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Age, Origin, Regional Relations, and Nomenclature of the Glenarm Series, Central Appalachian Piedmont: A Reinterpretation

ABSTRACT

The age and regional relations of the Glenarm Series in the central Appalachian Piedmont have been subjects of controversy for more than 60 years. The interpretation by Hopson in 1964 that the Glenarm Series is Precambrian and probably correlative with the Ocoee Series and related rocks of the southern Appalachians has become widely accepted. This interpretation was based (1) on radiometric ages of minerals from rocks interpreted as intrusive into Glenarm rocks, (2) on interpretation of the relative ages and genetic relations of these rocks and the Baltimore Gabbro, and (3) on correlation of the Wissahickon Formation of the Glenarm Series with the Lynchburg Formation in Virginia.

Evidence suggests that many of the radiometrically dated rocks that Hopson and later workers regarded as intrusive into the Glenarm Series and that they used to define the minimum age of the series are best regarded as either metamorphosed volcanic and volcaniclastic rocks or shallow intrusive bodies grading into and coeval with the Glenarm rocks. The radiometric ages of these rocks probably represent the approximate "actual" age of parts of the Glenarm Series rather than the minimum age. This interpretation also casts strong doubt on the existence of two series of plutonic rocks in the Maryland Piedmont and indicates that Hopson's Baltimore Gabbro is younger, not older, than the older group of radiometrically dated rocks.

Recent work in Virginia suggests that correlation of the Wissahickon Formation with the Lynchburg Formation and with other upper Precambrian rocks is highly unlikely, and shows that the Glenarm clastic rocks are conformable and gradational with metavolcanic rocks, which are in turn conformable and gradational with the Quantico Slate (Ordovician).

Reconsideration of the Martic line and Martic Hills in southern Pennsylvania, where the Wissahickon Formation has been interpreted as overthrust onto Cambrian and Ordovician rocks, indicates that the relations are best explained as the result of superposition of folds. Reconsideration of the Peach Bottom fold and the rocks involved in it indicates that it is probably an anticline rather than a syncline, and that the Peach Bottom Slate and Cardiff Metaconglomerate are probably correlative with the Hellam Member of the Chickies Formation.

The Glenarm Series is regarded as being chiefly Cambrian and Ordovician with a maximum age of about 650 m.y. and a minimum age of Late Ordovician; it is correlated with the Evington Group in the Virginia Piedmont and with some of the rocks in the Manhattan Prong in New York. The Wissahickon Formation is probably correlative with part of the Chilhowee Group of the Blue Ridge province. Metavolcanic rocks in the Glenarm are correlated with some metavolcanic rocks in the Carolina slate belt. In Maryland, these rocks are named the James Run Formation. A new nomenclature is proposed, in which the Glenarm Series consists of the Setters Formation, Cockeysville Marble, Peach Bottom Slate, Cardiff Metaconglomerate, Wissahickon Formation, James Run Formation, Chopawamsic Formation, and Quantico Slate.

The Glenarm metavolcanic rocks and their correlatives record the existence of a long belt of roughly contemporaneous volcanism, an "Atlantic seaboard volcanic province," probably an island arc, that extended at least from Georgia to New York during late Precambrian, Cambrian, and Ordovician time. The Appalachian geosyncline is regarded as an "intracontinental," pre–continental-drift geosyncline. The island arc was near the eastern part of the pre-Atlantic continent, and the Glenarm

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clastic rocks were probably deposited in a basin between the island arc and a shelf area represented by the Chilhowee sedimentary rocks. The source for much of the Glenarm Series was the eastern part of the pre-Atlantic continent. The numerous similarities between the Glenarm Series rocks and sequences in New England, New Brunswick, and Newfoundland suggest that the northern Appalachian crystalline belt need no longer be considered separate and distinct from the central and southern Appalachian belt.

INTRODUCTION

In the Maryland Piedmont, the Precambrian basement complex known as Baltimore Gneiss is unconformably overlain by a thick sequence of metasedimentary rocks called the Glenarm Series. The Glenarm Series underlies most of the Piedmont in Maryland, Pennsylvania, and Delaware, and has been traced southwest for more than 40 mi along strike into Virginia (Fig. 1). As presently defined (Hopson, 1964; Southwick and Fisher, 1967; Cleaves and others, 1968), it consists (from oldest to youngest) of the Setters Formation, Cockeysville Marble, and Wissahickon Formation. The Setters Formation, a basal, transgressive unit as much as 750 ft thick, is composed chiefly of feldspathic mica schist, mica gneiss, feldspathic quartzite, and micaceous quartzite (Hopson, 1964, p. 58–66). The Cockeysville Marble, about 750 ft thick stratigraphically, consists of metadolomite, calc-schist, calcite marble, calc-silicate marble, and calc-gneiss (Hopson, 1964, p. 66–70; Choquette, 1960). The Wissahickon Formation consists of at least 10,000 ft of metagraywacke, metaconglomerate, pelitic schist, and pebbly granitic-appearing gneiss.

The age and origin of the Glenarm Series has been a subject of controversy among Appalachian geologists for more than six decades. Not only does interpretation of the age and origin of these rocks directly affect the interpretation of a major part of the central Appalachian Piedmont, but as Hopson (1964, p. 203–204) pointed out, ". . . it bears strongly on one's interpretation of the geosyncline, as well as on certain aspects of its deformation."

There have been two main theories about the age and relations of the Glenarm Series: (1) that the Glenarm Series is correlative with the metamorphosed Paleozoic sequence of the Hanover-York, Lancaster, and Chester Valleys, and so with the unmetamorphosed Cambrian and Ordovician rocks of the Valley and Ridge province (*see* Swartz, 1948, and references therein); and (2) that the Glenarm Series is Precambrian and unrelated except structurally to the unmetamorphosed Paleozoic rocks (Swartz, 1948; Hopson, 1964). Hopson's arguments for a Precambrian age of the Glenarm Series have been widely accepted.

Hopson's interpretation is based primarily on: (1) radiometric dates on minerals from granitic rocks interpreted as intrusive into the Glenarm Series; (2) interpretations of the relations between the Baltimore Gabbro (*as used by* Hopson, 1964), the granitic rocks, and the Glenarm rocks; and (3) correlation of the Wissahickon Formation with thick clastic Precambrian sequences in the Virginia Blue Ridge and farther south.

Following Hopson's (1964) interpretations, Southwick and Fisher (1967) revised the stratigraphic nomenclature of the Glenarm Series. Their revision was used on the Geologic Map of Maryland (Cleaves and others, 1968).

This paper traces the most important steps in the evolution of nomenclature and interpretation of the Glenarm Series, and attempts to explain some of the interpretations and misconceptions that have led to confusion in nomenclature and in understanding the rocks. A revised nomenclature of the Glenarm Series is proposed, and alternative interpretations are given of some of the granitic rocks and their relations to Hopson's Baltimore Gabbro and the Glenarm Series, of the radiometric ages, and of the age and correlation of the Glenarm Series. Evidence is cited that makes correlation of the Wissahickon Formation with the Lynchburg Formation (upper Precambrian) of Virginia highly unlikely. The evidence indicates that the Glenarm Series is chiefly of early Paleozoic age.

Swartz (1948) and Hopson (1964) traced much of the evolution of Glenarm Series nomenclature and interpretation. This paper will necessarily repeat and paraphrase parts of their discussions.

HISTORY OF STRATIGRAPHIC NOMENCLATURE AND INTERPRETATION OF THE GLENARM SERIES AND RELATED ROCKS

The Glenarm Series was named and defined by Knopf and Jonas (1922, 1923). They stated (1923, p. 45):

*This contact between metavolcanic rocks formerly mapped as Baltimore Gabbro and intrusive magmatic Baltimore Gabbro is tentative. Future work may move it northwest or southeast, but it is approximately correct as shown here

**These contacts are tentative, based on rapid reconnaissance

(1) W-Woodstock Quartz Monzonite; E-Ellicott City Granodiorite; G-Guilford Quartz Monzonite; GP-Gunpowder Granite (as used by Hopson, 1964)
(2) These outcrop belts extend into Harford County, but their limits are not yet known. PD-former Port Deposit rocks
(3) Includes upper and lower pelitic schists of Southwick and Fisher (1967). Also includes some metagraywacke. PD-former Port Deposit rocks
(4) Includes rocks of probable metavolcanic origin. Also includes some tilloid gneisses. GT-Georgetown (mafic) Complex, which includes tilloid gneisses, metavolcanic rocks, and intrusive rocks
(5) PD-former Port Deposit rocks; S-Sykesville Formation and L-Laurel Formation (as used by Hopson, 1964)
(6) Includes some shallow plutons which are coeval with the volcanic rocks and contributed material to them. CV-former Cecil County volcanic complex; PD-former Port Deposit rocks; JG-James Run Gneiss of Southwick and Fisher (1967); BP-Baltimore paragneiss of Hopson (1964); BG-rocks formerly mapped as Baltimore Gabbro; R-former Relay Quartz Diorite
(7) Cambrian age based on Olenellus found farther south (see Mack, 1957)
(8) Correlative with Arvonia Slate (upper Middle and Upper Ordovician)
(9) PDf-rocks formerly mapped as Port Deposit. PDp-present Port Deposit Gneiss; K-Kensington Quartz Diorite and N-Norbeck Quartz Diorite (as used by Hopson, 1964)

Figure 1. Generalized interpretive geologic map of the Maryland and northern Virginia Piedmont.

