Tectonic Implications of the Indian Run Formation— A Newly Recognized Sedimentary Mélange in the Northern Virginia Piedmont

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By Avery Ala Drake, Jr.

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By AVERY ALA DRAKE, JR.

ABSTRACT

Sedimentary mélange in the northeastern part of Fairfax County, Virginia, contains both mesoscopic and mappable fragments of Accotink Schist, Lake Barcroft Metasandstone, metagabbro, and ultramafic rocks as well as smaller fragments of other rock types. This mélange was originally mapped as the Sykesville Formation, a major precursory sedimentary mélange in northern Virginia and Maryland. The fragments of Accotink Schist and Lake Barcroft Metasandstone within the Sykesville were considered to be rip-ups of these units over which the Sykesville slid when finally emplaced. More recent study has shown that fragments of Accotink and Lake Barcroft are restricted to a certain area of sedimentary mélange originally defined as Sykesville, and this part of the mélange is now considered to be a separate mappable unit, here named the Indian Run Formation. The Indian Run underlies the sequence Accotink Schist and Lake Barcroft Metasandstone which is here formally named the Annandale Group. The Indian Run is intruded by the Occoquan Granite of Cambrian age, so it is of Cambrian or Late Proterozoic age.

The Sykesville Formation (restricted) is a much more extensive unit than the Indian Run Formation and is characterized by its contained olistoliths of the Peters Creek Schist, the unit that tectonically overlies it. The Sykesville and Peters Creek constitute a precursory mélange-allochthon pair which is here termed a "tectonic motif." The Indian Run-Annandale pair then forms a tectonically lower motif, and the overlying pair, the Yorkshire Formation-Piney Branch Complex, forms a tectonically higher motif. The Chopawamsic Formation and underlying sedimentary mélange in the area south of Fairfax County may form a tectonic motif beneath the Indian Run-Annandale tectonic motif. Thus, three and perhaps four repetitions of precursory mélange-allochthon pairs occur in northern Virginia. Other percursory mélanges and motifs may occur in the Maryland Piedmont to the north.

The tectonic setting of the motif formation and assemblage is uncertain at this time. A model involving the obduction of several separate sheets onto the ancestral North American continental margin is appealing in that it involves the closing and destruction of a marginal basin, a relatively simple concept. This model fails, however, to supply a source for the sediment necessary to form the precursory mélanges. A trench-slope origin would supply the vast amount of needed sediment by accretion. The precursory mélange-allochthon motifs would then be stacked near the base of the trench slope. This model is appealing and requires a rather complicated assemblage of continental, arc, and oceanic fragments, such as those that occur on many modern continental margins.

INTRODUCTION

In recent years, Drake (1980) and Drake and Morgan (1981, 1983) have recognized the importance of precursory sedimentary mélanges (Elter and Trevisan, 1973) as tectonic indicators in the central Appalachian Piedmont. These mélanges contain small to very large fragments of rock units that now lie tectonically above them and thereby mark the boundaries of allochthons. The mélange and its overlying allochthon constitute a pair termed a "tectonic motif." Two such motifs, the Sykesville Formation-Peters Creek Schist and the Yorkshire Formation-Piney Branch Complex, have been mapped and described in the northern Virginia Piedmont (Drake and Lyttle, 1981; Drake and Morgan, 1981, 1983; Drake and others, 1979). In the eastern part of Fairfax County, Virginia, a problem has existed within the sedimentary mélange originally mapped as Sykesville Formation (Drake and others, 1979; Drake and Lyttle, 1981). The Sykesville as mapped in that area contains, in addition to exotic rock types, fragments of Accotink Schist and Lake Barcroft Metasandstone, rocks that tectonically underlie the Sykesville sedimentary mélange. This relation presents a structural dilemma in that a mélange contains fragments of a unit upon which it was supposed to have moved. This problem was rationalized (Drake and Lyttle, 1981) by considering the fragments of Accotink and Lake Barcroft to be rip-ups or possibly to be units that constituted a giant olistolith within the Sykesville. More recent reexamination of critical exposures in the field led to the recognition that the olistoliths of Accotink Schist and Lake Barcroft Metasandstone are not in the Sykesville Formation at all but are in an entirely different sedimentary mélange that lies beneath rather than above the Accotink and Lake Barcroft. This mélange is thought to be a precursory mélange to the allochthonous Accotink and Lake Barcroft as the Yorkshire Formation is to the Piney Branch Complex and as the Sykesville is to the Peters Creek Schist, thereby constituting a third tectonic motif in this part of northern Virginia (pl. 1). The primary purpose of this paper is to describe this newly recognized mélange and to name it the Indian Run Formation.

The Accotink Schist and Lake Barcroft Metasandstone lie between two mélanges, and in a sense, then, could be considered to constitute a megaolistolith within a mass of sedimentary mélange. The Eastern Fairfax sequence that is composed of the Accotink Schist and Lake Barcroft Metasandstone (Drake and Lyttle, 1981) is here formally named the Annandale Group.

The data for this paper were collected during detailed geologic mapping of the crystalline rocks of Fairfax County, Virginia, at the scale of 1:24,000 that resulted in a preliminary geologic map of Fairfax County (Drake and others, 1979) at the scale of 1:48,000.

REGIONAL GEOLOGY

The metamorphic rocks in northernmost Virginia occur in a stack of six lithotectonic units. These units, from highest to lowest, are the Popes Head Formation; the Piney Branch allochthon; the Peters Creek Schist, which constitutes the Potomac River allochthon; the Sykesville Formation; the Annandale Group (here named); and the newly recognized Indian Run Formation (here named). Most of these metamorphic rocks are intruded by the Occoquan Granite, the Falls Church pluton (Steidtmann, 1945), and several smaller secondary plutons of tonalite (Drake and Lyttle, 1981; Seiders and others, 1975; Seiders and Mixon, 1981). Only the northern part of the Occoquan batholith crops out in this area. Most of the Occoquan is monzogranite, but it has granodiorite and tonalite phases. The northern border of the batholith appears to be largely tonalite, and it has been suggested that the batholith may be a composite intrusion (Drake and Lyttle, 1981). The Occoquan Granite has been dated at about 560 Ma by U-Pb technique on zircon (Seiders and others, 1975) and at 494±14 Ma by the Rb-Sr whole-rock technique (Mose and Nagel, 1982). The Occoquan Granite, therefore, is almost certainly of Cambrian age.

