarp is well displayed on Seminary Road, just east of Pegram Street. The north and south ends of the scarp are truncated by the head of Lucky Run and Holmes Run Valley, respectively.

The north end of the Varsity Park scarp very nearly intersects the much larger, northwest-trending **Fort Ward escarpment (Tef)**, which consists of two sections, respectively, north and south of Shirley Highway. The **southern section** separates Seminary terrace from the much lower Chinquapin Village terrace. This is the longest and tallest upland scarp segment remaining in the city. The bold southern end of this section has some 60-75 feet of topographic relief and completely wraps around the southeastern end of the Episcopal Seminary, before bending northwest and extending through Fort Ward Park, where the relief is slightly less. The nature of the scarp landscape is well displayed on the slopes below Fort Ward, where a few inches to a few feet of gravelly and cobbly colluvium can be seen to overlie the Arell clay in the head of a ravine; all of these materials are deeply weathered and exhibit bright orange-brown soil colors at this location. Relict vegetation suggests that the scarp may have been a somewhat dry environment prior to settlement. Most of the southern section of the scarp exhibits moderate or gentle slopes and appears relatively stable; however, the steepest parts of this scarp may be prone to small landslides and rotational slumps due to the inherently unstable nature of the underlying clay. The southern end of the scarp appears to be offset across the Fort Williams fault, whereas the other end of the scarp is abruptly truncated above Shirley Highway by the head of Lucky Run. The map pattern suggests that the Fort Ward escarpment truncated the Varsity Park escarpment in this location prior to late Pleistocene incision of Lucky Run.

The **northern section** of the Fort Ward escarpment is very different and appears as isolated, erosional remnants at several places high in the deeply dissected upper Lucky Run watershed between Beauregard Street and Route 7 (figure 5-13). These remnants form moderately steep slopes that separate the Dowden and Chinquapin Village terraces. They typically exhibit about 40-50 feet of total relief, and are usually surrounded by steeper, more active slopes flanking the deeply entrenched ravines in the headwaters of Lucky Run. The surface is covered by a thin veneer of colluvial pebbles derived from the adjacent Dowden terrace, and overlies Lincolnia silty clay at shallow depth. Most of the soil profile is developed in the silty clay, and because of the relatively steep slopes on and surrounding this escarpment, it appears to be less stable than the others, with several landslide scars being noted on the steepest portions. The northernmost remnant is the largest of these, and follows the contact between the Lincolnia silty clay and the underlying Cameron Valley sand.

Figure 5-13. Left: Undissected remnant of the Fort Ward escarpment as seen from the edge of Dowden terrace, Washington Forest neighborhood. Right: Gentle rise of the Jefferson Park escarpment along Cameron Mills Road in Monticello Park. Photos by Tony Fleming.

The **Jefferson Park escarpment (Tej)** is the lowest and youngest of the upland scarps. It separates the Chinquapin Village and Beverley Hills terraces in the northeast part of the uplands, where it is developed on mixed sandy, silty, and clayey sediments of the

Chinquapin Hollow member of the Potomac Formation. Typical relief is about 40 feet at most places. Slopes are gentle to moderately steep, with abundant colluvial gravel. As seen in several small excavations, the colluvium was generally less than 2 feet thick, and occurred within the top of a brownish-yellow ultisol that extended down into the underlying Potomac Formation. These slopes are largely undissected and appear to be relatively stable, with no observed landslide scars.

The escarpment is a continuous feature in the vicinity of Monticello and Jefferson Parks (figure 5-13), where its markedly curved course marks the presence of a former bend in the river that cut the scarp. A prominent reentrant occurs on the north side of Timber Branch, where a high-level stream terrace on the valley wall appears to be graded to the Beverley Hills terrace. This relation suggests that Timber Branch existed at the time the escarpment was cut, and that the reentrant marks the confluence of the ancestral Timber Branch with the river when the latter occupied the Beverley Hills terrace. South of Timber Branch, the escarpment becomes fragmented by strong Pleistocene dissection associated with both Timber Branch and Taylor Run. Relations south of Timber Branch are further complicated by faulting, which appears to have interrupted the continuity of the escarpment, and by fluvial erosion. A series of narrow, bench-like surfaces and intervening colluvial slopes in Chinquapin Park and areas just to the southwest are probably a combination of down-faulted extensions of the Chinquapin Village terrace and benches cut by the river as it was downcutting to the Beverley Hills terrace. Unfortunately, strong late Pleistocene incision of Timber Branch and Taylor Run has severely attenuated these remnants and destroyed much of the evidence that might have helped interpret the relationship between tectonics and fluvial terrace formation. The remnants of this escarpment south of Timber Branch overlie Arell clay; parts of these are highly dissected and steepened by the adjacent valleys of Taylor Run, resulting in a heightened potential for slope failures along their edges.

Tertiary-Recent Slope Deposits
Slope deposits with a variety of textures, shapes, and origins are present in the map area. The most common types consist of gravelly and cobbly colluvium in a fine- or medium-grained matrix and can be found in a wide range of landscape positions. Most of these deposits are derived from the eroding edges of upland terraces and are readily recognizable by the telltale gravelly and cobbly surface soil on slopes (figure 5-14).

Figure 5-14. Left: Long colluvial slope between the Chinquapin Village terrace and Four Mile Run at Parkfairfax is characterized by a stony surface. Right: The gravelly character of many slope deposits is often visible around the bases of large trees, where the finer components of the deposit have been washed out by water running down the trunk during rainstorms. Rynex natural area. Photos by Tony Fleming.

Colluvium is defined as sediment that moves down hillsides under the influence of frost heaving and gravity: when the ground freezes, individual particles are lifted ever so slightly outward in a direction perpendicular to the slope; when the ground thaws, the particles settle vertically downward. With each freeze-thaw cycle, the particle is transported a few millimeters downslope. The process tends to mix particles moving downslope from sources above, such as terrace gravels, with particles derived from the material that underlies the slope, such as the Potomac Formation, producing a massive, homogeneous-looking sediment that commonly exhibits a crude, slope-parallel stratification (figure 5-15). Some colluvial motion may also occur by soil creep, caused by internal deformation of the underlying soil under its own weight. Creep chiefly affects clay-rich soils and is most active when soils are wet, such as right after spring thaw and heavy rainstorms.

Figure 5-15. Crude slope-parallel stratification of weathered high-level colluvium, exposed in the head of a ravine in Dora Kelley Park. Photo by Tony Fleming.

Landslide deposits are another common kind of slope deposit in the map area and range from coherent, *rotational slump blocks* to liquefied *debris flows*. They mainly occur on slopes underlain by clayey Potomac Formation units. Landslides and slope stability are the topics of **plate 7**. *Debris fans*, composed of a mixture of sandy to loamy slope wash, colluvium, and landslide debris are also abundant at the bases of some long, steep slopes.

The ages of the slope deposits are difficult to determine precisely, but appear to vary widely. Gravelly colluvium draped over knobs and slopes in the highest parts of the landscape commonly exhibits strong *weathering profiles* and may be nearly as old as the upland terraces, while colluvial fans along the margins of deeply entrenched valleys are clearly much younger. Some large complexes and many smaller bodies of slope deposits have probably experienced prolonged periods of motion; they may have originated as far back as the late Tertiary but have continued moving and accumulating through the Pleistocene and *Holocene*. The slope deposits are divided into four broad categories on **plate 5**, according to their physical properties, mode of origin, size, position in the landscape, and relative age: Quaternary colluvium (Qc); colluvial *fans* (Qcf); Seminary Valley debris fan (Qcf/Kp); and high-level colluvium (Tc).

