U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

TO ACCOMPANY MAP GQ–1768

GEOLOGIC MAP OF THE URBANA QUADRANGLE, FREDERICK AND MONTGOMERY COUNTIES, MARYLAND

By Scott Southworth

INTRODUCTION AND GEOLOGIC SETTING

The Urbana quadrangle is underlain by Late Proterozoic(?) and Lower Cambrian(?) metasedimentary and metavolcanic rocks and Lower and Middle Cambrian metasedimentary rocks of the western Piedmont (fig. 1 on plate). Lower Cambrian(?) metasedimentary rocks of the Sugarloaf Mountain anticlinorium are interpreted to be exposed in a tectonic window (A.A. Drake, Jr., oral commun., 1989; Horton and others, 1989; Rankin and others, 1989) through the complexly deformed allochthonous rocks of the Westminster terrane (Muller and others, 1989). Rocks of the Westminster terrane were interpreted to be rise-slope deepwater deposits of the Iapetus Ocean that were transported westward onto the Laurentian margin (ancestral North America) along the Martic thrust fault during the Ordovician Taconic orogeny (Horton and others, 1989). Continental margin strata, which underlie the Sugarloaf Mountain anticlinorium and Frederick Valley synclinorium, are here correlated with rocks of the Lower Cambrian Chilhowee Group that crop out on the limbs of the Blue Ridge-South Mountain anticlinorium to the west. Parts of the Urbana quadrangle were mapped by Jonas and Stose (1938a) (scale 1:62,500), Scotford (1951) (scale 1:12,500), Thomas (1952) (scale 1:25,000), Cloos and Cook (1953) (scale 1:62,500), and Froelich (1975) (scale 1:62,500).

STRATIGRAPHY

"Despite geological work in this region since 1890 there is still disagreement about the stratigraphic and structural relationships. The uncertainties stem from poor exposures, complex structure, lack of fossils, and lithologic similarity throughout much of the section" (Hopson, 1964).

Rocks of the Westminster terrane (Muller and others, 1989) were interpreted to constitute a tectonic assemblage of undated rocks of the rise and slope prism that were thrust onto Cambrian drift-facies, slope and platform rocks of Laurentia along the Martic thrust fault during the Ordovician Taconic orogeny (Drake and others, 1989; Horton and others, 1989). The relation of the Sugarloaf Mountain Quartzite (Jonas and Stose, 1938b) to surrounding rocks has been controversial (Scotford, 1951; Stose and Stose, 1951; Thomas, 1952). The Martic thrust fault (Jonas, 1924, 1927; Knopf and Jonas, 1929) and the interpretation that the Sugarloaf Mountain anticlinorium (Scotford, 1951; Thomas, 1952) is a tectonic window through the Martic thrust sheet (A.A. Drake, Jr., oral commun., 1989) further complicates the stratigraphic correlation of these rocks. Furthermore, thrust faults are here interpreted to bound the contacts of the Sams Creek Formation, Marburg Formation, and Ijamsville Phyllite. Therefore, the stratigraphy of the western Piedmont is here presented as a tectonic assemblage.

The map area is subdivided into three regions (fig. 1 on plate). Lower and Middle Cambrian rocks of the Araby Formation form the extreme east limb of the Frederick Valley synclinorium west of the Martic thrust fault. The Westminster terrane is thrust onto the Frederick Valley synclinorium along the Martic thrust fault. Within the Westminster terrane, the Sugarloaf Mountain Quartzite and Urbana Formation constitute the parautochthonous Sugarloaf Mountain anticlinorium. East of Ijamsville, Md., are rocks interpreted to be Urbana Formation in the parautochthonous Bush Creek window. The Sugarloaf Mountain anticlinorium and Bush Creek window are interpreted to be antiforms and windows through the Ijamsville thrust sheet of the allochthonous Westminster terrane.

Figure 1 (on plate) illustrates the interpreted geology of this study. A regional compilation of bedrock is currently impossible given the disparate maps available (see the adjoining maps of Fisher (1978) and Edwards (1986, 1994), for example). Because the age, stratigraphic order, and structural setting of these rocks are unknown and controversial (table 1), special attention was paid during mapping to premetamorphic lithologic characteristics and characteristics imposed upon the rocks by deformation. Grouping of rocks and formational names applied to them can be misleading (fig. 2, on plate, inset), so the dominant lithologic units of the allochthonous rocks of the Westminster terrane are shown with the major faults omitted in figure 2 (on plate). The type localities of the Ijamsville Phyllite and the Urbana Formation are within the map area, and the type locality of the Sugarloaf Mountain Quartzite is in the adjacent Buckeystown quadrangle (fig. 2 on plate) (Southworth and Brezinski, in press). These three rock units are well defined and can be confidently mapped away from their type localities. The stratigraphic names used for the other rocks are explained below. The age assignments and the structural interpretation are based on two important assumptions: (1) the Sugarloaf Mountain Quartzite is correlative with the Lower Cambrian Weverton Formation of the Chilhowee Group, and (2) metavolcanic greenstone of the Sams Creek Formation and Ijamsville Phyllite are correlative with the Late Proterozoic and Lower Cambrian Catoctin Formation of the Blue Ridge-South Mountain anticlinorium.

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Table 1.—Stratigraphic table showing various names used for rock units of the western Piedmont of Maryland.

Time scale (youngest to oldest): PHANEROZOIC Eon, PALEOZOIC Era — ORDOVICIAN System (UPPER, MIDDLE, LOWER epochs), CAMBRIAN System (UPPER, MIDDLE, LOWER epochs); PROTEROZOIC Eon, LATE Era.

Source	Rock unit	Range (oldest – youngest)
Jonas and Stose (1938), Stose and Stose (1946)	Antietam Quartzite	LOWER CAMBRIAN – MIDDLE CAMBRIAN
	Harpers Phyllite	LOWER CAMBRIAN – MIDDLE CAMBRIAN
	Sugarloaf Mountain Quartzite	? LOWER CAMBRIAN ?
	Ijamsville Phyllite, Urbana Phyllite, Marburg Schist, Wissahickon Formation	LATE PROTEROZOIC – LOWER CAMBRIAN ?
	Sams Creek Formation	? LATE PROTEROZOIC – LOWER CAMBRIAN ?
Cleaves and others (1968)	Antietam Formation	LOWER CAMBRIAN – UPPER CAMBRIAN
	Urbana Formation	? LATE PROTEROZOIC ?
	Sugarloaf Mountain Quartzite	? LATE PROTEROZOIC ?
	Sams Creek Metabasalt	? LATE PROTEROZOIC ?
	Ijamsville Formation	? LATE PROTEROZOIC ?
	Marburg Schist	? LATE PROTEROZOIC ?
Fisher (1978)	Sams Creek Formation	? LOWER CAMBRIAN – UPPER ORDOVICIAN ?
	Ijamsville Phyllite	? LOWER CAMBRIAN – UPPER ORDOVICIAN ?
Edwards (1986, 1988, 1994)	Marburg Formation	LOWER CAMBRIAN – LOWER ORDOVICIAN
	Araby Formation	LOWER CAMBRIAN – LOWER ORDOVICIAN
	Ijamsville Formation	LOWER CAMBRIAN – LOWER ORDOVICIAN
	Urbana Formation	? LOWER CAMBRIAN – UPPER CAMBRIAN ?
	Sugarloaf Mountain Quartzite	? LOWER CAMBRIAN – UPPER CAMBRIAN ?
	Sams Creek Formation	LATE PROTEROZOIC
This study	Araby Formation	LOWER CAMBRIAN – MIDDLE CAMBRIAN
	Urbana Formation	? LOWER CAMBRIAN ?
	Sugarloaf Mountain Quartzite	? LOWER CAMBRIAN ?
	Ijamsville Phyllite	? LATE PROTEROZOIC – LOWER CAMBRIAN ?
	Marburg Formation	? LATE PROTEROZOIC – LOWER CAMBRIAN ?
	Sams Creek Formation	? LATE PROTEROZOIC – LOWER CAMBRIAN ?

