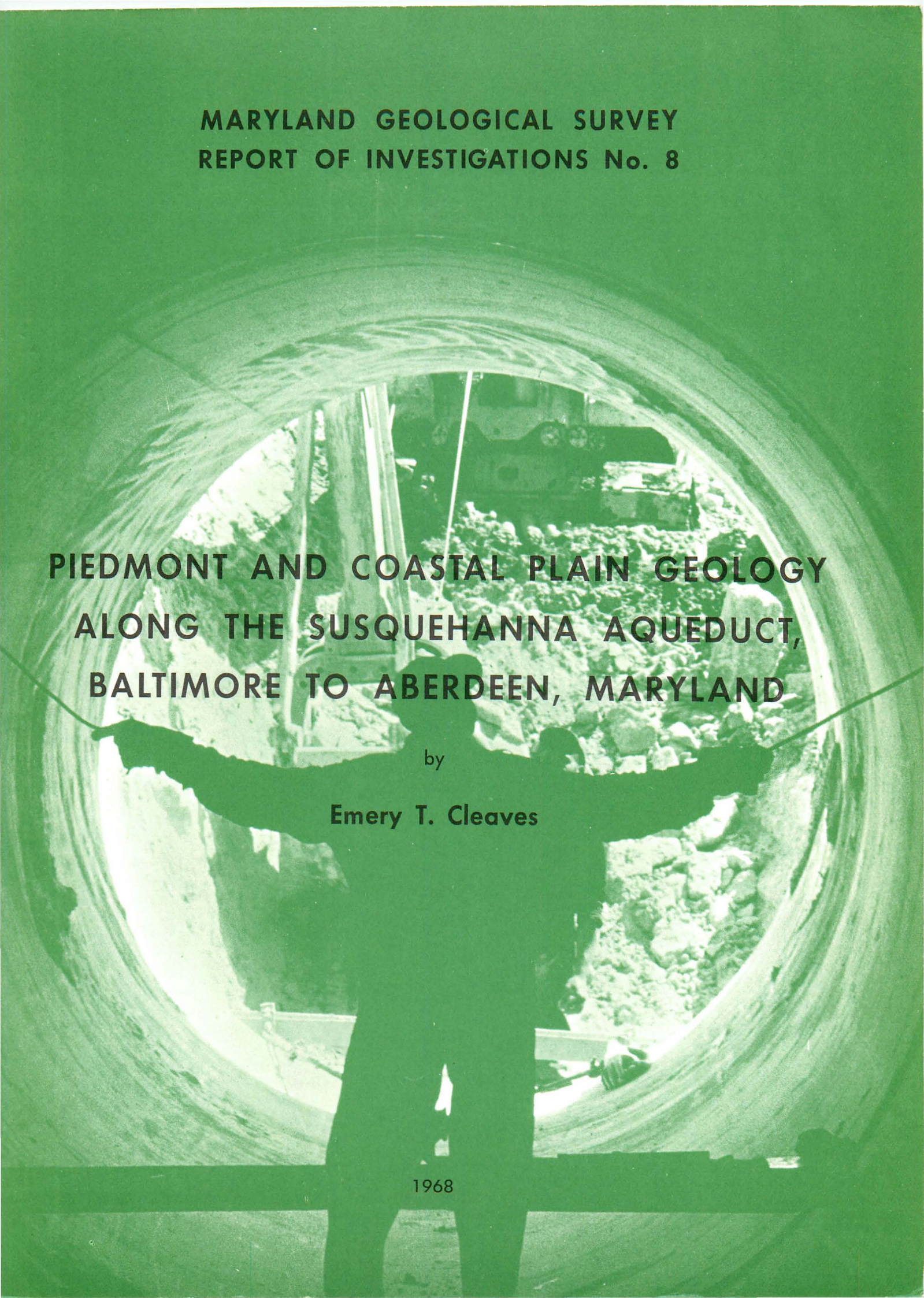
MARYLAND GEOLOGICAL SURVEY
REPORT OF INVESTIGATIONS No. 8



PIEDMONT AND COASTAL PLAIN GEOLOGY ALONG THE SUSQUEHANNA AQUEDUCT, BALTIMORE TO ABERDEEN, MARYLAND

by

Emery T. Cleaves

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Kenneth N. Weaver, *Director*

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PIEDMONT AND COASTAL PLAIN GEOLOGY ALONG SUSQUEHANNA AQUEDUCT, BALTIMORE TO ABERDEEN, MARYLAND

by

EMERY T. CLEAVES

Abstract

The geology of a twenty-two mile section of the Susquehanna Aqueduct was mapped from Baltimore to Aberdeen, Maryland. The trench for this water supply project crosses sediments of Lower Cretaceous (Potomac Group) and Quaternary Age and crystalline rocks upon which residual deposits (saprolite) have formed by weathering.

The crystalline rock is mantled by saprolite, a residual deposit formed by chemical weathering. Saprolite is divided into two zones, structured and massive. Structured saprolite retains structures and textures present in the parent rock, but massive saprolite, by definition, does not. Bank failures occurred only in structured saprolite and along planar features such as joints. Saturation and vibration were important contributing factors.

The alteration of rock to saprolite varies with mineralogy, texture, and structure in the parent rock. In equigranular rocks, like gabbro and quartz monzonite, joints are the focal point of weathering. In gneisses and schists, textural and mineral layering are the primary focal areas and joints secondary. Residual boulders and rock pinnacles are common in gabbro saprolite (the most common type along the Aqueduct) and excavation rates vary with frequency of bedrock boulders or pinnacles.

Alteration of rock to saprolite has taken place in early Cretaceous time and probably continues into recent time. Where sediments overlie saprolite, at least the upper portion of the saprolite was formed prior to sediment deposition. Four kinds of stratigraphic and sedimentologic evidence support this: (1) extension of the saprolite on the Piedmont beneath the Coastal Plain sediments; (2) truncation of massive and structured saprolite zones by sedimentary deposits; (3) incorporation of saprolite particles into basal sands and gravels; and (4), occurrence of lag gravels at saprolite-sediment contacts. The lower part of the saprolite may have developed after burial and thus be younger than the overlying sediment, but the extent of post-burial alteration of rock to saprolite is uncertain.

The Potomac Group consists of gravel, sand, silt, and clay which are characterized by abrupt horizontal and vertical changes. These sediments, deposited in a fluvio-deltaic environment, were derived from the adjacent Piedmont. A local source area is suggested by: (1) lithology of clasts in the gravel, mainly quartz and quartzite; (2) a non-opaque heavy mineral suite which consists primarily of staurolite and tourmaline; (3) presence of amphibole and epidote-clinozoisite in sand beds at the base of Potomac Group sediments; and (4) angularity of staurolite and tourmaline grains.

As a consequence of abrupt horizontal and vertical changes in lithology, excavation and wall stability characteristics of the sediments change abruptly. Average rates for excavating the Potomac sediments are: sand, 296 cu. yd./hr.; mixed sediments (gravel, sand, silt, and clay), 209 cu. yd./hr.; and clay, 162 cu. yd./hr. Bank failures occurred mainly in sand and were caused by a high water table and/or vibration.

Quaternary deposits in stream valleys consist of gravel overlain by a finer grained unit. In the major valleys the upper unit is a sand-silt-clay; in smaller valleys, the upper unit commonly is a gravelly clay. The gravel unit retards excavation; layers two to five feet thick were excavated at about 220 cu. yd./hr. Locally, deposits of loam occupy hollows on Potomac Group sediments. The loam is very sensitive to vibration and readily collapsed into the trench. As a consequence, excavation rates in loam were less than 170 cu. yd./hr.

The Quaternary sediments are derived from reworking of the Potomac Group sediments and from the adjacent saprolite and rock of the Piedmont, as indicated by lithology of the gravel clasts (quartz, quartzite, gabbro, amphibolite, schist, and gneiss) and by heavy minerals (amphibole and epidote-clinozoisite dominate the suites).

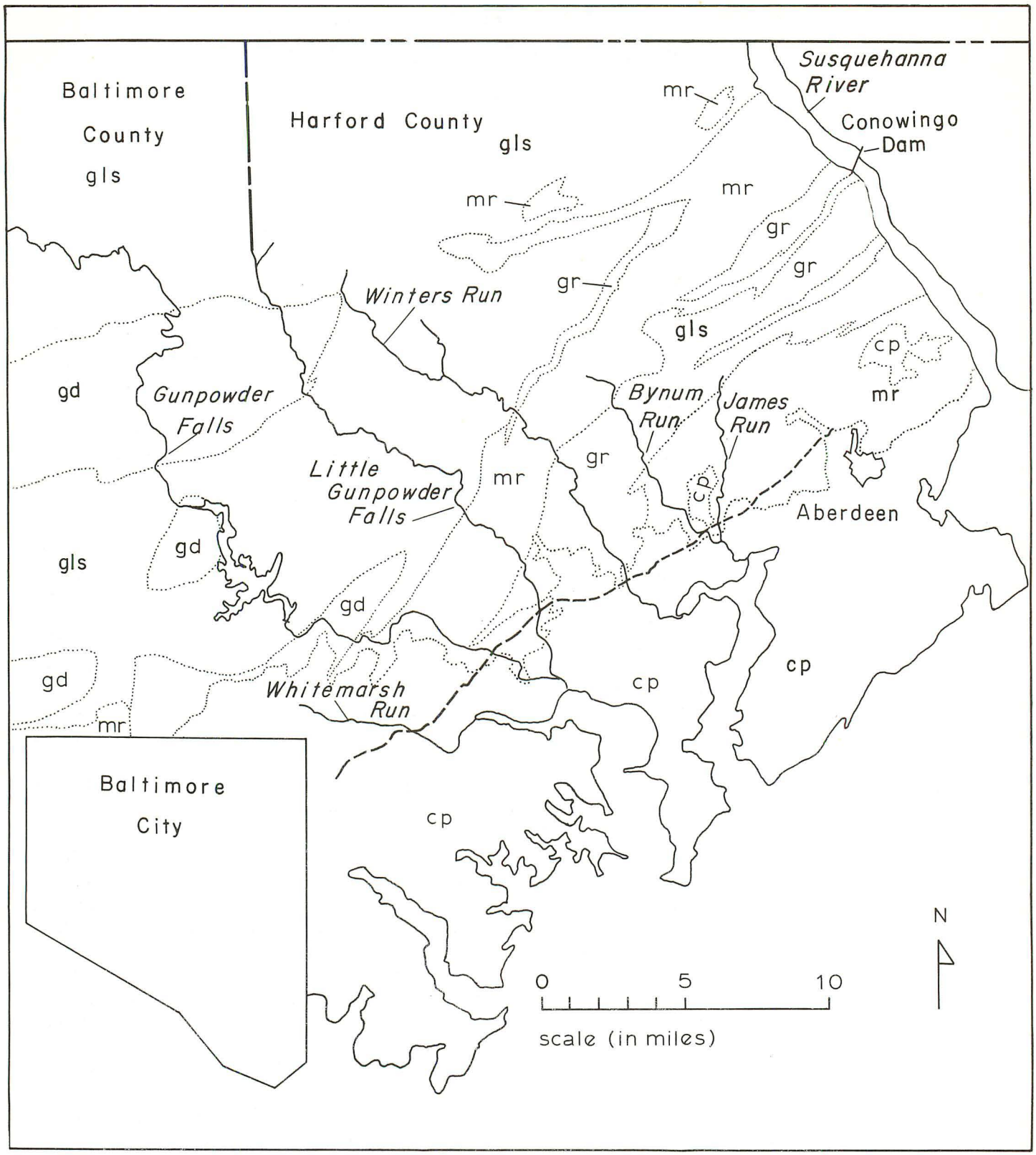


Figure 1. Map showing the location of the Susquehanna Aqueduct and general geology of the area. Aqueduct right-of-way is shown by a dashed line. Rock units are generalized from Geologic Map of Maryland (Cleaves, Edwards, Glaser, and Weaver, 1968). cp — Coastal Plain sediments, gd — gneiss domes, includes the Baltimore gneiss and Setters Formation, gr—granitic rock, includes Port Deposit Gneiss and muscovite quartz monzonite gneiss, gls—Glenarm Series includes Cockeysville Marble and Wissahickon Formation, mr—mafic rocks, includes James Run Gneiss, Baltimore Gabbro Complex, metagabbro, and ultramafic rocks.

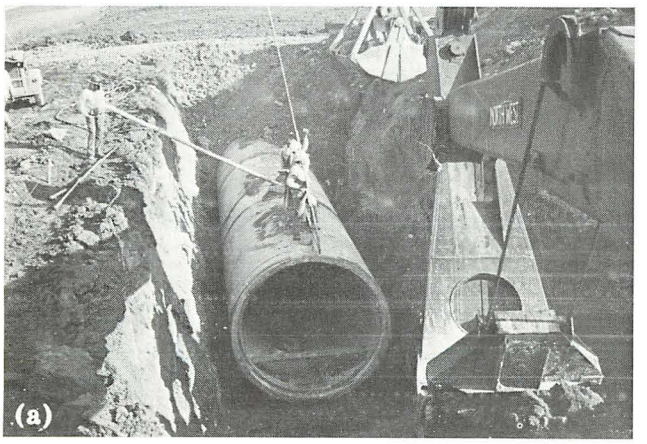
INTRODUCTION

The construction of a water conduit (Figures 1 and 2) from Trump Mill Road in Baltimore County to Maryland Route 22 in Harford County as part of the Susquehanna Water Supply Project provided a unique opportunity to record the geology along a continuous 22 mile section of the Fall Zone. Along this Zone Potomac Group sediments (Lower Cretaceous) of the Coastal Plain Province lap up onto Paleozoic and Precambrian granitic, gabbroic, metavolcanic and metasedimentary rocks of the Piedmont Province (Figure 1). Saprolite, a residual deposit formed by subaerial weathering, mantles the crystalline rocks except where bedrock has been exposed by stream erosion. The major streams are commonly incised into bedrock, and their valleys usually contain alluvium of Quaternary age.

The investigation is a salvage geology project and was not conducted to aid selection of alinement or construction of the Aqueduct. The project provided opportunities to study excavation and wall stability characteristics of the sediment and saprolite, to study heavy minerals of sediments at the base of the Potomac Group of Cretaceous Age and to compare these minerals to those in Quaternary alluvial deposits, and to study saprolite developed on the crystalline rock and to compare heavy minerals in the saprolite to those in the Cretaceous and Quaternary sediment. The major rock units encountered along the Aqueduct are described in Table 1. Detailed geologic cross-sections (vertical scale, one inch equals ten feet; horizontal, one inch equals fifty feet) prepared during the course of the investigation are on file with the Maryland Geological Survey.

The occurrence and distribution of the major rock units along the Aqueduct are shown on Figure 3. The Kennedy Memorial Highway part of the map was prepared from field maps of Professor Charles B. Hunt, who granted me permission to use the information. In this report, the Aqueduct has been divided into 17 subsections. Most of these boundaries are related to the field geology, but some are arbitrary. The station notation indicates distance, in feet, along the Aqueduct from two arbitrary points, one at the southwestern end of the Aqueduct, and a second near Mountain Road in eastern Harford County. The percentage of earth materials excavated from the trench was compiled in the following way. Vertical columns were measured at 100 foot intervals along the mapped parts of the trench. The data were compiled as column feet per earth material type, and the amount of each type computed as percent. Sand, silt, and clay are defined on the basis of the Wentworth grade scale. Gravel, as used in this report, refers to sediment in which the gravel size clasts touch one another.

Field work was begun in July 1963 and completed in August 1964. Two stretches of the Aqueduct totalling 5.7 miles were completed before mapping began.



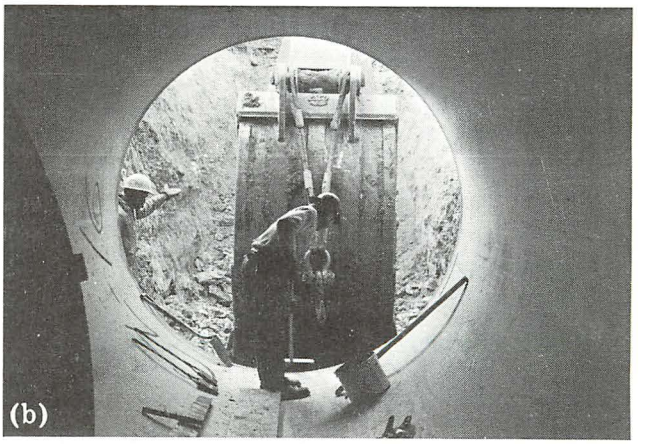


Figure 2. Views of Susquehanna Aqueduct construction. Location: Harford County, southwest of Bynum Run. The water conduit consists of 96 and 108 inch diameter pre-stressed embedded cylinder concrete pressure pipe laid in a cut and fill trench. (a) Concrete pipe 16 feet long and 9 feet wide (inside diameter) is placed in a cut and fill trench, which averages 14 to 15 feet in depth. The initial backfill is placed by a clamshell, and a bulldozer completes the job. The trench is being excavated by a backhoe which has a 4½ cubic yard capacity. (b) Trench being cut to grade by backhoe.

Table 1. Principal rock units encountered along the Susquehanna Aqueduct.

Age	Description
Quaternary	LOWLAND DEPOSITS: Generally below 50 feet in altitude. Includes Talbot Formation of Shattuck (1906) and floodplain deposits of modern streams. Commonly a lower gravel overlain by sand-silt-clay. Thickness 2 to 18 feet.
	PIEDMONT VALLEY FILL DEPOSITS, TYPE 1: Basal gravel overlain by gravelly clay. Occurs in dissected Piedmont terrain. Possibly equivalent to Lowland Deposits. Thickness 1 to 16 feet.
	UPLAND DEPOSITS: Generally above 50 feet in altitude. Includes Sunderland and Wicomico Formations of Shattuck (1906). At Gunpowder Falls alluvial deposits consist of gravel and sand and minor clay and silt. Thickness 1 to 15 feet.
mostly Quaternary, probably includes some Tertiary and perhaps some Cretaceous	PIEDMONT VALLEY FILL DEPOSITS, TYPE II: Gravel, gravelly sand and gravelly clay in undissected Piedmont terrain in Harford County.
Early Cretaceous	POTOMAC GROUP (UNDIFF.): Alluvial deposits of gravel, sand, silt, and clay. Abrupt horizontal and vertical changes in lithology. Derived from saprolite and rock in the adjacent Piedmont.
In part pre-Cretaceous in part younger	SAPROLITE: Residual deposits on crystalline rock of varying lithology.
Precambrian to Early Paleozoic	CRYSTALLINE ROCKS: Metamorphosed sedimentary and igneous rocks: includes gabbro, amphibolite, mafic gneiss, felsic schist, felsic gneiss, and quartz monzonite.

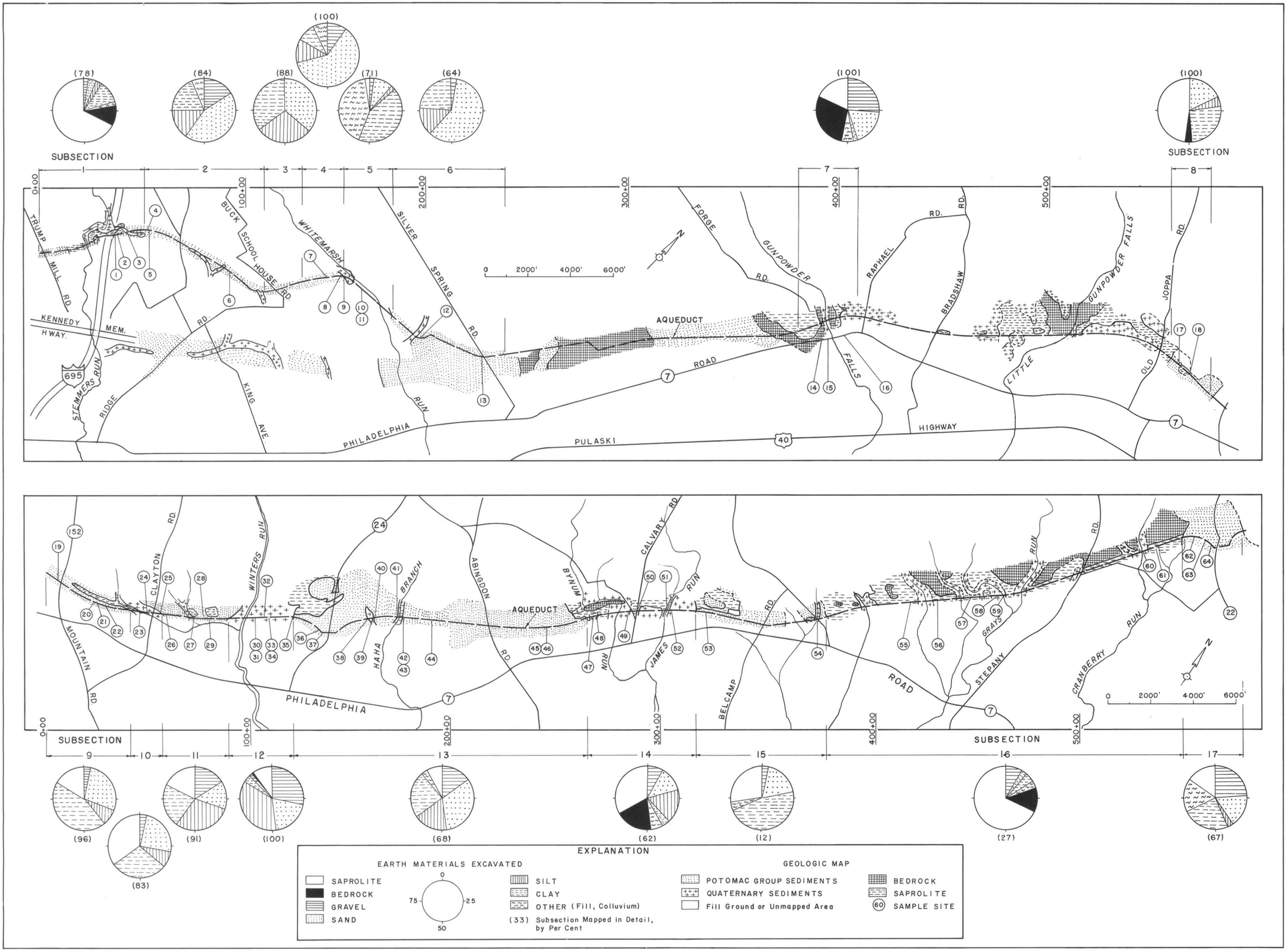


Figure 3. Geologic map showing the rock units, sample localities and earth materials along the Aqueduct.

