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Stratigraphic Notes, 1993

By AVERY ALA DRAKE, Jr., and LOUIS PAVLIDES

U.S. GEOLOGICAL SURVEY BULLETIN 2076

Two short papers propose changes in stratigraphic nomenclature in Maryland and Virginia

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1994

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CONTENTS

(Letters indicate the chapter)

Chapter A

The Soldiers Delight Ultramafite in the Maryland Piedmont

By Avery Ala Drake, Jr.

STRATIGRAPHIC NOTES, 1993

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CONTENTS

FIGURES

TABLE

The Soldiers Delight Ultramafite in the Maryland Piedmont

By Avery Ala Drake, Jr.

ABSTRACT

The Soldiers Delight Ultramafite is a 29 km-long, tadpole-shaped thrust sheet in the central Appalachian Piedmont of Maryland. It is a horse between the underlying Loch Raven Schist of the Loch Raven-Laurel tectonic motif and the Sykesville Formation of the Mather Gorge-Sykesville tectonic motif. It was plucked from a footwall ramp somewhere to the east of its present position.

Most of the ultramafite is serpentinized pyroxenite. Geochemically, the pyroxenite is enstatolite. Much of this rock has been further metasomatically altered to soapstone and talc schist. The most northeastern part of the rock body is serpentinized dunite that contains podaform chromite bodies that were exploited in the past. The Soldiers Delight also contains some metagabbro.

The pyroxenite of the Soldiers Delight differs geochemically from those in the Baltimore Complex of the Maryland Piedmont and the Piney Branch Complex of the northern Virginia Piedmont. It also differs from the ultramafic blocks in the Mather Gorge Formation of the northern Virginia-Maryland Piedmont, which are mostly serpentinized harzburgite. It is unlikely that all these ultramafic rocks had a common source, as was previously suggested.

INTRODUCTION

Ultramafic rocks are abundant in the Maryland and northern Virginia Piedmont (fig. A1). Most of these rocks occur in blocks interpreted as olistoliths within rocks of the Mather Gorge-Sykesville and the Loch Raven-Laurel tectonic motifs. Other bodies are part of the Baltimore Complex. These tectonic motifs also contain many other bodies of ultramafic and related mafic rocks that are too small to show at the scale of figure A1. Ultramafic and related mafic rocks also constitute two thrust sheets, (1) the Piney Branch Complex (Drake and Morgan, 1981) of the Piney Branch-Yorkshire tectonic motif and (2) the Soldiers Delight Ultramafite, the subject of this paper (fig. A1). All these rocks were interpreted as fragments of the Baltimore Complex by Morgan (1977). Drake and Morgan (1981) reinterpreted these rocks as being fragments of a very large central Appalachian ophiolite. This paper describes the Soldiers Delight Ultramafite and its tectonic setting, and compares it with other ultramafic rocks in central Maryland and northern Virginia.

REGIONAL GEOLOGY

The regional geology of the Maryland Piedmont in the area of the Soldiers Delight Ultramafite is generalized in figure A2. Middle Proterozoic Baltimore Gneiss (Yb on fig. A2, not to be confused with the Baltimore Complex) of the Laurentian craton (Rankin and others, 1989; Rankin, Drake, and Ratcliffe, 1993) forms the cores of gneiss anticlines that constitute the largest internal basement massif in the central Appalachians (Drake and others, 1988). The Baltimore Gneiss is stratigraphically overlain by quartzite and schist of the Setters Formation, and the Setters by the Cockeysville Marble. The Setters Formation and the Cockeysville Marble constitute the Glenarm Group (O€g on fig. A2). The Glenarm Group was redefined by Drake (1985b) and Drake and others (1989) to consist of the Setters Formation, Cockeysville Marble, and Loch Raven Schist. This is incorrect as current work (A.A. Drake, Jr., unpub. data, 1991–93) shows that the Loch Raven Schist is thrust onto either the Cockeysville Marble, the Setters Formation, the Baltimore Gneiss, or the Laurel Formation. The thrust concept was first put forth by Jonas and Stose (1946), and reiterated by Rodgers (1970) and Fisher (1989). Rodgers (1970), however, preferred to put the thrust fault at a higher tectonic level. Fisher's (1989) suggestion that the Loch Raven Schist is the offshore equivalent of the Setters Formation is unlikely because microcline is the feldspar in the Setters, whereas plagioclase is the feldspar in the Loch Raven Schist (Knopf and Jonas, 1929; Hopson, 1964). The stratigraphy of the Glenarm Group as here redefined (quartzite of the Setters Formation, schist of the Setters Formation, and Cockeysville Marble) is exactly the same as that of the Pine Mountain Group in Alabama, which consists of the Hollis Quartzite, Manchester Schist, and Chewacla Marble (Higgins and others, 1988). These rocks constitute the cover sequence on Laurentian basement in the Pine Mountain window, a major internal basement massif in the southern Appalachians (Drake and others, 1988). The Baltimore Gneiss and its Glenarm Group cover constitute the Baltimore terrane (BT on fig. A1) of Horton and others (1989, 1991).

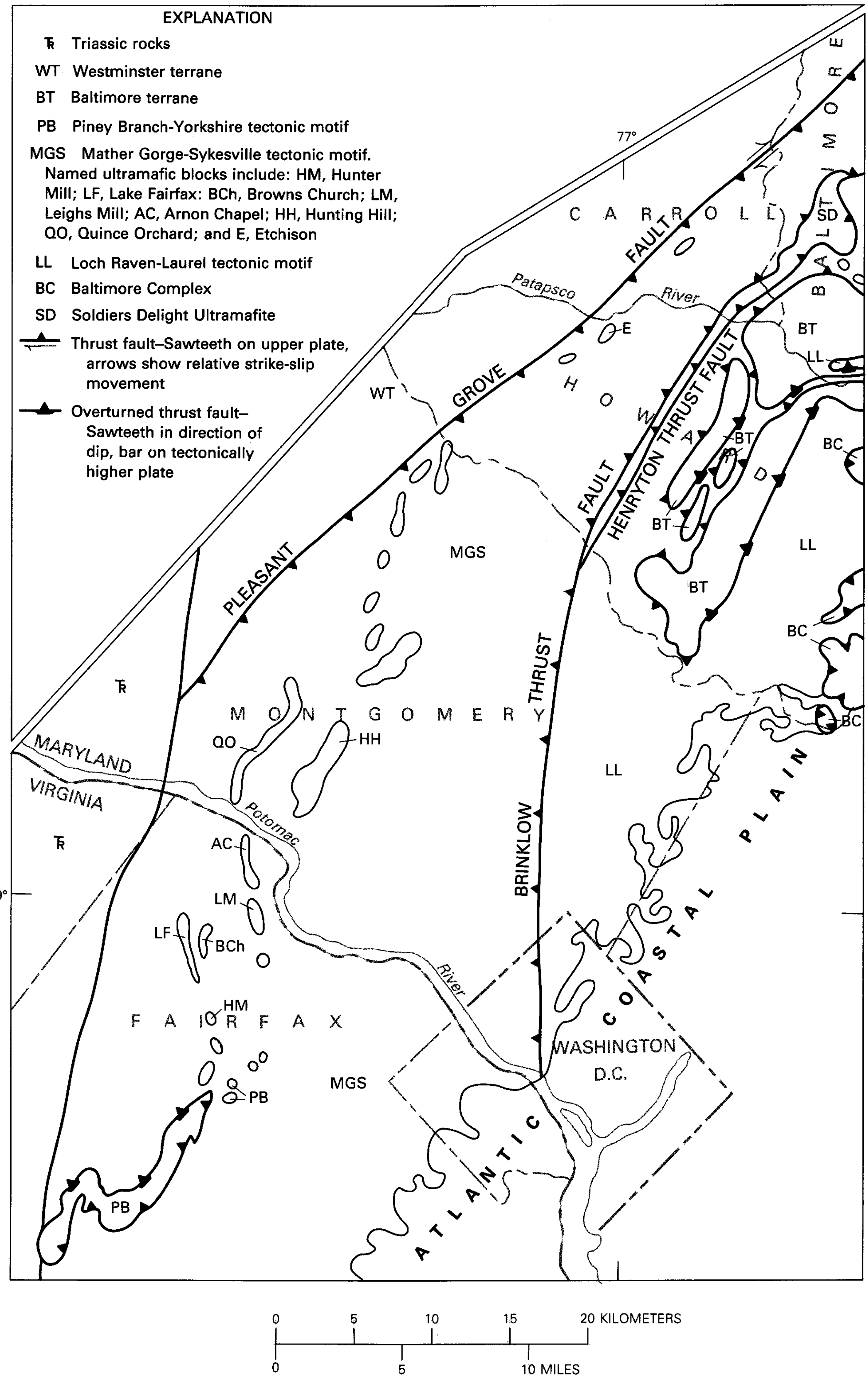


Figure A1. Highly generalized map of part of the Maryland-Virginia Piedmont showing the distribution of ultramafic rocks (modified from Drake and Morgan, 1981). Intrusive rocks not shown.

In the area of figure A2, rocks of the Baltimore terrane are overlain by two thrust sheet-precursory mélange pairs that are termed tectonic motifs (Drake, 1985a, 1985b). The Loch Raven-Laurel tectonic motif (LL on fig. A1) directly overlies rocks of the Baltimore terrane. The Loch Raven thrust sheet (€Zl on fig. A2) consists of the lower Loch Raven Schist (Crowley, 1976) and the upper Oella Formation (Crowley, 1976). The Loch Raven Schist is thin bedded, lustrous, medium- to coarse-grained, and consists of quartz, muscovite, biotite, and plagioclase. It is at garnet, staurolite, or kyanite grade depending on its position relative to the gneiss anticlines. At places, it contains some interbedded semipelitic schist and meta-arenite similar to the overlying Oella Formation into which it grades. The Oella Formation is light-gray, medium-grained, well-bedded quartz-plagioclase-biotite meta-arenite, which contains abundant interbedded schist similar to that in the underlying Loch Raven Schist. In the area of figure A2, the Loch Raven thrust sheet has completely overrun its precursory mélange, the Laurel Formation, and directly overlies rocks of the Baltimore terrane. Where present to the south, the Laurel is characterized by abundant olistoliths of Loch Raven Schist and Oella Formation, as well as ultramafic rocks, amphibolite, and other exotic rocks.

The Loch Raven-Laurel tectonic motif is overlain by the Mather Gorge-Sykesville motif (MGS on fig. A1) on the Brinklow thrust fault. In the area of figure A2, the Soldiers Delight Ultramafite lies between these tectonic motifs. The Mather Gorge Formation (€Zm on fig. A2) is the thrust sheet of the Mather Gorge-Sykesville motif. It consists of quartz-rich schist and metagraywacke. Many metagraywacke beds are graded. Where not obscured by the schistosity, the graded beds pass up into parallel laminated beds and then into schist. At only a few places is cross-bedding seen. The rocks are turbides that were probably deposited in a fairly high energy environment and were interpreted by Drake and Morgan (1981) to constitute a large submarine fan.

The formation experienced a prograde metamorphic event that ranged from chlorite grade in the west to sillimanite grade in the east (Fisher, 1963, 1970; Drake and Morgan, 1981; Drake, 1985c; Drake and others, 1989). About coincident with the appearance of sillimanite, the rocks become migmatitic. The migmatite in the eastern part of the Mather Gorge outcrop belt, near the Plummers Island thrust fault (fig. A2), is sheared and retrogressively metamorphosed into chlorite-sericite phyllonite. Phyllonitized migmatite was traced to the point where the Plummers Island thrust fault is cut off by the Pleasant Grove fault at the north end of Liberty Reservoir in the Finkburg quadrangle (fig. A2).

The abundant map-scale olistoliths of ultramafic rocks within the Mather Gorge-Sykesville motif on figure A1 are within the Mather Gorge Formation. There is no evidence that these bodies were tectonically emplaced.

The Mather Gorge Formation overlies the Sykesville Formation (€s on fig. A2), which is the classic precursory sedimentary mélange in the central Appalachians, on the Plummers Island thrust fault. The Sykesville is characterized by abundant olistoliths of Mather Gorge rocks, including phyllonite (A.A. Drake, Jr. and J.N. Roen, unpub. data, 1974–75, 1992). This relation clearly shows that the Mather Gorge thrust sheet was being emplaced during sedimentation of the Sykesville. Traditionally (Hopson, 1964), the Sykesville was interpreted to be a gigantic submarine slide deposit. There is abundant evidence to support this concept, but the slide surface is not the present base of the formation, which is the Brinklow thrust fault.

In northern Virginia (fig. A1), the Mather Gorge-Sykesville tectonic motif is overlain by the Piney Branch-Yorkshire tectonic motif (PB on fig. A1), which is the highest tectonic motif known in the central Appalachian Piedmont. It consists of the Piney Branch Complex and Yorkshire Formation. The Piney Branch Complex, thought to be an ophiolite fragment (Drake and Morgan, 1981), is a mixture of highly metamorphosed ultramafic and mafic rocks. It lacks discernible order and was interpreted to be a tectonic mélange resulting from the autoclastic deformation of a layered complex that contained repetitive cycles of ultramafic and mafic layers (Drake and Morgan, 1981). The ultramafic and mafic rocks are intruded by dikes and sheets of plagiogranite too small to show on the map. The Yorkshire Formation precursory mélange contains olistoliths of ultramafic and mafic rocks as well as plagiogranite.