ROCKS OF THE WESTMINSTER TERRANE

Sams Creek Formation

The Sams Creek Formation (Fisher, 1978) was named for exposures of greenstone (metabasalt) in the New Windsor quadrangle (fig. 1 on plate). Jonas and Stose (1938a) and Stose and Stose (1946) mapped all greenstone and interbedded chlorite, sericite, and chloritoid schist as Sams Creek Metabasalt. The Sams Creek Formation of Fisher (1978) consists of greenstone interlayered with chlorite phyllite and hematite-muscovite phyllite. The Sams Creek Formation as mapped by Edwards (1986, 1988, 1994) includes metabasalt, phyllite, and phyllitic metabasalt (undifferentiated), as well as quartzite and marble.

The Sams Creek Formation in the Urbana quadrangle consists of greenstone (ЄZscg), intermediate-composition metavolcanic and metavolcaniclastic schist (ЄZscf), muscovite-chlorite phyllite (ЄZscp), quartzite (ЄZscq), minor marble and calcareous metasiltstone (ЄZscm), and metasiltstone, phyllite, quartzite, and metagraywacke, undifferentiated (ЄZscu). Greenstone of the Sams Creek Formation is interlayered with different rock types that are interpreted to be in different thrust sheets. The western belt of the Sams Creek Formation consists of greenstone (ЄZscg) interbedded with quartzite (ЄZscq) and undifferentiated metasiltstone and metagraywacke (ЄZscu). The greenstone (ЄZscg) ranges from massive and porphyritic (chem. sample loc. 5) to a foliated rock that contains calcite filled amygdules (chem. sample loc. 9). Greenstone that contains abundant fist-sized nodules of epidosite is common along Fahrney Branch. Aphanitic, blue to gray metavolcanic schist that contains millimeter-wide, white quartz augen is interlayered with greenstone south of Fahrney Branch. It is intermediate in chemical composition (chem. sample loc. 6, table 2). Greenstone and flat-pebble metaconglomerate that contains greenstone clasts, north of State Route 80, appear to overlie calcareous quartzite and to underlie an undifferentiated suite of metasedimentary rocks in an antiform. The quartzite (ЄZscq) is massive and medium- to coarse-grained; the weathering of the calcite matrix and trough crossbeds give the rock a vuggy, porous texture. Thin beds of quartzite and metasiltstone, laminated phyllite, and metagraywacke interbedded with greenstone can be seen along Bennett Creek. These rocks superficially resemble some of the rocks of the Urbana Formation (Jonas and Stose, 1938a), but the Urbana Formation does not contain greenstone. Associated with the other metasedimentary rocks in the Sams Creek Formation are minor amounts of marble (north of the Baltimore and Ohio (B&O) tracks) and thin-bedded calcareous metasiltstone (along Fahrney Creek). The marble is pinkish-red and resembles the Wakefield Marble as seen in the Walkersville quadrangle to the north. Immediately west of the marble, phyllonites and mylonitic quartzite mark the trace of a thrust fault that was traced southward for 3.7 mi to Big Woods Road.

The eastern belt of Sams Creek Formation consists of greenstone overlain by and interbedded with muscovite-chlorite phyllite (ЄZscp) that is traced northward to the type locality of the formation (fig. 1 on plate). The phyllite is interbedded with quartz-muscovite schist and sparse quartzite that contains detrital potassium feldspar. The greenstone ranges from massive and porphyritic, as exposed west of Fountain Mills (chem. sample loc. 15), to strongly sheared and lineated, southeast of Monrovia. Primary layers that contain nodules of epidosite are exposed south of Bennett Creek. Intermediate-composition metavolcaniclastic schist is exposed along Fahrney Branch (chem. sample loc. 4) and intermediate-composition metavolcanic schist is exposed in the extreme northeast corner of the map area (chem. sample loc. 5).

Greenstone of the Sams Creek Formation is here considered correlative with metabasalt of the Late Proterozoic and Lower Cambrian Catoctin Formation (Mathews, 1905; Jonas, 1924; Edwards, 1986) of the Blue Ridge-South Mountain anticlinorium to the west (fig. 1 on plate). Metabasalt of the Catoctin Formation has a Rb-Sr whole-rock age of 570±36 Ma (Badger and Sinha, 1988), and a metarhyolite dike that cuts both Middle Proterozoic gneiss and a metadiabase dike in the Blue Ridge-South Mountain anticlinorium of northern Virginia has a U-Pb age of 571.5±5 Ma (Aleinikoff and others, 1995). These metavolcanic rocks are interpreted to reflect the continental rifting of Laurentia that resulted in the opening of the Iapetus Ocean (Rankin, 1976).

Major- and minor-element chemical data (table 2 and figs. 1 and 2) support the concept that the petrogenesis of the Sams Creek Formation is similar to that of the Late Proterozoic and Lower Cambrian Catoctin Formation. Greenstones of the Sams Creek and Catoctin Formations are mostly within-plate basalts on a Ti/100-Zr-Y×3 tectonomagmatic diagram (fig. 1*A*). Regardless of the metasomatic effects of greenschist-facies metamorphism, rocks of the Sams Creek and Catoctin Formations fall in virtually the same fields. Four samples of greenstone of the Sams Creek Formation from the New Windsor quadrangle (fig. 2 on plate) fall within the field of ocean floor basalt (Smith and Barnes, 1994). On an AFM projection (fig. 1*B*), the metavolcanic rocks have compositions indicative of continental tholeiitic basalts. The TiO_2 versus P_2O_5 diagram suggests that rocks of the Sams Creek Formation in the Urbana quadrangle are less differentiated than rocks of the Catoctin Formation (fig. 1*C*). The contents of TiO_2 (1.43–2.38 percent), MgO (2.55–13.3 percent), and P_2O_5 (0.21–0.37 percent) do not correspond to the distinct chemical suites of Late Proterozoic metadiabase dikes and metabasalt of the Catoctin Formation as described by Espenshade (1986) and Ratcliffe (1987), respectively. Some variations may be the result of metamorphic alteration as evidenced by masses of epidosite. Rare-earth-element (REE) plots of the metavolcanic rocks in the Urbana quadrangle (fig. 2*A*,*B*) show enriched light rare-earth elements with similar slopes; depletion of europium indicates fractionation of plagioclase in some samples of intermediate composition. The REE plots of the metavolcanic rocks of the Sams Creek Formation fall within the field of rocks of the Catoctin Formation (fig. 2*C*).

The metavolcanic rocks of the Sams Creek Formation may be distal lenticular flows and (or) sills fed by dikes or both. Alternatively, the greenstones were interpreted to record a constructive, island-building phase of Ordovician volcanic activity (Fisher, 1978). Edwards (1986, 1988, 1994) also correlates greenstone of the Sams Creek Formation with greenstone of the Catoctin Formation. He interprets the outcrops of Sams Creek Formation to be klippen of a regional nappe.