ACKNOWLEDGMENTS

The Bureau of Water Supply of the City of Baltimore granted permission to map the geology of the Aqueduct, and the cooperation and assistance of Ervin H. Mattee, John Edwards, and A. W. Kammer is gratefully acknowledged. The cooperation of James Fasone and Thomas Anderson of Wright Contracting Company, Columbus, Georgia, and Roy Hess of Smith and Sons, Kennett Square, Pennsylvania, is appreciated.

Two radiocarbon dates of Quaternary material were run by Meyer Rubin, U. S. Geological Survey. Arthur Knox, U. S. Geological Survey, analyzed two Quaternary samples for pollen and spores. James Doyle, Department of Botany, Harvard University, provided pollen and spore analyses of thirteen Cretaceous samples.

The manuscript benefited from the editorial criticism of many people. Owen P. Bricker, The Johns Hopkins University, and Bruce Hanshaw, U. S. Geological Survey, reviewed the saprolite portion; Arthur B. Cleaves, Washington University, St. Louis, Missouri, reviewed the engineering geology; Kenneth N. Weaver, John D. Glaser and Harry J. Hansen, all of the Maryland Geological Survey, reviewed the complete manuscript. I am particularly indebted to Charles B. Hunt of the Johns Hopkins University for his editorial criticisms.

SAPROLITE

TERMINOLOGY AND STRATIGRAPHY

Saprolite is a residual deposit; a decomposed, earthy, untransported material in which the major rock forming minerals other than quartz have been altered to clay. The term "saprolite" was originally proposed by Becker (1895, p. 289) as a general name for the thoroughly decomposed untransported mantle on the crystalline rocks of the southern Appalachians. Becker's definition was modified by Mertie (1959, p. 239) who defined saprolite as decomposed, earthy, untransported rock in which the major silicate minerals, except quartz, alter to clayey products, and the rocks cohere sufficiently to retain most of their textural and structural characteristics.

Saprolite can be divided into two zones for which the terms "structured" and "massive" have been suggested (Cleaves, 1964). The massive saprolite lacks foliation or other structures present in the parent rock, and it grades upward into the modern soil. Structured saprolite retains foliation, jointing, and other structures and textures present in the parent rock. It may grade gradually upward into the massive saprolite, or be separated from it by a sharp discontinuity. Where the massive zone is missing, the structured saprolite grades upward into the modern soil. The lower contact of the structured saprolite with the weathered rock is irregular; at a given locality the two may be separated by a sharp contact or be gradational over two or three feet. In some places the massive saprolite may be directly in contact with the weathered rock. Both massive and structured saprolite may be cut with a knife. The relationship of the saprolite to the modern soil above and weathered to fresh rock below is shown diagramatically in Figure 4. The massive saprolite varies in thickness from a few inches to 15 feet. Structured saprolite may exceed 100 feet in thickness but commonly is 40 to 50 feet thick beneath ridges and upland areas in the Baltimore area.

The massive saprolite occurs in the zone of aeration and may be an ancient B soil horizon or may be the result of oxidation of the saprolite. The

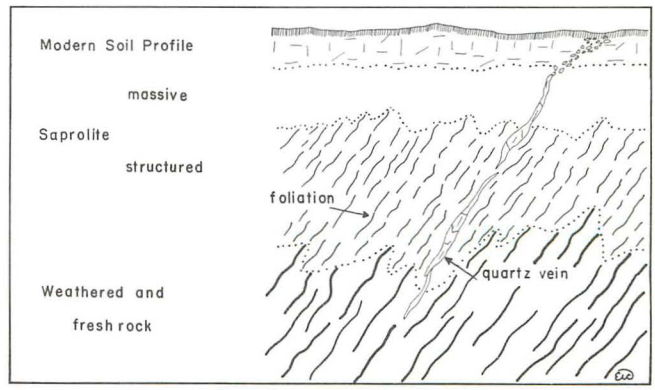


Figure 4. Idealized saprolite profile.

massive zone apparently does not result from soil forming processes in the modern A and B soil horizons, as massive saprolite occurs below the modern B soil horizon (Figure 5). Stratigraphic evidence also appears to eliminate a periglacial origin, as Lower Cretaceous age sediments truncate the massive zone (Figure 6).

The distinguishing feature of structured saprolite is its retention of primary textures and structures, such as banding, jointing, and quartz veins even though most of the original rock is altered to clay and hydroxides. Saprolite also preserves bolder features of the bedrock. An assymetric syncline was exposed in the Aqueduct trench between Trumps Mill Road and the Baltimore Beltway. In a second area near the Beltway a vertical shear zone, eight feet wide, trends N 30 E. to N 35 E. The fractured and sheared zone is composed of very coarse muscovite-feldspar-quartz gneiss, now saprolite, which is bounded on either side by saprolite developed from gabbro. Both kinds of saprolite preserve slickensides.

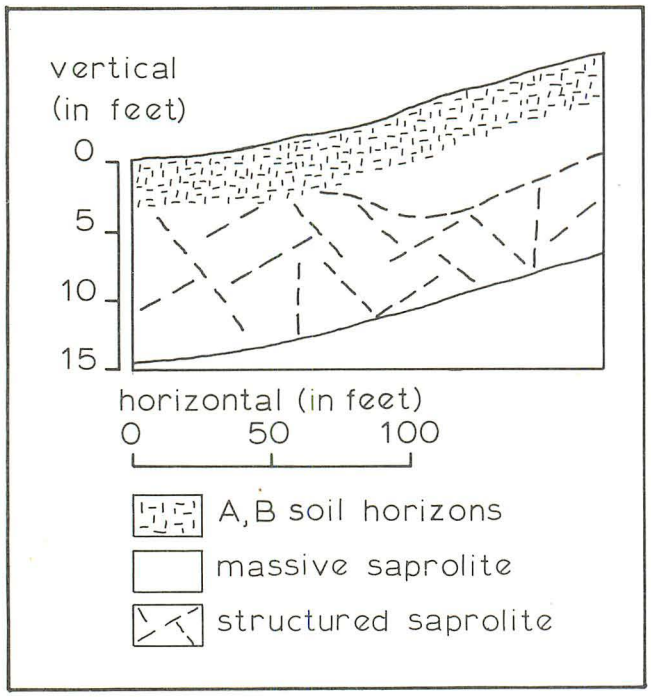


Figure 5. Soil horizons developed on massive and structured saprolite zones. Location: Harford County, Subsection 16, station 452 plus 88 to 454 plus 58. Saprolite has developed on a quartz monzonite gneiss. The soil profile is developed on structured saprolite, to the left, and massive saprolite, to the right. The massive saprolite zone merges into the soil horizon from right to left.

Contacts between rocks of different composition may also be well preserved in the saprolite. For example, a contact between amphibolite and mica schist was observed in the saprolite south of Winters Run. The amphibolite grades to schist over a zone of two feet and a few layers of amphibolite occur in the schist. In another area quartz monzonite intrudes gabbro south of Grays Run. A chill zone two to three feet wide in the quartz monzonite is well preserved in the saprolite.

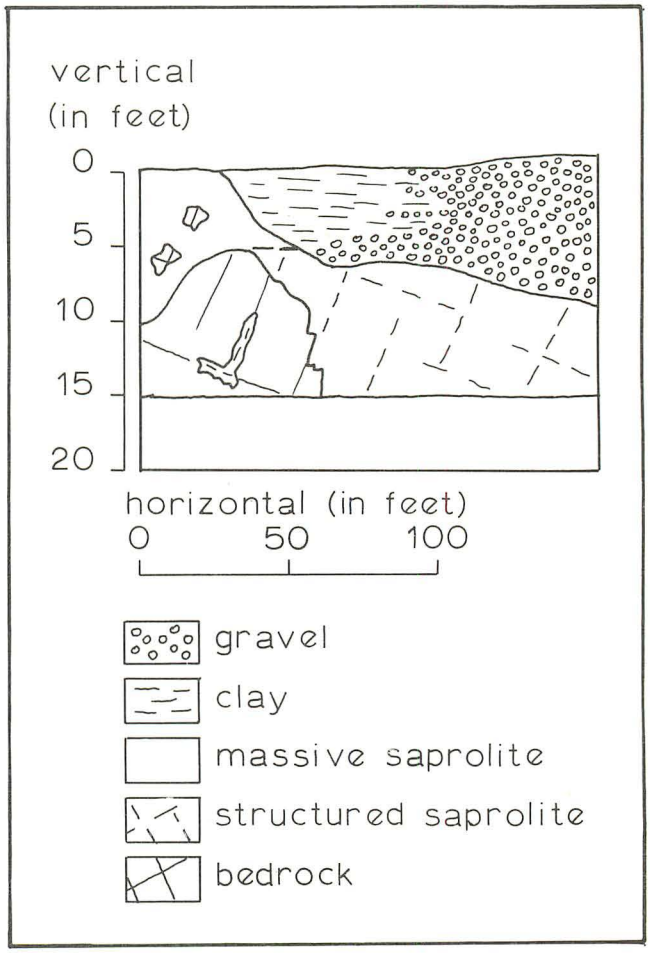


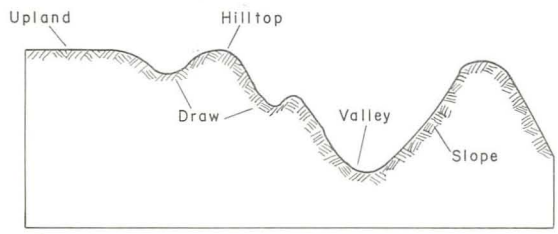
Figure 6. Massive saprolite zone truncated by Cretaceous sediments. Location: Harford County, Subsection boundary between 16 and 17, station 554 plus 48 to 556 plus 00. Massive and structured saprolite developed on gabbro. Basal sediments of the Potomac Group truncate the saprolite zones. Note the residual masses of gabbro in the massive saprolite and saprolite developing in the bedrock along joint planes.

DISTRIBUTION AND THICKNESS

Saprolite mantles the crystalline rocks of the Piedmont, and is thickest beneath ridges and upland areas and thinnest beneath valleys (Table 2). In many places along the Fall Zone the streams have cut through the saprolite or sediment and saprolite into the rock. Along the Aqueduct, Gunpowder Falls, Stemmers Run, Bynum Run, and Winters Run are examples of such streams.

Table 2. Depth of weathering in crystalline rocks in Baltimore and Harford Counties.

Topographic Element	Number of Wells	Average Depth (feet)
Upland	156	48
Slope	206	48
Draw	15	38
Hilltop	264	41
Valley	63	36



Along the inner edge of the Fall Zone, Potomac Group sediments, although thin, mask the underlying saprolite and bedrock. The surface of the crystalline material has a relief of at least 100 feet (Figure 7). As a consequence, saprolite and/or rock may occur near the surface at the crest or on the side of hills which seemingly are composed of sediment. For example, near Mountain Road, saprolite was exposed in the trench near the crest of a hill, and bedrock was exposed between Clayton Road and Winters Run.

In the Piedmont Province, although saprolite commonly is thickest beneath hills, bedrock may be found at or near a hillcrest. The topographic form of a hill provides a clue to depth of the saprolite. Gently rounded hills may or may not have bedrock near the surface, as illustrated by two hills immediately northeast of Creswell Road in Harford County. One, between stations 380 + 00 and 400 + 00, has bedrock near the crest; the other, between station 400 + 00 and 425 + 00, has no bedrock. Hills with sharp profiles have bedrock at or near the surface, as illustrated by the hill near station 433 + 00 and the one near station 456 + 00.

WEATHERING OF DIFFERENT ROCK TYPES

Rock alteration to saprolite depends, in part, on the position of the water table, and on mineralogy, texture, and structure of the parent rock. In equigranular rocks such as gabbro and quartz monzonite, joints are the primary nucleus of weathering. In gneissic and schistose rocks, mineral layering is the main nucleus of weathering.

In gabbro weathering starts along the joints. However, the texture and color of the resulting saprolite developed beneath the water table differs from that formed above the water table. In the zone of saturation, in valleys, lower flanks of hills, and beneath alluvial sediments, gabbro saprolite lacks residual boulders and pinnacles and has a silty clay texture. The saprolite is bluish green to greenish blue.

In the zone of aeration, on hilltops and the upper flanks of hills, the saprolite is reddish orange to brownish red clay, which is very sticky when wet. The saprolite contains numerous rock pinnacles and residual boulders (Figure 8).

The gabbro consists primarily of hornblende and plagioclase feldspar (Southwick and Owens, report in preparation), and weathering alters them respectively to montmorillonite and kaolinite (Table 3). Weathering of the gabbro may reduce its mass by one half, as indicated by a change in density from 3.0 (fresh rock) to as low as 1.4 (saprolite).

A high montmorillonite content in the saprolite may result in harmful engineering characteristics. Montmorillonite may cause "low permeability, slow compression, relatively large secondary compression under load application, high rebound on load removal, and loss of strength in the presence of moisture" (Grim, 1962, p. 272). None of these problems were encountered during excavation of the Aqueduct, but construction projects elsewhere in the Piedmont on gabbroic saprolite might encounter these difficulties.

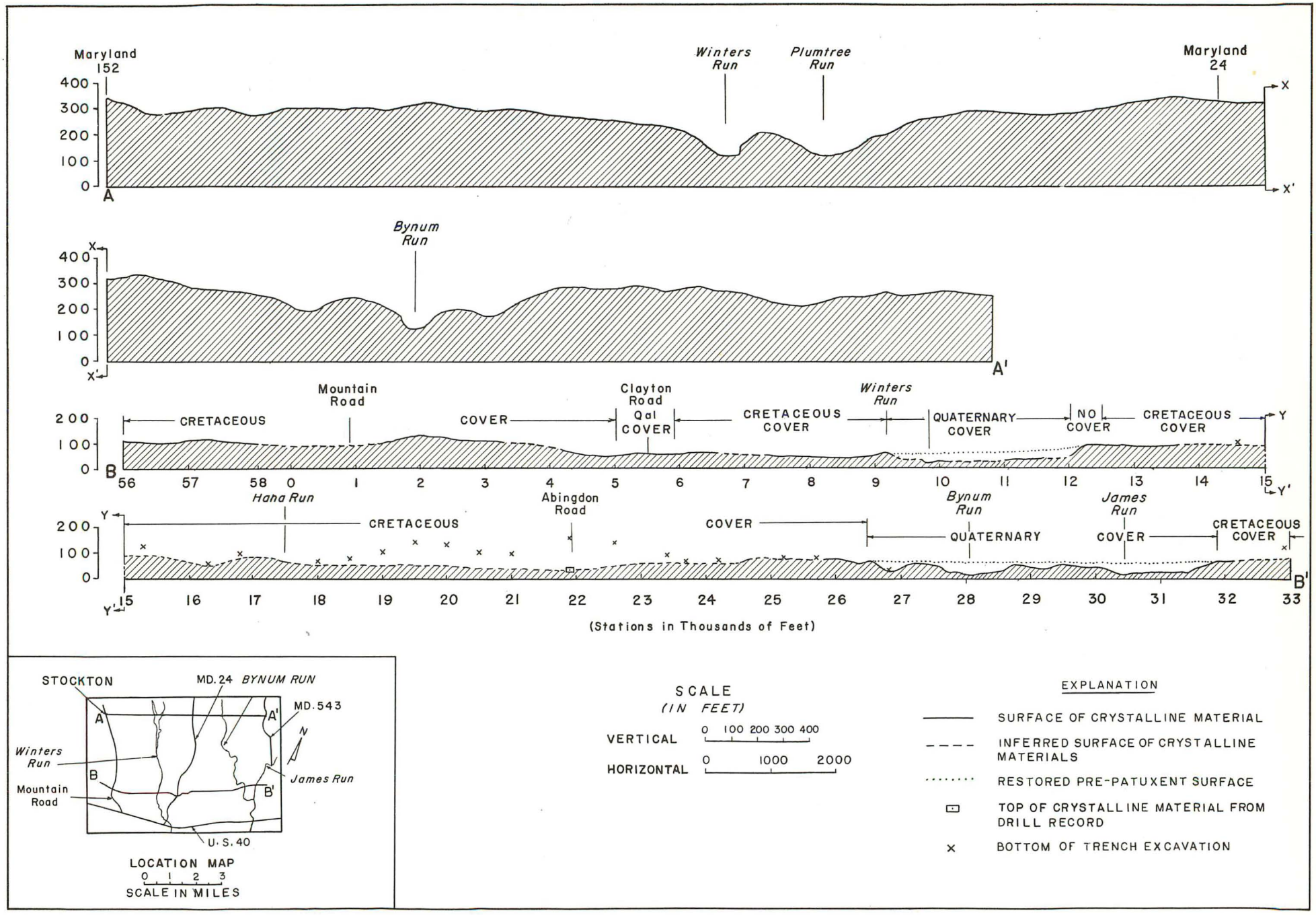


Figure 7. Topographic profiles of two surfaces on saprolite-bedrock.

Table 3. Clay minerals of saprolite.

Parent material	Sample no.	kaolinite	illite	montmorillonite	chlorite	vermiculite	feldspar	amphibole	quartz
felsic schist	24	x	x	-	-	-	-	-	x
felsic schist	20	x	x	-	-	-	-	-	-
felsic schist	29	x	x	-	-	-	-	-	x
felsic gneiss	25	x	x	-	-	-	-	-	-
felsic schist	35	x	x	-	x	-	-	-	x
James Run Gneiss	51	x	-	x	-	x	x	-	x
gabbro gneiss	1	x	-	x	-	-	-	-	-
gabbro gneiss	2	x	-	x	-	x	-	-	x
gabbro gneiss	3	x	-	-	-	-	-	-	-
metagabbro	54	x	-	x	-	-	-	x	-
amphibolite	55	-	-	x	-	-	-	x	-
metagabbro	62	x	-	x	-	-	-	-	-
metagabbro	63	x	-	x	-	-	-	-	x
metagabbro	57	x	-	x	-	-	-	-	x
quartz monzonite	56	x	x	x	-	-	-	-	x
quartz monzonite	58	x	x	-	-	-	-	-	x

Comments: Samples were sedimented onto glass slides and x-ray diffraction traces made using CuKα radiation. The clay minerals were identified from data cited in Brown (1961). Samples with 14 angstrom clay minerals were glycolated; a swelling clay is considered to be montmorillonite, and a non-swelling one vermiculite.