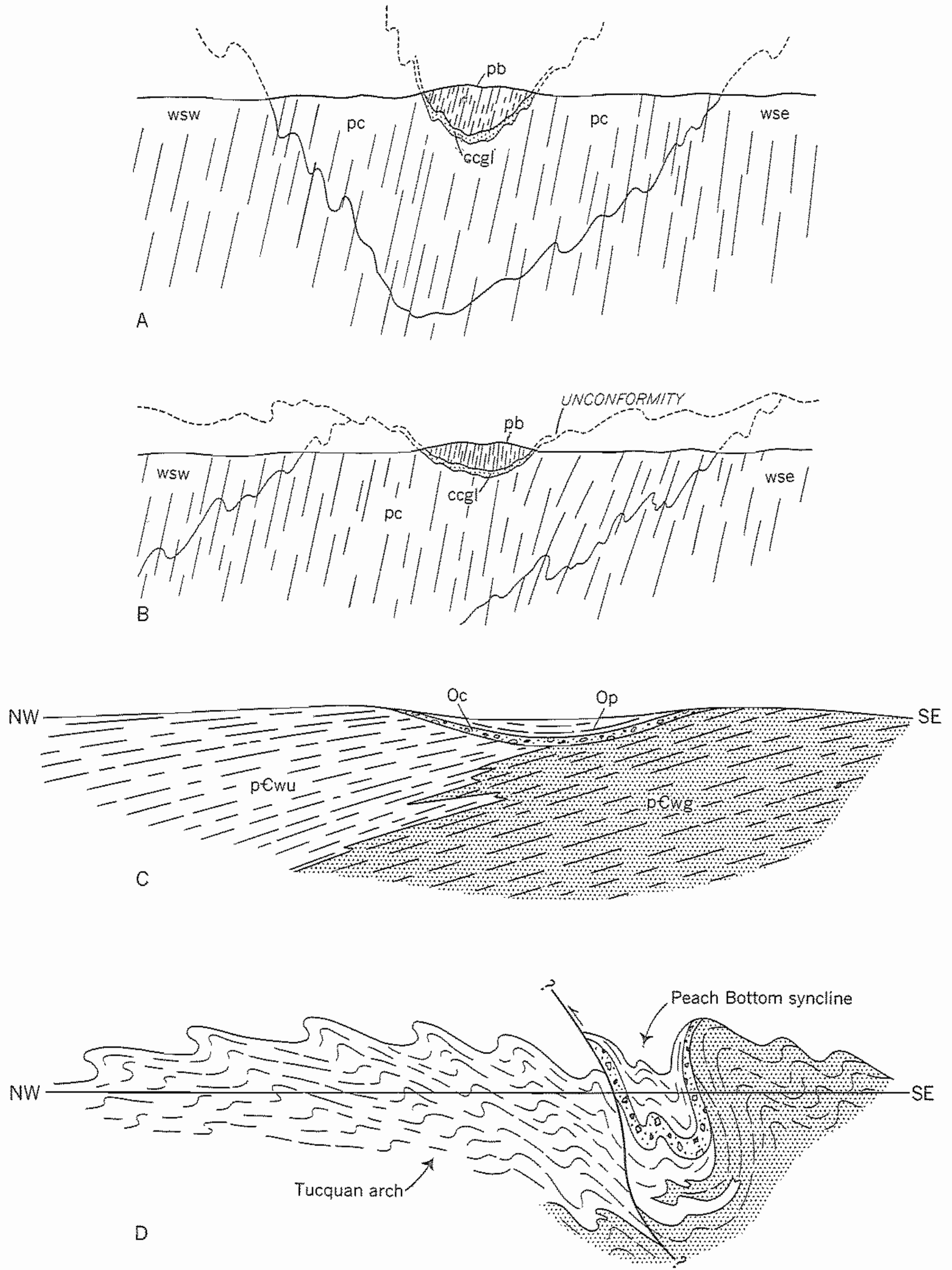


Figure 2. Possible interpretations of the Peach Bottom fold according to Hopson (1964) and Southwick and Fisher (1967). A and B show Hopson's (1964, Fig. 19) "Two possible interpretations of structure in the Glenarm Series at the Peach Bottom syncline." In A, the Glenarm formations (pc, Peters Creek Formation; wsw and wse, western and eastern facies of the Wissahickon Formation) are synclinally folded with the overlying rocks. The Wissahickon underlies the Peters Creek, and its western and eastern facies are stratigraphically equivalent. This is the interpretation of Knopf and Jonas (1923). In B, the Cardiff Conglomerate (ccgl) and Peach Bottom Slate (pb) rest unconformably on steeply dipping homoclinal Glenarm formations. The Peach Bottom syncline (center) is a second-order fold that does not significantly affect the Glenarm structure. The Wissahickon western facies is younger than the Peters Creek and the Wissahickon eastern facies.

C and D show Southwick and Fisher's (1967, Fig. 2) interpretation of the Peach Bottom fold. In C, the metagraywacke lithofacies of the Wissahickon Formation (pЄwg) is shown interfingering to the northwest with the upper pelitic schist lithofacies (pЄwu); the Wissahickon rocks are unconformably overlain by the Cardiff Metaconglomerate (Oc) and the Peach Bottom Slate (Op). D shows the sequence after tight folding. The Peach Bottom syncline and an anticline southeast of it are second-order, nearly upright folds about ½ mi in wavelength on the flank of the Tucquan arch. Near the crest of the arch, minor folds approach recumbency.

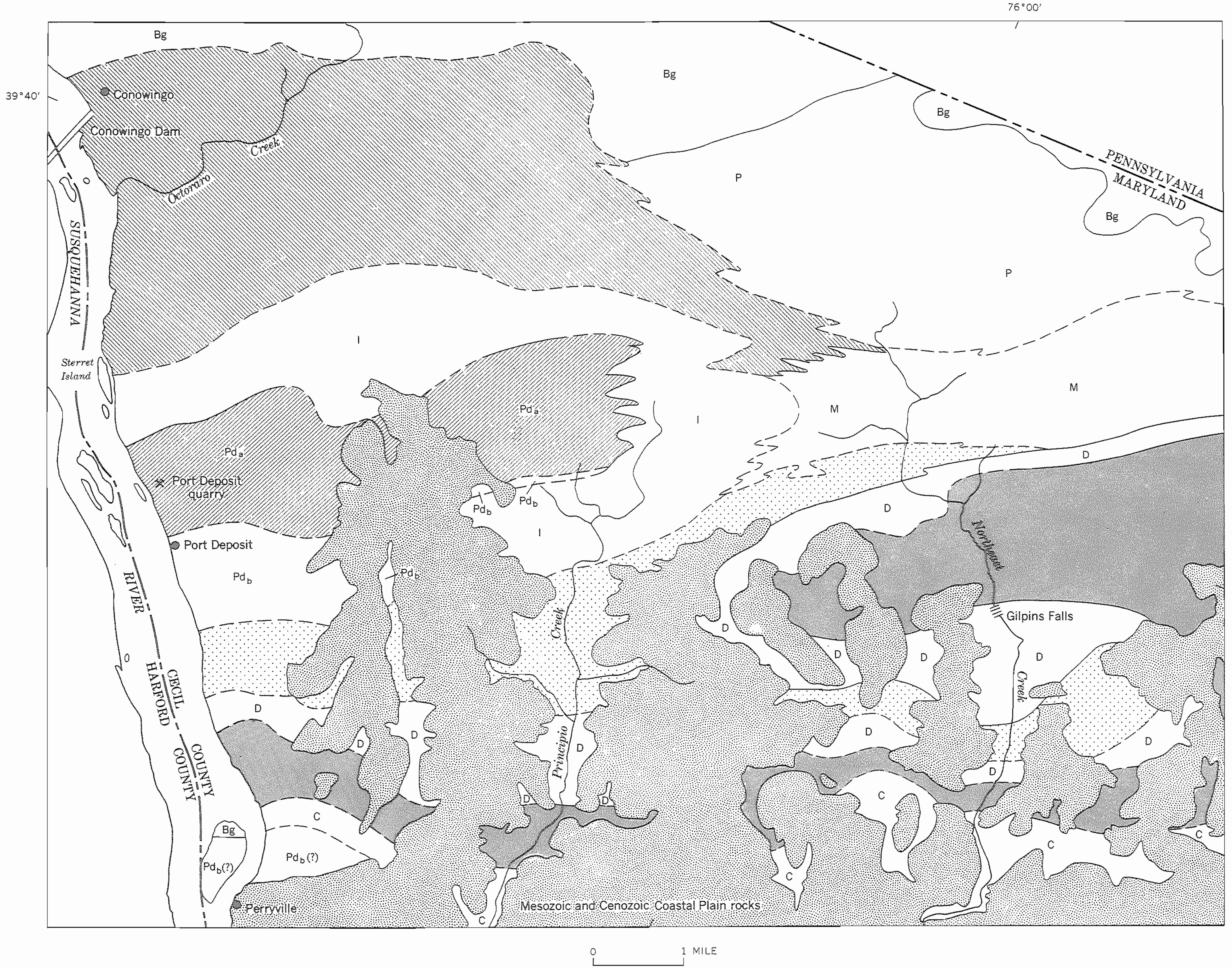


Figure 3. Generalized geologic sketch map of part of Cecil County, Maryland.

