Department of Natural Resources
MARYLAND GEOLOGICAL SURVEY
Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO. 27

THE GEOLOGY OF THE CRYSTALLINE ROCKS NEAR BALTIMORE AND ITS BEARING ON THE EVOLUTION OF THE EASTERN MARYLAND PIEDMONT

by
William Patrick Crowley

1976

LIST OF ABBREVIATIONS AND TABLE FOR CONVERTING METRIC UNITS TO ENGLISH UNITS

MULTIPLY METRIC UNITS	BY	TO OBTAIN ENGLISH UNITS
Millimeters (mm)	0.03937	inches (in)
Centimeters (cm)	0.3937	inches (in)
Decimeters (dm)	0.3281	feet (ft)
Meters (m)	3.281	feet (ft)
Kilometers (km)	0.6214	miles (mi)
Square Kilometers (km^2)	0.386	Square miles (mi^2)

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THE GEOLOGY OF THE CRYSTALLINE ROCKS NEAR BALTIMORE AND ITS BEARING ON THE EVOLUTION OF THE EASTERN MARYLAND PIEDMONT

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ABSTRACT

Extensive subdivision of rock units in the east-central Maryland Piedmont requires a radical restructuring of its classic stratigraphic framework. The Baltimore Gneiss is divided into five units and its type locality redefined. The Glenarm Series is changed to the Glenarm Supergroup. The Setters Formation and Cockeysville Marble are each divided into six units of member and lens rank. The Wissahickon Formation is elevated to group status and divided into six formations and numerous units of lesser rank.

The large mass of marble at Hydes is shown to be a synclinal lens within the Wissahickon, not an unroofed gneiss dome in Cockeysville Marble.

The Baltimore Mafic Complex (formerly Baltimore Gabbro Complex) is elevated to group status and divided into four formations. Felsic gneisses closely associated with the Mafic Complex and formerly grouped together as Port Deposit Gneiss are separated into three formations. Rocks of supracrustal origin, flanking the Mafic Complex on the southeast, are assigned to three new members of the James Run Formation and to the newly erected Jones Falls Schist.

The Baltimore Gneiss represents a pile of predominantly felsic, volcaniclastic rocks that were deposited, metamorphosed, folded, and intruded by granite in the Late Precambrian.

Resting uncomformably on the Baltimore Gneiss, the Setters Formation records an initial period of clastic sedimentation in coalescent basins on a shallow marine shelf, followed by development of a carbonate bank complex preserved as the overlying Cockeysville Marble.

Emergence of a land mass to the southeast led to an influx of clastic sediments (Wissahickon Group) accompanied in places by mafic volcanics, all of southeasterly derivation. The basal Wissahickon rocks include quartzite and marble in places, indicating localized persistence or re-establishment of shelf conditions. In general, the Wissahickon coarsens upward from meta-shale at the base through meta-graywacke and meta-diamictite. Exotic slide masses of mafic and ultramafic rock occur throughout the lower Wissahickon clastic sequence, and were derived from a composite allocthon (Baltimore Mafic Complex and associated rocks) which arrived during early Wissahickon time.

PART I

GEOLOGY OF THE CRYSTALLINE ROCKS

INTRODUCTION

Geologic mapping of Baltimore City and Baltimore County from mid-1967 to mid-1974 has led to the recognition of a number of new rock-stratigraphic units and a clarification of others in the eastern Maryland Piedmont. Stratigraphic and textural evidence discussed below support a volcanic origin for part of the Baltimore Gabbro Complex; hence, the earlier names for the Complex as a whole (Baltimore Gabbro Complex of Cleaves and others, 1968; Baltimore-State Line gabbro-peridotite complex of Southwick, 1969; Baltimore gabbro of Herz, 1951) are misleading, and it is here proposed that the non-genetic designation, Baltimore Mafic Complex, be adopted. Evidence will be presented below that a major thrust fault extending nearly the entire length of the Maryland Piedmont separates the Mafic Complex and associated rocks to the southeast from predominantly clastic rocks (Baltimore Gneiss and Glenarm Supergroup of this paper) to the northwest. The division so provided will be used in the following pages to describe the rocks in terms of the two major groupings separated by this thrust.

PROCEDURE

In erecting a new stratigraphic framework, I have been guided largely by the 1961 Code of Stratigraphic Nomenclature, but have disregarded recommendations of the Code with regard to names. The Code declares that, "The formal name of a rock-stratigraphic unit of any rank is binomial, consisting of a geographic name combined with a descriptive lithologic term or with the appropriate rank term alone." Where a lithologic term is used the Code discourages the use of compound terms and adjectives. Among the new names proposed in this paper are twelve that include compound lithologic terms. The following discussion sets forth my justification for this departure from the Code.

If stratigraphic names must be committed to memory, they should at least convey lithologic information. But if compound lithologic terms are prohibited, the available terms are too few to satisfy a detailed nomenclatural scheme. The alternative, a nomenclature employing only geographic names, burdens the memory but does not convey useful information. In my judgment, therefore, the increased awkwardness of employing a compound lithologic term is more than justified by its descriptive value.

I have also disregarded the Code in regard to completeness of definition of each rock-stratigraphic unit. Contact relationships are not discussed because contacts are rarely exposed. Thickness ranges are given only for those units whose upper and lower boundaries lie within the mapped area; shape is not discussed because of the dearth of subsurface data. And with the exception of a few radiometric age determinations (many of which are subject to differing interpretations), there is no direct evidence for the ages of any of the units.

The term, "complex", is described in the Code in a subsection defining "formation". At least one unit within the Baltimore Mafic Complex is equivalent to a formal stratigraphic unit of formational rank, the James Run Formation. If the Mafic Complex is treated as a formation, this means that the James Run must be a member rather than a formation. This is an awkward situation although not specifically prohibited by the Code. Further, the Complex comprises four rock-stratigraphic units within the area under discussion in this paper alone, and the Complex as a whole covers at least 400 square kilometers. These facts warrant assignment of group rather than formational status to the Complex in my judgment.

Foliated rocks in which the content of micaceous minerals is 30 percent or greater by visual estimate are designated as schist; rocks with less than 30 percent micaceous minerals are designated gneiss (see Osberg, 1952, p. 18-19). The terms amphibolite, quartzite, and marble are used according to the definitions of Turner and Verhoogen (1960, p. 454), dolostone and limestone according to Dunbar and Rodgers (1957, p. 219), graywacke according to Hopson (1964, p. 86), fels according to Winkler (1965, p. 211), and granofels according to Goldsmith (1959).

Schistose to massive actinolite rock is common within the Mafic Complex. Although described by Knopf and Jonas (1925) as pyroxenite, the premetamorphic nature of this rock can seldom be conclusively demonstrated in the field. The descriptive name, actinolite schist or actinolite fels, is preferable, but in the interest of brevity will be shortened in this paper to actinoschist and actinofels, respectively.

Metamorphic rocks whose parentage is obvious may be designated by the name of the parent rock prefixed by "meta" (metalimestone, for example). Mineral modifiers preceding rock names are in order of increasing abundance. The average grain diameter of fine-grained rocks is less than one millimeter; of medium-grained rocks, 1 to 5 millimeters; and of coarse-grained rocks, 5 millimeters to 3 centimeters.

All type localities are described in the appendix.

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BALTIMORE GNEISS

General Discussion

The name Baltimore Gneiss was first used by G. H. Williams (1892) to describe the widely distributed gneisses occurring within the limits of the Baltimore quadrangle (U.S. Geol. Survey, 15′ series topographic, 1904). Subsequent work by Mathews (1904) restricted the name to certain gneisses that everywhere lie stratigraphically beneath the Glenarm Supergroup (my usage) in the cores of anticlines. Later work by Hopson (1964) showed that layered gneisses along Jones Falls and Gwynns Falls in Baltimore City, which had always been assigned to the Baltimore Gneiss, were chemically and texturally different from the gneiss in the domes and might be considerably younger. Subsequent zircon age measurements (Tilton and others, 1970) confirmed this speculation. Unfortunately, the outcrops of these younger gneisses along Jones Falls and Gwynns Falls have generally been considered the type locality of the Baltimore Gneiss (see for example, Knopf and Jonas, 1929). To correct this serious error, I propose redefining the type locality of the Baltimore Gneiss (see appendix).

At least 95 percent of the exposed Baltimore Gneiss consists of quartzo-feldspathic gneiss of granodioritic to granitic composition (plutonic nomenclature of Streckeisen and others, 1973). The remaining five percent consists of amphibolite. Despite the overall homogeneity of the Gneiss, detailed mapping has led to the recognition of four reasonably distinct subdivisions (three of which are exposed at the type locality of the formation) which have been accorded member status. They are named as follows: layered gneiss member, augen gneiss member, streaked-augen gneiss member, and hornblende gneiss member. Detailed radiometric dating may enable one to arrange these in chronologic order, but to date this has not been attempted. Nevertheless, all four units probably fall within the time range 1.0-1.1 billion years (Late Precambrian) established by many of the Baltimore Gneiss radiometric mineral ages (Tilton and others, 1958).

Uniform, well foliated to massive granitic gneiss crops out in three discrete masses confined to the Baltimore Gneiss to which the name Slaughterhouse Gneiss is assigned. Superficially the granitic gneiss of these bodies resembles the Gunpowder Gneiss (Gunpowder Granite of Hopson, 1964), but in its areal distribution differs in two respects. The Slaughterhouse crops out in discrete mappable masses confined to the Baltimore Gneiss. The Gunpowder occurs largely as a sill swarm intrusive into both the Baltimore Gneiss and overlying rocks. Detailed chemical and geochronological studies may be required to determine conclu-

sively whether the Slaughterhouse Gneiss and Gunpowder Gneiss represent distinct rock units, but in the absence of such studies, field relations support the use of two separate names. Because of its uniformity, its confinement to the Baltimore Gneiss, its apparent truncation by Glenarm rocks, and its obliquity to the trend of layering in the Baltimore Gneiss, the Slaughterhouse Gneiss is considered to be pre-Glenarm granitic gneiss of probable intrusive origin. For convenience its description is included with the Baltimore Gneiss.

Layered Gneiss Member

The layered gneiss member consists of interlayered dark and light biotite-quartz-feldspar gneiss which can vary from biotite schist to granofels. The layered gneiss rarely bears hornblende or muscovite, and rarely has an augen texture. Variations in the ratio of biotite to quartz and feldspar combined with variations in grain size yield a diversity of rock types which are interlayered on a scale ranging from centimeters to tens of meters. Such names as banded gneiss, veined gneiss, granitic gneiss, and migmatite were used by Hopson (1964) to describe some of the more commonly encountered varieties.

Augen Gneiss Member

The name Hartley was used by Knopf and Jonas (1925, 1929) to designate augen-bearing Baltimore Gneiss, especially that near Hartley along Long Green Creek (plate 1). Hopson (1964) stated that augen gneiss was most abundant near the contact with the overlying Setters Formation, but was not well adapted for large-scale mapping. Both points are only partially true. Except for a few scattered, isolated outcrops of augen gneiss, most occurrences of this rock type are confined to discrete, mappable bodies where augen gneiss is interlayered with gneiss lacking augen. Thus, the designation augen gneiss is herein retained and accorded member status.

Characteristic of the augen gneiss member is fine- to medium-grained biotite-quartz-feldspar gneiss containing abundant, large, light colored ovoids (augen) consisting either of feldspar or quartz and feldspar. The augen gneiss is commonly pinkish, and interlayered with fine- to medium-grained, uniform biotite-quartz-feldspar gneiss, and pinkish, coarse-grained, locally pegmatitic biotite-quartz-feldspar gneiss. In places the augen gneiss is interlayered with gneisses typical of the layered gneiss member.

Streaked-Augen Gneiss Member

The streaked-augen gneiss consists of uniform, medium-grained biotite-quartz-feldspar gneiss generally bearing augen that have a "pulled-out" or "stretched" appearance; interlayered fine-grained dark gneiss is subordinate. Locally this member contains hornblende and/or magnetite. The latter is conspicuously abundant in places and probably accounts for the unusually high positive magnetic anomaly centered over the Texas dome (Bromery, 1968). Muscovite is very rare and has been noted only near the contact of the overlying Glenarm Supergroup.

Hornblende Gneiss Member

Hornblende is rare in the layered gneiss member. However, there are mappable zones of layered gneiss which contain from 25 to 50 percent interlayered hornblendic rock both in the form of amphibolite and hornblende-bearing biotite schist or biotite gneiss, both locally bearing garnet. Such zones have been assigned to a separate unit, the hornblende gneiss member.

Slaughterhouse Gneiss

The Slaughterhouse Gneiss is named for outcrops along Slaughterhouse Branch (see appendix). The Slaughterhouse is a pinkish to orange weathering, quite uniform, generally medium-grained microcline-quartz-plagioclase gneiss with muscovite or biotite or both.

GLENARM SUPERGROUP

Resting uncomformably on the Baltimore Gneiss is a thick section of largely metasedimentary rocks to which the name Glenarm Series was given by Knopf and Jonas (1922, 1923). As mapping of the Piedmont has progressed, additions and deletions of rock units to and from the Glenarm have been proposed. These developments were reviewed by Southwick and Fisher (1967) who proposed that the Glenarm include only the Setters, Cockeysville, and Wissahickon Formations, as defined by them. I concur with their proposal, but because I elevate the Wissahickon to group status, I propose elevation of the Glenarm to supergroup status. In so doing, the term, "series", can be abandoned, a term properly applied only to time-stratigraphic and not rock-stratigraphic units.

SETTERS FORMATION

General Discussion

The name "Setters" is taken from a conspicuous ridge (unnamed on modern maps) which forms the south side of Green Spring Valley in south-central Baltimore County. "Setters quartz schist" was first used by G. H. Williams (1892) in his report on the Baltimore 15′ quadrangle. Mathews (1904) renamed the unit "Setters quartzite" and restricted it to quartz-rich rocks everywhere in contact with the Baltimore Gneiss. He recognized a two-fold subdivision: a quartz-rich lower member and an argillaceous (micaceous) upper member. Knopf and Jonas (1929) renamed the unit "Setters Formation" and recognized a four-fold division, from bottom to top: mica schist, quartzite, mica schist, and mica gneiss. In contrast I recognize a six-fold subdivision of the Setters comprised of three members and three lenses. The entire sequence is not present at any one locality. Type localities are thus designated for each unit, and no attempt is made to designate a formational type locality. The names chosen for these six units are as follows, starting with the oldest: the quartzite member which includes the conglomerate lens and the schist lens, the gneiss member which includes the quartzite lens, and the garnet schist member.

The thickness of the Setters Formation varies from 0 to 500 meters.

Quartzite Member

Fine- to medium-grained, quartz-rich rocks bearing accessory tourmaline characterize the quartzite member. Most typical is thin-bedded, slabby-weathering muscovite-microcline quartzite. Less common is uniform, unlayered muscovite-microcline quartzite, and least common is massive, pure, vitreous quartzite. At the type locality, schist (described immediately below) is confined to a basal lens. Elsewhere, schist is interlayered with quartzite throughout the entire vertical extent of the quartzite member, although the schist is considerably subordinate in volume.

The thickness of the quartzite member varies from 0 to 180 meters.

Schist lens: Typically the schist lens consists of medium-grained biotite-microcline-quartz-muscovite schist, locally coarse-grained and very feldspathic, rarely finer and more biotitic. Tourmaline occurs sparsely. Interlayered quartzites a few decimeters thick are common; generally they contain mica and feldspar, but some are wholly quartz.

The thickness of the schist lens varies from 0 to 60 meters. It is too thin to show in plate 1 (but see Crowley and Cleaves, 1974), and is included with the quartzite member.

Conglomerate lens: Along the southern flank of the Phoenix dome are three lenses at the base of the Setters Formation consisting of muscovite quartzite bearing stretched quartz pebbles. The thickness of the conglomerate lens varies from 0 to 90 meters.

Gneiss Member

The bulk of the gneiss member comprises rocks which are fine-grained, quartz-rich, and usually contain conspicuous amounts of tourmaline. All contain either biotite, or biotite and muscovite, but rarely contain only muscovite. Locally, clots of biotite give the rock a distinctive spotted appearance. Knopf and Jonas (1929) refer to these rocks as mica gneiss, and although such gneissic rocks predominate in layers a few decimeters to more than a meter thick, quartzite and schist are also common. Layers of medium-grained biotite - muscovite - microcline - quartz schist occur locally; at the type locality (see

appendix) and for nearly 3 kilometers northeast along strike the lower 15 to 30 meters of the gneiss member is composed almost exclusively of this rock type. It resembles the schist of the schist lens but is much richer in tourmaline and contains garnet in places.