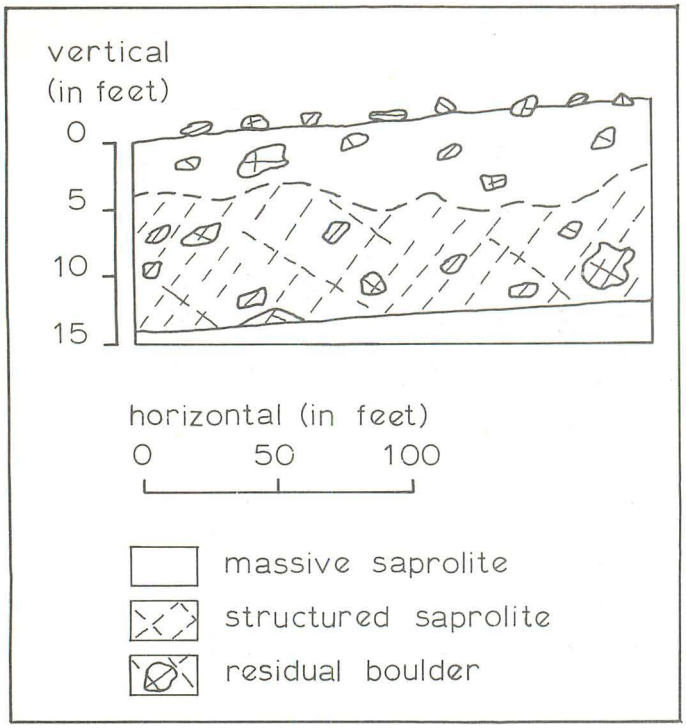


Figure 8. Residual boulders in massive and structured saprolite. Location: Harford County, Subsection 16, station 536 plus 00 to 537 plus 00. The geologic cross-section shows residual boulders in gabbro saprolite which is above the water table. The dashed line marks the boundary between massive saprolite (above) and structured saprolite (below). The joints in the structured saprolite above the water table are not as well preserved as joints in the structured saprolite below the water table. The surface of the ground is commonly littered with boulders and pebbles of all sizes which may be considerably rounded by chemical weathering prior to their erosion and incorporation into stream alluvial deposits. Angular, subangular, subrounded, and rarely, rounded gabbro pebbles are found in residual soils and on their surfaces.

Within the complex of gabbroic rocks crossed by the Aqueduct in the Piedmont province, four small areas of quartz monzonite were exposed between stations 445 + 00 and 476 + 00. The quartz monzonite is masked by a colluvium containing gabbro and amphibolite pebbles and cobbles and, in some places, is buried beneath alluvial sediments.

Weathering in the quartz monzonite begins along joint planes, which are more broadly spaced than in the gabbro, and spreads outward into the rock. The quartz monzonite saprolite lacks residual boulders, in contrast to gabbro saprolite (Figure 9). The monzonite weathers to a grey, silty sand.

At Grays Run the contact between quartz monzonite and the saprolite developed upon it is sharp. No weathering occurs along joints in the granitic rock. However, this locality is exceptional. Elsewhere in Maryland, gradational contacts have been observed, and in other areas where the transition from saprolite to granite bedrock has been studied, the transition is also gradational (for example Hong Kong, Ruxton and Berry, 1957; California Sierras, Roberts, 1966; Georgia, Watson, 1902); the granite changes downward from saprolite, to saprolite with residual boulders, to rock weathered along joints to jointed bedrock.

Two main groups of saprolite developed on gneiss and schist were exposed: a felsic type developed on muscovite-feldspar-quartz gneiss and schist, and a mafic type developed on amphibole-quartz-feldspar gneiss and schist. The saprolite on felsic schist and gneiss is grey and white in the zone of saturation, whereas the saprolite on mafic gneiss and schist is greyish green to bluish green. Both types are reddish brown in the zone of aeration, although the saprolite on the mafic rocks may be bright orange.

In the felsic schist and gneiss the feldspar weathers to kaolinite, the muscovite to illite and kaolinite, and the quartz remains unchanged. The same minerals in the mafic gneiss alter to similar clay minerals, and amphibole or pyroxene minerals weather to montmorillonite. Biotite weathers to vermiculite and kaolinite. Rarely, minor amounts of the plagioclase or hornblende remain in the saprolite.

In the gneiss and schist a combination of foliation and layers with alternating massive, gneissic, or schistose texture can result in weathering patterns quite different from those in granite or gabgro. One of these patterns is illustrated in Figure 10. The rock is a gabbro gneiss, and consists of dark grey, well foliated, medium to coarse grained, amphibole feldspar gneiss and bluish-black, fine-grained, weakly foliated gabbro. Weathering processes more readily attack the well foliated coarser grained rock. In some places the contact zone between saprolite and rock has a frayed appearance (between stations 396 + 00 and 398 + 00); at other places the zone is ragged with relief of 8 to 10 feet (station 398 + 00 to about 400 + 00), and in still others there is a smooth, abrupt transition (adjacent to station 391 + 00). The rock is

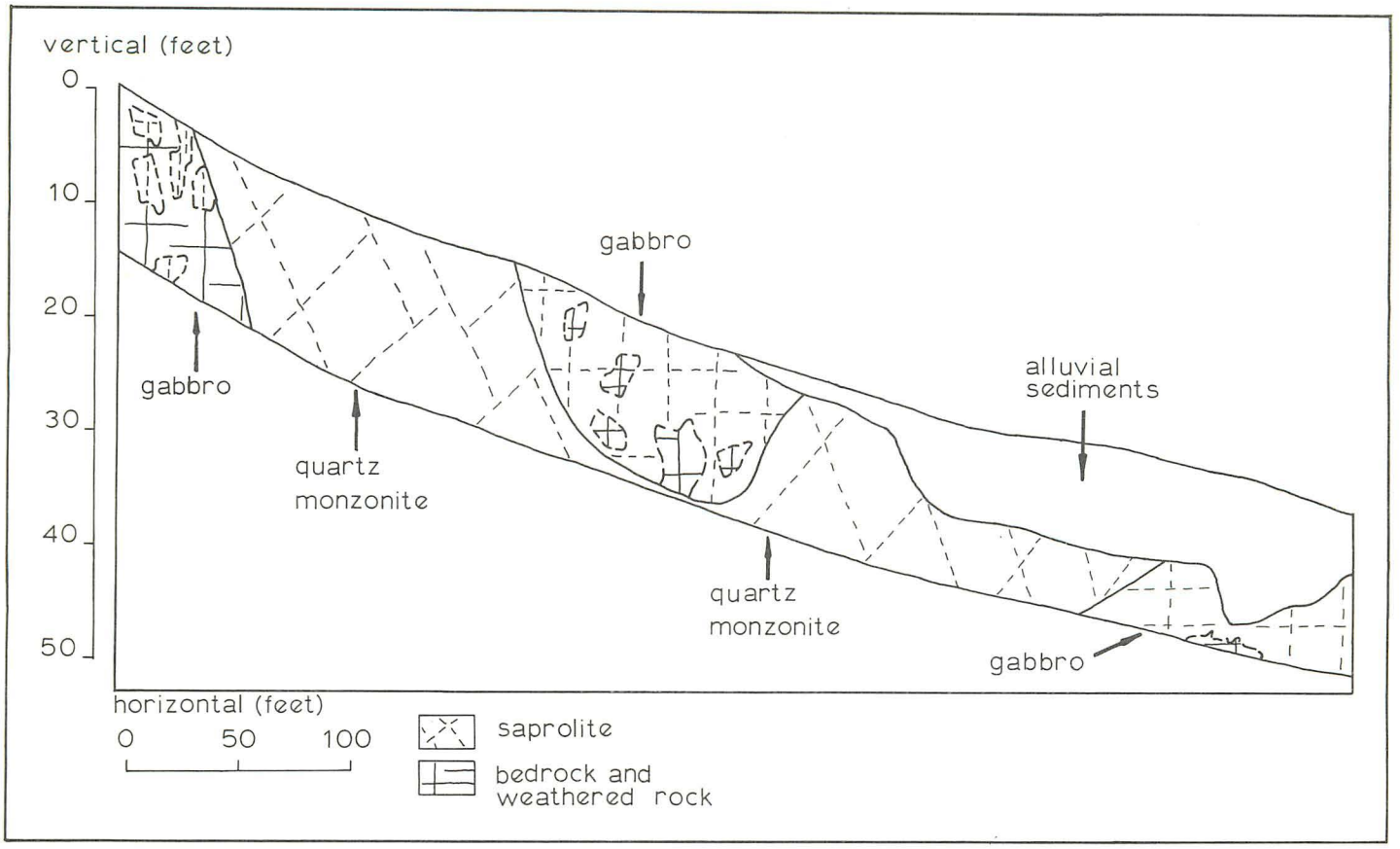


Figure 9. Contrasting saprolite development in quartz monzonite and gabbro. Location: Harford County, Subsection 16, station 456 plus 70 to 462 plus 15. The quartz monzonite has weathered to saprolite. The adjacent gabbro has weathered incompletely; residual boulders of gabbro remain in the saprolite and irregular masses of saprolite are developed in the weathered gabbro.

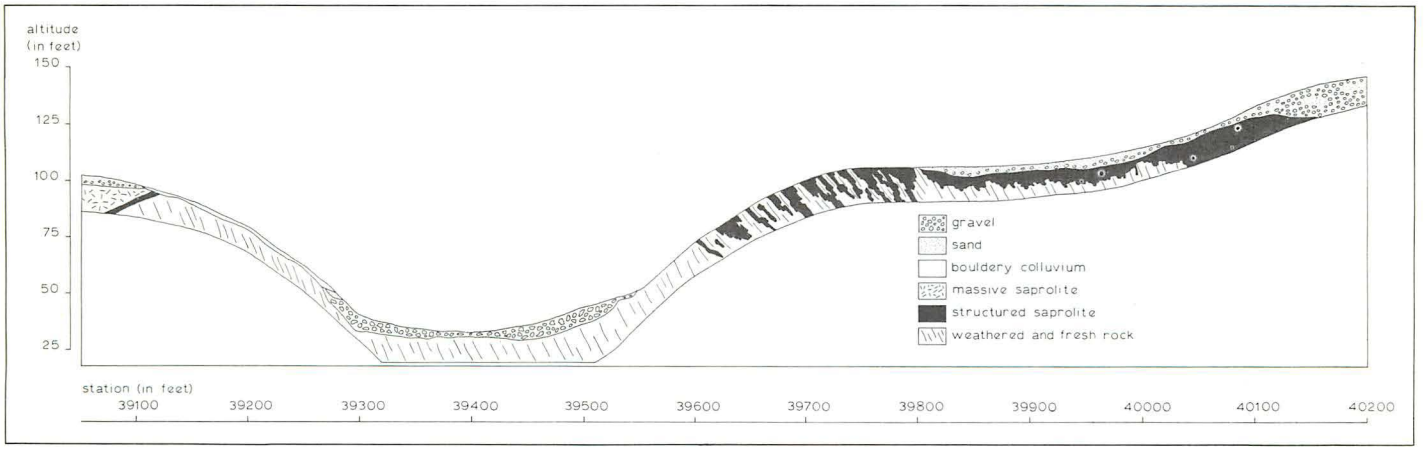


Figure 10. Gunpowder Falls geologic section.

well jointed, but the joints are a secondary focus of weathering. Similar weathering features were exposed at Stemmers Run in gabbro gneiss.

The inclination of the relic layering in the saprolite can affect excavation of the deposit. For example, a vertical layer of quartzose rock 2 to 3 feet thick in saprolite could probably be picked apart by a backhoe (Figure 14), but the same layer in a horizontal position might have to be blasted.

SAPROLITE CLASTS IN GRAVEL

Saprolite clasts are present in Cretaceous and Quaternary gravel beds, and are found together with fresh rock and weathered rock of the same lithology. For example, in Quaternary gravel greenish-blue gabbro saprolite clasts, gabbro clasts with a fresh rock core and a rind of weathered rock and saprolite, and fresh gabbro clasts may be found mixed together in a single bed (Table 15). Most of the saprolite clasts were probably derived by erosion of pre-existing saprolite, but some may have altered from rock to saprolite after deposition.

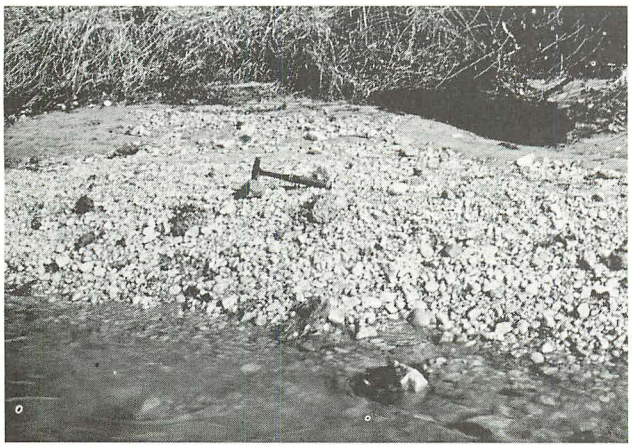


Figure 11. Saprolite clasts in a gravel bar deposit at Whitemarsh Run. Location: Baltimore County, Whitemarsh Run, adjacent to Subsection 4, station 150 plus 00 to 152 plus 00. Dark colored saprolite clasts are exposed in the gravel bar. The two clasts near the hammer were picked out from the submerged part of the bar to better illustrate their occurrence. Three saprolite clasts can be seen in the gravel deposit to the left of the hammer; they are slowly crumbling as they dry. The white clasts are vein quartz and quartzite.

Saprolite clasts are presently being formed and incorporated into gravel deposits in Whitemarsh Run in Baltimore County. The stream, flowing over saprolite, plucks chunks of saprolite from the stream bed; they round to saprolite-balls when rolled downstream, and are incorporated into gravel bar deposits (Figure 11). Formation and preservation of saprolite-balls requires three conditions: that the saprolite be coherent when moist, that it remain moist, and that it not be transported a long distance. Alternate wetting and drying results in the disintegration of the clasts.

HEAVY MINERALS

Relatively little work has been done in the eastern United States on the petrology of the sand fraction of saprolite, and the Aqueduct construction provided an opportunity to investigate the heavy minerals in saprolite developed on contrasting rock types. The heavy minerals passing the 1/2 mm. sieve and retained on the 1/16 mm. one were prepared and counted using procedures described by Krumbein and Pettijohn (1938). A 40 percent solution of warm hydrochloric acid was used to remove iron oxide staining from the particles. Two hundred grains per slide were counted to obtain the ratio of opaque to non-opaque minerals. Additional non-opaque grains were counted to a total of 200.

Saprolite developed on mafic metaigneous rock is dominated by amphibole and epidote-clinozoisite (Table 4). Mafic metasediments are dominated by these same two minerals but also contain staurolite, tourmaline, and zircon. Felsic metasediments have a variety of minerals: rutile, staurolite, tourmaline, zircon, brookite, epidote-clinozoisite, and amphibole. On the other hand, epidote-clinozoisite dominates the two granitic metaigneous samples.

Nine heavy minerals comprise the saprolite samples, and are described in Table 5. Four minerals that are present in the Cretaceous and Quaternary sediments (Table 10, and 17) are absent in the saprolite: kyanite, monazite, sillimanite, and sphene. Kyanite has been reported only from the Lower Pelitic Schist lithofacies of the Wissahickon Formation (formerly called oligoclase mica schist facies), a rock type not represented in the samples. Monazite, sillimanite, and sphene may be present in the rocks crossed by the Aqueduct, but are absent in these samples.

Table 4. Heavy mineral content of saprolites from contrasting rock types (frequency percent).

	rutile	staurolite	tourmaline	zircon	amphibole	brookite	chloritoid	epidote-clinozoisite	garnet	opaque minerals
mafic metaigneous										
54: gabbro	-	-	-	-	99	-	-	1	-	T
55: amphibolite	-	-	-	-	100	-	-	-	-	T
60: gabbro	-	-	-	-	98	-	-	2	-	T
61: gabbro	-	-	-	-	94	-	-	6	-	6
62: amphibolite	-	-	-	-	92	-	-	8	-	67
63: gabbro (?)	-	-	2	-	38	-	-	60	-	97
57: gabbro	-	-	-	-	56	-	-	44	-	1
mafic metasediments										
51: James Run Gneiss	-	-	-	-	24	-	-	76	T	32
50: James Run Gneiss	-	-	-	-	17	-	-	81	2	37
1: gabbro gneiss	-	-	17	-	12	-	-	57	14	90
14: gabbro gneiss	-	T	12	3	83	-	-	2	T	84
felsic metasediments										
24: schist	T	T	98	-	2	-	-	-	T	T
21: schist	4	4	66	6	1	19	T	-	-	55
20: schist	-	4	91	1	T	4	-	-	T	25
29: schist	-	71	7	T	2	2	2	-	16	18
25: gneiss	10	4	1	38	12	3	-	31	1	96
35: schist	-	2	24	43	29	2	-	-	T	89
granitic metaigneous										
56: quartz monzonite	-	-	T	-	3	-	-	96	1	3
58: quartz monzonite	-	-	-	-	1	-	-	99	-	7

Table 5. Description of heavy minerals in saprolite samples.

Rutile: red or yellow; some grains faintly pleochroic in red or yellow; grains occur as euhedral crystals, as angular to subangular fragments (some of which have crystal faces); a few grains are striated.

Staurolite: grains are pleochroic, colorless, pale yellow and yellow; no brownish yellow, deep honey yellow, and orange colors which are so common in the heavy mineral suites of the Potomac Group and Pleistocene sands; rarely, a sieve texture; inclusions rare; angular to subangular fragments, except sample 29 in which crystals with pyramidal terminations occur.

Tourmaline: variable pleochroism: north-south cross-hair, pale yellow, very pale pink,pink, colorless, very pale brown; east-west cross-hair, yellowish brown, very dark greenish brown, reddish brown, blackish brown, dark bluish green, very dark green; grains occur as broken prisms, prisms with one end broken, irregular fragments, basal plates (a few prisms have rounded ends); both opaque and non-opaque inclusions occur in many grains.

Zircon: colorless; rarely brown; grains mainly complete or broken prisms (in sample 35 grains occur as fragments); angular, rarely subrounded; occasionally grains have corroded surfaces.

Hornblende: strongly pleochroic, bluish green, greenish blue, green, blue, yellowish green; rarely, yellow, brown: grains occur as cleavage fragments, some with hackly edges, others with angular to subangular edges.

Tremolite-actinolite: cleavage fragments characterized by weak pale blue to pale green or bluish green to yellowish green pleochroism. (Tremolite-actinolite and hornblende are tabulated together as amphibole.)

Brookite: yellow, brown; pronounced tabular habit; most grains are striated; grains exhibit varying degrees of alteration, none are fresh.

Chloritoid: pleochroic, strong blue and green to weak pale blue and pale greenish blue; plate-like habit.

Epidote group: (both monoclinic and triclinic species occur, but have been tabulated together); in schist, gneiss, gabbro, and amphibolite samples grains are commonly colorless, rarely exhibit weak pleochroism -- pale green to colorless; in two quartz monzonite samples those grains which are pleochroic have intense green or pistachio green to colorless pleochroism; grains usually occur as cleavage fragments or as irregular fragments; in sample 57 numerous prismatic crystals occur; grains generally are fresh in appearance although corroded and altered grains occur in every suite.

Garnet: colorless, pale pink, pink; commonly angular to subangular fragments, rarely well preserved crystal faces on grains; grains remarkably fresh in appearance, although some are etched or corroded.

Although the parent rock determines the heavy minerals, chemical weathering affects the abundance of different heavy minerals present in a saprolite. Some weather more readily than others (Dryden and Dryden, 1946, Figure 1, p. 93), but no heavy mineral appears to be completely destroyed. Relatively unstable minerals such as amphiboles and garnet survive in the saprolite, although in reduced amounts, as well as the more stable minerals such as zircon, tourmaline, and rutile.

AGE

Regional and local evidence suggests that in the eastern United States some of the saprolite was developed on crystalline rocks before deposition of Potomac Group sediments. Regionally the saprolite extends eastward from the Piedmont and extends under the overlying Cretaceous formations (Maryland, Anderson 1948; Pennsylvania, Greenman et al, 1961; North Carolina, Le Grand and Mundorff 1952; South Carolina, Christl 1964; New Jersey, Southwick 1964; New York, de Laguna 1963). The heavy mineral assemblage of the Potomac Group in northern Delaware (Groot, 1955) indicates a period of intensive chemical weathering prior to Potomac time and therefore implies the development of an extensive saprolite on the Piedmont crystalline rocks by sub-aerial weathering processes, sometime in late Triassic, Jurassic, or early Cretaceous time.

Along the Aqueduct saprolite is truncated by Potomac Group sediments (Figure 12). Sand and gravel beds at the base of the Cretaceous commonly contain saprolite particles which were torn loose from exposures of the saprolite and incorporated into the sediment (Figure 13). Lag gravel may occur at the base of the sediment immediately overlying the saprolite.