The small tonalite plutons in the area seem similar to the tonalite of the Occoquan batholith and may be apophyses of an as yet unroofed composite intrusion as suggested by Drake and others (1979). The Falls Church pluton is very poorly exposed, but most of the rocks therein are identical to the tonalite plutons and the tonalite of the Occoquan batholith. The batholith contains some trondhjemite, but the relation of the trondhjemite to the tonalite cannot be determined.

POPES HEAD FORMATION

The Popes Head Formation (Drake and Lyttle, 1981) unconformably overlies all the other lithotectonic units and consists of a lower Old Mill Branch Metasiltstone Member and an upper Station Hills Phyllite Member. Both of these members contain interbedded felsic and mafic metatuff. These rocks are graded but lack current-produced flow marks. They have been interpreted to belong to the Bouma (1962) turbidite sequence T_{de} and to Mutti's and Ricci Lucchi's (1978) turbidite facies D, suggesting deposition from weak turbidity flows, and to have resulted from the bilateral filling of a backarc basin (Drake and Lyttle, 1981). The typical mineral assemblage of rocks of the Popes Head Formation is quartz-muscovite-biotite-plagioclase, and they are at biotite grade. The unit has a maximum thickness of more than 1,000 m.

The Popes Head is intruded by the Occoquan Granite so is older than that plutonic unit and is either of Cambrian or Late Proterozoic age (Drake and Lyttle, 1981). It is unconformable upon the other metamorphosed rocks in this area (Drake and Lyttle, 1981; Drake and Morgan, 1981) and has had a much less severe tectonic history than those rocks (Drake and Lyttle, 1981; Drake and Morgan, 1981; Drake, 1983).

PINEY BRANCH ALLOCHTHON

The highest of the allochthonous lithotectonic units, the composite Piney Branch allochthon, consists of the Piney Branch Complex and the Yorkshire Formation. The Piney Branch Complex is an intimate mixture of metamorphosed ultramafic and mafic rocks which are now serpentinite, soapstone, actinolite schist, and metagabbro intruded by small dikes and sheets of plagiogranite. The Complex lacks discernible order and is thought 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, 1983).

YORKSHIRE FORMATION

The Yorkshire Formation forms a thin discontinuous lower border to the Piney Branch Complex. This rock has a quartz-plagioclase-chlorite matrix which is characterized by abundant light-colored, chalky feldspar grains that contrast markedly with the dark, chlorite-rich phyllosilicate component of the rock. It resembles neither the Sykesville nor Indian Run Formations. Set in this matrix are fragments of the overlying Piney Branch Complex as well as quartz and exotic rocks. The

Yorkshire has been interpreted to be a precursory mélange to the Piney Branch (Drake and Morgan, 1981, 1983). The Yorkshire's discontinuous nature is thought to result from partial shearing-out during transport of the composite Piney Branch allochthon, an interpretation supported by the phyllonitic nature of the Yorkshire near its lower contact. The Piney Branch allochthon thus has had a multiple movement history which involved the subaqueous emplacement of the Piney Branch Complex upon the Yorkshire and the "hard-rock" thrusting on the Oakton thrust fault of the composite allochthon upon the Peters Creek Schist. Rocks of both the Piney Branch Complex and Yorkshire Formation contain mineral assemblages characteristic of greenschist facies metamorphism.

Neither the Piney Branch Complex nor the Yorkshire Formation is intruded by the Occoquan Granite. These rocks, however, are unconformable beneath the Popes Head Formation which is intruded by that unit, so they must be either Cambrian or Late Proterozoic in age. Because of their complex history, they are likely Late Proterozoic.

PETERS CREEK SCHIST

The Peters Creek Schist, which constitutes the Potomac River allochthon, consists of quartz-rich schist and graywacke. Although the sedimentology of the unit has not been studied in detail as yet, its general characteristics suggest that it is a turbidite that was deposited under fairly high energy conditions in a large submarine fan (Drake and Morgan, 1981). In northern Virginia and Maryland, the Peters Creek characteristically contains large olistoliths of ultramafic rocks (Drake and others, 1979; Froelich, 1975) and is considered to be a type of ophiolitic mélange (Drake and Morgan, 1981, 1983).

The Peters Creek Schist is polymetamorphic, ranging in grade from chlorite in the west to sillimanite in the east. About coincident with the appearance of sillimanite, the rocks become migmatitic (fig. 1). About at Sherwin Island in the Potomac River (Drake and Morgan, 1981), the highest grade rocks and migmatites become severely sheared and are retrogressively metamorphosed to chlorite-sericite phyllonites. The final metamorphic event recognized in these rocks is the growth of chloritoid within shimmer aggregate pseudomorphs of staurolite, andalusite, and garnet (Drake, 1980); in places, new muscovite and biotite have also formed. The Peters Creek Schist lies above the Sykesville Formation on the Plummers Island thrust fault (pl. 1).

