COMMONWEALTH OF VIRGINIA

DEPARTMENT OF CONSERVATION
AND ECONOMIC DEVELOPMENT

DIVISION OF MINERAL RESOURCES

GEOLOGY OF THE LINDEN AND FLINT HILL QUADRANGLES, VIRGINIA

MICHAEL T. LUKERT AND
ERNEST B. NUCKOLS III

REPORT OF INVESTIGATIONS 44

VIRGINIA DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

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GEOLOGY OF THE LINDEN AND FLINT HILL QUADRANGLES, VIRGINIA

By

MICHAEL T. LUKERT[1] AND ERNEST B. NUCKOLS III[2]

ABSTRACT

The Linden and Flint Hill 7.5-minute quadrangles are located in Clarke, Fauquier, Rappahannock, and Warren counties, northern Virginia. The quadrangles are mostly in the Blue Ridge and Piedmont physiographic provinces but the northwestern corner of the Linden quadrangle is in the Valley and Ridge province. Bedrock in these quadrangles ranges in age from Precambrian to Mesozoic and includes 14 formations in addition to 4 types of dikes; Quaternary terrace deposits and flood-plain alluvium are also present.

The area is located on the northwest limb of the gently northeastward-plunging Blue Ridge anticlinorium. The Stone Bridge anticline and the small-scale folds in the sedimentary rocks in the Linden quadrangle are overturned to the northwest and plunge gently to the northeast, a fold geometry that is concordant with the anticlinorium. Large-scale folding cannot be traced in the gneissic rocks, but variations in foliation trends suggest the possibility of its existence. Four major faults and several minor ones are present in the quadrangles. Deformation of the rocks is also delineated by shear zones in the plutonic rocks, pervasive cleavage, and greenschist metamorphism that is evident in all rocks of Cambrian or older age.

Crushed stone has been produced from quartizites of the Harpers and Antietam formations in the Linden quadrangle and from the layered gneiss in the Flint Hill quadrangle. Minor quantities of high-magnesium dolomite and copper mineralization occur locally.

Approximately 85 percent of the water wells for which data is available penetrate igneous and metamorphic rocks that are reliable producers of small to moderate yields from depths less than 300 feet. Wells in the Waynesboro Formation are the most shallow and successful from the clastic sedimentary rocks; information is not available for wells in carbonate rocks.

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INTRODUCTION

The Linden and Flint Hill 7.5-minute quadrangles (Plates 1, 2) are bounded by 78°00′ and 78°07′30″ west longitudes and by 38°45′ and 39°00′ north latitudes. The two quadrangles are located in portions of Clarke, Fauquier, Rappahannock, and Warren counties, Virginia (Figure 1) in the Valley and Ridge,

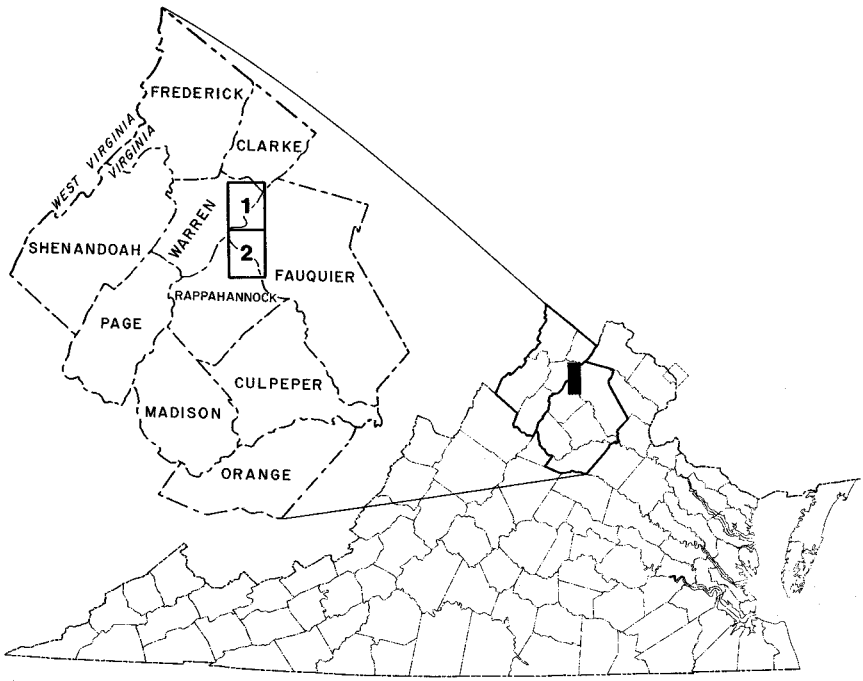


Figure 1. Index map showing location of the Linden (Plate 1) and Flint Hill (Plate 2) quadrangles, Virginia.

Blue Ridge, and Piedmont physiographic provinces. The topography of the portion in the Valley and Ridge province is dominated by the valley of the incised, meandering Shenandoah River, but the most prominent topographic feature in the two quadrangles is the northeastward-trending Blue Ridge. The highest point on this part of the Blue Ridge is in the southwestern corner of the Linden quadrangle where High Knob has an elevation of 2,388 feet (728 m). The Piedmont province is characterized by a gently-rolling, stream-dissected landscape with local topographic highs, the most prominent of which is Rattlesnake Mountain that rises 1,400 feet (427 m) above the adjacent lowlands. Buck, Fogg, Oventop, Dogwood, and Long mountains

are other significant topographic highs east of the Blue Ridge. The lowest elevation is at the southeastern boundary of the Flint Hill quadrangle where the Rappahannock River is 410 feet (125 m) above sea level. The Blue Ridge forms the major drainage divide, northwest of which the Shenandoah River and its tributaries flow in a northeasterly direction to the Potomac River, and southeast of which the Rappahannock River and its tributaries flow generally southeasterly toward Chesapeake Bay.

Keith (1893) and Butts (1933, 1940-41) have described some aspects of the geology of the Linden and Flint Hill quadrangles, and Theismeyer (1937) mapped a portion of each in considerable detail. In addition, many of the rock units in and adjacent to this study area have been described by Allen (1963, 1967), Brown (1958, 1970), Edmundson and Nunan (1973), Gathright and Nystrom (1974), Nickelsen (1956), Rader and Biggs (1975), Reed (1955, 1969), Schwab (1970), and Whitaker (1955 a, b). Field mapping was conducted by the writers during the summers of 1971, 1972, and 1973, and by E. B. Nuckols alone during the autumns of 1972 and 1973 and springs of 1973 and 1974.

Numbers preceded by "R" in parentheses (R-5112) and "F" (F-901) are repository numbers of rock and fossil samples collected at sites designated on Plates 1 and 2. These specimens are in the repositories of the Virginia Division of Mineral Resources, Charlottesville, Virginia; detailed descriptions of thin sections cut from these samples are on open file in the Division library. Modal analyses were done with a Vickers automatic point-counting stage, and all are based on a 2000-count total with a 1.0 mm interval between points. The chemical analyses were determined by x-ray fluorescense on samples fused into glasses with lithium tetraborate; the possible error within one standard deviation does not exceed 0.4 percent absolute for SiO_2, 0.3 percent absolute for Al_2O_3 and Na_2O, 0.1 percent absolute for Fe_2O_3, MgO, CaO, and K_2O, and 0.02 percent absolute for TiO_2 and MnO.

The writers wish to thank James L. Calver, Commissioner of Mineral Resources and State Geologist who authorized the project and Richard H. DeKay who supervised it. Of the many contributors of assistance on the staff of the Virginia Division of Mineral Resources, the writers are particularly indebted to Thomas M. Gathright II (photography) and Oliver Fordham (chemical analyses). We would also like to express our apprecia-

tion to the local residents for the many ways they aided us during the field mapping, and to J. W. Clarke of the U. S. Geological Survey.

STRATIGRAPHY

The rocks of the Linden and Flint Hill quadrangles are assigned to 20 lithologic formations and units (Table 1; Plates 1, 2). The Piedmont portion is underlain by Precambrian crystal-

Table 1.—Geologic formations in the Linden and Flint Hill quadrangles.

Age	Name	Character	Thickness in feet (meters)
Quaternary	Alluvium	Light- to dark-gray sand, silt, and clay with lenses of cobbles and medium to small pebbles; also colluvium consisting of boulders, cobbles, and sand in stream beds on the flanks of the larger mountains.	0-20± (0-7)
	Terrace deposits	Moderate- to well-rounded cobbles and other gravel surrounded by a matrix of sand, silt, and clay.	0-25± (0-8±)
Triassic	Diabase dikes	Commonly dark-gray diabase; predominantly composed of andesine, albite, and pericline.	
Cambrian	Conococheague Formation	Rusty-weathering, coarse-grained sandstone; bluish-gray, fine-grained limestone; and light-gray, fine-grained dolomite.	75+ (23+)
	Elbrook Formation	Medium- to dark-gray limestone with argillaceous and sandy laminae; light- to medium-gray, laminated dolomite; and rusty-brown, laminated, calcareous or dolomitic shale.	2,000 (610)
	Waynesboro (Rome) Formation	Maroon and green shale (upper part). Dark bluish-gray, saccharoidal dolomite and bluish-gray, fine-grained limestone (middle part). Maroon, olive, and dark-gray shale and maroon and yellowish-tan, fine- to medium-grained sandstone (lower part).	1,200 (366)
	Shady Formation	Light- to dark-gray, fine- to coarse-grained, medium- to thick-bedded, laminated dolomites; few chert rosettes and nodules.	70+ (21+)

Age		Name	Character	Thickness in feet (meters)
	Chilhowee Group	Antietam Formation	Fine- to coarse-grained, silica-cemented, vitreous quartzite and subarkose; phyllite partings common; characteristic *Skolithos* tubes present throughout formation.	600+ (183+)
		Harpers Formation	Dark greenish-gray, very fine-grained, thick-bedded to laminated, feldspathic graywacke and phyllite; upper portion contains interbeds of tan to white, coarse-grained sandstone, vitreous quartzite and dark-purple, iron-oxide stained, argillaceous quartz sandstone.	2,500 (762)
		Weverton Formation	Light-gray quartz-pebble conglomerate with interbedded pebbly, sericitic, quartzitic sandstone and ferruginous sandstone (upper part). Dark-gray, sandy phyllite and sericitic quartz sandstone (middle part). Light-gray to tan and purplish gray, medium- to coarse-grained, thick-bedded quartzite and quartz-pebble conglomerate with interbedded sandy phyllite (lower part).	440-500 (134-152)
Precambrian(?)	Catoctin Formation		Massive, dark- to grayish-green metabasalt with basalt-flow breccia, epidosite, and thin beds of purple amygduloidal slate (upper part). Dark- to grayish-green metabasalt, purple phyllite, and metasedimentary rock; locally pink to cream rhyolitic tuff (lower part). Basalt feeder dikes, dark grayish-green, fine-grained, occur in Precambrian granitic rocks.	2,000-2,500 (610-762)
	Swift Run Formation		Dark greenish-brown, sandy and pebbly, poorly sorted metagraywacke and meta-arkose; sericitic and chloritic phyllite; and locally purple, thin-bedded slate.	0-150+ (0-46+)
	Dikes		*Amphibolite dike:* medium- to dark-gray actinolite-rich amphibolite. *Augite-bearing dike:* light greenish-gray; mainly augite, chlorite, and epodite. *Felsic dike:* yellowish- to light-gray felsic igneous rock.	

Age	Name	Character	Thickness in feet (meters)
Precambrian	Robertson River Formation	Light- to dark-gray, medium- to coarse-grained hornblende-biotite granite.	
	Pedlar Formation	Light- to greenish-gray, medium-grained quartz monzonite.	
	Old Rag Granite	Light-gray, medium- to coarse-grained granite composed primarily of creamy to white microcline and blue quartz.	
	Augen-bearing gneiss	Light- to dark-gray, medium- to coarse-grained, well-foliated monzonite gneiss; augen-shaped megacrysts of potassium feldspar common.	
	Layered gneiss	Light-gray to gray, medium-grained, very well foliated, thin- to thick-layered quartz monzonite gneiss with blue quartz.	

line igneous rocks. Much of the Blue Ridge is capped by Precambrian(?) metavolcanic rocks underlain by small patches of metasedimentary rocks. Folded, faulted, unaltered to slightly metamorphosed Cambrian sedimentary rocks underlie the Valley and Ridge portion and have an aggregate thickness of nearly 7,000 feet (2,134 m).

Within this geographic area there are comparatively good exposures of plutonic igneous and metamorphic rocks, metavolcanic and metasedimentary rocks, and relatively unaltered sediments. The variation in deformational phenomena include overturned folds, thrust sheets, high-angle reverse faults, large and small transverse faults, and extensive zones of shearing.

PRECAMBRIAN ROCKS

Layered Gneiss

Within the Linden and Flint Hill quadrangles (Plates 1, 2) the layered gneiss has an areal exposure of approximately 15 square miles (39 sq km) in the form of an irregular, elongate area that trends 20° to 30° east of north. In width it varies from approximately 0.5 to 3.5 miles (0.8 to 5.6 km) across the Flint Hill quadrangle, and from 0.3 to 2.3 miles (0.5 to 3.7 km) south of the Front Royal fault in the Linden quadrangle. This rock

unit also occurs in a small area north of the Front Royal fault and along the southeastern edge of the Flint Hill quadrangle.

The layered gneiss is in contact with the augen-bearing gneiss, the Old Rag Granite, and the Pedlar, Robertson River, Swift Run, and Catoctin formations. Except for a few places such as on Hickman Run (Plate 2) where the contact can be placed to within 20 feet (6 m), the contact with the augen-bearing gneiss cannot be located closer than 100 feet (30 m) because it is poorly exposed, the contact is gradational, segments are marked by shear zones, and exposures of augen-bearing gneiss occur within the outcrop area of the layered gneiss. In the two small areas underlain by the Old Rag Granite in the Linden quadrangle its contact with the layered gneiss is almost entirely covered by alluvium and colluvium. Placement of the contact between the layered gneiss and the Pedlar Formation is questionable because in places these rock units are separated by shear zones, and in others the Pedlar rocks have a layered character as seen in exposures along State Road 663, approximately 2 miles (3 km) northwest of Flint Hill in the Chester Gap quadrangle.

Along the eastern edge of the Flint Hill quadrangle the layered gneiss contact with the Robertson River Formation can be located within 100 feet (30 m) even though it is covered. South of Linden a fault perpendicular to the Front Royal fault separates the Catoctin Formation from the layered gneiss along part of their contact, and another short segment of the contact is sheared. Northwest of Harrell Corner and northeast of Linden, the layered gneiss uncomformably underlies either the Catoctin Formation or discontinuous lenses of the intervening Swift Run Formation. The layered gneiss is intruded by metabasalt, amphibolite, and augite-bearing dikes.

In outcrop, the layered gneiss is light gray to gray and characterized by fine, dark, biotite-rich mafic layers interspersed with light, quartz- and feldspar-rich leucocratic layers. The mafic layers are generally less than 2 mm wide, but a few exceed 5 mm; the leucocratic layers are commonly of greater width although those in excess of 2 mm are rare. The layering is generally planar and semiparallel, but in the southeastern part of the Flint Hill quadrangle and in the Culpeper Stone Company quarry east of Flint Hill this layering is contorted (Figure 2). In the eastern portion of the quadrangle contortions are further evidenced by ptygmatic folding in which some mi-

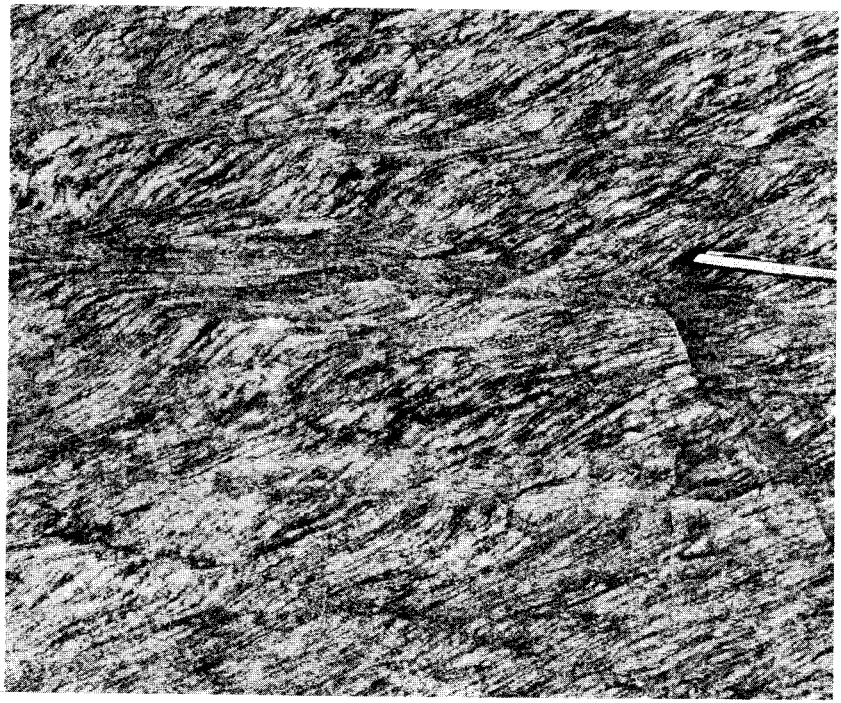
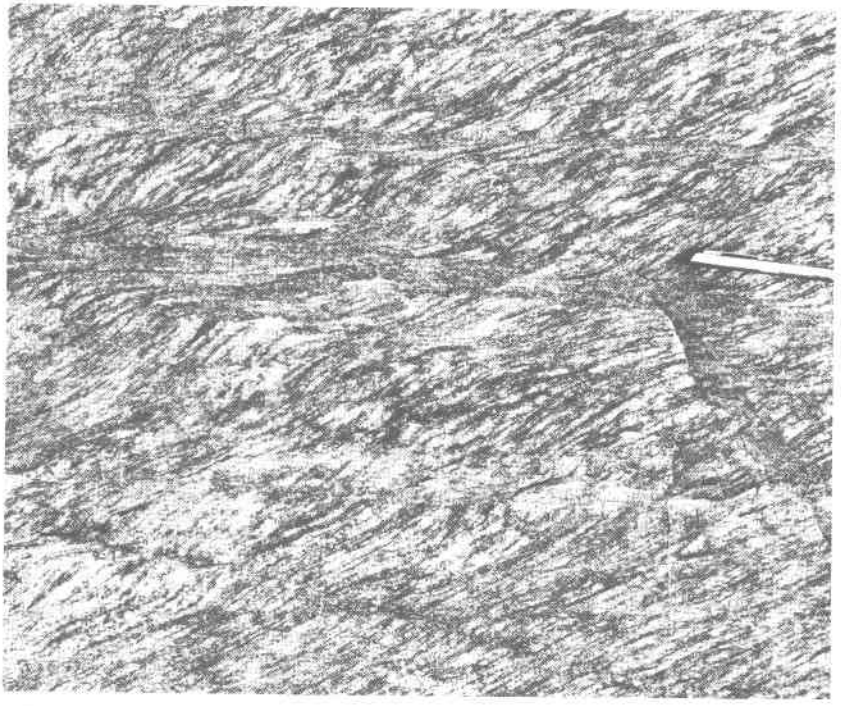


Figure 2. Layered gneiss exposed in the Culpeper Stone Company quarry, 2,500 feet (762 m) east of Flint Hill (Plate 2). A spaced cleavage has distorted layering into a wavy, kinky-banded form.

gration of the leucocratic material can be seen (Figure 3). Surfaces of weathered outcrops have a saccharoidal texture and are generally very light-gray to creamy white, reflecting the dominance of the leucocratic layers that stand out in slight relief.

Cataclastic materials generally concentrated in elongate zones within the rock and composed of finely granulated quartz, fine sericite, biotite, and epidote, is the principal feature in thin sections of the layered gneiss. The relative amounts of these components vary considerably from one sample to another; some, such as epidote and sericite may not occur in some specimens, but biotite and granulated quartz are nearly always present. The abundance of cataclastic material ranges from 1 to 40 percent of the rock, and particle sizes do not exceed 0.5 mm.

Potassic feldspar, quartz and plagioclase dominate the coarser part of the rock, the grains of which range in size from 1 to 2 mm. The quartz commonly displays strong undulatory extinc-



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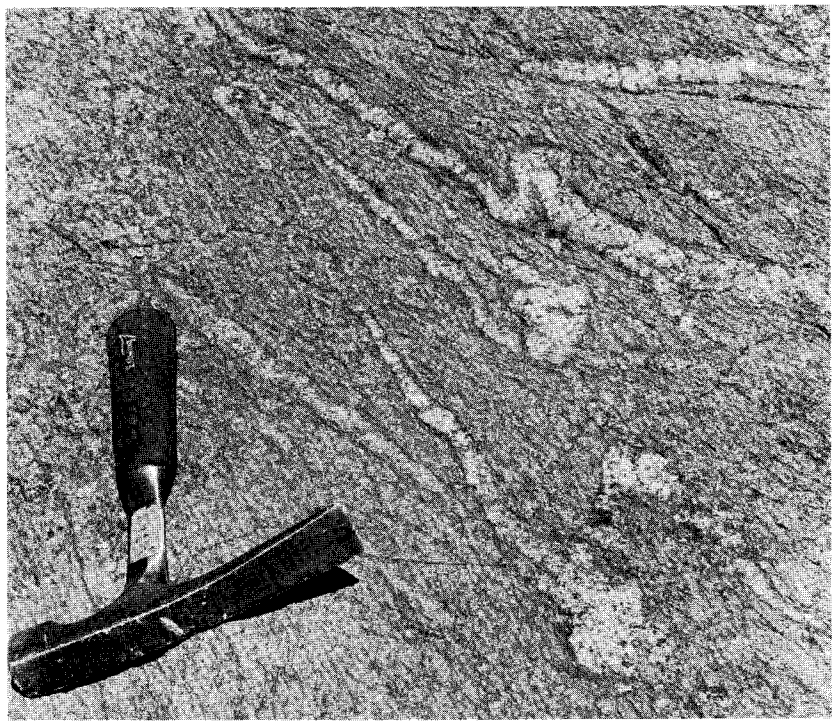
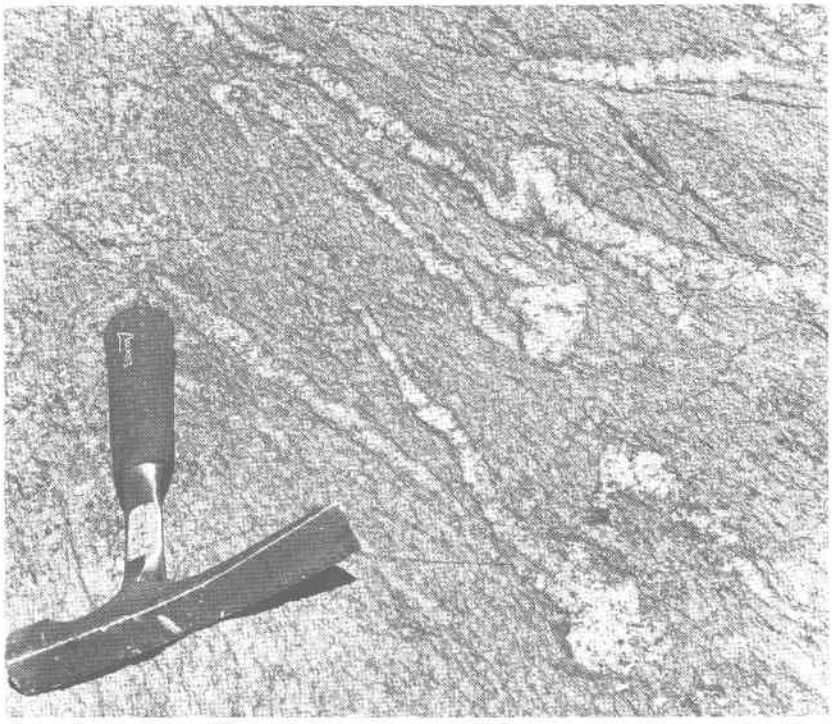


Figure 3. Ptygmatic folds in layered gneiss on the north side of State Road 635, 1.0 mile (1.6 km) east of Hitch (Plate 2). There is some indication of migration of leucocratic material into the axial portion of the lower folds.

tion and mortared grain boundaries (R-5061, R-5641). The potassic feldspar is mostly microperthitic microcline, although patch perthites are present in some samples (R-5071). Gridiron twinning is fairly common, and Carlsbad twinning was observed in samples R-5058 and R-5617. The anhedral microcline grains are generally subrounded and display a rind of sericite in some samples (R-5034), and grain-boundary alteration to albite is common.

The plagioclase consists of subhedral to anhedral grains of calcic oligoclase. Albite and Carlsbad twins predominate, although pericline twinning is present in some samples (R-5093). The extent of alteration varies from nearly unaltered plagioclase to complete saussuritization or sericitization. Broken and displaced twin lamellae were observed in most samples.

Biotite, the most common mafic mineral, occurs as subhedral flakes that are rarely more than 1 mm long. Pleochroic, reddish-brown biotite is most abundant in samples from near the Pedlar-



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Biotite, the most common mafic mineral, occurs as subhedral flakes that are rarely more than 1 mm long. Pleochroic, reddish-brown biotite is most abundant in samples from near the Pedlar-

layered gneiss contact (R-5066); the amount of green biotite increases with distance from the contact, and in some samples (R-5061) appears to be a retrograde product of the brown biotite. The common contiguity of these two types of biotite suggests that one is derived from the other; the generally fresher appearance of the green variety implies its formation may be at the expense of the brown type. Moorhouse (1959) states that such green mica may be intermediate between biotite and chlorite. If so, the triangular rutile nets in the green biotite are further evidence of its retrograde nature, as Harker (1950) accepts their presence in chlorite as clear evidence of retrograde derivation from biotite. Fine, euhedral green flakes of recrystallized biotite are commonly mixed with the cataclastic material.