Colluvium (Qc) of Pleistocene to Recent age is found on virtually every slope in the map area. It typically forms fan-shaped bodies at the bases of slopes, as well as aprons, sheets, and linear "chutes" that fill small rills and hollows. Colluvium typically consists of well-rounded *pebbles*, *cobbles*, and some *boulders* of quartz-rich lithologies identical to those found in the upland terraces. The coarse clasts are set in a loose to firm matrix composed of variable proportions of *sand*, *silt*, and *clay*. Although some of the matrix particles are also derived from the same upland gravels as the coarse clasts, the composition of the matrix on any particular slope also tends to be influenced by the texture of the underlying sediment: colluvium that moves downslope over clayey Potomac Formation sediment, for example, will have a heavier-textured matrix than colluvium that overlies sandy sediment (figure 5-16).

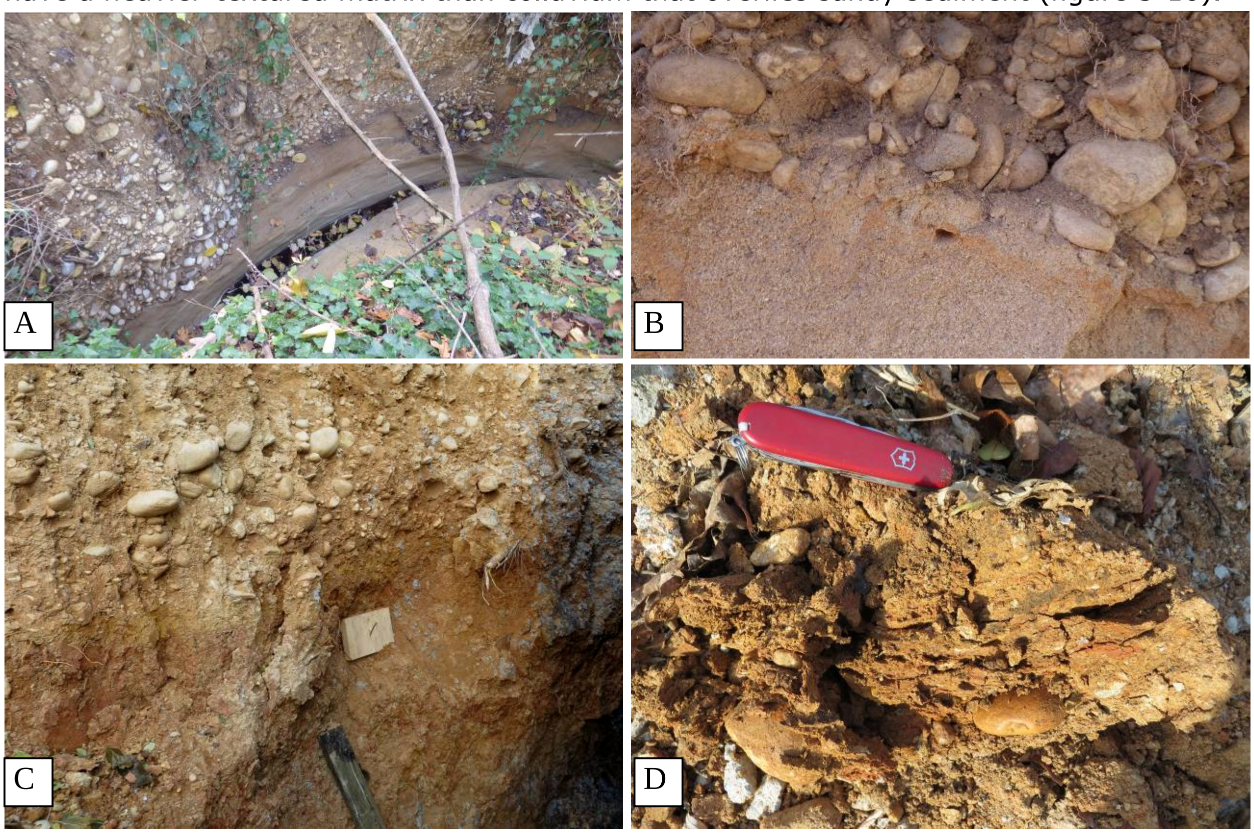

Figure 5-16. Colluvium at Fort Williams Park (A) has incorporated abundant sand from the underlying Cameron Valley sand member of the Potomac Formation, resulting in a sandy matrix (B). Colluvium overlying the Arell clay member below Shooters Hill (C) has a clayey matrix (D). Photos A-B by Rod Simmons, C-D by Tony Fleming.

The thickness of the colluvium is spatially variable, and is greatly influenced by slope shape: the thickest deposits are found in hollows, ravines, toeslopes, and other concave slope positions, while the colluvium is much thinner, and frequently discontinuous, on convex parts of hillsides. Observed thicknesses of mapped bodies are commonly in the range of 3 to

6 feet, but thicknesses approaching, or even exceeding, 10 feet were observed in several favorable exposures along toeslopes. Most bodies of colluvium are relatively well drained and are reasonably stable; however, bodies that overlie clayey Potomac Formation sediments at shallow depth on steep slopes, or that have entrained significant quantities of *expandable clay* from the underlying material, may become unstable and susceptible to slope failures if disturbed. Instability is particularly likely to result from the removal of the toes of bodies through "cut and fill" operations: doing so reduces the lateral strength of the material and changes its internal drainage properties.

Colluvium occurs at many positions in the landscape and probably ranges considerably in age. Some bodies (fig. 5-18) show a moderately well developed soil profile with appreciable clay pickup in the subsoil, suggesting they are at least as old as late Pleistocene, whereas others show only little or no soil horizonation, indicating they have accumulated relatively recently. No particular pattern was observed between the degree of soil development and position in the landscape of this unit (unlike "high-level colluvium", described below).

Colluvial fans (Qcf) composed of a mixture of sediment derived from other formations occupy the toeslopes below the Mount Ida escarpment and adjacent parts of the Four Mile Run Valley where long, steep slopes on the Potomac Formation abut the inboard edge of the Old Town terrace and other stream terraces. The unit comprises a linear belt of overlapping debris fans of relatively small size.

Seminary Valley debris fan (Qcf/Kp): One debris fan is vastly larger than the rest, and is sufficiently distinctive to map as a separate unit, here called the **Seminary Valley debris fan**, or Seminary Valley fan, for short. This feature is larger than some of the upland terrace remnants; it occupies the prominent embayment in the valley wall on the north side of Holmes Run, which extends downstream for a distance of almost two miles between Shirley Highway and Fort Williams Park (figure 5-17). The undulating surface of the embayment slopes some 100-125 feet down to Holmes Run from the base of the massive Hospital escarpment; the southward slope of the fan is frequently interrupted by small hills and low irregular ridges, as well as several almost perfectly level internal surfaces and small bluffs.