The Loch Raven-Laurel, Mather Gorge-Sykesville, and Piney Branch-Yorkshire tectonic motifs constitute the Potomac terrane (Drake and others, 1989) in this part of the central Appalachian Piedmont. They were interpreted to have been tectonically assembled in an oceanic trench and later obducted onto the Laurentian margin (Drake, 1985a, 1985b, 1985c).

Rocks of the Potomac terrane dip west because they are on the west limb of a major antiformal structure, the so-called Baltimore-Washington anticlinorium of Hopson (1964), a major area of tectonic windows that exposed Baltimore Gneiss and its Glenarm Group cover. The area was interpreted by Drake (in Rankin, Drake, and Ratcliffe, 1989) to consists of two large tectonic windows. The area actually consists of several tectonic windows, now that the Loch Raven Schist is known to be allochthonous. Subsequent to their emplacement, the Potomac terrane thrust sheets, remobilized Baltimore Gneiss, the Glenarm Group, and at least the Loch Raven Schist, were deformed into large, west-vergent recumbent folds (Crowley, 1976; Muller and Chapin, 1984). At a later date, the recumbent folds were refolded into east-vergent anticlines (the current gneiss anticlines) by a retrocharriage event. Loch Raven Schist of the lower limbs crops out within several gneiss anticline (Crowley, 1976; Muller and Chapin, 1984). This area of gneiss anticline is probably an antiformal stack, as windows

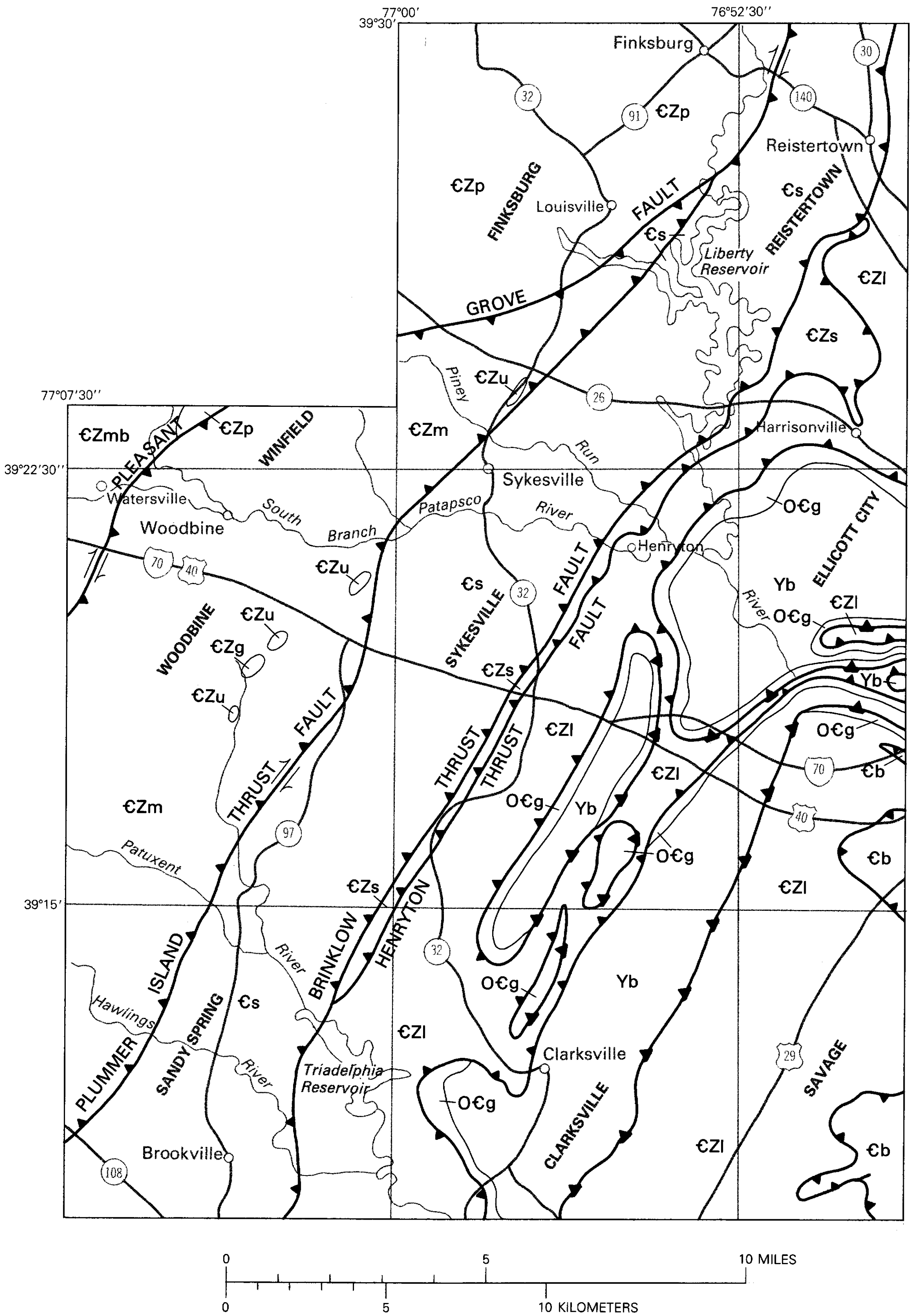
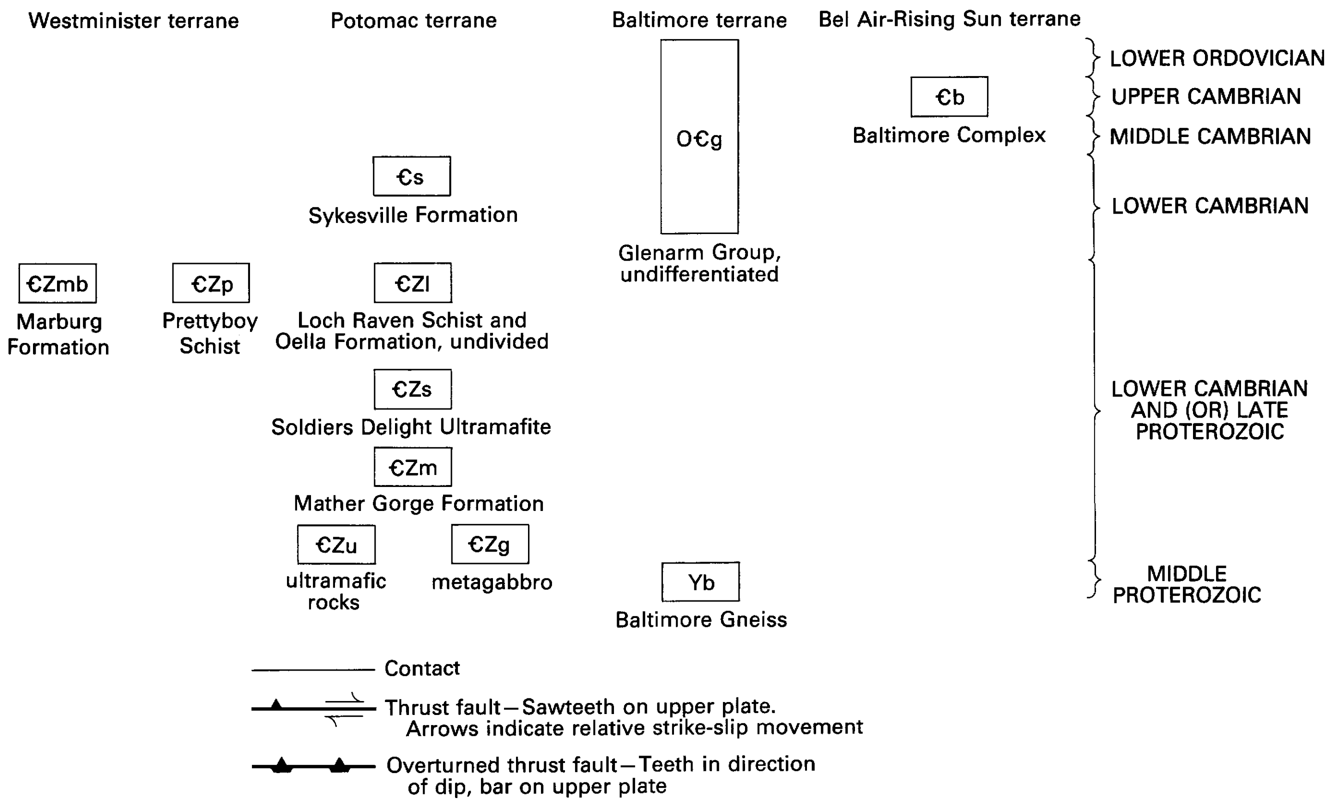


Figure A2. Generalized geologic map of part of the Maryland Piedmont. Intrusive rocks not shown. Geology of the Reisterstown quadrangle modified from Crowley (1977); geology of the Finksburg quadrangle modified from Muller and others (1989); geology of the Ellicott City quadrangle modified from Crowley and Reinhardt (1980); geology of the Sykesville quadrangle from unpublished data of J.N. Roen and A.A. Drake, Jr.; geology of the Woodbine, Sandy Spring, Clarksville, and Savage quadrangles from unpublished data of A.A. Drake, Jr.

EXPLANATION



invariably form on such structures (Hatcher, 1991). The idea that the window area has been jacked up is supported by the abundant extensional structures in the Loch Raven Schist on the west limb of the anticlinorium.

Rocks of the Potomac terrane are in contact with rocks of the Westminster terrane (WT on fig. A1) along the Pleasant Grove fault (figs. A1 and A2). In this area, the Westminster terrane (Muller and others, 1989; Horton and others, 1989, 1991) consists of the Prettyboy Schist (€Zp) (Crowley, 1976) and the Marburg Formation (€Zmb) (Jonas and Stose, 1938). The Prettyboy is the albite-chlorite schist of previous workers and is characterized by albite porphyroblasts. Jones and Stose (1938) named the unit the Marburg Schist. Fisher (1978) abandoned the name and placed its rocks in the Ijamsville Phyllite. The name is here reinstated as Marburg Formation because the Marburg is lithologically distinct from the purple phyllites of the Ijamsville. Marburg Formation is used here because the unit consists predominantly of phyllite rather than schist. The Marburg Formation contains chlorite phyllite, paragonite phyllite, muscovite phyllite, siltstone, greenstone, quartzite, and graywacke. The Prettyboy and the Marburg probably have a facies relation, the Marburg being more proximal, the Prettyboy more distal. These rocks were interpreted to be part of the Laurentian rise-prism by Drake and others (1989).

Rocks along the Pleasant Grove fault are intensely sheared into a wide zone of phyllonite. The Pleasant Grove Schist, as mapped by Crowley (1976), appears to consist of sheared Mather Gorge Formation, Prettyboy Schist, and Marburg Formation, and is not a separate formation; thus, the name Pleasant Grove Schist is here abandoned.

The Pleasant Grove fault was originally a thrust fault and was interpreted to be the Taconic suture by Drake and others (1989). There are abundant thrust faults in the rocks of the Westminster terrane in the footwall of the Pleasant Grove fault. In York County, Pa., rocks of the Westminister terrane were interpreted to contain a major duplex (C.S. Howard, written commun., 1991). This duplex undoubtably dips beneath the Baltimore window area and, thus, it would have been part of the motivating force for the antiformal stack.

The phyllonitic foliation surfaces along the Pleasant Grove fault, as well as the Plummers Island thrust fault, were reactivated by dextral strike-slip motion, probably during the late Paleozoic Alleghanian orogeny (Horton and others, 1989). The amount of strike-slip displacement on the Pleasant Grove is not presently known. It may have been large, however, because the Mather Gorge and Sykesville Formations disappear on its east side, and the Prettyboy Schist disappears on its west side.

Rocks of the Baltimore Complex (BC on fig. A1) were thrust onto those of the Loch Raven tectonic motif on the east flank of the Baltimore antiformal area (figs. A1 and A2). In the area of figure A2, the Baltimore Complex is in contact with the Loch Raven Schist; the Laurel precursory mélange is totally covered in this area. This part of the Baltimore Complex is the Laurel belt of Hopson (1964) and Crowley (1976). Most of the rock here is amphibolite (metagabbro) with minor pyroxenite interlayers. The Baltimore Complex constitutes the major part of the Bel Air-Rising Sun terrane of Horton and others (1989, 1991).

SOLDIERS DELIGHT ULTRAMAFITE (Here Named)

Rocks here named the Soldiers Delight Ultramafite form a tadpole-shaped serpentinite body along the western margin of the Baltimore terrane from the Soldiers Delight area of Baltimore County to just northeast of the Tridelphia Reservoir (figs. A1 and A2). The body was called the Soldiers Delight belt of serpentinite by earlier workers. That name is here formalized as Soldiers Delight Ultramafite, the type locality being the Soldiers Delight area of Baltimore County in the Reisterstown 7.5-minute quadrangle (fig. A2). Reference localities are two quarries along Piney Run, and outcrops and quarries along the South Branch of the Patapsco River in the Sykesville 7.5-minute quadrangle.