EXPLANATION

PRECAMBRIAN TO ORDOVICIAN

Glenarm Series

James Run Formation

Metamorphosed rhyolite and dacite tuffs, tuffaceous sedimentary rocks, and slump deposits; some andesite tuffs

Metamorphosed rhyolite, rhyolite and dacite tuff, and local tuffaceous sandstone

C — Metamorphosed tuffs, tuffaceous sedimentary rocks, metarhyolites, and metaandesites

D — Metamorphosed pillow basalt, basaltic tuff, and pillow breccias

I — Interbedded James Run amphibolite and Wissahickon metagraywacke

Wissahickon Formation

P — Pelitic schist facies

M — Metagraywacke facies

Diamictite facies (Conowingo gneiss)

IGNEOUS ROCKS

PALEOZOIC

Bg — Baltimore Gabbro of Hopson (1964) and related rocks

Pd$_a$ / Pd$_b$ — Port Deposit Gneiss
Pda, coarse-grained plutonic-appearing gneiss
Pdb, medium- to fine-grained gneiss and granofels transitional into metavolcanic rocks

Contact
Dashed where gradational

Overlying the Baltimore gneiss is a series of pre-Cambrian sediments here named the Glenarm series, from its typical development near Glenarm, 13 miles northeast of Baltimore. The Glenarm series comprises the Setters formation, the Cockeysville marble, the Wissahickon formation, the Peters Creek schist, the Cardiff conglomerate, and the Peach Bottom slate. The total thickness of the series probably amounts to between 8,000 and 10,000 feet, although no accurate estimates can be made, for the middle formations have been repeated by close folding. So far as now known, deposition of this series was not interrupted by erosion or by orogenic deformation, although the early formations are overlapping shore deposits.

Even before this, the units that Knopf and Jonas included in the Glenarm Series had a long history of nomenclature changes, and various interpretations of their age and mutual relations had been proposed.

By 1907, the pioneer work of G. H. Williams (1891a, 1891b, 1892; Williams and Darton, 1892; Williams and Clark, 1893), E. B. Mathews (1904, 1905, 1907; Mathews and Johannsen, 1904; Mathews and Miller, 1905), and Florence Bascom (1902, 1905) had established a basic geologic framework of the Piedmont in Maryland, Delaware, and Pennsylvania. There was general agreement on the following:

1. The oldest rock in the area is the Baltimore Gneiss (Williams, 1891b), which occurs in anticlinal domes (Mathews, 1907) unconformably overlain by the Setters quartz schist (Williams and Darton, 1892).
2. The Setters is conformably overlain by the Cockeysville Marble (Williams, 1892).
3. The Cockeysville Marble is conformably overlain by Wissahickon gneiss (Bascom, 1902) and schist (Wissahickon formation of Mathews, 1904, 1905). Included in the Wissahickon were nearly all of the pelitic gneiss, schist, and phyllite above the basement or above the Cockeysville Marble and Setters quartz schist, where either or both of the latter are present.
4. The Cockeysville Marble is correlative with the Cambrian and Ordovician carbonate rocks of the Chester Valley in Pennsylvania (Mathews, 1905), and because fine-grained Wissahickon schist of the South Valley Hills in Pennsylvania conformably overlies the Cambrian and Ordovician limestones of Chester Valley, the Wissahickon is Ordovician (Bascom, 1905).

In 1909, Bascom decided that the Wissahickon mica gneiss near Philadelphia was Precambrian because of its high metamorphic grade and because it is intruded by plutonic rocks that are absent from the phyllites and fine-grained schists to the west in the South Valley Hills and from the Paleozoic rocks farther west. She (Bascom and others, 1909) still regarded the fine-grained schists and phyllites to the west as Ordovician. Accordingly, these rocks were separated from the Wissahickon and named Octoraro schist. Because of the supposed age difference, the Octoraro and Wissahickon were inferred to be in fault contact, although they appeared to be gradational in the field (Bascom and others, 1909, p. 4).

In the Doe Run-Avondale district, Bliss and Jonas (1916) mapped a fault between fine-grained Octoraro schist and the coarser grained Wissahickon schist and mica gneiss, although there again the rocks appeared to be gradational. They also discovered "pre-Cambrian" Wissahickon above Setters quartzite and Cockeysville Marble, and because the last two were correlated with the Cambrian and Ordovician quartzites and limestones of Chester Valley, it was concluded that the Wissahickon had been placed upon the younger rocks by a major overthrust.

Later, Knopf and Jonas (1923) studied the area around the Peach Bottom syncline and found that the rocks adjacent to the Cardiff Conglomerate contain a higher proportion of quartzitic beds than most of the Wissahickon. These more arenaceous rocks, which straddle the boundary formerly drawn between the Wissahickon and Octoraro schists, were renamed Peters Creek schist. Knopf and Jonas (1923, p. 48) concluded that the "coarse-grained" Wissahickon oligoclase-mica schist plunges beneath the southern margin of the Peters Creek schist and emerges on the northern side of the Peters Creek belt as the "fine-grained" albite-chlorite schist that had formerly been called Octoraro, and that the Octoraro is simply a less metamorphosed stratigraphic equivalent of the Wissahickon. The name Octoraro was abandoned, and the fine-grained schists and phyllites became Wissahickon, and therefore Precambrian. Knopf and Jonas (1923) suggested that the Wissahickon rests on the Cockeysville Marble and Setters quartzite in normal sedimentary succession and not by the major thrust fault postulated by Bliss and Jonas (1916). Knopf and Jonas (1923) defined the Glenarm Series (*see* quote above) as a conformable sequence including the Cardiff

Conglomerate and the Peach Bottom Slate. Because the units are all conformable, the Cardiff and Peach Bottom were placed in the Precambrian with the rest of the Glenarm.

When the fine-grained schists and phyllites of the former Octoraro were defined as Precambrian, their relation to the Cambrian and Ordovician rocks of Chester Valley became anomalous, even though the rocks appeared conformable in the field. This required postulation of a great fault called the Martic overthrust (Knopf and Jonas, 1929b) to carry the schists of supposed Precambrian age over the younger rocks.

From 1929 until the 1960s, controversy over the age, origin, relations, and nomenclature of the Glenarm Series revolved chiefly around two features: the Martic overthrust and the fold at Peach Bottom.

Peach Bottom Syncline

Knopf and Jonas (1929b) reaffirmed the relations indicated in their definition of the Glenarm Series and gave detailed descriptions of the gradational and conformable nature of the contacts between the Wissahickon and Peters Creek, the Peters Creek and Cardiff, and the Cardiff and Peach Bottom.

Stose and Jonas (1939) correlated the Peach Bottom Slate with the Quantico and Arvonia Slates in Virginia. Late Middle to Late Ordovician fossils are found in the Arvonia. This correlation, coupled with acceptance of the Peters Creek and Wissahickon as Precambrian, necessitated invention of an unconformity beneath the Cardiff, although the contact is gradational. Thus the Peach Bottom Slate and Cardiff Conglomerate were removed from the Glenarm Series and assigned to the Ordovician. Later, Stose and Stose (1948) further entrenched the idea of an unconformity beneath the Cardiff into the literature and suggested that the Arvonia Slate is not Ordovician but Silurian or younger. They proposed that the Peach Bottom syncline is continuous from Arvonia through the Green Pond Mountain syncline in northern New Jersey and southern New York. The Green Pond Mountain syncline (now known as the Green Pond syncline) contains Silurian and Devonian rocks.

Agron (1950) made a detailed study of the Peach Bottom syncline and reaffirmed Knopf and Jonas' (1922, 1923, 1929b) observations of completely gradational and conformable contacts. He gave an excellent résumé of the questionable fossil evidence for the Peach Bottom (1950, p. 1277), and of Stose and Stose's (1948) suggested correlation, he stated: "The present writer does not know of any basis for correlating the slate of the Peach Bottom syncline with the Silurian and Devonian sediments in the Green Pond Mountain syncline. Furthermore, it is difficult to see how the Arvonia slates can be Silurian or Devonian if they carry Maysville fossils."

Despite Agron's study, the most commonly accepted interpretation of the Peach Bottom syncline during the 1950s was that of Stose and Jonas (1939).

Martic Overthrust (or Martic Line)

Soon after Knopf and Jonas (1929b) proposed the Martic overthrust, Miller (1935) and Mackin (1935) strongly opposed the idea and showed that the evidence favored the view that the Wissahickon of the South Valley Hills rests conformably on the limestone of Chester and Lancaster Valleys.

Meanwhile, Jonas (1929, 1932a, 1932b), Jonas and Stose (1930), and others (*see* Tectonic Map of the United States, Am. Assoc. Petroleum Geologists, 1944) had extended the assumed overthrust from Alabama to New Jersey.

In 1941, Cloos and Hietanen published the results of a detailed study of the Martic overthrust and Martic Hills. They cited much evidence for a conformable sequence and found no evidence of major thrusting at the Martic line. Cloos (Cloos and Hietanen, 1941, p. 193) concluded: "In spite of the amount of detailed data presented in this paper it is not possible to determine the age of the Glenarm series definitely. The author is fully convinced that it cannot be pre-Cambrian but is also certain that the whole series cannot be thrown into the Martinsburg group."

Swartz (1948) summarized the problems and evidence regarding the Martic overthrust (Martic line) and agreed with Cloos and Hietanen. Wise (1960, 1970) also gave valuable summaries and some new observations in the Martic Hills area.