Table 2.—Major and minor element chemical analyses of Late Proterozoic(?) and Lower Cambrian(?) metavolcanic rocks of the Urbana, Md., quadrangle. Map sample numbers 1, 2, and 12–15 are from Richard Goldsmith (USGS, unpub. data)

[All analyses were performed at the U.S. Geological Survey, Reston, Va. Major-element values were determined by X-ray spectroscopy by D.F. Siems, J.S. Mee, C.S. Papp, T.R. Peacock, and Z.A. Brown. Minor-element values were determined by instrumental neutron activation analysis (INAA) by G.A. Wandless and J.N. Grossman]

	Ijamsville Phyllite			Sams Creek Formation												
	Greenstone (€Zig)			Intermediate-composition metavolcanic rocks (€Zscf)			Greenstone (€Zscg)									
Map no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Field no.	U108A	U108B	U13	U14	U42	U16	U18	U20	U32	U3	U4	U131	U134	U138	U146	U15
Lab no.	W-245373	W-245374	W-257238	W-257239	W-533751	W-257241	W-257242	W-257243	W-257244	W-256123	W-256124	W-245375	W-245376	W-245377	W-245378	W-257240
SiO_2	35.5	40.2	46.4	56.8	63.9	54.9	48.2	47.2	44.6	47.3	46.2	49.9	46.8	47.2	45.6	45.6
Al_2O_3	12.4	14.5	16.8	15.4	13.9	13.5	16.5	15.4	14.7	15.1	15.2	13.2	14.6	14.8	15.0	14.4
Fe_2O_3	2.9	6.22	2.31	.96	2.44	8.54	.01	4.24	9.52	2.57	7.10	5.04	5.89	6.53	4.85	1.10
FeO	5.67	2.76	7.20	4.62	1.94	4.20	10.5	7.90	5.12	8.4	6.40	5.91	7.31	5.83	7.98	9.82
MgO	8.17	4.66	9.56	5.95	2.55	3.02	7.49	9.45	6.66	9.23	6.34	6.61	8.08	7.31	7.83	13.3
CaO	17.5	17.8	6.93	5.24	6.31	5.89	7.23	5.21	6.67	7.68	6.99	10.9	6.66	8.56	9.86	5.42
Na2O	1.99	1.82	2.80	5.61	4.59	6.57	4.06	3.87	4.63	3.24	2.93	3.70	4.16	3.67	2.86	2.59
K_2O	1.19	1.91	1.05	1.05	.41	.25	.02	.13	.34	.17	2.04	.06	.32	.43	.1	.45
H_2O+	3.90	2.56	4.62	2.21	1.24	.77	4.72	3.92	3.41	4.7	3.40	2.52	3.74	3.48	3.82	5.57
H_2O-	.07	<.05	.21	<.05	.06	.06	.06	.09	<.05	.14	.22	<.05	<.05	.11	.05	.08
TiO_2	1.43	1.45	1.73	1.61	1.62	1.54	1.63	1.85	2.22	1.60	2.38	1.70	2.01	1.89	1.87	1.54
P_2O_5	.27	.29	.35	.26	.29	.28	.27	.28	.37	.23	.35	.24	.27	.30	.21	.32
MnO	.17	.11	.16	.11	.07	.14	.14	.15	.19	.21	.23	.31	.22	.23	.21	.18
CO_2	9.32	5.84	<.01	<.01	.10	<.01	<.01	< .01	1.51	<.01	< .01	.30	.10	< .01	.01	<.01
Total	100.48	100.17	100.13	99.88	99.42	99.67	100.84	99.70	99.99	100.5	99.79	100.44	100.21	100.35	100.25	100.38
Scandium	26.4	27.1	37.3	34.9	29.3	30.5	39.6	44.1	37.7	37.9	40.3	32.2	37.8	35	38.8	29.2
Chromium	335	333	531	292	213	194	156.1	175	252	160	84.6	208	265	247	131	684
Cobalt	40.8	23.9	41	30.3	31.4	28.5	37.1	49	48.9	46.3	44.5	43.6	55.2	46.9	45.3	60.9
Nickel	140	91	198	104	77	318	68	74	59	79	43	120	110	110	85	266
Zinc	79	49	63	45.6	28.4	37	60	87	86.4	95	114	84	110	100	97	62.9
Arsenic	<2	<1.1	2.77	8.6	1.9	<.9	1.6	4.5	2.8	<.7	1.1	<1.3	<1.4	<1.4	25	4.12
Selenium	–	–	<.9	<.8	<.09	<.9	<.9	1.1	<.9	<.6	<1	–	–	–	–	<.8
Rubidium	24	36	19.9	24.7	5.5	<4	<5	<30	9.9	8	46.4	<7	19	11	<8	17.2
Strontium	260	580	165	159	590	257	198	<160	400	393	410	340	370	580	310	215
Zirconium	160	110	<300	<220	110	127	115	220	185	138	150	<160	240	190	<50	147
Molybdenum	<2	<2	<5	<5	<3	<8	<8	<8	<9	<5	<6	<2	<2	<2	<2	<6
Antimony	<.14	<.13	<.09	<.1	<.2	<.09	.21	.17	.12	<.1	<.3	<.16	<.18	<.16	.31	<.2
Cesium	.38	.66	.27	.46	.23	.25	< .2	< .3	.27	< .2	.79	< .23	<.25	.29	< .25	.19
Barium	300	470	293	668	187	105	<90	111	118	236	830	<120	95	120	99	348
Lanthanum	15	18.3	21.4	12.7	16.3	10.44	9.88	10.6	20.1	10.8	15.4	9.2	12	14	9.2	18.6
Cerium	29.8	33.5	41.9	25.7	30.8	22.4	20.1	23.6	41.5	22.5	33.7	21.2	26	28.1	20	37
Neodymium	15	17	20.5	17.1	18.4	13.7	14.9	15.3	23.2	13.0	19.0	14	17	18	13	18.5
Samarium	3.64	3.84	5.31	5.0	5.03	4.14	4.24	4.98	6.08	4.14	5.99	3.79	4.84	4.74	4.11	4.32
Europium	1.16	1.28	1.46	1.31	1.57	1.24	1.43	1.22	1.96	1.38	1.91	1.15	1.60	1.54	1.43	1.30
Terbium	.58	.66	.860	.850	.80	.717	.80	.90	1.033	.82	1.15	.72	.92	.89	.82	.65
Ytterbium	2.0	2.2	2.75	2.79	2.50	2.30	2.93	3.14	3.34	3.05	4.10	2.5	3.3	2.8	2.7	2.00
Lutetium	.27	.34	.392	.393	.354	.312	.389	.455	.485	.40	.559	.37	.47	.44	.41	.253
Hafnium	2.32	2.41	3.26	2.77	2.76	2.52	2.77	3.13	3.99	2.69	3.86	2.70	3.16	3.10	2.70	2.54
Tantalum	1.5	1.51	1.97	1.25	1.22	.967	.916	1.001	1.65	.92	1.32	.95	1.10	1.20	.81	1.90
Gold	25	4	<5	<4	<9	<5	<4	<5	<8	<5	<5	9.00	4.00	4.00	3.00	<4
Thorium	1.80	1.80	2.37	1.46	1.50	1.09	1.05	1.19	1.90	.98	1.38	1.00	1.30	1.40	.84	2.17
Uranium	.48	.36	.55	.34	.51	<.3	.55	< .7	.62	.26	.36	<.30	.31	.40	.21	.47