The thickness of the gneiss member varies from 0 to 350 meters.

Quartzite lens: On the north flank of the Texas dome is a large lens up to 150 meters thick of well foliated to massive, medium-grained, uniform muscovite-feldspar quartzite.

Garnet Schist Member

The garnet schist member is composed almost exclusively of fine-to medium-grained biotite-muscovite-plagioclase-quartz schist, generally with abundant garnet accompanied either by staurolite or kyanite, but rarely both; accessory tourmaline occurs sparsely. Interlayered quartzite in zones a few meters thick is very subordinate.

The thickness of the garnet schist member varies from 0 to 300 meters.

COCKEYSVILLE MARBLE

General Discussion

The existence of a major carbonate unit in the central Maryland Piedmont was well established long before systematic geological studies of the area were undertaken. It has long been quarried in the vicinity of Cockeysville and apparently for this reason was named Cockeysville Marble by G. H. Williams (1892).

Variations in the texture and mineralogy of the Cockeysville have been noted by everyone who has studied the formation, and even among quarrymen such terms as "alum stone", "bluestone", and "dolomite" have long been in use to denote certain varieties of the marble. Efforts to discern a systematic areal distribution of these different kinds of marble have not been notably successful. W. J. Miller, the first to undertake a detailed study of the Cockeysville, concluded in 1905 that, "In no case has it been possible to show that a definite order of superposition of the beds of one locality could be applied without any change to any other locality." Half a century later, Choquette (1957, 1960) also concluded that stratigraphic units could not be distinguished in the Cockeysville, but, nonetheless, recognized six major rock types and on the geologic map accompanying his doctoral thesis (1957) gave some idea of their areal distribution. The distribution of rock types within the Cockeysville clearly does not conform to patterns in the underlying or overlying formations except locally (plate 1), but this should not be interpreted as a denial of Cockeysville stratigraphy. Rather, it may mean that the stratigraphy reflects unusual complexity, including perhaps facies changes, unconformities, and deformation. Thus, I have erected a six-fold stratigraphy, five members and one lens, to accommodate the variety of Cockeysville rock types. They are named as follows: layered marble member, massive metadolostone member, layered metadolostone member, massive metalimestone member (includes the calc-gneiss lens), and the phlogopitic metalimestone member. The relative ages of these units are uncertain.

The thickness of the Cockeysville varies from 0 to 1.4 kilometers.

Massive Metadolostone Member

Characteristic of this unit is medium-grained, snow white, generally massive metadolostone consisting almost entirely of dolomite. The rock locally contains diopside, tremolite, phlogopite, and quartz, but these minerals rarely exceed 5 percent of the total rock volume. Many outcrops are partially disintegrated to dolomite sand. Phlogopitic metalimestone is known from a few localities and quartz-tremolite rock from one small area.

The thickness of the massive metadolostone varies from 0 to 400 meters.

Massive Metalimestone Member

This member consists chiefly of massive metalimestone and subordinate interlayered metadolostone. The metalimestone is characteristically coarse-grained and massive, forming large, rounded bosses of gleaming white calcite marble, locally weathered to calcite sand. Silicates are rare but where present are chiefly phlogopite with some muscovite, quartz, and tremolite. Locally the metalimestone is very coarse-grained with pegmatitic texture and cross cuts adjacent layers. In other places it is medium- to coarse-grained, more conspicuously foliated, and is streaked with bluish zones. The metadolostone is fine-grained, tan weathering, and commonly rich in silicates. It contains both calcite and dolomite accompanied by phlogopite, muscovite, tremolite, diopside, and quartz. In a few places the massive metalimestone

includes brown-weathering, massive calc-silicate fels composed of quartz and tremolite in layers on the order of one meter thick.

The thickness of the massive metalimestone varies from 0 to 450 meters.

Calc-gneiss lens: Along the southeast flank of the Texas dome are two lenses consisting of fine-grained, bluish-gray, warty-weathering calcite marble or calc-gneiss with quartz, tremolite, diopside, and scapolite. These rocks are generally pyritic, and rarely phlogopitic. The calc-gneiss lens includes a few zones of relatively pure calcite marble a few decimeters thick.

The thickness of the calc-gneiss lens varies from 0 to 225 meters.

Layered Metadolostone Member

This member is characterized by a pronounced layering on a scale of several decimeters in which beds of fine-grained, pure, white dolostone alternate with beds of darker dolostone containing silicate minerals, mainly diopside, tremolite, phlogopite, and quartz, and, in some places, small patches of calcite (1-2 centimeters), and, in others, accessory pyrite. Diopside and tremolite occur locally as conspicuous crystals with well developed crystal facies; individuals may be well over 2 centimeters in longest dimension. The quartz, probably metachert, tends to be concentrated in concordant layers generally 5 to 8 centimeters or less in thickness and in discontinuous zones of nodules. Some outcrops (but not in the type locality) are partially disintegrated to dolomite sand.

The thickness of the layered metadolostone varies from 0 to 1.4 kilometers.

Layered Marble Member

The layered marble member consists about equally of interlayered metalimestone and metadolostone. The metalimestone is commonly medium-grained and moderately silicate-rich, but may be finer grained or quite pure. The metadolostone is generally finer grained than the associated metalimestone, and commonly silicate-rich and calcite-bearing, but locally may be quite pure. Outcrops commonly weather to carbonate sand with residual metadolostone boulders.

The thickness of the layered marble varies from 0 to 200 meters.

Phlogopitic Metalimestone Member

The phlogopitic metalimestone member comprises fine- to medium-grained, white to bluish-white calcite marble, and purplish, phlogopitic calcite marble or calc-schist with quartz, muscovite, scapolite, feldspar, and accessory diopside and tremolite, interlayered on a millimeter to centimeter scale. Some bedding surfaces are graphite rich. Locally this member is uniformly silicate-rich or silicate-poor. A few outcrops include metadolostone.

The thickness of the phlogopitic metalimestone varies from 0 to 300 meters.

WISSAHICKON GROUP

The name Wissahickon was first used by Bascom (1902) for a belt of mica schist and mica gneiss that extends from near Philadelphia, Pennsylvania southwestward into Cecil County, Maryland. Mathews (1904) extended usage of the name to cover similar rocks in the Baltimore area. The name is still in formational use but its definition and subdivision have evolved considerably (see especially Southwick and Fisher, 1967). I accept Southwick and Fisher's (1967) definition of the Wissahickon "to include all the schists, phyllites, metagraywackes, and other metamorphosed clastic rocks that overlie the Cockeysville Marble and are bounded on the northwest by the Ijamsville Phyllite." I further propose elevation of the Wissahickon to group status and the erection within it of formations, members, and facies. Within the area I have mapped, I recognize six formations, the Loch Raven Schist, Oella Formation, Piney Run Formation, Sykesville Formation, Pleasant Grove Schist, and Prettyboy Schist. The Oella and Piney Run are probably correlative in that both are locally sandwiched between the Loch Raven and Sykesville (plate 1). The Sykesville is at least locally correlative with the upper part of the Piney Run and lower part of the Pleasant Grove (plate 1).

Loch Raven Schist

The name Loch Raven is proposed for the schistose rocks so well exposed along Loch Raven Reservoir between Warren Road and Ashland Avenue (plate 1). Included within the Loch Raven is the Hydes Marble Member and a discontinuous basal unit, the Rush Brook Member.

Uniformity of lithology characterizes the Loch Raven. Nearly everywhere it consists of medium- to coarse-grained biotite-plagioclase-muscovite-quartz schist with lenticles and pods of coarse-grained vein quartz. Garnet is very

common but not ubiquitous; staurolite and kyanite are less common. The occurrence of these three minerals in various combinations, or their absence, provides a basis for recognizing at least six distinct facies which are described below. Locally the Loch Raven is fine-grained, and in places rather biotite-rich and feldspathic, but these variations are not common. Even less common are layers of fine-grained quartzite. Amphibolite, commonly with epidote, is very sparsely distributed throughout the Loch Raven. The mineral facies are as follows:

1) garnet facies. Garnet common; staurolite and kyanite rare or absent.
2) staurolite facies. Staurolite common; garnet and kyanite rare or absent.
3) garnet-staurolite facies. Garent and staurolite common; kyanite rare or absent.
4) garnet-kyanite facies. Garnet and kyanite common; staurolite rare or absent.
5) garnet-staurolite-kyanite facies. Garnet, staurolite, and kyanite all common.
6) barren facies. Garnet, staurolite, and kyanite all rare or absent.

The thickness of the Loch Raven varies from 0 to at least 600 meters.

Hydes Marble Member: The Hydes Marble Member is named for the tiny village of Hydes (plate 1), situated in an elongate carbonate lowland of about 7.5 sq km known as Long Green in east-central Baltimore County. The earliest geologic maps of this area noted the occurence of marble here, and once the general stratigraphic framework of the Piedmont had been established, the Hydes Marble was assigned to the Cockeysville Marble and interpreted as an anticline (Mathews and Miller, 1905; Miller, 1905). This conclusion has not subsequently been challenged, but there are at least two lines of evidence (plate 2; Crowley and Cleaves, 1974) which suggest that the Hydes Marble is a lens within the Loch Raven Schist: (1) The Hydes Marble lies directly on strike with the axial trace of a major syncline, and (2) the Rush Brook, which separates the Cockeysville from the Loch Raven on both flanks of this syncline, is nowhere in contact with the Hydes Marble. Except for the tiny marble lens at Glencoe (plate 1), this is the only known occurrence of marble in the Loch Raven Schist apart from the Rush Brook Member. This observation, and the fact that rock types in the Hydes Member can generally be matched in the Cockeysville, raises the possibility that the Hydes may be Cockeysville Marble in thrust contact with the Loch Raven. In the absence of supporting evidence, this hypothesis is tentatively rejected.

There are only about a dozen outcrops of the Hydes Marble. The meager information supplied by these few outcrops has been supplemented by seven test borings drilled by the Maryland Geological Survey. From the total data thus available one can determine the rock types present, but their relative abundance and areal distribution are too poorly known to warrant drawing any contacts other than the one separating the Hydes from the surrounding Loch Raven Schist. Four rock types can be distinguished: clean metalimestone, phlogopitic metalimestone, metadolostone, and calc-silicate fels. The clean metalimestone is typically a sparkling, snow-white, rather massive rock consisting wholly of calcite and some minor phlogopite. The phlogopitic metalimestone is a calcite marble with abundant phlogopite and small amounts of other silicates - muscovite, feldspar, and quartz. The metadolomite is typically a pure, sparkling, snow-white, fine-grained rock consisting largely of dolomite, and locally containing minor calcite and tremolite. The calc-silicate fels is massive diopside-quartz rock.

The internal structure of the Hydes Marble is too poorly known to estimate its thickness with much precision. It varies from 0 to probably not more than 300 meters.

Rush Brook Member: The Rush Brook Member is named for outcrops along Rush Brook a tributary of Loch Raven reservoir, here designated the type locality (see appendix). A small, especially quartzite-rich part of this unit was mapped by Williams (1892) who assigned it to the Setters. Miller (1905) first recognized its correct stratigraphic position and dubbed it "Pseudo-Setters Quartz Schist." Subsequent maps failed to show the existence of this unit, although Choquette (1957, geologic map) hints at its existence.

Heterogeneity of rock type characterizes the Rush Brook with the scale of layering varying from decimeters to meters. Apart from amphibolite and several occurrences of marble, Rush Brook rocks are generally quartz-rich and fine-grained. Most typical are interlayered biotite-feldspar-quartz gneiss, biotite-feldspar-quartz schist, and muscovite-biotite-feldspar-quartz schist, all garnet free. Rarely these

schists bear small feldspar augen or biotite clots. Interlayered medium-grained quartzites are locally important; some are biotitic, some muscovitic, some have both micas and/or feldspar as well. Schists associated with these quartzites are fine- to medium-grained, more muscovitic, and may carry garnet, and, rarely, kyanite or sillimanite. Tourmaline is a common accessory mineral in this schist-quartzite assemblage, but is generally absent in outcrops devoid of quartzite or quartz-rich gneiss. Disseminated pyrite is common in parts of the Rush Brook.

Concordant layers of amphibolite occur throughout much of the Rush Brook. Their texture is quite variable, ranging from fine-grained to coarse-grained and from finely laminated to uniform. Most have epidote generally accompanied by quartz, either in pods or in thin laminae; the former appear locally to be boudinaged layers. Garnet occurs locally, particularly in lighter colored, less hornblendic rocks. Calcite is a very rare component of these amphibolites.

The thickness of the Rush Brook Member varies from 0 to 600 meters.

Oella Formation

The name Oella is proposed for the schists and gneisses that are exposed along the Patapsco River at Oella in southwestern Baltimore County (plate 1). The Oella is divisible into a lower metasedimentary unit not separately designated, and an upper, discontinuous, mixed metasedimentary-metavolcanic unit, the Sweathouse Amphibolite Member. The Oella is probably equivalent in part to the metagraywacke facies of Higgins and Fisher (1971).

The Oella consists of medium-grained biotite-plagioclase-muscovite-quartz schist, locally garnetiferous and tourmaline-bearing, interlayered on a scale of centimeters to decimeters with fine-grained biotite-plagioclase-quartz gneiss or fels.

The thickness of the lower, metasedimentary unit varies from 0 to at least 600 meters.

Sweathouse Amphibolite Member: The Sweathouse Member is named for outcrops along Sweathouse Branch, a tributary of Gunpowder Falls in eastern Baltimore County, here designated the type locality (plate 1). The Sweathouse consists of schist and gneiss, like that comprising the Oella Formation proper, described above, interlayered with epidote amphibolite. The amphibolite is fine-grained, commonly has alternating felsic and malfic laminae, and generally bears epidote, both as a disseminated phase and as epidote-rich pods and layers. In general, the metasediments and amphibolite are subequal in volume and interlayered on a scale of 5 to 10 meters.

The thickness of the Sweathouse Member varies from 0 to at least 700 meters.

Piney Run Formation

The name Piney Run is proposed for the rocks exposed along a 2 kilometer stretch of Piney Run and its tributaries in west-central Baltimore County, here designated the type locality (see appendix). The Piney Run is equivalent in part to the Peters Creek Formation of Knopf and Jonas (1929). The Piney Run consists chiefly of fine - grained plagioclase - chlorite - muscovite - quartz schist, locally with chloritized biotite, and commonly bearing garnet. Interlayered with the schist is fine-grained biotite quartzite comprising from 10 to 30 percent of the entire formation, distributed in beds generally no greater than one decimeter thick. Locally the Piney Run has a seamed appearance due to closely-spaced thin veins and lenses of milky vein quartz.

The thickness of the Piney Run varies from 0 to 2.1 kilometers.

Sykesville Formation

The nomenclatural evolution of the Sykesville Formation was discussed by Southwick and Fisher (1967) who recommended abandonment of the name Sykesville for the informal designation "boulder gneiss lithofacies" (diamictite facies of Higgins and Fisher, 1971). In so doing, they reduced an important and useful stratigraphic concept to a less useful, lithologic concept. Much more preferable is the usage of Fisher (1963) who used the name Sykesville Formation to designate the two belts of conglomeratic gneiss that converge at Washington, D.C., and outline the south-plunging hinge of the Baltimore-Washington anticlinorium (see fig. 1 of Southwick and Fisher, 1967). I concur with Fisher's usage and urge reclamation of the Sykesville as a formally recognized formation.

Rocks assigned to the Sykesville in Baltimore County are physically continuous with the Sykesville Granite and the Peters Creek Formation of Jonas (1928) in Carroll County. I recognize an informal two-fold division of the Sykesville in Baltimore County into a gneiss member and a schist member. The available evidence suggests that these two members are facies equivalent, but verification of this

relationship must await more detailed mapping in Carroll County.

Gneiss member: The gneiss member consists of poorly foliated to massive, fine- to medium-grained biotite-plagioclase-quartz gneiss, deceptively granite-like in appearance, bearing sparse to numerous clasts ranging in size from granules to cobbles and somewhat larger slabs. The clasts are chiefly chloritized biotite schist chips, commonly with garnet and magnetite or pyrite. Nearly as abundant are quartz pebbles and granules; less common are cobbles of light gray, fine-grained quartzo-feldspathic rock. Feldspar granules are rare.

Schist member: The schist member resembles the gneiss member but is generally finer grained, commonly garnetiferous, very muscovitic, well foliated, and locally devoid of clasts. It includes a few occurrences of amphibolite.