Chlorite is a common constituent, occuring as clots and stringers of fine flakes and may represent a retrograde alteration of biotite. Garnet is present in samples near the layered gneiss-Pedlar contact, and is generally fractured and partially chloritized. The opaque minerals include ilmenite, commonly surrounded by haloes of sphene and leucoxene, and euhedral magnetite is present in some samples (R-5058, R-5642). Zircon, apatite, and epidote are accessory minerals.

The degree to which the modal abundances shown in Table 2 reflect the true mineral compositions is no doubt affected by the amount and variable composition of the cataclastic material.

Table 2.—Modal analyses of the layered gneiss.

	R-5034	R-5037	R-5061	R-5066	R-5072	R-5092	R-5093
Quartz	29.7	33.0	30.9	29.0	21.6	26.0	22.4
Potassic feldspar	42.7	36.3	35.8	37.2	33.7	24.2	26.7
Plagioclase	9.6	2.9	18.1	17.0	23.9	27.2	15.8
Cataclastic material	1.1	21.4	8.7	8.6	9.6	5.0	26.0
Biotite	3.5	X	5.1	7.3	9.9	14.5	7.4
Muscovite and sericite	11.3	n.d.	X	X	X	1.6	X
Epidote	X	X	X	X	X	X	X
Apatite	X	X	X	n.d.	X	X	X
Opaques	1.3	X	X	X	X	X	X
Sphene	n.d.	X	X	X	X	X	X
Zircon	X	X	X	X	X	X	X
Garnet	n.d.	n.d.	n.d.	X	n.d.	n.d.	n.d.
Chlorite	X	4.1	n.d.	X	n.d.	n.d.	X
An content of plagioclase	25	28	28	28	28	25	28

X, Present in amounts less than 1 percent. n.d., not detected.

Modal analyses of samples least affected by cataclasis (R-5034, R-5092) yield quartz monzonite compositions according to Moorhouse's classification (1959). The chemical and normative analyses (Tables 3 and 4) indicate considerable variability in silica, iron, magnesia, and lime.

Table 3.—Whole-rock chemical analyses of the layered gneiss (normalized to 100 percent).

	R-5092	R-5093	R-5572	R-5576	R-5583
SiO_2	68.12	67.47	72.33	62.90	69.61
Al_2O_3	14.69	14.62	13.51	15.94	14.60
*Fe_2O_3	4.39	4.51	2.73	6.08	3.51
MgO	.65	1.05	.72	1.28	.30
CaO	2.60	1.42	.54	3.91	1.09
Na_2O	2.70	3.87	4.92	2.61	3.30
K_2O	5.58	4.94	3.62	4.51	5.90
TiO_2	.71	.70	.42	1.07	.38
MnO	.06	.07	.04	.08	.04
L.O.F.	.52	1.34	1.17	1.61	1.26

*Total iron as Fe_2O_3. L.O.F., loss on fusion.

Table 4.—Normative compositions of the layered gneiss.

	R-5092	R-5093	R-5572	R-5576	R-5583
Quartz	24.97	21.81	28.01	20.74	25.44
Orthoclase	33.13	29.58	21.63	27.12	35.30
Albite	22.99	33.19	42.14	22.45	28.26
Anorthite	11.56	7.14	2.70	18.79	5.47
Corundum	n.p.	.34	.53	n.p.	.83
Diopside	1.11	n.p.	n.p.	.72	n.p.
Enstatite	1.11	2.65	1.79	2.90	.75
Hematite	4.42	4.57	2.76	6.19	3.56
Rutile	.71	.71	.43	1.09	.39

n.p., not present.

Augen-Bearing Gneiss

The augen-bearing gneiss is exposed in an elongate, northeastward-trending area approximately 2 to 3 miles (3 to 5 km) wide and 12 miles (19 km) long (Plates 1, 2). It is composed of potassic feldspar crystals as large as 2 inches (5 cm) in diameter, set in a finer grained matrix of quartz, biotite, and feldspar (Figure 4). These large feldspar crystals may be

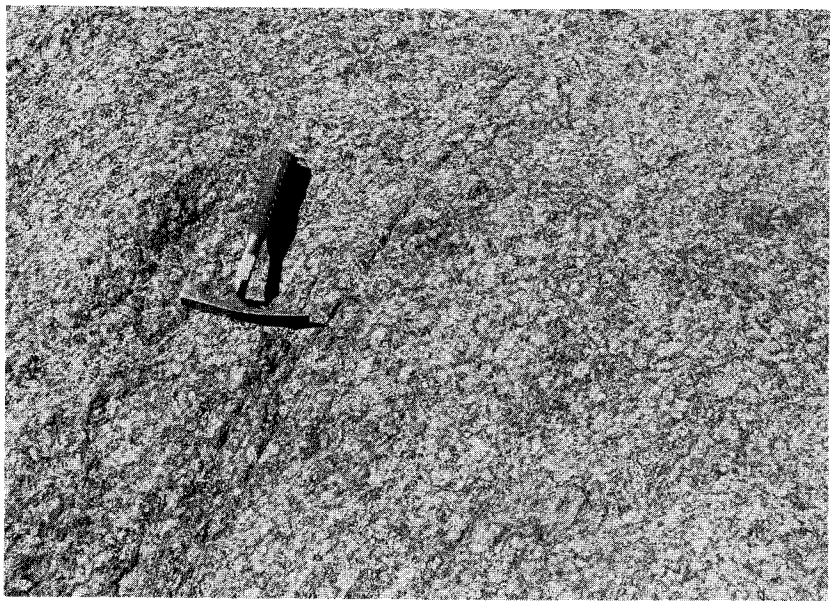

Figure 4. Typical texture of the augen-bearing gneiss in exposure on State Road 635, 1.0 mile (1.6 km) west of Hume (Plate 2). A well-developed feldspathic augen gneiss, with the augen ranging up to 1.5 inches (3.8 cm) in longest dimension. Note skialith of fine-grained felsic material near right bottom corner.

phenocrysts rather than augen because they range from equidimensional and anhedral to elongate and subhedral. Excellent exposures are present in the valley between Buck and Rattlesnake mountains (Plate 2) and on the crest of the hill 1 mile (2 km) northwest of Wind Hill (Plate 1). Although the large feldspar crystals characterize much of the unit, where they are locally absent the rock has the same mineral composition but the grain size is more uniform. Exposures of this phase are scattered throughout the augen-bearing gneiss although few occur along its eastern margin. Good examples may be observed in the fields along State Road 635 south of Oventop Mountain (Plate 2). A small epidotized (unakitic) zone is present approximately 1.2 miles (1.9 km) east of the Manassas Gap Shelter site (Plate 1).

The augen-bearing gneiss is in contact with the layered gneiss, Old Rag Granite, and the Robertson River, Swift Run, and Catoctin formations (Plates 1, 2). The western contact with the layered gneiss is sheared along part of its length and can

Figure 4. Typical texture of the augen-bearing gneiss in exposure on State Road 635, 1.0 mile (1.6 km) west of Hume (Plate 2). A well-developed feldspathic augen gneiss, with the augen ranging up to 1.5 inches (3.8 cm) in longest dimension. Note skialith of fine-grained felsic material near right bottom corner.

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be located with fair precision in a few places, but in most areas this contact is poorly defined due to lack of exposures and a gradational contact or because outcrops of augen-bearing gneiss are intermixed with those of layered gneiss. East of Belle Meade (Plate 1) this contact is truncated by the Front Royal fault, immediately north of which the augen-bearing gneiss is in unexposed contact with the Old Rag Granite.

The contact with the Robertson River Formation is somewhat irregular, particularly near the southern boundary of the Flint Hill quadrangle. Two small bodies of augen-bearing gneiss, one approximately 2.3 miles (3.7 km) southwest of Hume and another approximately 3.5 miles (5.6 km) south of Hume, seem to be entirely surrounded by the Robertson River Formation (Plate 2). Another small outlier of the augen-bearing gneiss occurs along State Road 647, approximately 0.4 mile (0.6 km) southwest of Cresthill. Foliation attitudes within these enclosed gneissic bodies are essentially the same as those within the main body of the augen-bearing gneiss to the west. In addition, the foliation attitudes within the three outliers are more or less perpendicular to parts of the contact with the enclosing granite, leading to the interpertation of these isolated gneissic bodies as roof pendants. A small (approximately 2-foot or 1-m wide) dike of Robertson River granite is in contact with the augen-bearing gneiss 1 mile (2 km) southwest of the intersection of State Roads 734 and 735 (Plate 2), and shows that the granite is intrusive into the augen-bearing gneiss.

North of the Front Royal fault (Plate 1) the augen-bearing gneiss is unconformably overlain by the Catoctin Formation and small discontinuous lenses of the intervening Swift Run Formation. These contacts are not well exposed due to an abundance of Catoctin debris from the Blue Ridge mountains. Metabasalt, felsic, amphibolite, augite-bearing, and diabase dikes intrude the augen-bearing gneiss throughout its occurrence in the two quadrangles.

In thin-section, the augen-bearing gneiss has a heteroblastic texture with microperthitic microcline, quartz, and plagioclase forming the larger crystals (R-5015, R-5026, R-5078). The finer matrix (grain sizes of approximately 3 to 6 mm) contains both gridiron-twinned microcline and microperthite. Cataclastic material consisting of very fine-grained (less than 0.1 mm) quartz, plagioclase, biotite, sericite, and epidote is always present but

varies considerably in nature and abundance. The plagioclase feldspar is mostly calcic oligoclase.

The anhedral quartz grains range in size from 2 to 4 mm and generally consist of a strained core surrounded by mortar structure. The biotite occurs as fine, euhedral grains and as subhedral, green, pleochroic flakes, the larger of which commonly have exsolved opaque minerals along their edges and triangular patterns formed by rutile needles that may be retrogressive after higher-grade biotite.

Epidote varies considerably in its nature and abundance, and is present in considerable quantities in some samples as large, discrete, subhedral grains. Green, pleochroic hornblende occures in samples from the eastern part of the outcrop area in the Linden quadrangle (R-5016, R-5018, R-5024, and R-5025), and pale-green chlorite was observed in sheared samples (R-5018).

The variability in the amounts of major minerals present in modal analyses (Table 5) results in part from statistical problems caused by the presence of the megacrysts. In addition, most of the cataclastic material is too fine-grained for the mineral components to be identified. The samples used for chemical analysis were the chips cut while making thin-sections for modal analysis. Consequently, the presence of the megacrysts in these small samples introduces potential error into the chemical and normative compositions (Tables 6 and 7). In spite of this potential error the chemical analyses are fairly uniform, and the lack of close correspondence between norms and modes of the same samples is probably due to the amounts and compositions of the cataclastic material in each sample. The mineral composition is that of a quartz monzonite (Moorehouse, 1959).

Old Rag Granite

The rock composition of the Old Rag Granite is dominated by creamy to white microcline and blue quartz; chlorite, biotite, and garnet are generally present in small amounts. Grain sizes in samples from the type locality range from 2 mm to nearly 5 cm, but in the Linden quadrangle few grains are larger than 2 cm. The contrasting colors of the quartz and feldspar give the fresh rock a striking appearance; weathered exposures are commonly light gray with some iron-oxide stains from the weathering of mafic minerals.

The Old Rag Granite is present on either side of the Front

Table 5.—Modal analyses of the augen-bearing gneiss.

	R-5018	R-5024	R-5025	R-5028	R-5036	R-5053	R-5059	R-5062	R-5063	R-5064	R-5074	R-5078	R-5081	R-5094	R-5095	R-5111
Quartz	11.6	23.0	29.2	22.5	19.4	26.9	15.0	16.8	39.7	37.1	33.3	23.3	24.0	19.7	31.1	18.3
Potassic feldspar	36.2	12.1	11.7	12.0	34.2	8.5	18.8	34.6	24.5	17.1	39.6	25.6	19.7	16.6	8.2	44.2
Plagioclase	6.4	20.9	4.5	16.7	4.3	12.4	43.2	29.0	25.9	27.6	20.3	18.3	26.9	41.0	32.3	6.7
Biotite	3.8	14.6	10.3	17.9	14.9	16.6	7.9	10.5	8.6	11.3	4.4	21.3	18.8	14.2	16.1	12.8
Chlorite	2.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Hornblende	X	1.4	X	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cataclastic material*	37.9	22.2	23.2	26.2	25.6	30.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	13.4
Epidote	X	X	X	1.0	X	1.7	11.6	6.8	X	X	X	2.4	3.5	3.6	3.7	X
Muscovite	n.d.	n.d.	19.6	n.d.	n.d.	n.d.	n.d.	X	n.d.	4.3	n.d.	3.2	1.8	2.9	1.8	n.d.
Apatite	X	1.3	X	X	X	X	1.1	1.0	X	1.1	n.d.	1.2	1.7	X	1.1	X
Opaques	1.1	3.8	X	2.3	1.0	X	X	X	X	X	X	X	2.1	X	2.8	X
Sphene	X	X	X	X	X	X	X	X	X	X	X	1.1	X	X	X	X
Zircon	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
An content of plagioclase	26	27	27	25	26	30	29	25	27	28	25	27	24	27	27	26

*See text for description of cataclastic material. X, present in amounts less than 1 percent. n.d., not detected.

Table 6.—Whole-rock chemical analyses of the augen-bearing gneiss (normalized to 100 percent).

	R-5094	R-5095	R-5111	R-5565	R-5567	R-5569	R-5578	R-5580
SiO_2	63.25	65.59	68.26	67.06	67.92	63.96	70.20	65.79
Al_2O_3	15.38	14.36	14.19	13.87	14.21	14.96	14.24	14.81
*Fe_2O_3	6.67	5.95	5.46	6.15	4.75	6.18	2.90	5.57
MgO	1.11	.93	.46	.88	.60	.95	.45	.62
CaO	2.02	2.60	1.14	1.69	2.06	3.78	1.78	2.62
Na_2O	4.52	2.89	2.50	2.82	2.72	2.75	2.97	2.87
K_2O	4.66	5.37	6.46	5.03	5.83	4.87	5.52	5.63
TiO_2	1.16	1.16	.61	1.16	.77	1.39	.47	.86
MnO	.09	.08	.08	.08	.06	.08	.05	.07
L.O.F.	1.15	1.07	.85	1.28	1.08	1.08	1.43	1.15

*Total iron as Fe_2O_3. L.O.F., loss on fusion.

Royal fault near Belle Meade (Plate 1). North of the fault weathered outcrops occur over an area of about 1 square mile (3 square km), and south of the fault a small body of the granite is present approximately 0.6 mile (1.0 km) south of Belle Meade in the stream valley just east of State Road 726. The granite is adjacent to the layered and augen-bearing gneisses, but the contacts are not exposed. The Old Rag Granite is also in contact with the Swift Run and Catoctin formations north of Belle Meade. Inferences from the type locality of the Old Rag Granite (Reed, 1969) indicate that it is unconformably overlain by the Catoctin Formation or the intervening, but discontinuous, Swift Run metasediments.

The appearance of the Old Rag Granite is as striking in thin

Table 7.—Normative compositions of the augen-bearing gneiss.

	R-5094	R-5095	R-5111	R-5565	R-5567	R-5569	R-5580
Quartz	13.79	22.09	26.13	26.85	24.97	21.06	21.74
Orthoclase	27.89	32.09	38.53	30.13	34.85	29.10	33.70
Albite	38.69	24.71	21.33	24.19	23.29	23.55	25.57
Anorthite	8.03	10.49	5.70	8.48	9.43	14.26	11.04
Corundum	n.p.	n.p.	1.03	.72	n.p.	n.p.	n.p.
Diopside	1.64	1.99	n.p.	n.p.	.70	3.66	1.64
Enstatite	2.03	1.43	1.15	2.22	1.18	.70	.80
Hematite	6.75	6.02	5.51	6.23	4.81	6.25	5.64
Rutile	1.17	1.17	.62	1.18	.78	1.41	.87

n.p., not present.

section as it is in outcrop. The texture is allotriomorphic-granular and grain sizes are fairly uniform, with anhedral grains of strained quartz and string perthites the major constituents (Figure 5). Untwinned albite is present in the ex-

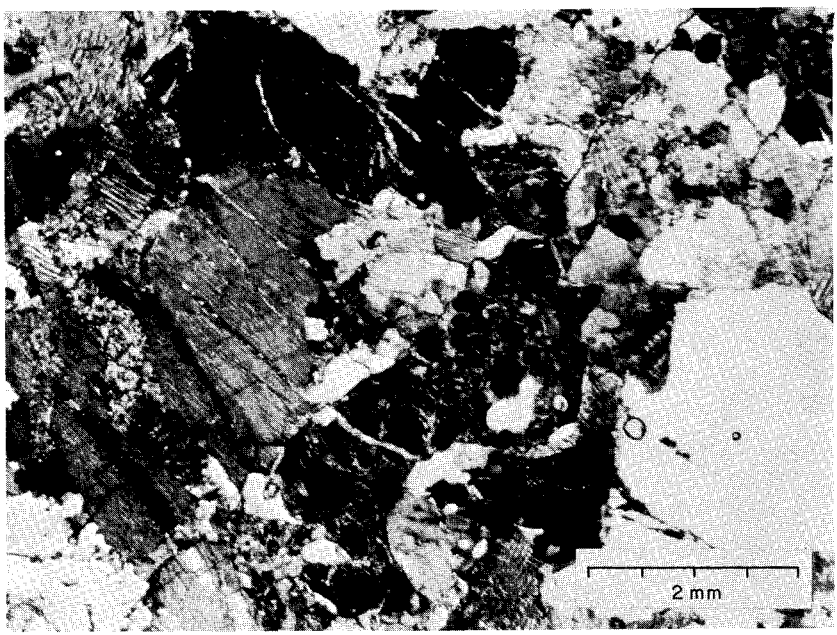

Figure 5. Photomicrograph showing fractured, chloritized garnet and typical string perthite in the Old Rag Granite (R-5107), 0.2 mile (0.3 km) due north of Belle Meade (Plate 1, crossed nicols).

solution lamellae of the perthites and also along the grain boundaries of both the perthite and plagioclase. The principal dark mineral is garnet, which is generally fractured; chlorite is present along these fractures as a retrograde alteration of the garnet.

The relative abundances of the constituent minerals are shown in Table 8; Tables 9 and 10 give the chemical and normative compositions, respectively. The very silicic nature of the Old Rag Granite is conspicuous in these tables. There is a marked difference between the amount of modal plagioclase and normative albite, which is due to the presence of albite in the fine exsolution lamellae in the perthite and in the mechanical difficulties of estimating its abundance by modal analysis. The chemical and mineralogical compositions of the Old Rag Granite are consistent with a plutonic igneous origin.

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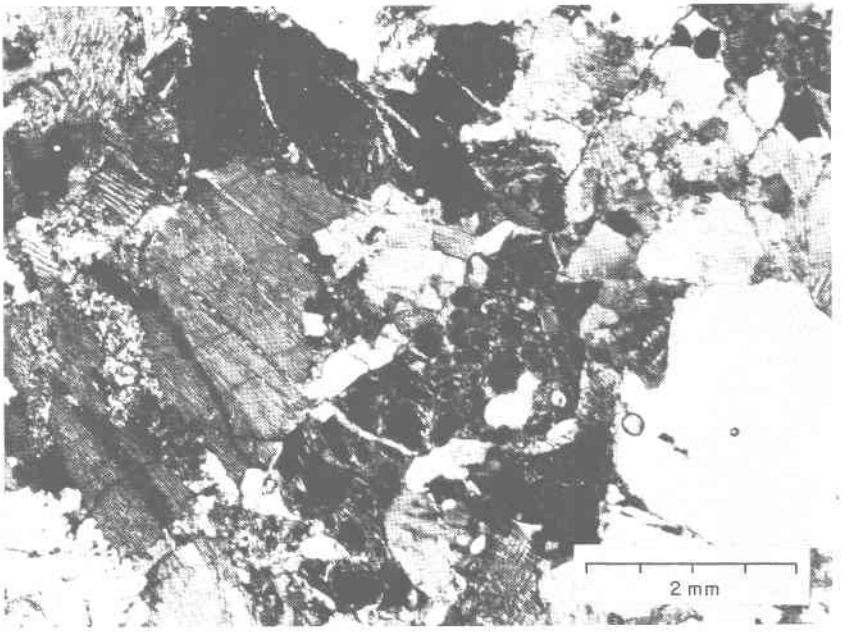

Figure 5. Photomicrograph showing fractured, chloritized garnet and typical string perthite in the Old Rag Granite (R-5107), 0.2 mile (0.3 km) due north of Belle Meade (Plate 1, crossed nicols).

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Table 8.—Modal analyses of the Old Rag Granite.

	R-5107	R-5108
Quartz	32.0	39.2
Potassium feldspar	49.2	45.0
Plagioclase	13.1	9.3
Garnet	1.1	2.3
Sericite	X	3.6
Chlorite	1.2	n.d.
Biotite	X	X
Apatite	X	X
Epidote	X	X
Zircon	X	X
Opaques	X	X
An content of plagioclase	30	24

X, Present in amounts less than 1 percent. n.d., not detected.

Pedlar Formation

Bloomer and Werner (1955) named the Pedlar Formation for rock exposures in the headwater area of the Pedlar River in Amherst County, Virginia. They included a number of similar rock types within this formational designation, including the hypersthene granodiorite of Jonas (1928, 1935).

Near Huntly (Plate 2) the contact between the Pedlar and the underlying layered gneiss is sheared. Northeast of Huntly, the layering that characterizes the adjacent layered gneiss persists for a short distance into the Pedlar Formation, indicating

Table 9.—Whole-rock chemical analyses of the Old Rag Granite (normalized to 100 percent).

	R-5107	R-5108
SiO_2	78.06	77.43
Al_2O_3	11.68	11.94
*Fe_2O_3	1.43	1.52
MgO	.11	.03
CaO	.54	.33
Na_2O	2.48	2.93
K_2O	4.96	4.75
TiO_2	.10	.14
MnO	.04	.04
L.O.F.	.60	.90

*Total iron as Fe_2O_3. L.O.F., loss on fusion.

Table 10.—Normative compositions of the Old Rag Granite.

	R-5107	R-5108
Quartz	43.62	41.86
Orthoclase	29.52	28.31
Albite	21.11	25.03
Anorthite	2.69	1.66
Corundum	1.26	1.39
Enstatite	.27	.07
Hematite	1.44	1.53
Rutile	.10	.14

an intermixed or gradational contact. The Pedlar Formation is overlain unconformably by the Swift Run Formation or by the Catoctin Formation where the Swift Run Formation is absent.

The Pedlar Formation is light to greenish gray, the lighter color derived from the dull, creamy appearance of weathered plagioclase. It is generally medium grained with sizes approximately 2 to 5 mm in diameter, although a few are nearly 3 cm in length. The grain size increases and the layered character of the outcrops diminishes with distance from the contact with the layered gneiss. In hand-specimen the potassic feldspar, plagioclase, and quartz are the most abundant constituents; biotite is always present but hornblende is not always discernible. Some unakite was observed along the small transverse fault 0.7 mile (1.1 km) southwest of Ravensden Rock in the Flint Hill quadrangle (Plate 2).

Thin-section examination reveals that many of the apparently large grains actually consist of several smaller crystals. The quartz grains range in size from 0.2 to 4 mm and show undulatory extinction.

The potassic feldspar is predominantly anhedral, microperthitic microcline that includes some grains greater than 5 mm in size. Subhedral to anhedral plagioclase grains are commonly less than 1 mm in size but some exceed 2 mm. Saussuritization and sericitization of the plagioclase is common, and the degree of alteration seems to increase with proximity to the layered gneiss.

Rutilated biotite is present in most samples, as is hornblende and hypersthene or uralite (Figure 6). Unaltered hypersthene was observed in only a few of the thin sections (R-5494), and

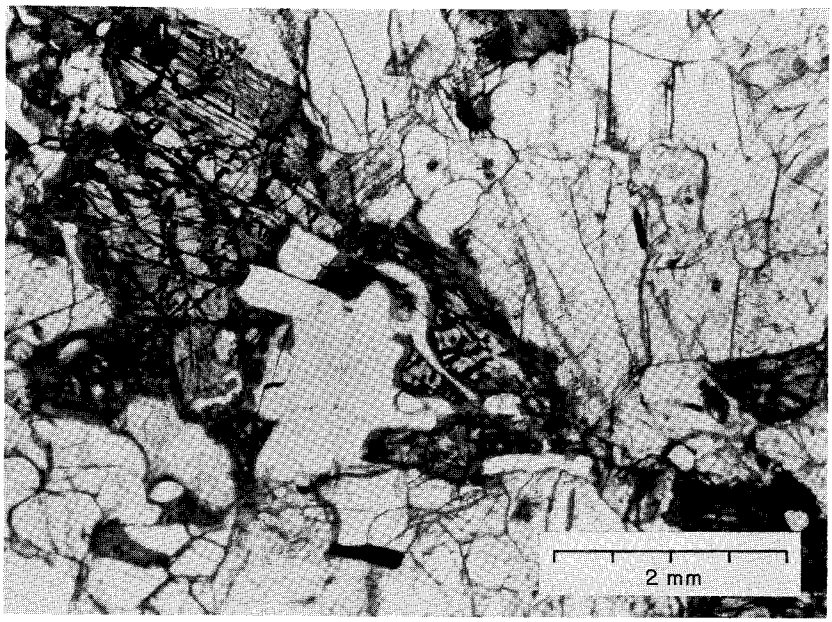

Figure 6. Photomicrograph showing alteration of hypersthene to uralite in Pedlar quartz monzonite (R-5637), 0.4 mile (0.6 km) northwest of Huntly (Plate 2, plane light).

those were from outcrops farthest from the contact with the layered gneiss. More commonly, the hypersthene is partially or completely altered to uralite, the most severe uralitization occuring near contacts with the layered gneiss. Garnets, generally somewhat fractured and partially retrograded to chlorite, are present in some samples collected near the contact with the layered gneiss.

The relative abundances of the constituent minerals are shown in Table 11. Based on the modal data the Pedlar Formation in the Linden and Flint Hill quadrangles is a quartz monzonite, according to Moorhouse's classification (1959), rather than a granodiorite. The texture is generally granoblastic and minor cataclasis is evident, particularly in samples from outcrops near the contact with the layered gneiss. This cataclasis is manifested primarily by the presence of fractured and deformed plagioclase twin lamellae (Figure 7), fractured garnets, mortar structures, and granulated quartz. The chemical and normative compositions are fairly consistent (Tables 12 and 13), the principal variations being in the iron, potash, and silica.