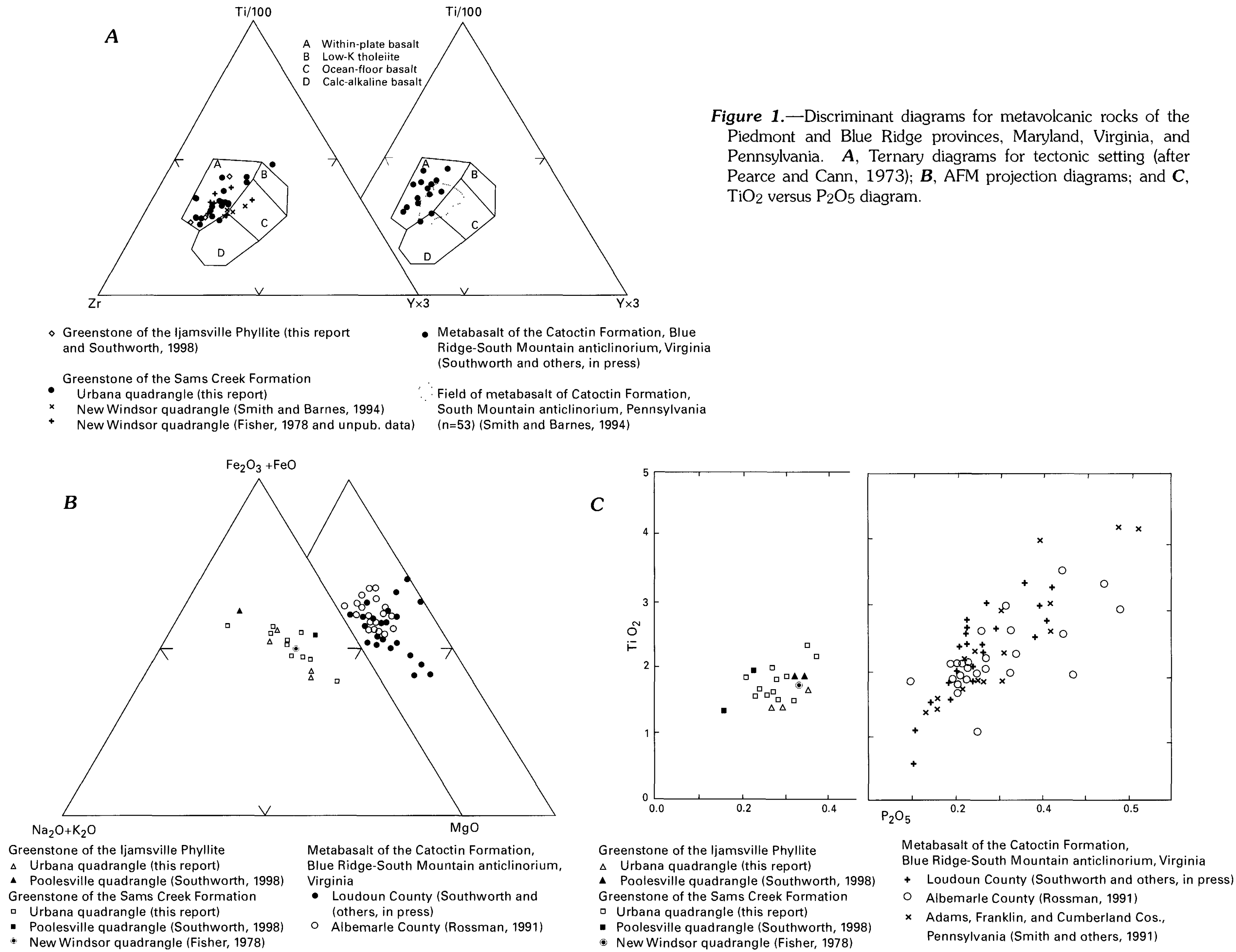

Figure 1.—Discriminant diagrams for metavolcanic rocks of the Piedmont and Blue Ridge provinces, Maryland, Virginia, and Pennsylvania. ***A***, Ternary diagrams for tectonic setting (after Pearce and Cann, 1973); ***B***, AFM projection diagrams; and ***C***, TiO_2 versus P_2O_5 diagram.

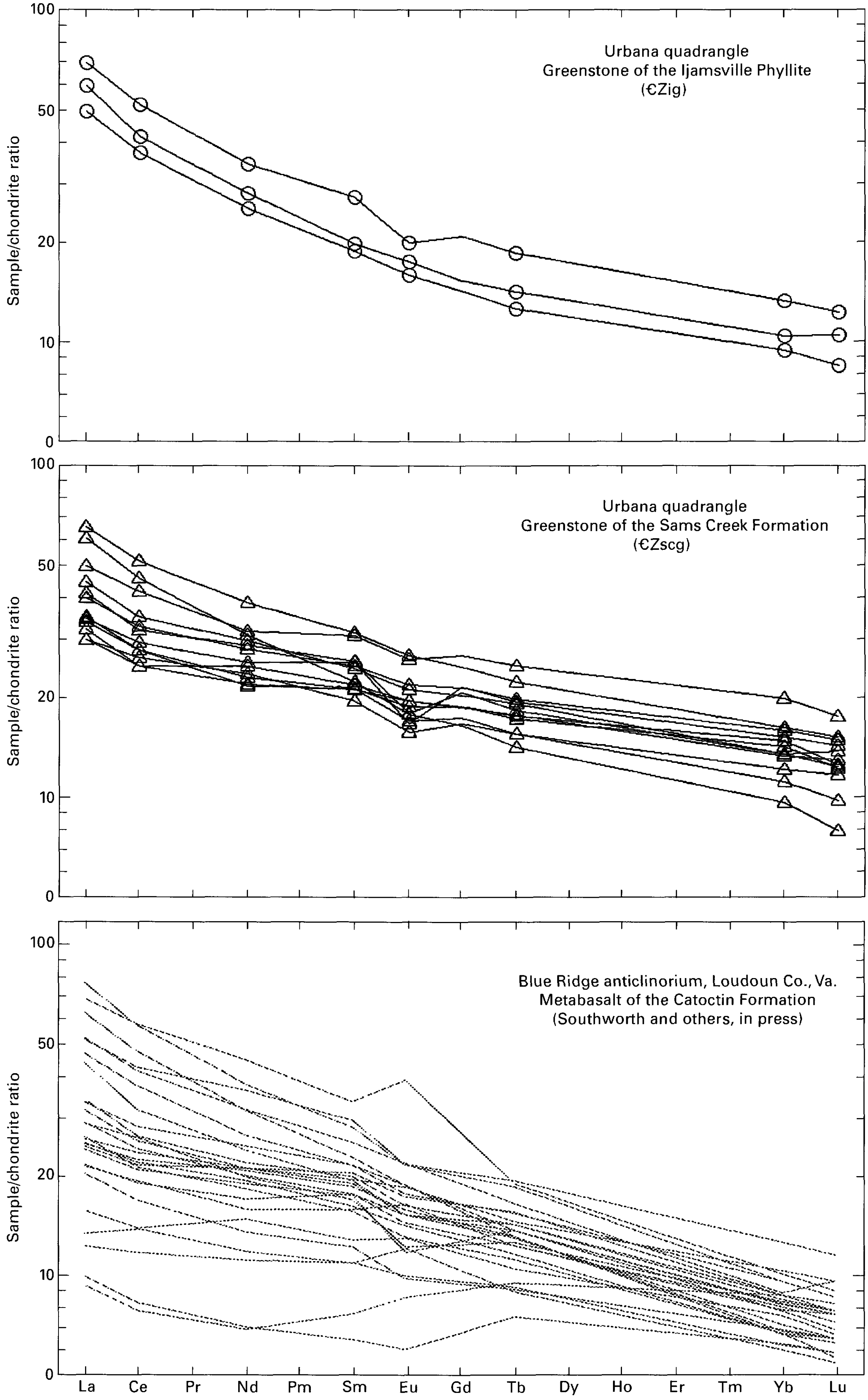

Figure 2.—Chondrite-normalized, rare-earth-element (REE) plots of metavolcanic rocks from the Piedmont and Blue Ridge provinces, Maryland and Virginia. REE's determined by instrumental neutron activation analysis. Analyses by G.A. Wandless and J.N. Grossman, U.S. Geological Survey, Reston, Va.