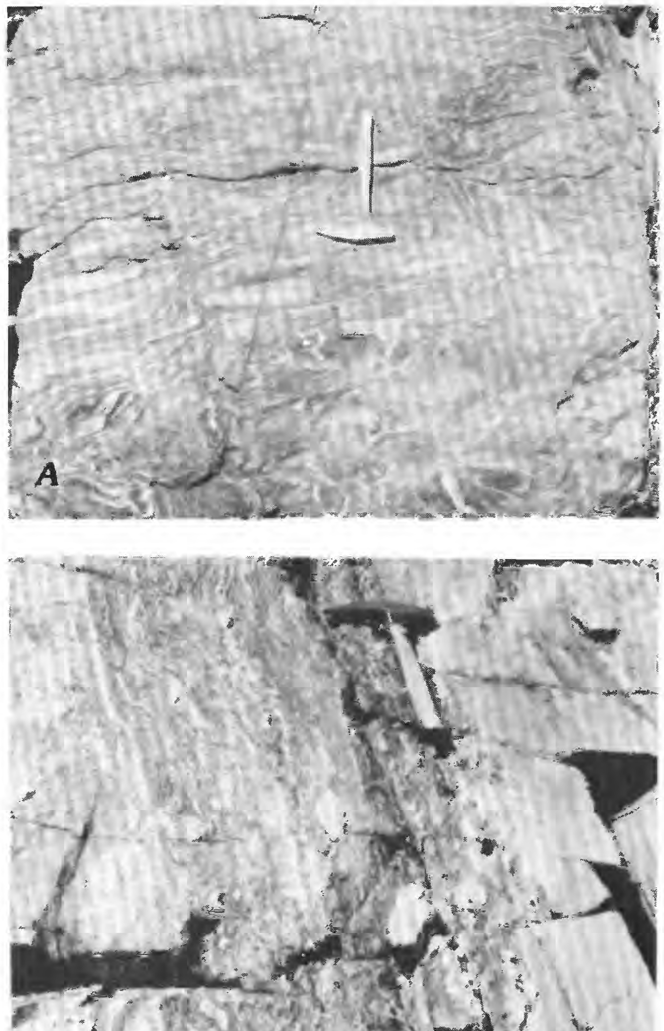

FIGURE 1.—Two outcrops of migmatitic Peters Creek Schist from confluence of Difficult Run and the Potomac River, northeast of the Falls Church quadrangle area, shown on plate 1. Note that the graywacke in *B* has not melted.

The Peters Creek Schist is not directly intruded by the Occoquan Granite. The Occoquan Granite does intrude the Sykesville Formation; the Sykesville, however, contains olistoliths of Peters Creek Schist so the

Peters Creek predates the Occoquan. The Peters Creek is intruded by the Falls Church pluton (Drake and Lytle, 1981; Drake and others, 1979) and lies unconformably beneath the Popes Head Formation which is intruded by the Occoquan granite. The Peters Creek then is of either Cambrian or Late Proterozoic age. Its complex metamorphic and structural history suggests that it is Late Proterozoic.

SYKESVILLE FORMATION

The Sykesville Formation is a complicated sedimentary mélange that has a light- to medium-gray, medium-grained, quartz-plagioclase-muscovite-biotite-chlorite matrix (table 1) that locally contains sparse amounts of garnet. Set in this matrix are characteristic quartz lumps as well as fragments of serpentinite (fig. 2), metagabbro, felsic and mafic metavolcanic rocks, Peters Creek Schist, and other exotic rock types. All outcrop-size or mappable olistoliths are either of the overlying Peters Creek Schist or of ultramafic and mafic rocks. The olistoliths of Peters Creek are invariably foliated and polydeformed and in many places are migmatitic (fig. 3). Directly beneath the overlying phyllonitized Peters Creek, the Sykesville is choked with fragments of Peters Creek phyllonite (Drake and Morgan, 1981; 1983). The olistoliths of ultramafic and mafic rocks were also deformed before being introduced into the Sykesville (Drake and Morgan, 1981, 1983).

Much of the Sykesville resembles medium-grained, very weakly foliated granite (see matrix in fig. 4 and pl. 1). At other places, however, the unit is more strongly foliated and resembles a granite gneiss. In fact, the unit is so granitic in appearance that in Maryland it was originally named the Sykesville Granite (Keyes, 1895), the olistoliths being considered inclusions. Cloos (Cloos and Cooke, 1953) first recognized the sedimentary origin of the unit, and Hopson (1964) proposed an origin by massive subaqueous sliding. This interpretation is supported by abundant field evidence such as soft sediment folding around protuberances of foliated, metamorphosed olistoliths (fig. 4).

The evidence presented above shows that the Peters Creek Schist was lithified, metamorphosed, deformed, migmatized, and phyllonitized prior to Sykesville deposition and that blocks of Peters Creek were emplaced during Sykesville deposition. The Peters Creek now overlies its own debris within the Sykesville on the Plummers Island thrust fault. The Sykesville then is a classic precursory mélange (Elter and Trevisan, 1973). All these data suggest that the Potomac River allochthon was emplaced subaqueously.

TABLE 1.—*Modes of Sykesville and Indian Run Formations*

[Percentages based on 2,000 points counted by the methods of Chayes (1949); sample no. locations described below]

	Volume percent				
	Sykesville Formation			Indian Run Formation	
Mineral Sample no.	1	2	3	4	5
Quartz	45.5	46.1	46.5	29.2	30.4
Plagioclase	14.3	11.5	14.2	24.2	21.9
Muscovite	25.6	27.7	23.2	32.1	33.2
Biotite	11.5	9.3	11.3	4.6	5.2
Chlorite	1.2	2.5	1.8	7.7	6.8
Garnet		.8	---	1.4	1.8
Epidote			.2	---	---
Opaques	1.9	1.8	2.8	.8	.7
Total	100.0	99.7	100.0	100.0	100.0

1. Outcrop in Lubber Run about 700 m north of Arlington Boulevard, Alexandria 7 1/2-minute quadrangle, Virginia. Rock is quite granitic in appearance and contains fairly abundant magnetite. Other outcrops in the area contain olistoliths of Peters Creek migmatite. Location is just to east of northeast corner of Annandale quadrangle on plate 1 (lat 38°52′18″, long 77°06′30″).
2. Outcrop on the south bank of the Potomac River about 2.3 km west of Key Bridge, Washington West 7 1/2-minute quadrangle, Virginia. Rock is quite granitic in appearance and contains abundant magnetite and some garnet. Location is northeast of northeast corner of plate 1 (lat 38°54′42″, long 77°04′06″).
3. Outcrop in unnamed stream just north of Old Dominion Drive about 500 m northwest of its intersection with Williamsburg Boulevard, Falls Church 7 1/2-minute quadrangle, Virginia. Location Z on plate 1 (lat 38°54′24″, long 77°09′12″).
4. Outcrop directly beneath spillway of Lake Barcroft, Annandale 7 1/2-minute quadrangle, Virginia. Rock contains abundant garnet (lat 38°50′30″, long 77°05′06″)
5. Outcrop in Fourmile Run about 200 m upstream from Wilson Boulevard, Falls Church 7 1/2-minute quadrangle, Virginia. Rock is mica- and garnet-rich and quite metasedimentary in appearance. Location Y on plate 1 (lat 38°52′36″, long 77°08′18″).