Recent Work and Interpretations

Hopson (1964) synthesized the geology of the Maryland Piedmont and concluded that the Glenarm Series is Precambrian. He reasoned (1964, p. 183–193, 203–207; *see also* Steiger and Hopson, 1965) as follows: (1) the Port Deposit Granodiorite, Relay Quartz Diorite, Norbeck Quartz Diorite, and Kensington Quartz Diorite are all intrusive into the Glenarm Series, and radiometric dates on zircons from these rocks give values of about 500 m.y. This establishes a minimum age of 500 m.y. for the Glenarm Series; (2) because the Baltimore Gabbro is also cut by some of these plutons, it must be older than 500 m.y.; (3) modal compositions, chemical compositions, the close field relations between the Relay Quartz Diorite and the Baltimore Gabbro, and the lack of such a relation between the gabbro and the other plutonic rocks can be interpreted as indicating two comagmatic groups of plutonic rocks in the Maryland Piedmont: ". . . an early gabbroic series and a later granitic series. The former includes the Baltimore gabbro and related ultramafic rocks, and the small bodies of diorite, leuco-quartz diorite, and albite granite that are collectively called Relay Quartz Diorite. Comprising the granitic series are most of the other intrusive masses of quartz diorite, granodiorite, and quartz monzonite in the Baltimore-Washington area." (Hopson, 1964, p. 189). By analogy with a similar plutonic sequence in northwestern Oregon, where the mafic and granitic series may be separated by at least 70 m.y., he concluded that the gabbroic intrusions in Maryland can be interpreted as being no younger than about 550 m.y., and that they could be much older. The Baltimore Gabbro cuts the Glenarm Series. Hopson (1964, p. 205–207) stated:

Thus the age of the Glenarm Series, based on the plutonic rocks that cut the Wissahickon and older formations, can be no younger than Cambrian . . . and in all likelihood no younger than Early Cambrian; [4] Although an Early Cambrian age is not precluded by the radiometric data the regional stratigraphic relations seem to rule it out; [5] A Late Precambrian age for the Glenarm Series has been held to be equally improbable, because sedimentary strata are lacking beneath the known Lower Cambrian rocks in Pennsylvania and Maryland. . . . This reasoning begins to lose force, however, if stratigraphic relations farther south in the Appalachians are considered. In the western part of the Virginia Piedmont the Lynchburg Formation comprises a thick sequence of metamorphosed Upper Precambrian clastic sediments. It rests unconformably on basement gneiss but lies beneath Catoctin Greenstone. . . . Still farther south, in the Great Smoky Mountains along the North Carolina–Tennessee border, the Ocoee Series forms an Upper Precambrian clastic sequence at least 30,000 feet thick. . . . A Precambrian age for the Glenarm Series cannot be excluded, therefore, on the grounds that known Precambrian strata are lacking. Upper Precambrian metasediments of comparable thickness and lithology occur in the Virginia Piedmont, approximately along strike, and for a long way to the south. . . . The Glenarm metasediments do not correlate readily with the know Cambrian section, but do appear to correspond to the thick clastic sequences of Late Precambrian age in the Virginia Piedmont and farther south.

Wetherill and others (1966) recently revised the radiometric ages using new spike concentrations, slightly different isotopic compositions, and different instrumental corrections, but the numbers changed only slightly, and their significance remained unchanged. Their conclusions regarding the age of the Glenarm are essentially the same as those of Hopson (1964).

Hopson (1964) also reinterpreted the Peach Bottom syncline to accord more closely with his interpretations of stratigraphy, age, and structure of the Glenarm Series. Pebbly, granitic-appearing rock in Howard, Carroll, and Montgomery Counties, Maryland, had been mistaken for granite (Sykesville Granite; Keyes, 1895; Jonas, 1928; Cloos and Broedel, 1940; Stose and Stose, 1946) until, while mapping Montgomery County, Cloos became convinced of its sedimentary origin and designated it the Sykesville Formation (Cloos and Cooke, 1953). Fisher (1963) and Hopson (1964) presented evidence for a sedimentary origin and added the Sykesville Formation to the Glenarm Series. They (Fisher, 1963; Hopson, 1964) also recognized similar rock known as Laurel Gneiss (Chapman, 1942) as sedimentary in origin. Fisher correlated it with the Sykesville. Hopson (1964) renamed it the Laurel Formation. Hopson (1964, p. 114) considered the Sykesville and Laurel Formations ". . . stratigraphic equivalents that outline the southward-plunging nose of the Baltimore anticlinorium." In accord with this structural-stratigraphic interpretation of the Sykesville and Laurel Formations, Hopson (1964) considered the Wissahickon rocks east of the Sykesville outcrop belt older than the Wissahickon rocks west of that belt. He based this partly on Fisher's (1963) interpretation that graded beds and cleavage-bedding relations in the isoclinally folded Wissahickon rocks west of the Sykesville show tops predominantly to the west, "despite local reversals due to small folds" (Hopson, 1964, p. 72); this is in conflict with the map and interpretation of Cloos and Cooke (1953). Hopson (1964, p. 119) also concluded that the Sykesville grades laterally along strike into the Peters Creek Formation. These interpretations forced him to reinterpret the Peach Bottom fold. All who had studied the fold (Knopf and Jonas, 1929b; Behre, 1933; Stose and Jonas, 1939; Agron, 1950) considered it a major syncline involving the Peters Creek and Wissahickon Formations as well as the Peach Bottom Slate and Cardiff Conglomerate. To fit his interpretation of the rocks in Howard and Montgomery Counties, and because he could find no evidence there for a syncline along the projected strike from the Peach Bottom, Hopson (1964, p. 55) considered the Peach Bottom a second-order syncline not involving the Peters Creek and Wissahickon Formations, which were regarded as essentially homoclinal in that area (Fig. 2, A and B).

Southwick and Fisher (1967) revised the stratigraphic nomenclature of the Glenarm Series based on Hopson's (1964) interpretations and on mapping by Southwick in Harford County, Maryland (Southwick and Owens, 1968). They accepted Hopson's interpretation of the age of the Glenarm, and stated (1967, p. 7): "Extensive radiometric data on intrusives cutting the Glenarm Series show that the Wissahickon and Peters Creek Formations cannot be younger than Cambrian and are probably late Precambrian." They also accepted Hopson's interpretation of the stratigraphy and structure. Southwick and Fisher (1967) demoted the Sykesville and Laurel Formations to a single lithofacies of the Wissahickon Formation. They (1967, p. 3) divided the Wissahickon into five lithofacies: ". . . the lower pelitic schist lithofacies; the boulder gneiss lithofacies (includes the former Sykesville and Laurel Formations); the metaconglomerate lithofacies; the metagraywacke lithofacies (includes the former Peters Creek Formation); and the upper pelitic schist lithofacies." The Peters Creek Formation was thus abandoned and incorporated into the Wissahickon.

Southwick and Fisher (1967) accepted the basic premises of Hopson's (1964) interpretation of the Peach Bottom syncline, but they were obviously troubled by the postulated unconformity beneath the Cardiff. They (1967) gave a good description of the conformable and gradational nature of the Peters Creek–Cardiff contact, stating that their examination confirms the observations of Knopf and Jonas (1923); but having accepted the Peters Creek as Precambrian and the Peach Bottom as Ordovician, they also had to accept an unconformity somewhere between the two. By this time, the idea of an unconformity had become so entrenched that they could place the burden of proof upon anyone who might deny its existence, instead of requiring proof *for* its existence (Southwick and Fisher, 1967, p. 6–7): "In order to use the small syncline in the Cardiff as evidence for a major syncline in the underlying Peters Creek and Wissahickon Formations, it must be demonstrated that the Cardiff is conformable with the underlying rocks."

However, realizing that the field evidence does show the Peters Creek–Cardiff contact to be conformable and gradational, they continued: "Such a break has been postulated at the base of the Cardiff, but it could occur at the base of the Peach Bottom. The Cardiff–Peach Bottom contact is not notably gradational; in fact it is less gradational than the Peters Creek–Cardiff contact." They finally settled on the interpretation shown in Figure 2, C and D. Southwick, however, was still troubled by the conflict between the field evidence and hypothesis. He wrote (1969, p. 44): "In summary, then, an angular unconformity at the base of the Cardiff cannot be proved. On the other hand the possible existence there of a disconformity or low-angle unconformity, now obscured by shearing and metamorphism, cannot be eliminated."

Inherent to Hopson's interpretation of the age of the Glenarm Series is the idea (Hopson, 1964, p. 102) that the Glenarm was ". . . already deeply buried and undergoing metamorphism . . ." when the intrusion of the plutonic rocks began, ". . . possibly as early as 570 but no later than 490 million years ago. . . ." Despite the fact that the Peach Bottom Slate is metamorphosed and deformed to the same degree as the Glenarm rocks around it (Agron, 1950; Southwick and Fisher, 1967; Southwick, 1969), Southwick (1969, p. 45) accepted Hopson's age interpretation and the Ordovician age for the Peach Bottom and stated: "It is important to note, however, that all the plutonic rocks that cut the Glenarm Series and whose radiometric ages bear on the age of that series are near the axis of the Baltimore-Washington anticlinorium. Perhaps this area was undergoing plutonism and uplift while sedimentation was continuing to the northwest in the axial part of the Peach Bottom syncline."

AGE OF THE GLENARM SERIES

"Plutonic" Rocks

The geologic map of Maryland (Cleaves and others, 1968) shows nine plutonic rock units of Hopson's (1964) "granitic series," including Gunpowder Granite, Kensington Quartz Diorite, Port Deposit Gneiss, Norbeck Quartz Diorite, Ellicott City Granodiorite, Guilford Quartz Monzonite, and Woodstock Quartz Monzonite[1]. Also shown are two "granitic" plutonic rocks of his "gabbroic series," Relay Quartz Diorite and Georgetown mafic complex (Fig. 1). Older maps included the Sykesville and Laurel Gneisses among the plutonic intrusions, but these rocks are now commonly accepted as metasedimentary. The evidence for a sedimentary origin of the Sykesville and Laurel Gneisses, as presented by Hopson (1964), is: (1) they have gradational contacts with Wissahickon metasedimentary rocks; (2) they have metasedimentary textures, with relict sand grains and pebbles; (3) they have the chemical composition of sediments, not of igneous granitic rocks (Hopson, 1964, p. 110); (4) their quartz/feldspar ratios are too high for magmatic granites; and (5) the foreign fragments and inclusions in them are not xenoliths but clasts.