Pleasant Grove Schist

The name Pleasant Grove is proposed for the schists exposed near Pleasant Grove Church in west-central Baltimore County, here designated the type locality (see appendix). The Pleasant Grove Schist consists of uniform, fine-grained plagioclase-chlorite-muscovite-quartz schist, locally with magnetite. The schist is commonly accompanied by numerous, thin veins and lenses of milky quartz and, in places, laminae and thin beds of quartzite, giving the rock a seamed appearance.

The thickness of the Pleasant Grove varies from 0 to 2.2 kilometers.

Prettyboy Schist

The name Prettyboy is proposed for the schists exposed in the vicinity of the dam at Prettyboy Reservoir, here designated the type locality (see appendix). The Prettyboy consists of uniform, fine-grained plagioclase-chlorite-muscovite-quartz schist, commonly with magnetite and conspicuous albite prophyroblasts that average 1 to 3 millimeters but may be as much as 10 millimeters in diameter. Limonitized pyrite cubes occur locally.

BALTIMORE MAFIC COMPLEX AND ASSOCIATED ROCKS

LAUREL BELT

General Discussion

The Laurel belt, particularly in and around Baltimore City, has been scrutinized more than any other part of the Baltimore Mafic Complex. Maps have been prepared by Williams (1892), Knopf and Jonas (1925), and Cohen (1937), and subsurface information has been presented by Herz (1950). Only the maps of Williams (1892) and Knopf and Jonas (1925) attempt to show the distribution of rock types within the plutonic part of the Complex. Williams shows mafic versus ultramafic rocks; Knopf and Jonas further divide the ultramafic rocks into serpentinite, peridotite, and pyroxenite. Later workers have disagreed about the distribution of these rock types. Cohen (1937, p. 222) states that, "When closely studied it seems that ultrabasics occur within a mile of every point within the complex." Hopson (1964, p. 134) claims that this is misleading and that, "Small amounts of ultramafic rocks occur throughout the complex in the Baltimore area, but the large masses are unmistakably concentrated toward the margins." My own mapping supports Cohen's conclusion, and I have found that, by and large, it is impossible to establish map units comprised exclusively of either mafic or ultramafic rock. Consequently, I have assigned the plutonic rocks of the Laurel belt to two formal units: the Hollofield Layered Ultramafite (largely ultramafic rocks) and the Mount Washington Amphibolite (largely mafic rocks).

Quartzo-feldspathic rocks are also known from the Laurel belt. Knopf and Jonas (1925) mapped both these and felsic rocks from the Bel Air belt largely as Port Deposit Gneiss because of their alleged similarity to the broad belt of rocks of that name in Cecil County east of the Susquehanna. In view of Higgins' (1972) restriction of the name Port Deposit to the very distinctive rocks in and around the Port Deposit

quarry, the extension of this name to Baltimore is considered unwarranted.

Intrusive granitic gneisses at Ellicott City were mapped as Woodstock Granodiorite by Knopf and Jonas (1925), but later described as Ellicott City granite (Knopf and Jonas, 1929). Hopson (1964) changed "granite" to "Granodiorite", but according to the plutonic nomenclature of Streckeisen and others (1973), the composition of the Ellicott City falls within the granite field. Restoration of Knopf and Jonas' (1929) original name is, therefore, desirable. The Ellicott City has been thoroughly described by Hopson (1964) and will not be further discussed in this paper.

Hopson (1964) also recognized quartzo-feldspathic rocks in the Laurel belt, and on a small scale (1 in. = 8 mi.) geologic map (1964, p. 29) assigned them to two formations, the Ilchester Gneiss and the Leakin Park Gneiss, neither of which he described nor mentioned elsewhere. My mapping demonstrates that most of the rocks embraced by these two units are part of a single, continuous unit intrusive into the Mafic Complex and overlying rocks for which the formal name Cold Spring Gneiss is here proposed.

On the southeast flank of the Laurel belt is a succession of felsic and mafic rocks largely of supracrustal origin. Knopf and Jonas (1925) assigned the mica-poor, felsic rocks to two formations, the Baltimore Gneiss and the Relay Quartz Diorite, and the mica-rich rocks to the Setters Formation. The equivalence of what Knopf and Jonas (1925) called "Baltimore Gneiss" in this area to the James Run Gneiss has been emphasized by Southwick (1969) and Tilton and others (1970) and justifies designation of these rocks by the name James Run (James Run Formation of Higgins, 1972). Because these rocks are isolated from the main body of James Run in the Bel Air belt, I propose for them the name Carroll Gneiss Member of the James Run Formation. Knopf and Jonas (1925) assigned the immediately adjacent belt of schist to the Setters Formation, apparently for no other reason than the fact that this schist was in direct contact with what they considered Baltimore Gneiss. But this schist is devoid of microcline and the slabby weathering muscovite quartzite so characteristic of the Setters, has no internal stratigraphy as the Setters commonly has, and includes rock types such as amphibolite and muscovite-quartz-feldspar gneiss that are unknown from the Setters. I propose that it be renamed the Jones Falls Schist.

The remaining felsic rocks of this succession were assigned by Knopf and Jonas (1925) to the Relay Quartz Diorite. As mapped by these authors and also by Cohen (1937), the Relay crops out as two discrete masses, a narrow belt extending 11 kilometers northward from the Patapsco River at Relay nearly to Druid Hill Park, and a bulbous mass of about one square kilometer north of Druid Hill Park. Higgins (1972) marshalled chemical and textural evidence in favor of a volcanic-volcaniclastic origin for the linear belt of Relay, and proposed assigning it to the James Run Formation (but see Seiders, in press). I concur with Higgins' proposal and further propose that it be designated the Relay Gneiss Member.

The bulbous mass of "Relay Quartz Diorite" north of Druid Lake can be traced around the north end of the tadpole-shaped body of Jones Falls Schist and into the Carroll Gneiss Member of the James Run Formation, which, in fact, it resembles. Thus, these two supposedly separate rock units are one and the same stratigraphic unit.

Immediately northwest of the Jones Falls Schist and the Relay Member of the James Run Formation is a belt of amphibolite with subordinate interlayered felsic gneiss and granofels that was included in the Baltimore Gabbro Complex by Knopf and Jonas (1925), but quite clearly interfingers with and replaces the Carroll southward as a more mafic facies of the James Run. I propose that it be designated the Druid Hill Amphibolite Member of the James Run Formation.

Graphical analysis according to the methods of Miyashiro (1975) of chemical analyses of the James Run Formation presented by Hopson (1964, Table 8) and Southwick (1969, Table 11) leads to the conclusion that the James Run is composed about equally of calc-alkalic and tholeiitic rocks, and thus was probably formed in a mature island arc.

Hollofield Layered Ultramafite

The name Hollofield Layered Ultramafite is proposed for the layered rocks exposed at the abandoned Hollofield quarry (see appendix) that has been described in detail by Hopson (1964, p. 138-139) and is here designated the type locality.

The Hollofield consists of ultramafic and mafic rocks interlayered on a scale that varies

from centimeters to tens of meters. Chief among these is actinofels and actinoschist comprised almost entirely of light green actinolite, generally as a tangled mass of fine needles, but in places coarser-grained and having a more granular appearance. With the addition of plagioclase, actinofels grades into plagioclase-actinolite amphibolite (metagabbro of earlier workers). Such interlayered amphibolite, either actinolitic or hornblendic, and very rarely bearing garnet, comprises one-third of the exposed formation. Less common is bluish-black, orange-weathering serpentinite generally with subordinate amphibole (metaperidotite of earlier geologists). Chlorite may occur in any of these three rock types, either as discrete flakes or as schistose zones. Talc is locally associated with serpentinite, and tremolite and anthophyllite with actinofels. In places the rocks contain relict pyroxene and olivine which provide direct evidence of the igneous origin of the formation. Characteristically, the Hollofield consists chiefly of actinofels with subordinate interlayered amphibolite and serpentinite, but certain areas can be outlined where serpentinite predominates; such areas have been mapped separately.

Mount Washington Amphibolite

The Mount Washington Amphibolite is named for outcrops in the Mount Washington section of Baltimore City (plate 1).

The Mount Washington consists largely of fine- and medium-grained, generally massive, dark green to black rock consisting of plagioclase and amphibole, and locally pyroxene with very rare chlorite-rich zones several meters thick. It includes very subordinate interlayered actinofels (less than 10%), most commonly as very thin layers (2 centimeters or less), but in a few places considerably thicker (several tens of meters). Serpentinite is very rare. Though typically uniform, the amphibolite locally exhibits a layering on a centimeter to decimeter scale defined by variations in the amphibole/plagioclase ratio. Where the rock is both layered and foliated, the two planar features are virtually parallel. In some places the darker, more mafic amphibolite serves as a host to irregular patches of much lighter and coarser-grained amphibolite (*net veins* of Hopson, 1964, p. 140). Thin veins, a few centimeters thick, of feldspathic or quartzo-feldspathic composition, cut the amphibolite in a few places. A few boulders of quartz-hornblende granofels and also of epidote amphibolite litter the ground near the northwest corner of the northern body of Mount Washington.

North of U.S. 40, the rock is generally but not invariably massive. South of U.S. 40, the rock is generally well foliated and less commonly massive. Where massive, the Mount Washington crops out poorly, usually as cobbles and boulders in a clay-rich, red saprolite.

There are a few areas in the Mount Washington Amphibolite where ultramafic rocks can be mapped separately. These have been assigned to two categories—actinofels and serpentinite. The former consists chiefly of massive actinolite and tremolite-actinolite rock, locally with relict pyroxene, but includes minor talc-chlorite schist and amphibolite. The latter consists of massive serpentinite with subordinate actinofels and talc-chlorite schist. Relict pyroxene is very common.

Near the northern boundary of the Mount Washington Amphobolite, 1½ kilometers west of the Baltimore City line, is a lens, about 1 kilometer long and 75 meters wide, of uniform fine-grained garnet-biotite-quartz-plagioclase schist.

James Run Formation

Interlayered quartz amphibolite and biotite-quartz-plagioclase gneiss of probable volcanic origin cropping out along James Run in Harford County were named James Run Gneiss by Southwick and Fisher (1967). The name was changed by Higgins (1972) to James Run Formation and expanded to include "all of the closely associated, approximately contemporaneous metavolcanic and metavolcaniclastic rocks that crop out near the Fall Line in the eastern and northeastern Maryland Piedmont." At Baltimore the James Run Formation of the Laurel belt is divisible into three members—the Carroll, Druid Hill, and Relay Members.

Carroll Gneiss Member: The Carroll Gneiss Member of the James Run Formation is named for outcrops near Carroll Park, Baltimore City (see appendix). The Carroll consists chiefly of fine- to medium-grained biotite-quartz-plagioclase gneiss, locally with muscovite and magnetite, and locally devoid of mica. Subordinate amphibolite, generally in layers a few centimeters to a few decimeters thick, but locally several meters thick, is conformably interlayered with the felsic gneiss. In places it contains biotite and garnet. Variations in the ratio of plagioclase to hornblende define a

centimeter-scale layering that characterizes many amphibolite outcrops. The southeasternmost outcrop of the Carroll Member is biotite-plagioclase-muscovite-quartz schist, beyond which bedrock is buried beneath Coastal Plain sedimentary rocks.

Druid Hill Amphibolite Member: The Druid Hill Amphibolite Member of the James Run Formation is named for the abundant outcrops scattered throughout the wooded parts of Druid Hill Park in central Baltimore City (plate 1). Characteristic of the Druid Hill is fine- to medium-grained, generally well-foliated amphibolite, locally with irregularly anastomosing patches of coarser-grained, lighter colored amphibolite. Chlorite fels and actinofels, locally foliated, are associated with the amphibolite in places. The Druid Hill includes subordinate quartzo-feldspathic gneiss and granofels which increase northward to nearly half the volume of the unit. The scale of layering ranges from a few decimeters to somewhat more than ten meters. The felsic rocks are highly variable from fine-grained and well-foliated to coarser-grained, massive, and intensely jointed. They generally contain biotite (commonly chloritized) and locally muscovite; magnetite and hornblende are present in places. Generally the relationship between amphibolite and felsic rock is simple interlayering, but in places the amphibolite is intricately veined and chaotically intermingled with the felsic rock in zones ranging from a few centimeters to a few decimeters thick.

The thickness of the Druid Hill is about 700 meters.

Relay Gneiss Member: First described by Knopf and Jonas (1929) for the outcrops along the B&O Railroad tracks at Relay (plate 1), as noted above, the unit here described corresponds to only part of the Relay as mapped by those authors. Much of the Relay is fine- to medium-grained biotite-quartz-plagioclase gneiss, locally containing muscovite and magnetite. Mica is absent in places. At Relay in particular the gneiss is quite mica poor, distinctly pinkish, and cut by numerous, randomly oriented joints. This marked jointing of the Relay is its most distinctive feature and lends a rough, craggy aspect to outcrops.

The thickness of the Relay varies from 0 to 250 meters.

Jones Falls Schist

Named for outcrops along Jones Falls just east of Druid Hill Park (plate 1), the Jones Falls Schist is composed largely of medium- to coarse-grained biotite-plagioclase-muscovite-quartz schist, in places accompanied by fine-grained biotite-plagioclase-quartz gneiss in layers a few centimeters thick. Garnet, and less commonly tourmaline, occur in some outcrops. The Jones Falls Schist includes very minor muscovite-plagioclase-quartz schist, quartzite, amphibolite, and muscovite-quartz-feldspar gneiss.

The thickness of the Jones Falls Schist varies from 0 to 250 meters.

Cold Spring Gneiss

Named for outcrops in Cold Spring Park, Baltimore City (see appendix), the Cold Spring consists chiefly of uniform, fine- to medium-grained biotite-muscovite-quartz-feldspar gneiss or schistose gneiss, locally devoid of muscovite. The gneiss commonly bears small feldspar augen several millimeters in length and locally up to one centimeter. The Cold Spring may be equivalent to the muscovite quartz monzonite gneiss of Southwick and Owens (1968) in Harford County.

BEL AIR BELT

General Discussion

In contrast to the well studied Laurel belt, the Bel Air belt has received scant attention within Baltimore County with the exception of the work of Knopf and Jonas (1925, 1929). In view of widespread blanketing by Coastal Plain sedimentary rocks, however, this is not surprising.

The most characteristic feature of the Bel Air belt is the layering of dark and light colored rocks. Most commonly such layering is expressed by a variation in the ratio of hornblende to quartz and feldspar giving rise to interlayered dark and light amphibolite, or amphibolite and hornblende-quartz-plagioclase gneiss. Less common is interlayering of mafic and felsic gneiss. Knopf and Jonas (1925) solved the problem of mapping such rocks by assigning the hornblendic rocks and the rare occurrences of ultramafic rocks generally to the Baltimore Gabbro, and the non-hornblendic, felsic rocks generally to the Port Deposit Gneiss. These authors noted the total absence of pyroxene from this belt, an observation supported also by

my studies, but concluded nonetheless that the mafic rocks were of gabbroic origin. Southwick (1969) demonstrated that some of the rocks in adjacent Harford County (his James Run Gneiss) which were physically continuous with the Gabbro Complex were actually altered marine volcanic rocks. The problem then arises of separating plutonic from supracrustal rocks in the Bel Air belt of Baltimore County. Given the totality of recrystallization in the Bel Air belt plus the widespread Coastal Plain cover, assignment of any given outcrop to one or the other of these parent rock categories is not always clear cut. To facilitate field mapping of these rocks while avoiding the necessity of determining their pre-metamorphic state, I have included all the nonfelsic rocks of this belt generally within the Baltimore Mafic Complex, assigning them to two formations, the Raspeburg (pronounced Razz' burg) Amphibolite and the Bradshaw Layered Amphibolite. If later studies demonstrate conclusively a supracrustal origin for one or both of these units, they may be reduced to member status and assigned to the James Run Formation, or, as seems more reasonable, be retained as formations within a James Run elevated to group status.

The belt of Port Deposit Gneiss mapped by Southwick (1969) in adjacent Harford County extends a short distance into Baltimore County. For reasons noted above, extension of the name Port Deposit to cover these felsic rocks is considered unwise and they are here renamed the Franklinville Gneiss. Another belt of felsic rocks, not physically continuous with the Franklinville, but similar to it in some respects, and originally assigned to the Port Deposit by Knopf and Jonas (1925) is here renamed the Perry Hall Gneiss.