The rocks were previously mapped at the scale of 1:62,500 in Baltimore County (Knopf and Jonas, 1925), Carroll County (Jonas, 1928), and Howard County (Cloos and Broedel, 1940). These geologists interpreted the Soldiers Delight body to be an intrusive sill, as did Hopson (1964), although Jonas and Stose (1946) recognized that it occurred between different rock units (their Wissahickon Schist and Peters Creek Formation). Hopson (1964) thought that it was the western feather edge of the Baltimore Complex.

Much more recently, the Soldiers Delight Ultramafite was mapped at the scale of 1:24,000 in the Reisterstown quadrangle (Crowley, 1977), Finksburg quadrangle (Muller and others, 1989), Sykesville quadrangle (J.N. Roen and AA. Drake, Jr., unpub. data, 1974–75, 1992), and Woodbine and Sandy Spring quadrangles (A.A. Drake, Jr., unpub. data, 1993). Outcrops are not abundant and most are small. The unit is easily traced, however, as the soil cover is thin and float is fairly abundant. The ultramafite weathers to chrome soils (Jonas and Stose, 1946), which support only a scanty growth of cedar and pine.

Crowley (1976, 1977) recognized that the Soldiers Delight Ultramafite is allochthonous, and called it the Soldiers Delight slide mass, thinking that it was emplaced by submarine sliding during the deposition of the Sykesville Formation. That tectonic concept was extremely popular during the early and middle 1970's. It is unclear as to how Muller and others (1989) interpreted the relation of the Soldiers Delight Ultramafite to the Oella and Sykesville Formations as on their figure 1 they show a west-dipping thrust fault on the east contact of the Soldiers Delight, whereas on their figure 5 they show an east-dipping thrust fault on the west contact of the Soldiers Delight and a sedimentary contact on the east.

Recent work in the Sykesville quadrangle (J.N. Roen and AA. Drake, Jr., unpub. data, 1974–75, 1992) clearly shows that the contacts of the Soldiers Delight Ultramafite are marked by phyllonitic foliation in both the ultramafite and the metasedimentary rocks (fig. A3). This relation can be best seen in exposures in quarries and natural outcrops along the South Branch of the Patapsco River and Piney Run (fig. A2). Good exposures of phyllonitic Sykesville Formation can also be seen in the extreme southeastern corner of the Woodbine quadrangle (fig. A2). The Soldiers Delight clearly forms a horse between the Brinklow and Henryton thrust faults (fig. A2). It is obviously far removed from its root, so it is properly a schurflingsfenster (Tollmann, 1968) or orphan in the sense of Lewis and Bartholomew (1989).

The Soldiers Delight Ultramafite is almost totally altered to serpentinite. The rock in the head of the tadpole shape at Soldiers Delight was largely peridotite, most likely dunite, as no bastite textures after orthopyroxene were observed by previous workers (Knopf and Jonas, 1929; Pearre and Heyl, 1960; Morgan, 1977) or during this study. The dunite interpretation is supported by five chromite mines in the area (Pearre and Heyl, 1960). The ore from those mines assayed 30–50 percent Cr_2O_3 (Knopf, 1922). Residual olivine containing accessory chromite can be seen in some specimens from the mine dumps. The border rocks of the tadpole head have been further altered to talc schist and soapstone (Crowley, 1977).

Knopf and Jonas (1925) mapped an area of metagabbro in the tadpole tail about 2.1 km northeast of the Liberty Reservoir (fig. A2). Crowley (1977), however, shows this area to be underlain by nonserpentinitic ultramafic rocks. These rocks were not examined during this study.

The bulk of the tadpole tail consists of serpentinized pyroxenite. The least altered parts of this rock retain a boxwork texture after orthopyroxene (fig. A4*A*). The orthopyroxene is altered to tremolite and lesser amounts of antigorite, chlorite, talc, and magnetite. These rocks are rather massive and retain some original textures (fig. A4*A*). With increased shearing and alteration, discontinuous zones of talc schist appear within the serpentinite (fig. A4*B*). Increased alteration produces distinct zones of talc schist (fig. A4*C*). A final alteration product is soapstone. Rocks of the Soldiers Delight Ultramafite have been exploited for talc and soapstone in two quarries along Piney Run, and for talc in a quarry along the South Branch of the Patapsco River (fig. A2). The mineralogy and chemistry (see below) of the pyroxenite of the Soldiers Delight Ultramafite suggests that it is enstatolite, that is, a rock composed largely of the magnesian orthopyroxene enstatite.

The age of the Soldiers Delight Ultramafite is uncertain. It lies tectonically between the Late Proterozoic and (or) Lower Cambrian Loch Raven Schist and Lower

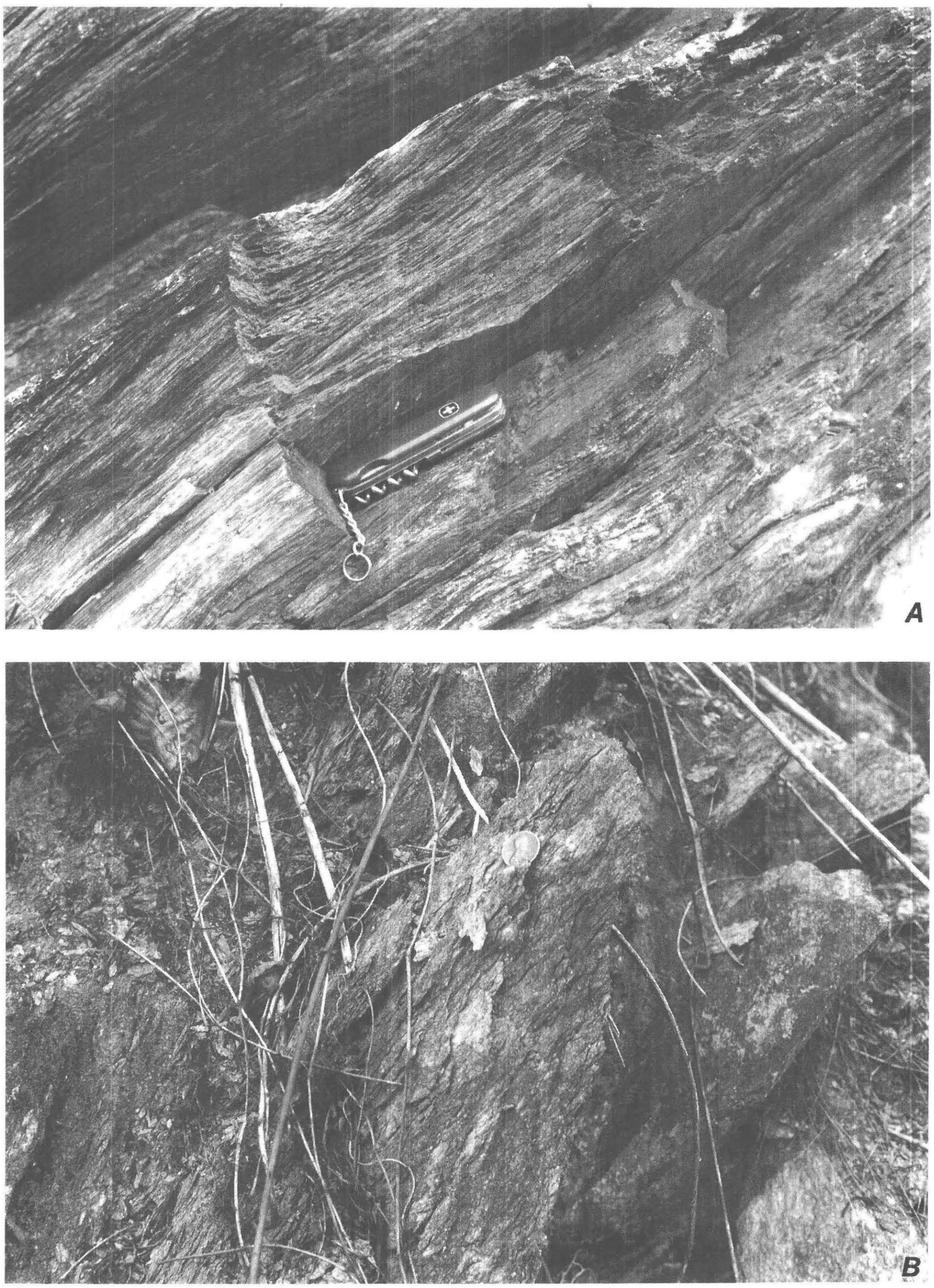


Figure A3. Photographs of phyllonitic foliation in the metasedimentary rocks that enclose the Soldiers Delight Ultramafite. *A*. Oella Formation just beneath the Soldiers Delight Ultramafite. Knife is 8.2 cm in length. Photograph looks north. *B*. Sykesville Formation just above the Soldiers Delight Ultramafite. Coin is 1.8 cm in diameter. Photograph looks north.

Cambrian Sykesville Formation. Other ultramafic rocks in the central Appalachian Piedmont are considered to be of Late Proterozoic and (or) Early Cambrian age because deformed bodies of this rock type occur within Lower Cambrian sedimentary mélanges. The Soldiers Delight Ultramafite, therefore, is considered to be Late Proterozoic and (or) Early Cambrian in age.

GEOCHEMISTRY

The chemistry of a sample of pyroxenite from the Soldiers Delight Ultramafite and that of some other ultramafic rocks from the Virginia-Maryland Piedmont are given in table A1 (rare earth geochemistry was not obtained for sample 3).

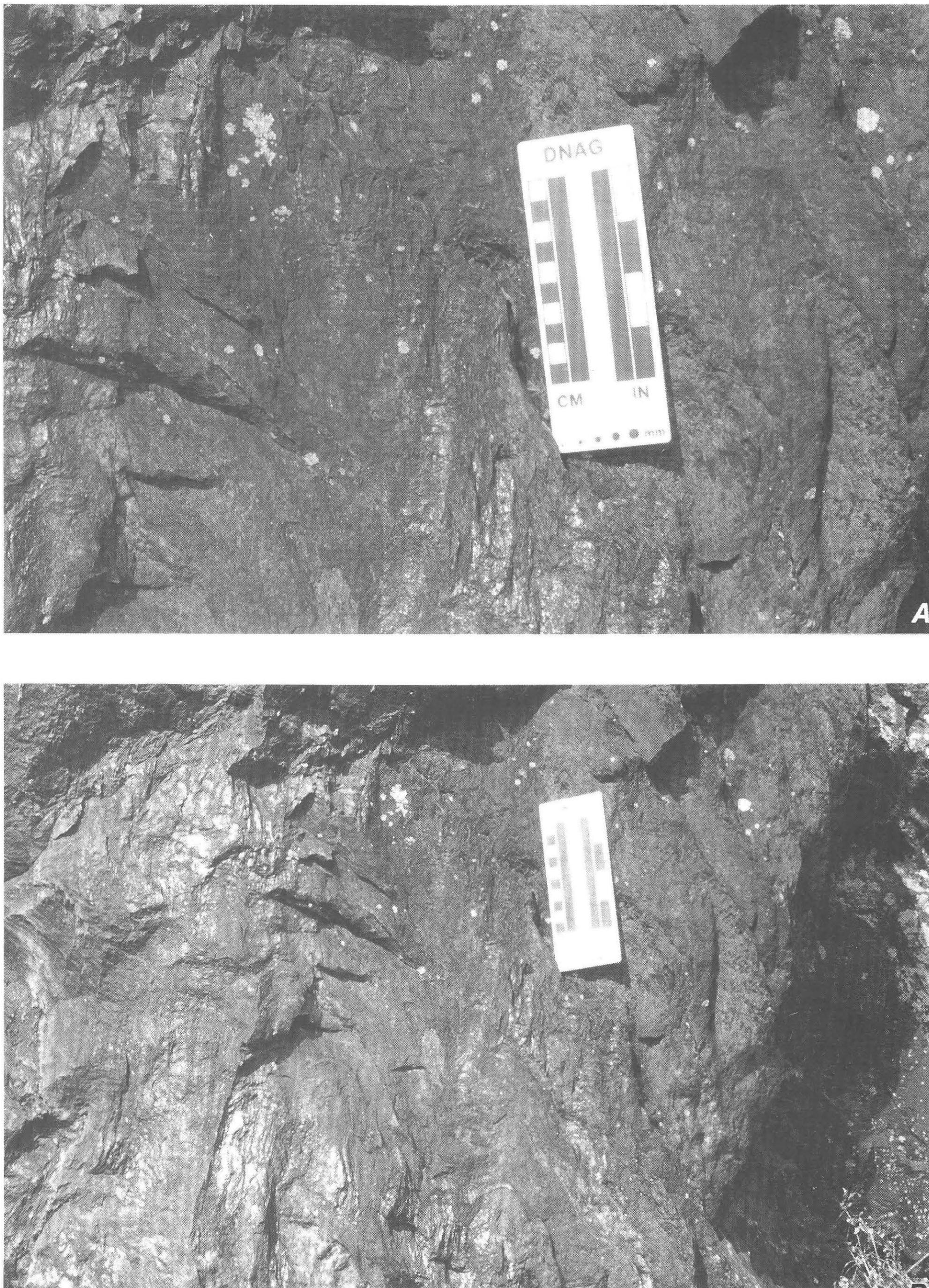


Figure A4. Photographs of serpentinized pyroxenite of the Soldiers Delight Ultramafite.