Hopson's (1964) minimum age of the Glenarm Series[1] is largely based on radiometric dates of some of the "plutonic" rocks listed above, which he interpreted as cutting the Glenarm. I believe that some of these rocks can be interpreted as either metasedimentary, and therefore part of the Glenarm Series, or as shallow, surface-breaking plutons, coeval with volcanic rocks of the Glenarm.

Port Deposit Gneiss (Granodiorite of Former Usage)

The geologic map of Maryland (Cleaves and others, 1968) shows Port Deposit Gneiss underlying a large area in northeastern Maryland. The area shown as Port Deposit Gneiss is actually underlain by several different kinds of rock (Fig. 3).

The name Port Deposit Gneiss is retained here only for the coarse-grained, foliated, even-textured, plutonic-appearing gneiss in and around the quarry on the northeastern side of the Susquehanna River north of Port Deposit, Maryland, and extending an unknown distance along strike into Harford County, Maryland.

Conowingo Gneiss Belt, Diamictite Facies, Wissahickon Formation

"Conowingo gneiss" is proposed as an informal geographic name for the belt of diamictite facies (Higgins and Fisher, 1971) metasedimentary rocks northwest of the Port Deposit Gneiss that were formerly mapped as Port Deposit.

The Conowingo gneiss is a metamorphosed gravelly muddy sandstone (Folk, 1960), well exposed on the northeastern side of the Susquehanna River for approximately 3 mi southeast (downstream) from Conowingo Dam. Excellent exposures are also found northeast of Rowlandsville, Maryland, along Octoraro Creek.

In most outcrops, Conowingo gneiss superficially resembles a weakly foliated granite, but it commonly has abundant pea-sized quartz lumps and grains and scattered pebbles of quartz, granite, and gneiss, and chips of mica schist (Fig. 4, A and B). Locally, pebbles, cobbles, and boulders of quartzite, granite, gneiss, schist, amphibolite, graywacke with contorted bedding, calc-silicate rock, and ultramafic rock are common (Fig. 4, C and D). Some fragments of volcanic rock similar to rocks of the James Run Formation occur in the coarser parts. Many of the quartz grains and granules in Conowingo gneiss are blue, but whether this is an original feature or due to metamorphism is unknown. The gneiss is generally massive and poorly bedded in the usual sense of the term, but the pebbles, cobbles, and boulders seem to be concentrated along certain zones or lenses parallel to the contacts.

The contacts of the Conowingo gneiss (Figs. 1, 3) are gradational. On its northwestern side, the gneiss appears to grade gradually into mafic rocks that have been considered part of the Baltimore Gabbro. On the southeast, the gneiss gradually becomes finer grained, and the number and size of inclusions decrease. Layers of pelitic schist appear and gradually become more prevalent. Thus by grain-size gradation and interlayering with pelitic schist, the gneiss passes into the Wissahickon metagraywacke facies (Higgins and Fisher, 1971).

[1] The nomenclature used here is discussed in a later section. Much of it is from Higgins and Fisher (1971).

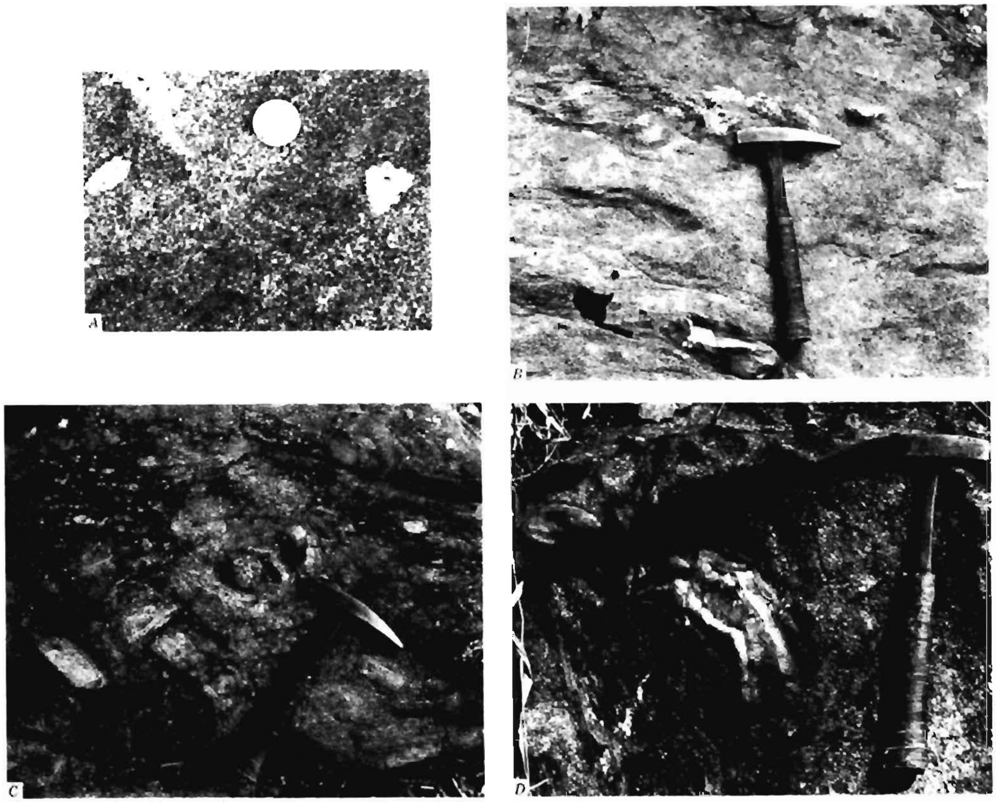


Figure 4. Photographs of Conowingo gneiss. A, along Octoraro Creek about 2,000 ft north of Rowlandsville, Maryland (Conowingo Dam quadrangle). Quartz pebbles and small mafic inclusions are visible. B, along Octoraro Creek about 200 ft downstream from the power line crossing a mile northeast of Rowlandsville, Maryland. The granular texture of the matrix is due chiefly to quartz granules and rounded grains. Black material, lower left, is tar. C, about 75 ft south of B. Some clasts are aligned parallel to the general matrix fabric, others lie at angles to it. D, calc-silicate inclusion in the gneiss along Penn Central Railroad tracks about 300 ft south of Conowingo Dam (Conowingo Dam quadrangle).

Petrography. Mineralogically, Conowingo gneiss is quite similar to Sykesville and Laurel gneisses (Hopson, 1964, p. 107, 115); the only difference is in its potassium feldspar content (Table A)[2]. It has a relict clastic texture in which quartz occurs as relict clastic grains, tiny matrix grains, and rounded aggregates of two or more grains. Hopson (1964, p. 106) stated of the Sykesville gneiss: "There is no difference, other than size, between the clastic quartz grains seen in thin section and the quartz 'lumps' so conspicuous in outcrop. Moreover, there are all gradations in size between them. It is evident that the quartz lumps are relict pebbles and granules, in a partly sandy matrix." This is also true of the Conowingo gneiss (Fig. 5, A and B). It is interesting to note that Hopson (1964) labled two samples of the rock below Conowingo Dam as metagraywacke of Peters Creek Formation, although he did not say how far below the dam they were found.

Plagioclase in Conowingo gneiss is of three kinds, similar to that described by Hopson (1964) in the Sykesville: (1) There are relict, rounded clastic grains having few inclusions and commonly clouded by sericite and tiny crystals of epidote or clinozoisite. In many of the relict grains, zoning or twinning is broken or rounded off, and some have new over-

[2] Table A, consisting of 10 modal analyses of Port Deposit and Conowingo gneisses is available by ordering NAPS Document 01720 from ASIS National Auxiliary Publications Service, c/o CCM Information Corporation, 909 Third Avenue, New York, New York 10022; remitting $2 for microfiche or $5 for photocopies. Checks may be made payable to CCMIC-NAPS.