Raspeburg Amphibolite

Named for Raspeburg, a section of northeastern Baltimore City (plate 1), the Raspeburg consists of generally uniform, fine- to medium-grained plagioclase-hornblende amphibolite, with rare, thin streaks of more felsic gneiss. In places a subtle layering on the scale of a few centimeters to a meter is defined by variations in grain size or hornblende/plagioclase ratio. Minor textural variations include millimeter-scale laminated amphibolite, coarse-grained, more massive amphibolite, and amphibolite bearing euhedral hornblende porphyroblasts up to 4 centimeters long. North of Gunpowder Falls, the Raspeburg includes abundant, lighter colored, feldspathic amphibolite, both as layers and as anastomosing stringers and pods. Included in the Raspeburg are four, widely separated, small outcrops of actinoschist, commonly bearing chlorite and/or talc, and two outcrops of talc-chlorite schist associated with very fine-grained quartzite.

The thickness of the Raspeburg varies from 0 to 1.2 kilometers.

Bradshaw Layered Amphibolite

Named for the small community of Bradshaw on Little Gunpowder Falls in east-south-central Baltimore County (plate 1), the Bradshaw comprises centimeter- to meter-scale interlayered amphibolite and hornblende quartz-plagioclase gneiss with subordinate biotite-quartz-plagioclase gneiss. In places the Bradshaw includes zones several meters thick of coarse-grained, massive amphibolite, and in others, zones equally thick of fine- to medium-grained, laminated amphibolite. Quartzite and epidosite occur in layers a few centimeters thick in places, and two outcrops of chlorite schist were noted.

Franklinville Gneiss

Named for the small community of Franklinville on Little Gunpowder Falls (plate 1), the Franklinville comprises remarkably uniform, medium- to coarse-grained biotite-quartz-plagioclase gneiss, locally with muscovite. A few quartz veins, both concordant and cross cutting, can be seen at nearly every outcrop. Concordant layers of amphibolite and hornblende-quartz-plagioclase gneiss are not common except near the contact of the underlying Bradshaw Layered Amphibolite. At Franklinville the rock contains sparse, "mafic inclusions". These inclusions are thin (less than 3 centimeters), short (generally less than three decimeters), fine-grained, mica-rich, concordant streaks of biotite-quartz-plagioclase gneiss. Associated with the mafic inclusions 300 meters north-northwest of the Franklinville bridge are cobble-size clasts of calc-silicate fels. The Franklinville also includes several occurrences of deformed chlorite schist in zones up to 15 meters across.

Perry Hall Gneiss

Named for the community of Perry Hall on U.S. 1 in east-south-central Baltimore County

CURRENT NOMENCLATURE (Higgins, 1972)		PROPOSED NOMENCLATURE
Glenarm Series		
Wissahickon Formation		Wissahickon Group
quartzite facies →	?	Prettyboy Schist
metagraywacke facies →	?	Pleasant Grove Schist
metaconglomerate facies →	?	Sykesville Formation
diamicite facies →	?	gneiss member
pelitic schist facies →	?	schist member
		Piney Run Formation
		Oella Formation
		Sweathouse Amphibolite Member
		Loch Raven Schist
		garnet facies
		staurolite facies
		garnet-staurolite facies
		garnet-kyanite facies
		garnet-staurolite-kyanite facies
		barren facies
		Hydes Marble Member
		Rush Brook Member
Cockeysville Marble	Glenarm Supergroup	→ Cockeysville Marble
		phlogopitic metalimestone member
		layered marble member
		layered metadolostone member
		massive metalimestone member
		calc-gneiss lens
		massive metadolostone member
Setters Formation		→ Setters Formation
		garnet schist member
		gneiss member
		quartzite lens
		quartzite member
		schist lens
		conglomerate lens
unconformity		
Baltimore Gneiss		→ Baltimore Gneiss
		hornblende gneiss member
		streaked-augen gneiss member
		augen gneiss member
		layered gneiss member

Table 1: Comparison of proposed stratigraphic nomenclature for the Baltimore Gneiss and Glenarm Supergroup with current nomenclature.

(plate 1), the Perry Hall comprises centimeter to tens of meters scale interlayered, fine- to medium-grained biotite-quartz-plagioclase gneiss, rarely muscovitic, and hornblende-quartz-plagioclase gneiss, commonly garnetiferous, with subordinate amphibolite. Thin layers of quartzite crop out in a few places.

PART II

EVOLUTION OF THE EASTERN MARYLAND PIEDMONT

INTRODUCTION

The Appalachian Piedmont near Baltimore has long been a classic geologic area. It is the type locality of the Baltimore Gneiss, Glenarm Supergroup (formerly Glenarm Series), and Baltimore Mafic Complex (formerly Baltimore Gabbro Complex), and is one of the best described localities in the world featuring mantled gneiss domes. It is totally covered by county geologic maps at 1:62,500 scale, two of which, Harford and Baltimore, have been completely remapped and published within the past ten years (Southwick & Owens, 1968; Crowley and others, 1976). Two 7½′ quadrangle geologic maps (scale 1:24,000) covering parts of the area have recently been published (Crowley & Cleaves, 1974; Crowley and others, 1975), and others are in preparation.

Nearly one hundred papers and maps have been published by professional geologists on various aspects of the geology of this area. The interested reader will find most of these up to and including 1970 in the references section of papers by Hopson (1964) and Higgins (1972).

This report is grounded in eight years of nearly continuous field work conducted in the Baltimore region, mapping an area in excess of 1100 square kilometers. My approach can best be described as stratigraphic-structural; my efforts have been directed toward a finely detailed subdivision of the mapped area into unique lithologic units and the determination of how these units are spatially related through structural analysis. In analyzing the structure I have relied chiefly on two techniques, correlation on the basis of lithologic and/or stratigraphic similarity, and analysis of the regional variation in attitude of compositional layering. Analysis of the regional variation in the attitude of linear and planar features other than compositional layering is discussed where the solutions it generates are compatible with solutions generated by the two techniques noted above.

BALTIMORE GNEISS

The most detailed description of the Baltimore Gneiss has been given by Hopson (1964, p. 37-45) who recognized five varieties of gneiss (banded gneiss, migmatite, veined gneiss, augen gneiss, and granitic gneiss) but did not attempt to show their distribution. Knopf and Jonas (1925), on the other hand, did separate out from the large mass of undifferentiated gneiss, two small areas of augen gneiss which they considered to be pre-Glenarm intrusive granite. I have mapped five varieties of gneiss. Interpretation of the origin of any of these units is hindered by the total absence of relict textures, a lament voiced also by Knopf and Jonas (1929) and Hopson (1964). But the chemistry of the gneiss, its layered nature, and the map pattern of its constituent units provide at least a basis for limited speculation.

All geologic maps of any area that includes Baltimore City published prior to 1972 assign certain layered gneisses along Jones Falls and Gwynns Falls to the Baltimore Gneiss. The work of Hopson (1964, p. 31-35, 53-54) and Tilton and others (1970) have demonstrated conclusively that these gneisses are chemically and texturally different from true Baltimore Gneiss and considerably younger. They are discussed below as the James Run Formation.

The igneous chemistry of its felsic and mafic gneisses is one of the most characteristic features of the Baltimore Gneiss (see Hopson, 1964, p. 36-45), but the biotite-rich schists locally associated with these rocks reflect a high K_2O content not readily accounted for by any igneous parent. Knopf and Jonas (1929) did not speculate about the origin of the schists but did consider the felsic rocks associated with them to be intrusive, the whole thus forming an injection complex. The augen gneisses were also considered intrusive, and, where separately mappable, were interpreted as the plutons which fed the injection complex.

Hopson (1964, p. 36, p. 43) noted the gross structural similarity of layered gneisses in the

Baltimore Gneiss to younger layered gneisses of volcaniclastic origin, but also recognized that large areas of uniform gneiss might represent intrusive complexes. He considered the augen gneiss a metasomatic phase of the Baltimore Gneiss, and not necessarily intrusive.

I concur with Hopson that the igneous chemistry and generally pervasive layering of the Baltimore Gneiss are at least compatible with an origin as volcaniclastic sediments. The amphibolites, which are invariably concordant with the felsic gneisses, might then be either of similar origin, but of mafic derivation, or have been deposited directly as mafic tuffs. The biotite-rich schists (see Hopson, 1964, p. 36, Table 9) might represent montmorillonitic shales derived from the weathering of quartz-poor, mafic igneous rocks. Two very localized details support this supracrustal origin for at least the layered part of the Baltimore Gneiss. First, on the east bank of the North Branch of the Patapsco River (plate 1), about 1.55 kilometers upstream from its mouth, is an outcrop of layered gneiss containing a single concordant bed of feldspathic quartzite a little less than three decimeters thick. There is no evidence that this can be interpreted as an extremely attenuated syncline of the overlying Setters Formation, and so it is taken as proof of the supracrustal origin of the Baltimore Gneiss in this area. Second, an outcrop 3.05 kilometers southeast of the one described above, and along the middle reaches of a minor tributary that joins the Patapsco 1.3 kilometers downstream from Woodstock, contains biotite schist that bears garnet and kyanite. The degree of alumina enrichment represented by the presence of kyanite is certainly too great for any intrusive rock and is taken as proof of supracrustal origin resulting either from intensive, *in-situ* weathering, or contamination by the products of such weathering, *i.e.*, alumina-rich clay.

Hopson (1964, p. 43) has correctly observed that augen gneiss *per se* is not separately mappable because it is interlayered with and gradational into other kinds of gneiss. Nonetheless, I have found that, except for a few, scattered, isolated outcrops of augen gneiss, all occurrences of this rock type are confined to discrete, mappable bodies of interlayered augen gneiss and non-augen gneiss. Two such bodies have been mapped. Hopson (1964, p. 43) has stated that, "augen gneiss is most abundant at the margins of the domes, just beneath the Setters contact", but this is not borne out by my mapping (plate 1, also Crowley and Cleaves, 1974).

There are eight distinct localities where layered gneisses, lying close to the mapped limits of the augen gneiss in both bodies, contain hornblende, three of which are large enough to be mapped as a separate hornblende gneiss member. These hornblendic rocks are clearly concordant, mafic layers and can in no way be construed as a contact metamorphic effect. Their distribution is thus taken to indicate that the mapped contact between the augen gneiss and layered gneiss members of the Baltimore Gneiss is a stratigraphic contact of supracrustal origin. The significance of this conclusion in the context of present understanding of the Baltimore Gneiss is that the truncation of this contact by the overlying Glenarm Supergroup (plate 1) is the first really hard evidence for an unconformity at the base of the Glenarm Supergroup.

Hopson (1964, p. 44-45) has noted the occurrence of uniform, granitic gneiss within the Baltimore Gneiss. I have mapped three such bodies which I have designated Slaughterhouse Gneiss. The uniformity of these bodies, their placement athwart the layering of the Baltimore Gneiss, and their truncation by the Glenarm Supergroup suggest that they are post-Baltimore Gneiss, pre-Glenarm intrusives.

In summary the Baltimore Gneiss probably represents largely a pile of predominantly felsic, volcaniclastic rocks that were deposited, metamorphosed, folded, and intruded by granite (Slaughterhouse Gneiss) in the late Precambrian.

SETTERS FORMATION

Overlying the basement rocks unconformably, the Setters Formation is a clastic, characteristically quartz-rich unit that can be resolved stratigraphically into at least six sub-units. Its total reconstructed areal extent in Maryland is probably on the order of at least 1600 square kilometers. Given the thinness of the Setters (nowhere greater than 500 meters, commonly much less) and its basal position, the structure upon which it was deposited evidently had the

nature of a shelf or platform. Evidence discussed below indicates that this shelf possessed an undulatory surface which gave rise to a number of coalescent basins.

The Setters does not form a complete carapace about the basement surface, and interpretation of this feature has led to two conflicting schools of thought (see Hopson, 1964; p. 58-59) which can be termed tectonic and sedimentological, respectively. The tectonic view holds that structural thinning along steeply overturned anticlinal limbs during folding can lead to total obliteration of part of the rock section. The sedimentological view holds that in those areas where the Setters is missing, it either was never deposited initially or was deposited and later eroded before deposition of younger sediments. Hopson (1964, p. 58-59) has pointed out that the distribution of Setters discontinuities is not what would be predicted by the tectonic model, and my own mapping supports his conclusion. The same conclusion can also be reached on the basis of stratigraphic analysis. Reference to plate 1 shows that the distribution of Setters subunits is far from uniform, and, locally, as along the south flank of the Phoenix dome and the north flank of the Texas dome, rather erratic. The lensoid nature of these units is most simply explained by irregularities in the basement surface during deposition, that is, the basement surface apparently had the form of a cluster of basins separated by positive areas which, though not emergent, remained free of sediment. Although the sedimentological record of each basin reflects strong local control, total independence was probably not achieved. The evidence for this lies in a chemical peculiarity of the Setters, unusually high K_2O and B_2O_3, expressed modally as microcline and tourmaline, respectively, and probably indicative of restricted water circulation (see Sheppard and Gude, 1973). The widespread occurrence of these minerals in the Setters indicates at least limited interconnection between basins of deposition.

The stratigraphy of the Setters may also bear directly on resolution of the structure of the Phoenix dome. A unique feature of this dome is the narrow inlier of Setters, Cockeysville Marble, and Loch Raven Schist completely surrounded by Baltimore Gneiss. The classic interpretation of this feature is simply an infolded syncline (Knopf and Jonas, 1925; Broedel, 1937). Rodgers (1970, p. 190), however, citing Bailey and Mackin (1937) noted that the map pattern and lineations of the Phoenix dome indicate it is probably an arched recumbent fold, an interpretation more compatible with the variation in the magnetic field over the dome (see Bromery, 1968, p. 90). The very sparse Setters cropping out in the inlier does not include the garnet schist member, whereas this member is well developed on both the north and south flanks of the dome. The interpretation of the inlier as a simple syncline would require a facies change so unusual as to be improbable. More likely the inlier is an antiformal syncline exposing the arched up, lower limb of a recumbent fold (see cross section, plate 1).

COCKEYSVILLE MARBLE

In the two most detailed studies of the Cockeysville Marble, Miller (1905) and Choquette (1957, 1960) both concluded that sub-formational stratigraphic units could not be distinguished. In the context even of their own work their conclusion is misleading because both authors, especially Choquette, recognized characteristic rock assemblages. On the whole the distribution of these assemblages does not conform to patterns in the underlying or overlying formations, but this may mean that Cockeysville stratigraphy records unusual complexity perhaps with respect to both sedimentation and later tectonics, and not that the Cockeysville is stratigraphically amorphous. But having said this much, I frankly admit that I am still without a model that satisfactorily explains Cockeysville stratigraphy.

One aspect of Cockeysville stratigraphy that is especially intriguing is the remarkable similarity between the phlogopitic metalimestone member, which is everywhere in contact with the overlying Wissahickon group, and the basal carbonate rocks of the Manhattan Schist in southeastern New York State (Hall, 1968), an observation which emerged from the Northern Piedmont Penrose Conference held in June 1972 (see Fisher and Higgins, Geotimes, Nov., 1972).

This discovery adds strength to the correlation of the rocks around Baltimore with those in the New York City area and increases the likelihood of a Cambro-Ordovician age for the Cockeysville (see Rodgers, 1970, p. 191).

Further support for the interpretation of the Phoenix dome as an arched recumbent fold comes from the observation that the Cockeysville flanking the dome in the vicinity of its western closure belongs to the massive metalimestone member whereas that of the western closure of the inlier belongs to the layered metadolostone member.

Although Cockeysville stratigraphy is not sufficiently clear for detailed environmental reconstruction, the fact that it directly overlies the Setters suggests that the platform which existed at that time in the Baltimore area evolved according to a pattern that is well known throughout the geologic record (Pettijohn, 1957, p. 611-615). Following initial immersion of a Precambrian terrane of very low relief and a blanketing by clastics which restored the surface to topographic equilibrium, marine life flourished and led to the development of a carbonate bank complex which was later metamorphosed to the Cockeysville Marble.

WISSAHICKON GROUP

INTRODUCTION

Overlying the Cockeysville Marble is the areally extensive, thick Wissahickon Group of largely clastic rocks. The stratigraphy and structure of the Wissahickon have been discussed by many workers with many of the major conclusions of each differing significantly. Rather than review these exhaustively, I direct the reader to the major works (Mathews, 1904; Knopf and Jonas, 1923; Cloos and Hietanen, 1941; Hopson, 1964; Southwick and Fisher, 1967; Higgins, 1972) and will instead present the results of my own mapping, and integrate the work of others into my model. As a guide to the lengthy discussion that follows, let me first state my major conclusions briefly. The Wissahickon begins with the deposition of shale (Loch Raven Schist) which is succeeded upward by interbedded shale and graywacke (Oella Formation and to a lesser extent the Piney Run Formation) and then wildflysch (Sykesville Formation). The coarsening upward sequence reflects the uplift and advance of a southeasterly source area, an enormous slab of which (Baltimore Mafic Complex and associated rocks) was emplaced during Sykesville time by thrust faulting.