Ijamsville Phyllite

The Ijamsville Phyllite (Jonas and Stose, 1938b) was named for blue, green, and purple phyllitic slate west and east of Ijamsville, Md. (fig. 1 on plate). In decreasing abundance, rocks mapped in the Ijamsville Phyllite are phyllite, phyllonite, and slate (undifferentiated) (€Zi), greenstone (€Zig), quartzite (€Ziq), and limestone and calcareous quartzite (€Zim). The muscovite-chlorite-paragonite-chloritoid phyllite at some places is characterized by composite foliations, abundant vein quartz that is strongly folded and transposed, and polymetamorphism. Virtually the entire map area of the Ijamsville Phyllite is a zone of thrust faulting.

The phyllonites have a greasy sheen with dull green clots and patches of retrograde chlorite. These rocks are well exposed northwest of Ijamsville opposite the "Sanitarium," west of Green Valley on the north side of Bennett Creek, and north of Little Bennett Creek, west of Hyattstown.

Where these rocks are less deformed they are slates that have been quarried for roofing material since the 1880's (Dale and others, 1914). Abandoned slate quarries were found east and west of Ijamsville, north of Ball Road, and north of the Frederick and Montgomery County line on the south side of Little Bennett Creek (Slate Quarry Road). Bedding is locally seen as fine laminations of opaque minerals and (or) quartz in the slates. The dark-reddish-purple color of the Ijamsville Phyllite results from abundant minute crystals of hematite.

A distinctive metaconglomerate of matrix-supported flat chips of muscovite-phyllite occurs immediately west of the Bush Creek window north of the B&O railroad tracks. The matrix contains a suite of detrital heavy minerals that include zircon, ilmenite, magnetite, sphene, tourmaline, and rutile. The protolith of this dense rock is interpreted to have been a submarine debris flow. The metamorphosed platy rip-up clasts of mudstone are aligned within an unsorted matrix of detrital heavy minerals.

Greenstone is interlayered with phyllite in the Ijamsville Phyllite from Route 109 to east of Centerville. The greenstone is aphanitic to medium grained, has a subophitic texture, and consists of quartz, epidote, plagioclase, actinolite, chlorite, calcite, and titanite. These schistose rocks are strongly sheared and contain nodules of epidosite. North of Little Bennett Creek, the greenstone is interlayered with purple phyllite on the scale of 3.9 in. in pavement outcrops in an old road bed. Locally, the greenstone is interlayered with massive quartzite that contains detrital orthoclase and zircon. Greenstone is best seen north of Bennett Creek, and quartzite beds can be seen west of Route 109. This belt of greenstone was traced southward for 6 mi into the Poolesville quadrangle (Southworth, 1998).

The hematite-rich phyllite in the Ijamsville Phyllite is interpreted to have been originally mud deposited in quiet (deep?) water on the slope (fig. 2 on plate). Chemical data (fig. 3) of phyllites show that the ratio of K_2O to total alkalies differs and may reflect different source areas of the parental muds (Fisher, 1978) or the result of a volcanic component (Clark, 1924). Lenses of quartzite and greenstone reflect the influx of channel deposits and volcanism. The hematite and color of the rock is derived from oxidized source material and rapid burial in a quiet marine environment before reduction, as suggested by Ziegler and McKerrow (1975). The Ijamsville Phyllite lithologically resembles some of the phyllite of the Lower Cambrian Loudoun Formation that locally overlies the Catoctin Formation in the Blue Ridge-South Mountain anticlinorium. Some phyllite of the Loudoun Formation is interpreted to be genetically related to Catoctin volcanism (Southworth, 1991) because it contains flattened amygdules, epiclastic volcanic debris, and is interlayered with thin sills of greenstone. Although the Ijamsville Phyllite contains greenstone, there is no evidence in Montgomery County, Md., (Hopson, 1964) that the phyllites are volcanic in origin as Stose and Stose (1946) interpreted the phyllites in Frederick County, Md., to be. To the north in the Walkersville quadrangle, rocks of the Ijamsville Phyllite contain flattened vesicles and epidote and are interpreted to be related to volcanism (Scott Southworth, unpub. data). Greenstone interlayered with Ijamsville Phyllite also was recognized by Fisher (1978) in the New Windsor quadrangle, and the chlorite phyllite unit of his Ijamsville Phyllite contained volcaniclastic debris. The interlayering of the greenstone and phyllite of the Ijamsville Phyllite in the Urbana quadrangle is here interpreted to be parastratigraphic although modified by folding and shearing, as opposed to constituting klippen as envisioned by Edwards (1986, 1988, 1994). The greenstone is interpreted to be distal flows and (or) dikes and sills of metabasalt in a marine mud.

Marburg Formation

The Marburg Formation (€Zmb) (Drake, 1994) (Marburg Schist of Jonas and Stose, 1938b) consists of a complex assemblage of phyllite, metasiltstone containing quartz ribbons, and quartzite (€Zmbq) that are largely undifferentiated due to intensive deformation. Quartz-sericite-chlorite phyllite containing 0.04-in-long crystals of chloritoid and albite

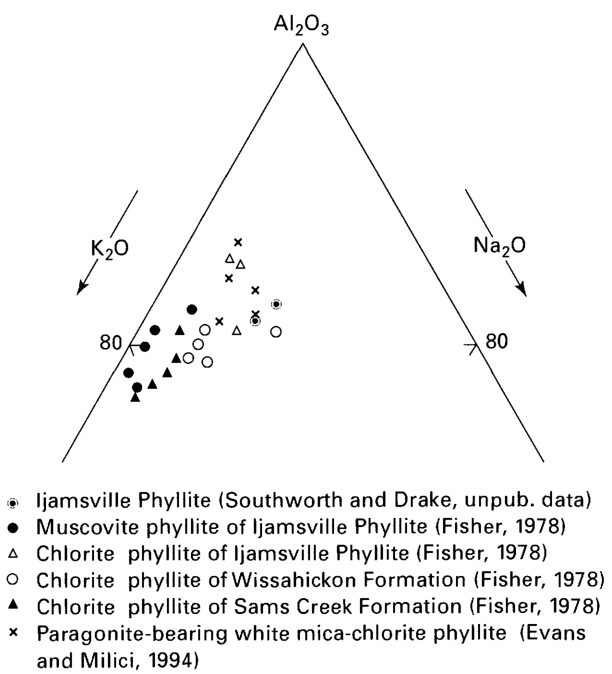

Figure 3.—Portion of an Al_2O_3-K_2O-Na_2O plot for phyllites in the Westminster terrane of Maryland (Fisher, 1978; Scott Southworth and A.A. Drake, Jr., unpub. data) and phyllite on the southeastern limb of the Blue Ridge anticlinorium in central Virginia (Evans and Milici, 1994).

porphyroblasts, tan to green metasiltstone containing quartz ribbons 0.04- to 0.08-in-thick, and the lack of metavolcanic rocks distinguish this unit from the fine-grained rocks of the Sams Creek Formation and Ijamsville Phyllite. These rocks are here called Marburg Formation because of their lithologic similarity to those in southern Pennsylvania (A.A. Drake, Jr., U.S. Geological Survey, and Scott Howard, University of Delaware, oral commun., 1992). Similar rocks were assigned to the Wissahickon Formation by Fisher (1978) and the Gillis Formation and Gillis Group by Edwards (1986, 1994).