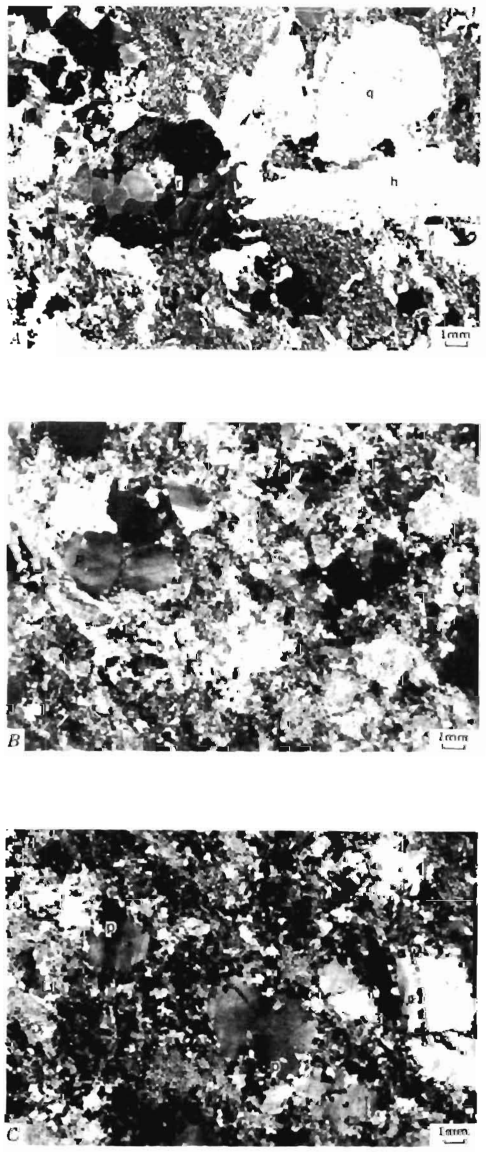


Figure 5. Photomicrographs of gneissic rocks. A, Conowingo gneiss along Penn Central Railroad tracks about 2,500 ft south of Octoraro Creek, Conowingo Dam quadrangle, Maryland. q, relict rounded quartz granule; r, rock fragments; h, hole in thin section. B, rock formerly mapped as Port Deposit Gneiss or Granodiorite (Southwick and Owens, 1968; Cleaves and others, 1968). p, relict quartz pebble. Along Little Gunpowder Falls exposure, 200 to 600 ft north of Franklinville Road, Baltimore County, Maryland. C, Port Deposit Gneiss in quarry north of Port Deposit, Maryland. Some patches of quartz and quartz and feldspar, p, may represent relict rock fragments in a highly recrystallized matrix.

growths on the old clastic grains. This relict plagioclase generally ranges from albite to oligoclase, but a few grains as calcic as An_{50} were seen. The overgrowths on relict grains are commonly albite. (2) There are also newly formed, commonly untwinned, unaltered, and unclouded porphyroblasts of albite or sodic oligoclase that are strongly sieved and have irregular amoeba-form shapes with arms that project into the matrix. These are least common. (3) The third kind is composed of tiny granoblastic grains in the matrix that range from albite to sodic oligoclase.

Potassium feldspar occurs in two forms: (1) Relict, clouded, rounded clastic grains which commonly show the crosshatch twinning of microcline; and (2) rare matrix grains which show no twinning and are recognizable only when stained.

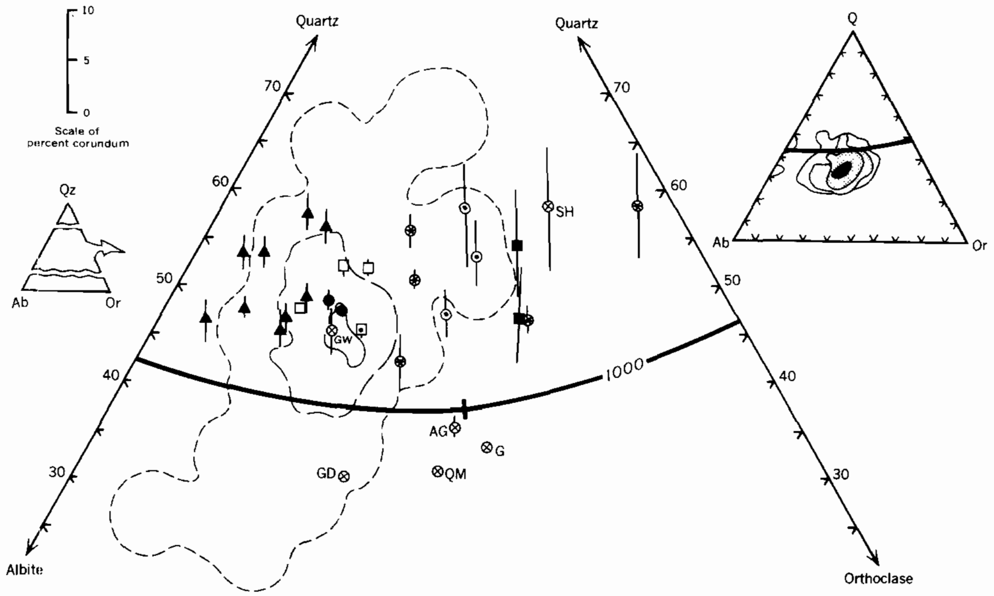
Polygranular aggregates of feldspar, quartz, or of both are fairly common (Fig. 5, A and B). These are granules of rounded rock fragments in what was a pelitic-psammitic matrix. Tiny slab and lens-shaped fragments of biotite schist and graywacke or quartzite and biotite schist are also present.

The micas are similar to those described by Hopson (1964, p. 108).

Chemistry. On the same plots that Hopson (1964) used as evidence for a sedimentary origin of the Sykesville, Conowingo gneiss plots as a sediment (Figs. 6 and 7). The Conowingo plots closer to the albite-quartz side of the triangle than does the Sykesville—more like graywacke than like a mixture of graywacke and shale. Most of the analyses show less normative corundum (Table B[3]; Figs. 6 and 7) than the Sykesville, but are not unlike analyses of graywackes in this respect.

Use of the quartz-albite-orthoclase plot to distinguish magmatic rocks from metamorphosed sedimentary rocks may be questioned if the anorthite contents are not taken into ac-

[3] Table B, consisting of 19 new chemical analyses and normative compositions, and 11 previously published chemical analyses and normative compositions of Conowingo gneiss, Port Deposit Gneiss, Norbeck "Quartz Diorite," Kensington "Quartz Diorite," Ellicott City Granodiorite, Woodstock Quartz Monzonite, and Guilford Quartz Monzonite is available by ordering NAPS Document 01720 from ASIS National Auxiliary Publications Service, c/o CCM Information Corporation, 909 Third Avenue, New York, New York 10022; remitting $2 for microfiche or $5 for photocopies. Checks may be made payable to CCMIC-NAPS.



EXPLANATION

- ⊛ Conowingo gneiss, Cecil County
- ■ Sykesville gneiss, Potomac Gorge. (J. C. Reed, Jr., and Janice Jolly, unpub. data)
- ● Port Deposit gneiss, Cecil County
- ▲ Port Deposit gneiss, Baltimore County
- □ Port Deposit gneiss, Harford County (Southwick, 1969)
- ⊡ Conowingo gneiss, Cecil County No. 6 table 2. (Southwick, 1969)
- ⊙ Sykesville gneiss, (Hopson, 1964)
- ⊗ Average rocks from Hopson (1964)

Figure 6. Plot comparing normative quartz-orthoclase-albite ratios and corundum compositions of Port Deposit Gneiss, Conowingo gneiss, and Sykesville gneiss with possible parent rocks (*as used by* Hopson, 1964, Fig. 28). Lines through symbols indicate percent corundum. Average rocks from Hopson (1964): GW–graywacke, SH–shale, GD–granodiorite, QM–quartz monzonite, G–granite, AG–alkali granite. The dashed and solid lines are contours of 51 unmetamorphosed graywackes; contours for the 20, 10, and 1 percent maxima (*from* Hopson, 1964). The heavy solid line is the projection of the synthetic granite minimum at 1,000 bars P_{H_2O} (Tuttle and Bowen, 1958, p. 75). The small q-or-ab plot, upper right, shows contours drawn on plots of 1,190 granitic rocks (*from* Winkler and von Platen, 1961). Magmatic rocks fall mostly below the 1,000-bar minimum line. This projected minimum moves down toward ab-or side on the triangle with increased P_{H_2O} (Tuttle and Bowen, 1958).

count. Nevertheless, q-or-ab ratio of 1,190 granitic rocks plotted and contoured by Winkler and von Platen (1961) define a field with only a small percentage slightly above the 1,000-bar projection (inset, Fig. 6). Because the analyses were taken from the literature, some metamorphosed sediments (like the Sykesville) are probably included and may account for part of the small percentage above the 1,000-bar line. An even smaller percentage of the ratios would fall above the 500-bar line. Similarly, q-or-ab ratios of all (571) analyzed plutonic rocks in Washington's (1917) tables with 80 percent or more q + or + ab contoured by Tuttle and Bowen (1958, p. 79) define a field with only a small percentage slightly above the 1,000-bar projection, and their data definitely include the Sykesville, Laurel, and Conowingo gneisses (*see* Washington, 1917). In both cases, comparison with the Conowingo and Sykesville plots shows that ratios from these two rocks plot for the most part outside the magmatic field and toward the quartz apex of the triangle. Plots of well-known igneous rocks further confirm the empirical observations (Figs. 8 and 9).

Origin. Chemical and mineralogic composition, texture, and field relations all indicate that the Conowingo gneiss is a metasedimentary rock similar to the Sykesville and Laurel masses of Wissahickon diamictite facies. The problems of deciphering its origin with respect to manner of deposition are the same as those of the Sykesville (Hopson, 1964). The Conowingo gneiss is tentatively considered to be a large submarine slump deposit.