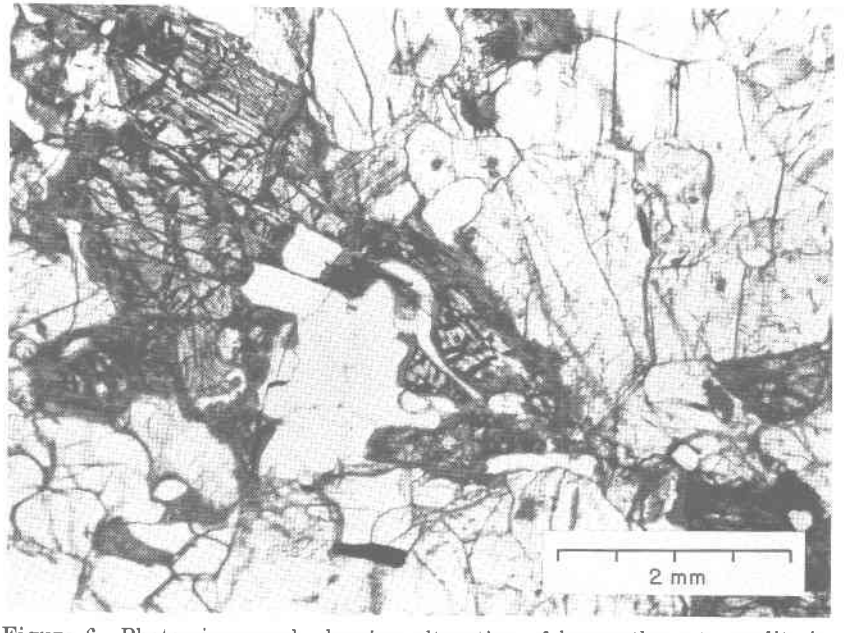

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Table 11.—Modal analyses of the Pedlar Formation.

	R-5112	R-5563
Quartz	19.2	9.7
Potassium feldspar	42.4	40.6
Plagioclase	29.4	30.7
Hornblende	X	1.5
Biotite	4.3	2.5
Uralite	X	13.2
Chlorite	3.9	n.d.
Epidote	X	X
Apatite	X	X
Magnetite and ilmenite	X	1.6
Zircon	X	X
An content of plagioclase	26	32

X, present in amounts less than 1 percent. n.d., not detected.

Robertson River Formation

The Robertson River Formation, a hornblende-biotite granite, is exposed in an area of almost 8 square miles (21 sq km) along

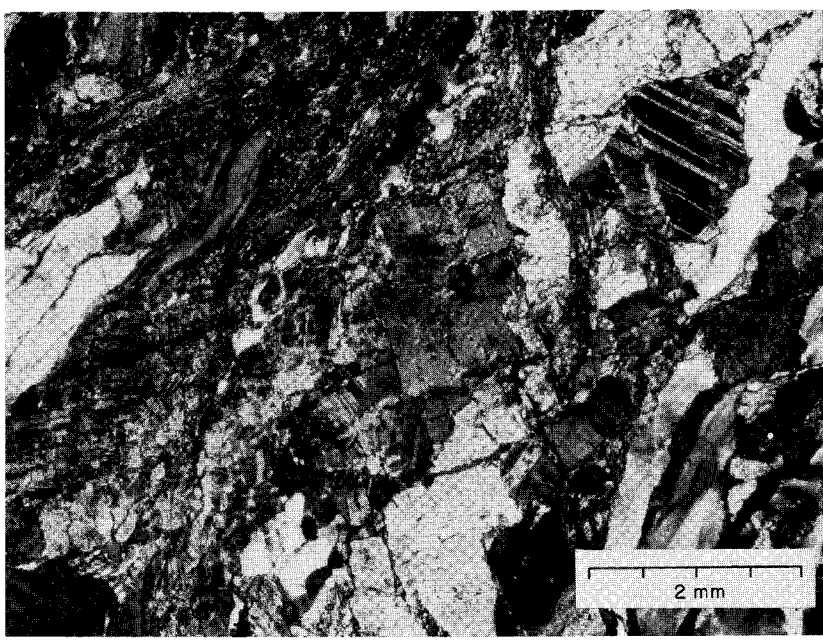

Figure 7. Photomicrograph showing fractured and deformed plagioclase twin lamellae in Pedlar quartz monzonite (R-5484), 2.0 miles (3.2 km) northeast of the intersection of U. S. Highway 522 and State Road 635 (Plate 2, crossed nicols).

Table 11.—Modal analyses of the Pedlar Formation.

	R-5112	R-5563
Quartz	19.2	9.7
Potassium feldspar	42.4	40.6
Plagioclase	29.4	30.7
Hornblende	X	1.5
Biotite	4.3	2.5
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Robertson River Formation

The Robertson River Formation, a hornblende-biotite granite, is exposed in an area of almost 8 square miles (21 sq km) along

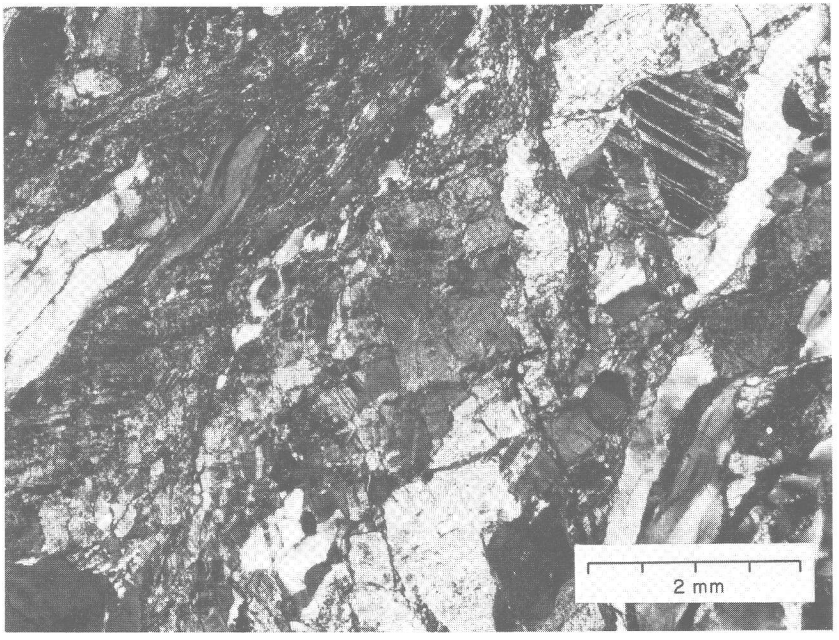

Figure 7. Photomicrograph showing fractured and deformed plagioclase twin lamellae in Pedlar quartz monzonite (R-5484), 2.0 miles (3.2 km) northeast of the intersection of U. S. Highway 522 and State Road 635 (Plate 2, crossed nicols).

Table 12.—Whole-rock chemical analyses of the Pedlar Formation (normalized to 100 percent).

	R-5112	R-5563	R-5646
SiO_2	71.57	68.56	65.92
Al_2O_3	14.48	14.30	14.88
*Fe_2O_3	2.59	4.06	5.38
MgO	.35	.48	1.09
CaO	1.70	1.75	2.41
Na_2O	2.98	2.38	2.74
K_2O	5.26	6.51	5.10
TiO_2	.34	.65	.76
MnO	.03	.05	.07
L.O.F.	.69	1.25	1.65

*Total iron as Fe_2O_3. L.O.F., loss on fusion.

the eastern boundary of the Flint Hill quadrangle (Plate 2). In a small area on the east-central edge of the quadrangle the granite of the formation is in contact with the layered gneiss. Xenoliths of layered gneiss are present in the granite near this contact zone (the sides of the small hill marked with elevation 615, approximately 1.25 miles or 2.01 km north of Cresthill), and provide evidence that the granite is intrusive into the layered gneiss (personal communication, J. W. Clarke, 1974). The western boundary of the Robertson River Formation is marked by a very irregular contact with the augen-bearing gneiss (Plate 2). The presence of gneissic roof pendants within the granite and Robertson River dikes cutting the augen-bearing gneiss provide clear evidence that the granite is also intrusive into the augen-bearing gneiss. Amphibolite and felsic dikes intrude the unit throughout its occurrence in the Flint Hill quadrangle.

Table 13.—Normative compositions of the Pedlar Formation.

	R-5112	R-5563	R-5646
Quartz	30.18	25.71	24.12
Orthoclase	31.28	38.97	30.64
Albite	25.41	20.40	23.58
Anorthite	8.49	8.80	12.17
Corundum	.81	.15	.49
Enstatite	.88	1.21	2.76
Hematite	2.61	4.11	5.47
Rutile	.34	.66	.77

Fresh exposures of the Robertson River Formation range from light to dark gray; weathered exposures are generally light gray. It is medium- to coarse-grained (2 to 10 mm in diameter). The major mineral constituents are feldspar and gray quartz, accompanied by the mafic minerals hornblende and biotite that give outcrops a somewhat speckled appearance (Figure 8).

Figure 8. Typical granitic texture of the Robertson River Formation, 0.8 mile (1.3 km) northwest of the intersection of State Roads 688 and 734 and 0.4 mile (0.6 km) southwest of Hume (Plate 2). The dark linear streaks are probably sheared areas that have concentrations of mafic material.

Thin-section examination confirms the predominance of quartz, potassic feldspar, and plagioclase (Table 14). The potassic feldspar occurs as both gridiron-twinned microcline and as perthite of the patch variety, and the plagioclase is mostly calcic oligoclase.

Green, strongly pleochroic biotite occurs as stringers or small flakes, as large flakes associated with hornblende, and as aggregates of large flakes. The anhedral grains of pleochroic green hornblende generally have very irregular grain boundaries.

The mineral abundances given in Table 14 and the chemical and normative compositions in Tables 15 and 16 reflect a gen-

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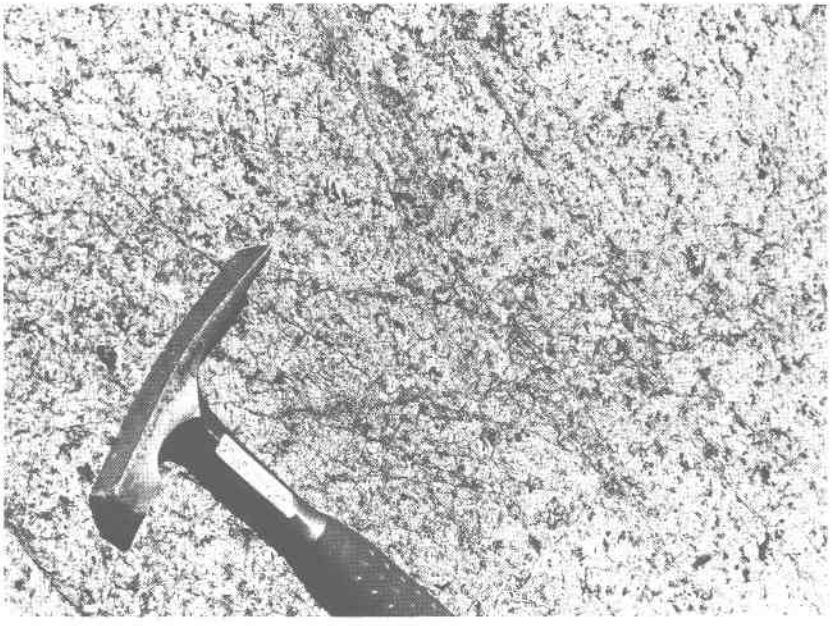

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Table 14.—Modal analyses of Robertson River Formation.

	R-5057	R-5086	R-5087	R-5096	R-5097	R-5098	R-5099	R-5100	R-5101
Quartz	13.2	14.3	14.7	37.8	10.9	31.9	8.9	17.0	7.5
Potassic feldspar	52.0	53.0	39.6	30.2	46.3	40.4	66.2	50.8	33.6
Plagioclase	23.5	17.7	28.8	25.0	31.3	20.5	20.6	17.3	47.2
Hornblende	1.5	11.1	12.6	1.4	10.2	3.1	1.0	5.1	X
Biotite	8.3	2.5	4.8	3.1	X	3.0	3.2	7.1	7.5
Epidote	X	X	X	2.0	X	X	X	X	2.6
Apatite	n.d.	n.d.	X	n.d.	X	n.d.	X	X	X
Sericite	X	n.d.	n.d.	X	n.d.	n.d.	n.d.	n.d.	n.d.
Zircon	X	X	X	X	X	X	X	X	X
Rutile	n.d.	X	n.d.	X	X	X	X	X	X
Ilmenite	X	X	X	X	X	X	X	X	X
Sphene	X	X	X	X	X	X	X	X	X
An content of plagioclase	27	26	27	28	26	30	27	28	25

X, Present in amounts less than 1 percent. n.d., not detected.

eral uniformity of composition throughout the Robertson River Formation. Normative albite is more abundant than modal plagioclase in most samples, but this is due primarily to the difficulty of determining the albitic component of the perthite by modal analysis.

Dikes

Most of the dikes display cleavage that is generally parallel to that of the Paleozoic rocks in the Linden quadrangle. The diabase dikes in the Flint Hill quadrangle, however, display no cleavage, and therefore represent the youngest igneous rocks.

Table 15.—Whole-rock chemical analyses of the Robertson River Formation (normalized to 100 percent).

	R-5096	R-5097	R-5098	R-5099	R-5100	R-5101
SiO_2	72.24	67.76	74.87	70.89	72.85	70.80
Al_2O_3	13.04	14.70	12.36	13.03	13.07	13.87
*Fe_2O_3	3.66	4.47	2.32	4.43	3.30	3.72
MgO	n.d.	.09	.11	.23	.19	n.d.
CaO	.80	1.65	.37	.88	.34	.68
Na_2O	3.72	4.46	3.53	3.41	3.46	4.36
K_2O	5.67	5.89	5.74	5.95	5.85	5.47
TiO_2	.30	.33	.13	.43	.30	.34
MnO	.07	.09	.04	.08	.05	.07
L.O.F.	.49	.56	.54	.67	.59	.71

*Total iron as Fe_2O_3. L.O.F., loss on fusion. n.d., not detected.

Table 16.—Normative compositions of the Robertson River Formation.

	R-5096	R-5097	R-5098	R-5099	R-5100	R-5101
Quartz	27.76	16.95	31.84	26.63	29.54	23.52
Orthoclase	33.69	35.01	34.09	35.44	34.78	32.58
Albite	31.64	37.95	30.00	29.06	29.45	37.14
Anorthite	2.15	2.75	.96	2.69	1.71	2.16
Corundum	n.p.	n.p.	n.p.	n.p.	.43	n.p.
Diopside	n.p.	.48	.58	1.24	n.p.	n.p.
Wallastonite	.77	2.03	.06	.05	n.p.	.51
Hematite	3.68	4.50	2.33	4.46	3.32	3.75
Rutile	.30	.33	.13	.43	.30	.34

n.p., not present.

The older dikes can be placed in one of four categories: 1) greenstone (Catoctin) dikes, distinguished by their aphanitic texture and dark grayish-green color, 2) amphibolite (metamorphosed diabase) dikes, characterized by an aphanitic texture and medium to dark-gray color, 3) augite-bearing dikes with a finely porphyritic texture and light greenish-gray color, and 4) felsic dikes that display a saccharoidal texture and are commonly yellowish to light gray.

The age of these older dikes is unknown; they all exhibit a presumed Paleozoic cleavage and were observed only in the Precambrian rocks. For these reasons, the dikes are probably no younger than Paleozoic and possibly are as old as Precambrian. The age relationships between the different types of dikes are uncertain as no clear-cut contact relationships were found. These dikes commonly have a strike to the northeast (Plates 1, 2), although individual dikes may show considerable departure from this orientation.

A few dikes are of considerable dimensions, such as those southeast of Linden (Plate 1) where the largest is 1.6 miles (2.3 km) long and 500 feet (152 m) wide. Aside from these, however, few of the dikes exceed a width of 50 feet (15 m), but many are of considerable linear extent such as the mile long amphibolite dikes at Hitch (Plate 2). Contact margins of small amphibolite dikes with the host rocks are clearly exposed in some areas (Figure 9), and their crosscutting relationships with one another are well displayed on a hillside (marked with elevation 615) south of State Road 735 about 3.4 miles (5.5 km)

Figure 9. Amphibolite dike approximately 2 feet (1 m) wide intruding the augen-bearing gneiss, 1.8 miles (2.9 km) east of Flint Hill on north side of State Road 647 (Plate 2). Contact margins seem to be unaffected by the intrusion.

south of Hume (Plate 2). Xenoliths of both the Robertson River Formation and the layered gneiss are present in the dikes that are offset by small-scale faulting. A few unique dikes also occur in this area; a dark-gray dike on the north side of State Road 647, just southwest of its intersection with State Road 645 near Cresthill (Plate 2) has phenocrysts of potassic feldspar (Figure 10).

The augite-bearing dikes are composed primarily of augite, chlorite, and epidote. Anhedral augite generally forms the largest grains (up to 1 mm) and commonly displays twinning. The principal opaque mineral is magnetite that displays the characteristic triangular shape of euhedral octahedrons. The chemical composition for an augite-bearing dike is given in Table 17.

Thin sections from the amphibolite dikes reveal a preponderance of actinolite that occurs as subhedral to anhedral grains up to 2 mm in length. Chlorite, epidote, and sphene are

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Figure 10. Porphyritic, northeastward-trending, dark felsic dike exhibiting spaced cleavage on the north side of State Road 647, 1,500 feet (457 m) southwest of Cresthill (Plate 2).

commonly present and plagioclase, when present, displays both albite and combined albite-Carlsbad twinning.

The felsic dikes range from aphanitic to porphyritic, with a mineral composition that varies only in the relative amounts

Table 17.—Whole-rock chemical analysis of an augite-bearing dike (normalized to 100 percent).

	R-5109
SiO_2	46.00
Al_2O_3	13.60
*Fe_2O_3	15.52
MgO	6.23
CaO	10.54
Na_2O	2.06
K_2O	.92
TiO_2	2.54
MnO	.23
L.O.F.	2.36

*Total iron as Fe_2O_3. L.O.F., loss on fusion.

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of the constituent minerals. Perthitic microcline and strained quartz are the most abundant minerals present, and plagioclase, biotite, epidote, magnetite, and ilmenite are commonly present in variable amounts.

PRECAMBRIAN (?) ROCKS

Swift Run Formation

The Swift Run Formation is a heterogenous unit of metagraywacke, sericitized meta-arkose, and phyllite that is overlain by volcanic and metasedimentary rocks of the Catoctin Formation and underlain by the Precambrian plutonic rocks. Excellent exposures occur in the Linden quadrangle 1.6 miles (2.6 km) northeast of Linden, 0.4 mile (0.6 km) north of U. S. Highway 55. In the Flint Hill quadrangle good exposures are accessible 0.5 mile (0.8 km) due north of Willis Chapel on U. S. Highway 522, 220 feet (67 m) west of State Road 634.

Late Precambrian erosion of the gneissic and granitic basement rocks produced a relief of several hundred feet. The coarse clastic material eroded from these rocks was deposited as heterogenous accumulations in the valleys, resulting in the mineral composition of the Swift Run Formation reflecting that of the plutonic rocks from which it was derived. The unit is fairly well exposed, but primary-bedding features are sometimes obscured by a very prominent slaty cleavage (Figure 11). Hand specimens are dominantly a dark greenish-brown, poorly sorted, pebbly and sandy, coarse-grained meta-arkose, metagraywacke, and phyllite with the quartz fraction (the most prominent clastic mineral) ranging from 1 to 5 mm in diameter. Sericite and quartz are uniformly distributed throughout most thin sections, with occasional elongated blebs and patches of chlorite. The quartz content usually ranges from 40 to 60 percent, sericite from 25 to 30 percent, and feldspar from 25 to 50 percent; the cumulative amount of chlorite, epidote, and opaque minerals ranges from 1 to 15 percent (Table 18). Locally, purple, thin-bedded slate crops out in the Linden quadrangle.

Due to the nature of its depositional environment, the Swift Run Formation ranges from 0 to more than 150 feet (46 m) in thickness. The thickest single exposure that was found is located due south of Ravensden Rock (Plate 2) where the metasediments form cliffs more than 80 feet (23 m) high.

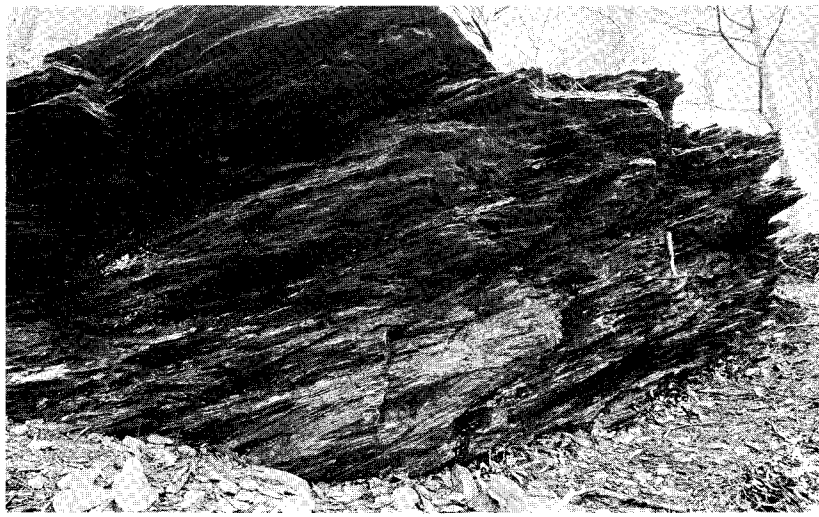

Figure 11. Schistose metasediments of the Swift Run Formation 1.8 miles (2.9 km) northeast of Linden and 0.4 mile (0.6 km) north of State Highway 55 (Plate 1). Dark greenish-brown, fine-grained, poorly sorted meta-arkose with a very prominent cleavage masking the bedding features.

Catoctin Formation

The main portion of the Blue Ridge in the Linden and Flint Hill quadrangles is underlain by metabasalt and associated metavolcanic and metasedimentary rocks of the Catoctin Formation (Geiger and Keith, 1891). This rock unit stratigraphically overlies the Swift Run Formation but is in unconformable contact with the older Precambrian granites and gneisses where the Swift Run metasediments are absent. The upper contact with the overlying Weverton Formation is placed at the top of the uppermost occurrence of metabasalt and volcanic purple slate.

The Catoctin Formation can be divided into two units. The lower unit occurs only in the Linden quadrangle where north of State Highway 55 it is 300 to 400 feet (91 to 122 m) thick and is composed of purple, tuffaceous phyllite, metabasalt, rhyolitic metatuff and metasediments. The boundary between the units is placed at the top of a fine-grained, cream or pink, epidote-bearing, rhyolitic metatuff (Figure 12). The metatuff attains a maximum thickness of 30 feet (9 m), and occurs only in a narrow, discontinuous belt along the east flank of the Blue Ridge north of U. S. Highway 55.

The upper unit comprises the bulk of the formation and

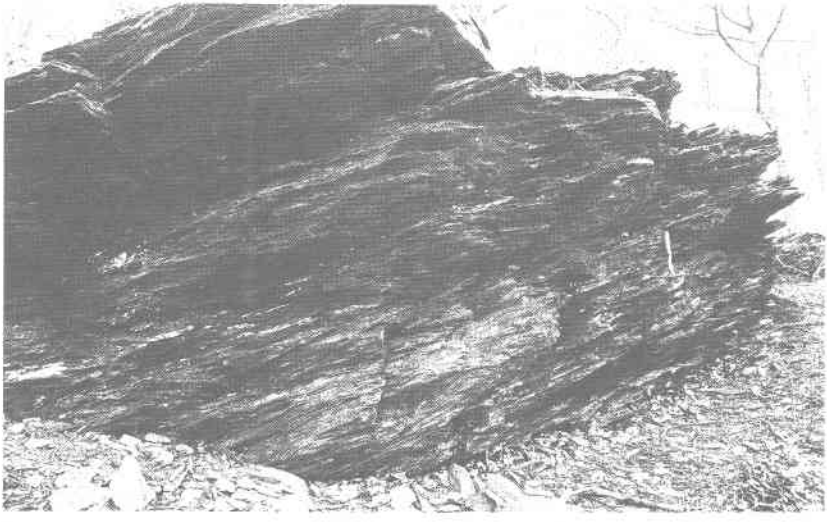

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Table 18.—Characteristic mineral assemblages in the Swift Run, Catoctin, Weverton, Harpers, and Antietam formations.

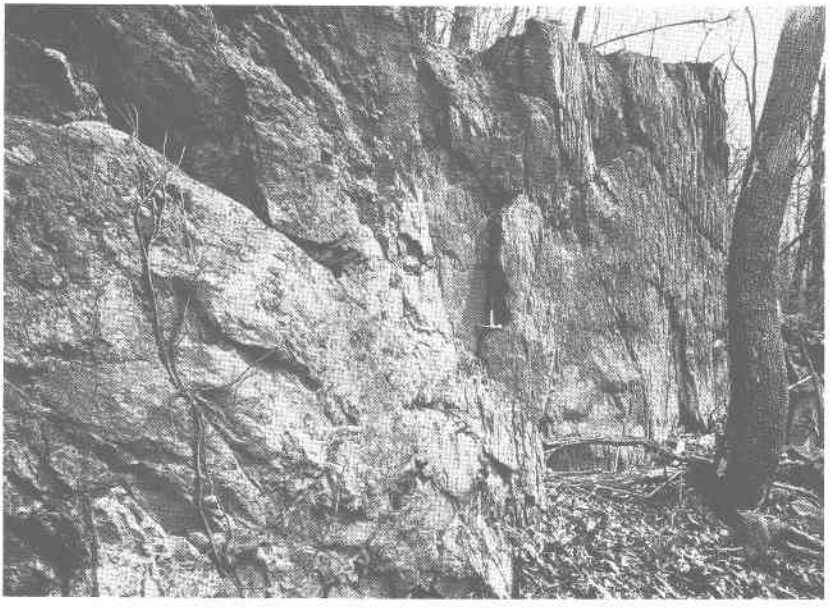
	Swift Run Formation				Catoctin Formation							Chilhowee Group				
					Phyllite and sediment			Rhyolitic metatuff		Metabasalt		Weverton Formation	Harpers Formation			Antietam Formation
	R-5017	R-5040	R-5052	R-5487	R-5019	R-5103	R-5106	R-5051	R-5104	R-5050	R-5486	R-5046	R-5045	R-5047	R-5048	R-5049
Quartz	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Plagioclase	X				X	X	X	X	X	X	X	X		X	X	X
Microcline	X							X	X	X	X					X
Perthite		X		X												
Orthoclase													X	X	X	X
Sericite	X	X	X	X	X		X	X	X	X	X	X	X	X	X	
Chlorite			X	X	X		X			X	X	X				
Actinolite										X	X					
Saussurite										X	X					
Epidote		X	X	X	X	X	X	X	X	X	X					
Magnetite and/or ilmenite	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Zircon	X	X		X						X	X	X	X	X	X	
Garnet		X														
Augite										X						
Pyroxene										X						

X, denotes minerals present in samples.