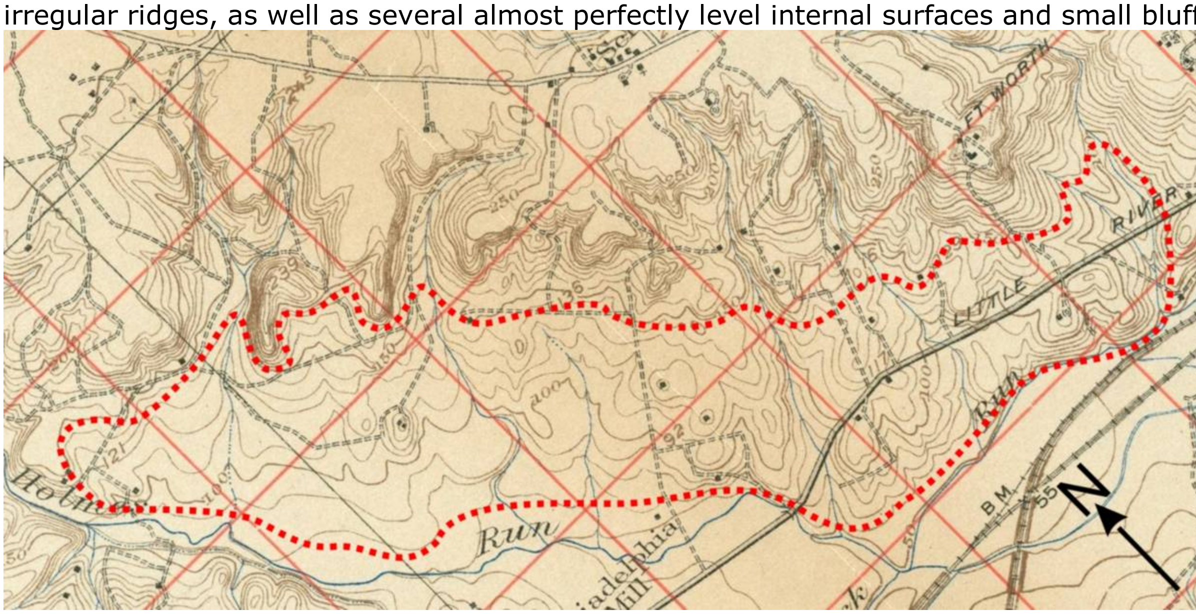

Figure 5-17. The distinctive physiography of the Seminary Valley fan (outlined by the red dotted line) and its relations to the Hospital escarpment and Holmes Run, as seen on this 1917 topographic map, which precedes widespread urbanization.

Previous workers (e.g., Johnston, 1964; Drake and others, 1979; Froelich, 1985) variously mapped this landscape as Potomac Formation, colluvium, Quaternary stream terraces, or some combination. In fact, it is all of these things and more, commingled in a complicated mosaic best described as a large debris fan complex derived from the collapse and retreat of the adjacent escarpment over a long period of geologic time. The Seminary Valley fan coincides closely with what Ward (1894) called the "Cameron Valley sand hills".

At various places, the surface of this landscape consists of *alluvium*, *colluvium*, *slope wash*, mudflows and other landslide debris, as well as sandy sediment of the Potomac Formation. The greatest compositional variability occurs near the top of the fan, where an assortment of materials freshly debouched off the oversteepened slopes of the escarpment has collected. Numerous landslide scars and rotated slump blocks dot the escarpment (one large modern slide was observed during the fieldwork for this study), suggesting that slope failures have played an important role in the retreat of the bluff and in generating a steady supply of debris to the head of the fan. Several steep, high-level ravines also terminate in small *alluvial fans* at the base of the escarpment, and provide another source of debris. The escarpment is capped by coarse gravel of the Seminary terrace, which is being undermined at many places by small, unstable scarps developed on Arell clay. This process generates abundant colluvium, which accumulates in fans along the toe of the scarp and is gradually transported outwards across the surface of the fan by water and gravity.

Figure 5-18. Coarse colluvial fan, one of several that make up the head of the Seminary Valley debris fan. The colluvium was derived primarily from the S terrace and Winkler sand member of the Potomac Formation, and has a sandy texture and a well-developed reddish-brown soil profile. Polk Street below Hospital escarpment. Photo by Rod Simmons.

Collectively, these varied processes result in a texturally heterogeneous assemblage of sediment near the summit of the debris fan. Further downslope, however, much of the debris has been reworked and homogenized by colluvial and alluvial processes as it has migrated down the surface of the fan, producing a relatively uniform sheet of sandy to loamy sediment. The thickness of the debris appears to be highly variable: borings near the summit of the fan suggest it may exceed 25 feet, whereas further down-fan, visual observation of small excavations and soil exposures indicates it ranges from a few inches to a few feet thick at most places.

Although the Seminary Valley fan is essentially one large body of sediment, the upper and lower parts of the fan appear to have experienced somewhat different histories. The steeper upper part of the fan is inferred to overlie a moderately hilly erosion surface developed on the Cameron Valley sand member of the Potomac Formation, which protrudes up through the surface of the fan at places, forming prominent isolated hills and ridges (figure 5-19).

Figure 5-19. One of the sand hills that poke up through the Seminary Valley fan. Soil exposures in these places invariably exhibit a fine-sandy texture and typically lack the abundant pebbles and cobbles that would be expected if these small hills were composed of colluvium or remnants of alluvial terraces. This more fertile soil quality made the sand hills favored places for the establishment of early farms and residences, some of which remain today as historical estates, such as the one pictured. Photo by Tony Fleming.

Such protuberances of the Potomac Formation are sparse in the western two thirds of the fan, but become increasingly numerous by the time the far eastern end is reached. This relation offers important insights into the *paleohydrology* and possible origin of the fan: it seems possible that several ravines that currently debouch from the escarpment above the western part of the fan were once part of an integrated drainage that flowed southward towards Holmes Run. The relatively small streams emanating from the ravines probably converged into one or more master streams in the area where the western part of the fan now is, thereby eroding out a relatively broad basin in the sandy Potomac Formation sediments. At some point, probably during the *Ice Age*, influx of debris from the retreating escarpment simply overwhelmed the capacity of the streams to remove it, resulting in relatively rapid inflation of the fan surface. Once this tipping point was reached, the flow that issued from the ravines simply disappeared into the relatively permeable fan sediment, becoming ground-water recharge, much as it does today, which (along with urbanization) may be why the fan surface seems to lack integrated drainage. The 1917 map in figure 5-17, for example, shows only three *intermittent streams* crossing the surface of the western part of the fan, along with many small, dry valleys. A considerable volume of *ground water* derived from the fan now emerges in many seeps and springs close to Holmes Run.

The gentler lower part of the fan is characterized by several prominent level surfaces, or benches, at different elevations. These are alluvial *terraces* deposited by Holmes Run during the Pleistocene, as it cut down in response to changing base level. At some places, the outer parts of the debris fan have clearly migrated over parts of these terraces, but at others, the fan surface is quite level and gravelly, reflecting reworking by running water and deposition of stream alluvium by Holmes Run. One conclusion is that the fan was particularly active during the late Pleistocene, perhaps as a result of increased amounts of debris being generated by a cold and wet Ice Age climate, and expanded outward into Holmes Run, pushing the stream southward into its present configuration.