A. Massive serpentinite retains boxwork texture in lower right hand corner of photograph. Glistening talc schist has formed along shear planes in center of photograph and in upper left hand corner of photograph

B. Serpentinite showing discontinuous zones of talc schist.

C. Serpentinite containing a distinct zone of crenulated talc schist that contrasts with the dark serpentinite.

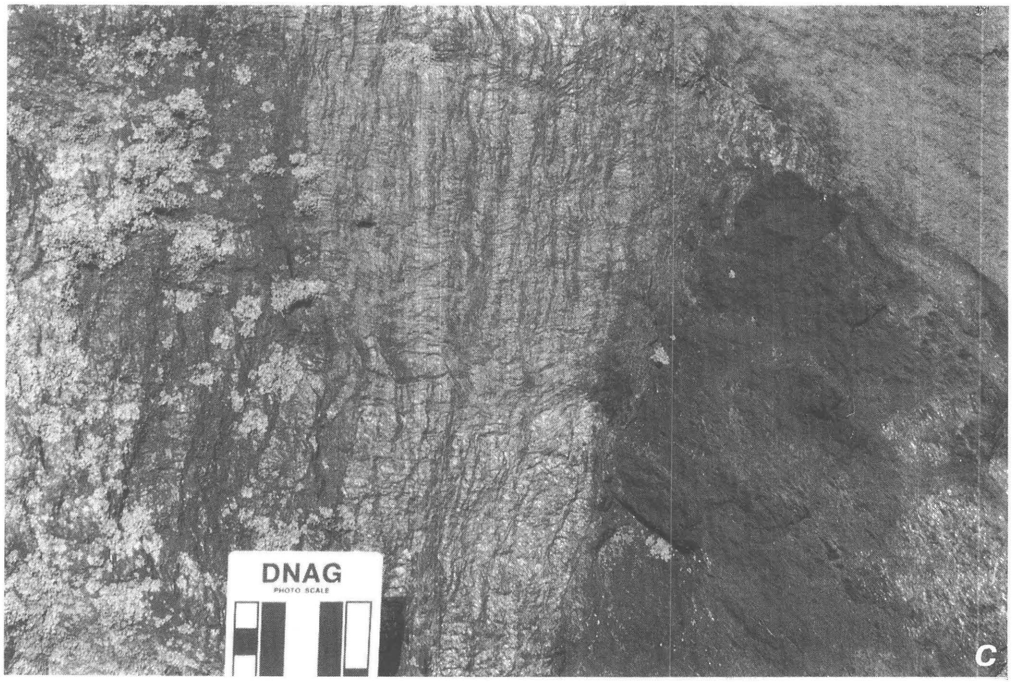


Figure A4.—Continued.

Pyroxenite from the Soldiers Delight Ultramafite (sample 1, table A1) contains much more SiO_2, MgO, and Al_2O_3, and much less CaO than the pyroxenites from the Baltimore Complex described by Morgan (1977, samples 4–7) and Hanan and Sinha (1989, samples 4 and 5). The pyroxenite contains very abundant Cr and moderate amounts of Ni and Co. The pyroxenite contains no normative diopside, supporting the interpretation that it is an enstatolite.

The pyroxenite contain much more SiO_2 and MgO, much less Al_2O_3, CaO and much more Cr than pyroxenites from the Piney Branch Complex (Drake and Morgan, 1981, samples Mq-RH-3 and Mq-RH-14). The pyroxenites of the Piney Branch, largely altered to actinolite schist of actinofels, were interpreted to be websterites by Drake and Morgan (1981). The Soldiers Delight chemistry clearly reflects the mineralogic difference between enstatolites and websterites.

The pyroxenite of the Soldiers Delight is depleted in light rare-earth elements (LREE) (table A1, fig. A5), as is typical of ultramafic rocks throughout the world (McDonough and Frey, 1989). It has a negative Eu anomaly (fig. A5) and a (Tb/Yb)n (the n indicates chondrite-normalized ratio, which are not shown in table A1) ratio less than 1 (table A1), suggesting that the source rock contained primary garnet (McDonough and Frey, 1989). The rare-earth elements (REE) plot is similar to those of the Thetford Mines Complex of Quebec, Canada (fig. A6*A*) and other pyroxenites and peridotites (fig. A6*B*, *C*), although it contains more La than any of the other rocks. Unfortunately, there are no REE analyses of Baltimore Complex rocks.

The ultramafic rocks that constitute the olistoliths within the Mather Gorge Formation of the Mather Gorge-Sykesville tectonic motif (fig. A1) are so thoroughly serpentinized that their original mineralogy and textures cannot be determined. An estimate of their original composition can be made from their chemistry (table A1). The relatively high SiO_2/MgO ratio and content of Cr and Ni of sample 2 suggests that the Quince Orchard block (QO on fig. A1) was originally harzburgite. The low SiO_2/MgO ratio, the very low CaO content, and the high content of Cr and Ni suggests that the rock of the Hunting Hill block (HH on fig. A1), sample 3, was originally dunite. Larrabee (1969) made the same interpretation. He also described a spotted serpentinite that appears similar to some rocks within the Piney Branch Complex that were interpreted to be cumulates by Drake and Morgan (1981). The rock of the Arnon Chapel block (AC on fig. A1), sample 4, has a strange chemistry. Its SiO_2/MgO ratio is less than 1, and it contains 12 percent Al_2O_3— hardly typical of an ultramafic rock. It contains relatively low amounts of Cr and Ni, again, not typical of an ultramafic rock. Some of the block has a boxwork texture after orthopyroxene. Perhaps this rock was originally an olivine gabbro. Rock of the Brown Chapel block (BCh on fig. A1), sample 5, has a relatively high SiO_2/MgO ratio and contains a large amount of Cr and Ni, suggesting that it may have originally been harzburgite. The minor amount of normative di, however, suggests that the rock probably had modal clinopyroxene and that it was probably harzburgite. Rock from the Leigh Mill block (LM on fig. A1), sample 6, has a high SiO_2/MgO ratio, contains a large amount of Cr and Ni, and contains 2.4 percent CaO,

Table A1. Chemical analyses and CIPW norms of some ultramafic rocks from the Virginia and Maryland Piedmont

Sample	1	2	3	4	5	6	7	8	9	10
Field No.	SY-H-5-2	R-18	R-10-1	S-86-A	V-231	V-210	V-161	V-240	V-6	WE-1
Major oxide composition (weight percent)[1]										
SiO_2	54.7	42.5	39.6	30.8	41.0	44.5	40.7	40.9	44.1	45.0
Al_2O_3	3.4	1.2	.69	12.0	1.6	.7	1.1	1.1	18	24.4
Fe_2O_3	2.8	3.4	5.3	8.3	3.6	4.0	6.5	5.1	6.8	.8
FeO	6.6	3.2	1.6	3.3	3.6	2.2	2.5	2.9	3.1	1.5
MgO	26.0	37.3	38.4	33.0	36.6	34.4	37.2	37.5	33.1	7.5
CaO	1.0	.4	.2	<.02	.8	2.4	<.02	.1	.6	16.7
Na_2O	.09	.2	.2	.02	.2	.2	.2	.2	.2	1.7
K_2O	.02	<.02	<.2	<.02	<.02	<.02	<.02	<.02	<.02	.06
H_2O+	4.5	10.9	12.0	11.7	11.5	10.2	11.5	11.6	8.9	1.9
H_2O-	.17	.1	.4	.02	.1	1.0	.4	.2	.1	.1
TiO_2	.17	<.02	<.02	1.1	<.02	<.02	<.02	<.02	.05	<.02
P_2O_5	<.02	<.05	.05	<.05	<.05	<.05	<.05	<.05	<.05	.03
MnO	.2	.09	.15	.1	.9	.1	.06	.08	.08	<.05
CO_2	<.01	.02	.6	—	—	—	—	—	—	.07
Total	99.6	99.41	99.19	100.3	99.9	99.7	100.2	99.7	98.8	99.8
CIPW norms (weight percent) (Based on analyses recalculated to 100 percent water free oxides)										
Q	9.1	—	—	—	—	—	—	—	—	—
C	1.5	.5	1.8	1.5	—	—	1.0	74	1.0	—
or	.1	.1	.1	.1	.1	.1	.1	.1	.1	.4
ab	.8	1.5	2.1	.2	1.9	1.8	1.8	1.9	1.6	5.4
an	5.2	1.9	—	—	3.8	1.1	—	.3	3.1	60.1
ne	—	—	—	—	—	—	—	—	—	5.0
di	—	—	—	—	.3	9.5	—	—	—	18.8
hy	78.2	46.7	42.5	22.9	38.8	50.6	45.0	43.1	63.8	—
fo	—	42.0	47.3	48.8	46.7	29.2	42.0	44.6	19.7	7.9
fa	—	1.6	—	—	2.1	.3	—	.6	.05	1.0
mt	4.2	5.5	6.4	9.0	6.0	6.5	9.3	8.4	10.9	1.1
hm	—	—	1.7	3.3	—	—	.1	—	—	—
il	.3	.04	.04	2.3	.04	.04	.04	.04	.1	.04
ap	.05	.13	.1	.1	.1	.1	.1	.13	.1	.1
cc	.02	.5	1.7	—	—	—	—	—	—	.04
Total	99.5	100.4	103.7	100.2	99.8	99.2	100.2	99.9	100.4	99.9
Trace-element abundances (parts per million) Large cations[2]										
Rb	<5	4	<2	<2	3	2	3	4	<2	3
Ba	4	6	10	10	<22	29	<23	<28	<24	6
Sr	<4	11	13	10	11	16	6	6	7	186
High valence-cations										
Th[4]	<.1	<.1	—	—	<.1	<.1	<.1	<.1	<0.1	—
Zr[2]	<100	15	14	27	11	<10	10	12	11	14
Hf[4]	.16	6	—	—	.1	<.08	<.12	.28	<.12	<.06
Nb[3]	<8	<10	—	<1	1	<1	1	1	<1	<10
Ta[4]	<.08	<.06	—	—	.1	<.07	<.08	<.08	<.09	<.04
Metals[4]										
Cr	3010	1570	1980	327	3040	2620	2390	2340	2440	694
Co	82	60.1	—	86.4	84.2	94.7	80.1	97	92	23
Ni	540	1340	2120	765	1920	1940	2080	2080	1760	337
Cu	<2	36	20	—	—	—	—	—	—	45
Sc	33.5	—	—	—	6.2	4.9	8.2	7.8	8.7	—
Zn	125	316	5	41	72	24	33	42	64	11
As	1.21	5.5	—	1.6	4.9	1.3	7.8	6.9	9.1	.87
Mo	<4	<3	—	—	—	—	—	—	—	—

Table A1. Chemical analyses and CIPW norms of some ultramafic rocks from the Virginia and Maryland Piedmont—Continued

Sample	1	2	3	4	5	6	7	8	9	10
Field No.	SY-H-5-2	R-18	R-10-1	S-86-A	V-231	V-210	V-161	V-240	V-6	WE-1
					Rare-earth elements					
La[4]	1.3	0.211	—	01.1	0.11	0.11	0.83	0.15	0.59	0.27
Ce[4]	1.4	<.9	—	2.0	<1.2	<.7	1.3	1.1	10	.53
Nd[4]	<2	<1	—	<4	<1.7	1.5	2	1.8	<1.7	<.8
Sm[4]	.424	.069	—	1.6	.06	<.02	13	.032	.95	.72
Eu[4]	.094	.03	—	.08	.05	.04	.06	.045	.27	.49
Tb[4]	.091	<.03	—	.59	<.04	<.05	<.05	<.06	.38	.031
Yb[4]	.46	.17	—	2.2	.15	<.08	.13	.16	1.7	.13
Lu[4]	.092	.029	—	.3	.04	<.015	.02	<.02	.26	.02
Y[2]	5	7	5	21	8	<7	7	8	17	3

[1]XRF Analyses by D.F. Siems and J.E. Taggart, Jr. FeO, CO_2, H_2O^+, H_2O^- analyses by J.W. Marinenko

[2]Analyses by J.K. Evans

[3]Analyses by M.W. Doughten

[4]Analysis of sample 4 by J.N. Grossman. All others by J.S. Mee

Description of Samples

1. Serpentinized pyroxenite of Soldiers Delight Ultramafite from eastern Mariottsville quarry in the Sykesville, Md., 7.5-minute quadrangle at lat. 39°21'54"N and long. 76°54'37"W.
2. Serpentinite from the Quince Orchard block in the Rockville, Md.-Va., 7.5-minute quadrangle at lat. 39°06'28"N and long. 77°14'60"W.
3. Serpentinite from the Hunting Hill quarry in the very large Hunting Hill block in the Rockville, Md.-Va., quadrangle at lat. 39°04'58"N and long. 77°13'42"W.
4. Serpentinite from the Arnon Chapel block in the Seneca, Md.-Va., 7.5-minute quadrangle at lat. 39°01'38"N and long. 77°16'47"W.
5. Serpentinite from the Browns Chapel block in the Vienna, Va.-Md., 7.5-minute quadrangle at lat. 38°58'39"N and long. 77°18'56"W.
6. Serpentinite from the Leighs Mill block in the Vienna, Va.-Md., 7.5-minute quadrangle at lat. 38°58'55"N and long. 77°16' 26"W.
7. Serpentinite from the Lake Fairfax block in the Vienna, Va.-Md., 7.5-minute quadrangle at lat. 38°59'27"N and long. 77°19' 30"W.
8. Serpentinite from the Lake Fairfax block in the Vienna, Va.-Md., 7.5-minute quadrangle at lat. 38°57'54"N and long. 77°19'20"W.
9. Serpentinite from the Hunter Mill block in the Vienna, Va.-Md., 7.5-minute quadrangle at lat. 38°55'37"N and long. 77°18' 21"W.
10. Serpenitized olivine gabbro from the Sligo Creek block in the Washington East, D.C.-Md., 7.5-minute quadrangle at lat. 38°58'14" and long. 76°59'04"W.

suggesting that it originally contained modal clinopyroxene. It too was probably a harzburgite. Rocks from the Lake Fairfax block (LF on fig. A1), samples 7 and 8, have relatively high SiO_2/MgO ratios and contain large amounts of Cr and Ni. The block also was probably harzburgite. Rock of the Hunter Mill block (HM on fig. A1), sample 9, has a high SiO_2/MgO ratio and a high content of Cr and Ni. Chromite is visible in hand specimens. This rock also was probably harzburgite.