Figure 12. Rhyolitic metatuff from the lower unit of the Catoctin Formation, 1.2 miles (1.9 km) east of WRFL Radio Tower and 0.6 mile (1.0 km) northwest of State Road 688 (Plate 1). Massive ledge of fine-grained, cream or pink, epidote-bearing, rhyolitic metatuff with abundant amygdules filled with epidote, quartz, and feldspar.

consists of metabasalt, basalt-flow breccia, epidosite, and some interbeds of purple, amygduloidal slate. Exposures of this unit which is 1,600 to 2,200 feet (488 to 670 m) thick, are accessible along State Road 638 north of Linden. The light- to dark-purple, amygduloidal slate (Loudoun Formation of earlier reports; Keith, 1894) is exposed just southeast of Camp Wamava and 1.1 miles (1.8 km) northwest of Yellow Rose Shelter in the Linden quadrangle. Columnar jointing, although relatively uncommon, was observed 1.4 miles (2.25 km) southwest of Ravensden Rock (Plate 1), and 0.8 mile (1.3 km) west of State Road 688 at the head of Wildcat Hollow (Plate 2). Although thick talus and saprolite deposits preclude complete measurements, a probable total thickness of between 2,000 and 2,500 feet (610 to 762 m) is inferred for the Catoctin Formation.

Individual basalt-flow thicknesses range from 75 to 150 feet (23 to 46 m) and generally contain a zone of amygdaloidal greenstone, phyllite, and red argillite breccia at the top. Mud-lump breccias, consisting of angular to subangular fragments of



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deep reddish-brown argillite in a matrix of fine-grained, schistose basalt (Rader and Biggs, 1975) are sporadically present at the base of some flows. The many metabasalt "feeder" dikes are solidified lava remnants in fissures from which the vast Catoctin lava flows issued. Excellent exposures of some metabasalt dikes are present in the Culpeper Stone Company quarry just east of Flint Hill.

Sediments associated with the Catoctin Formation are most abundant in the lower unit. Initial metasomatic effects of the basalt flows and later metamorphism have greatly altered these thin, discontinuous sedimentary deposits. Thin-section examinations (Table 18) revealed a fine- to medium-grained, quartzofeldspathic rock with as much as 25 and 15 percent very fine-grained sericite and epidote, respectively. The quartz and feldspar grains were initially round to subround, but have since been partially recrystallized to give a sutured-boundary appearance.

Metabasalts of the Catoctin Formation are either massive, porphyritic, or amygduloidal. The massive metabasalts are dark- to grayish-green, dense, and very fine-grained. A sample from a typical exposure of the metabasalt on State Road 638 near Skyland Estates in the Linden quadrangle was petrographically and chemically analyzed (R-5050; Figure 13; Tables 18 and 19). Amygdules that range from 1 to 6 mm in diameter are commonly present at the top and bottom of the basalt flows and are principally composed of quartz and feldspar with varying amounts of epidote, chlorite, and opaque minerals. Rare exposures of porphyritic basalt flows with light-colored plagioclase phenocrysts that range from 1 to 7 mm in length were also observed.

The occurrence of epidosite, a pale yellow-green, fine-grained rock, is fairly common throughout the formation. This early chemical-alteration product of metabasalt (Reed and Morgan, 1971) occurs as vein fillings and a cementing agent in flow breccia and interbedded quartzose sandstone. In thin section the composition is a fine-grained, equigranular, subhedral epidote with small aggregates of anhedral quartz. Where the metabasalt has been altered to epidosite, a relict basaltic texture may be preserved with little alteration of the amygdules (Gathright and Nystrom, 1974).

Light- to dark-purple, amygduloidal slates occur as thin, discontinuous layers at the top and at several horizons within the

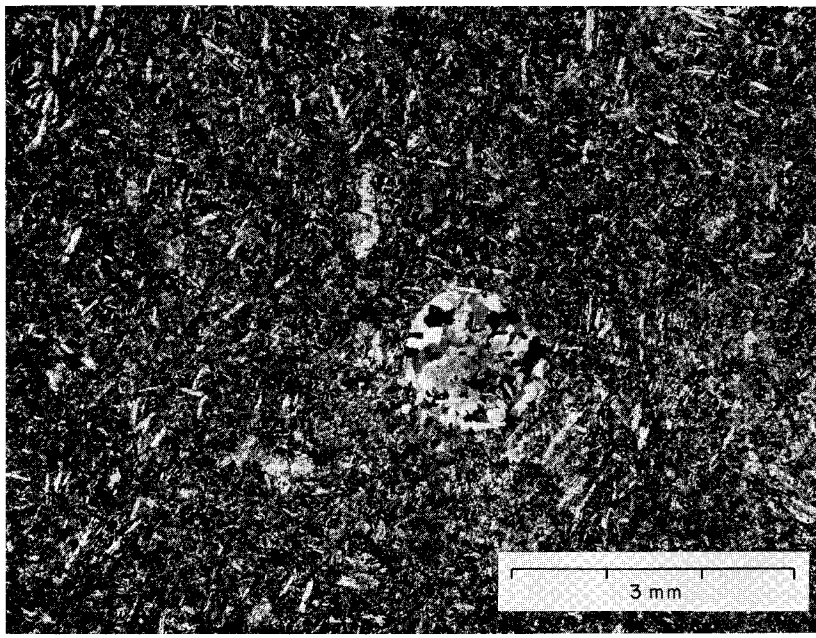
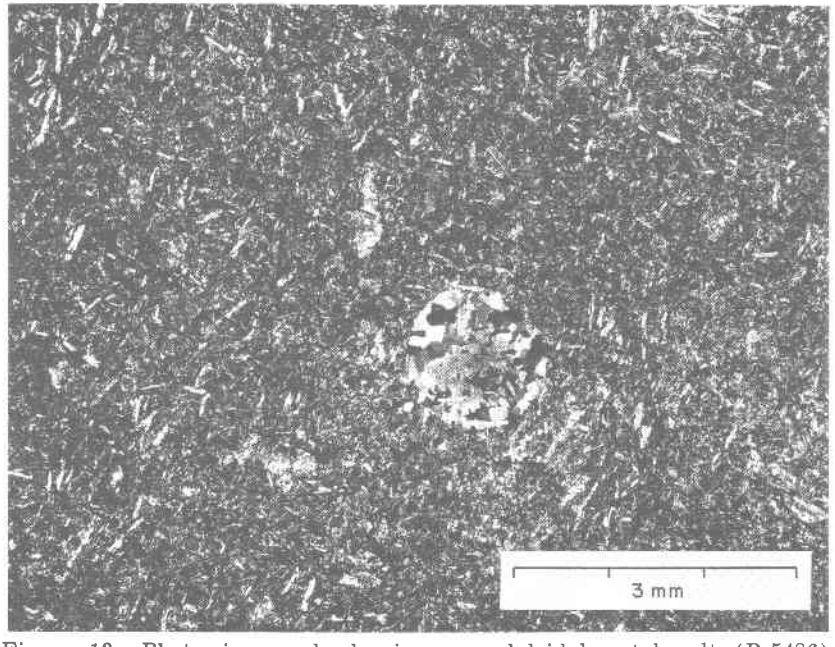


Figure 13. Photomicrograph showing amygduloidal metabasalt (R-5486) from the upper unit of the Catoctin Formation, 1.6 miles (2.6 km) northwest of the intersection of State Road 635 and U. S. Highway 522 (Plate 1). Amygdule of epidote (center) is surrounded by a metabasalt groundmass of randomly oriented plagioclase laths, epidote, chlorite, and opaque minerals (crossed nicols).

Table 19.—Whole-rock chemical analyses of the Catoctin Formation (normalized to 100 percent).

	R-5050	R-5104	R-5110	R-5571
Occurrence	Basalt Flow	Rhyolitic Tuff	Basalt Dike	Basalt Dike
SiO_2	48.46	74.67	48.65	48.14
Al_2O_3	13.54	12.31	14.70	14.49
*Fe_2O_3	15.46	1.16	12.44	12.06
MgO	4.82	0.00	6.49	7.47
CaO	9.72	1.56	11.38	11.38
Na_2O	1.37	1.27	1.63	1.50
K_2O	1.13	8.05	0.95	1.01
TiO_2	2.67	0.26	1.75	1.68
MnO	0.22	0.01	0.19	0.18
L.O.F.	2.61	0.71	1.82	2.11

*Total iron as Fe_2O_3. L.O.F., loss on fusion.



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Catoctin Formation. Thin-section examination reveals a foliated matrix of very fine-grained sericite, microcrystalline quartz, and magnetite or ilmenite with associated hematite (Figure 14).

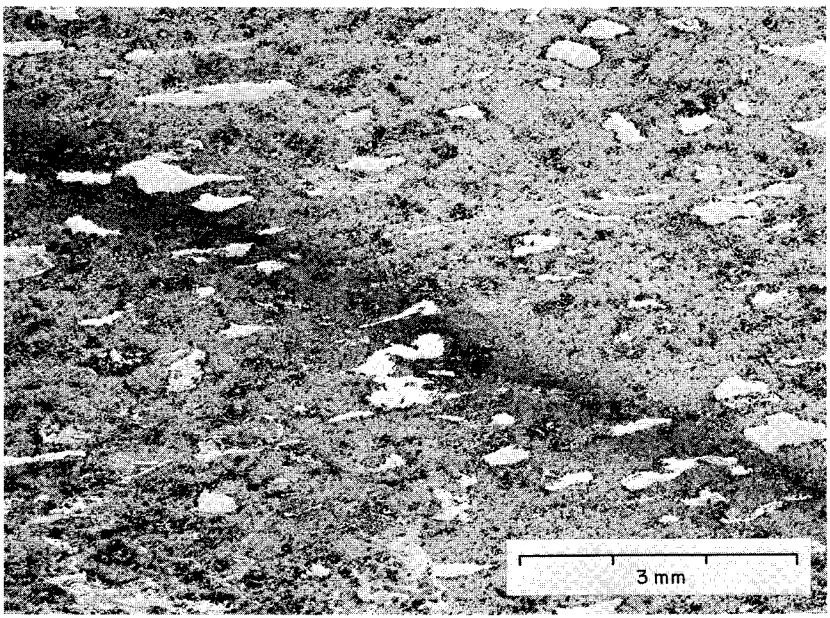

Figure 14. Photomicrograph showing purple amygduloidal slate (R-5019) from the uppermost portion of the upper unit of the Catoctin Formation, 1.1 miles (1.8 km) northwest of Yellow Rose Shelter (Plate 1). The elongated amygdules are composed of sericite and microcrystalline quartz in a groundmass of sericite, microcrystalline quartz, and magnetite or ilmenite (plane light).

Scattered throughout this fine-grained matrix are amygdules composed of quartz, sericite, and microcrystalline quartz. An excellent example of this lithology can be seen 1.1 miles (1.8 km) northwest of Yellow Rose Shelter and 1.8 miles (2.9 km) east of Venus Hill in the Linden quadrangle (R-5019). A sample of a possible varved, purple slate or phyllite containing thin, alternating dark and light bands with no visible relict amygduloidal structures near the bottom of the formation was also examined (R-5103, Table 18). The matrix consisted of 50 percent quartz, 45 percent feldspar, and less than 5 percent epidote and opaque minerals (magnetite or ilmenite with associated hematite); bedding was also revealed that ranged in thickness from less than 0.03 mm to 4.8 mm.

A cream to pink, very fine-grained, amygduloidal, rhyolitic

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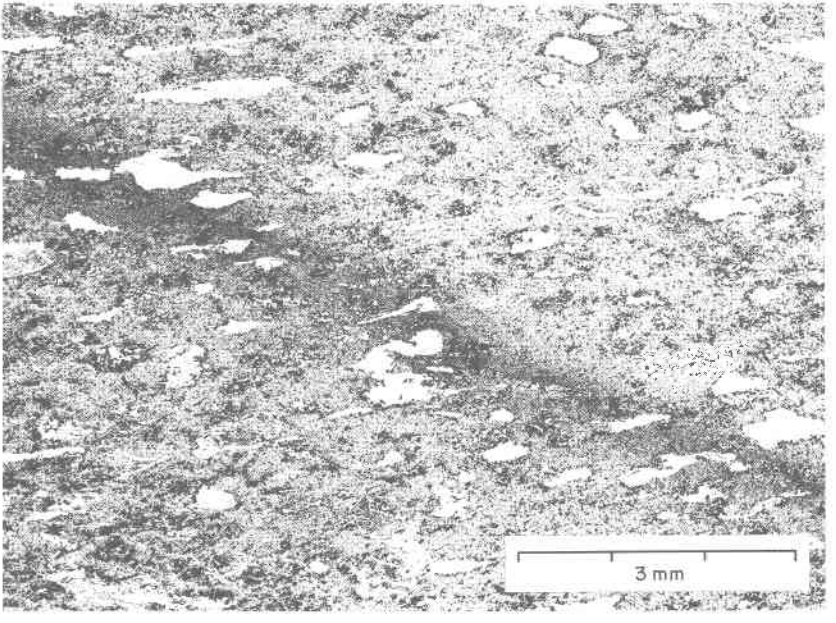

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metatuff occurs at the top of the lower member of the Catoctin Formation. Microscopic examination (R-5104, Table 18) revealed a very fine-grained matrix of sericite and microcrystalline quartz and feldspar with amygdules (0.4 to 2.6 mm in diameter) of quartz, feldspar, and epidote scattered throughout. A whole-rock chemical analysis of the tuff is given in Table 19 (R-5104). The mineral composition and chemical composition of the Catoctin dikes are very similar to that of the flow material (Table 19, R-5110 and R-5571).

CAMBRIAN SYSTEM

The western foothills of the Blue Ridge are underlain by early Cambrian sedimentary rocks of the Chilhowee Group consisting of the Weverton, Harpers, and Antietam formations. These detrital, marine sedimentary rocks (Reed, 1966, 1969; Schwab, 1970, 1971) have an aggregate thickness of approximately 3,350 feet (1,021 m) and have been metamorphosed to the greenschist facies. The group is unconformably underlain by the Catoctin Formation that includes the purple, amygdaloidal slates previously identified as the Loudoun Formation, the basal member of the Chilhowee Group (Butts, 1933; King, 1950; Nickelsen, 1956; Allen, 1963, 1967). As later investigations (Reed, 1969) indicated that the purple slates may be a metamorphosed saprolite of volcanic origin, they are now included in the uppermost portion of the Catoctin Formation, and the name Loudoun Formation discontinued (Gathright and Nystrom, 1974).

The younger Cambrian formations (Plate 1, Table 1) include the Shady Formation, Waynesboro (Rome) Formation, Elbrook Formation, and Conococheague Formation.

Weverton Formation

The Weverton Formation extends across the Linden quadrangle in a northeastward-trending belt 500 to 2,700 feet (152 to 823 m) wide. The quartzite and quartz-pebble conglomerate are the most resistant rocks in the area and underlie the first series of linear ridges west of the Blue Ridge.

The Weverton Formation can be subdivided into three lithologic units that have an aggregate thickness of 440 to 500 feet (134 to 152 m). The lower unit consists of resistant cross-laminated quartzite and pebbly or sandy phyllite 125 to 150 feet (38 to 46 m) thick. Two, and occasionally three 10- to 30-

foot (3- to 9-m) thick, light gray to tan and purplish-gray, quartzite ledges are present. These rocks are composed of medium- to coarse-grained, poor- to well-sorted, well-rounded quartz sand with some sericitic matrix material. Cross-bedding is common, and quartz-pebble conglomerate containing subrounded to well-rounded, pink and white quartz pebbles up to 8 mm in diameter are interspersed throughout. The conglomerate is interbedded with sandy phyllite. The lower unit is well exposed on a ridge along a housing-development road 2,000 feet (610 m) southwest of Camp Wamava, 1,250 feet (380 m) southeast of State Road 647.

The middle unit is composed of relatively nonresistant, dark-gray, pebbly and sandy phyllite and sericitic quartz sandstone. The sandstone is poorly sorted and contains subangular to subrounded quartz sand and pebbles that have a sericite-chlorite matrix. This unit, estimated to be 175 to 200 feet (53 to 61 m) thick, have outcrops that project as sharp linear ledges several hundred feet long and 3 or 4 feet (about 1 m) in height (Edmundson and Nunan, 1973).

The upper unit consists of resistant, light-gray, quartz-pebble conglomerate (Figure 15) interbedded with pebbly, sericitic, quartzitic sandstone. Scour-and fill structures, prominent cross-bedding (Figure 16), and some cross-bedding marked by discontinuous purple ferruginous bands are common. Iron-oxide cement commonly outlines the bedding and imparts a dark, purplish-gray appearance to outcrops. Feldspar, ilmenite, and magnetite clasts are more significant in this unit than in the two lower units. A sample (R-5046; Table 18) collected 1.2 miles (1.9 km) southeast of Wildcat Knob, just north of State Road 647 (Plate 1), also contained rounded to subrounded quartz clasts up to 4.6 mm in diameter. Massively bedded and well cemented, this unit forms cliffs as high as 50 feet (15 m). Upon weathering, the friable rock provides the colluvial material that masks the lower few hundred feet of the adjacent Harpers Formation. The upper unit is approximately 140 to 150 feet (43 to 46 m) thick, forms prominent linear ridges, and is best exposed in a breached anticline in a hollow 0.8 mile (1.3 km) southeast of Howellsville (Figure 17).

Harpers Formation

The Harpers Formation occupies a broad, northeastward-trending belt that attains a maximum width of 7,700 feet (2,347

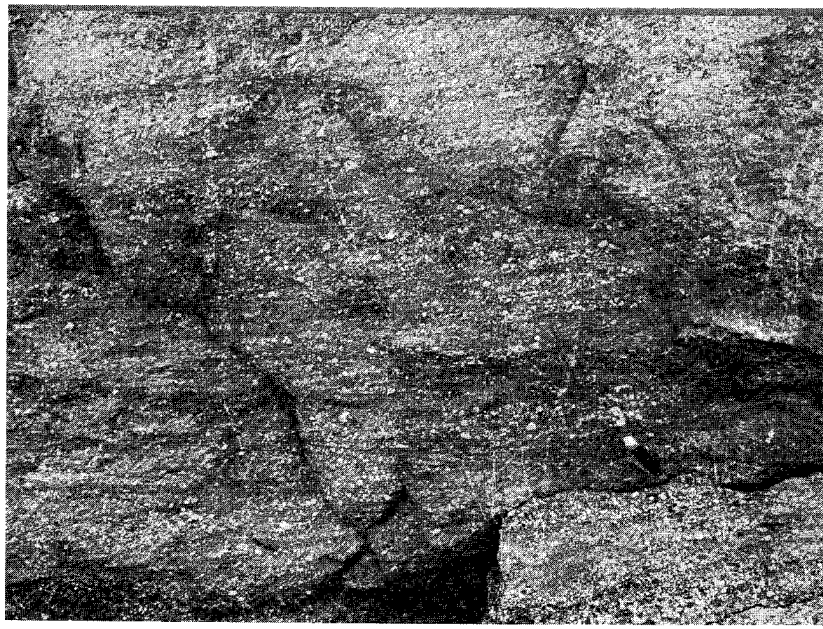
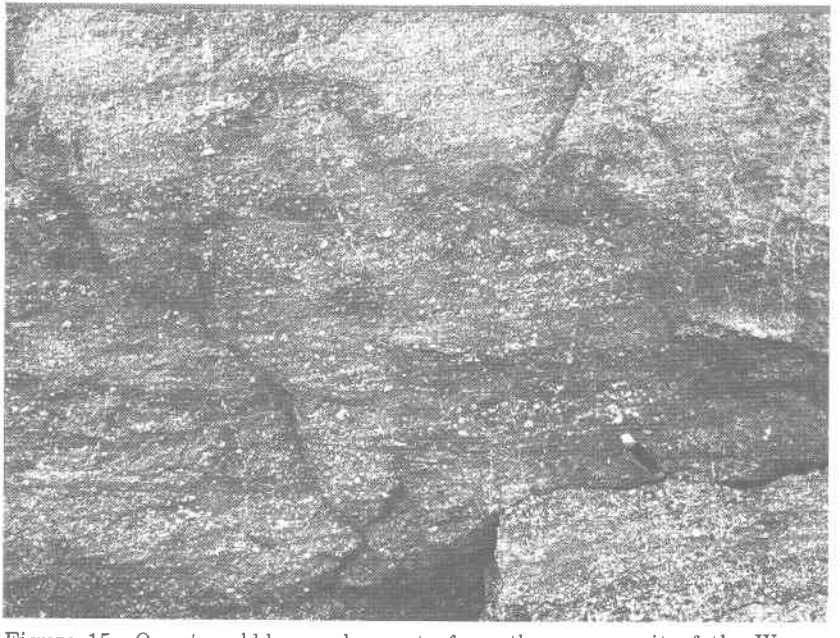


Figure 15. Quartz-pebble conglomerate from the upper unit of the Weverton Formation near a stream 4,000 feet (1,219 m) southeast of Howellsville (Plate 1). Pebbles up to 1 cm in diameter are set in a finer, iron-stained matrix of quartz, sericite, and feldspar.

Figure 16. Well-developed cross-bedding in the upper unit of the Weverton Formation, 2,000 feet (610 m) due north of Camp Wamava (Plate 1).



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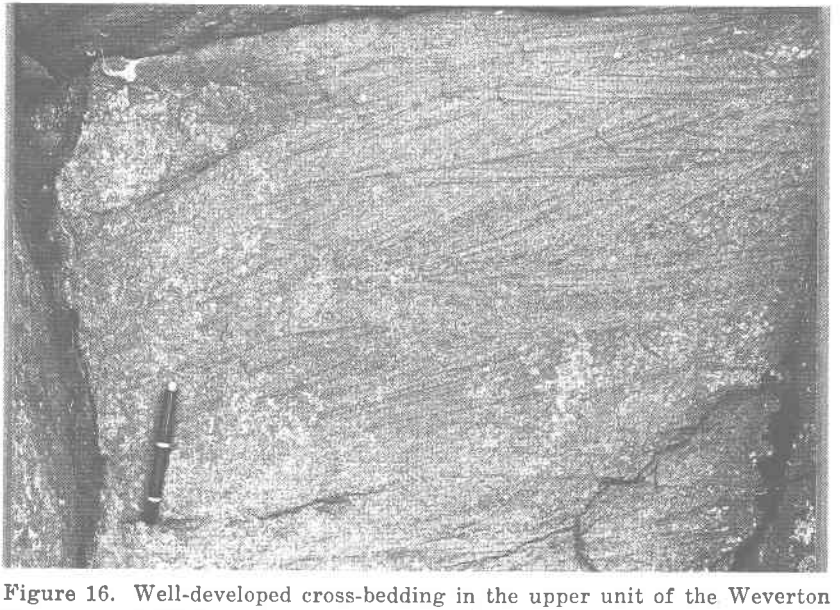

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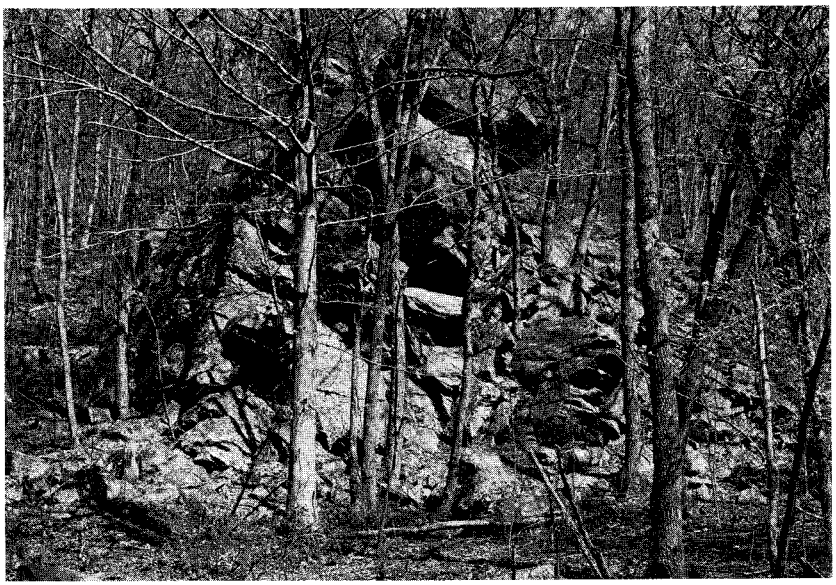
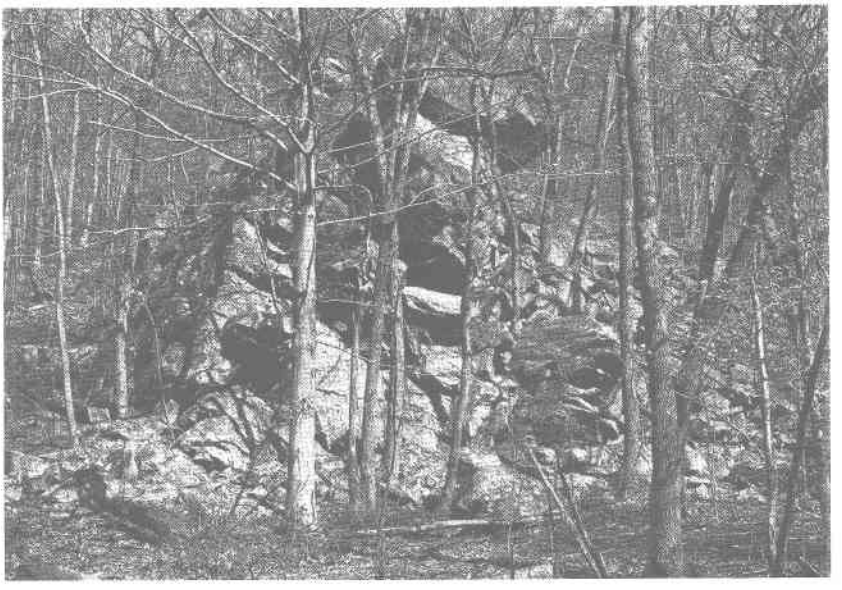


Figure 17. Ridge-forming upper unit of the Weverton Formation near an unnamed stream 4,000 feet (1,219 m) southeast of Howellsville (Plate 1). Massive beds of 12- to 24-inch (30 to 61 cm) quartz-pebble conglomerates with well-developed primary bedding features such as scour and fill structures and megaripple marks.

m) south of Venus Hill. The exposed zone narrows rapidly through Oregon Hollow to the southwest, primarily because of a thrust fault (Plate 1). Less resistant than adjacent rock units, the formation underlies the low hills between prominent ridges of the Weverton and Antietam formations. The conformable contact with the underlying Weverton Formation is placed at the top of the uppermost resistant ledge of quartz-pebble conglomerate or ferruginous, pebbly-quartz sandstone. The Harpers Formation is composed of laminated to thick-bedded, dark greenish-gray, very fine-grained, feldspathic graywacke and phyllite. Two and occasionally three ledge-forming, tan to white, medium- to thick-bedded, coarse-grained quartz sandstones, quartzites, and ferruginous sandstones occur near the top. Dark-purple, magnetite- and hematite-cemented, sericitic, argillaceous quartz sandstones are also present in thin, discontinuous beds near the middle of the formation.