Metasiltstone containing quartz ribbons is interbedded with medium- to coarse-grained quartzite in the Marburg Formation in Little Bennett Regional Park, east of Hyattstown. The metasiltstone with quartz ribbons is interpreted to be turbidites. As opposed to the quartzite layers in the Sams Creek Formation and Ijamsville Phyllite, the quartzite in the Marburg Formation is coarser grained and green due to chlorite content. One sample contains detrital orthoclase. The distinctive chloritoid phyllite is best seen along a tributary east of Beall Road in the Little Bennett Regional Park, north of Kingsley. The chloritoid is the manganese-rich variety called ottrelite (Stose and Stose, 1946) that has zoned prismatic crystals that are visible to the naked eye. These rocks were traced from Clarksburg northeastward to Bennett Creek.

Stratigraphic relations of the Marburg Formation are problematic. Like the Ijamsville Phyllite, rocks of the Marburg Formation constitute a fault zone characterized by transposition foliation, retrogressive phyllonites, and polydeformed vein quartz. The Marburg Formation is interpreted to be thrust onto rocks of the Sams Creek Formation. Map-scale overturned folds of Ijamsville Phyllite and Marburg Formation southeast of Hyattstown were traced from the Germantown quadrangle (A.A. Drake, Jr., oral commun., 1994). The direction of closure is undetermined but the Ijamsville Phyllite is interpreted to be above rocks of the Marburg Formation (A.A. Drake, Jr., oral commun., 1994). Sparse purple and blue muscovite-paragonite phyllite, too small to map within the Marburg Formation, is similar to rocks in the Ijamsville Phyllite. Because the Marburg Formation contains some rocks that are similar to the Ijamsville Phyllite, rocks of the Marburg Formation are interpreted to be deepwater rise deposits that are beneath and distal to the Ijamsville Phyllite (fig. 3).

LOWER CAMBRIAN(?) ROCKS OF THE SUGARLOAF MOUNTAIN ANTICLINORIUM AND BUSH CREEK WINDOW

Sugarloaf Mountain Quartzite

The Sugarloaf Mountain Quartzite (Ꞓsq) (Jonas and Stose, 1938b) was named for Sugarloaf Mountain in the adjacent Buckeystown quadrangle (figs. 1 and 2 on plate). It is a medium-bedded to massive, saccharoidal, white quartzite with medium to coarse grains of quartz sand cemented by silica with sericite. Dark-blue to black, laminated siltstone and phyllite are interbedded with the quartzite. The laminated siltstone is lithologically similar to rocks of the Urbana Formation that conformably overlie the highest quartzite. The quartzite contains detrital sphene, tourmaline, zircon, and ilmenite, and characteristic clots of hematite after magnetite(?). These rocks can be seen on the ridge west of Thurston.

The base of the Sugarloaf Mountain Quartzite is not exposed. The Sugarloaf Mountain Quartzite is correlated with quartzites of the Lower Cambrian Weverton Formation of the Chilhowee Group on the limbs of the Blue Ridge-South Mountain anticlinorium (fig. 1 on plate). The Weverton Formation ranges in thickness from 100 to 600 ft (Southworth and others, in press), whereas the Sugarloaf Mountain Quartzite is more than 800 ft thick (Southworth and Brezinski, in press).

Urbana Formation

Rocks of the Urbana Formation (Ꞓu) (Edwards, 1986) (Urbana Phyllite of Jonas and Stose, 1938b) (fig. 2 on plate) lie conformably above the Sugarloaf Mountain Quartzite. The rocks east of Ijamsville are interpreted to be rocks of the Urbana Formation that are exposed in the Bush Creek window through the Martic thrust fault at the base of the Ijamsville thrust sheet.

The Urbana Formation contains a wide variety of metasedimentary rocks that include, in decreasing abundance, metasiltstone and metagraywacke (Ꞓu), calcareous sandstone and quartzite (Ꞓuq), and marble (Ꞓul). In general, these rocks are poorly exposed because of the deep regolith of the decomposed calcareous and sandy strata. However, good outcrops can be seen along Bush and Bennett Creeks.

The calcareous sandstone and quartzite unit (Ꞓuq) of the Urbana Formation is lensoidal and discontinuous and is difficult to trace in the field. The calcareous sandstone is medium- to coarse-grained quartz sand in a clay-rich matrix that contains abundant crystals and seams of calcite. The rock is characteristically friable, contains many vugs, and is best seen in the footwall of a thrust fault north of Thurston. The quartzite consists of medium- to coarse-grained quartz and polycrystalline quartz lithic clasts cemented by silica; accessary detrital minerals include zircon, magnetite, orthoclase, perthite, plagioclase, and ilmenite. The quartzite is best seen at Thurston and east and west of Ijamsville. The detrital minerals in the metagraywacke and metasiltstone are saussurite, calcite, orthoclase, tourmaline, and olivine(?). At many places, concentrations of the heavy minerals define bedding, as is seen in the creek along Sugar Loaf Road as well as along Bush and Bennett Creeks. The marble contains sericite, chlorite, graphite, and detrital quartz, zircon, microcline, plagioclase, and orthoclase. This rock unit is best seen south of Interstate 270 along Bennett Creek and along Bush Creek, east of Ijamsville.

Rocks of the Urbana Formation are correlated with lithologically similar metasiltstone, metasandstone, and limy metashale of the Lower Cambrian Harpers Formation of the Chilhowee Group in the Blue Ridge-South Mountain anticlinorium (Scotford, 1951). Rocks of the Urbana Formation are crossbedded with ripple marks as first recognized by Hopson (1964) and are interpreted to be continental margin deposits.

LOWER AND MIDDLE CAMBRIAN ROCKS OF THE FREDERICK VALLEY SYNCLINORIUM

Araby Formation

The Lower and Middle Cambrian Araby Formation (Ꞓa) (Reinhardt, 1974, 1977) consists predominantly of argillaceous, burrowed, mottled metasiltstone that contains sandy intervals.

The type locality is immediately east of the quadrangle along Bush Creek in the Buckeystown quadrangle (fig. 1 on plate) in the footwall of the Martic thrust fault. Rocks of the Araby Formation are restricted to the extreme northwestern corner of the Urbana quadrangle. The metasiltstone is highly cleaved and jointed, and the bedding is obscured. Where the Araby Formation is tightly folded with the Frederick Limestone to the north, a classic Valley and Ridge topography is developed.