The age of the Seminary Valley fan depends to an extent on the ages of the upland terraces, and particularly the adjacent Seminary terrace and Hospital escarpment, whose erosion and retreat have furnished most of the debris that makes up the fan. It is not known how long an escarpment has existed at this location. Theoretically, one could have formed shortly after deposition of the Seminary terrace, when the river cut down to the level of the Dowden and(or) Chinquapin Village terraces, but evidence that might indicate whether this occurred here was stripped away when Holmes Run Valley was cut. The head of the fan is typically at an elevation of around 150 feet, similar to the Beverley Hills terrace. The present form of the fan could not have been established until local streams, including Holmes Run, cut down below this level. Thus, the inception of the fan post dates the Beverley Hills terrace. Retreat of the escarpment probably accelerated greatly with the onset of the Pleistocene and rapid downcutting of Holmes Run Valley. A wetter Ice Age climate with more freeze-thaw cycles may have also helped to oversteepen the slope of the escarpment and trigger slope failures, increasing the volume of sediment transported onto the fan.

At the other end of the fan, the toe appears to terminate on an eroded terrace, remnants of which can be traced almost continuously down Holmes and Cameron Runs into the main part of the Old Town terrace, which is late Pleistocene age. There is no evidence, however, that the fan extends out over any terraces below the Old Town, or onto the modern floodplain. Based on these relations, the fan was clearly still being deposited during and after the Old Town terrace formed, but deposition appears to have ceased by the time the lower terraces (latest Pleistocene-Holocene age) had formed. Taken together, the weight of the evidence suggests that most of the Seminary Valley fan formed between the early Pleistocene and the early Holocene. The surface of the fan is not static, however, and the same kinds of processes that operated in the Pleistocene continue to operate today, though presumably at a significantly slower rate. This is especially true of the upper part of the fan, which continues to receive landslide debris and colluvium shed from the escarpment.

High-level colluvium (Tc) is distinguished from the previous units chiefly by its much higher position in the landscape and in most cases by stronger soil development. It forms sheets, fans, and lag gravel along the edges of the four large upland terraces and in the heads of high-level ravines. It is very common along the escarpments separating these terraces and is deeply weathered, typically forming the upper part of deep, brightly colored *ultisols* that extend down into the underlying Potomac Formation (figure 5-18).

Figure 5-18. Examples of high-level colluvium. A) Deep red brown colluvium overlying equally weathered fine sandy clay of the Potomac Formation on the Jefferson Park escarpment. The knife lies just below the contact; B) Reddish colluvium with faint slope-parallel bedding overlying sandy Potomac Formation strata, Fairfax County; C) Orange brown colluvium overlying weathered bedrock below Dowden terrace, Fairfax County. Weathering profiles in all three locations are, for all intensive purposes, continuous across the colluvium and underlying strata. Photos A and C by Tony Fleming; B by Rod Simmons.

This unit consists chiefly of iron-stained pebbles and cobbles identical to those found in the upland terraces. The pebbles are embedded in a firm to stiff, fine- to medium-grained matrix composed of variable proportions of sand, silt, and clay. As with the previous units, the particular composition of the matrix on any given hillside tends to reflect the texture of the underlying sediment, but the relationship is less pronounced because of the stronger soil development and attendant increase in clay content. The greatest thickness observed in outcrop is about 10 feet, in the head of a ravine below Dowden terrace in Chambliss Park, but the unit may locally be as much as 15 or 20 feet thick based on some geotechnical borings. Most bodies of high-level colluvium are relatively well drained and stable, but some instability is possible where the colluvium overlies clayey Potomac Formation sediments at shallow depth on or adjacent to steep slopes—a common setting of this unit since it tends to occur along the eroding edges of the upland terraces, above major ravines and drainages. The age spectrum of this unit is broadly comparable to that of the upland terraces: colluviation is believed to have occurred mainly in the late Tertiary, though some movement clearly continues today on some of the mapped bodies. A few bodies of colluvium mapped on nearly level, high-elevation spur ridges and summits may simply be lag gravel left over from the weathering of the adjacent upland terrace; in such cases, the material has moved little from where it originated.

Pleistocene-Recent Stream Deposits

Alluvial deposits of *Quaternary* age occur in a variety of landscape positions, ranging in elevation from just below the upland terraces to the tidal estuaries of modern streams. Their distribution records the periodic incision of the major valleys during the Pleistocene: during periods of maximum ice cover, sea level was depressed by as much as several hundred feet, causing local streams to vigorously incise their valleys. In contrast, during prolonged warm interglacial periods, sea level returned to levels comparable to today's; streams eventually stabilized during these periods and deposited terraces. This cycle repeated several times during the *Pleistocene*.

Several kinds of alluvial deposits are mapped on **plate 5** based on their composition, form, and position in the landscape relative to other landforms. The bottoms of the major valleys are flanked by an array of terraces and other deposits associated with the modern streams. Coarse sand and gravel is the predominant component of most of these, but fine-grained sediments are also important at places, for example, in swamp deposits and *overbank deposits* that cap some terraces. By virtue of their close relationship to modern streams, the ages of most of these deposits can be better constrained than the upland terraces, but are still somewhat speculative, given the absence of radiometric dates or fossil evidence from within the city. As discussed below, most of the lowland alluvial deposits are probably *Holocene* in age, but some terraces and alluvial fans are clearly older.

High-level terrace remnants (Qtu) consist of isolated, gravelly patches and somewhat larger terraces found at a wide range of elevations and positions along the valley walls of most of the major drainages, especially Cameron and Holmes Runs. Although some of these still preserve a relatively convincing, level, terrace-like surface, many are small scraps of moderately sloping gravel that have been strongly dissected, and some may simply represent *lag gravel* or colluvium.

The details of these terraces are poorly known. No outcrops with a complete *soil profile* were observed during this study, and few geotechnical borings penetrate them, so information is derived largely from scattered small surface exposures (figure 5-19), soil texture, and their geomorphic settings.

The high-level terraces probably represent sediment reworked from the upland terraces in response to continued downcutting of the Potomac River and tributaries during the Pleistocene. Most appear to consist of weathered sand and gravel dominated by the same siliceous *lithologies*—quartzite, vein quartz, sandstone—and thus indistinguishable from the gravel in colluvium and the upland terraces. Brightly colored weathering colors were observed in 2 or 3 places. Based on the map pattern, the apparent thickness of most of these terraces is less than 10 feet, though the largest ones could be thicker. Functionally, these bodies act much like gently-sloping colluvium in the landscape: they are well drained and promote ground-water recharge, and they tend to create a dry, acidic soil environment.

Some of these terrace remnants could date back to the early or mid Pleistocene, and some may even be late Tertiary. They occur at higher landscape positions than the Old Town terrace, and are thus older. Most are at lower elevations than the Beverley Hills terrace, but some units mapped on the sides of Holmes Run Valley are higher, suggesting a pre-Pleistocene age. Assigning an age is highly problematic, however, not only for the reasons elucidated elsewhere in this explanation, but also because, unlike the upland terraces or Old Town terrace, they are small and widely scattered and do not form readily identifiable geomorphic surfaces traceable over any great distance.