There is no evidence that any attempt was made in the past to exploit a chromite deposit from any of these blocks. There were, however, two chromite mines in the Etchison block (E on fig. A1) (Pearre and Heyl, 1960), which is also in the Mather Gorge Formation. The ore from these mines contained from 35 to 45 percent Cr_2O_3, but was very rich in iron (Pearre and Heyl, 1960). Although this block has not been studied or sampled, it is probably dunite because of the podaform chromite.

The Sligo Creek block, sample 10, is too small to show on figure A1, but is located approximately at the contact of the Loch Raven-Laurel motif with the Coastal Plain at the word "Washington" on figure A1. It is an olistolith within the Laurel Formation of the Loch Raven-Laurel motif. From field observation, part of the block appears to be metamorphosed gabbro. The chemistry of the serpentinite shows that it was also gabbro, probably an olivine gabbro, not an ultramafic rock.

All the samples, particularly 2, 5, 6, 8, and 10, are depleted in LREE. The patterns of most of the samples interpreted to be harzburgites vaguely resemble those of low-alumina harzburgites from the western Alps (McDonough and Frey, 1989).

CONCLUSIONS

The Soldiers Delight Ultramafite is a horse between rocks of the Loch Raven-Laurel and Mather Gorge-Sykesville tectonic motifs. It was probably plucked from a distant footwall block to the east. Available data suggests that it differs petrologically from the rocks of the Baltimore Complex, which are also at a different tectonic position. It tectonically overlies the Loch Raven Schist, so blocks of ultramafic rock within that unit may have been shed from

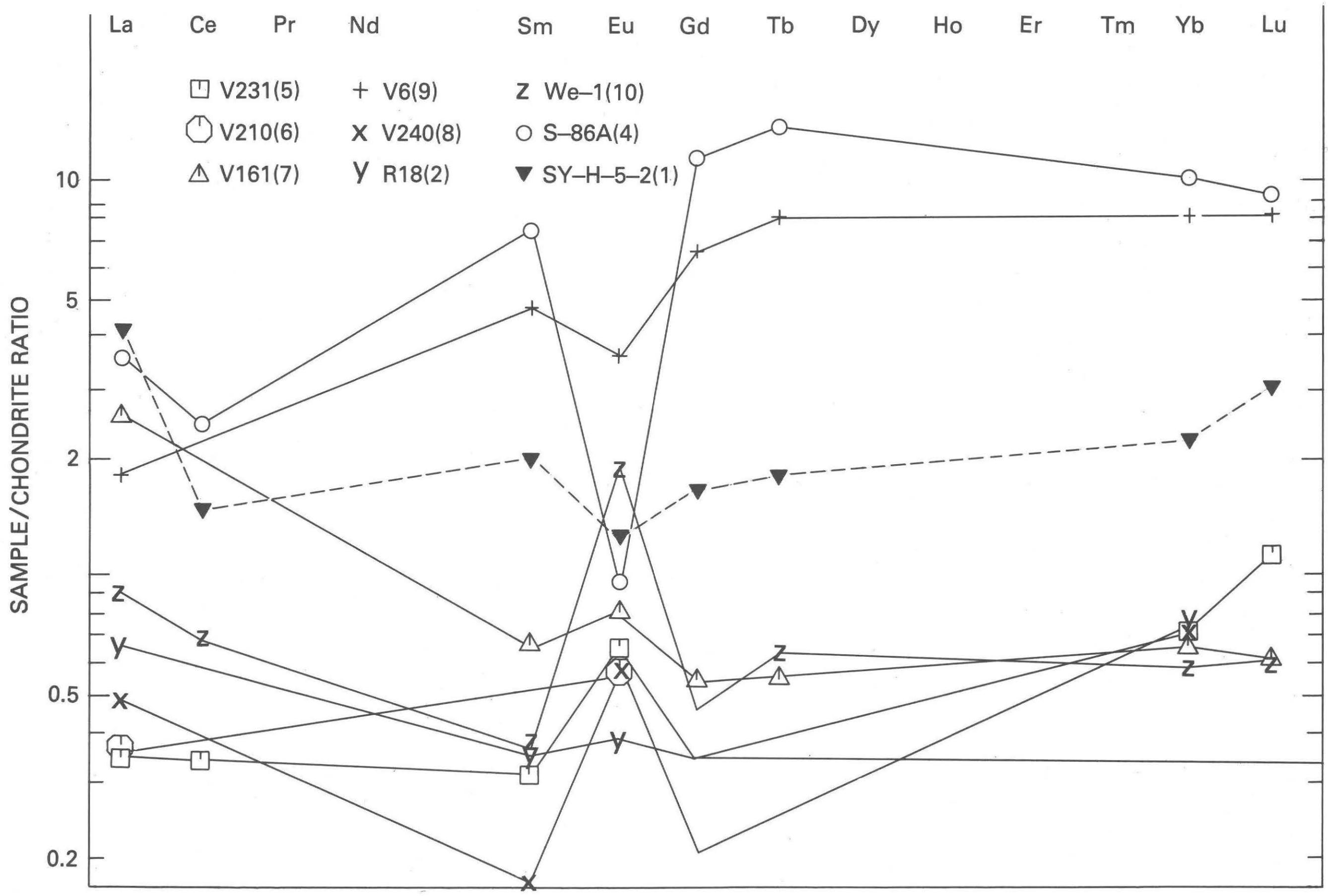


Figure A5. Chondrite-normalized rare-earth element (REE) plots of some ultramafic rocks from the Maryland-Virginia Piedmont.

the Soldiers Delight, but these blocks have not been studied. The Soldiers Delight Ultramafite tectonically underlies the Mather Gorge-Sykesville tectonic motif, so it could not have been the source of the ultramafic and related mafic rocks in either the Mather Gorge or Sykesville Formations. In addition, it differs petrologically from the sampled blocks in the Mather Gorge Formation.

The serpentinite blocks so far sampled in the Mather Gorge Formation appear to have largely formed from harzburgite. These rocks are similar to some of those in the Piney Branch Complex. The abundant actinolite schist-actinofels and metagabbro of the Piney Branch appear to be very sparse in the Mather Gorge Formation. Small olistoliths of these rock types are, however, fairly abundant in the Sykesville Formation. Although it is tectonically appealing to interpret the ultramafic-mafic debris in the Mather Gorge to have been shed from the Piney Branch, it is by no means certain. In any case, the concept of Morgan (1977) and Drake and Morgan (1981) that all the ultramafic and related mafic rocks were shed from one gigantic thrust sheet and were recycled into different tectonic units remains to be proved.

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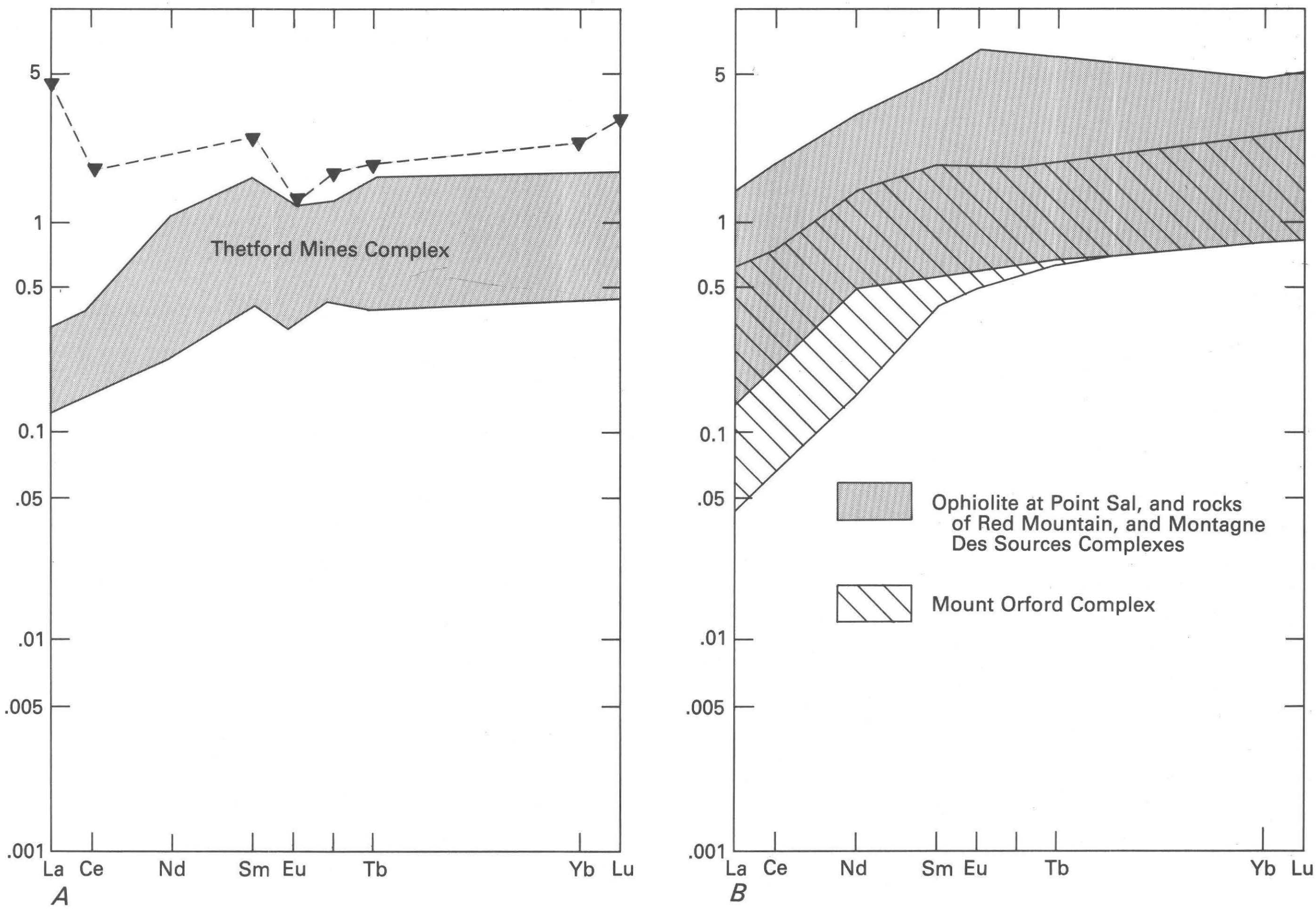

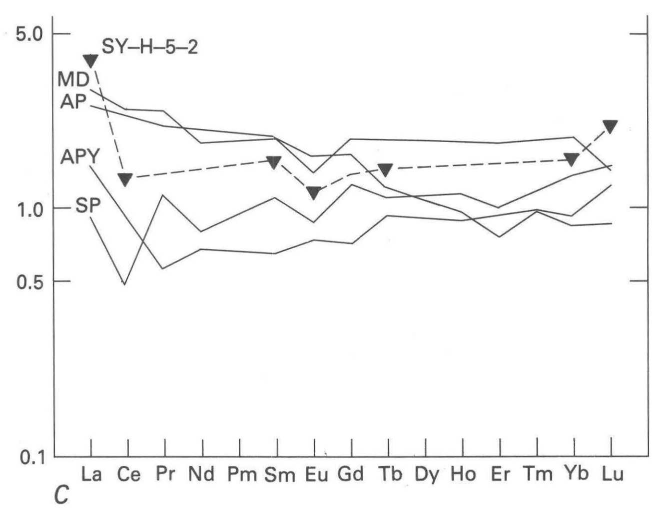

Figure A6. Chondrite-normalized plots comparing pyroxenite of the Soldiers Delight Ultramafite (Sy-H-5-2) with other ultramafic rocks

A. Soldiers Delight Ultramafite compared with pyroxenites from the Thetford Mines Complex, Quebec, Canada. (Data from Harnois and others 1990.