Saprolite along the Aqueduct, and in the Piedmont Province in general, probably has formed at numerous times since early Cretaceous time. This is suggested by red and yellow podzolic soils which

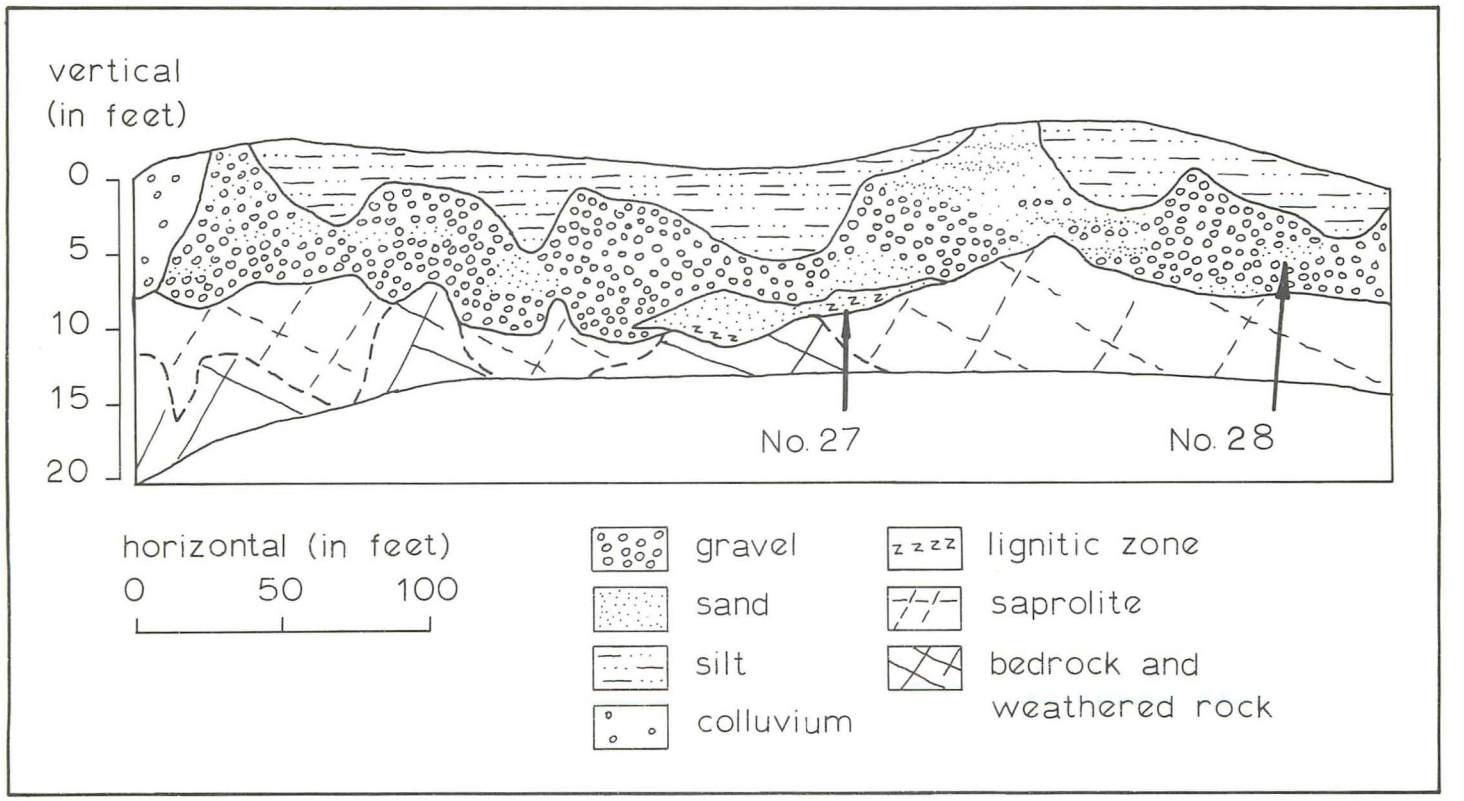


Figure 12. Structured saprolite zone truncated by Potomac Group sediments. Location: Harford County, Subsection 11, station 75 plus 00 to 79 plus 00. Muscovite schist saprolite and weathered rock are overlain by Potomac Group sediments. Pollen and spores from sample No. 27 indicate a Potomac age. A sand lens in the gravel was sampled and the heavy mineral suite, sample No. 28, is recorded in Table 10.

are developed on many Tertiary formations on the Coastal Plain, by the saprolitization of a boulder bed at the base of the Talbot Formation of Pleistocene age (Southwick and Owens, report in preparation), by the truncation of a massive saprolite zone by Quaternary sediments (Figure 14), and by reworking of saprolite into Quaternary gravel deposits in Winters Run and James Run (p. 28).

Movement of ground water plays a key role in the weathering and alteration of crystalline rock to saprolite. Water, falling as precipitation on the surface, seeps into the ground, and in the temperate climate of the Baltimore area passes through it into streams. Some water moves laterally along the weathered zone at the base of the structured saprolite, and where the contact is truncated by a hillside or roadcut, the water emerges as seeps or springs. Additional water passes through the saprolite and weathered rock into the fresh rock where its circulation depends upon factors such as fractures, joints, lithology, relief of the rock surface, and drainage density. In both cases, the water reacts with the saprolite and rock, and the products of weathering are carried away as dissolved matter. Presumably similar ground water weathering may take place where saprolite is buried beneath hundreds of feet of sediments, as it is beneath the Atlantic Coastal Plain. However, evidence to support post-burial alteration of tens of feet of rock to saprolite beneath the Coastal Plain is lacking, and seemingly depends upon circulation of ground water to remove the weathering products.

Evidence concerning circulation of water in rock buried beneath the Coastal Plain sediments is limited. Data on water pressure in rock beneath saprolite and sediment is available from one site in Baltimore City and the Savannah River Nuclear Plant site near Aiken, South Carolina. At the Baltimore City site (per. comm., A. B. Cleaves) about 200 feet of sediment rest on saprolite which is 18 to 20 feet thick. The water pressure in the rock beneath the saprolite ranges from 160 to 300 feet of head above the rock-saprolite interface. At the Aiken plant site the piezometric head on the rock water is 20 feet higher than in the lowermost sedimentary aquifer of the Tuscaloosa Formation (Christl, 1964, p. E-11). Hydrologic and geochemical data suggest that the rock water is in an "aquifer" that is hydraulically separated from the lowermost aquifer in the Tuscaloosa Formation (Christl, p. E-16). At these two sites, the water pressures bar downward movement of water

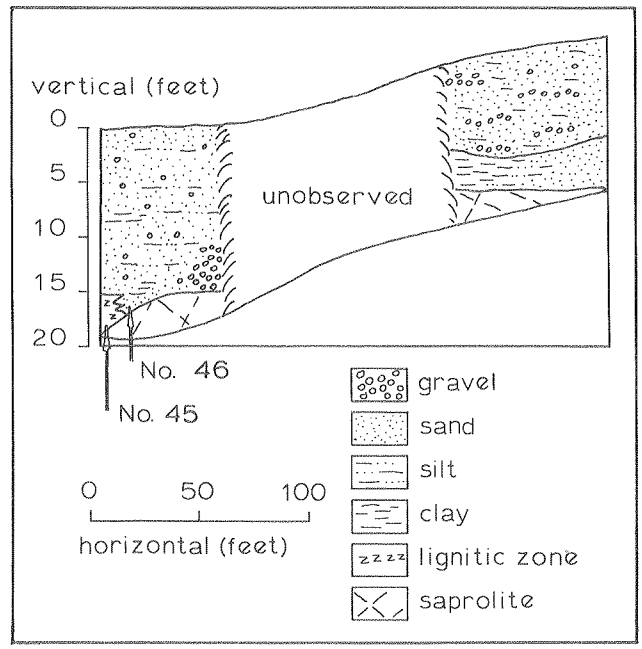


Figure 13. Amphibolite saprolite reworked and incorporated into sand at the base of the Potomac Group. Location: Harford County, Subsection 13, station 245 plus 35 to 247 plus 50. Bluish amphibolite saprolite is overlain by Potomac Group sediments. Pollen and spores from a plantiferous clay lens (Sample No. 45) indicate a Patuxent-Arundel Zone I assemblage. Basal gravelly sand above the saprolite contains reworked saprolite, and heavy minerals from this reworked zone (sample No. 46, Table 10) contain 38 percent amphibole.

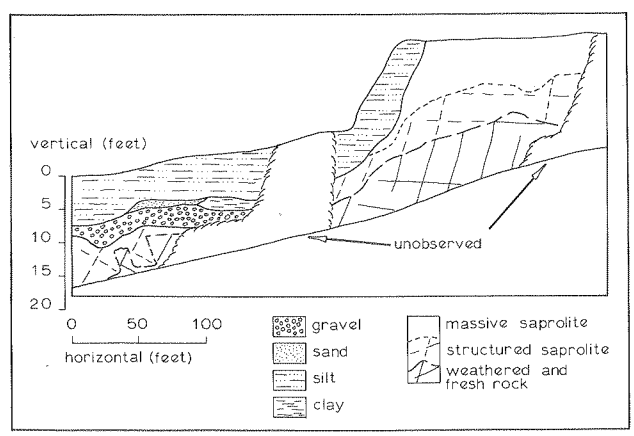


Figure 14. Massive saprolite zone truncated by Quaternary sediments. Location: Harford County, Subsection 14, station 284 plus 20 to 288 plus 00. The saprolite has formed on the James Run Gneiss. On the left, two quartz rich layers in a hornblende-feldspar gneiss protrude up into the saprolite.

through a mantle of saprolite, although lateral movement is not precluded. The geochemical data from the Aiken site also suggests that water transfer from rock, through saprolite, to overlying sedimentary aquifers is limited, if indeed there is any transfer at all.

Saprolite, however, may function as a semipermeable membrane; if so, osmotic diffusion may be partly responsible for the observed differences in hydrostatic pressures. This possibility, suggested for the Aiken site (Siple, 1964, p. C182), has been postulated also to explain anomalous pressures and salinites across shales in central Alberta, San Juan Basin, Colorado, and San Joaquin Valley, California (Berry and Hanshaw, mss, p. 1). Where saprolite is like a membrane separating water with different salt concentrations, water could move from the least saline to the more saline water body, building up pressure in the more saline side. The pressure data from the Aiken and Baltimore City sites are in accord with the suggested behavior for semipermeable membranes, as is the chemical data from the Aiken site. Thus, a semipermeable membrane might provide the circulation of water necessary for postburial alteration of rock.

EXCAVATION RATES AND WALL STABILITY

Subaerial weathering of rock may result in bouldery saprolite, in alternating layers of hard rock and saprolite, and in rock which has completely altered to saprolite. Excavation rates differ considerably with the degree of decomposition. Quartz monzonite which decomposed completely to a silty sand saprolite was excavated at 270 cu. yds. per hour (Figure 15). Bouldery saprolite developed on gabbro varied considerably in excavation rate depending upon the size and number of boulders, from 230 cu. yd. per hour to 140 cu. yd. per hour. Where bedrock was encountered, excavation was retarded even more; 120 cu. yd. per hour in the example shown in Figure 15.

Where schist and gneiss were encountered some areas of the rock were altered completely to a clayey silty sand and were excavated at a rate similar to a sediment of like texture (about 240 cu. yd. per hour, Figure 20). In other places in-

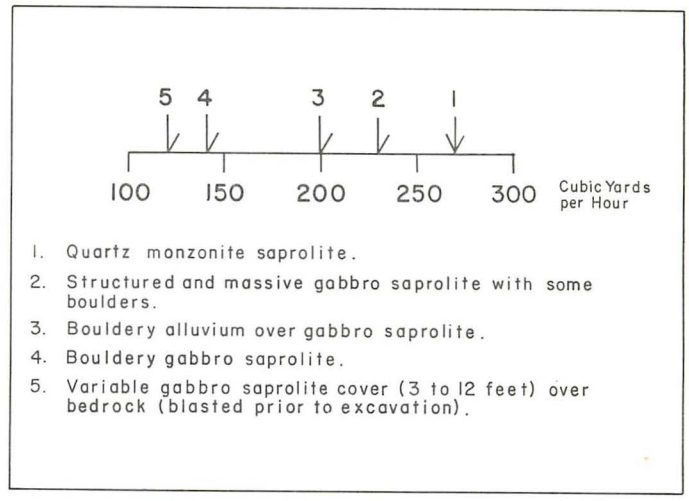


Figure 15. Excavation rates in saprolite.

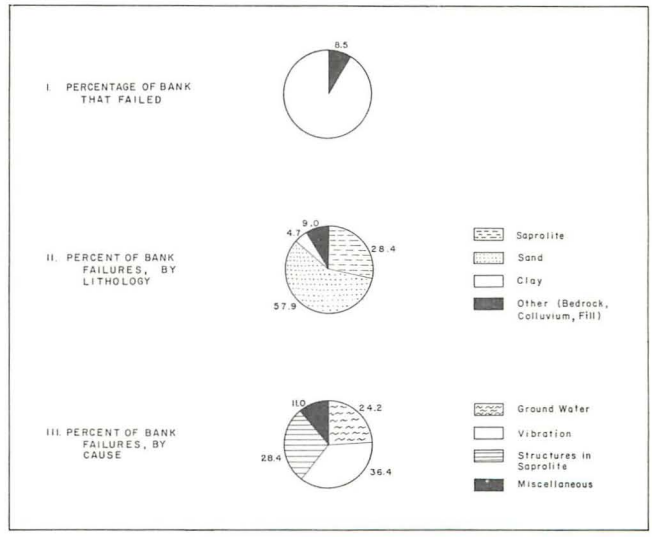


Figure 16. Bank failures in sediment and saprolite.

Figure 17. Failure in gabbro saprolite along a joint plane. Location: Baltimore County, Subsection 1, near station 40 plus 10. The white surface of the joint plane is exposed opposite the fourth pipe from the end; the slide is opposite the first and second pipes.

complete weathering or quartz rich zones results in alternating layers of saprolite and rock which slowed excavation below 150 cu. yd. per hour.

Saprolite ranked second after sand as unstable wall material (Figure 16). Bank failures in saprolite are related to three factors: preservation of primary rock structures such as joints and foliation, ground water, and vibration. All the failures in saprolite occurred in the structured zone. In particular, joint and foliation planes sloping towards the trench were the focii of bank failures, both above and below the water table. A joint plane failure is illustrated in Figure 17.

The occurrence of ground water adversely affects the stability of walls in saprolite (Table 6). Where structured saprolite was exposed beneath the water table, failures were more likely than where structured saprolite was exposed above the water table. In addition, saprolite that was exposed beneath sediments was less stable than that with no sediment cover because the sediment covered saprolite was more likely to be water saturated.

Vibration from construction equipment was a contributing factor in many bank failures, and was probably the most important factor in a few failures in the zone of aeration.

Table 6. Influence of ground water on saprolite wall stability.

	percent of saprolite	percent of bank failures
zone of saturation	50	91
zone of aeration	50	9
	percent of saprolite	**percent of bank failures**
saprolite overlain by sedimentary deposits	64	79
saprolite with no overlying sedimentary deposits	36	21

SEDIMENTARY DEPOSITS

CRETACEOUS, POTOMAC GROUP

Stratigraphy and age

Potomac Group sediments in the Baltimore area and along the Aqueduct have traditionally been divided into three formations, Patuxent, Arundel, and Patapsco (Mathews, 1925; Clark, 1904). More recently, however, these sediments have been mapped as Potomac Group (undivided) in Harford County (Southwick and Owens, 1968). Along the Aqueduct lithic characteristics of the sediments do not support a tripartite division. Pollen and spore data indicate that Zone 1, Patuxent-Arundel, of Brenner (1963) is present and heavy mineral data suggest that the Patuxent facies (Glaser, 1967, p. 69) is present. But these data, by themselves, are insufficient evidence to support a formational assignment. Because of the absence of mappable lithologic units along the Aqueduct, the sediments are mapped as Potomac Group (Undifferentiated).

The sediments were deposited in a continental environment as indicated by abrupt horizontal and vertical changes in lithology, conglomeratic lenses of clay clasts, lignitic beds, and absence of marine fossils.

In the Baltimore-Aberdeen region the Potomac Group and its subdivisions, the Patuxent, Arundel, and Patapsco Formations, have been described by Clark, Bibbins, and Berry (1911), Berry (1929), and Bennett and Meyer (1952). According to these descriptions, the contact between the Patuxent and Arundel and between the Arundel and Patapsco (or Patuxent and Patapsco if the Arundel is missing) is an erosional unconformity. The Arundel Formation, described as clay with a minor amount of sand, separates the Patuxent and Patapsco, which are mostly sand and gravel. Except where the Arundel Formation is present the Patuxent and Patapsco can probably be distinguished only by heavy minerals (Glaser, 1967, p. 219) or fossils (Brenner, 1963).

A three-fold subdivision of the Potomac Group is not indicated in the excellent exposures revealed by Aqueduct excavation. Contacts mapped by Mathews (1925) and Clark (1904) between the formations and exposed in excavation along the Aqueduct (Figures 18 and 19) show numerous discontinuities and gradational changes between sediments of different lithologies. Local hiatuses are impossible to distinguish from major erosional

unconformities. These features and the lack of any extensive clay or other beds make it inappropriate to subdivide the Potomac Group along the Aqueduct.

In addition heavy mineral and pollen and spore data suggest that one unit, the Patuxent, is present rather than three. Heavy mineral suites from seventeen sample localities have a staurolite-tourmaline-kyanite-zircon mineral assemblage. This assemblage is characteristic of the Patuxent facies; the Patapsco heavy mineral suites are mostly tourmaline, zircon, and rutile (Glaser, 1967, p. 219). Eight of the seventeen heavy mineral localities have been dated as Patuxent-Arundel (Zone 1 of Brenner, 1963) by pollen and sporomorph data. The average heavy mineral composition of samples from the eight localities is similar to the average of the seventeen localities (Table 10). Because of this similarity the nine localities undated by pollen and spore data are believed to be from the Patuxent-Arundel zone of Lower Cretaceous age.

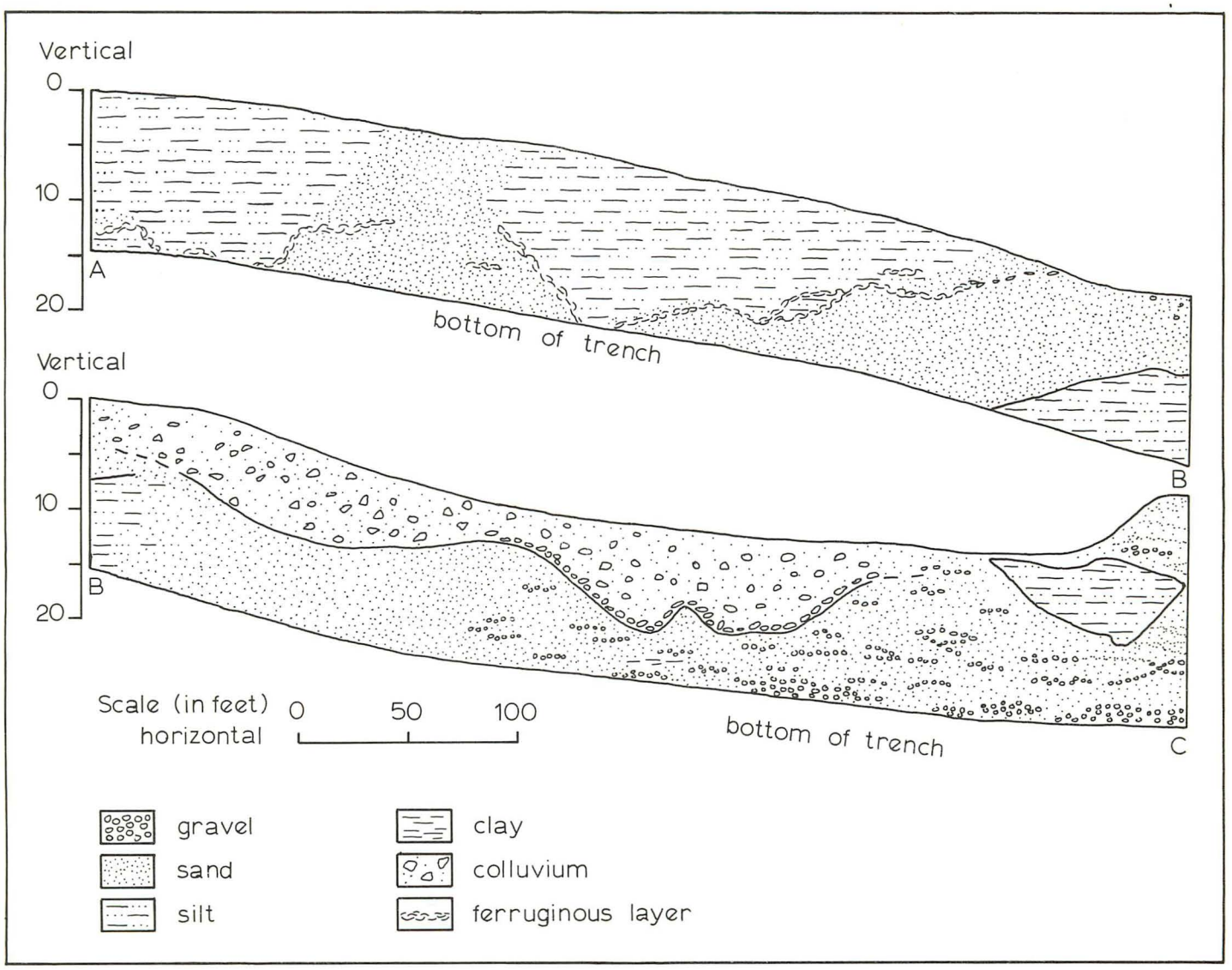


Figure 18. Lateral gradation of sediments across an area where a Patuxent-Arundel boundary was previously mapped. Location: Baltimore County, Subsection 3 and 4, stations 128 plus 00 (upper left) to 136 plus 00 (lower right). A boundary between the Arundel and Patuxent Formations supposedly occurs in the 800 foot exposure (Mathews, 1925). Instead the exposure shows lateral gradations between silt and fine to medium grained sand, and silt to fine sand to cross-bedded gravelly sand. A colluvial deposit of gravelly and sandy loam overlies the Potomac Group sediments between points B-C.