Port Deposit Gneiss

The southeastern contact of the Port Deposit Gneiss (Fig. 3) is completely gradational. Southeast of the area around the quarry (the type locality) north of Port Deposit, Maryland, the gneiss gradually becomes finer grained and grades over a wide interval into porphyritic felsites, and finally into metamorphosed tuffs and tuffaceous sediments. The northwestern contact is

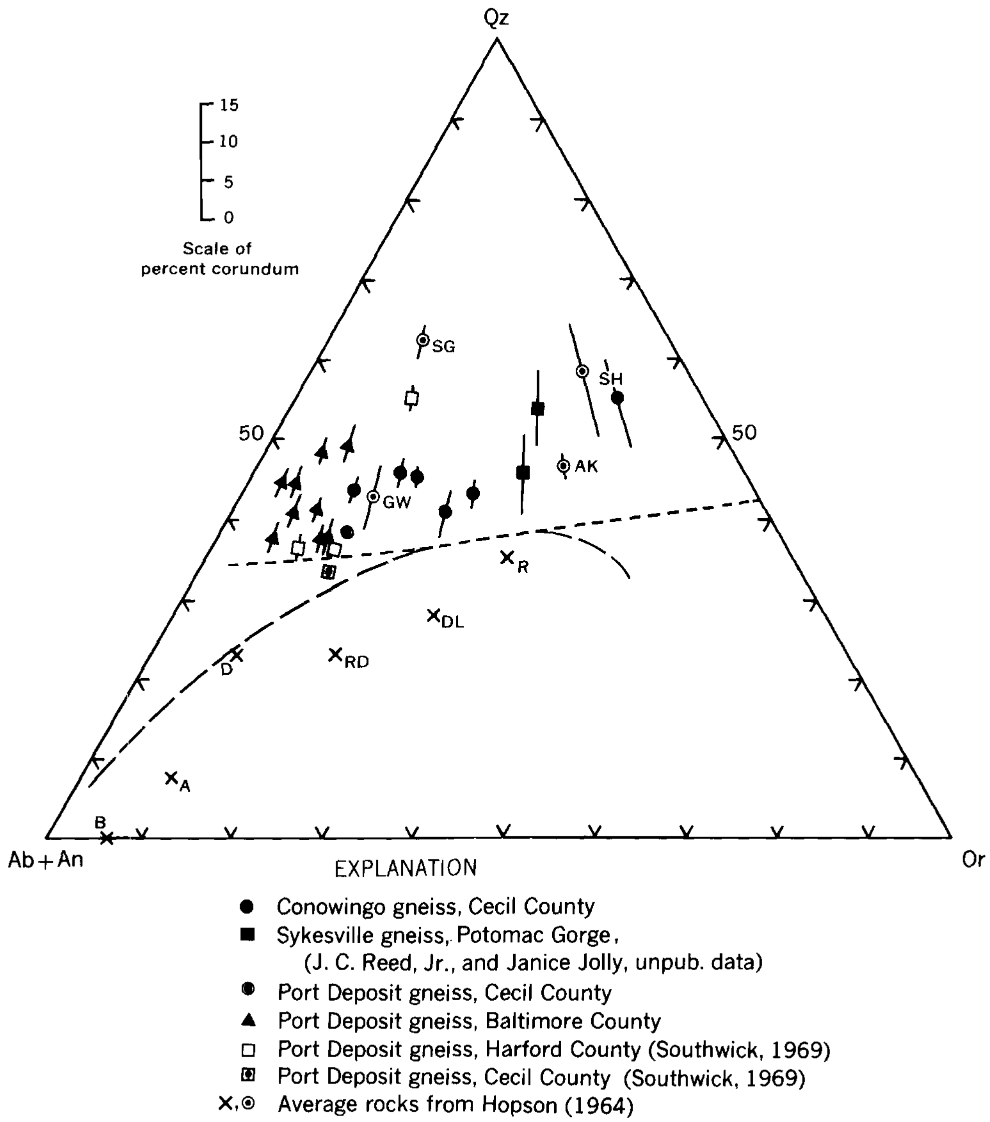


Figure 7. Plot comparing q-or-ab + an ratios and corundum compositions of Port Deposit Gneiss, Conowingo gneiss, and Sykesville gneiss with possible parent rocks (*adapted from* Hopson, 1964, Fig. 13). Lines through symbols indicate percent corundum. Average rocks from Hopson (1964): SH–shale, AK–arkose, SG–subgraywacke, GW–graywacke. A series of average calc-alkaline lavas is also from Hopson (1964): R–rhyolite, DL–dellenite, RD–rhyodacite, D–dacite, A–andesite, B–tholeiitic basalt. The dotted line separates the fields of SiO_2 and alkali feldspar on the liquidus of the "dry" system AB-OR-SiO_2; the long-dashed curve approximately separates the region where calc-alkaline lavas and unaltered volcaniclastic rocks plot (below the curve) from that in which albitized and zeolitized pyroclastic and epiclastic volcanic rocks plot (*from* Hopson, 1964, p. 34).

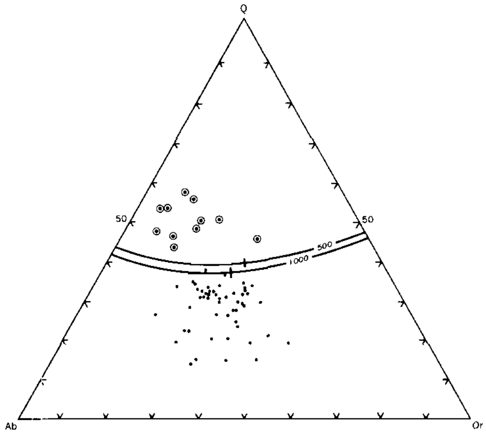
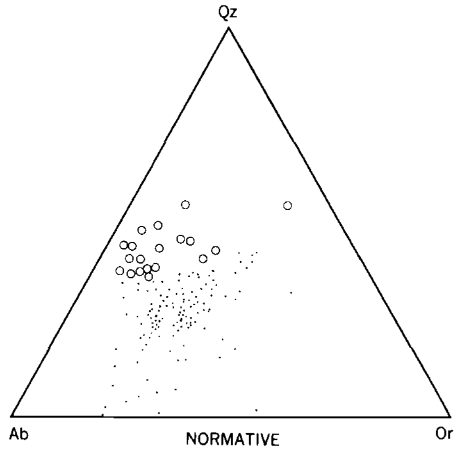


Figure 8. Normative quartz-orthoclase-albite plot of 51 well-known magmatic granitic rocks (dots) and 11 samples of Port Deposit Gneiss and Conowingo gneiss (circled dots). Projections of 500- and 1,000-bar P_{H_2O} lines from Tuttle and Bowen (1958). All analyses plotted have: (1) ab/an ratios of 2.0 to 4.5, (2) percent an of 2.5 to 15.5, and (3) q + or + ab of 73.5 to 84.0 percent. No analyses excluded except those which do not fit the above ranges. Analyses from Nockolds (1954) are averages. Data compiled from Albers (1964), Bateman and others (1963), Becraft and others (1963), Cady and others (1955), Dietrich (1961), Haslam (1968), Hietanen (1963), Hutchinson (1956), Larsen and Cross (1956), Larsen and Schmidt (1958), Nockolds (1954), Parker and Calkins (1964), and Wheeler (1960).



Open circles indicate Port Deposit and Conowingo gneisses
Dots indicate granitic plutonic rocks:
26 Sierra Nevada (Bateman and others, 1963)
16 Alaska (Cady and others, 1955)
21 Laramide stocks
15 Idaho batholith (Larsen and Schmidt, 1958)
31 Boulder batholith (Klepper, in Bateman and others, 1963)
8 Vancouver Island (Fyles, 1955)

not well exposed, but appears to be less gradational; here the gneiss is bordered by Wissahickon metagraywackes with interlayered amphibolites probably derived from basaltic tuffs. To the northeast, in central Cecil County, the Port Deposit interfingers with Wissahickon pelitic schists and metagraywackes.

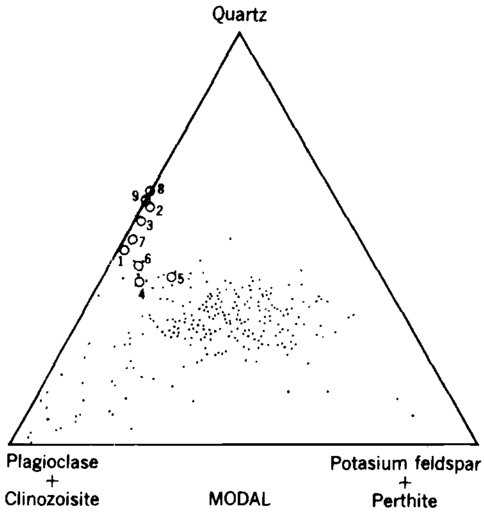
Petrography. Most thin sections of Port Deposit Gneiss have completely recrystallized metamorphic textures. Nevertheless, pods and lenses of quartz grains (Fig. 5C; Hopson, 1960, Fig. 4) are conspicuous and abundant and strongly resemble the relict pebbles and granules of the Wissahickon diamictite facies. One thin section from the east quarry wall north of Port Deposit contains a relatively undeformed quartz granule. Hopson (1960) described the texture of the Port Deposit Gneiss as much deformed, and Southwick (1969, p. 66) called it a "mylonite gneiss." The rock is well foliated and locally slightly granulated, but it is definitely not a mylonite gneiss or any other kind of cataclastic rock, and the quartz granules are certainly not porphyroclasts, as Southwick (1969, p. 66) thought; in fact, quartz porphyroclasts are very rare in cataclastic rocks (Higgins, 1971b). Hopson (1960) has given a good petrographic description of the gneiss, and no good purpose would be served in repeating it here.

Both Hopson (1960) and Southwick (1969, p. 66) place much emphasis on the presence of zoned "relict" plagioclase crystals in the Port Deposit and interpret them as evidence for the rocks' plutonic origin. I agree that these crystals are of relict *igneous* origin, but they can just as readily be interpreted as relict volcanic crystals.

Mineralogically, Port Deposit Gneiss is a quartz-rich biotite granodiorite (Table A); it has a relatively high quartz/feldspar ratio. Most samples contain some potassium feldspar, but commonly less than 10 percent.