The metasiltstone consists predominantly of quartz grains, polycrystalline quartz, and opaque minerals that are supported by a clay-rich matrix containing abundant hematite. Sericite, chlorite, magnetite octahedra, sphene, zircon, microcline, sanidine, and plagioclase are accessory grains. Rocks of the Araby Formation have been interpreted to be a deepwater slope facies of a starved clastic basin that persisted in the Cambrian (Reinhardt, 1977). It is conformably overlain by carbonate rocks of the Frederick Limestone (Southworth and Brezinski, in press). The Araby Formation is correlative with rocks of the Lower Cambrian Antietam Formation of the Chilhowee Group of the Blue Ridge-South Mountain anticlinorium. The base of the Araby Formation is not exposed. Rocks of the Araby Formation are interpreted to overlie the Urbana Formation based on regional correlations because the two units are not in contact.

MESOZOIC ROCKS

Diabase Dikes

Near-vertical, en-echelon, north-trending diabase dikes (Jd) are interpreted to have been emplaced at about 200 Ma (Kunk and others, 1992) during continental rifting that led to the opening of the Atlantic Ocean. The diabase is dense, resistant, and weathers to large spheroidal boulders aligned along ridges. The swarm of diabase dikes that transects the northwest corner of this quadrangle near Reels Mill has been traced for 106 mi from Fauquier Co., Va., to Emmitsburg, Md. (J.P. Smoot, A.J. Froelich, and R.E. Weems, unpub. data).

STRUCTURAL GEOLOGY

In the Urbana quadrangle, an imbricate stack of thrust sheets of polydeformed and polymetamorphic rocks of the Westminster terrane are interpreted to have been thrust on parautochthonous rocks of the Sugarloaf Mountain anticlinorium and Frederick Valley synclinorium along the Martic thrust fault (A.A. Drake, Jr., oral commun., 1989; Horton and others, 1989; Rankin and others, 1989). In this interpretation, the Martic thrust sheet was folded with rocks of the anticlinorium, and erosion has exposed the Sugarloaf Mountain Quartzite and Urbana Formation in fensters (windows) (fig. 1 on plate). Rocks of the Sugarloaf Mountain anticlinorium, Bush Creek window, and Frederick Valley synclinorium are considered to be Laurentia, and they contain evidence of only one phase of folding and axial planar cleavage development. The overlying Westminster terrane rocks, that are interpreted to be allochthonous, contain more cleavages and fold phases. Contractional motion of some faults in the Westminster terrane has been interpreted to have occurred in the Ordovician Taconic orogeny (Horton and others, 1989). These faults later experienced thrust and dextral strike-slip motion in the late Paleozoic (Pennsylvanian?) Alleghanian orogeny. Because the geology is complex and controversial, an interpretative sequence of cross sections (fig. 3 on plate) portrays this model.

Structural elements in the rocks include bedding, schistosity and cleavage, transposition foliation, crenulation cleavage, mineral lineations, intersection lineations, folds, and faults. These elements are discussed below by terrane and geographic location. Figure 4 (on plate) shows stereonets of the dominant foliations in the rock formations. In summary, bedding, cleavage, and bedding-cleavage intersections of the Sugarloaf Mountain Quartzite and Urbana Formation support one phase of folding. Cleavage in these parautochthonous rocks is generally coplanar to transposition foliation and composite schistosity in the allochthonous rocks. However, the crenulation cleavage in the allochthonous rocks is interpreted to be synchronous with the cleavage in the parautochthonous rocks. The F_2 folds of foliations and vein quartz in the allochthonous rocks of the Westminster terrane show various orientations that define fault blocks.

ALLOCHTHONOUS ROCKS OF THE WESTMINSTER TERRANE

Allochthonous, polydeformed, and polymetamorphic rocks of the Westminster terrane constitute an imbricate thrust system that is floored by the Martic thrust fault. In the map area, the Westminster terrane can be divided into at least four major lithotectonic units that are separated by thrust faults. The thrust sheets were defined by deformation fabric in distinctive lithologies, domains of different fold orientations (fig. 4 on plate), map patterns of units, and the truncation of subunits. The Ijamsville Phyllite (west and east belts), the Sams Creek Formation, and the Marburg Formation are lithotectonic units that constitute the thrust sheets from west to east.

Martic Thrust Fault

The Martic thrust fault (Jonas, 1924, 1927; Knopf and Jonas, 1929) has brought the Ijamsville Phyllite onto rocks of the Urbana and Araby Formations and Frederick Limestone. The tip of the Martic thrust fault has a straight trace from the Potomac River (Southworth, 1998) northward to the Gettysburg basin (Edwards, 1988) suggesting a steep attitude at the surface (fig. 1 on plate). The Martic is folded, and erosion has exposed rocks interpreted to be footwall rocks in tectonic windows. On the west limb of the Sugarloaf Mountain anticlinorium, the Martic was reactivated as rocks of the Urbana Formation overrode the Ijamsville Phyllite during formation of the anticlinorium. On the east limb of the anticlinorium, the tip of the Martic has a more sinuous trace and truncates units in both the hanging wall and footwall blocks. The trace of the fault southeast of Urbana suggests a westward-verging parasitic fold on the Sugarloaf Mountain anticlinorium. The Bush Creek window and "bottleneck" in the Sugarloaf Mountain anticlinorium (near Ball Road) result from erosion of southwest-plunging folds as shown by bedding-cleavage intersections (fig. 4 on plate). The Martic thrust fault is interpreted to be a Taconic thrust fault by Horton and others (1989). The linear trace of the fault suggests that it was contractionally reactivated during the Alleghanian orogeny.

The dominant structure in the Ijamsville Phyllite is a composite foliation that consists of mostly a transposition foliation that is overprinted with phyllonitic foliation, schistosity, and several generations of cleavage. Vein quartz that has impregnated the rock has been sheared, transposed, and folded into steeply plunging isoclines. The transposition foliation and folded vein quartz were deformed by westward-verging inclined F_2 folds with plunges that range from steep to gentle, in all directions (fig. 7). These folds have attendant northeast-dipping axial-planar, pressure-solution crenulation cleavage. Bedding is only seen as laminae in phyllite and slate and as concentrations of heavy minerals in quartzite. Rocks of the Ijamsville Phyllite constitute a fault zone. The least deformed rocks are slates seen in abandoned quarries.

Barnesville-Monrovia Thrust Fault

Greenstone and muscovite-chlorite phyllite of the eastern belt of the Sams Creek Formation were thrust onto the Ijamsville Phyllite along the Barnesville-Monrovia thrust fault. Rocks of the Sams Creek Formation were overridden by rocks of the Marburg Formation to the east. Phyllonitic Ijamsville containing abundant isoclinal folds of vein quartz underlie a ridge in the footwall until it is truncated to the north. The hanging-wall strata are poorly exposed in a linear swale. Greenstone of the Sams Creek Formation is structurally aligned parallel to the trace of the fault. An outcrop of Wakefield Marble in the hanging wall of the Barnesville-Monrovia thrust fault to the north in the Walkersville quadrangle (Scott Southworth, unpub. data) suggests that locally the scarp may be accentuated by a karst valley. The fault trace is straight for more than 16 mi and suggests a steep attitude. At Monrovia, rocks of the Sams Creek Formation are strongly sheared to phyllonites, and greenstone is structurally aligned parallel to the transposition foliation along a subsidiary fault. East and southeast of Monrovia, sheath folds of greenstone plunge moderately to the south-southeast (fig. 4 on plate). The map pattern of the greenstone is a cross section of the F_2 folds. The sheath folds formed in a zone of high strain in a duplex between the bounding thrust faults.