B. Plot of pyroxenites from the ophiolite of Point Sal, California, and the rocks at Red Mountain, New Zealand; Montagne Des Sources, New Caledonia; and Mount Oxford, Quebec. (After Harnois and others 1990.)

C. Soldiers Delight Ultramafite compared with Alpine peridotites, AP; Alpine pyroxenites, APY; Stillwater pyroxenite, Montana, SP; and Muskox, Greenland, dunites. (Data from Frey and others, 1971.)

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Chapter B

Continental Margin Deposits and the Mountain Run Fault Zone of Virginia—Stratigraphy and Tectonics

By Louis Pavlides

STRATIGRAPHIC NOTES, 1993

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CONTENTS

FIGURE

Continental Margin Deposits and the Mountain Run Fault Zone of Virginia—Stratigraphy and Tectonics

By Louis Pavlides

ABSTRACT

Metasedimentary rock units interpreted as continental margin deposited along the western side of a back-arc basin are herein formally named. The Blue Ridge anticlinorium is the massif on which these sediments were deposited. The Tomahawk Creek Formation, a lenticular unit of graywacke and slate of Cambrian(?) or Proterozoic(?) age and as much as 300 m thick, is considered as part of the massif terrane.

Unconformably overlying the massif rocks (here the Catoctin Formation of Late Proterozoic age and the Tomahawk Creek Formation) is the Nasons Formation. It is a lenticular, siliciclastic deposit as much as 125 m thick and composed of quartz-granule conglomerate that locally grades upward into quartz arenite and siltstone. It is considered to be of Cambrian age, probably correlative with the basal parts of the Weverton Formation and the Chilhowee Group. The Nasons is overlain by the True Blue Formation, which is about 600 m thick and is composed mostly of calcareous slate. Locally it contains argillite, calcareous phyllite, impure limestone, and small lenses of chert and ironstone. It also contains the lenticular Everona Limestone Member, a platy, fine-grained, thin-bedded, and finely laminated silty to nearly pure metalimestone as much as 160 m thick. The Everona occurs as lenses along and within parts of the Mountain Run fault zone. The lenses of the Everona Limestone Member were probably pulled apart and locally underwent complex deformation during pre-Mesozoic deformation. The True Blue Formation and its Everona Limestone Member provisionally are assigned a Cambrian(?) and (or) Ordovician(?) age.

The Mountain Run fault zone includes rocks of both the True Blue Formation as well as phyllites of part of the Mine Run Complex. The Mine Run Complex is mostly a fault-segmented mélange that had formed offshore of the continental margin deposits in a more eastern part of a back-arc basin. The Mine Run Complex had been thrust along the Mountain Run fault zone onto the continental margin terrane of the True Blue Formation at the end of the Ordovician. Subsequently, the Mountain Run fault zone underwent dextral strike-slip movement in the pre-Mesozoic. Scarp-forming normal faults developed in the Cenozoic (Pleistocene?) and a small thrust fault also developed locally at this time within the Mountain Run fault zone.

INTRODUCTION

A sequence of metasedimentary rocks that occur locally along the southeast margin of the Blue Ridge province of central Virginia have heretofore been named informally or only designated by lithology (Pavlides, 1987, 1989, 1990). These informal units are herein named formally, and, along with the Mountain Run fault zone, which bounds as well as includes one of them on their southeast side, are described and discussed more extensively. Previously, the Geologic Map of Virginia (Milici and others, 1963) showed this terrane (fig. B1) to consist of undivided metamorphosed sedimentary rocks of uncertain age that locally enclosed a thin limestone unit previously named the Everona Limestone by Jonas (1927) and later more fully described by Mack (1965).

GEOLOGIC SETTING

The Paleozoic rocks described in this report are interpreted as sedimentary deposits that formed along the continental margin of ancestral North America (Laurentia) during Late Proterozoic through early Paleozoic time. Only a part of the massif of ancestral North America, the Catoctin Formation (Ƶc) of Late Proterozoic age, is shown on figure B1. The continental margin deposits thus are bounded by the Late Proterozoic Catoctin Formation (Ƶc) on the west, and separated from allochthonous rocks to the east by the Mountain Run fault zone (fig. B1). The Catoctin Formation here is along the southeast limb of the Blue Ridge anticlinorium, an allochthonous massif of Precambrian rocks. Successively eastward from the Mountain Run fault zone are the mélange zones of the Cambrian and (or) Ordovician Mine Run Complex (Pavlides, 1989), which include zone IV (OЄm IV) and two of its lenticular units (OЄm IVq and OЄm IVv) (fig. B1). The mélange deposits of the Mine Run Complex are interpreted as having formed in a back-

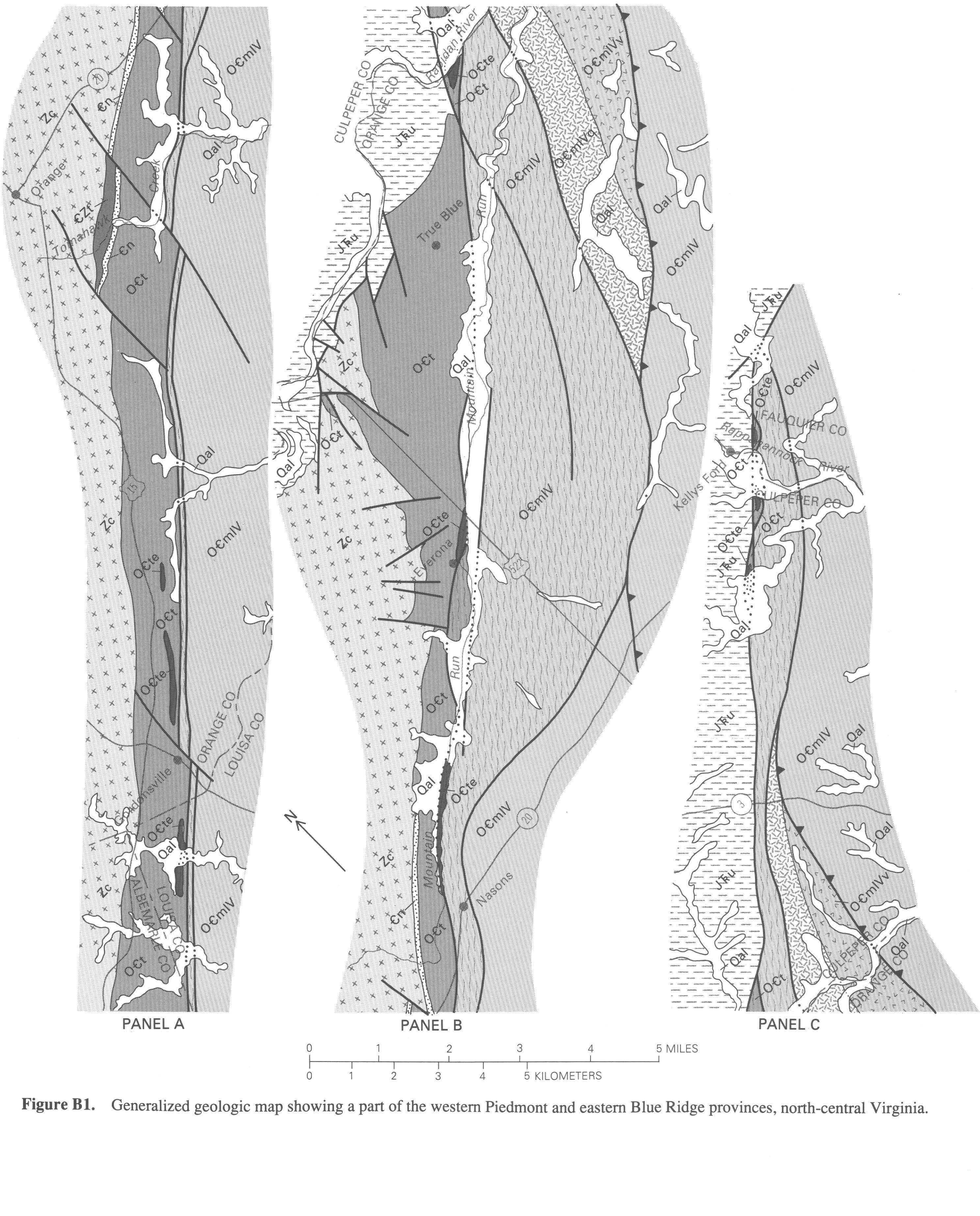
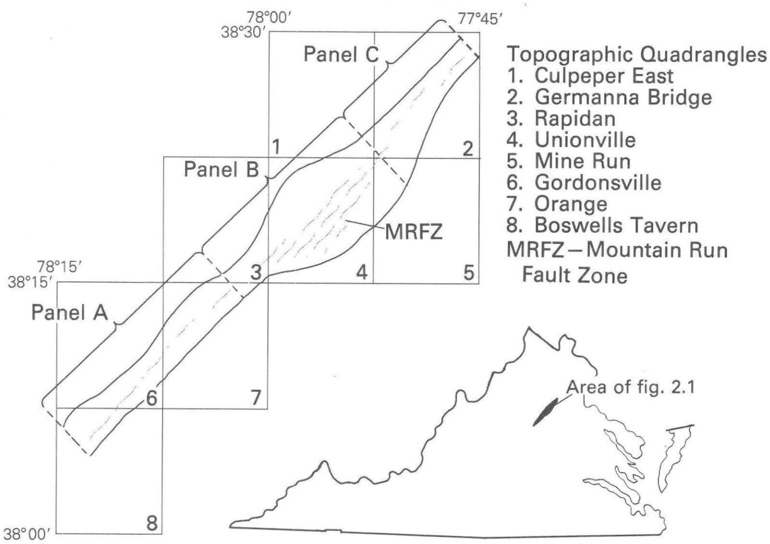
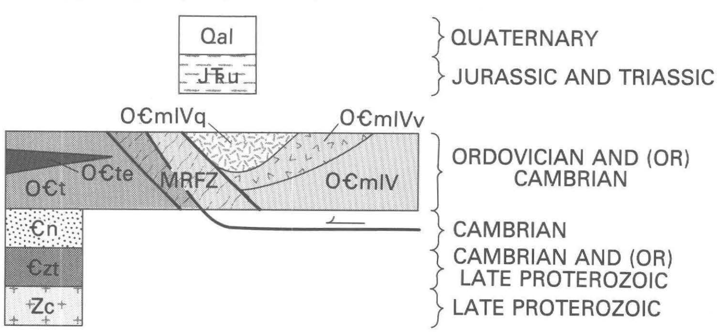


Figure B1. Generalized geologic map showing a part of the western Piedmont and eastern Blue Ridge provinces, north-central Virginia.

INDEX MAP OF FIGURE B1.



CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qal — **Alluvium (Quaternary)**—Sand, gravel, silt, and clay; brown to gray and gray green. In stream channels and flood plains. Grades into colluvium along margins of some streams. Locally may include swamp deposits.

JTRu — **Rocks of the Culpeper basin (Jurassic and (or) Triassic)**—Reddish conglomerate, sandstone, siltstone, and shale (Triassic) with gray to black basaltic intrusions (Jurassic); undivided

O€mlV — **Melange zone IV of the Mine Run Complex (Ordovician and (or) Cambrian)**—Gray-to-green phyllite and intercalated phyllite and meta-arenite. Westward, the **O€mlV** grades into fine-grained, gray-green to green metavolcanic phyllites intercalated with metavolcaniclastic phyllites and other metasedimentary rocks (**O€mlVv**). The metavolcanic and intercalated metasedimentary rocks pass gradationally westward into mostly fine-grained metasandstone and metasiltstone (**O€mlVq**)

O€t — **True Blue Formation (Ordovician and (or) Cambrian?)**—Consists primarily of calcareous and noncalcareous slate and siltstone and lesser amounts of argillite. Includes lenses of the Everona Limestone Member (**O€te**). Minor amounts of chert and ironstone are also locally present

€n — **Nasons Formation (Cambrian)**—Quartzite, siltstone, and granule conglomerate

€Zt — **Tomahawk Creek Formation (Cambrian? or Late Proterozoic?)**—Green and phyllite and graywacke

Zc — **Catoctin Formation (Late Proterozoic)**—Greenstone, green phyllitic tuff and greenschist fragmental rocks (brecciated pillows?)

Contact—Dotted where concealed

Fault—Normal, reverse, and strike slip. Dotted where concealed

Thrust fault—Sawteeth on upper plate

Mountain Run Fault Zone

arc basin, which, to the east, was bounded by a volcanic island-arc terrane of Cambrian age (Pavlides, 1981). The island-arc and back-arc basin terranes are allochthonous and probably were thrust westward onto the continental margin during the Taconic orogeny at the end of the Ordovician (Pavlides, 1989).