Figure 5-19. Small, slumped bank exposing gravelly sediment underlying a high-level terrace-like surface near Taney Avenue, one of several high-level terrace remnants mapped in the Dalecrest neighborhood. Photo by Tony Fleming.

Old Town terrace (Qto, Qto-c) is one of the largest and most readily recognizable landforms in the city. It occupies an area larger than all the other Pleistocene-Recent stream deposits combined and nearly as large as the expansive Dowden terrace. The main part of the terrace underlies all of Del Ray, Potomac Yards, and Old Town, where it forms a largely undissected plain whose surface elevation is most commonly in the range of 30 to 45 feet. A set of prominent terraces that is clearly graded to the main Old Town terrace can be traced almost continuously for several miles up the Cameron Valley. Somewhat less extensive terraces in the lowermost part of Four Mile Run Valley are also thought to correlate with the Old Town terrace, based on their comparable elevations and characteristics. A set of narrow terraces that flank Timber Branch also are graded to the main Old Town terrace and are thus interpreted to be part of the same terrace system.

The surface of the Old Town terrace has been extensively modified by some 300 years of European habitation; consequently, fill and disturbed land are ubiquitous. The near-surface geology is relatively well known, however, because it is penetrated by hundreds of geotechnical borings and more than 20 old water wells scattered across the terrace from the mouth of Cameron Run northward to Glebe Road and Four Mile Run. Terrace sediments also crop out at several places in the bluffs along the river and in the Cameron and Backlick Valleys. Much of the upper 30-50 feet of the main terrace is composed of medium to coarse, golden-colored ***sand*** (figure 5-20), especially in the southern half; further north, ***gravel*** is somewhat more common in shallow borings and in the bluffs along the river, though sand still dominates in this near-surface interval. In contrast, the part of the terrace in the Cameron Valley is mainly gravel.

Figure 5-20. A) Large parts of the surface of the main terrace in Old Town are underlain by tens of feet of medium-coarse sand similar to this bluff exposure on S. Payton St. near the wastewater treatment plant; B) Brown-gray silt loam commonly caps the sand at elevations above about 30-35 feet, with a thin organic layer (dark layer in photo) locally present along the interface. Bethel Cemetery; C) In Del Ray and North Old Town, the silt cap is commonly 10 or more feet thick, as in this railroad cut near Bashford Street in north Old Town; D) The Old Town terrace also forms expansive remnants in the Cameron Valley, one of the largest being at Brenman Park. Photos A and D by Tony Fleming, B and C by Rod Simmons.

Most of the terrace surface in Del Ray, and nearly all of it above 30-35 feet elevation elsewhere, is underlain by *silt* with minor interbedded sands. The silt cap appears to be thickest and most continuous to the north, where thicknesses on the order of 10-20 feet are commonly reported in borings. A thin organic horizon is locally present at the interface between the silt and the underlying sand (figure 5-20B).

The particle-size distribution and clay mineralogy of two representative samples from the Old Town terrace are presented below in tables 5-4 and 5-5, one of sand (map unit Qto) and another of silt (Qto-c). The particle size distributions are also depicted in the textural triangle in figure 5-6. Not surprisingly, the sand contains significantly less silt and clay than the upland terraces, reflecting much less weathering of the younger Old Town terrace surface. The sand fraction in this sample consists mostly of medium sand. The silt unit contains sufficient fine sand and clay to make it silt loam. Texturally, it is very similar to the silt loam caps of the upland terraces, though much less weathered.

Exposure No.	Terrace Name	Map Unit	Description	% Gravel	% Sand	% Silt	% Clay
302	Old Town	Qto	Yellow-brown medium sand	-	77	13	10
303	Old Town	Qto-c	Gray-brown mottled silt	-	16	65	19

Table 5-4. Particle size distribution of two samples from the Old Town terrace.

Illite is the dominant *clay* mineral in both samples. The proportion of illite is significantly greater than in all other samples analyzed for this study, including both the Potomac Formation and the upland terraces. This suggests that the Old Town terrace may have had a different, or additional source, of sediment, at least in the upper part of the terrace where the samples were taken. The relatively low percentages of both kaolinite and chlorite are consistent with a much shorter weathering history. Neither sample contains appreciable *expandable lattice clay minerals*. This result is consistent with geotechnical borings in the Old Town terrace, most of which describe shallow silty clay bodies as being composed of "*lean clay*" and non-elastic silt.

Exposure No.	Terrace Name	Map Unit	Expandable Clays	Illite	Kaolinite	Chlorite	Vermiculite Index
302	Old Town (sand)	Qto	5%	71%	12%	12%	-17
303	Old Town (silt)	Qto-c	8%	54%	15%	24%	-8

Table 5-5. Clay mineralogy of two samples from the Old Town terrace.

The thickness of the Old Town terrace is substantial and increases from west to east. Beneath Old Town, the thickness of the terrace is almost everywhere greater than 50 feet, and it approaches 125 feet over what is inferred to be the *thalweg* of the late Pleistocene Potomac River, roughly coincident with the modern waterfront. Closer to the Mt. Ida escarpment, however, the terrace is commonly between 25 and 50 feet thick.

The subsurface geology of the Old Town terrace was not investigated in detail for this atlas, but several general observations can be made. The most important of these is that the terrace does not appear to represent one major depositional sequence or event. Instead, in a number of geotechnical borings, the terrace consists of a stack of two or more, broadly upward-fining sedimentary sequences. The lower half or so of each sequence consists chiefly of interbedded gravel and(or) sand, which grades up through interbedded pebbly sand and muddy sand into interbedded silt, clay, and fine sand at the top of the sequence. Some of the silty clay bodies are locally as much as 20-30 feet thick, but they are generally thinner and less continuous than the granular units, and are often cut out, resulting in thick composite sand and gravel sections. These thick granular sections are typically saturated and represent a potentially major source of ground water that merits further investigation.

Another interesting observation is that the individual sedimentary sequences within the terrace are commonly separated by prominent organic horizons, especially where silty clay units are present at the top of the sequences. Some geotechnical borings report wood, "*lignite*", and other plant material from these horizons. These organic zones probably represent *paleosols* that formed during prolonged periods of non-deposition. Much more work is needed to make sense of the history and distribution of the several depositional sequences and intervening organic horizons that make up the terrace, but some geotechnical sites offer a tantalizing glimpse of the possibilities (figure 5-21).