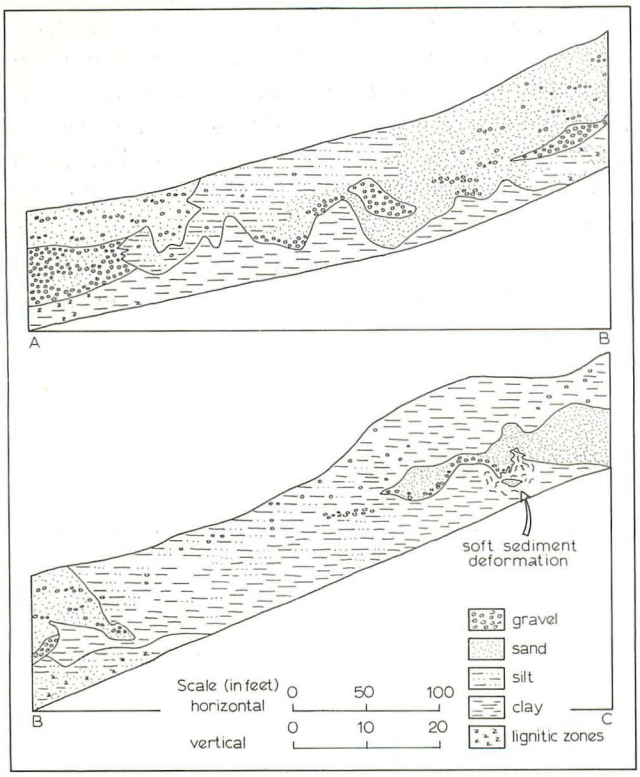


Figure 19. Cross-section showing an area in which a contact between the Patuxent and Patapsco Formations was previously mapped. Location: Harford County, Section 7, 187 plus 00 (upper left) to 195 plus 00 (lower right). The cross-section exposes a supposed boundary between the Patuxent and Patapsco Formations; the Arundel Formation is missing (Clark, 1904). Many hiatuses are evident, some of which probably are local ones, but one or more may be a major erosional unconformity. The cross-section also exposes facies changes (silt to sand, silt to clay) and abrupt lithologic variations in both horizontal and vertical directions.

Influence of sediment type on excavation and wall stability

The excavation of the sediments was influenced by engineering, hydrologic, and lithologic factors. Depth of excavation is an example of an engineering factor. A section of trench which averaged 24 feet deep was excavated in beds of clay, sand, and silty sand at a rate of 85 cu.yd./hr. This combination of the clay and sand in a trench of average depth (14 ft.) probably could have been excavated at about a rate of 130 cu.yd./hr. The 45 cu.yd./hr. difference indicates the influence of depth upon excavation rates.

Water saturated sediment is an example of a hydrologic factor. For instance, marshy ground just southwest of Clayton Road in Harford County consists of alluvial gravel, sand, and silt from 7 to 15 feet thick over saprolite. Under dry conditions the sediments could be excavated at an average of 220 cu.yd./hr. or better, (the average rate for saprolite) whereas the actual rate was 100 cu.yd./hr.

Conditions such as those described above were the exception. Usually, lithology of the sediments was the major factor influencing excavation rates, as well as wall stability. Ten percent of the material excavated was gravel, both in the Coastal Plain and in the Piedmont (Table 7). As used in this report gravel refers to sediment in which the clasts touch one another. Extensive deposits of gravel crop out in Subsections 2, 11, and 13. Characteristics of the gravel are summarized in Table 8.

The thickness of a gravel bed influences the rate at which the gravel can be excavated. Quaternary gravel beds 2 to 5 feet thick were excavated at 216 cu.yd./hr. (Figure 20). No thicker beds were encountered, and rate of excavation of beds thinner than 2 feet depended upon the adjacent sediment. In valleys excavation of gravel was complicated by high water table conditions.

Table 7. Sediment, saprolite, and rock excavated (by percent).

	Coastal Plain (Subsection 1-15)	Piedmont (Subsection 16)
saprolite	17	67
bedrock	4	14
gravel	10	10
sand	28	1
silt	15	--
clay	21	5
colluvium	2	2
peat	1	--
fill	3	1
	100	100

Table 8. Description of Cretaceous sediments.

Sediment Type	Lithology	Excavation and wall stability characteristics
Gravel	Red to yellowish brown, some beds grey or white. Matrix commonly sand, or less commonly, clay and loam; clasts mainly quartz and quartzite. Observed longest diameter of clasts: quartz-quartzite, 8 inches; sandstone - conglomerate, 27 inches.	Stable walls; beds 5 feet or less thick excavated at 216 cu. yd/hr.
Sand	Grey to white, less commonly yellowish to reddish brown, locally yellow, orange, or red. Fine to medium grained, locally coarse. Commonly cross-bedded, may be massive. Clay seams and partings in a few beds. Locally sands are lignitic. In places, layers of iron cemented sand and gravel.	Cave-ins common, due to ground-water or vibration in dry sand; rate of excavation, 364 cu yd/hr in sand, drops to 236 cu yd/hr in clayey sand.
Silt	Grey, yellowish brown, brown, locally green or pink. Commonly grades into sand or clay, locally lenticular.	Stable walls. No data on excavation rates.
Clay	Maroon to red, or grey to dark grey, may be black,brown, yellow, white, or pink. Commonly mottled. Texture varies from clay, to silty, sandy, or gravelly clay. Pure clay commonly tough, may be plastic, in one place soft and chunky. Many beds have vertical joints. Lignite and macerated plant matter in many grey and black clay layers.	Stable walls. Most difficult sediment to excavate, rates vary from 120 cu yd/hr. in tough clay to 229 cu yd/hr. in sandy clay.

The gravel consists of vein quartz and quartzite with minor amounts of iron cemented sandstone and quartz conglomerate. However, some gravel beds immediately overlying saprolite or bedrock contain minor amounts of crystalline rock clasts (Table 9).

Sand is the most common type of sediment, comprising 28 percent of the material excavated in the Coastal Plain and 1 percent of that in the Piedmont. Extensive deposits occur in Subsections 2, 4, and 6. Characteristics of the sand are summarized in Table 8.

Sand beds were the least stable wall material (Figure 16). Readjustment of the sand to its angle of repose plus contributing factors of ground-water saturation and/or vibration from construction equipment resulted in more failures in sand than in any other material. Cave-ins in water saturated sand were more common in Subsections 6, 9, and 13 than in any other Subsection.

Table 9. Composition of gravels at base of the Cretaceous.

Locality section: station	Distance above basement* in feet	lithology of clasts (in percent)	
		quartz and quartzite	others
6: 45+08	0-2	95	5 conglomerate
7: 133+93	less than 10	95	5 sandstone
7: 137+97	0-2	95	5 weathered gabbro
7: 173+15	less than 5	90	10 conglomerate, sandstone
7: 173+77	0-2	100	0----------
7: 175+88	3-4	100	0----------
7: 257+00	less than 10	80	20 gneiss saprolite
7: 263+40	3-4	100	0----------
7: 556+00	0-2	85	15 amphibolite

Twenty clasts were counted at each locality. A 10 by 2 foot grid was laid out on a vertical section and the lithology of the clast at each of 20 points was recorded.

*Basement is defined as saprolite, or crystalline bedrock if the saprolite is absent.

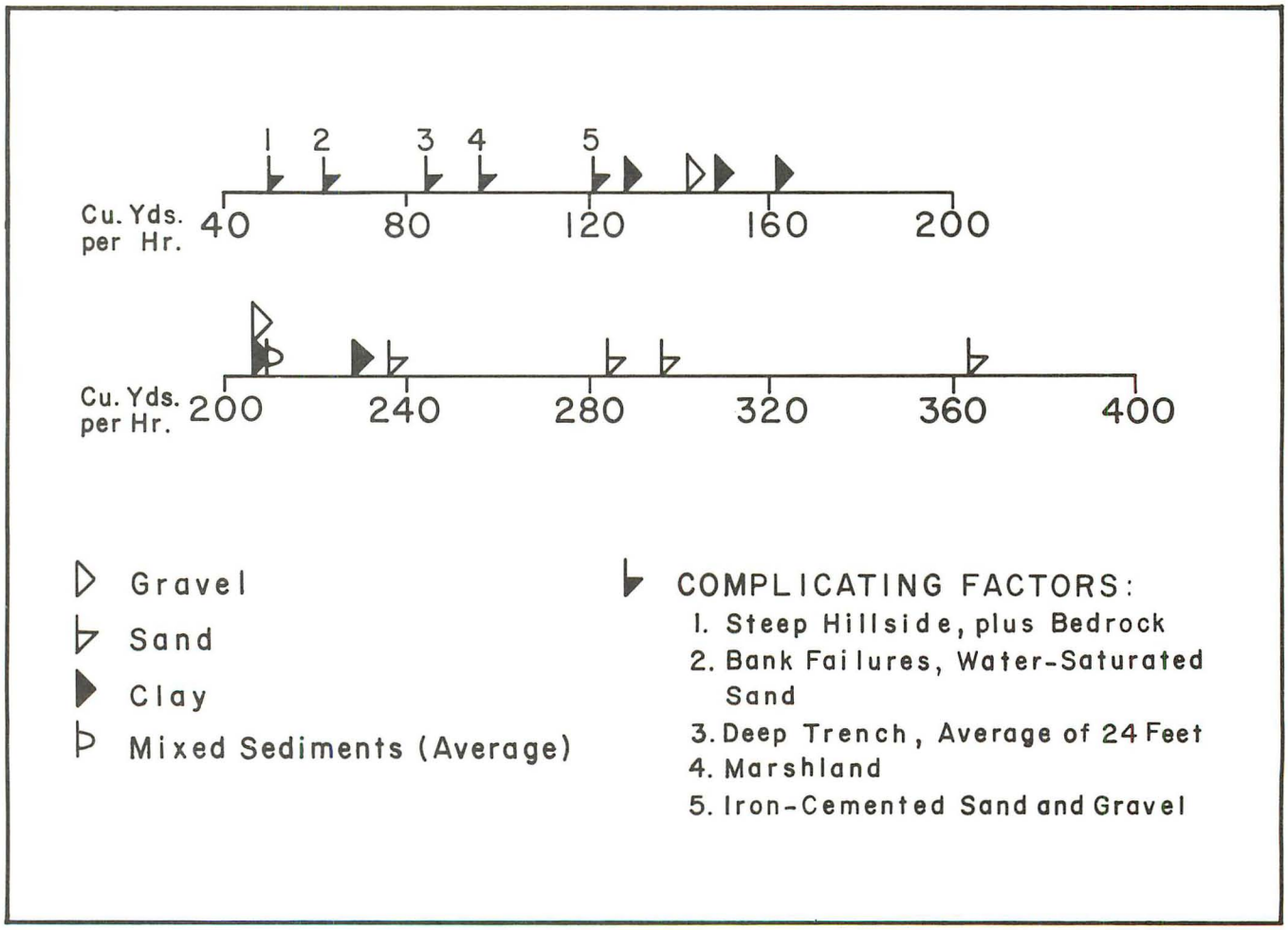


Figure 20. Excavation rates in sedimentary deposits.

Vibration was an important factor in failures in Subsections 2, 4, 6, and 17, and were reduced (or eliminated) by sloping the banks and reducing vibration in the sediments adjacent to the trench. Where sand beds were neither dry nor water saturated, vertical trench walls remained stable. Apparently the sand did not readjust to its angle of repose because of the cohesion provided by the moisture during the relatively short time the trench was open at any given point.

Except where cemented by iron oxide, sand beds are non-cohesive and easily moved by backhoes, but the rates varied considerably. Sand and gravelly sand was moved at a rate of 364 cu.yd./hr., but with increasing silt and clay content rates dropped to 236 cu.yd./hr. Many sands were permeable and the associated springs and seeps caused drainage problems and unstable walls. Because of cave-ins, the rate of excavation in water saturated sand dropped to as low as 62 cu.yd./hr.

Thin layers of iron-cemented sand and sandy gravel did not require blasting, but they were difficult for the backhoe to pick apart. One iron-cemented layer one to two feet thick was excavated at 121 cu.yd./hr.

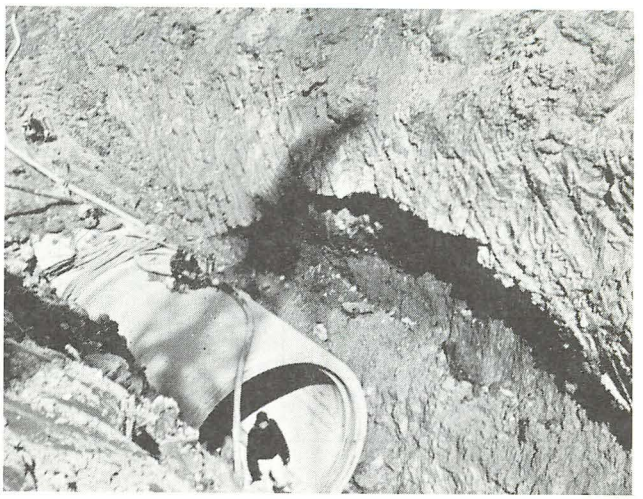
Silt, which is less extensive than sand along the Aqueduct, averages 15 percent of the earth materials. Lenses and layers of silt are common, but silt may also grade into sand or clay. Silt walls are stable.

Clay deposits average 21 percent of the earth materials in the Coastal Plain and 5 percent in the Piedmont. The characteristics of the clays are summarized in Table 8.

Clay is generally the most difficult sediment to excavate. Along the Aqueduct the clay varies from dense, tough, and very cohesive to a sandy and silty mixture which is less cohesive. The change in cohesiveness has a marked affect on excavation rates. Dense, tough clay could be moved at a rate of 120 cu.yd./hr.; silty and sandy clay at 216 to 229 cu.yd./hr. The variation in excavation rates could probably be predicted from the drilling rates through the clay beds.

Clay is a stable wall material (Figure 16). Only one failure occurred (Figure 21), and that in soft clay.

Lignitized plant fragments and macerated plant matter are present in many of the grey, dark grey,



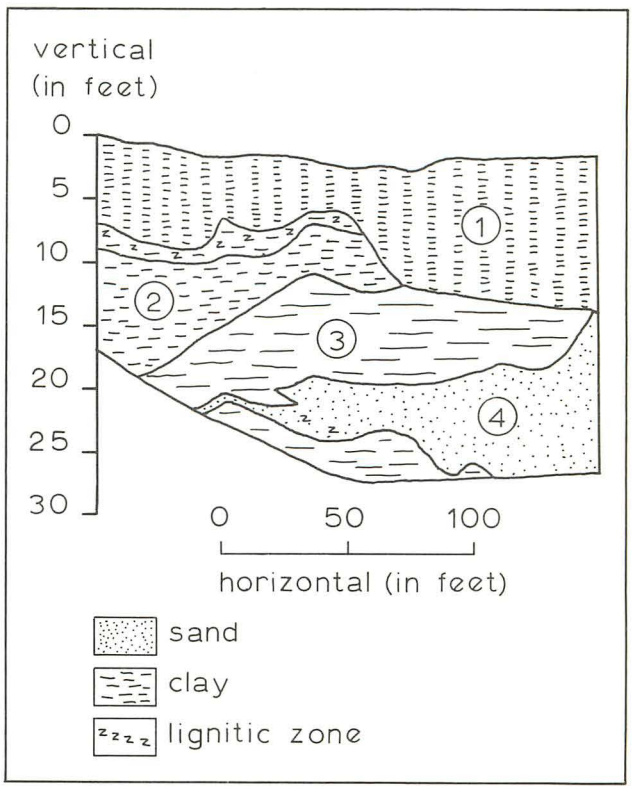


Figure 21. Bank failure in clay. Location: Baltimore County, Subsection 5, vicinity of station 160 plus 50. (a) Photograph of bank failure. (b) Sketch of geology. The bank failure took place in unit 2, a soft grey clay, and caused undermining and collapse of parts of unit 1, a plastic maroon and red clay, and the lignitic greyish black clay beneath unit 1. Unit 3, a tough light grey clay, did not fail. Unit 4 is a partly cemented, massive, grey and brown medium grained sand. The striations on the clay are hoe marks.

Table 10. Frequency of heavy minerals in Cretaceous sand beds (in percent). (Samples arranged geographically from south to north).

Sample No.*	opaques	kyanite	staurolite	tourmaline	rutile	zircon	amphibole	brookite	chloritoid	epidote-clinozoisite	garnet	sillimanite	monazite	sphene	altitude above saprolite-rock (in feet)
5[1]	69	8	27	45	7	3	1	7	1	1	-	-	-	-	25
6	65	16	36	34	2	3	5	2	-	1	-	-	-	1	25-50
7	81	5	18	54	8	5	2	5	T	-	T	-	3	-	50-75
11[1]	80	8	25	31	4	15	3	10	-	1	T	-	-	2	25-50
12	82	7	22	37	18	7	2	7	-	T	T	-	-	-	25-50
13	81	3	10	31	12	36	3	5	-	T	-	-	-	-	75-100
17[1]	86	1	13	58	12	5	7	-	2	-	-	-	2	-	0-5
19	78	7	19	50	5	10	-	7	T	1	-	T	-	1	25-50
22	70	11	34	42	4	3	-	5	1	T	T	T	T	-	less than 25
26	71	3	4	77	3	3	1	7	1	1	1	-	1	-	less than 5
28[1]	60	10	37	39	3	1	3	2	-	5	-	-	-	-	0-5
36[1]	65	11	44	22	4	2	12	T	-	5	-	T	-	-	0-5
40[1]	91	2	16	45	5	18	2	2	-	9	1	-	-	T	less than 25
43[1]	87	4	8	48	6	12	10	3	1	6	T	1	1	-	20-25
46[1]	74	3	4	40	1	3	38	T	1	5	5	-	-	-	0-5
53	94	2	14	44	6	25	3	-	-	6	-	T	-	-	less than 5
64	65	8	60	13	1	1	1	1	-	1	-	2	-	2	15-25
Average	76	7	23	42	6	9	6	4	T	2	T	T	T	T	
Avg. of 8 pollen dated samples	75	6	22	41	5	7	10	3	T	4	1	T	T	T	

[1] Dated by pollen and sporomorphs

* See Figure 3 for location.

and black clays. In some places, plant matter is disseminated through a clay layer; in others it forms thin layers and lenses in the clay. The plant fragments are greatly compressed and flattened. In some lignitized plant fragments, marcasite forms pseudomorphs of twigs and branches or, more commonly, replaces the interior of a branch or twig. Marcasite branches, or branches with marcasite interiors, are compressed very little, if at all.

The clay has joints that are vertical, or nearly so, and many show a filigree-like pattern of rootlets, or impressions of rootlets. In maroon clay, the joint surfaces are grey, which suggests that the organic matter has reduced the iron in the immediately adjacent clay.

The gravel, sand, silt and clay in the Coastal Plain occur in lenses and layers of irregular thickness and extent. These lenses complexly intertongue with the consequence that the excavated sediments are generally a mixture of two or more lithologies. Mixed sediments could be moved at an average rate of 209 cu.yd./hr., which varied from a high of 249 cu.yd./hr. to a low of 169 cu. yd./hr., depending upon the proportion of gravel, sand, silt, and clay.

Heavy minerals

The heavy minerals in the 1/2 - 1/16 mm. sand fraction were studied to compare them to heavy minerals in the saprolite, and to heavy minerals in Quaternary sand beds. The samples were selected on the basis of geographic distribution, proximity to saprolite, and proximity to pollen and spore bearing clay beds. By being able to determine the age of the sediments from pollen and spores and correlate this with the heavy mineral samples, the heavy mineral assemblage may be used to identify Potomac Group sediments in areas where pollen and spores are absent. This correlation, in turn, identifies the Potomac Group sediments for the engineer, who may then expect to find sediments in which the lithology changes abruptly from one type to another.

Non-opaque minerals comprise 24 percent of the Cretaceous heavy mineral suites (Table 10). These minerals and those in the Quaternary sediments are similar in properties to those described in Krumbein and Pettijohn (1938). In the Cretaceous samples the major non-opaque heavy minerals are tourmaline and staurolite. Minor minerals are zircon, kyanite, rutile, amphibole, brookite, and epidote-clinozoisite. Present in trace amounts are chloritoid, garnet, sillimanite, monazite, and sphene.