STRATIGRAPHY

The continental margin deposits are weakly metamorphosed and folded, and have a slaty cleavage. The metavolcanic Catoctin Formation consists of metavolcanic greenstone and greenstone fragmental rocks, and is at greenschist facies of metamorphism. It has a foliation that trends similarly to that of the slaty cleavage of the overlying metasedimentary deposits.

TOMAHAWK CREEK FORMATION

This lenticular formation occurs within one small fault block immediately south of the town of Orange (panel A, fig. B1). It was originally informally named the "Tomahawk Creek formation" by Pavlides (1990) and is herein formally designated the "Tomahawk Creek Formation" after Tomahawk Creek, which crosses the area of outcrop. The scattered outcrops of graywacke and phyllite north and south of Tomahawk Creek are designated the type area of the formation. On the assumption that it is a southeast dipping homoclinal sequence in this area, the formation ranges from a thickness of about 300 m to almost zero at its southwestern end. Its upper and lower contacts are not exposed and it may rest unconformably on the Late Proterozoic Catoctin Formation as well as be unconformably overlain by the Nasons Formation (new) of Cambrian age described below. The Tomahawk Creek Formation, therefore, is provisionally assigned a Late Proterozoic(?) or Cambrian(?) age. At present the only known correlative of the Tomahawk Creek Formation along strike to the southwest is, in part, the BRA unit of Rossman (1991, pl. 1).

The Tomahawk Creek Formation occurs at about the same stratigraphic position as the Loudoun Formation, which occurs on both flanks of the Blue Ridge anticlinorium (Whitaker, 1955; Nickelsen, 1956). The Tomahawk Creek and Loudoun Formations are, in general, lithologically dissimilar and the nature of the Loudoun has been somewhat controversial. The generally accepted view of the Loudoun is that it is of Cambrian age and that it occurs as a mappable unit between the Catoctin Formation of Late Proterozoic age and the Weverton Formation of Cambrian age (McDowell and Milton, 1992). The Tomahawk Creek Formation also occurs between the Catoctin and Nasons Formations—a possible correlative of the lower part of the Weverton (see below). Provisionally, the Tomahawk Creek is considered, in part, as a possible stratigraphic correlative of the Loudoun Formation.

NASONS FORMATION

This lenticular formation was informally designated as an unnamed Cambrian quartzite (€q) by Pavlides (1989, fig. 2) and, subsequently, as an unnamed Cambrian quartzite-siltstone-granule conglomerate (Pavlides, 1990). It is herein named the Nasons Formation after the community of Nasons where it is exposed in the farm fields on either side of Route 600 about 1 km northwest of Nasons (panel B, fig. B1), which is designated as its type area.

At the designated type area, the Nasons Formation is primarily a pea-sized granule quartz conglomerate but locally grades to finer and coarser grain sizes. Where it wedges out to the northwest approximately 2.1 km northeast of the community of Nasons (panel B, fig. B1), granule quartz conglomerate is a minor lithology of the formation. The granule conglomerate is successively overlain to the southeast by quartz meta-arenite (quartzite) and then siltstone. Thin sections show the meta-arenite is poorly sorted, with well-rounded quartz grains. More angular, silt-sized quartz makes up the matrix. All quartz grains show undulose extinction and some are fractured. The rock texture ranges from clast supported to matrix supported within the area of a single thin section. Some of these siliciclastic rocks are cross bedded or contain channel scours that indicate the formation is facing to the southeast, where it is overlain by the True Blue Formation (new) described below. Farther along strike to the northeast, quartzite of the Nasons Formation is exposed in a few scattered outcrops (too small to show on fig. B1) that are between the Catoctin and True Blue Formations. The Nasons Formation is considered to be a lenticular deposit ranging from zero to as much as 125 m thick. Its contacts with its enclosing rocks are not exposed. The Nasons is apparently a siliciclastic deposit that may locally unconformably overlie the Catoctin (Zc) and the Tomahawk Creek (€Zt) Formations (fig. B1) and, in turn, is unconformably overlain by the True Blue Formation. It is provisionally assigned a Cambrian age and considered to be, in part, correlative with part of the Weverton Formation and basal part of the Chilhowee Group exposed elsewhere along the flanks of the Blue Ridge anticlinorium.

TRUE BLUE FORMATION

This formation is named after the crossroads of True Blue where scattered outcrops of the formation are exposed. It was informally designated the "True Blue formation" by Pavlides (1987, 1990) and is herein formally so designated.

The True Blue Formation is presumed to unconformably overlie both the lenticular Nasons Formation (€n) and the Catoctin Formation (Zc). It is bounded on its southeastern side by the Mountain Run fault zone, which locally encloses part of it. The True Blue occurs in a continuous outcrop belt from the Boswells Tavern quadrangle northeastward into the Unionville quadrangle (fig. B1). There, on its north side, the True Blue is in fault contact or is unconformably overlain by siltstone, arkose, conglomerate, and basaltic rocks of Mesozoic age of the Culpeper basin (panel B, fig. B1). Farther to the northeast, the True Blue is interpreted to be present in several isolated fault slices, along with the Everona Limestone Member (panel C, fig. B1) described below.

The True Blue Formation is primarily a gray, generally slaty to locally phyllitic metasiltstone or metamudstone that weathers tan-to-buff. Other lithologies locally include lenses of quartzite, graywacke, calcareous slate and slaty limestone, black chert, carbonate and oxide ironstones, and platy limestone of the Everona Limestone Member.

Slate.—Tan-to-buff weathered slate is the most common lithology of the True Blue Formation. These rocks locally are phyllitic, especially near the Mountain Run fault zone. The slate consists mostly of fine-grained white mica, quartz, carbonate, and chlorite. The mineral grains all show a dimensional alignment conformable with the planar orientation of slaty cleavage.

Argillite.— Laminated argillite is present near the base of the True Blue Formation. The argillite is well exposed at the intersection of Routes 522 and 611, about 4.9 km north of Everona (panel B, fig. B1). These rocks are tan-weathered and finely laminated with vertical slaty cleavage at an angle to the inclined right-side-up bedding. Graded bedding is present in some of the thin bedded layers. In thin sections, the argillite consists of quartz-rich siltstone laminae with interleaved micaceous laminae of fine-grained white mica, chlorite, and some carbonate. A stained, white-weathered argillite was encountered from within the True Blue in a drill core that, in thin section, contains abundant silt-sized quartz as well as angular to subhedral clast of feldspar. The abundance and morphology of this feldspar suggests it may be of volcanic pyroclastic origin. This rock is therefore interpreted to be a local air-fall tuff within the True Blue Formation.

Chert.—Scattered angular blocks of black, finely laminated chert occur locally. This rock is a carbonaceous, cryptocrystalline chert with small-scale preconsolidation faults offsetting laminae. Euhedral pyrite is accessory.

Locally, phyllitic rocks of the True Blue Formation within the Mountain Run fault zone contains black, carbonaceous quartzose mylonite in boudins up to 1 m long and 0.5 m thick. A black carbonaceous chert as described above may have been the protolith of this mylonite. Black carbonaceous chert lenses or layers, therefore, may occur at several stratigraphic levels within the True Blue Formation.

Phyllite, calcareous phyllite, and impure metalimestone.—These rocks of the True Blue Formation occur mostly within the northwestern part of the Mountain Run fault zone. Manmade excavations and cores from drill holes provided the best samples of these lithologies.

The phyllites are believed to be more highly deformed slaty rocks of the True Blue, but the metalimestones are probably stratigraphically nearer the top of the formation as exposed within the Unionville quadrangle. The phyllite is a fine-grained micaceous rock consisting, in thin section, of white mica, chlorite, and finely dispersed silt-sized quartz grains. Some compositional layers are micaceous, whereas others are quartzose (silty). Steeply dipping to vertical layer-parallel foliation is a characteristic feature of the phyllite and kink bands that dip at a shallow angle commonly crenulate the steeply dipping foliation. The axial surfaces of kink bands locally are thrust faults.

Calcareous phyllite contains fine-grained carbonate as an essential mineral, which occurs mostly disseminated or in thin impure laminae that contain sparse quartz and mica. Such calcareous phyllite grades into layers of impure limestone. Some of the carbonaceous folia originally may have formed as stylolites.

Impure limestone is gray, fine-grained, and readily reacts with hydrochloric acid. It characteristically is composed of finely crystalline calcite with sparse silt-sized quartz suspended and dispersed within the carbonate matrix. Quartz silt also occurs as thin layers with scattered calcite grains. Thin laminae of quartz and mica are also present. Dimensional orientation of grains in the metalimestone imparts a cleavage that is a layer parallel foliation as in the phyllite.

Ironstone.—Scattered float fragments of carbonate ironstone are locally present at various places within the outcrop belt of the True Blue Formation, indicating the presence of such ironstone layers in the substrate. Hematitic ironstone, which displays spherulitic texture, crops out at one place in contact with calcareous slate.

Thickness.—The thickness of the True Blue Formation is difficult to evaluate because of its folded nature and because its eastern and presumably younger part merges into, and eventually becomes part of, the Mountain Run fault zone. Judging from the width of its outcrop area and from the geometric relations deduced for folds that have deformed it, the formation probably is at least 600 m thick.

Age.—The age of the True Blue Formation is deduced as Cambrian(?) and (or) Ordovician(?) on indirect evidence, as datable fossils have not been found in it. Jonas (1927, p. 842–843) reported finding undatable trilobite fragments "in sandy beds near the contact of blue limestone south of Orange," but neither this locality nor her collection have been recovered subsequently.

The age of the True Blue cannot be closely constrained based strictly on its contact relationships with other formations and because it is bounded by and, in part, included within the Mountain Run fault zone on its west side. However, on the basis of these field relationships, the True Blue is older than the Mesozoic Culpeper Basin rocks and younger than the Late Proterozoic Catoctin Formation (Zc), which it overlies.

A tectonic model proposed for the central Virginia Piedmont and part of the Blue Ridge provinces (Pavlides, 1989) implies that the Paleozoic True Blue Formation, its Everona Limestone Member, and the subjacent Nasons Formation were deposited on Blue Ridge rocks that include the Tomahawk Creek and Catoctin Formations, which formed a continental margin beginning in Cambrian time. These Paleozoic rocks were the western part of a back-arc basin age that was bounded on its oceanward (eastern) side by the Central Virginia Volcanic-Plutonic Belt (Pavlides, 1981, 1989) of Cambrian age. The deformed mélange zones of the Mine Run Complex (see below) are believed to be remnants of back-arc basin rocks and are intruded by the Lahore pluton, which is dated at about 452 Ma or Late Ordovician age (Pavlides and others, 1994). Therefore, in so far as this model has merit, the True Blue Formation is older than 452 Ma and younger than the Late Proterozoic Catoctin Formation. Thus, the True Blue Formation provisionally is assigned a Cambrian(?) and (or) Ordovician(?) age.

EVERONA LIMESTONE MEMBER

Anna I. Jonas (1927, p. 842–843) applied the name Everona Limestone to a belt of blue slaty limestone that was described as extending from Mitchells Ford on the Rapidan River to southwest of the Rivanna River near Charlottesville, Va. The type locality for the Everona was originally established by Jonas (1927) as near Everona, Va. (fig. B1). She considered this belt of rocks to have an average width of 2 mi (3.2 km) and to occupy a valley northwest of the

Wissahickon Schist of her usage. She also suggested that the Wissahickon Schist was overthrust westward onto the Everona Limestone along a strand of the Martic thrust. These geologic features are shown on the Geologic Map of Virginia (Nelson, 1928).

Mack (1965), however, has mapped the Everona Formation as a limestone unit less than 200 m thick (Mack, 1965, pl. 1) that extends from Rockfish Creek in Albermarle County, Va., up to the Potomac River. He describes the unit as containing five lithologic varieties in different proportions, namely (1) banded limestone, 60 percent; (2) massive limestone, 10 percent; (3) slaty limestone, 8 percent; (4) ferruginous limestone, 4 percent; and (5) black slate, 9 percent. Mack's mapped distribution and thickness of the Everona Formation is, in general, that used on the Geologic Map of Virginia compiled by Milici and others (1963). On that map the Everona Limestone is shown as enclosed by and extending across four different lithologic units. The usage of Mack (1965) and Milici and others (1963) therefore contrasts with the original definition of the Everona Limestone applied by Jonas (1927).

The Everona is here designated as a lenticular, as well as tectonically broken, limestone member of the True Blue Formation. The Everona Limestone Member is considered to have been deposited as lenses (Pavlides, 1987) rather than as a contiguous formation of regional extent as mapped by Mack (1965). It is proposed that some of these lenticular deposits are pull-apart masses and that some of them locally were complexly folded by a later deformation as well. These structural differences in style of deformation are best seen in the lens of Everona Limestone Member centered about 1.8 km northeast of Gordonsville (panel A, fig. B1). There, the Everona Limestone Member is complexly deformed, containing doubly plunging folds as well as shear zones. In contrast, the Everona Limestone Member centered about 2.2 km northwest of Nasons is generally undeformed except for a few beds with convolute layering. The change in structural style of the Everona Limestone Member along strike is believed to be due to differences related to differential tectonic stress distribution along and within the Mountain Run fault zone. Mapping by Rossman (1991, pl. 1) along the Mountain Run fault zone in contiguous terrane southwest of the area in figure B1 also indicates that the Everona Limestone Member is not a continuous unit as shown by Mack (1965, pl. 1). Rossman's map shows Everona Limestone as being elongate, thin masses that are in fault contact along their southeast side with the Mountain Run fault zone.