The mineral assemblage of the Sykesville suggests that it is at biotite±garnet grade, and there is no evidence of polymetamorphism. The olistoliths in the unit have not equilibrated to the apparent metamorphic regime experienced by the Sykesville.

The Sykesville Formation is intruded by and thus clearly predates the Occoquan Granite. It then is of Cambrian or Late Proterozoic age like the other metamorphosed rocks. The Sykesville, however, also contains fragments of metamorphosed, polydeformed Peters Creek Schist and unconformably underlies the Popes Head Formation. It, therefore, has not experienced the complex history of the Peters Creek but is older than the Popes Head. Although the formation must be considered to be of Cambrian or Late Proterozoic age, I believe that it is more likely Cambrian.

FIGURE 2.—Olistolith of serpentinite in Sykesville Formation in outcrop on Virginia bank of Potomac River directly opposite Glen Echo, Maryland, northeast of the Falls Church quadrangle area shown on plate 1.

FIGURE 3.—Peters Creek migmatite olistoliths in Sykesville Formation. *A*, Little Pimmit Run about 250 m upstream from its confluence with Pimmit Run, north of the Falls Church quadrangle area shown on plate 1. Migmatitic foliation in Peters Creek olistolith is transected at about right angles by the Sykesville Formation. *B*, Fourmile Run about 650 m upstream from Columbia Pike, Alexandria 7½-minute quadrangle, east of the area shown in plate 1. Swirly migmatite of Peters Creek olistolith is overlain by essentially nonfoliated Sykesville Formation.

ANNANDALE GROUP (here named)

The Annandale Group is here named after the city of Annandale, Fairfax County, Virginia, which is located about 800 m east of a large area of rocks included in the Annandale Group (pl. 1). The Group was originally included in the informal Eastern Fairfax sequence by Drake and Lyttle (1981). The Group was not formally named at that time because of the uncertainty of its relation to adjoining rocks. Because of the work reported herein, it seems plausible to formally name these rocks.

The Annandale Group lies above the newly recognized Indian Run Formation on the Red Fox thrust fault and is overlain by the Sykesville Formation on the Burke thrust fault (pl. 1). It consists of the lower Accotink Schist and the upper Lake Barcroft Metasandstone. Typical exposures of the group can be seen along Accotink Creek, Holmes Run, and Tripps Run. The Annandale Group was interpreted by Drake and Lyttle (1981) to be a coarsening-upward sequence of an outer submarine-fan association of rocks.

Rocks of the Annandale Group are intruded by the Occoquan Granite, tonalite, and the Falls Church pluton so they are of either Cambrian or Late Proterozoic age. They unconformably underlie the Popes Head Formation and have had a far more complex tectonic history (Drake and Lyttle, 1981; Drake, 1983) and are polymetamorphic (see below), whereas the Popes Head has experienced only a single metamorphism. For

FIGURE 4.—Foliation in the Sykesville around the protuberance of an olistolith of metagraywacke from the Peters Creek Schist. Soft sediment folding is suggested as the Sykesville Formation otherwise parallels the contacts with the olistoliths. Outcrop on Virginia bank of Potomac River directly opposite Offutt Island, northeast of the Falls Church quadrangle area shown on plate 1.

these reasons, the Annandale Group is likely Late Proterozoic although it must be considered Cambrian or Late Proterozoic.

ACCOTINK SCHIST

The Accotink Schist is a quartz-muscovite-biotite-chlorite-plagioclase (garnet-magnetite-epidote) schist that is characterized by turbidite sequences T_e and T_{de} of Bouma (1962) and is assigned to turbidite facies D and E of Mutti and Ricci Lucchi (1978) by Drake and Lyttle (1981). The Accotink is polymetamorphic and is at biotite±garnet grade (Drake and Lyttle, 1981). Its thickness is not known as its base is not exposed.

LAKE BARCROFT METASANDSTONE

The Lake Barcroft consists of two types of metasandstone: thick-bedded quartzofeldspathic granofels without interbedded schist and thin- to medium-bedded micaceous metagraywacke containing schist layers. The quartzofeldspathic granofels is a meta-arenite that has been interpreted by Drake and Lyttle (1981) to be a sequence of T_a turbidites (Bouma, 1962) and to belong to turbidite facies B_2 of Walker and Mutti (1973).

Micaceous metagraywacke has been interpreted by Drake and Lyttle (1981) to belong to turbidite facies C of Mutti and Ricci Lucchi (1978) and Walker and Mutti (1973).

The Lake Barcroft has experienced the same metamorphic history as the Accotink Schist and is at biotite±garnet grade. As much as 400 m of the unit are present in the area of the Annandale 7½-minute quadrangle.