Before discussing Wissahickon stratigraphy in detail, it is convenient at this point to say something about a very minor component of these clastic rocks. Amphibolite, commonly bearing epidote, occurs as concordant layers ranging in thickness from decimeters to tens of meters throughout much of the Wissahickon, though overall it constitutes far less than one percent of these rocks. The amphibolite is commonly thin bedded, even delicately laminated, probably representing the slow accumulation of basaltic tephra. Two aspects of the distribution of these amphibolites are especially worth noting: (1) they are confined exclusively to the Wissahickon and are unknown from the Setters or Cockeysville, and (2) the greatest accumulation of these rocks is to the southeast; they are virtually unknown northwest of the Phoenix dome. From these two observations, I conclude that the amphibolites and the Wissahickon were both derived from the same source area and that this source area lay to the southeast, beyond the present day Fall Zone.

LOCH RAVEN SCHIST

Throughout most of the Baltimore area, Cockeysville Marble is succeeded directly upward by the Loch Raven Schist, a uniform, medium-grained biotite-plagioclase-muscovite-quartz schist, commonly garnetiferous and locally bearing staurolite and/or kyanite, and interpreted to be the metamorphosed equivalent of shale. The Loch Raven also includes a discontinuous basal unit, the Rush Brook Member, whose chief interest derives from its

peculiar heterogeneity. On the one hand it includes quartz-rich, aluminous rocks and amphibolites like those typical of the Wissahickon as a whole. On the other hand it includes layers of marble; tourmaline-bearing, feldspathic quartzite; and quartz-pebble metaconglomerate identical to rocks in the underlying Setters and Cockeysville. I interpret this assemblage as the product of two distinct source areas, the sediments of Wissahickon affinity derived from a southeasterly provenance and those of Setters-Cockeysville affinity derived perhaps from a cratonic source probably to the north or west. In other words, the Rush Brook represents localized persistence or re-establishment of platform conditions in the face of a southeasterly derived clastic flood.

At the Northern Piedmont Penrose Conference of 1972 (Fisher and Higgins, Geotimes, Nov., 1972), Leo Hall suggested that the Rush Brook might be the metamorphosed equivalent of a "blocks-in-shale" unit, an idea also endorsed by John Rodgers, presumably analagous to similar units in the Taconics and Western Newfoundland (see summary in Rodgers, 1970, p. 79, 150-152). Nonetheless, despite its heterogeneity, the Rush Brook is regularly layered and shows none of the structures associated with an undeniable "blocks-in-shale" unit such as the Sykesville Formation (see Hopson, 1964, p. 108-112).

Recognition of the Rush Brook as a distinct stratigraphic unit has also led to the interpretation of the carbonate mass at Hydes (plate 1) as a lens in the Loch Raven rather than an unroofed gneiss dome in Cockeysville Marble. Moreover, the Rush Brook may also crop out in southeastern Harford County (plate 2) where it was mapped as Setters Formation by Southwick and Owens (1968; see also Southwick, 1969, plate 4). The rocks there are slabby weathering, quartz rich, and, very significantly, include a bed of calcite marble as thick as four meters (Southwick, 1969, p. 25). Southwick assigned the marble to the Setters Formation on the basis of the immediately adjacent rocks which resemble Setters rock types. Carbonate rocks are nowhere else associated with the Setters, making this a unique occurrence. On the other hand, the Rush Brook, which includes carbonate rocks, is remarkably like the Setters, so much so that it was originally named "pseudo-Setters quartz schist" by Miller (1905). In the light of these facts, it seems reasonable to assign these rocks in southeastern Harford County to the Rush Brook. But regardless of whether they are Setters or Rush Brook, this analysis strengthens Southwick's (1969) conclusion that they occur low in the Glenarm Supergroup (my usage) and are not part of the James Run Formation as argued by Higgins (1972, p. 1018, 1020).

OELLA FORMATION

Almost everywhere along the southeast flank of the Baltimore-Washington anticlinorium and locally along the northwest flank, the Loch Raven Schist is succeeded upward by interlayered biotite-plagioclase-quartz gneiss and biotite-plagioclase-muscovite-quartz schist which I have assigned to the Oella Formation. The biotite gneiss is mineralogically similar to gneiss which Hopson (1964, p. 79) concluded, chiefly on chemical grounds, was metagraywacke, although sedimentary structures described from metagraywackes by Hopson (1964, p. 88-93, Fisher (1970, p. 300-301), and Southwick (1969, p. 36) are absent from the Oella except for a few questionable occurrences of graded bedding. The Oella might constitute an example of an uncommon phenomenon, namely, a flysch unit in which graded bedding is rare (Kuenen, 1964, p. 16).

On the southeast flank of the Baltimore-Washington anticlinorium I have traced the Oella discontinuously from as far south as Ellicott City northeastward to the southern boundary of Harford County. Southwick (1969, p. 29) has described identical rocks on strike in Harford County, and, based on his description, I propose that the Oella can be traced into the unit that Southwick and Owens (1968) mapped as the "metagraywacke lithofacies of the Wissahickon Formation" in the manner shown in plate 2. This in turn requires a modification of Southwick's stratigraphical-structural scheme putting his "metagraywacke facies" lower than his "boulder gneiss facies" rather than at the same level. Additional support for this model comes from the direction of younging as deduced from graded bedding and shown by Southwick and Owens (1968) on the Harford County geologic map, all occurrences of which are compatible with the scheme outlined above.

The upper part of the Oella locally includes abundant interlayered epidote amphibolite (Sweathouse Amphibolite Member). In the past most workers have included this with the Baltimore Mafic Complex, but the distinctive

mineralogy and texture of these amphibolites, and especially the fact that they are clearly interlayered with clastic rocks, proves that they are part of the Wissahickon. They probably represent the volcanic half of the well known graywacke-greenstone association (Pettijohn, 1957, p. 308-312). Where separately mappable, I have designated this unit the Sweathouse Amphibolite Member of the Oella Formation.

Of special interest is the fact that the Sweathouse is the repository of an important copper deposit near Bare Hills (plate 1), once mined but now abandoned (Heyl and Pearre, 1965). As is evident from the previous paragraph, the copper deposit was thought to be associated with the Baltimore Mafic Complex. That it is associated not with plutonic rocks, but with what are probably the metamorphosed equivalent of basaltic volcanics requires a reassessment of its probable origin. The deposit is now entirely covered over by housing but the excellent description by Heyl and Pearre (1965, p. 60-65) provides a basis for speculation.

Heyl and Pearre's observation that the deposit was in the form of a lens of massive sulfide whose chief ore mineral was chalcopyrite, together with my conclusion that the host rocks were greenstone volcanics, clearly places the Bare Hills deposit in the "Besshi-type" of Mitchell and Bell (1973). Citing the work of Japanese geologists, Mitchell and Bell note that the deposits at Besshi occur, "mostly within a succession...of basic, pelitic, and quartzose schist", a description that fits the Bare Hills deposit precisely. Citing Ernst (1972) they state that, "the sedimentary environment has been interpreted as a continental slope and shelf, although mafic tuffs and subsequent metamorphism suggests a volcanic arc environment." This too invites comparison with the Baltimore area where I interpret a shelf environment up to the end of Cockeysville time followed by subsidence and exogeosynclinal sedimentation caused by the uplift and advance of an ophiolite sheet that carried along with it island arc volcanics. Mitchell and Bell (1973) cite several authors in support of a syngenetic, volcanic-exhalative origin for deposits of the Besshi-type. Of additional interest in this regard is the observation of Heyl and Pearre (1965, p. 61) that lenses of calcite marble occur within the epidote amphibolite in the vicinity of the copper deposit. I have summarized descriptions of numerous occurrences of sulfide mineralization in the vicinity of marble-amphibolite assemblages in Western Connecticut (Crowley, 1968) and have marshalled evidence in support of a syngenetic origin for these also.

PINEY RUN FORMATION

On the northwest flank of the Phoenix dome, the Loch Raven Schist is succeeded upward by the Piney Run Formation, predominantly a pelitic schist unit with 10 to 30 percent interlayered biotite quartzite. Although having in common with the Oella the interlayering of quartzite and schist, the quartzites in the Piney Run are neither as abundant nor as mica- and feldspar-rich as those in the Oella. Nevertheless, I consider the two units as approximately correlative in that both are locally sandwiched between the Loch Raven Schist and Sykesville Formation. The Piney Run can perhaps be interpreted as a more distal facies of the clastic apron whose proximal facies is represented by the Oella.

SYKESVILLE FORMATION

The evolution of ideas concerning the origin of the Sykesville and the most detailed discussion of its present interpretation as a submarine slide mass are presented by Hopson (1964, p. 101-112). To this superb treatment there is nothing I can add. The contribution made by my mapping is in another direction, namely, the demonstration that the Sykesville is areally more extensive than formerly recognized. On the northwest flank of the Baltimore-Washington anticlinorium, I have traced it northeastward to the vicinity of Reisterstown (plate 1) where it feathers out, but beyond which it is present for at least another seven kilometers in the form of sparse lenses of metadiamictite in the Piney Run Formation. On the southeast flank of the anticlinorium I have mapped the Sykesville as a string of discontinuous lenses, each of which is in direct contact with the Baltimore Mafic Complex. Two conclusions can be drawn from these new data, first, that the Sykesville very nearly forms a complete sheet whose arching defines the doubly plunging Baltimore-Washington anticlinorium; and, second, that this sheet constitutes a discrete stratigraphic unit resting everywhere on the Oella Formation or its stratigraphic equivalent, the lower part of the Piney Run.

The most crucial questions regarding the Baltimore Mafic Complex and associated rocks are still the basic geologic questions—what are their origin and how are they related to the Glenarm Supergroup? To this end, much structural, petrologic, and chemical research has been directed, and the interested reader is referred to the stimulating syntheses of Hopson (1964) and Southwick (1969, 1970) and the references cited therein. Again my analysis will be based to a large extent on the observed relationships between map units.

Fundamental to any discussion of the Mafic Complex is the relationship, if any, of the isolated mafic and ultramafic bodies distributed throughout the lower Wissahickon on the northwest flank of the Baltimore-Washington anticlinorium to the Mafic Complex itself on the southeast flank. I propose that these isolated mafic and ultramafic bodies were originally parts of a single, unified mass whose partial disintegration occurred during tectonic emplacement. A critical observation in this regard is the fact that the Mafic Complex, from its northeastern terminus in Pennsylvania to Scarboro, a small village seven kilometers southwest of the Susquehanna River (plate 2), is everywhere bounded by a continuous basal sheet of ultramafic rock, almost exclusively, variably steatized serpentinite. Beyond this point the basal sheet veers westward into clastic rocks of the Wissahickon while the Mafic Complex continues southwestward devoid of its base. To be sure, ultramafic rocks do occur at the base of the Complex in a few places farther southwest, but they are, by-and-large, not serpentinitic; Southwick and Owens (1968) show two small lenses of actinoschist in southern Harford County, and I have also mapped two small lenses farther south yet, one actinoschist and the other serpentinite. Farther along strike beyond the southern margin of the Towson dome, the Hollofield Layered Ultramafite is in direct contact with the base of the Complex along two segments, but this is a layered unit which includes only very subordinate serpentinite in contrast to the uniformity and near monolithology of the basal sheet at the Susquehanna. In this same area, I have mapped two small lenses of actinofels and a rather large serpentinite mass about 1.7 square kilometers in area. This latter is the nearest thing to a remnant of the basal ultramafic sheet, but it too differs somewhat in that it includes subordinate interlayered actinofels comprising perhaps 10—20 percent of the total volume. Farther south along strike to the southern terminus of the Complex in Howard County, no ultramafics of any sort have been reported from the base (Cloos and Broedel, 1940). From this accumulated evidence, therefore, one can conclude that from Scarboro southward, the basal serpentinitic sheet is nearly if not totally absent. On the other hand there is strong evidence that where the basal serpentinite is missing, fragments of it can be found in the adjacent clastic rocks to the northwest. Crucial to this argument is the distribution of chromite, and in the following discussion, I rely largely on the detailed study of Pearre and Heyl (1960).

Within the basal serpentinite from its northeastern terminus in Pennsylvania southwestward to Scarboro, there are more than thirty old chromite mines, placers, and prospect pits. In this same area only a single chromite mine is known from the several ultramafic bodies that lie within the clastic rocks to the northwest of the basal serpentinite. From Scarboro southwestward there is not a single old chromite operation of any sort associated with the Baltimore Mafic Complex whereas there are more than thirty in the isolated ultramafic bodies in the Wissahickon. Examination of plate 40 in Pearre and Heyl's (1960) study seems to refute this generalization for they show the chromite-bearing Bare Hills serpentinite, which crops out just north of Baltimore, as being attached to the base of the Mafic Complex, based on the mapping of Knopf and Jonas (1925). But my own mapping has demonstrated that at least 500 meters of interlayered meta-clastics and epidote amphibolite (Sweathouse Amphibolite Member of the Oella Formation) crop out between the Bare Hills serpentinite and the Mafic Complex (plates 1 and 2). Moreover, I am not the first to have mapped the rocks this way. Williams

(1892) and Miller (1905) both show other rock types separating the Bare Hills mass and the Mafic Complex. Therefore, the conclusion that the Mafic Complex south of Scarboro is entirely devoid of old chromite operations is correct. Such operations, however, are known from several serpentinite bodies in the Wissahickon southwest of Scarboro, thus lending strength to the hypothesis that these bodies were originally attached to the base of the Mafic Complex. Not all of the ultramafic masses in the Wissahickon are variably steatized serpentinite, however, nor do they all contain chromite. Of the non-chromiferous masses, all except the one intersecting Falls Road (Md. 25) and the much smaller mass immediately southeast of it, consist either of variably steatized serpentinite, chloritic actinoschist, or the two interlayered, with or without interlayered amphibolite and chlorite schist. Such layered rocks resemble nothing that has been mapped in the Mafic Complex proper in the vicinity of the Susquehanna, but they do resemble closely a mixed zone (*Pzug* of Southwick and Owens, 1968; *um* of plate 2) that hugs the southern margin of the basal serpentinite where it veers westward at Scarboro, and nearly replaces it entirely still farther west. As noted below, I consider this mixed zone a tectonic unit generated during separation of the chromiferous serpentinite sheet from the Mafic Complex, and thus its occurrence as isolated masses farther southwest is further evidence that these masses were originally part of the Mafic Complex. The two exceptional bodies, the one crossing Falls Road and its neighbor to the southeast, include actinofels and quartz-bearing amphibolite. Locally they have an unmistakably clastic texture, and in places resemble volcanic agglomerate composed of amygdaloidal basalt fragments (John Suppe, personal communication). They may have been derived from the fragmentation of a predominantly volcanic thrust slice overlying the plutonic slice, and in this connection it is worth noting that the segment of the Baltimore Mafic Complex directly across strike to the southeast is indeed floored by probable volcanic rocks, although they do not resemble the rocks under discussion.

The string of ultramafics mapped by Southwick and Owens (1968) along the contact separating their upper pelitic schist and metagraywacke lithofacies of the Wissahickon do not at first glance appear to be a part of the ultramafic belt discussed above, but my modification of their mapping equating their metagraywacke with my Oella Formation brings them essentially into stratigraphic equivalence (plate 2).

Having established that the isolated ultramafic masses embedded in the Wissahickon northwest of the Mafic Complex were originally part of that Complex, I turn now to the problem of determining the nature of the relationship between the Mafic Complex and the Wissahickon Group. The most striking fact bearing on this problem is the knowledge that all of the isolated ultramafic masses northwest of the Mafic Complex are confined exclusively to the Wissahickon Group. No geologic map of any part of the Maryland Piedmont shows ultramafic rocks in formations stratigraphically below the Wissahickon Group, and my own mapping has uncovered no exceptions to this important generalization. The only possible exception is the small ultramafic body at Glencoe in the Phoenix dome (plate 1). Although it is in contact with Baltimore Gneiss along its north side, on the south it rests against Wissahickon (Loch Raven Schist) and is most simply interpreted as an ultramafic at the base of the Wissahickon in an area where the Setters and Cockeysville are locally absent.