Eight sample localities in the Patuxent-Arundel zone (Zone 1 of Brenner (1963)) have been dated by pollen and spores. The average heavy mineral composition from the eight pollen site assemblages is similar to the average of the seventeen suites (Table 10). Because of this similarity the nine suites not dated by pollen and spores are also considered to be from the Patuxent-Arundel zone (Lower Cretaceous) of the Potomac Group.

Amphibole, and epidote-clinozoisite exhibit an upward decrease in frequency (Table 11). The combined percentage of tourmaline-zircon-rutile, the most chemically stable heavy minerals, and staurolite, intermediate in stability, were also plotted because they might be expected to vary and because they are important minerals in the heavy mineral assemblages. The combined frequency of tourmaline, zircon, and rutile generally increases from the base upward, as does the ratio of tourmaline-zircon-rutile to staurolite (Table 11, column 5), but the number of samples is too limited to indicate a trend.

The heavy minerals in the Cretaceous sediments do not vary systematically in frequency laterally along the Aqueduct. But in the Quaternary sediments kyanite and staurolite exhibit lateral variation (Table 17). They are found in sand deposited by streams that drain Wissahickon terrain (Glenarm areas, Figure 1).

Table 11. Frequency distribution of selected heavy minerals versus height above the base of the Cretaceous (in percent).

		Column					
		1	2	3	4	5	6
Height above base of Cretaceous (in feet)	Number of samples	amphibole	epidote-clinozoisite	tourmaline-zircon-rutile	staurolite	ratio: column 3 to 4	ratio: fresh staurolite to etched staurolite
76-100	1	3	0	79	10	8/1	1/1
51-75	1	2	0	67	18	4/1	1.9/1
26-50	4	2½	1	54	26	2/1	2.5/1
6-25	5	3	3	51	29	2/1	3.4/1
0-5	6	11	4	58	19	3/1	2.6/1
Average frequency percent	-	6	2	57	23	-	-

Source Area

A Piedmont source area for the Potomac Group sediments along the Aqueduct is indicated by lithologies of pebbles and by heavy minerals. Vein quartz and quartzite make up most of the gravel (Table 9) ; present in small amounts are saprolite, weathered rock, and fresh rock clasts of gabbro, amphibolite, schist, and gneiss. No chert, limestone, or other rocks were found which would indicate a source area in the Appalachian Province.

The non-opaque heavy mineral suite indicates that the sediments were derived from a metamorphic rock terrane. Tourmaline and staurolite, which are abundant heavy minerals in nearby felsic schist and gneiss, comprise the bulk of the suite.

The amphibole and epidote-clinozoisite were probably derived from a belt of mafic rocks adjacent to the Aqueduct (Figure 1). These rocks, and the saprolite developed on them, contributed amphibole and epidote-clinozoisite to the lowermost sand beds of the Potomac Group. This source area was later buried, as indicated by: (1) isolated Potomac Group outliers on the Piedmont; (2) finger-like extensions of Potomac Group sediment which cap ridges; and (3) decrease upward in abundance of amphibole and epidote-clinozoisite. Intrastratal solution has affected amphibole, but is not the major factor in the vertical decrease in abundance of this mineral. This conclusion is suggested but not proved by the ratio of fresh staurolite grains to etched ones (Table 11, column 6). Staurolite has apparently not been selectively attacked by intrastratal solution. This suggests that the amphibole has not been, either.

The lack of rounding of staurolite and tourmaline also suggests that the Piedmont Province was the source area of the Potomac Group. Staurolite and tourmaline grains in the sand beds are predominantly angular; particles of the same minerals in the saprolite suites are only slightly more angular (Table 12).

Not only do the sediments come from the Piedmont, but also this source had less relief than it does at present. Topographic profiles of the saprolite surface buried beneath the Potomac Group sediments and of the Fall Zone adjacent to the Aqueduct suggest this (Figure 7). The maximum relief on the saprolite surface is 100 feet (profile B-B′). This surface has less relief than that shown in profile A-A′ (a profile of the topography developed on crystalline rock and saprolite in the Fall Zone adjacent to the Aqueduct). In profile A-A′, stream dissection presumably of Pleistocene age is apparent; Winters Run, Plumtree Run, a tributary of Winters Run, and Bynum Run have cut through the cover of saprolite and are eroding weathered rock and fresh rock. These profiles, the chemical maturity of the Cretaceous heavy mineral suites, which contrasts to their mechanical immaturity, and the chemical maturity of the clasts in the gravel beds indicate that the Piedmont terrain was strongly affected by chemical weathering in early Cretaceous or pre-Cretaceous time.

Table 12. Rounding of tourmaline and staurolite grains (1/2 - 1/16 mm) in Cretaceous and saprolite heavy mineral suites. (Roundness scale of Rittenhouse, 1948, p. 12. Fifty grains per sample were counted).

Potomac Group heavy mineral suites		Percent of grains angular	subangular
(1) Tourmaline			
Sample	11	92	8
	28	94	6
	40	96	4
	43	100	0
	46	100	0
(2) Staurolite			
Sample	11	96	4
	28	96	4
	40	100	0
	43	100	0
	46	96	4
Saprolite suites			
(1) Tourmaline			
Sample	24	100	0
	21	98	2
	20	98	2
(2) Staurolite			
Sample	29	100	0

Table 13. Pollen and spore analyses of two Quaternary samples (analyzed by Arthur Knox, U.S. Geological Survey).

No. 33[1]	percent total	percent arboreal pollen	No. 47[2]	percent total	percent arboreal pollen
Bryophytes	2.2		Bryophytes	1.3	
Filicineae	16.2		Filicineae	0.2	
Lycopodiaceae	0.4		Lycopodiaceae	1.9	
Isoetes	1.7		Pinus (pine)	26.9	32.4
Pinus (pine)	14.1	18.2	Picea (spruce)	54.4	65.5
Tsuga (hemlock)	1.3	2.0	Larix (larch)	0.2	0.2
Taxodium (cypress)	0.9	1.3	Abies (fir)	2.9	
Gramineae	2.6		Juniperus (juniper)	0.2	
Cyperaceae	1.7		Potomogeton	0.9	
Carya (hickory)	9.2	14.2	Gramineae	0.2	
Alnus	1.3		Cyperaceae	5.9	
Fagus (beech)	11.4	17.4	Betula (birch)	1.1	1.3
Castanea (chestnut)	0.4	0.7	Populus (poplar)	0.3	0.3
Quercus (oak)	28.0	42.9	Alnus	0.3	
Liquidamber (sweetgum)	0.9	1.3	Quercus (oak)	0.3	0.3
Platanus	0.4	0.7	Nympheaceae	0.2	
Rosaceae	1.3		Dryas cf.	0.2	
Ilex	0.4		Cruciferaceae	0.2	
			Rosaceae	0.2	
Nyssa	0.9	1.3	Rhamnus	0.3	
Compositae	2.6		Ericaceae	0.3	
			Labiatae	0.1	
other	2.1		Galium	0.1	
			others	1.4	
Total	100.0	100.0	Total	100.0	100.00
Arboreal pollen	65.6			87.0	
Non-arboreal pollen and spores	34.4			13.0	

1. Age: Quaternary, postglacial or interglacial. Remarks: peat in alluvium: appears to be a leaf mould deposited in a wet, shaded environment. No evidence of standing water. Formed under climatic conditions similar to present. Location: Winters Run, Subsection 12, 108+51.

2. Age: Pleistocene, glacial. Remarks: peat layer in channel fill; a sedge or marsh peat. Area was covered with a boreal coniferous forest; climate much colder than present. Location: Bynum Run area, subsection 14, station 268+45.

QUATERNARY SEDIMENTS

Stratigraphy and age

Quaternary deposits in the Baltimore region have been divided into Upland and Lowland deposits (Bennett and Meyer, 1952, p. 68). Upland deposits form thin caps on ridges generally above 50 feet in altitude, and include the Sunderland and Wicomico Formations of previous authors (Shattuck, 1906; Clark, 1904). Lowland deposits are mostly below 50 feet and include floodplain deposits, and sediments formerly mapped as Talbot Formation (Bennett and Meyer, p. 68). Previously unmapped deposits include loam in depressions and hollows on Potomac Group sediments and alluvial deposits in valleys in the Piedmont.

Pollen and spore data (Table 13) and radiocarbon dates indicate a Quaternary Age for Lowland alluvial deposits in Winters Run and in an abandoned stream channel adjacent to Bynum Run. Two samples dated by radiocarbon (Meyer Rubin, U.S. Geological Survey) are listed below: No. 30, 6310 ± 250 yrs. BP, Winters Run, Subsection 12, Station 102 + 15; No. 47, >32,000 yrs. BP, Bynum Run area, Subsection 14, Station 268 + 45. Lowland deposits in other areas are also believed to be Quaternary because the heavy minerals in the sand beds, lithology of the gravel fraction, and topographic setting are similar.

Lowland deposits

Distribution and lithology: Lowland deposits are extensive in four areas, Clayton Road, Winters Run, Bynum Run, and James Run and small deposits are present in Whitemarsh Run, Stemmers Run, and Gunpowder Falls. The deposits occur in the floodplains of the streams, and range from 2 to 18 feet in thickness. In Winters, Bynum, and James Runs the deposits are predominantly gravel and silt and those at Clayton Road are mainly sand (Table 14).

Gravel is the most extensive of the floodplain sediments. In Winters Run, James Run, and Bynum Run, gravel layers vary from 1 to 7 feet thick, and have a continuous horizontal extent of 1,000 feet in James Run, 340 feet in Bynum Run, and 1,800 feet in Winters Run. Gravel beds of similar thickness and extent were not encountered in the Cretaceous sediments in the Aqueduct.

Table 14. Description of Quaternary Lowland sediments.

1. Gravel: Brown, yellowish brown. Beds are massive, interstices filled with medium to coarse grained sand. Locally cemented by iron oxide. In places, reworked saprolite incorporated into basal few inches of gravel. Clasts tabular to equidimensional. Observed longest diameter, 36 inches.
2. Sand: Brown, yellowish brown, reddish brown; in places, grey, green or black. Fine to medium grained, locally coarse. Varies from sand to clayey, silty, and gravelly sand. May be crossed bedded.
3. Silt: Brown, yellowish brown, greyish brown, in places, grey. Poorly sorted, commonly clayey or sandy silt.
4. Clay: Grey, black, reddish brown, may be mottled brown or grey. Massive. Gravel clasts common.

The gravel beds contain numerous clasts of crystalline rock and saprolite in contrast to the quartz and quartzite in the Cretaceous gravel beds. Four pebble counts indicate a range of 30 to 75 percent non-quartzose clasts (Table 15). In a few places weathered rock or saprolite comprise more than 25 percent of the clasts. The non-quartzose clasts come from exposures of fresh rock, weathered rock and saprolite in the stream bed or valley sides, or both. Quartz and quartzite come from quartz veins and quartzite layers in the crystalline rock and from Cretaceous gravel. Saprolite clasts are considered to be primary; that is, clay-like balls of saprolite are incorporated into the deposits as saprolite and not altered to saprolite after deposition.

Geomorphological and sedimentological features: Along the Fall Zone streams issuing from the Piedmont cut down through the saprolite cover into bedrock and as they emerge onto the Coastal Plain are eroding Coastal Plain sediments. Along the Aqueduct downcutting and lateral planation by the streams is best illustrated at James Run, Bynum Run, and Winters Run. Cross-sections of the streams (Figure 22) show pronounced escarpments and a series of planed surfaces each at different heights, an occurrence which suggests successive periods of downcutting. Four surfaces, and their deposits are preserved at James Run, but only two at Winters Run and two at Bynum Run. Each stream has the same base level, Chesapeake Bay, or the ancestral Susquehanna River in Late Wisconsin time. The altitude and width of the cut surfaces in the three streams are tabulated in Table 16.

Table 15. Lithology of clasts in seven Quarternary gravel deposits.

	Location	Distance above bedrock/saprolite (feet)	Lithology of clasts (in percent)				
			quartz, quartzite	gabbro, amphibolite	schist, gneiss	Weathered Rock	Saprolite
Lowland deposits	Gunpowder Falls Section 6: station 403+15	10	70	--	5	20 (gabbro, gneiss)	5 (schist)
	Bynum Run 7: 284+89	0-4	60	20	10	--	10 (gabbro, geniss)
	James Run 7: 302+43	0-1½	35	60	5	--	--------
Piedmont Province deposits	Piedmont Valley alluvium 7: 397+50	0-3	25	30	-	5 (gabbro)	40 (gabbro)
	Piedmont Valley alluvium 7: 463+00; Grays Run	0-4	25	70	-	5 (gabbro)	--------
	Cranberry Run, basal gravel 7: 531+32	0-1	50	35	15	--	--------
	Cranberry Run, gravelly sand 7: 531+32	1-3	55	10	30	--	5 (gabbro)

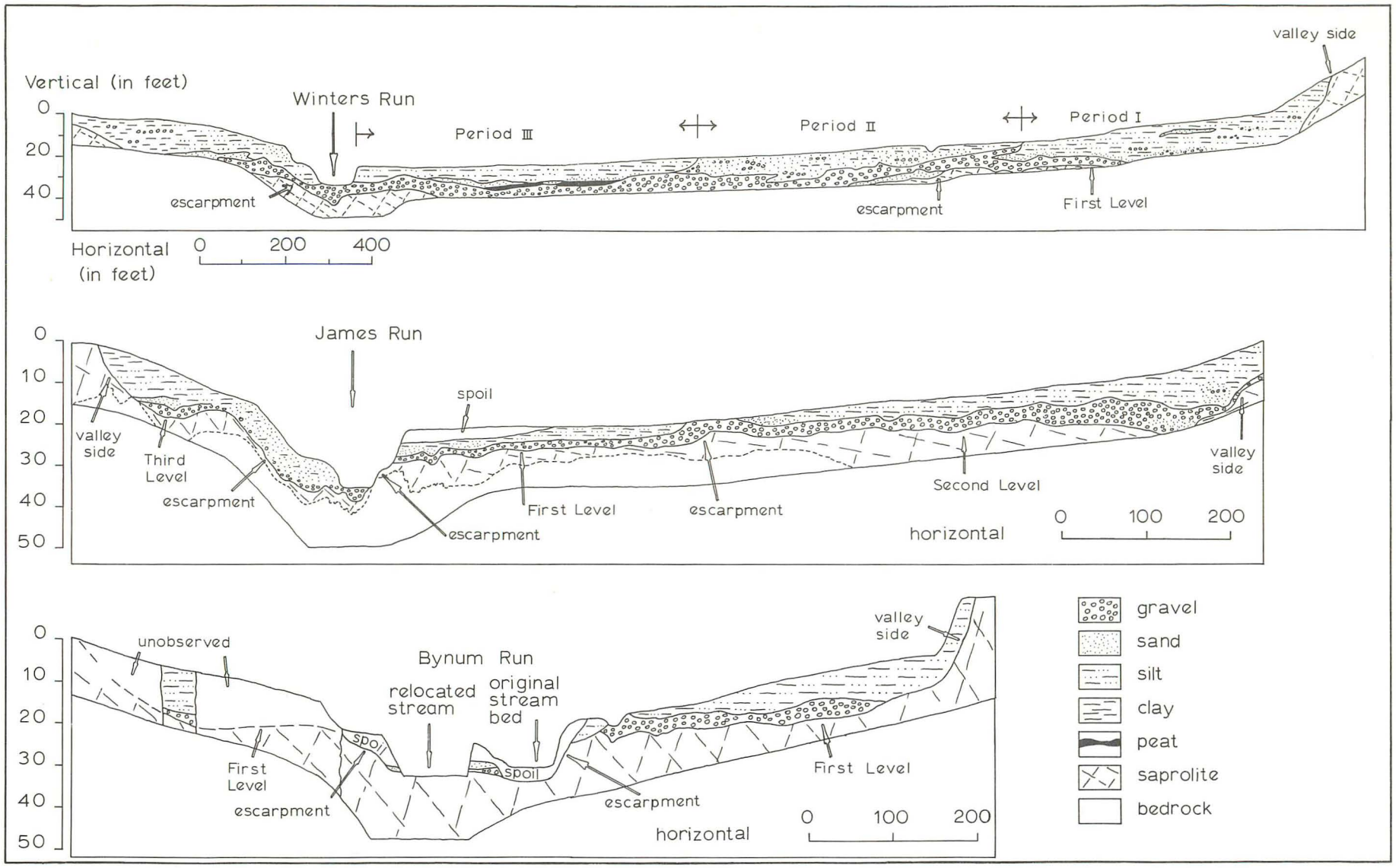


Figure 22. Geologic cross-section of Winters Run, James Run and Bynum Run.

James Run, Bynum Run, and Winters Run have eroded pronounced escarpments at the outer margins of their valleys and have cut surfaces on crystalline bedrock and saprolite beneath the alluvial deposits in the valleys. The most impressive valley margin escarpment, on the northwest side of Winters Run, rises 69 feet above the stream bottom (Figure 22). The escarpments bordering James Run rise 64 feet above the stream bottom on the northwest side and 48 feet on the southeast. At Bynum Run, the relief is 40 feet on the northeast escarpment and 53 feet on the southwest one.

By way of contrast, Stemmers Run and Gunpowder Falls are incised into saprolite and bedrock. Above the gorge in Gunpowder Falls, two cut surfaces are present on each side, but none occur within the gorge (Figure 10). At Stemmers Run, two cut surfaces occur in the gorge.

The ground surfaces at James Run, Bynum Run, and Winters Run show no relationship to the surfaces cut on bedrock, the escarpments between the surfaces, or the alluvial deposits (Figure 22). However, the basal gravel deposits parallel, and, in part, mirror the underlying cut surfaces and escarpments. This feature is best illustrated in James Run.

The alluvial deposits crossed by the Aqueduct in James Run, Bynum Run and Winters Run each represent a single fluvial cycle of deposition. The thickness of sediment in a cycle varies from 5 to 18 or more feet. From one side of a valley to the other, a number of cut and fill sequences can be recognized. For example, in Winters Run, at least three such sequences are present. A cycle consists of a lower, gravel unit, and an upper, sand-silt-clay unit (Figure 23). The lower unit represents the bed load deposited by the stream. The gravel

Table 16. Altitudes* and widths of surfaces cut on bedrock and saprolite in James Run, Bynum Run and Winters Run (in feet).

		James Run		Bynum Run		Winters Run	
		altitude	width	altitude	width	altitude	width
Modern Stream		6-9	110	10	200	19-27	1325
First Level	southwest side	---	---	20-30	200	34-40+	380
	Northeast side	15-19	350	20-30	320	34-36+	750
Second Level	Southwest side	----	---	-----	---	------	---
	Northeast side	21-26	550	-----	---	------	---
Third Level	Southwest side	27-29	75	-----	---	------	---
	Northeast side	-----	---	-----	---	------	---
Valley Sides	Southwest side	54	---	63	---	59	----
	Northeast side	70	---	50	---	88	---

*Altitude is referenced to the Baltimore City datum, mean low tide. The formula to convert to U.S. Geological Survey elevation is U.S. Geological Survey elevation plus 0.83 feet equals City elevation.

is generally massive; bedding is evident only where sand lenses occur or where the lower unit becomes very sandy.

The upper unit contains overbank and point bar deposits which consist of sand and silt with a few lenses of clay, peat, and gravel. In the overbank deposits three episodes of deposition can be recognized by the top of the peat layer, and three paleosols (Figure 23). The surfaces occur at progressively higher elevations and indicate periods of non-deposition. The three paleosols in Winters Run are the only ones identified in the three Runs. Each paleosol is developed on silt and consists of an upper greyish black silt which is two to three inches thick over a brown, platy layer that grades downward to brown and yellowish brown silt.

The alluvial deposits also preserve evidence of fluvial erosion, especially in Winters Run valley (Figure 22). Three periods of erosion and deposition can be identified in the upper unit, Period I, the oldest, Period II, intermediate in age, and Period III, the youngest. In each case, the younger deposit truncates and partly overlaps the older deposit.

In the James Run cross-section, two erosional-depositional periods can be identified on the northeast side of the Run. The boundary between the two is marked by the scarp between the first and second cut surface levels, and by the sharp break in the upper surface of the basal gravel. A third period is suggested by the third level cut surface and the alluvial deposits on it.

The cutting of a particular surface and the covering of it by bed load deposits probably occurred penecontemporaneously. This synchroneity is suggested by the coincidence of the modern James Run and Winters Run with the basal gravel.