INDIAN RUN FORMATION (here named)

The Indian Run Formation is here named for exposures along Indian Run from just southeast of the intersection of Little River Turnpike and Evergreen Lane (x on pl. 1) to the point at which the Run is crossed by Braddock Road in the Annandale quadrangle (pl. 1). The excellent exposure of the unit here is purely fortuitous, as Indian Run traverses at right angles across its outcrop width. Although most of the rock is saprolitized to some degree, the features of the previously deformed and metamorphosed olistoliths in the Indian Run matrix are remarkably evident. Other exposures are scattered and poor, but the Indian Run can be seen to good advantage below the spillway to the dam on Lake Barcroft (pl. 1, Annandale quadrangle) and along Fourmile Run on the boundary between the Annandale and Falls Church quadrangles (pl. 1). Like the Sykesville, the Indian Run has a quartz-plagioclase-muscovite-biotite-chlorite matrix, and in many places also contains abundant garnet. It appears to contain more plagioclase and phyllosilicates and less quartz than the Sykesville (table 1) and is generally finer grained than the Sykesville. Like the Sykesville it contains quartz lumps, but apparently fewer and smaller in size. In addition, the matrix contains fragments of foliated felsic and mafic metavolcanic rocks, metagabbro, and ultramafic rocks. The ultramafic fragments, either serpentinite or soapstone, range in size from microscopic to mesoscopic to mappable (fig. 5). Unlike the Sykesville, however, the Indian Run contains fragments of Accotink Schist and Lake Barcroft Metasandstone rather than Peters Creek Schist. All outcrop-size and mappable olistoliths in the Indian Run are of Accotink Schist, Lake Barcroft Metasandstone, metagabbro, or ultramafic rock (pl. 1).

At its type locality, the northernmost exposures of Indian Run are about 100 m southeast of Evergreen Lane, where the unit contains small to moderate-size fragments of Accotink Schist (pl. 1; fig. 6). About 230 m farther southeast along the Run, an olistolith of soapstone crops out (fig. 6). This olistolith has a length of about 169 m, a width of about 40 m, and is oriented essentially parallel to the foliation in the Indian Run, which strikes N. 55° E. and dips 60° NW., its internal structures being truncated by the contacts.

About 250 m farther southeast along the Run, an olistolith of Accotink Schist, about 300 m by 80 m in dimension, crops out. The schistosity in the Accotink strikes N. 70° W. and is about vertical, contrasting markedly with the foliation in the Indian Run which strikes N. 15° E. and dips 40° SE. About 150 m farther to the southeast, several "knockers" of extremely altered, fine-grained metagabbro (fig. 7) float in the Indian Run matrix.

An olistolith of Lake Barcroft Metasandstone, about 350 m by 100 m in size, crops out about another 200 m to the southeast and consists of the meta-arenite type of Lake Barcroft. The rock is isoclinally folded, the fold axes plunging 20° N. 65° W., and is approximately normal to the long dimension of the olistolith and to the foliation in the Indian Run. Another olistolith of similar meta-arenite crops out just west of the point where Old Columbia Pike crosses Indian Run. This body is about 300 m by 600 m in size. The bedding in the olistolith lies perpendicular to its long dimension and to the foliation in the Indian Run. Another olistolith of Lake Barcroft Metasandstone crops out about 280 m downstream, and an olistolith of serpentinite crops out about 180 m, even farther downstream. Here again, the foliation in these olistoliths strikes normal to the long dimension of the bodies and to the foliation in the Indian Run. Three olistoliths of the micaceous metagraywacke type of Lake Barcroft Metasandstone crop out farther downstream. One of these bodies shows

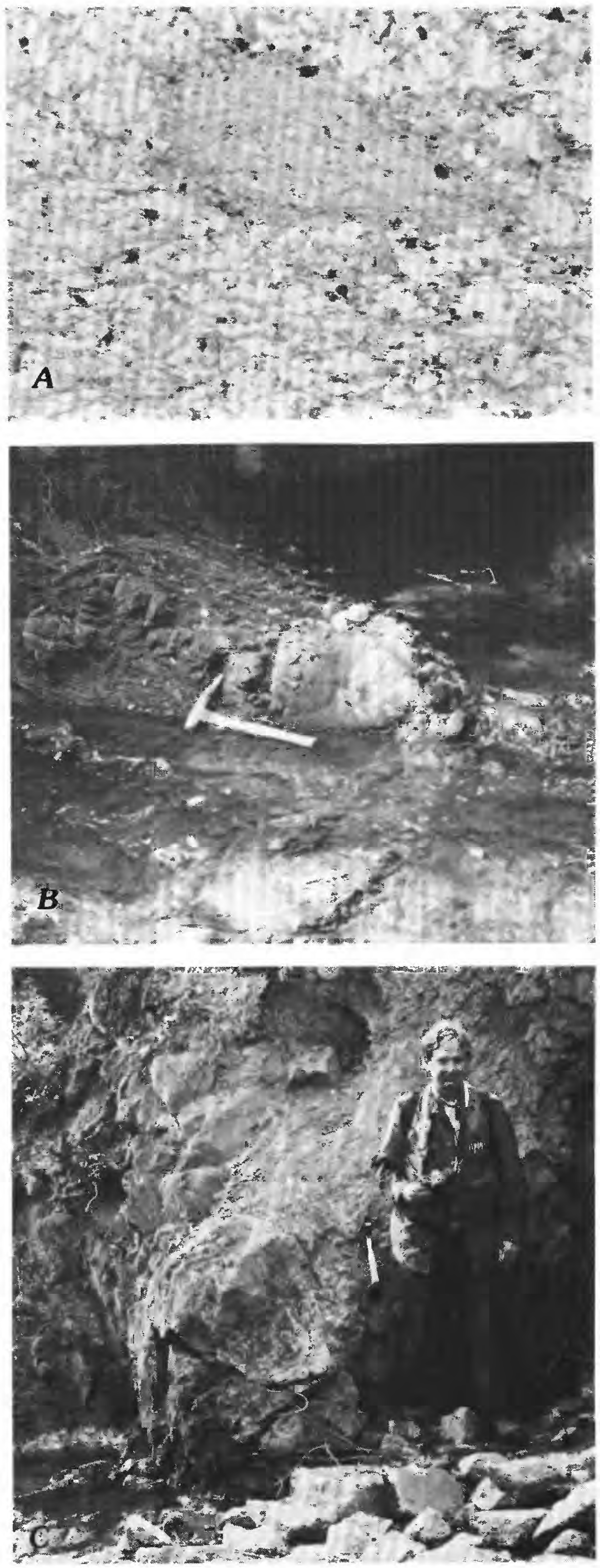

FIGURE 5 (right).—Ultramafic rock fragments in Indian Run Formation. *A*, Small fragments of serpentinite in the Indian Run Formation from outcrop on north side of Wilson Boulevard about 160 m west of Fourmile Run, Annandale quadrangle. Field of view is 275 cm^2. Unpolarized light. Photomicrograph by P. T. Lyttle. *B*, "Knocker" of soapstone in Indian Run Formation from outcrop at type locality about 430 m southeast of Old Columbia Pike, Annandale quadrangle. Photograph by P. T. Lyttle. *C*, Large body of soapstone in Indian Run Formation at type locality about 330 m southeast of Evergreen Lane, Annandale quadrangle. Hammer point is placed in contact which is approximately parallel to the foliation in the Indian Run. Photograph by P. T. Lyttle.