The absence of ultramafics from the Baltimore Gneiss, Setters Formation, and Cockeysville Marble raises a serious objection to the thesis that ultramafics in the Wissahickon were emplaced as mantle diapirs or as any other kind of intrusion derived directly from deeper levels. The objection arises, of course, from the fact that to have been so emplaced in the Wissahickon, the ultramafics would have had to pass through the pre-Wissahickon stratigraphy, but nowhere in the widely exposed pre-Wissahickon formations is there any evidence at all of such passage. This conclusion, coupled with the conclusion reached above that the isolated ultramafics were originally attached to the Mafic Complex leads to the further conclusion that the Mafic Complex itself could not have had such an origin, contrary to Southwick's (1970) analysis and the assertion of Higgins (1974, p. 156). Note also, in this connection, that nowhere is the Mafic Complex itself in contact with pre-Wissahickon rocks.

The evidence discussed above is also difficult to reconcile with the interpretation of the Mafic Complex as a sill (see Knopf, 1921, p. 89; also

Hopson, 1964, p. 132-135). In support of this idea, Hopson (1964, p. 134-135) argued that the Soldiers Delight serpentinite was at the same stratigraphic level as the Mafic Complex, representing its greatly thinned edge, and that the two would have been connected were the present level of erosion not quite so deep. Although this argument cannot be refuted directly, the Soldiers Delight serpentinite is identical to the Bare Hills serpentinite, and if this is accepted as evidence of stratigraphic correlation, then the Soldiers Delight mass lies below the Mafic Complex, and the two cannot be part of a single sheet. And even if this specific correlation is not accepted, one must still account for the emplacement of the Bare Hills mass as other than a sill or diapir.

The plutonic nature of the Mafic Complex, at least locally (Williams, 1886; Hopson, 1964, p. 134-141), is most simply explained by interpreting the Complex as an intrusive body. But the discussion above rules out both any direct intrusive relationship such as a dike, diapir, or stock and any laterally intrusive relationship such as a laccolith or sill. By elimination one is led to postulate a fault contact separating the Mafic Complex from the underlying Wissahickon Group. Moreover, additional support for the fault hypothesis comes from two lines of evidence. The volcanic James Run Formation in Harford County (Southwick and Owens, 1968) can be traced directly into the Bradshaw Layered Amphibolite on the southeast limb of the Franklinville syncline. The Bradshaw in turn can be traced around the Franklinville and Perry Hall synclines into the Raspeburg Amphibolite which rests directly on the Wissahickon Group. Stratigraphically this raises the possibility that the Bradshaw and Raspeburg might be volcanic, at least in part, and in an effort to evaluate this proposal, I have led a number of field trips through these rocks to gain the benefit of other geologists' experience in interpreting textural evidence. In this regard I gratefully acknowledge the stimulating discussions with many individuals, especially Michael Higgins, Louis Pavlides, and Thomas Thayer of the U.S. Geological Survey, George Fisher of Johns Hopkins University, Harold Williams of Memorial University, John Rodgers of Yale University, and David Southwick of Macalester College. From these field trips I have concluded that the delicate laminations and thin layering, defined by abrupt changes in mafic/felsic ratio and grain size locally exhibited by these rocks, are most satisfactorily explained by volcanic or volcanic-sedimentary processes. This is not to say that these units are devoid of possible plutonic rocks, but that they are, at least in part, supracrustal, and that such supracrustal rocks are, in places, at the base of the Complex. If the floor of the Mafic Complex is occupied by supracrustal rocks in some places and by plutonics in others, then its lower contact must necessarily be a fault.

The internal map pattern of the Mafic Complex at Baltimore also suggests a basal fault. Immediately south of the Susquehanna, the Mafic Complex exhibits a tripartite stratigraphy with serpentinite at the base overlain by hypersthene gabbro and topped off by quartz gabbro (Southwick and Owens, 1968; see also plate 2). The contacts separating these units are all internally concordant and conform also to contacts in the adjacent Wissahickon Group. South of Scarboro, where the basal serpentinite parts company with the Complex, relations might be expected to be less simple. Such is the case at Baltimore where the Complex appears to possess a bipartite stratigraphy. The Mount Washington Amphibolite probably corresponds to the hypersthene gabbro of the Susquehanna section, and the Hollofield Layered Ultramafite may correspond with the mixed zone at Scarboro although this is less certain. At any rate, compositional layering generally parallels the contact between these two units, and regardless of which is the older, they probably represent a valid stratigraphic sequence. The fact that the contact separating them is truncated by the base of the Complex supports the fault interpretation of that base.

The major appeal of the sill hypothesis has been the stratigraphic nature of the Complex, that is, the fact that the Complex as a whole has the geometry of a layer intercalated in the Wissahickon Group. This topological constraint taken together with the evidence of a faulted base implies a very low angle fault, indicating that the Complex was emplaced along a thrust fault and not a normal fault. The stratigraphic interval occupied by the Mafic Complex on the southeast flank of the Baltimore-Washington anticlinorium is devoid of any such sheet on the northwest flank except for the small ultramafic masses scattered throughout the Wissahickon discussed above, and from this I conclude that prior to its tectonic emplacement the Complex resided somewhere to the southeast of its present location.

The process by which the basal ultramafic sheet was ejected from the Mafic Complex is frozen into the rock record at Scarboro, south of which the serpentinite sheet and Mafic Complex go their separate ways. As Southwick (1970, p. 403-405) has shown, the map pattern in this area cannot be explained by folding, and although he admits the possibility of a fault solution, he proposes instead a complex magmatic-tectonic origin in line with his overall intrusive model. The objections to this model have been discussed above, and an allocthonous model is proposed instead. At Scarboro, the basal ultramafic sheet veers westward and into stratigraphically lower rocks. The simplest explanation of this unusual map pattern is that during tectonic emplacement of the Complex, its base, from Scarboro southward, was sheared out from under it. I propose the following sequence of events to explain this phenomenon. During initial thrusting of the Mafic Complex, before any significant movement had occurred, seawater overlying the Complex migrated into its interior along the zone of faulting, and, as it was heated, reacted with the mafic and ultramafic rocks with which it came into contact. The most significant result of this process was serpentinization of the ultramafic layer at the base of the Complex causing a marked reduction of its strength (see Cowen and Mansfield, 1970, for a discussion of the low strength and high mobility of serpentinite). The gravitational force exerted by the overlying part of the Complex then mobilized the newly serpentinized ultramafics and forced them out along the thrust surface. As they moved along this surface they interacted physically with the overlying, largely mafic rocks to generate a tectonic unit composed of sheared mafic and ultramafic rocks (*um* of plate 2). Note in this connection the description of this unit given by Southwick and Owens (1968, their *Pzug*), "Intimately mixed metagabbro, serpentinite, metapyroxenite and various kinds of talc-, actinolite-, chlorite-, and epidote-bearing schists. Rocks of gabbroic and ultramafic composition subequal in abundance." As the ultramafics reached the earth's surface, they calved off from the thrust zone like icebergs from a glacier, and moved westward, downslope into the Wissahickon basin of deposition. Locally such ultramafics crop out virtually at the base of the Wissahickon, thus dating the initiation of thrusting as earliest Wissahickon time, and tying in the southeasterly derived Wissahickon clastic flood with the initial movements of the Mafic Complex.

I turn now to the internal structure of the Mafic Complex and of the supracrustal rocks associated with it, the relationship between these two assemblages, and the possibility that they may constitute in part an ophiolite.

I have proposed above that the conformable sequence of rocks comprising the Mafic Complex at the Susquehanna represents the Complex in its least deformed state. If the succession of rocks there, from ultramafic on the northwest through successively less mafic, more felsic to the southeast, is accepted as a valid stratigraphic section from lower to higher rocks, then at Baltimore the disposition of a relatively mafic unit (Mount Washington Amphibolite) on either side of a relatively ultramafic unit (Hollofield Layered Ultramafite) may reasonably be interpreted as an anticlinal structure striking about east-west (plate 2). Moreover, the truncation of this structure by the James Run Formation on the southeast suggests either an unconformity or a fault at the base of the James Run.

Turning to the Bel Air belt, its structural interpretation is complicated by the uncertainty regarding the origin of the rocks there. As discussed above, supracrustal rocks make up some fraction, perhaps the whole, of this belt in Baltimore County, whereas on strike at the Susquehanna the entire section, at least up to the base of the quartz gabbro, is plutonic. The transition from wholly plutonic rocks on the north to possibly wholly supracrustal rocks on the south may occur in the very poorly exposed rocks near Bel Air, but the nature of this transition remains unclear. It is shown as a thrust fault in plate 2.

Bromery (1968, p. 95) has presented geophysical evidence that the Franklinville Gneiss (his Port Deposit Gneiss) lies in a trough floored by the Mafic Complex, and my mapping near the southern termination of the Franklinville supports this thesis. Along Little Gunpower Falls where the Franklinville is best exposed, it is characterized structurally by a uniform, steeply northwest-dipping foliation (and compositional layering wherever manifest) and a uniform, moderately north-plunging mineral lineation. Traced southwest, the Franklinville narrows and terminates about 2 kilometers north of Gunpowder Falls, a little west of I-95 (plate 1). Thus, the map pattern and structural details indicate a north-plunging syncline overturned to the

southeast, an interpretation borne out also by the systematic variation in minor fold asymmetry across the hinge of the structure. There is no compelling evidence for a synclinal interpretation of the Perry Hall Gneiss, but such an interpretation is consistent with the limited structural data and overall map pattern, and also with the lithologic similarity of the Perry Hall and Franklinville Gneisses.

The origin of the Franklinville Gneiss is not entirely clear. Its uniformity and high feldspar/quartz ratio suggest an igneous origin. Its structure rules out a vertically-direct intrusive origin as proposed by Southwick and Owens (1968, all cross sections) for their equivalent Port Deposit Gneiss, although it could be interpreted as a sill. The local occurrence of clasts in the Franklinville and in the equivalent rocks to the northeast (Southwick, 1969, p. 64) indicates a supracrustal, partly volcaniclastic, partly sedimentary origin for the Franklinville, and suggests correlation with the Sykesville Formation. The similar Perry Hall Gneiss, though devoid of clast-bearing rocks, is more commonly layered and contains a few, thin quartzites (metacherts?). Its volcaniclastic parentage is more probable.

Support for the Franklinville syncline from both geophysical and geological reasoning firmly establishes this structure as an important element in the crustal architecture of the eastern Maryland Piedmont, and invites speculation about regional stratigraphic relationships in other areas to the northeast through which the syncline passes, specifically Harford and Cecil Counties. In Harford County the syncline is flanked on the southeast by the volcanic James Run Formation which is succeeded northeastward by the metagabbro body at Aberdeen. This succession from supracrustal rocks on the south to plutonic rocks on the north mirrors the similar succession described above on the northwest flank of the syncline, with the transition on both flanks occurring in the same part of the structure. In contrast to the poorly exposed Bel Air area, the transition zone on the southeast flank has been mapped in considerable detail (Southwick and Owens, 1968; Southwick, 1969, plate 4). There the plutonic rocks appear to overlie the volcanics, and the sharp contact separating them is conformable with the internal structure of the volcanics. The simplest interpretation of these facts in accordance with the interpretation of the main body of the Mafic Complex is that the plutonics rest in thrust fault contact with the volcanics. If the symmetrical distribution of volcanic versus plutonic rocks on either flank of the Franklinville syncline is accepted as proof of their correlation, one could propose a similar fault relationship in the Bel Air area on the northwest flank. This would require the Bel Air Metagabbro to rest on the Bradshaw Layered Amphibolite in thrust contact. But where the base of the Metagabbro is undeniably exposed farther north, it rests directly on metasediments (Oella and Sykesville Formations) with no intervening rocks of Bradshaw affinity. The reverse relationship seems more probable, *i.e.*, that the Bradshaw rests on the Bel Air in thrust fault contact. The probability that the Bradshaw is correlative with the James Run (discussed above in both parts I and II) suggests that this fault is the same as the fault that may separate the James run from the Mafic Complex in the Laurel belt. This in turn strengthens the probability discussed above that the Bel Air Metagabbro and associated ultramafics of the Bel Air belt are correlative with the Mount Washington Amphibolite and Hollofield Layered Ultramafite of the Laurel belt. This line of reasoning further requires that the Aberdeen Metagabbro constitute a still higher thrust sheet and that the Franklinville and Perry Hall Gneisses unconformably overlie the three assembled thrust slices.

Turning now to the concluding question, does the Baltimore Mafic Complex constitute an ophiolite? As the Bel Air belt is demonstrably the least deformed segment of the Complex, particularly north of Scarboro where its ultramafic base is still attached, the question is best answered there, where the excellent study of Southwick (1970) presents much important data. According to criteria established by the Penrose Ophiolite Conference as reported in Geotimes (Dec., 1972, p. 25) the base of an ophiolite comprises an "ultramafic complex, consisting of variable proportions of harzburgite, lherzolite and dunite, usually with a metamorphic tectonic fabric (more or less serpentinized)." Southwick (1970, p. 405) describes the base of the Complex as extensively serpentinized and steatized "rocks that originally were dunite, peridotite, olivine pyroxenite, and pyroxenite." Regarding fabric he says, "To a great extent the mesh texture which typically results from serpentinization of olivine-rich rocks has been modified by subsequent shearing and recrystallation." Ex-

cept for the presence of pyroxenite this description meets the criteria stated above.

Overlying the ultramafic complex in a typical ophiolite is a "gabbroic complex, ordinarily with cumulus textures commonly containing cumulus peridotites and pyroxenites and usually less deformed than the ultramafic complex" (Geotimes, Dec., 1972, p. 25). Overlying the ultramafic complex in the Bel Air belt is a gabbroic complex (Southwick, 1970, p. 405-409). It is devoid of clearly identifiable cumulus textures, though these are known from the Hollofield Layered Ultramafite in the Laurel belt, but is less recrystallized and hence probably less deformed than the ultramafic complex.

The upper components of a typical ophiolite are a "mafic sheeted dike complex and a mafic volcanic complex, commonly pillowed" (Geotimes, Dec., 1972, p. 25). Neither of these components are present in the Bel Air belt though mafic volcanics overlie the Mafic Complex in the Laurel belt.

Of the three rock types commonly associated with ophiolites (*ibid.* p. 25) podiform chromite is known from the Bel Air belt, and felsic, sodic rocks (the Relay Gneiss Member of the James Run Formation) are known from the Laurel belt.

At best then, the Baltimore Mafic Complex in part, particularly the Bel Air belt, can be considered a "partial ophiolite". In view of the common dismemberment of ophiolites and the evidence for considerable faulting and folding in the Baltimore Complex, this conclusion is not surprising.

PLATE TECTONICS MODEL

The early geological evolution of the eastern Maryland Piedmont set forth above has obvious parallels with the early Paleozoic evolution of the Appalachians as a whole, particularly the Taconic region and western Newfoundland (see for example Williams and Stevens, 1974), and validates some of Rodgers' (1970, p. 191) brilliantly prescient speculations. This in turn suggests that plate tectonics models developed for the northern Appalachians by Bird and Dewey (1970) and Dewey (1974) may be generally applicable for the central Appalachians, and in the following paragraphs (and fig. 1), I suggest a possible model for the Baltimore area.

Sometime in the Late Precambrian, perhaps as early as 800 million years ago, rifting was initiated in the Baltimore area leading to the development of a continental shelf characterized by an interconnected cluster of shallow basins. The basins accumulated a relatively thin filling of clastic sediments (Setters Formation, fig. 1A) with an unusual enrichment in boron and potassium resulting perhaps from restricted circulation of water between the continental shelf and Iapetus (the Paleozoic Atlantic Ocean). Gradually sedimentation restored the foundered continental edge to topographic equilibrium and, beginning sometime in the Cambrian, shallow, warm waters covering the shelf nurtured a rich, marine fauna whose hard parts accumulated to form a carbonate bank (Cockeysville Marble, fig. 1B). Commencing probably in the Late Cambrian or Early Ordovician, divergent plate motion was replaced by convergent motion (fig. 1C) which led to the development of a volcanic island arc (James Run Formation) along with upwarping and the initiation of thrusting in the ocean floor. Concomitantly, the carbonate bank was downwarped and flooded by clastics (Loch Raven Schist and Oella Formation) derived from the uplifted ocean floor, together with mafic tuffs from the James Run volcanic arc and ultramafic masses extruded from the thrust faults. Continued convergence led to stacking of three westward moving thrust slices; from east to west and top to bottom these were the Aberdeen basin (Aberdeen Metagabbro), the James Run volcanic island arc (James Run Formation and probably the Raspeburg Amphibolite and Bradshaw Layered Amphibolite), and the Laurel-Bel Air marginal ocean (Hollofield Layered Ultramafite, Mount Washington Amphibolite, Bel Air Metagabbro). Following stacking of these thrust slices, compressive stresses were temporarily relieved (fig. 1D), the combined allocthon was subjected first to erosion and then blanketing by felsic clastics of sedimentary and volcanic provenance, locally conglomeratic (Franklinville and Perry Hall Gneisses), while the depressed, exogeosynclinal shelf continued to receive clastic sediments (Sykesville Formation). The combined allocthon with its unconformable cover was then emplaced westward onto the former shelf (fig. 1E), the Pleasant Grove and Prettyboy Schists were deposited, and the entire section was folded, metamorphosed, and injected by plutonic rocks.