Hyattstown Thrust Fault

The Hyattstown thrust fault has brought rocks of the Marburg Formation onto rocks of the Sams Creek Formation. The Hyattstown thrust fault has a straight trace over a distance of 27 mi and appears to have regional significance. It has minor greenstone in its hanging wall in the Libertytown (Edwards, 1994), New Windsor (Fisher, 1978), and Damascus (A.A. Drake, Jr., oral commun., 1993) quadrangles, but no greenstone was found in rocks of the Marburg Formation in the Urbana quadrangle or to the south in the Poolesville quadrangle (Southworth, 1998). The Hyattstown thrust fault mostly rides in phyllonite of the Sams Creek Formation, but it cuts greenstone of the Sams Creek Formation between Hyattstown and Green Valley. The dominant foliation in the hanging-wall rocks of the Marburg Formation is a transposition foliation. Bedding is sparse and randomly oriented (fig. 4 on plate) due to folding events. The transposition foliation and schistosity are folded by westward-verging inclined and recumbent folds. Crenulation cleavage is axial planar to F_2 folds that plunge steeply and gently to the northeast and southwest (fig. 4 on plate). The entire map unit is a fault zone. Exposures along Little Bennett Creek suggest a thrust fault every 10 ft or so, but only seven intraformational thrust faults are shown on the map.

PARAUTOCHTHONOUS ROCKS OF LAURENTIA

Rocks of the Sugarloaf Mountain anticlinorium, Bush Creek window, and Frederick Valley synclinorium have experienced a history of deformation and metamorphism similar to that of the Blue Ridge-South Mountain anticlinorium. These rocks are structurally and stratigraphically discordant to rocks of the Westminster terrane. In general, the Sugarloaf Mountain anticlinorium and Frederick Valley synclinorium constitute a system of west-verging folds subsidiary to the Blue Ridge-South Mountain anticlinorium (figs. 1 and 3 on plate).

Sugarloaf Mountain Anticlinorium

Scotford (1951) and Thomas (1952) demonstrated that Sugarloaf Mountain and environs constitutes a regional doubly plunging anticlinorium that is overturned to the west. An anticline-syncline-anticline triplet constitutes the north-plunging nose of the anticlinorium west of Thurston. The folded beds of Sugarloaf Mountain Quartzite are cut by normal faults that are interpreted to be Mesozoic in age (Southworth, 1998).

The Sugarloaf Mountain Quartzite and rocks of the Urbana Formation have a cleavage that is axial planar to a single phase of folds that constitute the Sugarloaf Mountain anticlinorium (fig. 4 on plate). The most distinctive features of the rocks of the Urbana Formation are bedding, one cleavage, and a conspicuous bedding-cleavage intersection lineation. Folds of the Urbana Formation are disharmonic to folds of the Sugarloaf Mountain Quartzite. The map pattern of quartzite beds in the Urbana Formation east of Urbana defines folds verging westward up the limb of the anticlinorium. These folds are cut by at least one intraformational thrust fault. Bedding-cleavage intersection lineations in the rocks of the Urbana Formation plunge to the northeast away from Sugarloaf Mountain and southwest away from Bush Creek (fig. 4 on plate).

Frederick Valley Synclinorium

Cambrian and Lower Ordovician rocks underlie the Frederick Valley in an asymmetrical synclinorium (Reinhardt, 1974) on the east limb of the Blue Ridge-South Mountain anticlinorium. Highly cleaved metasiltstone of the Araby Formation north of the B&O railroad tracks in the northwest corner of the map area is in an anticline that plunges to the northeast. The folds on the east limb of the synclinorium are upright to westwardly overturned and are accompanied by a steep axial-planar cleavage.

METAMORPHISM

WESTMINSTER TERRANE

Rocks of the Westminster terrane have had a complex metamorphic history under greenschist-facies conditions. Phyllites in the Ijamsville Phyllite as well as the Sams Creek and Marburg Formations contain varying proportions of muscovite-chlorite-paragonite-quartz-magnetite and calcite, of a first metamorphic event. Greenstone of the Sams Creek Formation and Ijamsville Phyllite contain varying proportions of actinolite, epidote, and stilpnomelane. Quartzites contain sericite and chlorite. In fault zones, the phyllites have been retrogressively metamorphosed and sheared into phyllonitic diaphthorites (Knopf, 1931). Such rocks are characterized by "sick-looking" (Knopf, 1931) retrograde chlorite and recrystallized quartz. Abundant leucoxene in these rocks also suggests retrogressive metamorphism (Stose and Stose, 1946; Scotford, 1951; Hopson, 1964). Phyllites of the Marburg Formation and Ijamsville Phyllite locally contain chloritoid or albite of a later prograde metamorphic event that overgrows the early foliation. Static chloritoid increases in size and abundance to the southeast. The transposition foliation and static chloritoid is cut and rotated by a pressure-solution crenulation cleavage of subgreenschist-facies conditions.

ROCKS OF THE SUGARLOAF MOUNTAIN ANTICLINORIUM, BUSH CREEK WINDOW, AND FREDERICK VALLEY SYNCLINORIUM

The Sugarloaf Mountain Quartzite and rocks of the Urbana Formation are at chlorite grade from a single greenschist-facies metamorphic event. The matrix of the quartzites is rich in sericite and contains sparse chlorite porphyroblasts. Cleavage in metagraywacke and metasiltstone of the Urbana Formation is marked by aligned minute sericite crystals. The metasiltstone rocks contain abundant chlorite porphyroblasts that locally give them a green hue.

Rocks of the Araby Formation contain sparse tiny crystals of sericite and minor chlorite porphyroblasts, both of which are crudely aligned in the cleavage.

TECTONIC HISTORY

The interpreted tectonic history of this region is summarized in figure 3 (on plate). Isoclinal folds and attendant schistosity formed under prograde greenschist-facies conditions that formed muscovite, chlorite, paragonite, quartz, magnetite, and calcite in phyllites, and actinolite, epidote, and stilpnomelane in greenstone during the Westminster deformation phase (D_1). Folding, transposition of bedding into schistosity and cleavage, phyllonitization, and ductile thrust faulting formed in a continuum (Knopf, 1931; Howard, 1994). Fluids entered along faults and impregnated the phyllitic rocks with veins of quartz. The rise-slope rocks of the Ijamsville Phyllite were emplaced onto the continental margin strata (fig. 3*A* on plate) along the Martic thrust fault (fig. 3*B* on plate). Because only the Ijamsville Phyllite makes up the thrust sheet, perhaps it was detached from its underlying strata, which are interpreted to be rocks of the Sams Creek Formation. Rocks of the Sams Creek Formation were later transported along out-of-sequence thrust faults.

Sugarloaf Mountain deformation (D_2) is named for the Sugarloaf Mountain anticlinorium. The deformation produced westward overturned folds and minor thrust faults. The Martic thrust sheet was folded during this deformation phase, which is interpreted to have formed the Blue Ridge-South Mountain anticlinorium and Frederick Valley synclinorium. In the parautochthonous rocks of the Sugarloaf Mountain Quartzite, Urbana Formation, and Araby Formation, cleavage is marked by chlorite and sericite, whereas the allochthonous rocks of the Westminster terrane contain a late pressure-solution cleavage. In this interpretation, the Sugarloaf Mountain deformation was an Alleghanian event. During Alleghanian deformation, the Martic thrust fault was reactivated as a thrust that results in the regional linear trace of the fault. Further contractional deformation locally produced southwest-verging, southeast-plunging F_2 folds and the northwest-striking, attendant pressure-solution cleavage in the Martic thrust sheet that may be related to late dextral strike-slip motion.

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