The Harpers Formation consists of two uniits that have an aggregate thickness of approximately 2,500 feet (762 m). The lower unit, 1,750 feet (533 m) thick, is composed of a basal 400



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feet (122 m) of dark bluish-gray, sandy phyllite that weathers to a light-tan, flaky phyllite and tan, sandy chips. Also present in the lower unit are scattered inclusions of medium-grained ferruginous quartzite chips from the underlying Weverton Formation. The upper 1,350 feet (411 m) of the lower unit consists of various shades of olive, green, and gray phyllite and graywacke (Figure 18) that weather grayish-green to bluish-

Figure 18. Dark greenish-gray, sandy phyllite from the lower unit of the Harpers Formation near an unnamed stream 3,500 feet (1,067 m) southeast of Howellsville (Plate 1). All primary bedding features have been obliterated by a well-developed, southeastward-dipping, spaced cleavage.

gray. The graywacke is composed of very fine- to medium-grained sand that microscopic examinations show to be composed of quartz (60 to 90 percent), feldspar (5 to 35 percent), sericite (1 to 5 percent), and opaque minerals (Table 18). Matrix material makes up approximately 40 percent of the graywacke and nearly 70 percent of the phyllite. Good exposures of this member occur east of Howellsville near State

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Road 638. Because of a well-developed axial-plane cleavage, bedding features are often difficult to interpret.

The upper unit of the Harpers is approximately 750 feet (229 m) thick, and is distinguished by its lighter color and the presence of quartzites. It is composed of bluish-gray sandy phyllite, light-gray and tan quartzite, vitreous white quartzite, ferruginous sandstone, and sandy feldspathic phyllite that form low, linear ridges from southwest of Wildcat Knob to just east of Venus Hill (Plate 1). The resistant arenaceous strata comprise less than 20 percent of this unit within which are two well-defined, light-tan to white sandstone beds and one ferruginous sandstone bed. The ferruginous sandstone, lowest stratigraphically of these three beds, consists predominantly of interbedded subgraywacke, iron-oxide stained subarkose, poorly cemented subarkose, and vitreous quartzite. This sandstone bed ranges from 15 to 30 feet (5 to 10 m) in thickness, and contains occasional *Arenicolites* burrows that can be seen in rock outcrops 3,000 feet (914 m) due south of Venus Hill. Light-green to gray phyllite, siltstone, and subgraywacke separate the ferruginous stratum from the overlying sandstone. The sandstone, 30 feet (10 m) thick in places (Figure 19), contains well-sorted and well-cemented and vitreous quartzites, iron-oxide stains along some cleavage and bedding surfaces, and abundant *Skolithos* tubes.

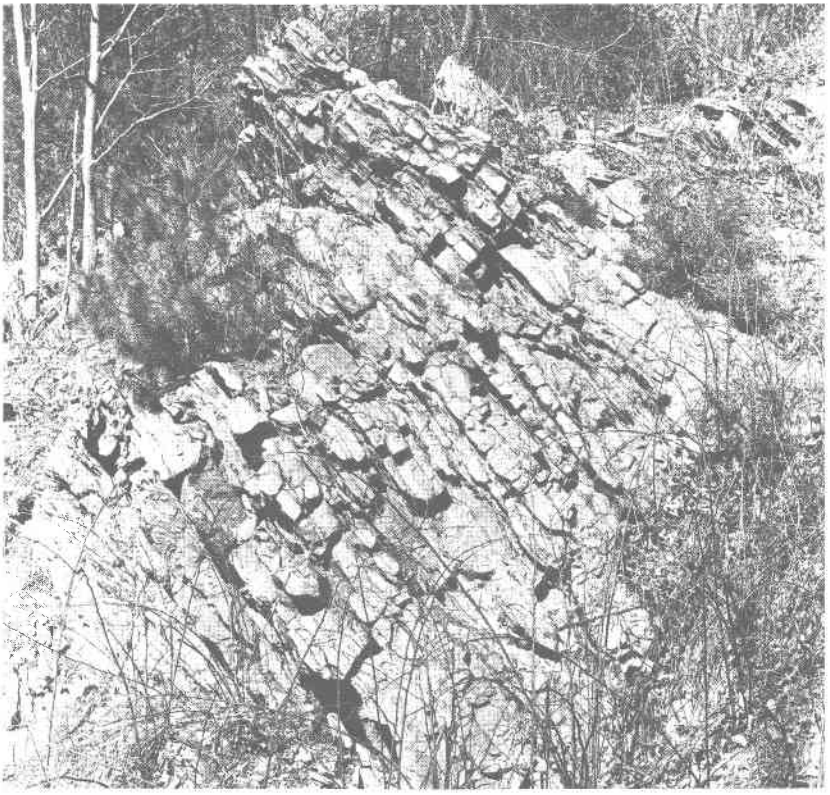
The uppermost sandstone is the best exposed of the three arenaceous strata, and can be observed on the first low ridges west of the Weverton Formation. This unit, 20 to 35 feet (9 to 11 m) thick, is primarily composed of very well-sorted, silica-cemented quartz arenite and very clean, white, vitreous quartzite. Several *Arenicolites* burrows (Figure 20) were collected on a ridge crest 2,000 feet (610 m) south of Howellsville (F-901) and 4,000 feet (1,220 m) southwest of Venus Hill (F-902). These burrows, which have not previously been reported in the Appalachian Mountains, are commonly present in the upper sandstone, good exposures of which can be seen on the crest of Wildcat Knob and the hills south of Venus Hill.

Microscopic examination of samples collected from the three sandstones (Table 18) revealed a composition of 85 to 90 percent very fine-grained quartz, plagioclase, orthoclase, and perthite clasts of which quartz clasts comprised about 70 to 90 percent of the sand fraction for the impure sandstones. The matrix material (10 to 15 percent) is composed of sericite and chlorite

Figure 19. Thin sandstones and quartzites that constitute the middle portion of the upper unit of the Harpers Formation, 4,000 feet (1,219 m) south of the intersection of State Roads 603 and 643 (Plate 1). This portion is approximately 20 feet (6 m) thick with beds of fine-grained sandstone and quartzite 7 to 25 cm thick. The beds are somewhat iron-stained with the greatest concentrations occurring in the shaly partings between individual beds.

that occurs in small masses and intergrowths. The quartzitic portions consist of very fine- to coarse-grained sand cemented by silica as overgrowths on the quartz with little or no matrix.

Thin beds of phyllite and subgraywacke separate the three arenaceous layers and also occur with thin, tan sandstone and quartzite beds above the uppermost quartzite. Near the contact with the overlying *Skolithos*-bearing, vitreous quartzite of the Antietam Formation, these tan sandstone and quartzite beds increase in abundance and range in thickness from 6 inches (15 cm) to several feet. The gradational Harpers-Antietam



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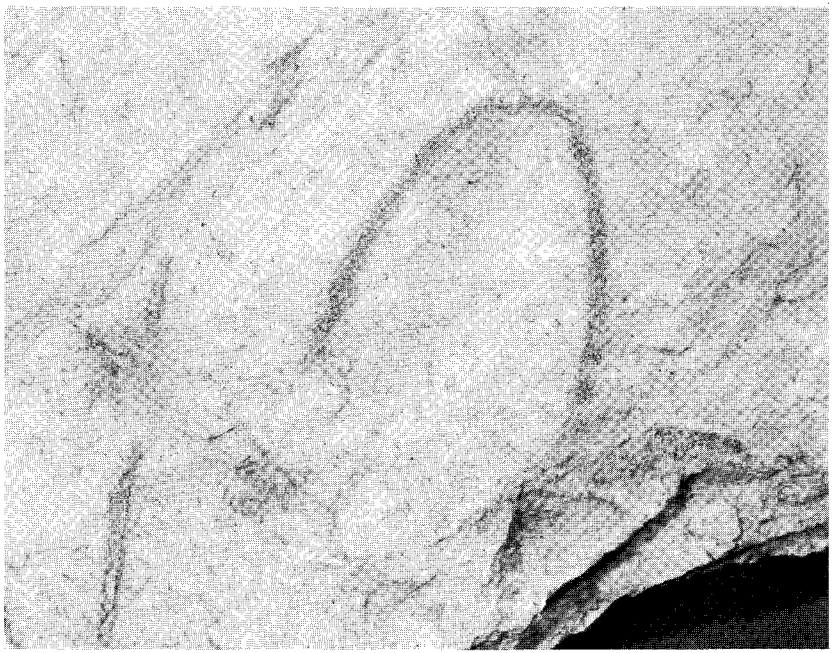

Figure 20. *Arenicolites* sp. borings in the upper quartzite portion of the upper unit of the Harpers Formation, 2,500 feet (762 m) southwest of Venus Hill (Plate 1). These "fishhook"-shaped borings are commonly found within this upper portion in the Linden quadrangle.

contact can best be observed about 1.0 mile (1.6 km) northeast of Wildcat Knob along State Road 603.

Antietam Formation

The Antietam Formation caps the crests of Wildcat Knob, Venus Hill, and several other low, sharp-crested ridges east of the Shenandoah River (Plate 1). Good exposures occur east of Venus Hill in Venus Branch where vitreous quartzite ledges have a steep dip to the east. The conformable contact with the underlying Harpers Formation is placed at the base of the first continuous sequence of white, medium- to thin-bedded *Skolithos*-bearing, feldspathic quartzite beds.

The Antietam Formation consists of fine- to coarse-grained, silica-cemented, vitreous quartzite and subarkose; phyllite partings are common. The silica cement occurs as overgrowths on the detrital grains and makes up as much as 15 percent of the rock. Sericitic matrix material occurs most commonly in less

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The Antietam Formation consists of fine- to coarse-grained, silica-cemented, vitreous quartzite and subarkose; phyllite partings are common. The silica cement occurs as overgrowths on the detrital grains and makes up as much as 15 percent of the rock. Sericitic matrix material occurs most commonly in less

persistent layers that accentuate the bedding. The quartz content ranges from 80 to 95 percent; feldspar, 5 to 20 percent; sericite 1 to 10 percent; and opaque minerals 1 to 2 percent (Figure 21, Table 18). *Skolithos* tubes are abundant in most of the quartzite beds, and their shape is often outlined by iron-oxide (goethite or hematite) stains.

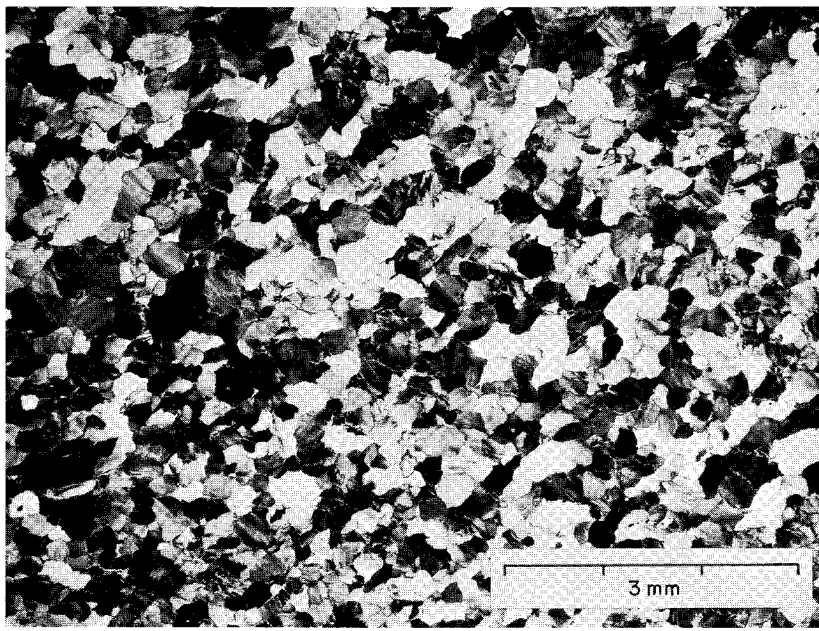


Figure 21. Photomicrograph of vitreous quartzite (R-5049) from the lower portion of the Antietam Formation, 2,000 feet (610 m) southeast of Venus Hill on the north side of Venus Branch Drive (Plate 1). A very mature quartz arenite composed of subrounded to well-rounded quartz (80 to 95 percent) and feldspar clasts along with a very minor amount of opaque minerals and sericite (crossed nicols).

Fault breccias, which are shown separately on Plate 1, are present along the Happy Creek fault that separates the Antietam from the Shady and Waynesboro formations. These breccias contain angular fragments and blocks of vitreous quartzite that range from 2 mm to 1 m (3 feet) in longest dimension, and are cemented by iron oxide (goethite and hematite) (Figure 22). Excellent exposures of these breccias can be found 4,000 feet (1,219 m) west of Venus Hill and along State Road 603 (Plate 1).

A minimum thickness of 400 to 600 feet (122 to 183 m) is

persistent layers that accentuate the bedding. The quartz content ranges from 80 to 95 percent; feldspar, 5 to 20 percent; sericite 1 to 10 percent; and opaque minerals 1 to 2 percent (Figure 21, Table 18). *Skolithos* tubes are abundant in most of the quartzite beds, and their shape is often outlined by iron-oxide (goethite or hematite) stains.

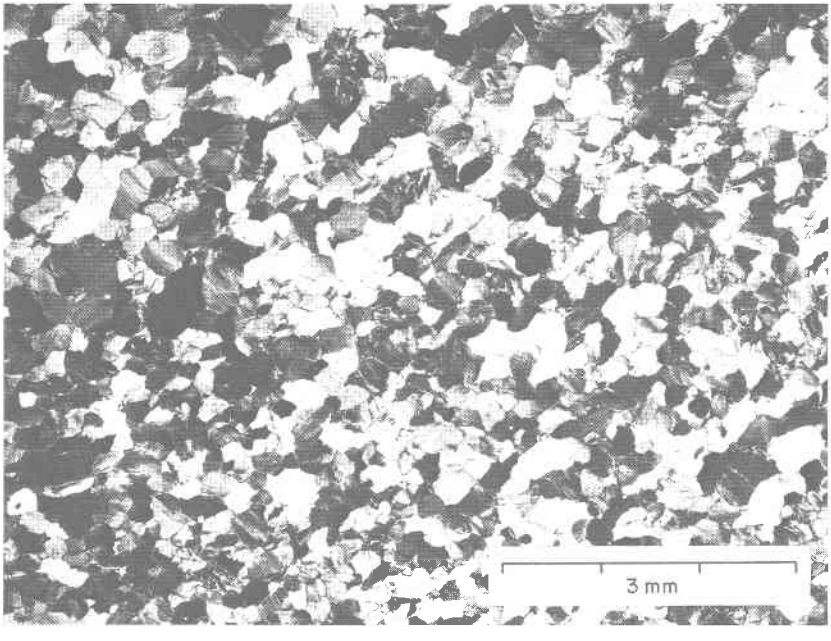


Figure 21. Photomicrograph of vitreous quartzite (R-5049) from the lower portion of the Antietam Formation, 2,000 feet (610 m) southeast of Venus Hill on the north side of Venus Branch Drive (Plate 1). A very mature quartz arenite composed of subrounded to well-rounded quartz (80 to 95 percent) and feldspar clasts along with a very minor amount of opaque minerals and sericite (crossed nicols).

Fault breccias, which are shown separately on Plate 1, are present along the Happy Creek fault that separates the Antietam from the Shady and Waynesboro formations. These breccias contain angular fragments and blocks of vitreous quartzite that range from 2 mm to 1 m (3 feet) in longest dimension, and are cemented by iron oxide (goethite and hematite) (Figure 22). Excellent exposures of these breccias can be found 4,000 feet (1,219 m) west of Venus Hill and along State Road 603 (Plate 1).

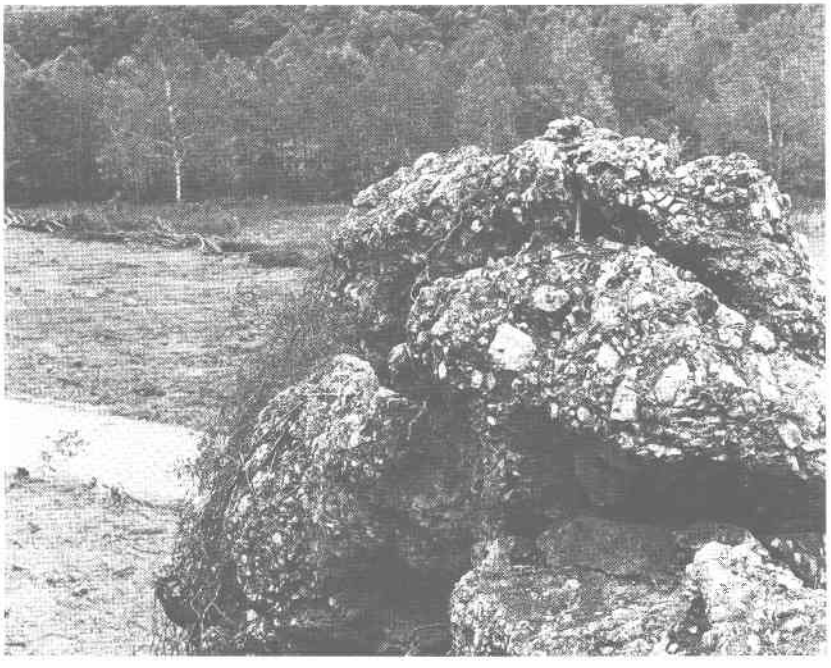
A minimum thickness of 400 to 600 feet (122 to 183 m) is

Figure 22. Fault breccia from the Antietam Formation, 4,500 feet (1,372 m) southwest of Wildcat Knob near the eastern boundary of the Front Royal quadrangle. Excellent exposures (since destroyed in construction of Interstate Highway 66) of fault breccias with white, vitreous quartzite fragments (ranging up to 30 cm in diameter) cemeted together by iron-oxide cement.

estimated for the lower portion of the formation on Venus Hill, but the total formation thickness cannot be determined because of faulting.

Shady Formation

In the Linden quadrangle (Plate 1) the Shady Formation is a high-magnesium dolomite poorly exposed in a narrow belt west of the Antietam quartzite with which it is in fault contact. Only the upper few tens of feet of light- to dark-gray, fine- to coarse-grained, medium- to thick-bedded, laminated dolomite is present because of the faulting, and determination of structural, lithologic and stratigraphic relationships are further hindered by a thick residuum and local terrace, alluvial, and colluvial deposits. A few small outcrops occur 4,000 feet (1,219 m) east of Morgan Ford, 3,000 feet (914 m) west of Howellsville, and 4,000 feet (1,219 m) west-southwest of Venus Hill.



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Chert rosettes and nodules were observed in the upper dolomite 1.8 miles (2.9 km) south of Milldale on the west bank of the Shenandoah River.

The total thickness of the formation was not ascertained because of faulting and poor exposure, but recognition of the uppermost 50 to 70 feet (15 to 21 m) proved useful for correlations with previous work in adjacent quadrangles (Edmundson and Nunan, 1973; Gathright and Nystrom, 1974).

Waynesboro (Rome) Formation

The alternating limestone, dolomite, varicolored shale and other fine-grained clastic rocks that comprise the Waynesboro Formation are exposed in a zone that ranges in width from 2,500 to 4,200 feet (762 to 1,280 m) and extends in a northeasterly direction across the northwest portion of the Linden quadrangle (Plate 1). Good exposures can be found on the north side of Morgan Ford, and along two streams southeast of Milldale. The lower contact is placed at the top of the very dark-gray, fine-grained Shady dolomite.

The formation can be subdivided into lower clastic, middle carbonate, and upper clastic units. The lower unit is characterized by maroon, olive, and dark-gray shale and maroon and yellowish-tan, fine- to medium-grained sandstone. The middle unit is composed of dark bluish-gray, saccharoidal dolomite and bluish-gray, fine-grained limestone. The upper unit consists of maroon and green shale with a few thin, fine-grained, maroon-gray, quartz sandstone beds. Only portions of these members could by measured because of the thick terrace and alluvial deposits, but a total thickness of 1,200 feet (366 m) is estimated for the Waynesboro.

Elbrook Formation

The Elbrook Formation is poorly exposed in a broad belt that has a maximum width of about 9,000 feet (2,743 m) in the northwest corner of the Linden quadrangle. The best exposures are along two streams southeast of Milldale where the total thickness is estimated at 2,100 feet (640 m). The lower contact is gradational and is placed at the top of the uppermost green shale of the Waynesboro Formation.

The Elbrook Formation is composed of medium- to dark-gray limestone with argillaceous and sandy laminae; light- to

medium-gray laminated dolomite; and rusty-brown, laminated calcareous or dolomitic shale. The dolomite beds range from 2.0 cm (0.8 inch) to 1.0 m (3.3 feet) in thickness. Weathering of thick beds produces a ribbon-banded appearance and yields pale-yellow, orange, and red shale-like chips upon complete decalification of the argillaceous bands.

Conococheague Formation

The basal 50 to 75 feet (15 to 23 m) of the Conococheague Formation occurs in the extreme northwest corner of the Linden quadrangle. It was not possible to determine lithologic and stratigraphic relationships due to the poor and few exposures of bedrock in that small area, but in the adjacent Front Royal (Rader and Biggs, 1975) and Boyce (Edmundson and Nunan, 1973) quadrangles the gradational contact with the underlying Elbrook Formation is placed at the base of the lowest quartz sandstone. The Conococheague consists of rusty-weathering sandstone, bluish-gray limestone, and light-gray dolomite.

TRIASSIC SYSTEM

Diabase Dikes

Dense, compact, medium-textured, uncleaved diabase dikes were noted at five localities in the Flint Hill quadrangle. The diabase outcrops are commonly dark gray and protrude in erosional relief. Grain diameters of about 1 mm dominate the allotriomorphic-granular texture of which andesine, albite, pericline, and combined albite-Carlsbad twins are all prominent. Augite, biotite, ilmenite, and sphene are present as accessory minerals.

Because these dikes lack the cleavage prominent in the surrounding rocks, their intrusion postdates the last major deformation. As this deformation is probably no older than Silurian, and may be as young as early Mississippian (Bryant and Reed, 1970), the diabase dikes are considered to be of Triassic age.

QUATERNARY SYSTEM

Terrace Deposits

Irregularly shaped and discontinuous terrace deposits occur on either side of the Shenandoah River in the Linden quadrangle. These deposits range from 0 to 25 feet (0 to 8 m) in thickness and are present on many low ridges and hills at elevations as

high as 120 feet (37 m) above river level. The deposits consist mainly of moderately to well-rounded cobbles and some small and occasional large boulders in a matrix of sand, silt, and clay.

Alluvium

Alluvial deposits are located along the flood plains of many streams in the Linden and Flint Hill quadrangles, and are distinguished from the higher terrace deposits by the fact that the former are relatively undissected (Hack, 1965). In the Linden quadrangle the alluvium is composed of dark-gray sand, silt, and clay with lenses of cobbles and medium to small pebbles of quartzite, metabasalt, limestone, and dolomite. In the Flint Hill quadrangle the alluvial material consists of light- to dark-gray sand, silt, and clay with some deposits including pebbles and cobbles of metabasalt, granodiorite, gneiss, granite, and felsic material. Thicknesses of the alluvium range from 0 to about 20 feet (0 to 6 m) and can usually be observed in river-bank exposures. Graded bedding is common with pebble-cobble material near the base and sand and sandy silt toward the top.

Colluvium (debris fans and trains) is common in stream beds on the east and west flanks of the Blue Ridge and also on the sides of several mountains and ridges in the Flint Hill quadrangle. Cobbles and boulders in various stages of weathering and sand comprise most of these deposits that are believed to be the result of ancient debris-avalanche landslides (Gathright and Nystrom, 1974). The colluvium grades upslope into talus and scree deposits made up of rock debris from the most resistant beds at higher elevations. Well-developed debris fans and trains are located on the east side of the Blue Ridge where the slopes are underlain by the Catoctin Formation.