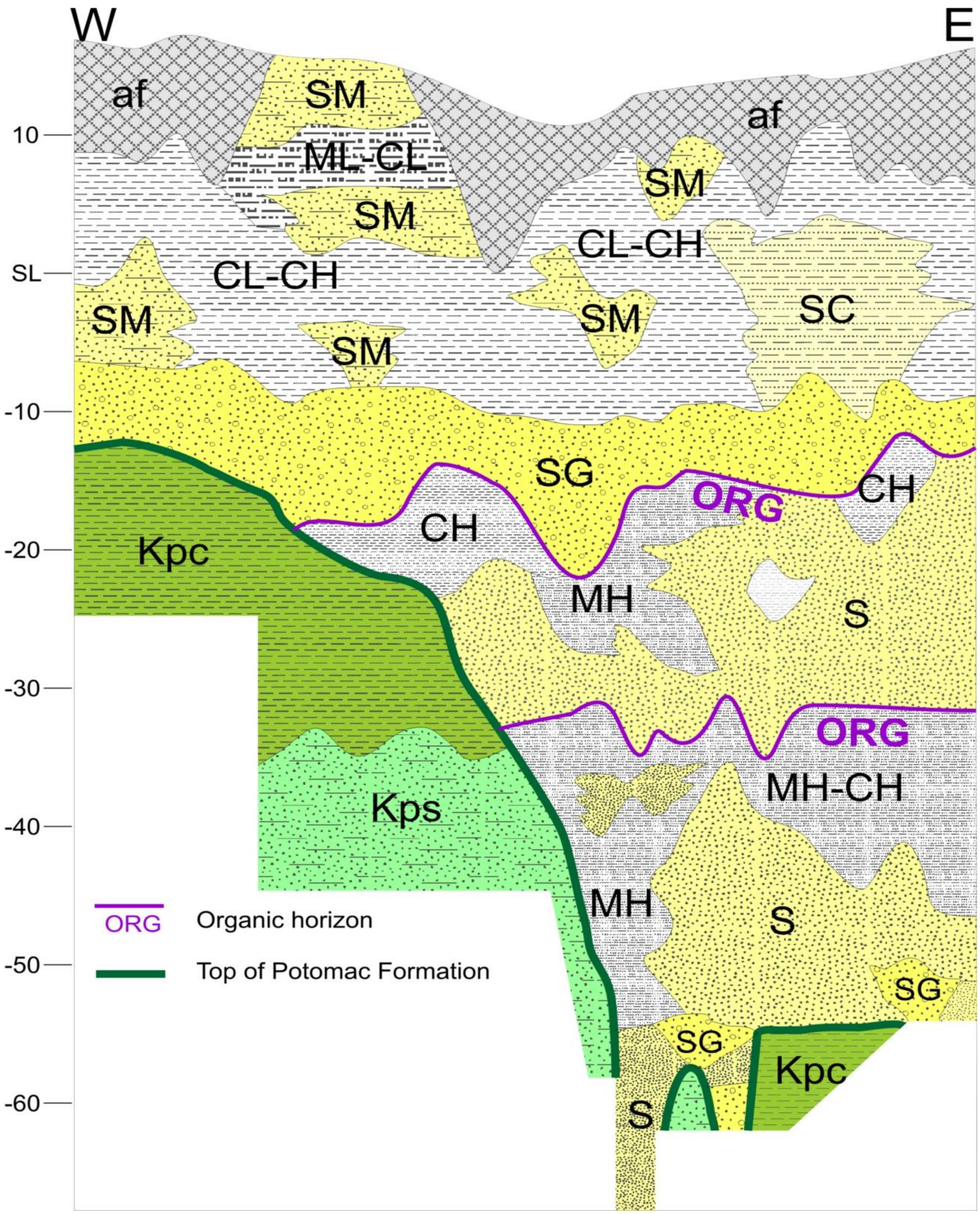

Figure 5-21. Subsurface interpretation of geotechnical boring site 117 in the northern part of the Old Town terrace (see ***plate 1*** *for location). The site is about 1,200 feet wide, with dozens of deep borings. Units are: Kps, Kpc-sand and clay of the Potomac Formation; SG-sand and gravel; S-medium-coarse sand; SM-silty sand; SC-clayey sand; CH, MH-plastic clay and silt; CL, ML-non-plastic clay and silt; af-artificial fill. The sharp east-facing escarpment on the top of the Potomac Formation appears to bound the thalweg of the late Pleistocene Potomac River.*

Drake and others (1979) regarded the age of the Old Town terrace as *Sangamon*, or about 140,000 to 70,000 years old. The Old Town terrace is probably correlative with a similar terrace that underlies parts of the mall and adjacent places in Washington, D.C. (Fleming and others, 1994), the upper part of which was correlated with fossiliferous units on the Coastal Plain about 70,000 years old (late Sangamon). The Old Town terrace is almost certainly correlative, at least in part, with late Pleistocene *backswamp* deposits of the Potomac River at Hybla Valley. The upper 100 feet or so of the Hybla Valley deposits is now established to be between 150,000 and 15,000 years old (Litwin and others, 2013). Much more work is needed, however, to establish how and which of the sequences within the Old Town terrace correlate with the Hybla Valley deposits, but the Hybla Valley ages nevertheless help to broadly bracket the deposition of the Old Town terrace. It is entirely possible that the deepest sequences at the base of the terrace may be older still, a supposition supported by the apparent presence of multiple paleosols within the terrace sequence, and the likelihood that *alluviation* of the terrace occurred in discrete episodes punctuated by periods of exposure, vegetation growth, and soil formation.

Late Pleistocene-Holocene Stream Terraces (Qt): Low-lying stream terraces occur in all of the major valleys. The terraces border the modern channels of the streams. The lowest of these terraces broadly correspond to the modern *floodplain*, and are periodically inundated by floods at intervals ranging from every few years to perhaps as long as 100 years. In exceptional cases, the terrace surfaces may stand as much as 25 feet above modern streams. This situation is found mainly along Cameron and Backlick Runs, where multiple sets of terraces are present.

Figure 5-22. A typical low-lying Holocene stream terrace. The street occupies the terrace surface, which is separated from the modern floodplain on the far right by a low scarp less than 5 feet high along and to the right of the trail. Holmes Run Park, Brookvalley. Photo by Tony Fleming.

The terraces are composed of *alluvium* of mainly *Holocene* age. The thickness of the alluvium ranges up to 25 feet, but is mostly much less. The sedimentary architecture of the terraces is similar to modern alluvium, consisting of a stack of coarse-grained, accreted *point bar* deposits overlain by and locally interleaved with finer-grained *overbank sediments*. Scattered small exposures and borehole data indicate that the alluvium in most of these terraces consists principally of coarse cobble gravel below, grading up into finer sand and *mud* near the terrace surfaces. The higher portions of the terraces furthest from the modern streams tend to have more fine-grained sediment in the section. Some of the larger terraces exhibit multiple fining-upwards sequences, complex cut-and-fill structures, and shallow, meandering swales, all produced by erosion and deposition during different flood events and migration of the stream channel across the former floodplain. All of these terraces are lower in the landscape than the Old Town terrace, hence they are inferred to range from latest *Wisconsin* to Holocene in age, with most being the latter.

Alluvial fans (Qaf): Small alluvial *fans* were mapped at the mouths of several ravines, where they debouch onto relatively level terraces and floodplains. All of the fans occupy positions directly in front of steep Pleistocene age escarpments and valley walls where colluvial processes and slope deposits are prominent features; the latter have undoubtedly contributed to the growth of the fans, which might be better called "alluvial-colluvial fans". Most of the fans are heavily urbanized with no major exposures; sparse geotechnical borings and a few small exposures of the surface soil indicate that the composition of the fans is varied, and consists mainly of gravelly sand and *loam*-textured sediment.

Figure 5-23. Alluvial-colluvial fan at Barcroft Park in southern Arlington County, illustrating the classic fan-shaped profile radiating from a prominent apex at the summit, directly in front of the contributing ravine. Photo by Tony Fleming.