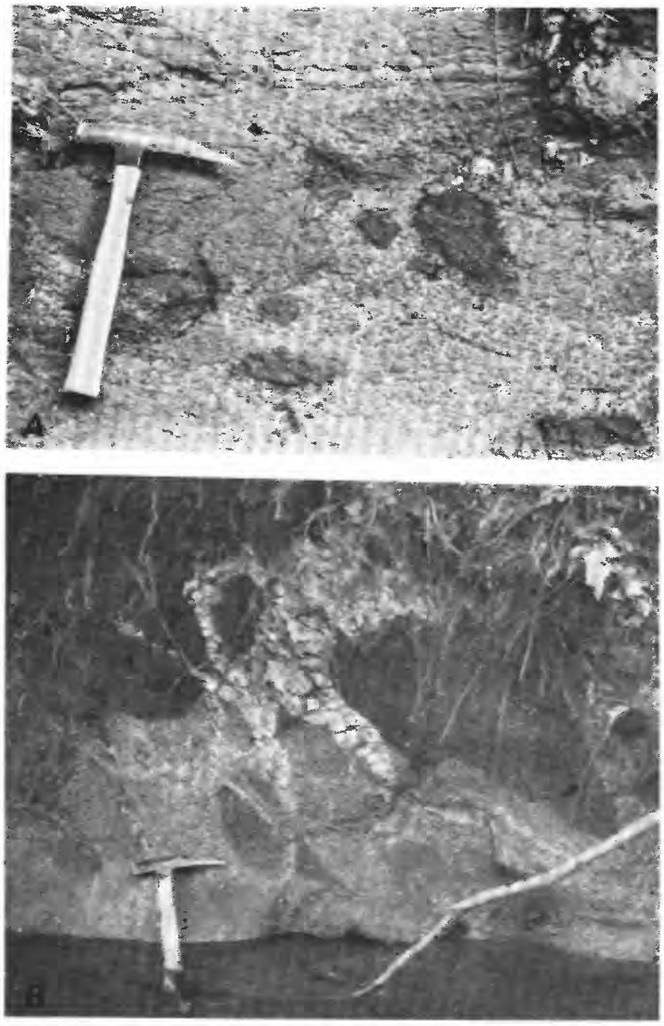

FIGURE 6.—Fragments of Accotink Schist in Indian Run Formation at type locality about 100 m southeast of Evergreen Lane, Annandale quadrangle. Photograph by P. T. Lyttle. *A*, Small fragments of Accotink Schist (dark colored). Hammerhead rests on weathered Indian Run matrix. *B*, Angular larger fragments. Quartz veining postdates olistolith emplacement.

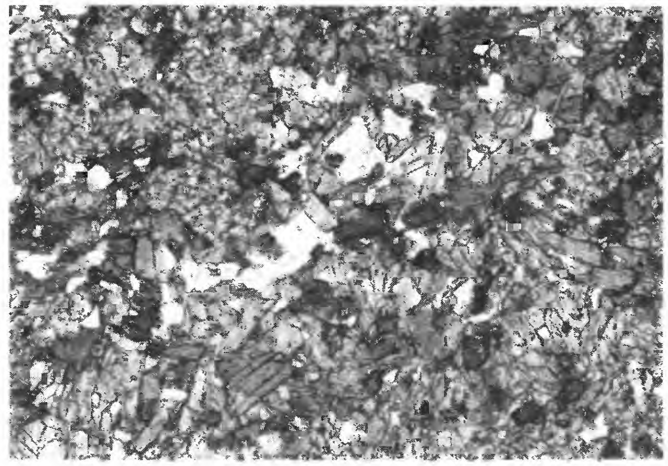

FIGURE 7.—Extremely altered, fine-grained metagabbro from "knocker" in Indian Run Formation at its type locality about 450 m northwest of Old Columbia Pike, Annandale quadrangle. Plain light. Field of view is 10.5 cm^2. Photomicrograph by P. T. Lyttle.

the effect of polyphase deformation in which early recumbent folds plunging 35° N. 75° W. are further deformed by folds which plunge 30° S. 30° E. The foliation in the Indian Run in this area strikes N. 75° E. and dips 80° NW. Finally, about 80 m northwest of Braddock Road, a small olistolith of serpentinite crops out.

Abundant olistoliths are present elsewhere where the unit is exposed in short stream segments as in the extreme western and north-central parts of the Annandale quadrangle (pl. 1). This occurrence suggests that the olistoliths are likely present although unexposed throughout the quadrangle.

Rocks of the Occoquan batholith crop out about 80 m southeast of Braddock Road, and granitic rocks crop out to the point where the crystalline terrane is overlapped by the Coastal Plain deposits east of Shirley Highway. Almost all the exposures of Occoquan Granite are loaded with inclusions of all the rock types viewed along Indian Run.