STRUCTURE

The Linden and Flint Hill quadrangles are located on the northwest limb of the gently northeastward-plunging Blue Ridge anticlinorium. Compressional and tensional tectonic forces acting upon the plutonic and sedimentary rocks have produced a complex structural setting. High- and low-angle reverse faulting and a pervasive, southeastward-dipping axial-plane cleavage are the prominent structural features in the two quadrangles. The pervasive cleavage and the cataclasis prominent in the plutonic rocks are associated with the regional greenschist facies

metamorphism present in the rock sequence. Relict pyroxene-granulite facies metamorphism is locally evident in the Pedlar Formation where shearing and cataclasis is least intense.

FOLDS

Large-scale folding of the Precambrian plutonic rocks cannot be observed directly, but small-scale isoclinal folding is present in the layered gneiss around Flint Hill. Schistosity is defined by the felsic layers that are present throughout the gneiss in widths that range from less than 2 mm to more than 25 cm. Common reversals in the attitude of schistosity between parallel, monoclinally dipping zones and major changes in the direction in which these zones trend suggest that larger-scale folds and probably refolded folds may be present. Poles to the schistosity plotted on Schmidt equal-area projection steronet diagrams reveal two prevalent schistosity trends (Figure 23), the most

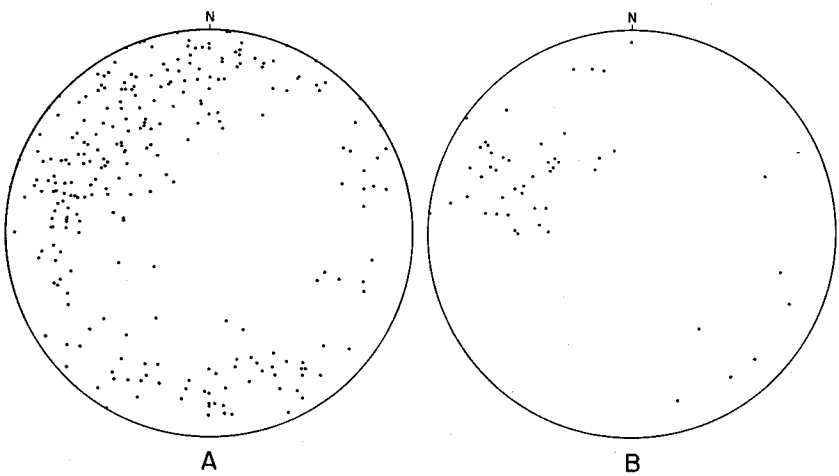

Figure 23. Schmidt equal-area projection steronet plots:

A 264 poles to schistosity from the layered gneiss. From the data two general trend directions can be discerned—a northeasterly lineation that probably coincides with the prevalent structural trend (Paleozoic) in the Blue Ridge (Cloos, 1971, p. 56, Figure 24) and a northwesterly lineation previously unrecognized in this portion of the Blue Ridge. These two diverse trends lend support to the theory that this rock unit has undergone two or more major periods of intense deformation;

B 50 poles to cleavage from the layered gneiss. The data points cluster in a northeasterly direction that coincides with the prevalent structural trend (Paleozoic) of the Blue Ridge structural province (Cloos, 1971, p. 56, Figure 23).

prominent of which is to the northeast although trends to the northwest and west are also present. These data suggest the possibility of two periods of deformation, with the northeasterly trend established by the second of these events. Schistosity attitudes in the augen-bearing gneiss were obtained from the planar alignment of feldspar augen. Schmidt equal-area projection steronet diagrams (Figure 24) of these foliations reveal a

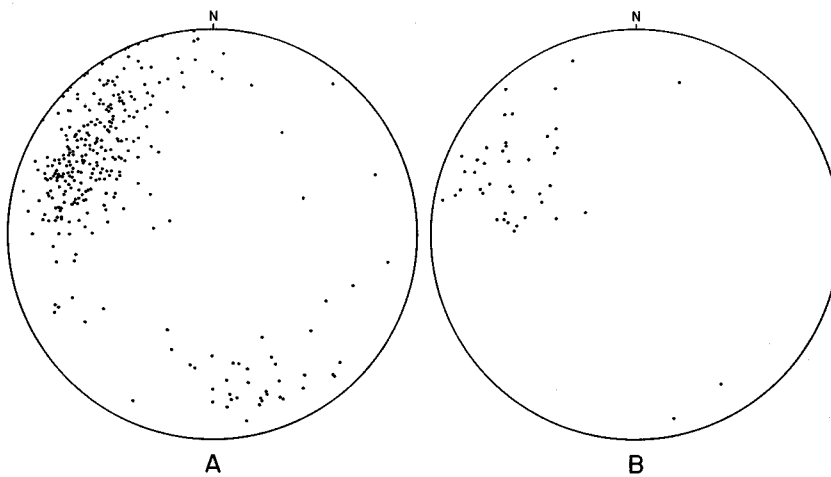

Figure 24. Schmidt equal-area projection steronet plots:

A 304 poles to schistosity from the augen-bearing gneiss. An apparent clustering of data points that trend in a northeasterly direction coincides with the prevalent structural trend (Paleozoic) of the Blue Ridge structural province (Cloos, 1971, p. 56., Figure 23);

B 43 poles to cleavage from the augen-bearing gneiss. The data points cluster in a northeasterly direction that coincides with the foliation trend.

cluster of attitudes that trend northeasterly with little indication of the prominent northwesterly trend in the layered gneiss. An example of the change in schistosity trends is evident in the southern portion of the augen-bearing gneiss unit (Plate 2); schistosity patterns that trend in an easterly direction immediately surrounding Fogg Mountain gradually change to a more northeasterly trend east and northeast of the mountain.

A southeastward-dipping spaced cleavage (Dennis, 1967) is present throughout most of the basement complex units. Schistosity and spaced-cleavage trends within the augen-bearing gneiss and Pedlar Formation usually parallel one another, but in places are nearly perpendicular to each other in the layered gneiss. Although spaced cleavage is the most prominent cleavage

feature developed, continuous cleavage is also present in many places. This occurs predominantly in shear zones where the relict fabric has been altered to protomylonites or mylonites (Higgans, 1971). Well-defined cleavage surfaces are rarely found in exposures of Old Rag and Robertson River granites.

Characteristic structures in the Chilhowee Group on the west flank of the Blue Ridge and in the carbonate and clastic rocks of the Shenandoah valley are north-northeastward-plunging, asymmetric and overturned folds such as the Stone Bridge anticline. Complex folds are not expressed in the Antietam, Shady, and lower Waynesboro formations but are abundant in the Weverton, Harpers, upper Waynesboro, and Elbrook formations in which many subsidiary folds have been developed on the limbs of major folds. Formation of these subsidiary folds may be due to interbedded, ductile shales and limestones. The east limbs of anticlines are right-side up and have low to moderate southeasterly dips, but the west limbs are very steeply dipping and in many places are overturned. Readily apparent when viewing fold structures downplunge is a significant thickening of some rock units in the axial portion of the folds and thinning along the limbs (Mackin, 1950). A probable mechanism for this development is flexural-flow, which is best developed locally in the incompetent and ductile shales and limestones interbedded in the Waynesboro and Elbrook formations.

Altitudes were difficult to measure in the Catoctin and Swift Run formations because of the degree of weathering in the homogenous, massive basalts and heterogenous, thin metasediments, but the fold orientation seems to be similar to that in the younger Cambrian rock units. Folding in the Swift Run and lower Catoctin formations is broad and open, but the upper Catoctin basalt flows have been folded almost as intensely as the quartzites of the overlying Weverton Formation. Predominant throughout all these igneous, metamorphic, and sedimentary rock units is a pervasive, southeastward-dipping, spaced cleavage that is well displayed in the phyllitic rocks of the Harpers Formation (Figure 18).

FAULTS

Within the Linden quadrangle are a thrust fault, a high-angle transverse fault, two high-angle reverse faults and ten small transverse faults. The most prominent of these features is the

thrust fault southwest of Howellsville that displaces rock units as old as Catoctin metabasalts and as young as Antietam quartzites (Plate 1). Precambrian and Cambrian formations have been thrust over rocks of similar age, with an apparent stratigraphic displacement of nearly 2,000 feet (610 m). The southeastern end of the fault trace ends abruptly in the adjacent Front Royal quadrangle where it probably underlies the Front Royal fault. It has been estimated that the plane of the fault southwest of Howellsville has a dip 70° to the southeast in the Front Royal quadrangle (Rader and Biggs, 1975) and 60° to the southeast through Oregon Hollow in the Linden quadrangle. In its western trace southwest from Howellsville to just north of Wildcat Knob the fault plane has a dip of 15° to 20° northwest. Termination of the upper unit of the Harpers quartzites and Antietam quartzites at Howellsville, tectonic brecciation of quartzites along State Road 603, and termination of a northwestward-striking transverse fault in the Weverton Formation near Camp Wamava substantiate this thrust configuration.

The Happy Creek high-angle reverse fault in the Linden quadrangle displaces rock uniits that have been earlier thrust-faulted to the northwest by the thrust fault southwest of Howellsville. Displacement along the Happy Creek fault has left lower Antietam quartzites in contact with upper Shady dolomites and lower Waynesboro shales (Plate 1). This shows a stratigraphic displacement of at least 1,200 feet (366 m), and possibly more since the thickness of the Antietam Formation cannot be accurately determined in this area. Fault breccias of Antietam quartzites are common along the fault trace with good exposures west of the Shenandoah River near the Boyce-Linden quadrangle boundary. Due to the linearity of the fault just south of this boundary, it most likely enters the Boyce quadrangle at a high angle of dip and is terminated by a younger transverse fault just east of Byrd Bridge in the Ashby Gap quadrangle (Gathright and Nystrom, 1974).

The high-angle transverse fault on the south side of State Highway 55 in the Linden quadrangle continues westward into the Front Royal quadrangle where it was previously mapped as the Front Royal fault (Wickham, 1972). From the south-central portion of the Front Royal quadrangle the fault appears to steepen as it is traced eastward and becomes almost vertical in the Linden quadrangle. There is little evidence for significant stratigraphic offset in the Linden quadrangle, and the Front

Royal fault has not been traced east of Manassas Gap, but on LANDSAT imagery a linear feature that crosses the Front Royal and Linden quadrangles may continue for a short distance into the Upperville quadrangle. It is possible there has been both right-lateral strike-slip and vertical movement along the fault, with the north side being downthrown.

A small high-angle reverse fault trends almost due south from Linden with the layered gneiss upthrown on the east side and Catoctin metabasalt downthrown on the west (Plate 1). The fault is terminated on the north by the Front Royal fault, and can be traced about 1.2 miles (1.9 km) south where it appears to die out in the Catoctin Formation west of State Road 638. Ten minor transverse faults are also located in the Linden quadrangle (Plate 1).

A high-angle reverse fault, two transverse faults, and several shear zones are present in the Flint Hill quadrangle (Plate 2). The most prominent structural feature in the quadrangle is the high-angle reverse fault that trends in a northeasterly direction just west of Huntly. The fault block has upthrown layered gneiss and Pedlar quartz monzonite on the southeast and downthrown Catoctin metabasalt and Pedlar quartz monzonite on the northwest. The fault continues to the southwest into the Chester Gap quadrangle and to the northeast until it either terminates or becomes unrecognizable in the Pedlar Formation southeast of Ravensden Rock. Drilling conditions encountered in several water wells north of Rockland Cemetery near the north-central boundary of the Flint Hill quadrangle indicate the probability that the high-angle reverse fault southeast of Linden is the northern extension of the fault near Huntly. Cataclastic rocks near the trace of the fault in the Huntly area have a few concentrations of vein quartz in the most severely deformed areas.

The two small transverse faults in the Flint Hill quadrangle each extend across formation boundaries—the one 2 miles (3 km) southeast of Hitch across the layered and augen-bearing gneiss contact, and the other 0.7 mile (1.1 km) south of Ravensden Rock across the Pedlar-Swift Run and Swift Run-Catoctin contacts (Plate 2). Shearing within the plutonic rock units is common and varying amounts of granulation are present in the shear zones where protomylonites, mylonites, and ultramylonites are found. Faulting may have occured along part of the contact of the layered gneiss and augen-bearing gneiss north of the

Jordon River where the rocks have been sheared into planer bands for several hundred yards on either side of the contact. Another zone of intense shearing northeast of Flint Hill is approximately 1.2 miles (1.9 km) long and contains mylonites and ultramylonites (R-5267) along its trace. No recognizable stratigraphic displacement was observed along most shear zones, but this may be due to the lack of traceable lithologies within the Precambrian plutonic rocks. Local concentrations of white vein quartz, probably from nearby fault or shear zones, are common throughout the Flint Hill quadrangle where they occur either as residual boulder mounds or aligned debris trains.

Examination of LANDSAT imagery reveals a linear feature that coincides with a portion of the Rappahannock River and continues to the northwest into the Front Royal quadrangle. No field evidence has been obtained to confirm a fault corresponding to this linear within the Flint Hill quadrangle.

ECONOMIC GEOLOGY

CRUSHED AND BROKEN STONE

The northwest third of the Linden quadrangle is underlain by clastic and carbonate rocks, some of which may have a limited potential for commercial use. The Waynesboro, Elbrook, and Conococheague formations contain interbeds of shale, sandstone, and chert that reduce their potential for industrial use. Of the carbonate units only the beds of high-magesium dolomite in the Shady Formation have been of economic importance. Quartzites in the upper 100 feet (30 m) of the Harpers Formation and throughout the Antietam Formation are suitable for crushed-stone aggregate. The only active quarry in the Linden quadrangle is located 2,000 feet (610 m) south of State Road 643, 0.7 mile (1.3 km) east-southeast of the intersection of State Roads 624 and 643 (Plate 1). Here Rappawan Lumber, Inc. is quarrying and crushing stone from the upper portion of the Harpers Formation for road aggregate (Figure 25) (Plate 1, active quarry number 1). Previously, a quarry was operated in the lower Antietam Formation just south of State Road 643, 0.9 mile (1.4 km) by road east of its junction with State Road 624 (Harris, 1972, p. 11) (Plate 1, abandoned quarry number 2).

A small quarry operated by the Culpeper Stone Company (Figure 26) is located 0.5 mile (0.8 km) east of Flint Hill (Plate 2, active quarry number 1). The layered gneiss is quar-

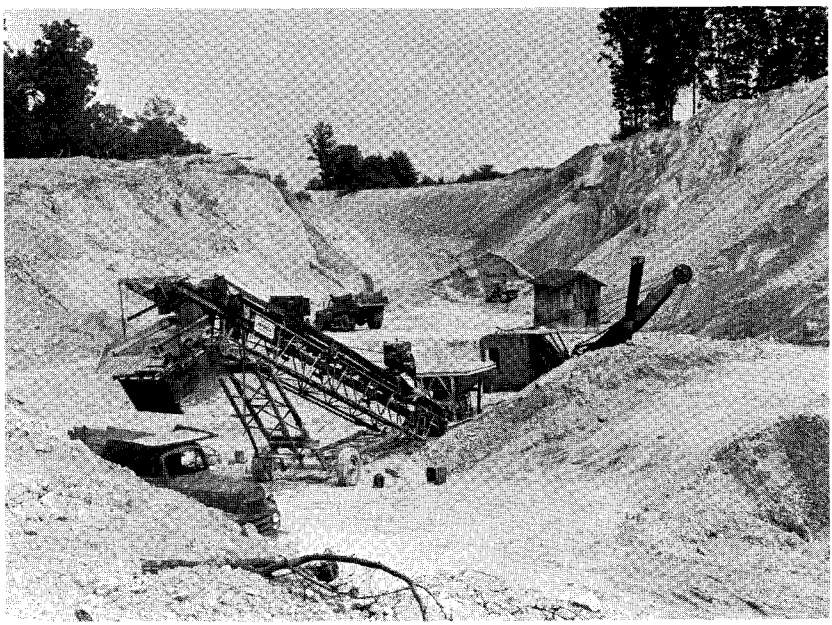

Figure 25. Active crushed stone quarry of Rappawan Lumber, Inc. in the Harpers Formation, 2,500 feet (762 m) south of State Road 643 and 0.8 mile (1.3 km) east of the intersection of State Roads 624 and 543 (Plate 1). Thin beds of tan quartzite separated by thin beds of shale along with tectonic fracturing has produced a readily extractable crushed stone.

ried and crushed there, with almost 700,000 tons (634,900 MT) having been processed since 1965 (personal communication, George A. Ramer, 1974).

Robertson River granite underlies the eastern quarter of the Flint Hill quadrangle; reconnaissance in the adjacent Orlean and Upperville quadrangles has revealed the continuation of the granite to the northeast where "The coarse-grained granites northwest of Little Cobbler Mountain, between there and Markham, and the exposure about a mile northeast of the mountain may offer possible sources of dimension stone. These sites would afford excellent crushed stone." (Steidtmann, 1945, p. 39).

COPPER

The occurrence of copper has been reported at three localities in the Linden and Flint Hill quadrangles. The abandoned Sealoch (Sealoch, Marshall, Ravenswood) mines are located 3 miles (5 km) southwest of Linden, southeast of High Knob, and also 1.5

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Figure 26. Culpeper Stone Company quarry in the layered gneiss, 2,000 feet (610 m) east of Flint Hill along State Road 647 (Plate 2).

miles (2.4 km) farther west: "Deposits occur in an altered and sheared zone of the Catoctin Greenstone. Copper-bearing quartz lenses and stringers occur along lines of jointing or schistosity in epidotized and chloritized rock" (Luttrell, 1966, p. 117). The abandoned Manassas Gap mine (Plate 2, abandoned mine number 2) in the same vicinity is located on the west slope and crest of Ravensden Mountain, and on the slope of High Knob. Here, native copper and cuprite (with quartz, calcite, tourmaline, and epidote) occur in masses and along joint planes in epidotized Catoctin metabasalts (Luttrell, 1966, p. 89). A third abandoned mine (Ambler) is located on the southwest side of High Knob near the Sealoch mine. This mine contained native copper and bornite in irregular masses within the epidotized Catoctin metabasalt (Luttrell, 1966, p. 8).

HYDROGEOLOGY

By Richard H. DeKay

FORMATION PERMEABILITY

The dominant factor that influences the occurrence of subsurface fluids is the geology of an area (Wisler and Brater,

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The dominant factor that influences the occurrence of subsurface fluids is the geology of an area (Wisler and Brater,

1959). This is particularly true where the underlying consolidated rocks have a very low primary permeability. In such places subsurface fluids are transmitted mainly through fracture and solution openings, which were formed by the deformation of the bedrocks and their soluble mineral compositions. Such voids are referred to as secondary permeability and are directly related to the structure and lithology of the rock units present. In the Linden and Flint Hill quadrangles 14 geologic formations have been mapped in addition to dikes that intrude them and a veneer of unconsolidated materials that cover them (Plates 1, 2). The mineral compositions of these formations are numerous, but insofar as their exploitable permeability characteristics are concerned only three categories are discernible: massive igneous and metamorphic rocks, insoluble clastic rocks, and soluble carbonate rocks.

Approximately 75 percent of the Linden and Flint Hill quadrangles is underlain by seven formations that consist predominantly of metabasalt, quartz monzonite, granitic and gneissic rocks; some phyllite, slate, and schistose rocks are also present. Most of these rocks have porosities of less than 3 percent and primary permeabilities so small that they may be regarded as zero for all practical purposes (Davis and DeWiest, 1966). These are the oldest rocks in the area, however, and have been subjected to several periods of deformation that has resulted in some regional faulting and considerable local fracturing and shearing. The massive nature of these rocks generally restricts the depth of most open fractures to the first 200 feet (61 m) beneath the ground surface. Most of these fractures are steeply inclined, but in some areas erosional unloading may produce a sheet structure in the granitic rocks, and such horizontal openings would greatly increase their permeability at shallow depths. Some of the metamorphic rocks that are laminated, strongly cleaved, fractured, or contain some soluble minerals have developed a moderate secondary permeability locally, but others are massive and recrystallized and are virtually impermeable.

The Weverton, Harpers, Antietam, and part of the Waynesboro formations are clastic rock units composed of relatively thin-bedded sandstone, shale, siltstone, and quartzite. The cementing material in most of these rocks is insoluble although some calcareous cement is present in a few beds. Other than the interbedded quartzites, these rocks are more susceptible to de-

formation because of their thin-bedded and relatively incompetent nature. A moderate secondary permeability has been developed locally by folding and faulting that has fractured these rocks to some extent and opened bedding and cleavage planes to influent streams. Most of these openings are encountered at depths of 300 feet (91 m) or less below the ground surface. The clastic rocks have a relatively high porosity, but unless they are poorly cemented have a low primary permeability.

The Conococheague, Elbrook, Shady, and the remaining portion of the Waynesboro formations are carbonate rocks that are soluble to some degree. Their bedded, crystalline nature makes them brittle when subjected to crustal deformation, and circulating subsurface fluids enlarge the resulting fracture openings. Under certain conditions solution and fracture openings may be enlarged to a considerable lateral extent, but rarely to any appreciable degree at more than 400 feet (122 m) below the ground surface. These rocks have a moderate porosity but a very low primary permeability.

The dikes that intrude bedrock are the least permeable of all rocks in the two quadrangles. Younger than the host rocks, they have not been subjected to earlier periods of deformation and are consequently less fractured. In the absence of fracturing, these insoluble rocks lack both primary and secondary permeability.

It can be seen, therefore, that aside from the soluble carbonate rocks, secondary permeability is mainly fracture permeability. In most instances the fractures have a single orientation, are steep to vertical, and are most numerous in the upper 300 feet (91 m) of bedrock. In general, the average permeability decreases rapidly with depth, the soft foliated rocks having the smallest yields because of the smaller openings, and the carbonates having the largest yields where large fracture or solution openings occur. Otherwise, all consolidated rocks in the Linden and Flint Hill quadrangles have the same type of fracture-localized permeability that varies according to the local deformation of the rock unit and its relationship with sources of perennial recharge.

FORMATION PRODUCTIVITY

The evaluation of ground-water production from individual formations is generally achieved through synthesis of well-drilling results. As the Linden and Flint Hill quadrangles embrace

a sparsely populated area with virtually no public or industrial water-well supplies, nearly all available records are for domestic water wells. Most wells on which this report is based were drilled by Larry LeHew of the LeHew Drilling Company in Front Royal, whose cooperation for many years has made possible this summation. Because of the limited areal extent of some formations and the sparsely inhabited areas underlain by others, sufficient data is available for evaluation of the ground-water potential of only half the rock formations in the two quadrangles.

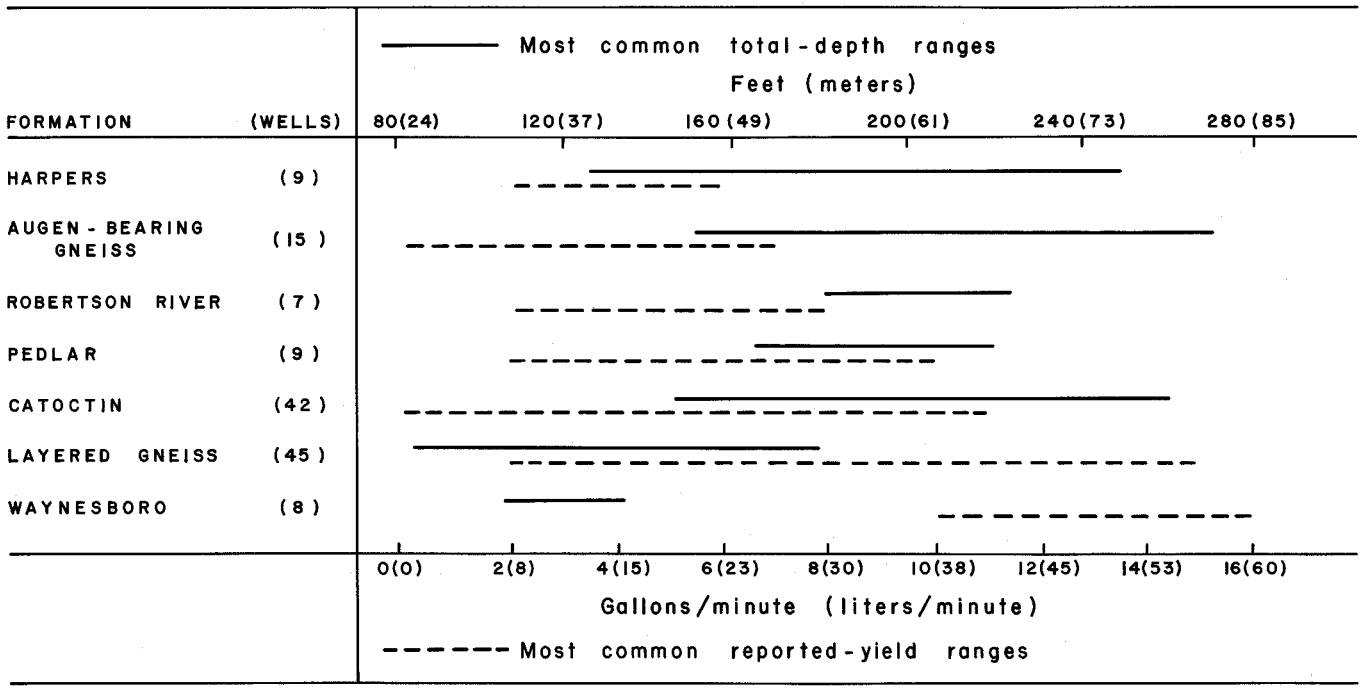
Table 20 is a summary of the drilling depths and yields of 135 water wells in 7 of the 14 bedrock formations. Although these are informative data, it should be noted that the records on which the tabulations are based are for reported yields from wells drilled at sites selected for convenience rather than for favorable hydrogeologic reasons. As statistical data is sometimes misleading, Table 21 was prepared to graphically depict the most *common* total-depth and reported-yield ranges for wells in each of the seven formations listed in Table 20.