Alluvial fans were mapped chiefly on the basis of their classic, fan-shaped landforms (figure 5-23) that radiate from the mouths of steep-sided ravines. The thicknesses of the alluvial fans shown on the map are not well known but are probably similar to the one near Van Dorn Street and Edsall Road, which appears to range from 5 to 20 feet thick in geotechnical borings. The morphologies of the fan surfaces and their relationships to the lowlands they debouch into suggest the fans are of different ages. Some fan surfaces slope smoothly into the lowlands, grading into Holocene alluvium and stream terraces, indicating they are relatively young features whose deposition has been ongoing since the terraces were deposited. Other fans are graded to remnants of the Old Town terrace, suggesting they may be late Wisconsin or older. The fans in the southwestern part of the city are of this type. Still others have steep fronts that appear to have been incised by modern streams, suggesting they are not in equilibrium with the elevations of modern valley bottoms, and may be significantly older. The fan on the south side of Four Mile Run at Shirley Highway is one example.

<u>Recent swamp deposits</u> consist chiefly of silt and clay deposited in broad, slack swales and in backwaters along the major drainages. Some contain appreciable organic matter and are very dark in color. Natural exposures of swamp deposits occur for several hundred feet along an unnamed tributary of Cameron Run in Tarleton Park between Wheeler and Vermont Streets, but otherwise, exposures are lacking due to the extremely flat landscape characteristic of these areas. Most of these deposits consist of clayey silt (figure 5-24). A faint slabbiness or fissility, along with layers of organics that presumably represent soil horizons, are the only suggestions of stratification; otherwise the deposits appear fairly massive.

The thickness of these deposits is not well known, but it is probably not great in most places, perhaps 5 feet or less, because the unit typically occupies relatively shallow swales. On the other hand, it could be more substantial in some of the larger backwater swamps along Four Mile and Cameron Runs, and in the much larger swale complex known as the Del Ray swamp on the inner part of the Old Town terrace.

Figure 5-24. Swamp deposits exposed in an excavation in Del Ray. The face on the left shows a sharp color change from light brown to gray about 30 inches below the surface, marking the elevation of the water table. The darker brown material in the upper 12-18 inches is artificial fill. These deposits are very poorly permeable and are typically gleyed and mottled (right). Photos by Rod Simmons.

The swamp deposits are closely associated with both the Old Town terrace and younger terraces. Extensive areas of these deposits occupy swales on the main part of the Old Town terrace and result in a very poorly drained landscape that still exhibits a large number of old, relict swamp trees, such as pin oak, green ash, sweet gum, and silver maple. Soils formed in these deposits are gray, waterlogged <u>*entisols*</u> with very poor permeability. The water table typically lies within 24 inches of the surface in undrained areas.

Figure 5-25. View looking east across a low alluvial terrace and up a swale underlain by swamp deposits at Tarleton Park. The swale follows the base of the Old Town terrace, just to the left of the photo. Holmes Run is directly behind the photographer, and deposition of alluvium probably helped to impound the swale, creating a swamp. Photo by Tony Fleming.

Some of these deposits occur in small to medium-sized *backwaters* between the terraces along drainages. Good examples occur along the lowermost reaches of Four Mile Run, as well as the aforementioned site in Tarleton Park (figure 5-25). In some of these places, the mouths of these backwater swales are dammed by alluvium, either as *natural levees* or small terraces, or may have been in the past, producing backwater swamps. The map very probably underrepresents the abundance of swamp deposits in the landscape: extensive parts of Cameron, Holmes, and Four Mile Run Valleys have been greatly altered by stream channelization and artificial fill. Many of the altered areas appear to have consisted of swamps, judging by a comparison to old topographic and historical maps of the area.

Recent Estuarine Deposits (Qe): Extensive freshwater *tidal marshes* existed as recently as the early 1900's in the lowermost parts of Four Mile Run and Hunting Creek and adjacent parts of the Potomac River (figure 5-26). Nearly all of them are now filled; the only example remaining in the city is a small remnant preserved in Four Mile Run Park east of Arlandria. Details about the deposits in the estuaries are poorly known because of the extensive historical alterations. A small number of geotechnical borings that penetrate the former estuaries indicate they are underlain mainly by silt and clay interbedded with thin layers of *peat* and *muck* and small, lenticular bodies of sand and minor gravel. Roughly the upper 20 feet of the profile shown in figure 5-21 is an example. Sand and gravel bodies appear to be more common in the upstream portions of the estuaries, presumably deposited during floods where the channels of Four Mile and Cameron Runs debouched into the estuaries.

Figure 5-26. Four Mile Run estuary circa 1899, showing a tidal marsh and mud flat exposed at low tide. Photo credit: G.S. Miller, courtesy of the US Herbarium, Washington, D.C.

Recent alluvium (Qa) occurs in the *floodways* of every natural stream in the map area, and consists of laterally and vertically variable deposits of boulders, cobbles, gravel, sand, and mud. In the larger streams, the sand-sized fraction commonly contains abundant mica derived from weathered bedrock higher in these watersheds. This map unit also includes a few very low-lying stream terraces of probable *Recent* age (figure 5-27). The thickness of the alluvium ranges widely and is greatest along the master drainages, and much less in the smaller ravines. The largest thickness observed in outcrop is about 10 feet, along Cameron Run, but the bottom of the unit was not exposed there. In the records of wells and geotechnical borings, it is often difficult to differentiate recent alluvium from older alluvium in terraces; the two are often closely associated, for example, the channels of many modern streams are often cut into older alluvial terraces, with the channel being floored by older deposits.

Figure 5-27. Coarse gravelly alluvium occupies the floodway of Holmes Run in the foreground of the left photo. Behind it is a low terrace floored by finer-grained overbank deposits left by major floods. The right photo, also from Holmes Run, illustrates a point bar and cut bank, which are the fundamental architectural elements of alluvium and stream channels. As the creek slowly expands its valley by cutting into the bedrock on the right bank, the leading edge of the point bar on the left expands in the same direction by depositing gravel, while the accretion of finer overbank sediment further away from the stream channel causes the top of the point bar to build upwards. Photos by Tony Fleming

A variety of fluvial features are associated with alluvial bottomlands, the most common being *point bars*, *natural levees*, and small sloughs and *oxbows*, all of which typically occur together. These features are indicated on the map where they are particularly prominent or of high quality from an ecological standpoint. The best remaining example of a high-quality natural levee – oxbow system within the city limits occurs on the north side of Holmes Run just downstream of North Chambliss Street. This system is developed on a large, well-established point bar and is virtually pristine. It experiences regular natural disturbances from high-energy floods, leading to a variety of unique ecological habitats concentrated in a small area. Similar places were undoubtedly common at one time along many of the larger drainages, but nearly all of these streams are severely altered by urbanization, channelization, and excessive storm-water inputs.

Figure 5-28. Left: Alluvium, and overbank deposits in particular, tend to produce rich, base-saturated soil because of the regular, annual deposition of fresh sediment on the floodplain surface. Right: Rich soil on a remnant point bar at Ward's Woods (Cameron Run Regional Park), now hydraulically isolated by the channelization of Cameron Run, still supports a biologically diverse natural community with several unique species. Photos by Tony Fleming.