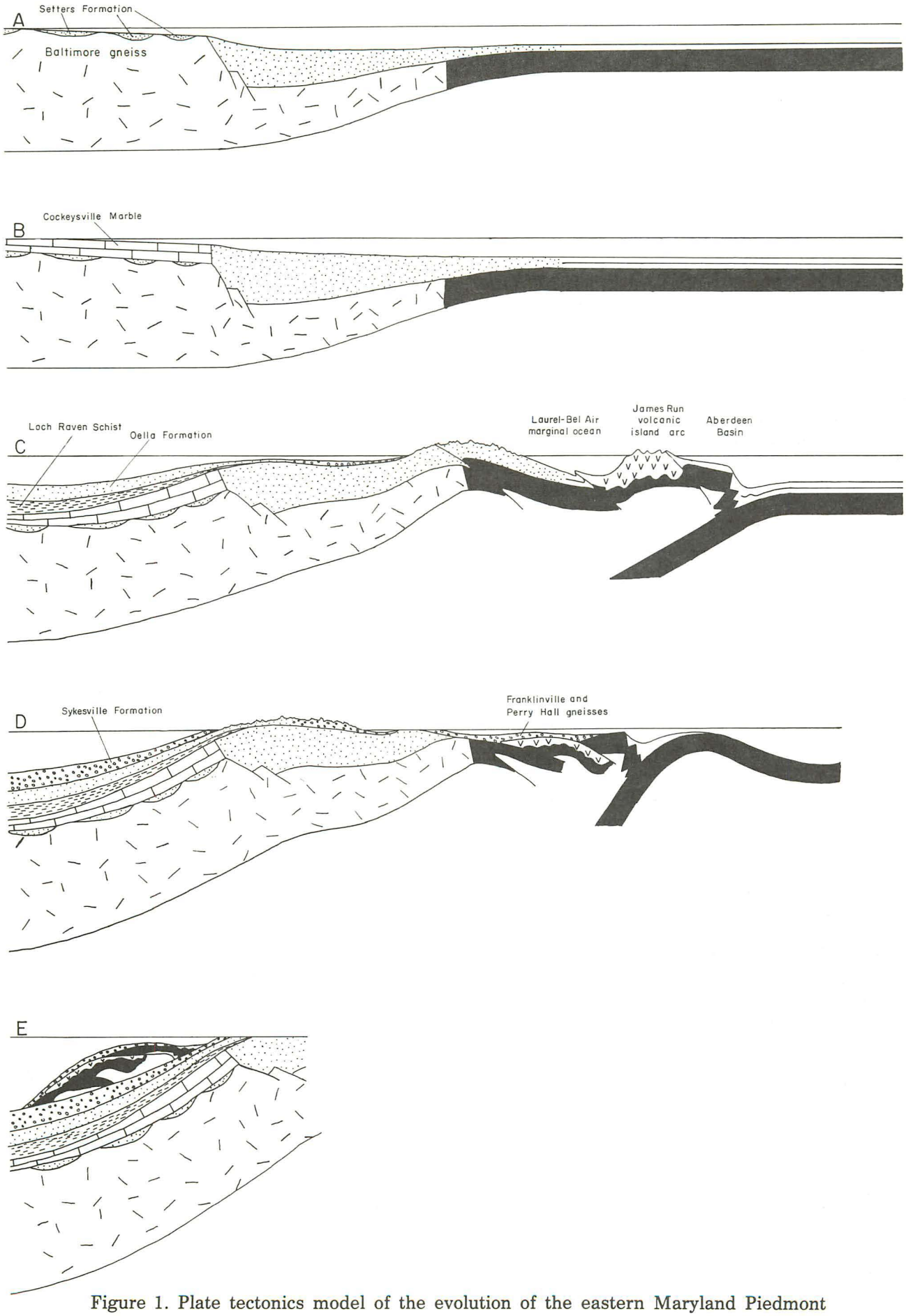

Figure 1. Plate tectonics model of the evolution of the eastern Maryland Piedmont

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APPENDIX

DETAILED LOCATIONS OF TYPE LOCALITIES

(Described with reference to U.S. Geological Survey topographic maps, 7.5-minute series, most recent edition)

BALTIMORE GNEISS

Baltimore Gneiss. Towson (1966) and Cockeysville (1966) quadrangles. Outcrops along Towson Run from Bellona Avenue to Towsontown Boulevard.

Layered gneiss member. Baltimore East quadrangle (1966). Morgan State College. Streamcuts along Herring Run for 255 meters on either side of the Arlington Avenue bridge.

Augen gneiss member. White Marsh quadrangle (1966). Outcrop on Long Green Creek 385 meters southeast of the Glenarm Road bridge.

Streaked-augen gneiss member. Towson quadrangle. Long streamcut along Merryman Branch commencing 125 meters upstream from the Dulaney Valley Road bridge.

Hornblende gneiss member. Cockeysville quadrangle. Outcrops along unnamed stream between Malvern Avenue and Boyce Avenue.

Slaughterhouse Gneiss. Cockeysville quadrangle. Outcrops along Slaughterhouse Branch immediately southeast of the Baltimore Beltway (I-695).

SETTERS FORMATION

Quartzite member. White Marsh quadrangle. Outcrops holding up slopes on either side of Long Green Creek 155 meters southeast of the Glenarm Road bridge.

Conglomerate lens. Phoenix quadrangle (1957). Outcrops along crest of very prominent ridge west of Phoenix Road immediately south of Phoenix and adjacent to the Hunt Valley golf club.

Schist lens. Towson quadrangle. Outcrops underlying the slope on the north side of Gunpowder Falls 455 meters upstream from the right angle bend in Notch Cliff Road.

Gneiss member. Towson quadrangle. Outcrops on the northern and eastern slopes of the hill surmounted by Luskins at the intersection of Cromwell Bridge Road and the Baltimore Beltway (Interchange 29).

Quartzite lens. Towson quadrangle. Outcrops along Warren Road immediately south of the bridge across Loch Raven Reservoir.

Garnet schist member. Towson quadrangle. Long outcrop along west side of road leading into Stella Maris, 535 meters in from Dulaney Valley Road.

COCKEYSVILLE MARBLE

Massive metadolostone member. Towson quadrangle. Outcrops along Minebank Run immediately northeast of the Baltimore Beltway at Interchange 29.

Massive metalimestone member. Towson quadrangle. Outcrops along the east shore of the north and central portions of the arm of Loch Raven Reservoir which extends to the mouth of Dulaney Valley Branch.

Calc-gneiss lens. Towson quadrangle. Outcrop on northeast side of road leading into Stella Maris, 300 meters in from Dulaney Valley Road.

Layered metadolostone member. Towson quadrangle. Streamcuts along Long Quarter Branch for 300 meters on either side of the Charmuth Road bridge.

Layered marble member. Cockeysville quadrangle. Abandoned quarry across from the Texas landfill on Beaverdam Road.

Phlogopitic metalimestone member. Towson quadrangle. Numerous outcrops in an area bounded by Dulaney Valley Road on the west, Seminary Avenue on the north, the Baltimore Beltway on the south, and Gateshead Road, Windy Gate Lane, and Hampton House on the west.

LOCH RAVEN SCHIST

Loch Raven Schist. Phoenix and Towson quadrangles. Outcrops on both banks of Loch Raven Reservoir from Papermill Road (Ashland Avenue) south for 1.5 kilometers.

Hydes Marble Member. No type locality established because of paucity of outcrop and heterogeneity of rock type. See discussion in text.

Rush Brook Member. Towson quadrangle. Streamcuts along Rush Brook from Loch Raven Road south for 155 meters.

OELLA FORMATION

Oella Formation. Ellicott City quadrangle

(1966). Outcrops along both banks of the Patapsco River right at Oella.

Sweathouse Amphibolite Member. White Marsh quadrangle. Streamcuts along Sweathouse Branch from its mouth to Mountvista Road.

PINEY RUN FORMATION

Piney Run Formation. Hampstead quadrangle (1974). Outcrops along Piney Run and its tributaries for a 1.7 kilometer segment northward from the north end of the long, unimproved road that starts near Dover Church.

SYKESVILLE FORMATION

Gneiss member. Reisterstown quadrangle (1966). Outcrops along and near Oakland Road leading from Tyler to Liberty Lake.

Schist member. Finksburg quadrangle (1971). Outcrops along Liberty Lake between the mouths of Keysers Run and Norris Run.

PLEASANT GROVE SCHIST

Pleasant Grove Schist. Hampstead quadrangle. Outcrops along McGill Run and a short southeast-flowing tributary immediately west and south of Pleasant Grove Church.

PRETTYBOY SCHIST

Prettyboy Schist. Hereford quadrangle (1974). Outcrops in the vicinity of the dam at Prettyboy Reservoir.

LAUREL BELT

Hollofield Layered Ultramafite. Ellicott City quadrangle. Abandoned quarry along east bank of the Patapsco River 80 meters south of the first bridge crossing the Patapsco north of I-70.

Mount Washington Amphibolite. Baltimore West quadrangle (1966). Outcrops in the Mount Washington section of Baltimore City, especially along the unnamed south flowing tributary that joins Western Run near the intersection where Cross Country Boulevard becomes Kelly Avenue.

Carroll Gneiss Member of the James Run Formation. Baltimore West quadrangle. Outcrops along unnamed tributary that flows through the west end of Carroll Park and into Gwynns Falls.

Druid Hill Amphibolite Member of the James Run Formation. Baltimore West quadrangle. Outcrops scattered along tributary streams throughout the wooded parts of Druid Hill Park, especially in ravine flanking the east side of Druid Park Drive.

Relay Gneiss Member of the James Run Formation. Relay quadrangle (1966). Outcrops along the B&O railroad tracks near Relay at the intersection with the Thomas viaduct and for 450 meters to the northwest.

Jones Falls Schist. Baltimore West quadrangle. Outcrops along Jones Falls, northeast of Druid Lake, especially between the Falls Road and 28th Street ramps onto the Jones Falls Expressway.

Cold Spring Gneiss. Baltimore West quadrangle. Outcrops along the unnamed east-flowing tributary of Jones Falls within Cold Spring Park.

BEL AIR BELT

Raspeburg Amphibolite. Baltimore East quadrangle. Outcrops in the Raspeburg section of Baltimore City, especially those on the Glenmount School property and the abandoned quarry along the west side of Bel Air Road 400 meters south of its intersection with Raspe Avenue.

Bradshaw Layered Amphibolite. White Marsh quadrangle. Outcrops along little Gunpowder Falls on either side of Old Philadelphia Road (Md. 7) near Bradshaw.

Franklinville Gneiss. White Marsh quadrangle. Outcrops on either side of the bridge that crosses Little Gunpowder Falls at Franklinville.

Perry Hall Gneiss. White Marsh quadrangle. Outcrops along Bel Air Road (chiefly the west side) north of Perry Hall, especially along the unnamed northeast flowing tributary of Gunpowder Falls and in the abandoned quarry 450 meters northeast of Gunpowder Falls.

EXPLANATION

SEDIMENTARY ROCKS

Quaternary

at — Artificial Fill

Composed of heterogeneous materials such as: rock, unconsolidated sediment, slag, refuse, and sludge spoil. Only major areas of filled ground have been mapped and include areas such as: former quarry sites, diked marshes, and areas of extensive topographic modification for roads, railroads, and transportation corridors across topographically low areas. Three meters or more thick.

Qal — Alluvium

Interbedded gravel, sand, silt, and clay of variable composition and sorting. Typically confined to flood plains of perennial streams, upland gathering areas, and topographically low areas of extensive flat terrain. Deposit ages are strongly controlled by the source geology and geomorphic setting. The quartzose sands and polymict gravels are typically well-bedded and well-sorted compacted; the silts and clays are often water saturated and poorly bedded.

Minor amounts of colluvium (unmapped) may intervfuge with alluvium at or near the base of slopes. Alluvial deposits are commonly anthropogenically altered in a commonly manner by artificial fill and/or has been extensively modified. Unit thickness is 0.5 to 5 meters.

Qac — Colluvium and Alluvium

Unsorted, massive clays to gravels interbedded and interfingering with poorly sorted alluvial (?) sands and gravels. Defined on the basis of lithology, geomorphic setting and soil series around gneiss domes. The only region in which this unit has been mapped is the Towson and Cockeysville Quadrangles. Unit thickness 0.5 to 5 meters.

Qtg — Alluvial Terrace Gravels

Very coarse quartz and quartzite gravel dominates volumetrically in this unit. Cobbles and boulders are commonly encountered in the gravel. Geomorphically, this unit is thickest about 3 meters above the present river flood plain. Unit thickness varies from 0.5 to 5 meters.

Cretaceous

Qts — Talbot Formation

Qts Silt-clay facies: Typically buff to orange, poorly sorted, poorly bedded quartz silts with kaolinite, illite, and montmorillonite clays. Very coarse leaf and twig debris is bedded silts. In the Spurrows Point area, thick accretionary soils are developed on the deposit. Deposition is interpreted as in numerous tied hollows and water well logs. Silt and silty clays probably accumulated in alluvial flood plain-open marsh environments. Clays probably accumulated in an estuarine environment.

Qts Sand facies: Well-bedded, medium to coarse quartz sand, typically cross-bedded and occasionally containing pebbles and cobbles. The degree of sorting suggest a beach or strandline as possible environment of deposition. The Talbot Formation varies from 0.5 to 10 meters in thickness.

Late Tertiary - Quaternary (?)

Qug — Upland Gravel

Orange-brown, poorly sorted, fine sand to boulder size particles commonly with a clay matrix. Clasts are commonly subangular and show little textural and vertical sediment size changes with ferruginous cement along horizons of abrupt change. Deposits are occasionally well-bedded; fining-upward gravel and sand beds are rare. Clasts are mainly quartz, quartzite, and occasional large blocks of fresh to weathered mafic rock are diagnostic framework components. Thickness varies from 0.5 to 8 meters.

Potomac Group (Lower Cretaceous)

Kpc — Patapsco Formation

Clay facies (Kpc) (0.5-10 meters thick): Typically buff, red-yellow, and mottled kaolinitic clays. Well-developed soil horizons are common at top of pods and interbeds, dispersed throughout the clay. Rare occurrences of irregular siderite concretions and lignitized plant remains. Rare laminated silt-clay and sand-clay beds occur. Deposition in oxidized flood plain-oxbow environment is postulated.

Sand facies (Kpc) (0.5-30 meters thick): Well-sorted, medium to fine-grained quartz sand with locally abundant quartz gravel and clay clasts. Minimal clay-silt matrix in sand interstices. Sands are planar to high-angle cross-bedded and occasionally contain abundant mica. Sand bodies are lenticular-bedded and commonly are exposed as ledges at sand-clay boundaries or as discontinuous sands in pods within the sand. Tourmaline and zircon with minor staurolite and rutile constitute the heavy mineral suite. Deposition in and around channels of low gradient streams.

Kdc — Arundel Formation

Clay facies (Kdc) (0.5-10 meters thick): Gray, brown, black and red mottled kaolinitic clays. Well-developed soil horizons are common at top and near lenses and pods. The clays are typically poorly bedded to massive with occasional color mottling. Sparse to abundant irregular siderite ledges or concretions are present throughout the Formation. Rare to common laminated silts and clays contain sparse to abundant fern, cycadoid, and conifer remains.

Lithologically similar but stratigraphically distinct from Kcc. Deposition primarily within a flood plain-back swamp complex.

Sand facies (Kdc) (0.5-3 meters thick): Well-sorted, medium to fine-grained quartz sand with locally abundant lignite fragments. Thin sand beds are commonly associated with laminated silt-clay beds and less commonly clasts of quartzo-feldspathic rock and biotite schist.