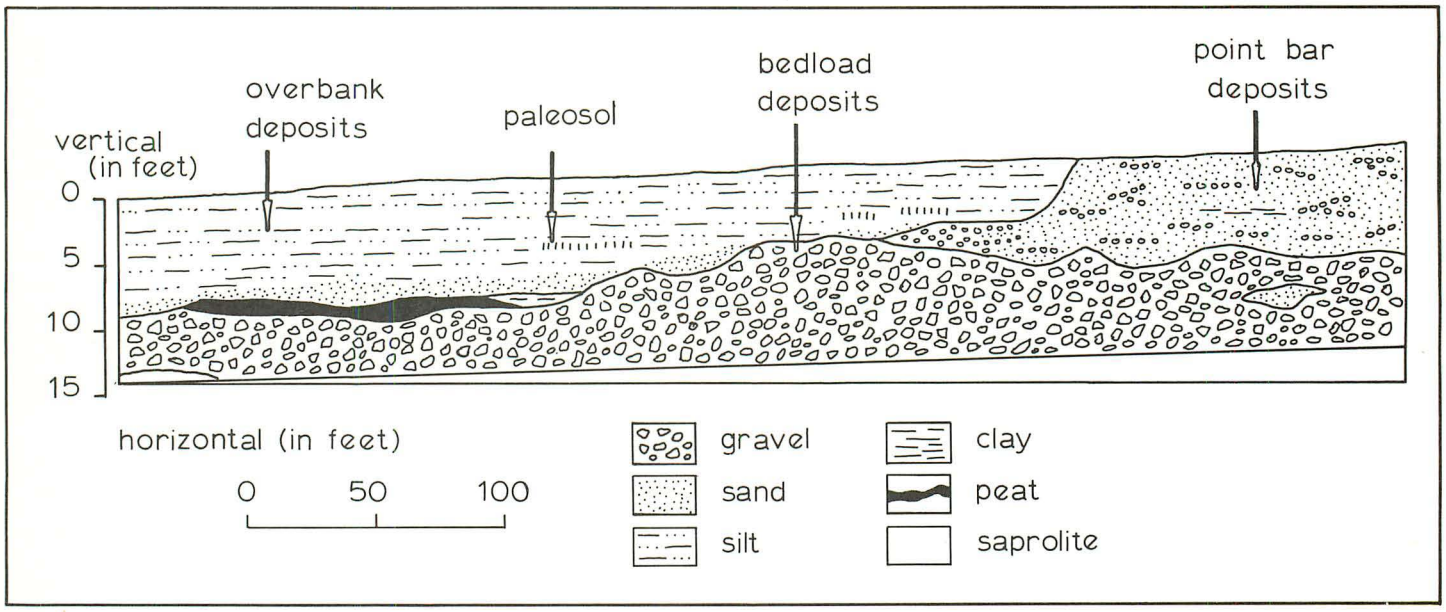


Figure 23. Fluvial cycle in Winters Run alluvial deposits. Location: Harford County, Subsection 12, station 103 plus 00 to 108 plus 00. See text for explanation.

Upland deposits

Upland alluvial deposits, mapped as Sunderland Formation by Mathews (1925), cover surfaces cut on rock and saprolite at Gunpowder Falls (Plate 2). On the northeast side, the lower surface at 102-108 feet elevation is thinly covered by a brownish red gravelly loam. The upper surface (129 + feet) is covered by gravel more than 15 feet thick. The gravel, reddish brown and poorly sorted, is like Quaternary Lowland gravel (Table 15) as it contains a high percent of non-quartzose clasts. Cross-bedded yellowish to brownish red sand lenses occur in the gravel.

The sediments on the southwest side of the Falls consist of loam, clay, silt, sand, and minor gravel. The lower surface (95-100 feet) is overlain by a reddish brown very gravelly loam. Lag gravel 2 inches to 3 feet thick lies on saprolite. The upper surface (105 + feet) is overlain by three units which thin and thicken abruptly in both horizontal and vertical directions. The units include a brown gravelly silt-clay, brownish orange sand, and very micaceous brownish red to maroon cross-bedded gravelly sand.

Loam

Loam, presumably of Quarternary age, fills many hollows on the Potomac Group sediments. Loam averages 3 percent of earth material excavated and ranges from zero to 7 percent (in Subsection 2). The deposits have a low density and proved quite sensitive to vibration, resulting in some of the worst wall stability conditions encountered.

Deposits of loam are excavated with an ease approaching that of sand, but unstable wall conditions slowed excavation rates. Two large deposits are crossed by the Aqueduct; one, in Subsection 2, was excavated at 169 cu.ft./hr. and the other, in Subsection 4, at 155 cu.yd./hr. Both rates are over 100 cu.yd./hr. less than the average rate for sand.

The loam deposits originate in at least three ways. First, loam may accumulate in draws, depressions, or at the base of steep slopes by the processes of soil creep and overland flow of water. Second, loam may be developed by soil forming processes. Loam deposits developed in these two ways are illustrated in Figure 24.

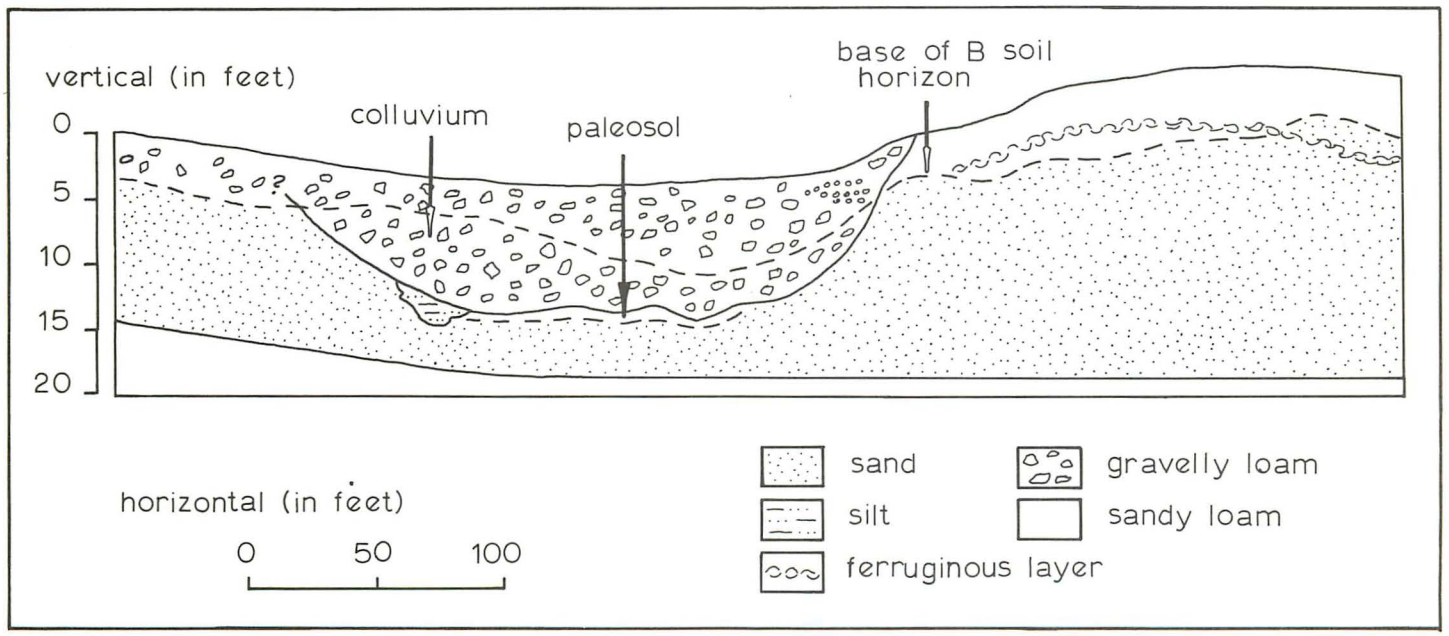


Figure 24. Geologic cross-section illustrating loam deposits formed by soil creep and overland flow and by soil forming processes. Location: Baltimore County, Subsection 2, station 96 plus 80 to 101 plus 80. Two loam deposits are illustrated in the cross-section: (1) gravelly loam has accumulated as colluvium in a depression, apparently by soil creep and overland flow of surface water; the colluvium has buried an old soil, and part of the B soil horizon has been preserved. Gravel stringers in the colluvium indicate a limited period of stream flow. (2) To the left of the colluvium, a gravelly loam has developed by soil forming processes, and to the right a sandy loam has developed. Both the gravelly and sandy loam soil profiles have developed on a white fine grained sand.

Loam may also develop by movement of ground water from the subsurface to the surface. At times of high water table, ground water moves from sand and sandy gravel into draws as base flow. The water carries ferrous iron in solution and clay size particles in suspension. The clay is deposited as a thin coat on sand particles. As the water moves from an oxygen deficient environment into one with sufficient oxygen to react with the soluble ferrous iron, the iron is precipitated as ferric oxide.

Piedmont Province deposits

Sedimentary deposits in the Piedmont Province, between Creswell Road and Maryland Route 22, consist of alluvial deposits and minor amounts of colluvium. The alluvial deposits are of two types, one thought to be Quaternary, the other probably much older.

Type 1 deposits, interpreted as Quaternary, occur in the dissected terrain between Creswell Road and the north side of Grays Run. They are characterized by a lower gravel unit and an upper gravelly clay unit (Figure 25). Sand layers are rare. The gravel commonly extends all the way across the valley, and merges with gravelly colluvium on the flanks, as illustrated on the left side of "unnamed run" and the right side of Grays Run.

The gravel in these deposits is poorly sorted and has a grain supported framework. The matrix of the gravel ranges in texture from sand, to clayey sand, to sandy clay and varies in color from brown to grey to brown mottled grey. Gravel counts in Grays Run and "unnamed run" show similar lithologies (Table 15). However, the number of saprolite clasts varies considerably, and probably reflects a contrast in exposure of fresh rock and saprolite in the two drainage areas. The saprolite at the contact with the gravel is commonly reworked and incorporated in the lower part of the gravel. In a few places fresh gabbro clasts have been pressed into the surface of the saprolite. The gravel-saprolite contact is usually a spring zone.

The gravelly clay lies upon the basal gravel, except towards the sides of some valleys where it rests directly on the saprolite. The clay varies from yellowish brown, to brown, to grey. In a few areas the brown clay is mottled grey. Gravel clasts in the clay are quartz and gabbro.

Sand layers are rare, the only noteable one being exposed at "unnamed run". Heavy mineral analysis, sample 59, shows a suite which is dominated by hornblende and epidote (Table 17).

The older, type 2, possibly pre-Quaternary deposits, occur in the upland between Grays Run and Maryland Route 22. Two deposits, both alluvial in origin, were crossed by the Aqueduct, one at Stepany Road and the other at Cranberry Run.

At Cranberry Run sand predominates over gravel and clay (Figure 25). The gravel is poorly sorted, has a grain supported framework, and a brown clayey sand matrix like the other Quaternary deposits. The gravel rests on saprolite and some saprolite is reworked into the basal part. A grey to bluish-grey gravelly sand overlies the gravel. The clasts are similar in lithology to those in the basal gravel (Table 15). Bluish grey clayey sand with occasional pebbles and boulders of gabbro and amphibolite overlies the sand. At the top is a brown gravelly silty clay.

A Quaternary age for Type I deposits in inferred from the similarity of the heavy minerals (Table 17), gravel lithology, and topography, to Quaternary deposits in Winters Run, James Run, and Bynum Run. One heavy mineral analysis, No. 59, indicates a suite similar to other Quaternary age sediments (Table 17). The gravel is similar to other Quaternary gravels, consisting of crystalline rock, gabbro, amphibolite, and gabbro-gneiss.

The older, type 2 sediments referred to as Quaternary (?) are apparently younger than the Potomac Group and may be Tertiary.

Heavy minerals

The heavy mineral assemblages from streams rising in the eastern Piedmont of Harford and Baltimore Counties (Table 17) contrast greatly with assemblages reported for Quaternary sediments deposited by the ancestral Potomac (Schlee, 1957) and by the ancestral Delaware (Jordan, 1964) both of which originated in the Appalachians. The contrast is two-fold: first, in frequency percentage of opaque minerals and second, in major non-opaque heavy minerals (Table 18). Both the ancestral Potomac and Delaware sediments contain greater percentages of opaque minerals (83 percent, Potomac, and 77 percent, Delaware) than the local streams (25 percent). The major non-opaque minerals also differ: zircon and

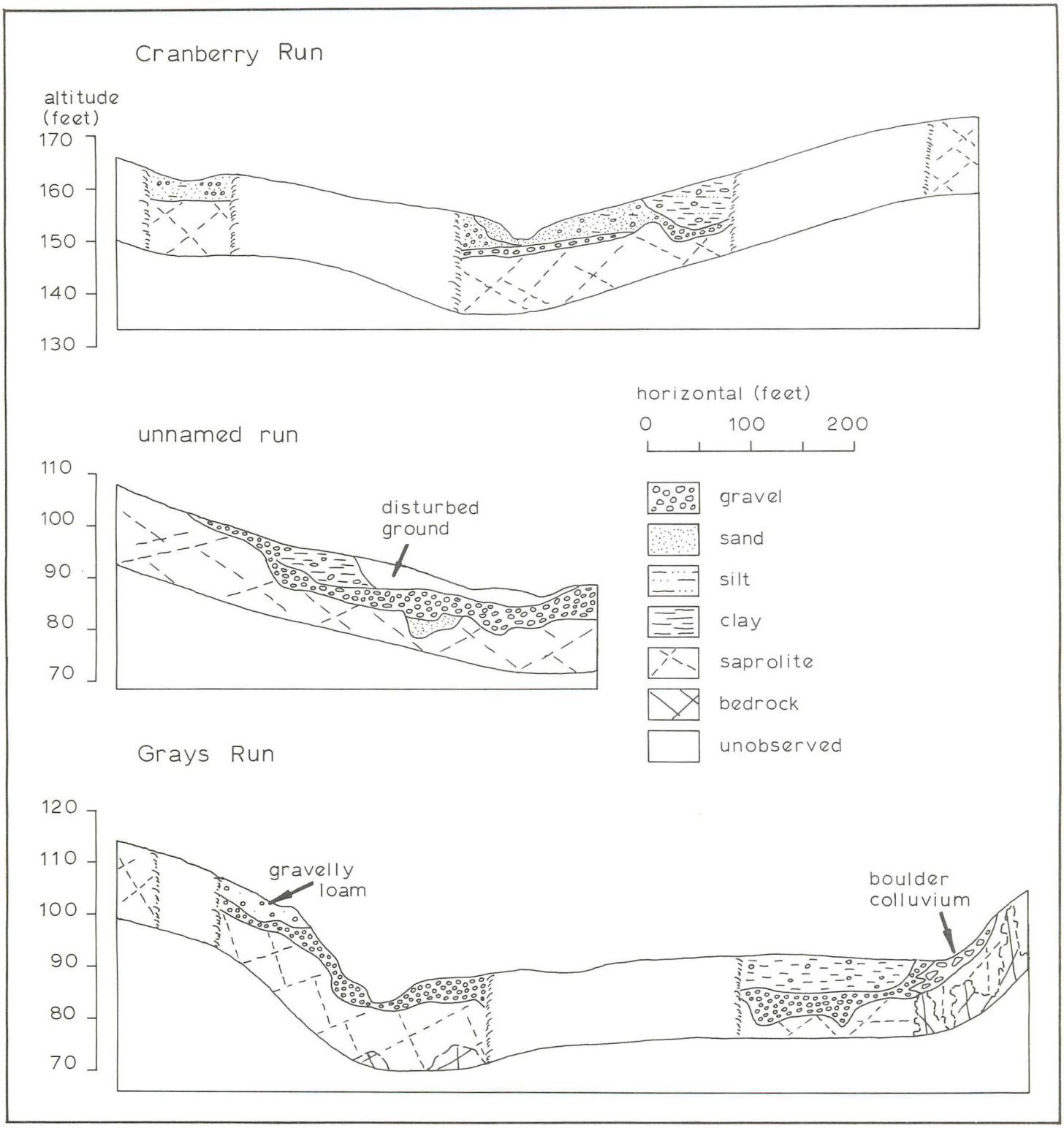


Figure 25. Geologic cross-sections of three Piedmont alluvial deposits.

tourmaline (Potomac); zircon, sillimanite, epidote, and amphibole (Delaware); and epidote and amphibole (local streams). The heavy minerals in the sand beds are characteristic of three different metamorphic rock provenances; the Appalachian contribution in the Delaware and Potomac sediments is evident primarily in the gravel which has chert clasts and clasts bearing Paleozoic fossils.

In the local streams amphibole and epidote are the major heavy minerals in nine of the Quaternary sand beds and comprise 78 percent or more of each suite (Table 17). The tenth, No. 16, contains a suite similar to that of Cretaceous sand. The nine amphibole-epidote suites are low in opaque minerals, and have only small amounts of minerals which are characteristic of the Cretaceous sands: kyanite, staurolite, tourmaline, rutile, and zircon. These samples differ from No. 16 in two ways: (1) the heavy mineral suite; (2) the nine are Lowland deposits and No. 16 is an upland deposit.

Three minerals in the Lowland deposits, kyanite, staurolite, and tourmaline reflect differences in the source rocks. These minerals are rare north of Winters Run, where the streams are almost entirely confined to mafic rocks in which amphibole and epidote are the major heavy minerals (Figure 1). Winters Run, and streams to the south, extend into the Wissahickon Formation in which tourmaline and staurolite are major accessory minerals and kyanite has its only reported occurrence.

The distribution of opaque minerals also varies. North of Winters Run the opaque minerals average 14 percent of the total suite; in the Run and southward, they average 28 percent. The cause of this distribution is not known.

Table 17. Frequency of heavy minerals in Quaternary sand beds (in percent).

sample number	LOCATION	opaques	kyanite	staurolite	tourmaline	rutile	zircon	amphibole	brookite	chloritoid	epidote-clinozoisite	garnet	sillimanite	sphene
9	Whitemarsh Run	18	T	3	1	T	2	70	T	T	21	3	-	T
15	Gunpowder Falls	23	2	11	3	1	2	51	T	T	28	1	1	T
16	Gunpowder Falls	59	15	46	7	4	5	19	2	1	--	-	1	-
31	Winters Run	25	2	8	2	T	T	68	-	-	10	10	-	-
32	Winters Run	47	2	11	2	T	T	58	1	1	25	T	-	-
34	Winters Run	28	T	3	2	1	T	67	T	T	26	-	1	-
48	Bynum Run	10	-	T	T	T	T	78	T	1	21	T	T	-
49	Bynum Run	14	-	T	T	T	T	81	-	T	17	2	-	-
52	James Run	16	T	T	T	-	T	89	-	-	11	T	T	-
59	Grays Run	14	-	T	-	-	-	72	-	T	25	2	1	-
	average	25	2	8	2	1	1	65	T	T	19	2	T	T

Table 18. **Contrasting Quarternary heavy mineral suites from Southern Maryland, Baltimore-Aberdeen area and Delaware.**

opaques	kyanite	staurolite	tourmaline	rutile	zircon	amphibole	brookite	chloritoid	epidote-clinozoisite	garnet	sillimanite	sphene	apatite	monazite	spinel	andalusite	pyroxene	cassiderite	anatase	glauconite	
25	2	8	2	1	1	65	T	T	19	2	T	T	-	-	-	-	-	-	-	-	this report
83	-	M	8	M	65	M	-	-	T	T	T	M	-	T	T	T	M	T	T	T	Schlee (1957), p. 1382-1383
77	2	4	6	4	34	14	-	1	18	2	13	T	T	T	T	T	T	-	-	-	Jordan (1964), p. 25

T: less than one percent

M: minor (less than 8, more than one percent)

REFERENCES

ANDERSON, J. L., *1948, Cretaceous and Tertiary subsurface geology: Maryland Dept. Geology, Mines, and Water Resources,*[1] *Bull. 2.*

BECKER, G. F., *1894-95, A reconnaissance of the goldfields of the southern Appalachians: 16th Annual Report, U.S. Geol. Survey, p. 289-290.*

BENNETT, R. B. and MEYER, R. R., *1952, Geology and ground-water resources of the Baltimore area: Maryland Dept. Geology, Mines, and Water Resources,*[1] *Bull. 4.*

BERRY, A. F. and HANSHAW, B. B., *1960, Geologic field evidence suggesting membrane properties of shales: mss; 21st Internat. Geol. Cong. (Copenhagen 1960), Abstract Volume, p. 206.*

BERRY, E. W., *1929, The Coastal Plain deposits: Maryland Geol. Survey, Baltimore County.*

BRENNER, G. J., *1963, The spores and pollen of The Potomac Group of Maryland: Maryland Dept. Geology, Mines, and Water Resources,*[1] *Bull. 27.*

BROWN, G. *(editor), 1961, The x-ray identification and crystal structures of clay minerals: Mineralogical Society (London).*

CHRISTL, R. J., *1964, Storage of radioactive wastes in basement rock beneath the Savannah River Plant: USAEC Rept. DP - 844, Office of Technical Services, U.S. Dept. of Commerce.*

CLARK, W. B., *1904, Map of Harford County showing the geological formations: Maryland Geological Survey.*

CLARK, W. B., BIBBINS, A. B., and BERRY, E. W., *1911, The Lower Cretaceous deposits of Maryland: Maryland Geol. Survey, Lower Cretaceous.*

CLEAVES, E., *1964, Laboratory procedures for mechanical and heavy mineral analyses of saprolites and soil profiles: unpublished M. A. Thesis, The Johns Hopkins University.*

CLEAVES, E., EDWARDS, J., GLASER, J. D., and WEAVER, K. N., *1968, Geologic Map of Maryland: Maryland Geological Survey.*

DINGMAN, R. J., and FERGUSON, H. F., *1956, The ground water resources of the Piedmont part:* in *The Water Resources of Baltimore and Harford Counties: Maryland Dept. Geology, Mines, and Water Resources,*[1] *Bull. 17.*

DRYDEN, L., and DRYDEN, C., *1946, Comparative rates of weathering of some common heavy minerals: Jour. Sed. Petrology, vol. 16, p. 91-96.*

GLASER, J. D., *1967, Nonmarine Cretaceous sedimentation in the Middle Atlantic Coastal Plain: The Johns Hopkins University, Ph.D. dissertation.*

GREENMAN, D. W., RIMA, D. R., LOCKWOOD, W. N., and MEISLER, H., *1961, Ground-water resources of the Coastal Plain area of southeastern Pennsylvania: Penn. Topographic and Geologic Survey, Bull. W13, p. 26, 28.*

GRIM, R. E., *1962, Applied clay mineralogy: McGraw-Hill Book Co., Inc.*

GROOT, J. J., *1955, Sedimentary petrology of the Cretaceous sediments of northern Delaware in relationship to paleogeographic problems: Delaware Geological Survey, Bull. 5.*

JORDAN, R. R., *1964, Columbia (Pleistocene) sediments of Delaware: Delaware Geol. Survey Bull. 12, 59 p.*

KRUMBEIN, W. C., and PETTIJOHN, F. J., *1938, Manual of Sedimentary Petrology: Appleton-Century-Crofts, Inc., N. Y.*

LAGUNA, WALLACE, DE, *1963, Geology of Brookhaven National Laboratory and vicinity, Suffolk County, N. Y.: U.S. Geol. Survey Bull. 1156-A, p. A12-A13.*

LEGRAND, H. E., and MUNDORFF, M. J., *1952, Geology and ground water in the Charlotte area, North Carolina: North Carolina Dept. of Conservation and Development, Div. Min. Resources, Bull. 63.*

MATHEWS, E. B., *1925, Map of Baltimore County and Baltimore City showing the geological formations: Maryland Geol. Survey.*

MERTIE, J. B., JR., *1959, Quartz crystal deposits of southwestern Virginia and western North Carolina: U.S. Geol. Survey Bull. 1072-D.*

ROBERTS, G. D., *1966, Residual soils—some engineering characteristics: Geol. Soc. Amer. Spec. Paper No. 87, p. 137-138.*

RITTENHOUSE, G., *1948, Analytical methods as applied in petrographic investigations of Appalachian Basin: U.S. Geol. Survey Circular 22.*

[1] The name of this agency was changed to Maryland Geological Survey in 1964.