A noteworthy comparison in Tables 20 and 21 is that of the productivity and depth of wells in the two clastic rock units, the Harpers and Waynesboro formations. All eight wells in the Waynesboro Formation penetrate and produce from the sandstone, siltstone, shale, and quartzite in the lower portion of the unit, but the 9 wells in the lithologically similar Harpers Formation are nearly twice as deep and produce only one-half as much water. The reason for this disparity is mainly the result of the geographic and topographic position of well locations, although structural deformation must be considered due to the proximity of the Happy Creek fault to the Shenandoah River. The eight wells in the Waynesboro Formation for which records are available are located near the south bank of the Shenandoah River from which abundant recharge is furnished the generally southeastward dipping rocks. In addition, the surface elevations of these wells is less than 50 feet (15 m) above river level and the wells penetrate permeable alluvium and terrace gravels before entering the thin-bedded rocks. It is likely that wells drilled in the western third of the exposed area of the Waynesboro Formation, which occurs at higher elevations on low hills several thousand feet west from the fault and the river, will have less favorable depth and yield statistics. The Harpers Formation is a much-maligned rock unit in terms of productivity because

Table 20.—Summary of depth and yield data for 135 water wells in the Linden and Flint Hill quadrangles (arranged by rock formation in order of decreasing average depth and increasing average yield).

Geologic formation (Wells)		Depth in feet (m) Minimum	Maximum	Average	Yield in gpm (l/m) Minimum	Maximum	Average
Harpers	(9)	125 (38)	420 (128)	239 (73)	0 (0)	15 (57)	6 (23)
Augen-bearing gneiss	(15)	70 (21)	330 (101)	180 (55)	0 (0)	15 (57)	6 (23)
Catoctin	(42)	85 (26)	700 (213)	221 (67)	0 (0)	61(231)	11 (42)
Robertson River	(7)	115 (35)	225 (69)	182 (56)	2 (8)	25 (95)	11 (42)
Pedlar	(9)	60 (18)	220 (67)	173 (53)	1 (4)	25 (95)	11 (42)
Layered gneiss	(45)	72 (22)	420 (128)	166 (51)	0 (0)	60(227)	12 (45)
Waynesboro	(8)	60 (18)	270 (82)	136 (41)	1 (4)	20 (76)	12 (45)

Table 21.—Relative drilling-depth and reported-yield ranges for 135 water wells in 7 prominent formations in the Linden and Flint Hill quadrangles (arranged by formation in order of increasing reported productivity).



at most places in Virginia it occupies the west flank of the Blue Ridge or the crests of the western Blue Ridge foothills. In these positions soil and alluvial cover is thin, surface runoff is rapid, and the presence of influent streams to recharge any rock openings is negligible. Although the lithologic and permeability characteristics of these two rock units are similar, the mitagating effects of topography and recharge have resulted in dissimilar well productivity. Whereas the depth and yield of new wells in the Waynesboro Formation in the Linden quadrangle will probably vary from the average for the eight recorded wells, the statistics of additional wells in the Harpers Formation are likely to be very similar to those listed for that unit in Tables 20 and 21.

A similar comparison can be made between wells in the layered and augen-bearing gneiss units. These rocks are lithologically comparable and have undergone the same periods of deformation which has resulted in similar permeability characteristics, namely, moderate solution activity along some mineralized shear zones but otherwise strictly fracture permeability. The reason for the greater average yield and shallower average depth of wells in the layered-gneiss (Table 20) is their juxtaposition to several prominent shear zones and the fault near Huntly in the western part of the Flint Hill quadrangle, and to better recharge conditions at the foot of the Blue Ridge. Some wells near shear zones in the augen-bearing gneiss have greater than average productivity, but the decrease in deformation in the central and eastern portions of the quadrangle and fewer influent streams farther from the east flank of the Blue Ridge have relegated this rock unit to one of lower productivity. A few wells of moderate or even high yield may be drilled where the augen-bearing gneiss is fractured near influent streams, but most will probably be of moderate depth and small yield. Several areas have potential for wells of moderate and relatively high yield in the layered gneiss, however, and it is likely that many can be developed in the sheared and faulted portions of this rock unit.

The other three formations for which well records are available vary somewhat in lithology but not in permeability. The Catoctin, Robertson River, and Pedlar formations are massive rock units that transmit ground water only through fracture and cleavage openings. These formations are all impermeable, similarly deformed, relatively brittle, and have the same average yield (Table 20). The relatively small difference in the average

depth of wells in these rock units can be mainly ascribed to the difference in topographic location of the reported wells. Although brittle under earth stresses, these are all competent rock units in which fractures generally remain open to depths of approximately 200 feet (61 m) below the ground surface in contrast to the many fractures that close at shallower depths in the less competent clastic, carbonate, and metamorphic rocks. Because of this characteristic, and because they have been severely fractured during several periods of deformation, the Catoctin, Pedlar, and Robertson River formations are among the more dependable, if only moderate, producers of ground-water supplies in this area. It is probable that a few high-yield wells will be drilled in each of these formations, but most yields are likely to be near the average figures given in Table 20.

No data are available for wells drilled in the carbonate rocks, the dikes, or the thick alluvium that covers small portions of the two quadrangles. Carbonate rocks have historically been considered the most productive bedrock aquifers, and in many places they are. Conversely, however, in areas of little crustal deformation and limited solution activity, ground-water production from carbonate rocks is similar to that from any other unfractured, impermeable rock unit—very small. Where records are available, it is common to find that wells in carbonate rocks have greater range in both depth and yield than in any other type. It is anticipated that wells in the Conococheague, Elbrook, and Shady formations in the Linden quadrangle will have such a statistical range. It is also expected that the smallest range in depth and yield will be for wells drilled in the several dike rocks. Their extremely resistant and abrasive lithology generally results in relatively shallow holes being drilled, and their insoluble and unfractured constitution commonly results in very small yields. Wells drilled in thick, permeable alluvium and terrace deposits such as those along the Shenandoah River and to a lesser extent in some of the other drainage systems, have a potential for moderate to high yields. These relatively shallow wells will require different construction procedures, however, as casing and well screens are necessary to prevent the unconsolidated materials from collapsing into the well bore.

Additional information concerning the location, construction, and development of water wells may be obtained from the State Water Control Board, P.O. Box 11143, Richmond, VA 23230.

FORMATION PROTECTION

If a geologic formation is regarded as a potential water source, certain environmental considerations should be afforded for its protection. The case in point is the nature of aquifers in consolidated rocks—open fractures and solution channels. These narrow water-bearing zones are neither limitless nor self-cleansing and must therefore be protected against the ravages of overdraft and pollution.

Of paramount importance are the large surface openings that lead to cavernous carbonate rocks such as may underlie the northwest corner of the Linden quadrangle. Land-spreading of sludge from waste treatment plants, landfills, garbage dumps, and untreated industrial waste disposal are among the common uses of land underlain by these soluble rocks. The very nature of their large subsurface openings not only makes for easy entry of foreign substances into the ground-water supply but also permits the transmission of pollutants for much greater distances than in unconsolidated formations (Todd, 1959) or unfractured rocks. In addition to pollution of these aquifers, extensive pumping of several high-yield wells in a limited area may considerably reduce the local ground-water supply. Further, as the relatively noncompressible water may serve as a support to overlying rock strata, its removal may cause collapse of those rocks into the dewatered opening. The development of such sinkholes is no respecter of property and can result in costly damage to surface facilities.

In clastic rocks such as underlie the area from the Shenandoah River to the crest of the Blue Ridge in the Linden quadrangle, ground-water supplies are more limited due to the fine-grained, less competent nature of the rocks. In these formations the construction of several wells in a limited area of only moderate recharge may lead to the development of a local cone of depression that can have an adverse effect on the productivity of all wells in that area. Also, because of the low permeability of these rocks, pollutants are not transmitted rapidly from the source, thus endangering the bacteriological quality of water in nearby wells. Of particular importance are drain fields and septic tanks in the soil and weathered portion of these rocks. Failure of such individual sewage-disposal systems may contaminate near-surface ground-water supplies and are particularly detrimental to shallow, uncased wells (Ecolsciences, Inc., 1974).

Much of this probem can be negated by the construction of deeper wells that are cased and grouted into firm bedrock (Clayton, 1973).

As permeability in igneous and most metamorphic rocks is mainly restricted to steep fractures in the first 200 feet (61 m) below ground surface, the quantity of water is limited and the quality susceptible to unsanitary sources in the area of recharge. In developments with a high density of ungrouted wells, septic tanks, and drain fields the possibility of eventual contamination of ground-water supplies is high. Such contamination may be accelerated by overpumping in a given area; this creates a local cone of depression into which effluent from drain fields and ruptured septic tanks can be drawn and fed to open fractures. Indications of such a cone of depression may first be through well piracy, i. e., failure or decrease in the productivity of one or more wells due to ground-water withdrawals from nearby wells. Only the proper casing and grouting of wells judicially spaced in a developed area will afford protection of the water-bearing fractures against the degradation of local ground-water supplies.

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GLOSSARY[1]

alaskite—A granitic rock containing only a few percent of dark minerals.

albite twinning—Found in triclinic feldspars, in which the albite twin is usually multiple and lamellar in configuration and shows fine striations on the (001) cleavage plane.

allotriomorphic-granular—Said of the granular texture of an igneous rock having or characterized by crystals not bounded by their own crystal faces and which have their form impressed upon them by preexisting adjacent mineral crystals.

amygdule—A mineral-filled gas cavity or vesicle in an igneous rock.

anhedral—Said of an individual mineral crystal (in an igneous rock) that has failed to develop its own bounding crystal faces naturally.

anticlinorium—An anticlinal structure of regional extent composed of lesser folds.

aphanitic—Said of any igneous rock whose components are not distinguishable with the unaided eye.

aquifer—A permeable geologic formation that transmits appreciable quantities of water.

arenaceous—Said of a sedimentary rock consisting wholly or in part of sand-size fragments.

argillaceous—Said of a sedimentary rock largely composed of, or containing clay-size particles or clay minerals.

argillite—A compact rock, derived either from mudstone or shale that has undergone a somewhat higher degree of induration (hardening by heat, pressure, or introduction of cementing materials) than is present in mudstone or shale and that is less clearly laminated than shale or slate.

arkose—A feldspar-rich, typically coarse-grained sandstone composed of angular to subangular grains that may be either poorly or moderately well sorted.

augen—In foliate metamorphic rocks, large, lenticular mineral grains or mineral aggregates having the shape of an eye in cross section.

breccia—A coarse-grained clastic rock composed of large, angular, and broken rock fragments that are cemented together in a finer grained matrix.

carbonate—Said of soluble rocks such as limestone and dolomite composed predominantly of carbonates of calcium, magnesium, or iron.

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[1] Definitions predominantly adapted from American Geological Institute (1972) and Dennis (1967).

Carlsbad twinning—A type of twinning found in feldspar, that is a penetration twin in which the twin axis is the c crystallographic axis and the composition surface is irregular.

cataclastic—Pertaining to the structure produced in a rock by action of severe mechanical stress during dynamic metamorphism.

clastic—Said of a consolidated sedimentary rock composed principally of broken fragments that are derived from preexisting rocks.

cleavage—The property of a rock to split along secondary, aligned fractures or other closely spaced, planar structures or textures, produced by deformation or metamorphism.

columnar jointing—Parallel, prismatic columns, either hexagonal or pentagonal in cross section, in basaltic flows.

cone of depression—A depression in the potentiometric surface of a body of ground water that has the shape of an inverted cone around a well from which water is being withdrawn.

continuous cleavage—Pervasive cleavage; the planes of cleavage are continuous rather than spaced.

euhedral—Said of an individual mineral crystal in an igneous rock that is completely bounded by its own regularly developed crystal faces and whose growth was not restrained or interfered with by adjacent crystals.

exsolution—The process whereby an initially homogeneous solid solution separates into two or more distinct crystalline phases without addition or removal of material to or from the system.

foliation—A general term for a planar arrangement of textural or structural features in rock.

gneiss—A foliated rock formed by regional metamorphism in which bands of granular minerals alternate with bands and lenticles and in which minerals having flaky or elongated prismatic habits predominate.

granulite—A metamorphic rock consisting of even-sized, interlocking mineral grains less than 10 percent of which have any preferred orientation.

graywacke—A dark and very hard, tough, and firmly indurated, coarse-grained sandstone that has a subconchoidal fracture and consists of poorly sorted and extremely angular to subangular grains of quartz and feldspar with an abundant variety of small, dark rock and mineral fragments embedded in a compact, partly metamorphosed clayey matrix.

greenschist—Schistose metamorphic rock containing an abundance of green minerals which are produced by regional and dislocation metamorphism at low and intermediate temperatures and at low to moderate hydrostatic pressures.

heteroblastic—Said of the texture of a metamorphic rock in which the essential mineral constituents are of two or more distinct orders of magnitude of size.

influent stream—A stream that contributes water to (recharges) the ground-water reservoir.

leucocratic—Said of a light-colored igneous rock relatively poor in dark (mafic) minerals.

mafic—Said of an igneous rock composed chiefly of one or more dark-colored ferromagnesium minerals.

metamorphism—The mineralogical and structural adjustment of solid rocks to physical and chemical conditions which have been imposed at depth below the surface zones of weathering and cementation.

metasomatism—The process of almost simultaneous capillary solution and deposition by which a new mineral of partly or wholly different chemical composition may grow in the body of an old mineral or mineral aggregate.

permeability, primary—The original capacity of a geologic formation to transmit fluids through interconnected pore spaces.

permeability, secondary—The transmission of fluids through physical (fracture) or chemical (solution) openings developed after a rock was formed.

phenocryst—A relatively large crystal surrounded by a finer crystalline matrix in an igneous rock.

phyllite—An argillaceous rock (originally clay) commonly formed by regional metamorphism and intermediate in metamorphic grade between slate and mica schist.

pleochroism—The ability of an isotropic crystal to absorb differentially various wavelengths of transmitted light in various crystallographic directions and thus to show different colors in different directions.

plutonic—Said of igneous rock formed at great depth.

porosity—A measure of interstices in a rock expressed as the percentage of void space to the total rock mass.

porphyritic—Said of the texture of an igneous rock in which larger crystals are set in a finer matrix.

saccharoidal—Said of a granular or crystalline texture resembling that of sugar.

saprolite—A soft, clay-rich, thoroughly decomposed, but untransported, rock formed in place by chemical weathering of igneous and metamorphic rocks.

saussuritization—The replacement, especially of plagioclase in basalts and gabbros, by a fine-grained aggregate of albite, calcite, epidote, sericite, and zeolites, and zoisite.

schistosity—The foliation in schist or other coarse-grained, crystalline rock due to the parallel, planar arrangement of mineral grains.

sericitization—A hydrothermal or metamorphic process that involves the introduction of, or replacement by, sericite.

shear zone—A tabular zone of rock that has been crushed and brecciated by numerous parallel fractures due to shear strain.

spaced cleavage—The spacing or separation of cleavage planes from a few millimeters to a microscopic scale.

subhedral—Said of an individual mineral crystal in an igneous rock that is partly faced or incompletely bounded by its own crystal faces and partly bounded by surfaces formed against preexisting crystals.

synclinorium—A synclinal structure of regional extent composed of lesser folds.

twin—An intergrowth of two or more single crystals of the same mineral in a mathematically describable manner, so that some lattices are parallel but others are in reversed position.

unakite—A metamorphosed igneous rock composed of abundant epidote with lesser amounts of pink orthoclase and quartz.

xenolith—An inclusion in igneous rock to which it is not genetically related.

APPENDIX

ROAD LOG

Distances shown are between points of geologic interest within the Linden and Flint Hill quadrangles, and the stops are places where formational contacts, structures, and interesting rock types or minerals may be observed. *Permission should be obtained from the owner before entering and collecting any samples from private property. Failure to obtain permission to enter violates trespass laws and is punishable under law.*

Cumulative miles (km)	*Distance*	*Explanation*
0.0	0.0	*STOP 1.* Begin road log in Culpeper Stone Company quarry (Figure 26), 2,000 feet (610 m) east of the village of Flint Hill on the south side of State Road 647 (Plate 2). Exposures in the quarry walls are representative of the layered gneiss and clearly display the unit's banded appearance. A very prominent and pervasive southeastward-dipping cleavage can be observed along with many dikes. Crushed stone has been produced from this quarry since 1965. Turn left on State Road 647 after leaving quarry entrance.
0.3 (0.5)	0.3 (0.5)	Junction with U. S. Highway 522; turn right onto U. S. Highway 522 heading north.
0.8 (1.3)	0.5 (0.8)	Cross Wilson Branch.
0.9 (1.5)	0.1 (0.2)	*STOP 2.* Pull off right side of road. Massive outcrop of white vein quartz. Continue north on U. S. Highway 522.
2.2 (3.5)	1.2 (1.9)	Cross Hittles Mill Stream.
2.3 (3.7)	0.1 (0.2)	Junction with State Road 630; turn left onto State Road 630 heading west.
3.0 (4.8)	0.8 (1.3)	Cross bridge. Junction with State Road 628; turn right and continue west on State Road 630.
3.2 (5.2)	0.2 (0.3)	*STOP 3.* Cross stone fence on left side of road. Outcrop of layered gneiss with garnets (R-5572). The leucocratic layering has been distorted in many areas resulting in the formation of augen-like structures. Further west on State Road 630 are lithologies transitional between the layered gneiss and Pedlar quartz monzonite. Continue west on State Road 630.

Cumulative miles (km)	*Distance*	*Explanation*
3.6 (5.8)	0.4 (0.6)	*STOP 4.* Pull off left side of road. A layered zone of Pedlar quartz monzonite with garnets. This lithology is characteristically present within the transition zone between the layered gneiss and Pedlar quartz monzonite. The outcrop contains prominent alternating mafic and felsic bands that range in width from 2 to 20 cm. Continue west on State Road 630.
3.7 (6.0)	0.1 (0.2)	Junction with State Road 631; continue southwest on State Road 630.
4.0 (6.4)	0.3 (0.5)	Turn right off State Road 630 and onto Flint Hill Estates private road. Continue west on private road to top of hill.
4.1 (6.6)	0.1 (0.2)	*STOP 5.* Pull off right side of road just past private drive entrance. Cross road and observe typical outcrop of fine-grained, massive, glassy, mafic Pedlar quartz monzonite. The trace of a northeastward-trending fault zone is present in the valley to the west. The mountains west of the fault zone are underlain by down-faulted Catoctin metabasalts. Turn around and retrace route to State Road 630.
4.2 (6.8)	0.1 (0.2)	Junction with State Road 630; turn left onto State Road 630 heading northeast.
5.3 (8.5)	1.1 (1.7)	Junction with State Road 628; turn right onto State Road 628 heading south.
5.9 (9.5)	0.6 (1.0)	*STOP 6.* Pull off right side of road. Exposure of a mafic Catoctin feeder dike containing light-green feldspar phenocrysts. Continue south on State Road 628.
6.8 (10.9)	0.9 (1.5)	Junction with State Road 659; continue southwest on State Road 628.
7.2 (11.6)	0.4 (0.6)	Junction with State Road 629; turn left and continue on State Road 628 heading south.
8.0 (12.9)	0.8 (1.3)	Junction with State Road 606; turn left onto State Road 606 heading east-northeast.
8.2 (13.2)	0.2 (0.3)	*STOP 7.* Pull off right side of road and park in front of wooden gate. Go through gate and to exposure of layered gneiss 20 yards (18 m) ahead. Two distinct directions of schistosity are evident,

Cumulative miles (km)	*Distance*	*Explanation*
		one trending northeasterly and the other northwesterly along which are large well-developed augens. Several portions of the outcrop contain blue-quartz veins. Continue east on State Road 606.
9.0 (14.5)	0.8 (1.3)	Junction with State Road 641; continue east on State Road 606.
9.4 (15.1)	0.4 (0.6)	Junction with U. S. Highway 522; turn left onto U. S. Highway 522 heading north.
9.6 (15.5)	0.2 (0.3)	Junction with State Road 647; turn right onto State Road 647 heading east.
11.8 (19.0)	2.2 (3.5)	*STOP 8.* Pull off right side of road. Small stone barn on hill on the left side of road. Cross road and go through red gate to outcrop of augen-bearing gneiss. Small amphibolite dike transects the general foliation trend with no apparent alteration of the augen-bearing gneiss (Figure 9). To the southwest is Fogg Mountain, which is mostly underlain by the augen-bearing gneiss. Continue east on State Road 647.
13.2 (21.2)	1.4 (2.2)	Junction with State Road 638; continue east on State Road 647.
13.9 (22.4)	0.7 (1.2)	Junction with State Road 637 on left; turn left onto State Road 637 heading north.
14.3 (23.0)	0.4 (0.6)	Stop before bridge over Rappahannock River, turn around, and head south on State Road 637.
14.4 (23.2)	0.1 (0.2)	*STOP 9.* Pull off right side of road and cross road. Typical exposure of hornblende and biotite-rich Robertson River Granite. There is little indication of cleavage or schistosity within the granite that weathers to a coarse, pebble-like soil. Continue south on State Road 637.
14.7 (23.7)	0.3 (0.5)	Junction with State Road 647; turn left onto State Road 647 heading east.
15.2 (24.5)	0.5 (0.8)	Cross the Rappahannock River.
16.0 (25.7)	0.8 (1.3)	*STOP 10.* Pull off right side of road. Cross road and climb wooden fence. Exposure of a northeastward-trending, dark, felsic dike with unusually large feldspar phenocrysts up to 15 mm (0.6 in.) in diameter (Figure 10). Continue northeast on State Road 647.

Cumulative miles (km)	*Distance*	*Explanation*
16.2 (26.1)	0.2 (0.3)	Junction with State Road 645; continue northeast on State Road 647.
16.4 (26.4)	0.2 (0.3)	*STOP 11.* Pull off right side of road. Cross road and climb wooden fence. Typical exposures of Robertson River granite with some nondirectional shearing. The landscape to the west and north is typical of topography developed on the granite. Continue northeast on State Road 647.
17.2 (27.7)	0.8 (1.3)	Junction with State Road 770; continue northeast on State Road 647.
18.1 (29.1)	0.9 (1.5)	Junction with State Roads 688 and 735; turn sharp left onto State Road 735 heading northwest.
20.8 (33.5)	2.7 (4.3)	Junction with State Road 734; turn right onto State Road 734 heading northeast.
21.3 (34.3)	0.5 (0.8)	*STOP 12.* Pull off right side of road and park across from white, wooden frame house. Cross road to observe good exposure of amphibolite dike. This dike is quite extensive and parallels the road to the north; its total length is estimated to be 2,875 feet (876 m). Continue northeast on State Road 734.
22.0 (35.4)	0.7 (1.1)	Junction with State Road 688; turn left on State Road 688 heading north to the village of Hume.
23.0 (37.0)	1.0 (1.6)	In the village of Hume. Junction with State Road 635; turn left on State Road 635 heading west.
24.1 (38.8)	1.1 (1.8)	Large white house on right belonging to A. P. DiGiulian.
24.3 (39.1)	0.2 (0.3)	*STOP 13.* Pull off right side of road. Typical exposure of augen-bearing gneiss containing large feldspar augen (Figure 4). Buck Mountain to the northeast and Oventop and Rattlesnake Mountain to the northwest are mostly underlain by this rock unit. Continue west on State Road 635.
24.5 (39.4)	0.2 (0.3)	*STOP 14.* Pull off road and park in front of metal gate on right. Go through gate and observe outcrops in field just ahead. This zone of the augen-bearing gneiss is nonaugenous as the cataclastic event that formed and aligned the feldspar porphyblasts in most of the unit was less intense in this area. Several amphibolite dikes that trend in a general northeasterly direction occur in these outcrops. Continue west on State Road 635.

Cumulative miles (km)	*Distance*	*Explanation*
26.0 (41.8)	1.5 (2.4)	Cross Fiery Run.
26.9 (43.3)	0.9 (1.5)	*STOP 15.* Pull off right side of road at the entrance to private drive. Go through cattle guard and cross wooden fence on right. Good exposures of layered gneiss with ptygmatic folding (Figure 3). Note small dike cutting base of exposure. Continue northwest on State Road 635.
28.0 (45.1)	1.1 (1.8)	*STOP 16.* Junction with State Road 726. Park at intersection and climb fence on right. Large outcrops of layered gneiss with two directions of cleavage. Continue west on State Road 635.
30.4 (48.9)	2.4 (3.9)	Junction with U. S. Highway 522; turn right and head north.
31.2 (50.2)	0.8 (1.3)	Junction with State Road 632; continue north on U. S. Highway 522.
31.4 (50.5)	0.2 (0.3)	*STOP 17.* Pull off road and park at Blue Ridge Grocery Store. Walk 75 yards (69 m) north on U. S. Highway 522 to observe Catoctin Formation on west side of road. The metabasalt has been strongly cleaved, leaving small, thin, tan chips when weathered. Also occurring within this exposure is a 5-foot (2-m) thick bed of steeply dipping, purple tuffaceous material with elongated amygdules. Turn around and head south on U. S. Highway 522.
32.5 (52.3)	1.1 (1.8)	Junction with State Road 635; turn left onto State Road 635 heading east.
34.8 (56.0)	2.3 (3.7)	Junction with State Road 726; turn left and head north on State Road 726.
36.0 (57.9)	1.2 (1.9)	Cross Fiery Run.
37.3 (60.0)	1.3 (2.1)	Large gray stucco house on right.
37.5 (60.3)	0.2 (0.3)	*STOP 18.* Pull off right side of road just past exposure of Pedlar quartz monzonite. Fine, pervasive, alternating felsic and mafic bands well displayed in outcrop. Continue north on State Road 726.