Modern Stream Morphology and Hydrologic Disturbance: At places along all of the major drainages, as well as in many of the smaller ones, the modern streams flow in artificial channels created for flood control or to make way for urban development. These artificial channels seldom follow the original, pre-settlement courses of the streams, and sometimes deviate dramatically from them. This is particularly true of Cameron Run, which has been radically altered by filling and channelization. In most parts of this valley, therefore, the distribution of map units, such as Recent alluvium and some stream terraces, in no way corresponds to the present location of the stream. The original, presettlement locations of Cameron and Four Mile Runs shown on plate 5 were determined from maps that predate major alterations, including several historical maps (some available in the Alexandria Public Library, and others in Stephenson, 1981) and the 1917 USGS Washington topographic map, supplemented by field observations of bottomland geomorphology (figure 5-29).

Figure 5-29. Left-A rare, only partially filled remnant of the original channel of Cameron Run. Right-Cameron Run today is confined to an unnaturally straight, artificial channel lined with rip rap. Photos by Tony Fleming, Cameron Run Regional Park and vicinity.

References

Bleuer, N.K. 1991, The Lafayette Bedrock Valley System of Indiana-Concept, form, and fill stratigraphy, *in* Melhorn, W.N. and Kempton, J.P., eds., Geology and hydrology of the Teays-Mahomet Bedrock Valley System: Boulder, Colorado, Geological Society of America Special Paper 258, p. 51-77. http://specialpapers.gsapubs.org/content/258

Darton, N.H., 1947, Sedimentary formations of Washington, D.C. and vicinity: U.S. Geological Survey map, scale 1:31,680.

Darton, N.H., 1950, Configuration of the bedrock surface of the District of Columbia and vicinity: U.S. Geological Survey Professional Paper 217, 42 p. plus 4 plates. http://pubs.er.usgs.gov/publication/pp217

Drake, A.A., Jr., and Froelich, A.J., 1986, Geologic Map of the Annandale Quadrangle, Fairfax County, Virginia: U.S. Geological Survey Geologic Quadrangle Map GQ-1601, scale 1:24,000. http://pubs.er.usgs.gov/publication/gq1601

Drake, A.A., Jr., and Froelich, A.J., 1997, Geologic Map of the Falls Church Quadrangle, Fairfax and Arlington Counties and the City of Falls Church, Virginia: U.S. Geological Survey Geologic Quadrangle Map GQ-1734, scale 1:24,000. http://pubs.er.usgs.gov/publication/gq1734

Drake, A.A., Jr., Nelson, A.E., Force, L.M., Froelich, A.J., and Lyttle, P.T., 1979, Preliminary Geologic Map of Fairfax County, Virginia: U.S. Geological Survey Open-File Report 79-398, scale 1:48,000. http://pubs.er.usgs.gov/publication/ofr79398

Fleming, A.H., and Drake, A.A., Jr., 1998, Structure, age, and tectonic setting of a multiply-reactivated shear zone in the Piedmont in Washington, D.C., and vicinity: Southeastern Geology, v. 37 (3), p. 115-140.

Fleming, A.H., Drake, A.A., Jr., and McCartan, L., 1994, Geologic Map of the Washington West Quadrangle, District of Columbia, Montgomery and Prince Georges Counties, Maryland, and Arlington and Fairfax Counties, Virginia: U.S. Geological Survey Geologic Quadrangle Map GQ-1748, scale 1:24,000. http://ngmdb.usgs.gov/Prodesc/proddesc_277.htm

Force, L.M., 1975, Preliminary geologic map of the Coastal Plain of Fairfax County, Virginia: U.S. Geological Survey Open-File Report 75-415, 2 plates, scale 1:48,000.

Froelich, A.J., 1985, Folio of geologic and hydrologic maps for land-use planning in the Coastal Plain of Fairfax County, Virginia, and vicinity: U.S. Geological Survey Miscellaneous Investigations Series Map (IMAP) I-1423. Scale 1:100,000.
http://pubs.er.usgs.gov/publication/i1423

Hallberg, G., 1986, Pre-Wisconsin glacial stratigraphy of the central plains regions of Iowa, Nebraska, Kansas, and Missouri, *in* Sibrava, V., Bower, G.Q., and Richmond, G.M., eds., Quaternary glaciations in the northern hemisphere: Quaternary Science Reviews, v.5, p. 11-15. http://www.sciencedirect.com/science/journal/02773791/5

Johnston, P.M., 1964, Geology and ground-water resources of Washington, D.C. and vicinity: U.S. Geological Survey Water Supply Paper 1776, 98 p.
http://pubs.usgs.gov/wsp/1776/report.pdf

Langer, W.H., 1978, Surface materials map of Fairfax County, Virginia: U.S. Geological Survey Open-File Report 78-78, 9 p., 1 plate, scale 1:48,000.

Litwin, R.J., Smoot, J.P., Pavich, M.J., Markewich, H.W., Brook, G., and Durika, N.J., 2013, 100,000-year-long terrestrial record of millennial-scale linkage between eastern North American mid-latitude paleovegetation shifts and Greenland ice-core oxygen isotope trends: Quaternary Research, v. 80, p. 291-315.
http://www.sciencedirect.com/science/article/pii/S0033589413000513

McCartan, Lucy, 1989a, Geologic map of Charles County, Maryland: Maryland Geological Survey, scale 1:62,500.
http://www.mgs.md.gov/output/maps/countygeo/Charles/CHGEO2003_1_pg1_S83.pdf

McCartan, Lucy, 1989b, Atlantic Coastal Plain sedimentation and basement tectonics southeast of Washington, D.C.: American Geophysical Union, 28th International Geological Congress, field trip guidebook T214, Washington, D.C., 25 p.
http://onlinelibrary.wiley.com/book/10.1029/FT214

Mixon, R.B., and Newell, W.L., 1977, Stafford Fault system: structures documenting Cretaceous and Tertiary deformation along the Fall Line in northeastern Virginia: Geology, v. 5, p. 437-440. http://geology.gsapubs.org/content/5/7.toc

Naeser, N., Naeser, C., Southworth, S., Morgan, B., and Schultz, A., 2004, Paleozoic to recent tectonic and denudation history of rocks in the Blue Ridge province, central and southern Appalachians—evidence from fission-track thermochronology: Geological Society of America Abstracts with Program, v. 36, no.2, p. 114. https://gsa.confex.com/gsa/2004NE/finalprogram/abstract_69646.htm

Southworth, S., Drake, A.A., Jr., Brezinski, D., Wintsch, R., Kunk, M., Aleinikoff, J., Naeser, C., and Naeser, N., 2006, Central Appalachian Piedmont and Blue Ridge tectonic transect, Potomac River corridor, *in* Pazzaglia, F.J., ed., Excursions in geology and history: field trips in the middle Atlantic states: Geological Society of America Field Guide 8, p. 135-167. http://fieldguides.gsapubs.org/content/8

Stephenson, R.W., 1981, The cartography of northern Virginia—1608 to 1915: Fairfax County, VA Office of Comprehensive Planning, History and Archaeology section, 145 p.

U.S. Geological Survey, 1917, Washington and vicinity, scale 1:31,680

Ward, L.F., 1894, The Potomac Formation: U.S. Geological Survey 15th Annual Report, 1893-1894, p. 313-397. http://pubs.er.usgs.gov/publication/ar15

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