The Indian Run is believed to have been emplaced by massive subaqueous sliding, but as its base is not exposed, the unit serving as the slide surface is not known. In fact, the Indian Run may have been transported subsequent to its original emplacement. The Indian Run is overlain by the allochthonous Annandale Group on the Red Fox thrust fault, where those rocks are present and by the Sykesville Formation where they are absent (pl. 1). The Sykesville is also believed to have been emplaced by massive subaqueous sliding upon both the Annandale Group and the Sykesville Formation. This slide surface is here termed the Burke thrust fault. Needless to say, the slide surface is difficult to locate between the Indian Run and Sykesville because of the generally poor exposure and the similarity of the rocks. Like many contacts in the Piedmont, it is largely defined by extrapolation between typical exposures of each rock type. The Sykesville Formation commonly causes an aeromagnetitc high (U.S. Geological Survey, 1980).

The gradient of this high coincides with the Sykesville-Indian Run contact where that contact is reasonably well established, and this gradient is used to define the contact in the western part of the area (pl. 1). In the eastern part of the area, the aeromagnetic signatures are absent where intrusive rocks intervene.

The Indian Run and Annandale Group probably crop out in an antiformal window through the Sykesville Formation. This interpretation is supported by exposures of Sykesville containing typical olistoliths of migmatized Peters Creek Schist (fig. 3*B*) which occur east of the Indian Run at the Coastal Plain overlap in Fourmile Run in the Alexandria quadrangle, just to the east of the northeast corner of the Annandale quadrangle (pl. 1). The Indian Run almost certainly occurs south of the area mapped as pendants of the overlying Annandale Group that occur within the Occoquan batholith. Sedimentary mélange has been mapped farther south in the Occoquan and Quantico 7½-minute quadrangles as Wissahickon Formation by Seiders and Mixon (1981) and Mixon and others (1972), and even farther south as diamictite by Pavlides (1981). Casual examination of some of these rocks suggests a similarity to the Indian Run. The critical study of the olistolith type has not been made. An aspect of some of this mélange, however, is that it contains olistoliths of and underlies the Chopawamsic Formation (Southwick and others, 1971; Seiders and others, 1975; Seiders and Mixon, 1981; Drake and Lyttle, 1981), a metavolcanic unit that is widespread throughout the central Virginia Piedmont (Pavlides, 1981). Pavlides and others (1982) report that the Chopawamsic is at many places thrust upon an extensive mélange zone in central Virginia. Thus, there is yet another motif of thrust sheet and related precursory mélange—Chopawamsic Formation and Chopawamsic olistolith-bearing sedimentary mélange—in the northern Virginia Piedmont.

The Indian Run Formation, like the other metamorphic rocks of the area, predates the emplacement of the Occoquan Granite. Its age then is Cambrian or Late Proterozoic.

TECTONIC IMPLICATIONS

Modern workers in the Maryland and Virginia Piedmont have accepted Hopson's (1964) concept that the Sykesville Formation represents a gigantic submarine slide deposit that moved on a west-facing slope and that the material was derived from the east. Hopson (1964), in a pre-plate tectonic interpretation, believed that the Sykesville stemmed from a geanticlinal landmass of crystalline rock that, along with his Wissahickon Formation and other eastern Piedmont rocks, constituted what we would now consider to be a foreland basin sequence of Proterozoic age. Although it was not explicitly stated, Crowley (1976) apparently believed, as judged from his figure 1, that the Sykesville had its origin on a peripheral bulge resulting from the aborted subduction of the North American craton beneath his Laurel-Bel Air marginal ocean. In his view, the Sykesville and his Wissahickon Group constituted a part of the central Appalachian foreland basin sequence of Cambrian and Ordovician age. Crowley (1976) was the first geologist to recognize that thrust sheets of ophiolitic and island arc metavolcanic rocks were being emplaced during Sykesville sedimentation. Fisher and others (1979) essentially follow Crowley's (1976) ideas with the additional concept that the thrust emplacement of the Baltimore Complex ophiolitic rocks served as the trigger for Sykesville sliding. Drake (1980), Drake and Lyttle (1981), and Drake and Morgan (1981, 1983) visualize a more complex obduction event in which allochthons of both metasedimentary and ophiolitic rocks were involved and in which each allochthon had its own precursory mélange. Higgins (in press) recognizes a sedimentary mélange (the Sykesville?) beneath the allochthonous ophiolitic rocks of the Baltimore Complex along the Susquehanna River and another sedimentary mélange, the Conowingo, above the Baltimore Complex and beneath the allochthonous metavolcanic rocks of the James Run Formation. Finally, I describe yet another thrust sheet and attendant precursory mélange in northern Virginia. As yet, however, no one has really come to grips with the tectonic setting of the Sykesville Formation and the other subaqueously emplaced sedimentary mélanges.

It is difficult to interpret a tectonic setting for these large central Appalachian subaqueous slides, for as pointed out by Woodcock (1979), there are few such deposits in the on-land ancient geologic record. One such deposit, the Chain Lakes Complex in Maine (Boudette and Boone, 1976), is quite similar to the Sykesville, Indian Run, and Conowingo mélanges, but it is more poorly understood and has even been interpreted to be a metasuevite (Boudette and Boone, 1982). I have also seen similar rocks in the Inner Piedmont of North Carolina, but these rocks are interpreted, as was the Sykesville originally, to be intrusive igneous rocks. A consideration of modern deposits seems warranted.

The Casanova Complex in the Italian Apennines seemed a likely model for the Central Appalachian sedimentary mélanges in that it is a large transported sedimentary mélange that contains olistoliths of ophiolithic and other oceanic rocks and it was interpreted to be a precursory mélange to the northeast-moving Ligurid nappes (Elter and Trevisan, 1973). More recent work (Naylor, 1982) has suggested that the debris within the Casanova was deposited during the Cretaceous but that the Ligurid nappes were not created until the Miocene. If this work is correct, the Casanova can hardly be a precursory mélange to the Ligurid nappes and is not a satisfactory model for the central Appalachian mélanges.