Lithology.—The Everona Limestone Member as used herein is a gray-blue, fine-grained, thin-bedded, and finely laminated silty to nearly pure metalimestone. In thin section, the limestone is a finely laminated, fine-grained, and locally has thin laminae of carbonaceous matter. Quartz occurs as fine-grained clastic grains suspended in the calcitic matrix or in irregular, discontinuous laminae. Euhedral pyrite crystals are sparsely present. Calcite veinlets crosscut bedding at a high angle.

Judging from the studies of Mack (1965, pl. 1) and my own mapping, outcrop widths of about 160 m are probably reasonable for the Everona. If the assumption is made that some of these Everona lenses are free of structural complication, then this figure of about 160 m is acceptable as general maximum thickness for the Everona.

Age.—Jonas (1927, p. 843) assigned an Ordovician age to the Everona on the basis of what she considered its lithologic similarity to the Frederick Limestone of Maryland, which at that time was dated as Ordovician in age. Since then, Reinhardt (1974) has subdivided the revised Frederick Formation into three members and assigned a Late Cambrian age to it, and an Early Ordovician age to the overlying Grove Formation. The descriptions published by Reinhardt (1974) for the Frederick and Grove Formations of Maryland and comparisons by me in the field of these formations with the Everona Limestone Member of the True Blue Formation in Virginia do not indicate any great lithologic similarities between these Maryland and Virginia rocks.

Because of the lack of definitive paleontologic data as to the age of the Everona Limestone Member, it is assigned a similar provisional Cambrian(?) and (or) Ordovician(?) age as the enclosing True Blue Formation.

MÉLANGE ZONE IV OF THE MINE RUN COMPLEX

This Cambrian and (or) Ordovician mélange zone is bounded on its western side by the Mountain Run fault zone and on its eastern side by the inferred thrust fault that separates it from mélange zone III (Pavlides, 1989, 1990). Southwestward, beyond the map area, mélange zone IV apparently merges into, or is a continuation of, some of the phyllitic rocks assigned to the Lower Cambrian(?) Candler Formation of the Evington Group. Mélange zone IV contains few exotic blocks in the map area. However, some large mafic-ultramafic masses, enclosed within what has been mapped as Candler Formation by others, have been interpreted as exotic blocks within this mélange zone.

MOUNTAIN RUN FAULT ZONE

The Mountain Run fault zone is a regional geologic and topographic feature of central Virginia (Pavlides, 1986) that was considered by Jonas (1927) to be a strand of the Martic fault of Maryland and Pennsylvania. Within the Unionville quadrangle, Mountain Run, for which the Mountain Run fault zone is named, flows northeastward for a considerable distance within this zone (fig. B1). The fault zone has also been mapped for a considerable distance along strike beyond the area in figure B1 by Rossman

(1991) and Conley (1987). Two prominent linear scarps (described below) occur within the Mountain Run fault zone. The Mountain Run fault zone has a highly variable width and is defined as a zone on the basis of its variable width and because it includes rocks of the True Blue Formation as well as parts of the Mine Run Complex.

LITHOLOGIES WITHIN THE MOUNTAIN RUN FAULT ZONE

Phyllite and phyllonite.—The most abundant rock type within the Mountain Run fault zone is green to greenish-gray phyllite. Phyllite occurs in a continuous belt of varying width that extends from the northeast end of the Germanna Bridge quadrangle southwestward into the Boswells Tavern quadrangle (fig. B1). In many places this highly deformed phyllite has a fish-scale structure related to the wavy, anastomosing foliation surfaces, which form a phacoidal foliation that characterizes this rock. The Mountain Run fault zone is widest near Everona, but is not closely constrained there. The limiting eastern boundary of the bulge is defined by the last recognized occurrence of phyllite with weakly developed fish-scale or button-schist structure. Phyllite with fish-scale structure is irregularly interspersed with less deformed phyllite within this bulge of the Mountain Run fault zone.

Milky quartz veins are folded, pulled apart, and locally formed into small boudins, which, together with the phacoidal foliation, impart a gnarled appearance to phyllite and phyllonite in outcrops, particularly along some of the scarps. Some folia and laminae are folded, and locally, the phyllite is broken and sheared and forms a breccia. The complex deformation that characterizes the phyllite and phyllonite is especially notable in thin section. In outcrops, the prominent vertical to steeply dipping phacoidal foliation and the folded and sheared quartz veins are the characterizing structural features of these rock. Less conspicuous foliations of several generations are indicated by the variously oriented intersection lineations visible on the phacoidal foliation surfaces. At several places along strike within the Mountain Run fault zone, compositional layering is folded into mesoscopic dextral (Z) folds with steep to vertical plunges.

Petrographically, the phyllite consists mostly of quartz and white mica, and locally, lesser amounts of chlorite and chloritoid. Most of the quartz occurs either in laminae, which represent original sedimentary bedding, or in quartz veins and lensoid masses. White mica is in folia concordant in many places to the quartz rich laminae, forming layer-parallel foliation that represent limbs of mesoscopic and microscopic isoclinal folds. The nose of such early isoclinal folds can be seen as sheared remnants enclosed by layer-parallel foliation at a few places in several thin sections.

Chlorite occurs as discrete grains along foliation or in clots near hinge areas of folds. The chlorite is considered to have formed through greenschist-facies regional metamorphism. Fine-grained chloritoid of two generations is also present in several places. It occurs along layer-parallel foliation as aligned grains parallel to the foliation, even where this foliation has been folded. In addition, second generation elongate chloritoid is parallel to the axial surfaces of chevron folds.

Mylonite and breccia.—The types of rocks underlying the valley of Mountain Run within the Mountain Run fault zone are poorly known. Almost all of the lithologic information available for this area comes from four shallow drill holes that penetrated bedrock for only a short distance in the Unionville quadrangle. Furthermore, the drill core intercepted a very narrow lithologic interval in each hole because the vertical drill holes invariably penetrated steep- to vertical-dipping rocks with layer-parallel foliation.

Mylonitic, carbonaceous phyllite, and carbonaceous and micaceous metalimestone were encountered in only two of the core holes. Much of the ductile deformation in these rocks was by movement along the carbonaceous folia. Some of these folia are ornamented with subhorizontal striations. Thus, the last recorded movement within these rocks was apparently strike-slip, but the sense of movement could not be determined in the unoriented and broken core. Some of the carbonaceous folia and laminae, particularly in the micaceous and quartzose metalimestone beds, may have formed originally as stylolites because of pressure solution, and subsequently became slip planes during ductile deformation and produced mylonitic phyllite. Later, brittle deformation produced fault breccia from such phyllitic mylonite.

The mylonitic, carbonaceous, calcareous, and noncalcareous rocks encountered in drill holes are considered to be deformed segments of the True Blue Formation within the northwest margin of the Mountain Run fault zone. Mylonite is exposed along the subdued upland on the southeast side of the Mountain Run fault zone in the Rapidan quadrangle (panel B, fig. B1). Here, quartz veins and quartzose metasedimentary rocks have been deformed into mylonite with fluxion texture.

SCARPS

On the southeast side of Mountain Run, along most of its course within the Unionville quadrangle (fig. B1), there is a conspicuous, linear northeast-trending scarp, named the Mountain Run scarp (Pavlides, 1986, 1990). This scarp (fig. B1, MRs) clearly has controlled the northeasterly flow direction of Mountain Run and the alignment of its associated northeast-trending valley. At its northeastern and widest portion, the valley terminates essentially where the scarp ends and Mountain Run abruptly changes course from a northeasterly to an easterly flow.

Another northeast-trending scarp occurs along strike with, but slightly en echelon to, the Mountain Run scarp in the northeast corner of the Germanna Bridge quadrangle (panel C, fig. B1). This scarp has been named the Kellys Ford scarp (Pavlides, 1986) after Kellys Ford, which lies immediately to the northwest of this scarp (Pavlides, 1990). The Kellys Ford scarp (KFs) controls the southwest-flowing course of Marsh Run where this stream impinges against it before entering the Rappahannock River.

Deformed phyllite, lithologically similar to rocks exposed in the Mountain Run and Kellys Ford scarps, occur along strike in the area between these scarps. This intervening area between the scarps, especially the area between the Rapidan and Rappahannock Rivers, is locally covered by colluvium. Undeformed diabase dikes of Jurassic(?) age cut rocks of the Mountain Run fault zone at several places so that major thrusting, strike-slip movement, and associated mylonitization and brecciation within this fault zone occurred in pre-Jurassic time. The Kellys Ford and Mountain Run scarps (Pavlides, 1986) are interpreted as Cenozoic (possibly Pleistocene) fault-line scarps, formed by normal faults, with the scarp-bearing blocks being on the upthrown side. Subdued upland terrane on the northwest side of the Mountain Run fault zone locally contains small surficial deposits of sand and gravel. The absence of these deposits on the southeast side of the scarps suggests that the surficial deposits were removed by erosion as a consequence of uplift related to faulting. Furthermore, the deep weathering characteristic of the Piedmont province has resulted in generally subdued topography throughout the province. Therefore, the preservation of the Kellys Ford and Mountain Run scarps also suggest these scarps are relatively young.

A young small-scale thrust fault was exposed within rocks of the True Blue Formation in the Mountain Run fault zone about 400 m southwest of Everona (Pavlides and others, 1983). There, an upland stream channel deposit is cut by a northeast-trending thrust fault that dips 20° to the southeast and has a throw of about 1.5 m. Saprolitized phyllite of the True Blue Formation is clearly overthrust northwestward upon the basal gravel of the stream channel deposit. The tectonics responsible for this minor late Cenozoic thrust faulting are enigmatic. Speculatively, it may be related to the movements involved with the formation of the nearby Mountain Run scarp or related movements.

SUMMARY AND CONCLUSIONS

The Late Proterozoic metavolcanic Catoctin Formation (Zc) and the Late Proterozoic(?) or Cambrian(?) Tomahawk Creek Formation (€Zt) are considered to be the basement of ancestral North America (Laurentia) upon which the various continental margin sedimentary deposits of early Paleozoic age accumulated. The earliest continental margin deposit in the area is the lenticular siliciclastic Nasons Formation of Cambrian age, which unconformably overlies the basement rocks. The Nasons Formation was followed by the argillaceous, arenitic, and calcareous sediments of the True Blue Formation. Speculatively, as rocks of the True Blue were accumulating, lenses of ironstone and chert were chemically deposited at various levels within the True Blue. The iron and silica needed to form ironstone and chert deposits probably were supplied by the influx of iron- and silica-rich waters from the back-arc basin (Pavlides, 1989) that lay to the east of the continental margin. In and along this back-arc basin, volcanic activity was occurring from time to time from the Cambrian into the Ordovician and periodically may have locally enriched the back-arc basin seas with silica and iron. Such chemical contributions could have been supplied by the Cambrian island-arc chain of the Central Virginia Volcanic-Plutonic Belt that bordered the back-arc basin on its east side or by volcanism from elsewhere within the back-arc basin, as attested to by the volcanic rocks contained in O€mIVv of the Mine Run Complex (fig. B1). The ash bed from within the True Blue Formation also indicates volcanism during the accumulation of the True Blue Formation sediments. Finally, as the True Blue sediments accumulated and prograded eastward into the back-arc basin, limestone of the Everona Limestone Member of the True Blue Formation formed as a fairly laterally extensive offshore deposit.

The island-arc and back-arc Mine Run Complex deposits underwent Cambrian and Ordovician deformational events (Pavlides, 1989) before being thrust westward upon the continental margin deposits along the Mountain Run fault zone at the close of the Ordovician. During this thrusting event, the Everona Limestone Member of the True Blue may have been locally fragmented and deformed and, in places, incorporated as fault slices or horses within the deformed True Blue Formation now contained in the Mountain Run fault zone. Probably, slightly prior to and during the major thrusting along this fault, some rocks were impregnated extensively by quartz veins. The quartz veins were then folded and broken during the major episode of movement and produced the gnarled textures locally present along this fault.

The major thrust faulting along the Mountain Run fault zone is interpreted to have occurred at the end of the Ordovician. Since then, the fault underwent dextral strike-slip movement and local brecciation. This strike-slip movement occurred prior to the middle Mesozoic because the Mountain Run fault zone rocks are cut by undeformed basaltic dikes of Jurassic age. It was this strike-slip deformation that probably resulted in pulling apart the lenses of the Everona Limestone Member and locally folding them complexly. Finally, local vertical to steep faulting, which occurred in the Cenozoic, possibly in the Pleistocene, developed the Mountain Run and Kellys Ford scarps along the upthrown blocks. It is also probable that the minor thrust southwest of Everona formed within the True Blue Formation of the

Mountain Run fault zone late in the Cenozoic, possibly from stresses imposed when the scarps were formed.

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