RUXTON, B. P., and BERRY, L., *1957, Weathering of granite and associated erosional features in Hong Kong: Geol. Soc. America Bull., vol. 68, p. 1263-1292.*

SCHLEE, J. S., *1957, Upland gravels of southern Maryland: Geol. Soc. America Bull., vol. 68, p. 1371-1409.*

SHATTUCK, G. B., *1906, Pliocene and Pleistocene: Maryland Geol. Survey.*

SIPLE, G. E., *1964, Geohydrology of storage of radioactive waste in crystalline rocks at the AEC Savannah River Plant, South Carolina: U.S. Geol. Survey Prof. Paper 501-C.*

SOUTHWICK, D. L., *1964, Petrography of the basement gneiss beneath the Coastal Plain sequence, Island Beach State Park, New Jersey: U.S. Geol. Survey Prof. Paper 501-C, p. C55-C60.*

SOUTHWICK, D. L., and OWENS, J. P., *Geology of Harford County: Maryland Geological Survey, report in preparation.*

———, *1968, Harford County Geologic Map: Maryland Geological Survey.*

WATSON, T. L., *1902, A preliminary report on a part of the granites and gneisses of Georgia: Georgia Geol. Survey Bull. 9-A, 367 p.*

APPENDIX A: DESCRIPTIONS OF SAMPLES CITED IN REPORT

1. Location; Baltimore County, Subsection 1. Saprolite; greenish white gabbro gneiss.
2. Location; Baltimore County, Subsection 1. Saprolite; blue gabbro gneiss.
3. Location; Baltimore County, Subsection 1. Saprolite; greenish grey gabbro gneiss.
4. Location; Baltimore County, Subsection 2. Potomac Group; dark grey to black lignitic clay.
5. Location; Baltimore County, Subsection 2. Potomac Group; grey fine grained sand.
6. Location; Baltimore County, Subsection 2. Potomac Group; brownish grey medium grained sand.
7. Location; Baltimore County, Subsection 4. Potomac Group; brownish grey, micaceous, medium grained sand.
8. Location; Baltimore County, Subsection 4. Potomac Group; grey clayey lignitic sand.
9. Location; Baltimore County, Subsection 4. Quaternary, Lowland deposit; greyish yellow, medium grained sand.
10. Location; Baltimore County, Subsection 5. Potomac Group; dark grey to black lignitic sand.
11. Location; Baltimore County, Subsection 5. Potomac Group; grey medium grained sand.
12. Location; Baltimore County, Subsection 6. Potomac Group; grey, medium grained sand.
13. Location; Baltimore County, Subsection 6. Potomac Group; light grey medium grained sand.
14. Location; Baltimore County, Subsection 7. Saprolite; reddish brown coarse grained gabbro gneiss.
15. Location; Baltimore County, Subsection 7. Quaternary, Lowland deposit; greyish yellow medium grained sand.
16. Location; Baltimore County, Subsection 7. Quaternary, Upland deposit; yellowish brown medium grained sand.
17. Location; Harford County, Subsection 8. Potomac Group; yellowish brown medium grained sand.
18. Location; Harford County, Subsection 8. Potomac Group; lignitic clay.
19. Location; Harford County, Subsection 9. Potomac Group; grey medium grained sand.
20. Location; Harford County, Subsection 9. Saprolite; reddish brown tourmaline-muscovite schist.
21. Location; Harford County, Subsection 9. Saprolite; grey muscovite schist.
22. Location; Harford County, Subsection 9. Potomac Group; white medium grained sand.
23. Location; Harford County, Subsection 10. Potomac Group; micaceous black sand.
24. Location; Harford County, Subsection 10. Saprolite; grey, tourmaline-muscovite-quartz-feldspar schist.
25. Location; Harford County, Subsection 10. Saprolite; yellowish grey, fine grained epidote gneiss.
26. Location; Harford County, Subsection 10. Potomac Group; grey and white sand, from a thin sand seam in black clay.
27. Location; Harford County, Subsection 11. Potomac Group; dark grey lignitic clay.
28. Location; Harford County, Subsection 11. Potomac Group; brown medium grained sand.
29. Location; Harford County, Subsection 11. Saprolite; grey garnet-muscovite schist.
30. Location; Harford County, Subsection 12. Quaternary, Lowland deposit; brown spongy peat with numerous twigs and branches.
31. Location; Harford County, Subsection 12. Quaternary, Lowland deposit; light grey coarse grained sand.
32. Location; Harford County, Subsection 12. Quaternary, Lowland deposit; brownish grey medium grained sand.
33. Location; Harford County, Subsection 12. Quaternary Lowland deposit, peat.
34. Location; Harford County, Subsection 12. Quaternary, Lowland deposit; grey fine grained sand.
35. Location; Harford County, Subsection 12. Saprolite; brownish grey muscovite schist.
36. Location; Harford County, Subsection 13. Potomac Group; yellow medium grained sand.
37. Location; Harford County, Subsection 13. Potomac Group; dark grey lignitic clay.
38. Location; Harford County, Subsection 13. Potomac Group; dark grey, plastic, lignitic clay.

39. Location; Harford County, Subsection 13. Potomac Group; brownish grey, sandy, lignitic clay.

40. Location; Harford County, Subsection 13. Potomac Group; pale yellowish grey medium grained sand.

41. Location; Harford County, Subsection 13. Potomac Group; grey lignitic clay.

42. Location; Harford County, Subsection 13. Potomac Group; dark grey lignitic clay.

43. Location; Harford County, Subsection 13. Potomac Group; white fine grained sand.

44. Location; Harford County, Subsection 13. Potomac Group; dark grey to black lignitic silt.

45. Location; Harford County, Subsection 13. Potomac Group; grey silty lignitic clay.

46. Location; Harford County, Subsection 13. Potomac Group; grey, coarse to medium grained sand.

47. Location; Harford County, Subsection 14. Quaternary Lowland deposit, peat.

48. Location; Harford County, Subsection 14. Quaternary, Lowland deposit; bluish grey medium grained sand.

49. Location: Harford County, Subsection 14. Quaternary, Lowland deposit; orangy brown, medium grained sand.

50. Location: Harford County, Subsection 14. Saprolite; James Run Gneiss.

51. Location; Harford County, Subsection 14. Saprolite; James Run Gneiss.

52. Location; Harford County, Subsection 14. Quaternary, Lowland deposit; brown medium grained sand.

53. Location; Harford County, Subsection 15. Potomac Group; white medium grained sand.

54. Location; Harford County, Subsection 15. Saprolite; bluish green metagabbro.

55. Location; Harford County, Subsection 16. Saprolite; bluish green amphibolite.

56. Location; Harford County, Subsection 16. Saprolite; light to dark grey quartz monzonite.

57. Location; Harford County, Subsection 16. Saprolite; grey mottled yellow metagabbro.

58. Location; Harford County, Subsection 16. Saprolite; grey mottled pink and green quartz monzonite.

59. Location; Harford County, Subsection 16. Quaternary, Piedmont alluvium; brown coarse grained sand.

60. Location; Harford County, Subsection 16. Saprolite; white and bluish green metagabbro.

61. Location; Harford County, Subsection 16. Saprolite; yellowish brown mottled white and greyish blue, garnetiferous metagabbro.

62. Location; Harford County, Subsection 17. Saprolite; bluish green metagabbro.

63. Location; Harford County, Subsection 17. Saprolite; olive green metagabbro.

64. Location; Harford County, Subsection 17. Potomac Group; grey coarse grained sand.

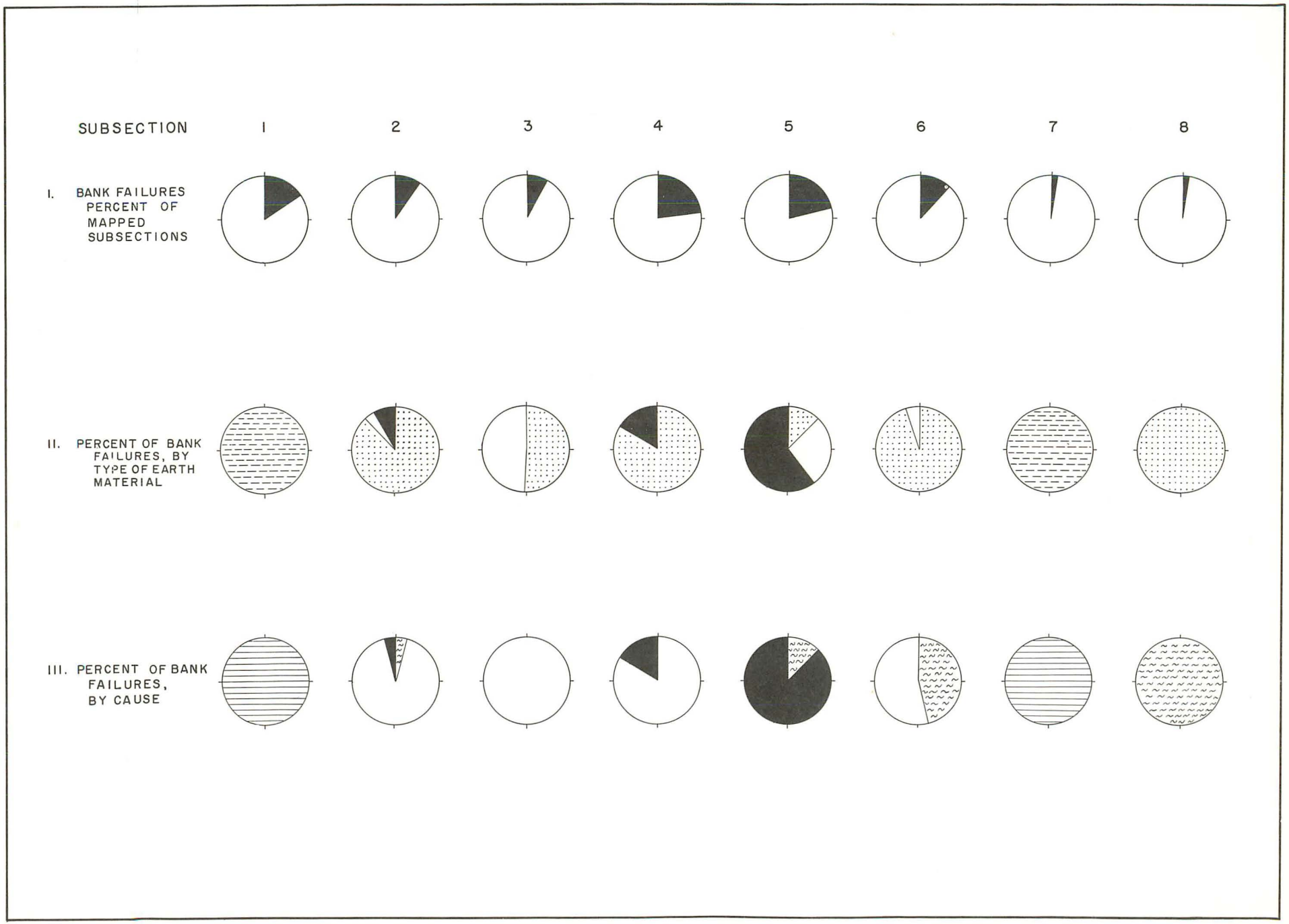
Appendix B. Floral list showing distribution of sporomorphs in 13 samples of Potomac Group sediments. (in percent).

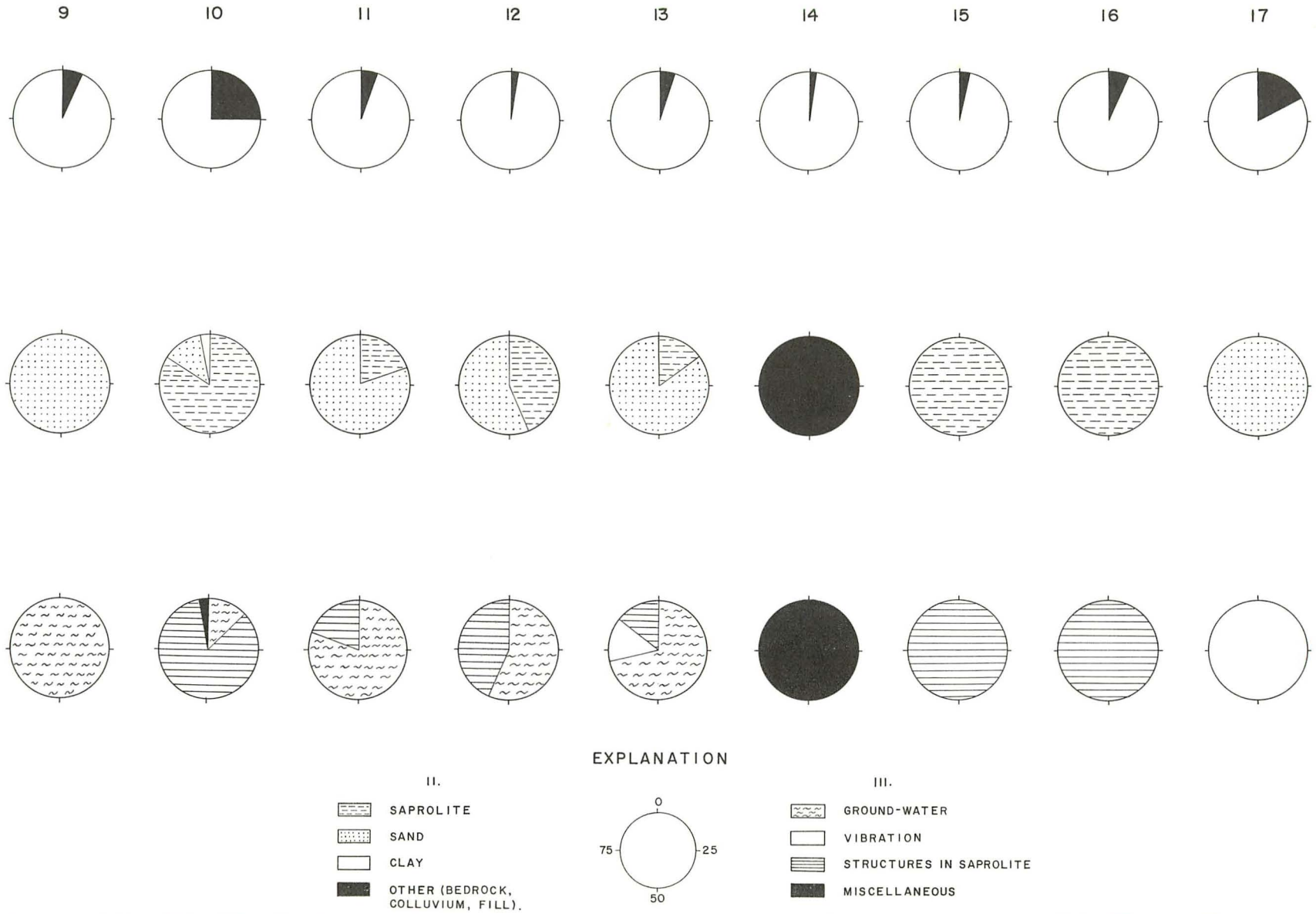
SAMPLE NO.	18	23	27	37	41	42	44	39	38	4	45	8	10
Cyathidites minor	5	10	12	48	25	6	22	18	35	62	13	22	7
Cyathidites cf. australis	1	10	x	9	9	x	17	6	7	30	x	2	10
Gleicheniidites spp.	x	x		5	1		21	x	1				
Cicatricosisporites spp.	4	7	6		7	22	3	2		1	2	3	3
Appendicisporites spp.		x	x		3	x		x					x
Trilobosporites spp.	x	x			1	x	x		x			1	x
Pilosisporites trichopapillosus		x				x	x		x			1	x
Concavissimisporites spp.			x		2	x	x	x	1			x	x
Densoisporites perinatus							x						
Taurocusporites reduncus				x		x			x				
Other trilete spores	x	x	x	2	1	1	2	x	1			3	x
Laevigatosporites fracilis	x	x	2	x	2	x	1	x		1	x	1	x
Classopollis classoides	x	3	10	1	3	3	7	x	3			1	1
Exesipollenites tumulus	x	x	1			1	1				x		x
Laricoidites spp.	x	x	1			1			1		x	1	x
Inaperturopollenites dubius	50	52	13		17	47	2	50	3	x	39	17	18
Araucariacites australis			1			x	2		x				
Tsugaepollenites mesozoicus	x			x		2	x	2					
Bisaccate conifer pollen	13	10	6	17	13	7	21	18	23	5	28	33	43
Vitreisporites pallidus	x	x	x	14	3	x		x	2	1	2	x	
Eucommiidites troedssonii		x	x	x	2	x		1	x		7		x
Ephedroid pollen	x	x	1		1	2		x	x				x
Decussosporites microreticulatus				x				x		1	x		
Monosulcates: psilate	x	x	41	1	6	2	2	1	14	x	7	9	1
Monosulcates: low reticulum			x	1	1			x	5		1	2	1
Peromonolites cf. retuculatus	11	3		1		x			1			x	11
Clavatipollenites hughesii	x	1	3	1	x	x	1	x	3		x	1	x
Schizosporis spp.			x									1	
Unknown reticulate monosulcate						4							
Number of grains counted	218	231	215	165	205	233	195	241	353	146	258	255	207

All percentages of total flora
x: less than 0.5%

*The age identifications from pollen and spore data and floral list were kindly provided by James A. Doyle, Department of Biology, Harvard University. All the assemblages are from Zone I (Patuxent-Arundel) of Brenner (1963).

Appendix C. Bank failures in sediment and saprolite, tabulated by subsection.




9
10
11
12
13
14
15
16
17
EXPLANATION
II.
SAPROLITE
SAND
CLAY
OTHER (BEDROCK, COLLUVIUM, FILL).
0
25
50
75
III.
GROUND-WATER
VIBRATION
STRUCTURES IN SAPROLITE
MISCELLANEOUS

Piedmont and Coastal Plain Geology along the Susquehanna Aqueduct, Baltimore to Aberdeen, Maryland R.I. No. 8, 1968