Kcc — Patuxent Formation

Sand facies (Kcc) (0.5-35 meters thick): Highly variable, intercalated sand, gravel, silt, and clay with kaolinite-limonite cements. Sands and gravels are typically quartzose and well-rounded; a buff kaolinitic clay-quartz silt matrix is common throughout the Formation. Cross-bedded sands are commonly well-sorted medium to fine sands with planar-bedded gravels and clay clasts. Sands are commonly coarse at the base to laminated or massive silt-clay at the top. Elsewhere vertical sequences show abrupt sediment size changes and erosive contacts. The heavy mineral suite is characterized by staurolite, zircon, tourmaline, and rutile.

Spare silicified and abundant iron oxide-replacements or pseudomorphs of cycadeids and conifers are present throughout the Formation. These megafossils were deposited in a high gradient braided and meandering stream complex.

Clay facies (Kcc) (0.5-4 meters thick): Light gray to black and brown clays containing variable amounts of quartz silt, gravel, local concentrations of lignite, partially gritified wood, or macerated leaf and crow debris. Clays are commonly associated with thin sand beds and/or gravelly clays are interbedded with massive clays.

CRYSTALLINE ROCKS

LAUREL BELT

Lower Cambrian (?)

Ꞓ — Poultney Schist

Uniform, fine-grained plagioclase-biotite-muscovite-quartz schist, commonly with magnetite and conspicuous white porphyroblasts that average 1 to 3 mm but may be as much as 10 mm in diameter. Sparse, limonitized pyrite cubes occur locally.

Cambrian (?)?

Ꞓ — Pennsylvania Green Schist

Uniform, fine-grained plagioclase-biotite-muscovite-quartz schist, locally with magnetite. Commonly accompanied by numerous thin veins and lenses of milky quartz and, locally, lenses and thin beds of quartzite imparting a banded appearance to the rock.

Wissahickon Group (Cambro-Ordovician?)

Ꞓ — Sykesville Formation

Sy1 Gneiss member. Poorly foliated to massive, fine- to medium-grained biotite-feldspar-quartz gneiss, deceptively granoblastic in appearance, with sparse to numerous clasts ranging in size from granules to cobbles and larger slabs. Clasts closely resemble the host rock but are distinguished by their coarser grain and magnetite content. Nearly as abundant are quartz pebbles and granules and numerous six cobbles of light gray, fine-grained quartzo-feldspathic rock. Feldspar granules rare. Facies equivalent of the schist member.

Sy2 Schist member. Resembles gneiss member but generally finer grained, commonly garnetiferous, very massive, well foliated, and locally devoid of clasts. Includes a few occurrences of amphibolite.

Ꞓ — Piney Run Formation

Chiefly fine-grained plagioclase-chlorite-muscovite-quartz schist, locally with biotite, garnet, and commonly bearing garnet. Includes 10 to 30 percent fine-grained biotite-plagioclase-quartz gneiss no thicker than one decimeter. Locally has mottled appearance due to clear-spotted thin zone and lenses of milky quartz.

Ꞓ — Oella Formation

Oe Oella Formation. Medium-grained biotite-plagioclase-muscovite-quartz schist, locally garnetiferous, and in places with tourmaline, interlayered on a scale of centimeters to meters with fine-grained biotite-plagioclase-quartz gneiss or felsic.

Ꞓ Ephemeral Amphibolite Member. Schist and gneiss as described above, but contains a wide of 1 to 10 meters with epidote amphibolite.

Ꞓ — Loch Raven Schist

1 Loch Raven Schist. Uniform, medium- to coarse-grained biotite-plagioclase-muscovite-quartz schist with lenticles and pods of vein quartz. Locally rich in biotite and feldspar. Includes rare quartzite.

( ) barren facies. Garnet, staurolite, and kyanite all rare or absent.

(g) garnet facies. Garnet common; staurolite and kyanite rare or absent.

(s) staurolite facies. Staurolite common; garnet and kyanite rare or absent.

(g-s) garnet-staurolite facies. Garnet and staurolite common; kyanite rare or absent.

(g-k) garnet-kyanite facies. Garnet and kyanite common; staurolite rare or absent.

(g-s-k) garnet-staurolite-kyanite facies. Garnet, staurolite, and kyanite all common.

Glenarm Supergroup (Cambro-Ordovician?)

[1] Hydes Marble Member. Very poorly exposed, sparse outcrops of phlogopitic metalimestone, clean, massive, coarse-grained metalimestone, and generally white to light gray, medium-grained dolomite marble. Hydes is considered younger than Cockeysville Marble (preferred interpretation) or a Cockeysville engulped by early thrust faulting, based upon location of the Hydes outlier a synclinal axis and the absence of Ruth Brook in contact with the Cockeysville.

[ ] Ruth Brook Member. Discontinuous basal member consisting of fine- and medium-grained, shiny, weathering, quartz-rich schist and gneiss with subordinate medium-grained quartzite, interlayered on a scale of decimeters to meters. Rarely garnetiferous but commonly bearing tourmaline. Quartz pebble metaconglomerate very rare. Finely disseminated pyrite common along northeast flank of Towson dome.

Ꞓ — Cockeysville Marble

C Cockeysville Marble undivided. Jagged boundaries between differentiated members imply a facies relationship.

C[1] Layered marble member. Metalimestone and metadolostone generally interlayered on a scale of one meter. Metalimestone commonly medium-grained and moderately silicate-rich (chiefly phlogopite), but may be fine-grained and calcite-rich. Metadolostone typically fine-grained, calcite-bearing metalimestone, and generally silicate-rich (chiefly phlogopite and tremolite) and calcite-bearing, but locally quite pure. Outcrops commonly weather to a carbonate sand with embedded dolostone boulders.

C[2] Layered metalimestone member. Pure, white metalimestone interlayered on a scale of meters with impure, medium-grained metalimestone containing minerals, mainly diopside, tremolite, phlogopite, and quartz. The darker metalimestone locally contains small patches of calcite (less than one cm in diameter) which weather out to leave cavernous surfaces. In places outcrops are partially distinguished by dolomite sand.

C[3] Massive metalimestone member. Medium- and coarse-grained, commonly blue-streaked, massive, clean calcite marble. Silicates sparse, and, where present, are chiefly phlogopite with some muscovite, quartz, and tremolite. Rare, thin layers of medium-grained, silicate-rich marble and calc-silicate dolostone, generally silicate rich, in layers ranging from a few centimeters to a few tens of meters thick. Includes rare, brown-weathering, massive quartz-tremolite-diopside rock in layers about one meter thick.

C[3]C Calc-gneiss lens. Fine-grained, black-gray, quartz-weathering calcite marble with abundant graphite and minor muscovite. Commonly contains generally pyritic, rusty phlogopite. Locally includes layers of relatively pure calcite marble a few decimeters thick.

C[4] Phlogopitic metalimestone member. Fine- to medium-grained, white to bluish-white calcite marble; and purplish, phlogopitic calcite marble or dolomite marble with abundant phlogopite. Commonly contains diopside and tremolite, interlayered on a millimeter to centimeter scale. Some foliation surfaces graphite rich. Locally uniformly silicate-rich or silicate poor. A few outcrops include metadolostone.

C[5] Massive metadolostone member. Medium-grained, white, generally massive dolomite marble with sparse to abundant, fine-grained, white, acicular tremolite, phlogopite, and quartz. Includes a few occurrences of phlogopitic metalimestone and a single occurrence of quartz-tremolite rock. Commonly weathers to dolomite sand.

Setton Formation

§ Gneiss member and quartzite member undifferentiated.

§[2] Garnet schist member. Fine- to medium-grained biotite-muscovite-plagioclase-quartz schist with garnet, locally with staurolite, kyanite, or sillimanite, but rarely both; sparse accessory tourmaline. Subordinate interlayered quartzite in zones a few meters thick.

§[1] Gneiss member. Decimeter-scale-layered, fine-grained, quartz-rich, feldspathic gneiss and schistose gneiss with biotite or biotite and muscovite, and subordinate amphibolite. Rocks have a salt-and-pepper appearance and a distinctive, spotted appearance. Subordinate interlayered quartzite and schist. Along the northeast flank of the Towson dome, the lower 15 to 20 percent of the section is biotite-muscovite-microcline-quartz schist with tourmaline, and, locally, garnet.

§[3] Quartzite lens. A single lens 150 meters thick on the north flank of the Texas dome of well foliated to massive, medium-grained, uniform muscovite-microcline quartzite.

§[4] Quartzite member. Typically fine- to medium-grained, thin-bedded, shiny-weathering muscovite-microcline quartzite with accessory tourmaline, and subordinate biotite-muscovite-plagioclase-quartz schist. Quartzite along the northeast flank of the Towson dome a basal zone up to 60 meters thick is composed almost exclusively of schist.

§[5] Conglomerate lens. Three lenses up to 30 meters thick along the southern flank of the Phoenix dome consisting of muscovite quartzite with stretched quartz pebbles.

unconformity

pCp — Baltimore Gneiss

The relative ages of the four members of the Baltimore Gneiss are unknown.

pCp[3] Layered gneiss member. Dark and light biotite-microcline-quartz-plagioclase gneiss interlayered on a scale ranging from centimeters to tens of meters. Dark layers commonly have a granoblastic-polygonal texture. Subordinate hornblende or muscovite, and rarely both, occur in some layers. Completely folded locally.

pCp[2] Hornblende gneiss member. Similar to the layered gneiss member described above, but with 25 to 50 percent interlayered hornblende rock, both as layers with biotite and hornblende-bearing biotite schist or biotite gneiss, locally with garnet.

pCp[1] Augen gneiss member. Fine- to medium-grained biotite-quartz-feldspar gneiss containing abundant, large, light-colored ovoids (augen) consisting either of feldspar or quartz and feldspar. Commonly pinkish, and interlayered with dark, hornblende-bearing biotite-quartz-feldspar gneiss. Locally, coarse-grained, locally pegmatitic biotite-quartz-feldspar gneiss. Locally interlayered with gneisses typical of the layered gneiss member.

pCp[4] Streaked-augen gneiss member. Uniform, commonly pinkish, medium-grained biotite-microcline-quartz-plagioclase gneiss generally with augen that are less than 1 cm in diameter. Augen are commonly streaked out and contain minor garnet and hornblende locally. Includes subordinate, fine-grained, dark biotite-quartz-feldspar gneiss in layers ranging from a few decimeters to a meter in thickness.

BEL AIR BELT

Cambro-Ordovician (?)

Ꞓ — Perry Hall Gneiss

Complex interlayering of meter-scale interlayering, fine- to medium-grained biotite-quartz-plagioclase gneiss, hornblende-quartz-plagioclase gneiss, commonly garnetiferous, and hornblende amphibolite. Thin layers of quartzite at a few localities.

Ꞓ — Freedmansville Gneiss

Uniform, medium- to coarse-grained biotite-quartz-plagioclase gneiss, locally with muscovite, but lacking garnet and hornblende. Freedmansville contains sparse, small inclusions of fine-grained, dark biotite-quartz-feldspar gneiss, and rare sub-silicate pods. Includes several zones up to 15 meters thick of biotite-muscovite schist. Concordant layers of amphibolite and hornblende-quartz-plagioclase gneiss common near contact with underlying Perry Hall Gneiss and Baltimore Gneiss. Equivalent to adjacent Port Deposit Gneiss of Harford County Geologic Map (1968).

Baltimore Mafic Complex (Cambro-Ordovician?)

Ꞓ — Raspberry Amphibolite

Uniform, fine- to medium-grained, massive, black, locally with shade of more felsic grain. Subtle layering on the scale of a few centimeters to meters is locally defined by variations in grain size or hornblende/plagioclase ratio. Rock is dense, massive. Rock includes abundant light-weathered, felsiphyric amphibolite, both as layers and as some remaining stringers and pods.

Ꞓ — Brubaker Layered Amphibolite

Centimeter to meter-scale interlayering of biotite-quartz-hornblende-quartz-plagioclase gneiss with subordinate biotite-quartz-plagioclase gneiss. Rock includes some several meters thick of coarse-grained, massive amphibolite. Rock is locally equally thick of fine- to medium-grained, laminated amphibolite, biotite schist and epidote-rich rocks to known a few centimeters thick locally.

Mount Washington Amphibolite

*Fine- and medium-grained, generally massive amphibolite locally with layering on a scale of centimeters to meters. Layering is less distinct than 10% actinolite and actinolite as layers 2 centimeters or less thick, but is a few places several tens of meters thick. Serpentinite rare. Amphibolite locally includes irregular patches of lighter-colored, coarse-grained amphibolite (see above). Layering is defined by variations in hornblende/plagioclase ratio

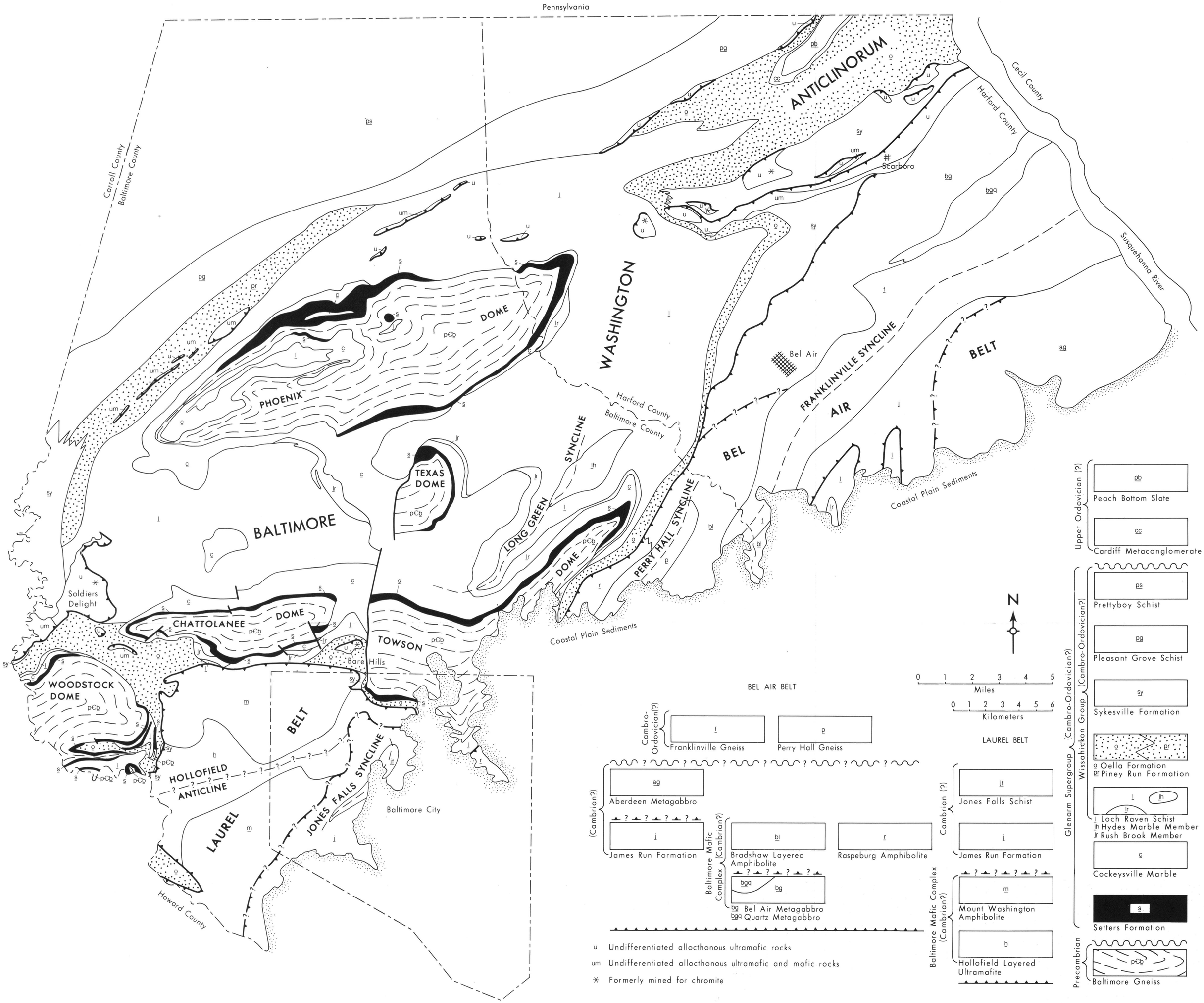

PLATE 2. GENERALIZED GEOLOGIC MAP OF BALTIMORE AND HARFORD COUNTIES. (Intrusive rocks omitted)

MARYLAND GEOLOGICAL SURVEY
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