In a summary paper on more recent submarine slides, Moore (1977) found that large-scale submarine slides occur principally in two dramatically contrasting lithospheric plate provinces. These are (1) the passive, midplate, continental margin provinces, such as the current Atlantic coast of the United States, or (2) subduction zone provinces where the ocean floor is being subducted beneath either a continent or other oceanic crust. Although the processes are different, these two tectonic provinces share the necessary prerequisite factor, a thick sedimentary section. On a passive margin, much time has been available to accumulate thick sediment, whereas in the subduction zone province a thick section is built up by accretion. Passive margin slides do not seem applicable to the Central Appalachian Piedmont, but subduction zone types could be. The Bassein slide (Moore and others, 1976) is a well-described example of a major slide in a forearc-trench subduction setting. The Bassein slide occurred on the submerged seaward side of an orogenically uplifted sedimentary arc related to the convergence of the Indian and Eurasian plates that generated the Sunda Arc subduction zone. The tectonically emplaced strata of this arc were blanketed with additional sediments from a nearby river behind the arc. Moore and others (1976) believe that the slide results from this enormous amount of sediment which was deposited on the trench slopes. Given the complex origin of the region and the terrane affected by the slide, it is apparent that the ages and lithologies of the displaced materials could vary widely.

Another large sedimentary mélange, the Lichi, has recently been described by Page and Suppe (1981). The Lichi also has a forearc setting, but it is in a forearc basin, not a trench or subduction zone site. As with the Bassein, an outer nonvolcanic arc (accretionary wedge) is thought to be the source for the Lichi. The olistoliths of ophiolitic, deep-sea fan, and continental rise rocks in the Lichi are appropriate for an accretionary ridge source terrane. Page and Suppe (1981) feel that Lichi-type mélanges may be more common than generally believed because the collapse of the relatively thin forearc basins is inevitable during collision.

A search of the literature failed to disclose any report of emplacement of large sedimentary mélanges in a backarc position other than the classic model for the Apennine mélanges in which the matrix for the mélanges supposedly had its source in the advancing nappes. If Naylor (1982) is correct in his view that the Italian mélanges have no relation to nappe emplacement, it is impossible to use that model for the central Appalachian mélanges. All major submarine slides then appear to have occurred in forearc areas, either in forearc basins (Lichi) or on trench slopes (Bassein). The Lichi has been well studied by Page and Suppe (1981), and it is clearly not precursory to an overlying allochthon. In many ways, the Bassein is an appealing model for the central Appalachian sedimentary mélanges. A tremendous amount of sediment was needed to form those mélanges.

The Sykesville Formation, as currently mapped, is as much as 3 km thick and has a width of about 125 km from Liberty Reservoir, Maryland (Cleaves and others, 1968), to Garrisonville, Virginia (Pavlides, 1976). If the sedimentary mélange beneath the Baltimore Complex along the Susquehanna River is Sykesville (Higgins, in press), the unit has a width of about 200 km. If the Sykesville and other sedimentary mélanges formed on a trench slope like the Bassein, a mechanism must be rationalized to develop the mélange-allochthon motifs of the central Appalachians. Just such a mechanism is suggested by Karig (1982) in a recently published essay pointing out the importance of forearc deformations to mountain belts. Karig suggests that near the base of a trench slope, an upper thrust plate is stretched over the thrust toe thereby generating debris that slumps to the base of the scarp. With continued thrusting, the debris is overrun by the thrust plate, the process continuing as long as deformation persists. This process would develop deposits like the forethrust debris beneath subaerial thrusts (Brock and Engelder, 1977) and the precursory mélanges of the central Appalachians. Thus, a mixture of deformational fabrics, reflecting both gravitational and tectonic processes, would be preserved in the same or closely positioned outcrops, but all would form part of a tectonically generated boundary. Although a trench slope origin for the sedimentary mélanges and the mélange-allochthon motifs is appealing, it is difficult to fit a trench model into current concepts of the tectonic setting of this part of the central Appalachians which most geologists visualize as representing the remains of a small ocean basin that was flanked to the east by the Chopawamsic volcanic island arc. The trench of this system would have been outboard of this island arc. The allochthonous rocks of the area, however, constitute different lithotectonic environments including oceanic (Piney Branch Complex); two different submarine fans, one of which contains ophiolitic debris and one that does not; the Peters Creek Schist and the Annandale Group; and rocks of a volcanic arc in the central Virginia volcanic-plutonic belt. Perhaps this part of the Piedmont consists of many mashed-together terrane fragments and constitutes an ancient analogue to Hamilton's (1969) prediction for the Indonesian region, once Australia has closed with Eurasia.

CONCLUSIONS

The Sykesville Formation as originally mapped in northern Virginia actually consists of two precursory sedimentary mélanges, the Sykesville and Indian Run Formations. The Indian Run and its overlying allochthon, the Annandale Group, form a third and lower mélange-allochthon motif beneath the Sykesville Formation-Peters Creek Schist and the Yorkshire Formation-Piney Branch Complex.

The quartzo-feldspathic matrix of both the Sykesville and Indian Run suggests a common source and suggests that care must be taken to recognize individual slide sheets in geologic mapping. It is suggested that the Chopawamsic Formation and underlying sedimentary mélange to the south of this area may constitute yet another, lower mélange-allochthon motif. Other slide sheets and motifs may well occur to the north in Maryland.

The sediment source for the mélange matrix is unknown, and the tectonic setting of the motif formation and assemblage is still uncertain. The original, stacked thrust sheet model is appealing in that the sheets are now obducted onto the North American craton and the closing and destruction of a marginal basin and its flanking island arc is a relatively straightforward tectonic model. The major problem with this concept is lack of a source for the immense amount of sediment necessary to form the sedimentary mélanges.

A trench-forearc tectonic site could supply the necessary sediment through accretion, and it has been shown that stacked tectonic motifs could form at such a site. The assemblage of the current terrane would require a far more complicated tectonic history than the simple destruction of a marginal basin. Perhaps this more complex solution is the correct one as the rocks involved have been shown to have a tectonic history older and different from that of North American rocks of the Blue Ridge and Great Valley to the west (Drake and Lyttle, 1981; Drake, 1983). Continental margins are complex places, and judging from other areas of the world, such a history is not impossible.

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