Cumulative miles (km)	*Distance*	*Explanation*
38.0 (61.1)	0.5 (0.8)	Junction with State Road 727; turn left onto State Road 727 heading west.
38.6 (62.1)	0.6 (1.0)	Turn right off State Road 727 into private drive.
38.7 (62.3)	0.1 (0.2)	*STOP 19.* Pull into second private drive on left. The cut bank on the right side of road contains platy fragments of sheared Pedlar quartz monzonite. Turn around and head back to State Road 727.
38.8 (62.4)	0.1 (0.2)	Junction with State Road 727; turn left onto State Road 727 heading north.
39.3 (63.2)	0.5 (0.8)	Junction with State Road 726; turn left onto State Road 726 heading north.
39.5 (63.6)	0.2 (0.3)	Junction with State Road 638; continue northeast on State Road 726.
40.1 (64.5)	0.6 (1.0)	*STOP 20.* Park on right side of road and walk back 75 yards (69 m) to outcrops of the Pedlar Formation on south side of road. Very thin-layered, leucocratic gneiss. Continue northeast on State Road 726.
40.4 (65.0)	0.3 (0.5)	Junction with State Road 638; continue northeast on State Road 726.
41.8 (67.3)	1.4 (2.3)	*STOP 21.* Pull off left side of road. Walk back southwest and observe outcrops on right side of road. Good exposures of an extensive dark-green, fine-grained, amphibolite dike. Continue northeast on State Road 726.
42.6 (68.5)	0.8 (1.3)	Cross Southern Railway tracks.
42.9 (69.0)	0.3 (0.5)	Junction with State Highway 55; turn right onto State Highway 55 heading east.
43.6 (70.2)	0.7 (1.1)	*STOP 22.* Pull off right side of road into private drive with wooden gate. Exposures of augen-bearing gneiss with large, pink feldspar augen up to 3.7 cm in diameter. These augen have not been aligned as much as in other areas. Turn around and head west on State Highway 55.
46.8 (75.3)	3.2 (5.2)	Village of Linden. Junction with State Road 638; turn right on State Road 638 heading north.

Cumulative miles (km)	*Distance*	*Explanation*
47.5 (76.4)	0.7 (1.1)	*STOP 23.* Pull off road into private drive on right. Outcrops of Catoctin metabasalt with a southeastward-dipping cleavage. The surface of the outcrop is approximately coincident with the top of a basalt flow. Generally massive and fine-grained, these exposures contain areas of epidosite concentration, abundant amygdules (with quartz, albite, and epidote), vesicles, and asbestos. Turn around and head south on State Road 638.
48.2 (77.6)	0.7 (1.1)	Junction with State Highway 55 at the village of Linden; turn right onto State Highway 55 heading west.
49.6 (79.8)	1.4 (2.3)	Junction with State Road 647; turn right onto State Road 647 heading west.
50.6 (81.4)	1.0 (1.6)	Junction with State Road 651; continue on State Road 647 heading west.
51.1 (82.2)	0.5 (0.8)	*STOP 24.* Pull off road and park in private drive on right. Walk back 480 feet (146 m) on road and observe the lower Weverton quartzo-feldspathic unit, the most easterly outcrops of which have a steep dip to the west. Nearest the parking area, quartz-pebble conglomerate beds of the upper unit have been overturned to the west. Features such as gash veins, ferruginous-stained cross bedding, and graded bedding are well exposed. Continue west on State Road 647.
51.3 (82.5)	0.2 (0.3)	Junction with State Road 603; turn right onto State Road 603 heading north.
52.4 (84.3)	1.1 (1.8)	Road to Camp Wamava on right.
52.5 (84.5)	0.1 (0.2)	*STOP 25.* Pull off left side of road and park. Walk 600 feet (183 m) north and cross stream on left side of road to observe the west, anticlinal limb of the cliff-forming upper unit of the Weverton Formation. Here, State Road 603 roughly parallels the axial trace of the small northward-plunging anticline. Outcrops at this location contain gash veins with good primary bedding features such as ferruginous-stained cross bedding (Figure 16). Continue northeast on State Road 603.

Cumulative miles (km)	*Distance*	*Explanation*
52.7 (84.8)	0.2 (0.3)	*STOP 26.* Junction of State Road 603 and private road on the right. A very nearly east-west trending cross-fault terminates and offsets the Weverton Formation here. The fault is terminated to the west by the thrust fault near Howellsville, which trends northeast through Oregon Hollow. Wildcat Mountain to the west is capped by sandstones in the upper unit of the Harpers Formation and vitreous quartzites of the lower part of the Antietam Formation. The lower hills to the east are capped by quartzites and quartz-pebble conglomerates of the Weverton Formation. Continue northeast on State Road 603.
53.5 (86.1)	0.8 (1.3)	*STOP 27.* Cross bridge over Oregon Hollow stream and pull off road into private drive on the right. Outcrop on right side of road is the lowest bed in the upper unit of the Harpers Formation. These overturned, light-tan, iron-oxide stained quartzite beds are 7 to 25 cm thick and have an aggregate thickness of approximately 25 feet (8 m) at this location. Continue north on State Road 603.
53.7 (86.4)	0.2 (0.3)	*STOP 28.* Pull off right side of road. Massive, thick, very steeply dipping (west) quartzite beds near the base of the Antietam Formation. Abundant *Skolithos* tubes. Continue north on State Road 603.
54.2 (87.2)	0.5 (0.8)	Junction with State Road 643; turn right and continue northeast on State Road 603.
55.2 (88.8)	1.0 (1.6)	*STOP 29.* Pull off right side of road across from metal gate. Walk back (south) along State Road 603 and observe tectonic breccia in the Antietam quartzites exposed on the left side of road. The brecciation was probably caused by movement of the thrust sheet near Howellsville. The trace of the fault parallels the west foot of the small hills to the east and gradually turns eastward around the mountain in the distance to the north at Howellsville. Continue north on State Road 603.
56.6 (91.1)	1.4 (2.2)	Junction with State Road 638; turn left onto State Road 638 heading northwest.
58.5 (94.1)	1.9 (3.1)	*STOP 30.* Pull off left side of road at intersection of State Road 638 and natural gas pipeline. Venus Hill to the east is capped by vitreous quartzites of

Cumulative miles (km)	*Distance*	*Explanation*
		the Antietam Formation. An extremely well-developed tectonic breccia in the same quartzites forms cliffs and ledges in the hills to the west across the Shenandoah River. This brecciation was caused by the Happy Creek high-angle reverse fault that brings Antietam quartzites into contact with upper Shady dolomites, indicating a minimum stratigraphic displacement of 1,150 feet (350 m). Continue northeast on State Road 638.
58.9 (94.8)	0.4 (0.6)	Cross small stream on concrete bridge.
59.2 (95.3)	0.3 (0.5)	Turn right off State Road 638 onto private road and cross cattle guard heading east. Stone monument on left side of cattle guard commemorating Captain Thomas Ashby's home.
59.4 (95.6)	0.2 (0.3)	Turn right off private road onto Venus Branch Drive heading southeast.
59.7 (96.1)	0.3 (0.5)	Steeply dipping (southeast) beds of Antietam quartzite are exposed on left side of road.
59.8 (96.2)	0.1 (0.2)	Oak Lane heading south.
59.9 (96.4)	0.1 (0.2)	Cross natural gas pipeline.
60.2 (96.9)	0.3 (0.5)	*STOP 31.* Pull off right side of road. On the left side of road, approximately 75 feet (23 m) back in woods, are quartzite beds near the top of the upper unit of the Harpers Formation that dip to the west. A northwestward-trending cross fault, that traces along Oak Lane Road, has offset these beds to the west by approximately 750 feet (229 m). Turn around and head north on Oak Lane.
60.6 (97.5)	0.4 (0.6)	Junction with Venus Branch Drive; turn left on Venus Branch Drive heading northwest.
61.0 (98.2)	0.4 (0.6)	Turn left into private drive and cross cattle guard; continue west.
61.2 (98.5)	0.2 (0.3)	Junction with State Road 638; turn left onto State Road 638 heading southwest.
63.8 (102.7)	2.6 (4.2)	Junction with State Road 603; turn right and continue on State Road 603 heading southwest.

Cumulative miles (km)	*Distance*	*Explanation*
66.2 (106.6)	2.4 (3.9)	Junction with State Road 643; continue straight ahead on State Road 643 heading west.
66.4 (106.8)	0.2 (0.3)	*STOP 32.* DO NOT PARK. Abandoned quarry in Antietam quartzite on left side of road. Continue west on State Road 643.
66.5 (107.0)	0.1 (0.2)	*STOP 33.* Pull into private road on left. Walk 100 yards (91 m) south up the road and look at thick, massive, fine-grained beds of Shady dolomite across small stream on left side of road. Continue west on State Road 643.
66.8 (107.5)	0.3 (0.5)	*STOP 34.* Pull into private drive on right side of road. Outcrops of the middle unit of the Waynesboro Formation on left side of road are thin- to medium-bedded, locally laminated limestone with dolomite beds.
67.3 (108.3)	0.5 (0.8)	Continue west on State Road 643 to junction with State Road 624.
68.9 (110.9)	1.6 (2.6)	Turn left and proceed south on State Road 624 to junction with State Road 647.
72.4 (116.5)	3.5 (5.6)	Turn right on State Road 647 and proceed west to junction with U. S. Highway 522 in Front Royal.

End of Road Log

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COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

Linden

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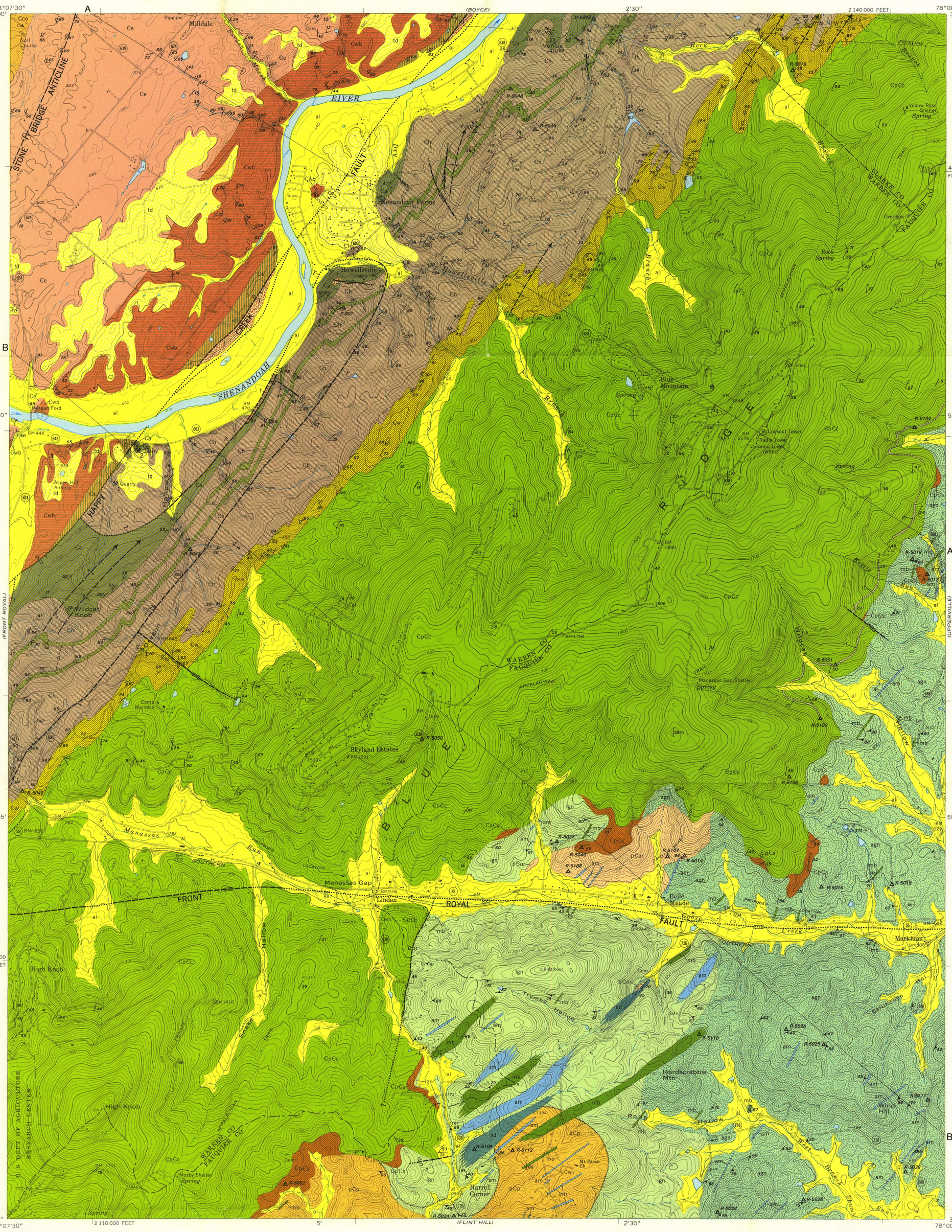

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Linden Quadrangle, 7½ Minute Series

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GEOLOGIC MAP OF THE LINDEN QUADRANGLE, VIRGINIA

Geology by E. B. Nuckols, III and Michael T. Lukert

MN GN
7° 124 MILS
1°51' 33 MILS
UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000
1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

1976

VIRGINIA
QUADRANGLE LOCATION

EXPLANATION

CENOZOIC — QUATERNARY

al — Alluvium
Dark-gray sand, silt, and clay with lenses of cobbles and medium to small pebbles; colluvium consisting of boulders, cobbles, and sand in stream beds on the east and west flanks of the Blue Ridge.

td — Terrace deposits
Moderate to well-rounded cobbles and boulders in a matrix of sand, silt, and clay.

PALEOZOIC — CAMBRIAN

Ꞓco — Conococheague Formation
Rusty-weathering sandstone, bluish-gray limestone, and light-gray dolomite.

Ꞓe — Elbrook Formation
Medium- to dark-gray limestone with argillaceous and sandy laminae; light- to medium-gray laminated dolomite; rusty-brown laminated calcareous or dolomitic shale.

Ꞓwb — Waynesboro (Rome) Formation
Maroon and green shale (upper part). Dark bluish-gray dolomite and bluish-gray limestone (middle part). Maroon, olive, and dark-gray shale and maroon and yellowish-tan sandstone (lower part).

Ꞓs — Shady Formation
Light- to dark-gray laminated dolomite; few chert rosettes and nodules.

Ꞓa — Antietam Formation
Quartzite and subarkose; phyllite partings common; characteristic Skolithos tubes present.

q / Ꞓh / q / Ꞓh / fs — Harpers Formation
Dark greenish-gray feldspathic graywacke and phyllite; q, tan to white sandstone and quartzite; fs, dark-purple, magnetite- and hematite-cemented, argillaceous quartz sandstone.

Ꞓw — Weverton Formation
Light-gray quartz-pebble conglomerate with interbedded pebbly, sericitic quartzitic sandstone and ferruginous sandstone (upper part). Dark-gray, sandy phyllite and sericitic quartz sandstone (middle part). Light-gray to tan and purplish-gray quartzite and quartz pebble conglomerate with interbedded sandy phyllite (lower part).

ꞒpꞒc / rt — Catoctin Formation
Dark- to grayish-green metabasalt with basalt-flow breccia, epidosite, and thin beds of purple amyduloidal slate (upper part). Dark- to grayish-green metabasalt, purple phyllite, and metasedimentary rock; rt, pink to cream rhyolitic tuff (lower part).

mb — Metabasalt
Dark grayish-green metabasalt dike (Catoctin feeder).

ꞒpꞒs — Swift Run Formation
Dark greenish-brown, sandy and pebbly metagraywacke and meta-arkose; sericitic and chloritic phyllite; locally, purple thin-bedded slate.

ad / am — Dikes
ad, *light greenish-gray augite-bearing dikes;* am, *medium- to dark-gray actinolite-rich amphibolite.*

PRECAMBRIAN

pꞒp — Pedlar Formation
Light- to greenish-gray quartz monzonite.

pꞒor — Old Rag Granite
Light-gray granite composed primarily of creamy to white microcline and blue quartz.

agn — Augen-bearing gneiss
Light- to dark-gray quartz monzonite gneiss; augen of potassium feldspar common.

lgn — Layered gneiss
Light- to dark-gray quartz monzonite gneiss with blue quartz.

f — Fault breccia
Angular fragments and blocks of quartzite cemented with iron oxide.

CONTACTS

Dashed where approximate, dotted where covered or inferred

FOLDS

Anticline — trace of fold and direction of plunge

Syncline — trace of fold and direction of plunge

Overturned anticline — trace of fold

FAULTS

U D T

Dashed where approximate, dotted where covered or inferred, tick mark indicates direction of dip; U, upthrown side; D, downthrown side; T, upper sheet; arrows indicate direction of relative movement

In cross section
T/A Horizontal movement:
T — relative movement toward observer
A — relative movement away from observer

SHEAR ZONE

ATTITUDE OF ROCKS

25 — Strike and dip of beds
80 — Strike and dip of overturned beds
Strike of vertical beds
Horizontal beds

FOLIATION

45 — Strike and dip of schistosity
60 — Strike and dip of cleavage

QUARRIES

1 — Active quarry
1. Rappawan Lumber, Inc. (quartzite)

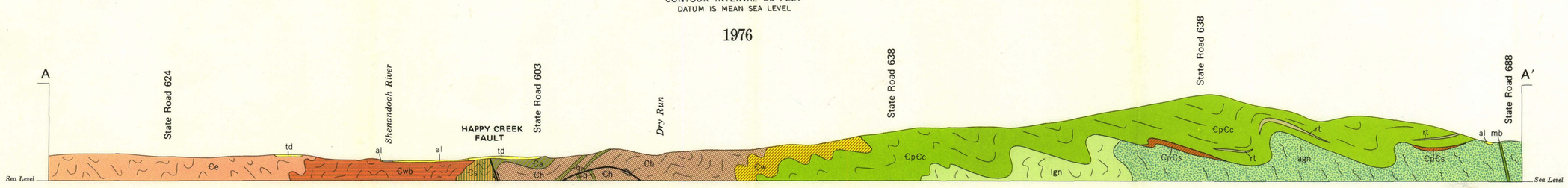
2 — Abandoned quarry
2. Quartzite quarry

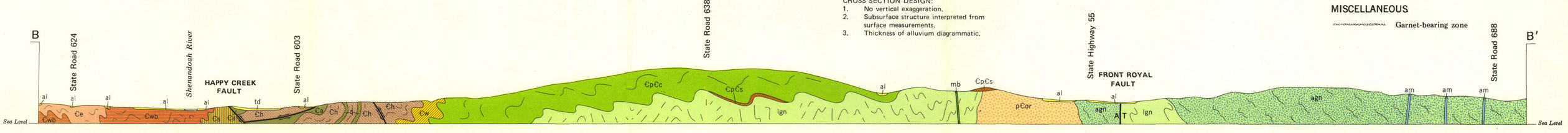
SAMPLE LOCATIONS

R-5112 — R, repository number of sample
F-901 — F, repository number of fossil sample

MISCELLANEOUS

Garnet-bearing zone





CROSS SECTION DESIGN:
1. No vertical exaggeration.
2. Subsurface structure interpreted from surface measurements.
3. Thickness of alluvium diagrammatic.

COMMONWEALTH OF VIRGINIA
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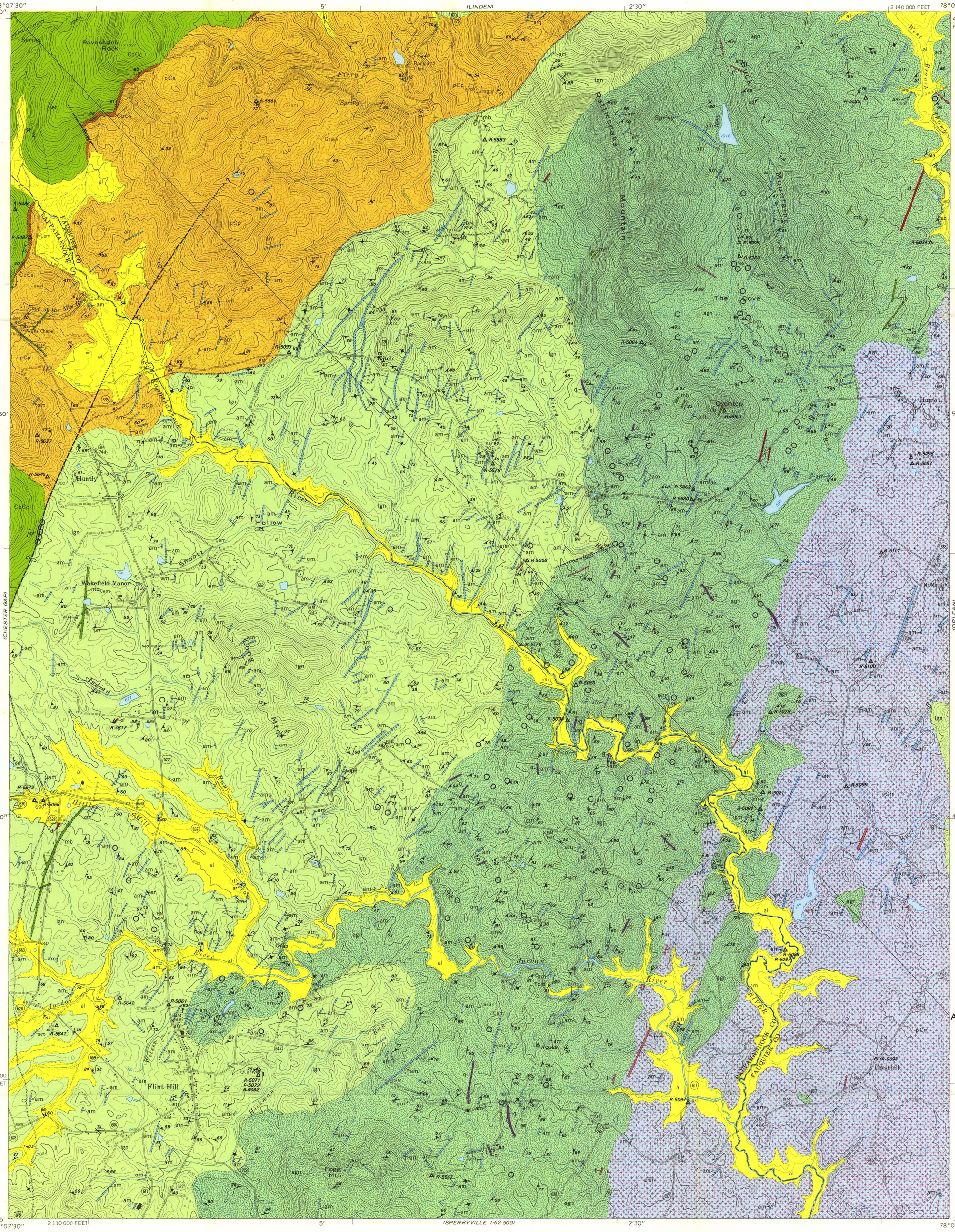

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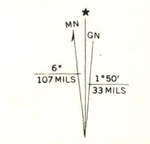
GEOLOGIC MAP OF THE FLINT HILL QUADRANGLE, VIRGINIA

Geology by E. B. Nuckols, III and Michael T. Lukert



UTM GRID AND 1966 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
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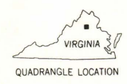


QUADRANGLE LOCATION

EXPLANATION

QUATERNARY

al — Alluvium
Light- to dark-gray sand, silt, and clay with lenses of cobbles and pebbles; colluvium consisting of boulders, cobbles, and sand in stream beds on the flanks of the larger mountains.

TRIASSIC

d — Diabase dikes
Dark-gray diabase.

PRECAMBRIAN(?)

ЄpЄc — Catoctin Formation
Dark- to grayish-green metabasalt with basalt-flow breccia, epidosite, and thin beds of purple amyduloidal slate.

mb — Metabasalt
Dark grayish-green metabasalt dike (Catoctin feeder dike).

ЄpЄs — Swift Run Formation
Dark greenish-brown, sandy and pebbly metagraywacke and meta-arkose; sericitic and chloritic phyllite.

PRECAMBRIAN

am, f — Dikes
am, *medium- to dark-gray, actinolite-rich amphibolite;* f, *yellowish- to light-gray felsic igneous rock.*

q — Quartz Veins
q, *very large quartz vein; circle is local concentration of quartz float*

pЄrr — Robertson River Formation
Light- to dark-gray hornblende-biotite granite.

pЄp — Pedlar Formation
Light- to greenish-gray quartz monzonite.

agn — Augen-bearing gneiss
Light- to dark-gray quartz monzonite gneiss; augen of potassium feldspar common.

lgn — Layered gneiss
Light- to dark-gray quartz monzonite gneiss with blue quartz.

CONTACTS

Dashed where approximate, dotted where covered or inferred

FAULTS

Dashed where approximate, dotted where covered or inferred; U, upthrown side; D, downthrown side; arrows indicate direction of relative movement

SHEAR ZONE

ATTITUDE OF ROCKS

40 — Strike and dip of beds

FOLIATION

50 — Strike and dip of schistosity

Strike of vertical schistosity

55 — Strike and dip of cleavage

Strike of vertical cleavage

MINE AND QUARRY

1 — Active quarry

1. Culpeper Stone Company quarry (gneiss)

2 — Abandoned mine

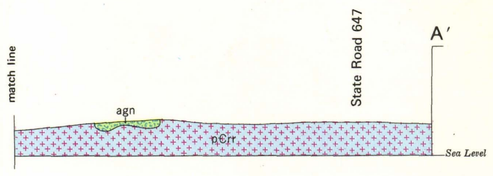
2. Manassas Gap mine (copper)

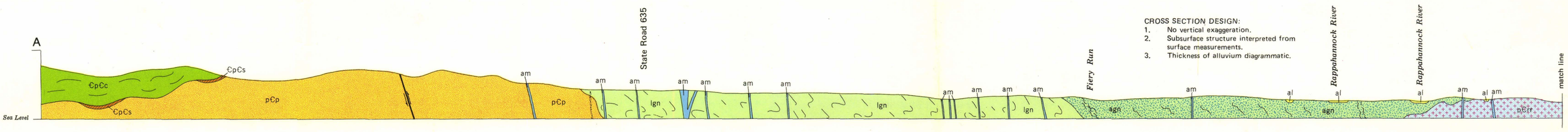
SAMPLE LOCATIONS

R-5564 — R, repository number of sample

MISCELLANEOUS

Garnet-bearing zone





CROSS SECTION DESIGN:
1. No vertical exaggeration.
2. Subsurface structure interpreted from surface measurements.
3. Thickness of alluvium diagrammatic.