Chemistry. Most analyses of Port Deposit Gneiss plot outside the magmatic fields on q-or-ab and q-or-ab + an diagrams; they plot with graywackes (Figs. 6 and 7). They differ from the Sykesville and Laurel gneisses (Hopson, 1964) chiefly in having less normative corundum.

Origin. Its chemistry and some petrographic aspects suggest that the Port Deposit



Open circles indicate Port Deposit and Conowingo gneisses. Numbers refer to table A

Dots indicate granitic plutonic rocks:

Averages of modal analyses of granitic intrusions of the east-central Sierra Nevada; points representing a total of 597 modes, from Bateman and others, 1963, p. D 30

79 samples of Butte Quartz Monzonite (Boulder batholith) from Becraft and others, 1963

24 samples of various rocks from the Enchanted Rock batholith, from Hutchinson, 1956

46 samples from north of Davis Inlet, Labrador, from Wheeler, 1955

12 samples from the Bethel area, Maine, from Fisher, 1962

24 samples of granitic rocks from near North Indian Lake, Manitoba, Canada, from Kretz, 1967

15 samples of Ellicott City Granodiorite, 6 samples of Woodstock Quartz Monzonite, 6 samples of Guilford Quartz Monzonite, 9 samples of Bear Island Granite, and 6 samples of Gunpowder Granite, all from Maryland, from Hopson, 1964

Figure 9. Normative and modal plots of well known magmatic granitic rocks, Port Deposit Gneiss, and Conowingo gneiss. The q-or-ab+an plot includes all the analyses from the areas and references listed. In each diagram, some points coincide.

Gneiss is metasedimentary, whereas its outcrop appearance suggests a metaplutonic rock. If it was originally a sediment, it must have been well sorted, and it must have received fresh detritus from a nearby volcanic terrane. If it was originally plutonic, it must have been a very shallow, surface-breaking pluton, intimately associated in time and space with the flanking James Run volcanic rocks it grades into. In many respects, the Port Deposit is reminiscent of the shallow Tatoosh pluton in Washington, which grades into volcanic rocks erupted from the same magma (Fiske and others, 1963). The Tatoosh is also fairly coarse grained despite the fact that it broke surface, and it has volcanic-appearing plagioclase crystals. Many Port Deposit thin sections have textures similar to those shown by Cater (1969) in his descritpion of the Cloudy Pass batholith (Washington) and the subvolcanic rocks it grades into. If the Port Deposit Gneiss (as restricted areally here) is a metamorphosed Tatoosh-like pluton, then the seemingly anomalous quartz blebs may be granulated and recrystallized quartz phenocrysts and quartz-filled vesicles.

Regardless of which of these origins is correct, the age of the Port Deposit is approximately the same as that of the James Run metavolcanic rocks it grades into.

James Run Formation

James Run Gneiss was the name Southwick and Fisher (1967) gave to interlayered quartz amphibolite and biotite-quartz-plagioclase gneisses of volcanic and volcaniclastic origin well exposed along James Run in Harford County, Maryland (Southwick and Owens, 1968). The unit is here redefined as the James Run Formation. It is 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 and is added to the Glenarm Series (Fig. 1). The formation also includes metamorphosed epiclastic rocks derived largely from volcanic sources, and small plutons and masses of hypabyssal intrusives that are indistinguishable in the field from some of the volcanic rocks.

The James Run Formation is divided into four informal units (Fig. 3), for ease of description. Unit *A* consists of metamorphosed rhyolitic and dacitic tuffs (Fig. 10A) and tuffaceous volcaniclastic sediments intimately interbedded with "intraformational" conglomerates and submarine slump deposits. Thin, metamorphosed andesite tuffs are locally present. Unit *B* consists of metamorphosed rhyolite, rhyolite and dacite tuff, and local

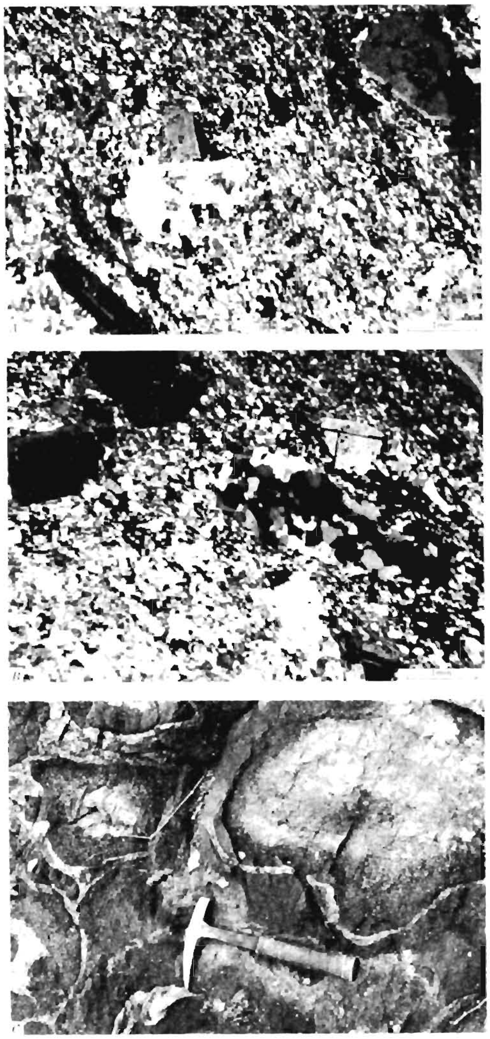


Figure 10. Rocks of the James Run Formation. A, metamorphosed tuff along Penn Central Railroad tracks on east bank of Susquehanna River about 150 ft south of Happy Branch. B, metamorphosed volcaniclastic sedimentary rock from Principio Creek at Principio Furnace, Cecil County, Maryland. Note euhedral to subhedral plagioclase phenocrysts and the elongate relict quartz granule. C, pillow basalts near Gilpin's Falls, Northeast Creek, Cecil County, Maryland.

tuffaceous sandstone. Unit *C* consists of metamorphosed tuffs and siliceous, tuffaceous volcaniclastic and volcanic-epiclastic rocks (Fig. 10B), with some metarhyolites and meta-andesites. Unit *D* consists of metamorphosed pillow basalts (Fig. 10C) and associated nonpillowed flows, basaltic tuffs, and broken pillow breccias. Parts of all four units were once called Port Deposit Gneiss or Granodiorite, and units *A*, *B*, and *C* constitute a major part of the Port Deposit shown on the geological map of Maryland (Cleaves and others, 1968). Port Deposit Gneiss (usage of this paper) grades into rocks of unit *B*. The basalts of unit *D* were called "metarhyolite" and later "metadacite" by Bascom (1902, 1905; Bascom and Miller, 1920), probably on the basis of a chemical analysis of material from between the pillows. She did not recognize the pillow structure and thought the interpillow material was the unaltered part of a badly altered rock. Hershey (1937) and Marshall (1937) followed Bascom and mapped the basalts as metadacite and the other volcanic rocks as Port Deposit Granodiorite. The geologic map of Maryland (Cleaves and others, 1968) is based on their mapping.

Kensington and Norbeck Quartz Diorites of Hopson

Hopson (1964) classified the Kensington and Norbeck rocks as "early kinematic" (*also see* Wetherill and others, 1966). This was based partly on their zircon ages (discussed later) but also on field relations. He stated (1964, p. 167–168, 160–161): "The Kensington Quartz Diorite shows a striking relation to regional structure. The main body and its satellites form thin, steeply dipping concordant sheets or wedges localized along the plunging crest of the Baltimore anticlinorium. . . . The contacts of the Norbeck pluton are not exposed . . . its internal structure is also parallel with the contacts and with the structure of the country rock."

Hopson did no geologic mapping in Maryland (1964, p. 27). The contacts and plan of the Norbeck and Kensington rocks (Hopson, 1964, Pl. 7; Cleaves and others, 1968) are based on the map of Cloos and Cooke (1953). The contacts are generally not exposed and were drawn with the belief that the rocks are plutonic. Significantly, the slight discordances of some of the contacts are similar to the Sykesville contacts (Cloos and Cooke, 1953; Cloos and Broedel, 1940; Cleaves and others, 1968).

In outcrop, the Kensington appears highly sheared, as noted by Hopson (1964). A relatively high percentage of elongate quartz grains and lenses is common, but foreign inclusions are rare. In contrast, the Norbeck has abundant round quartz grains and lumps (Fig.

11A) and a variety of rock inclusions ranging in size from a few inches to several feet (Fig. 11, B and C). Some Norbeck outcrops resemble "subvolcanic" breccias or explosion breccias (Cater, 1969; Fiske and others, 1963). Locally the Norbeck is bordered by fine-grained schistose greenstones, probably metamorphosed mafic tuffs, but whether the coarser parts of the Norbeck are gradational into these greenstones or not is unknown. Neither the Kensington nor the Norbeck has associated dikes or discordant satellitic bodies.

Petrography. Hopson (1964, p. 109) stated: "Nor does the Sykesville correspond mineralogically to magmatic granites, in which feldspars equal or exceed quartz." In the Norbeck and Kensington rocks, quartz commonly slightly exceeds feldspars (Hopson, 1964). Mineralogically the Kensington is similar to a metamorphosed graywacke. Its plagioclase/potassium feldspar ratio makes it a quartz diorite in Johannsen's (1931) system as modified by Hopson (1964), but its over-all mineralogy does not agree well with what is generally accepted as quartz diorite. Moreover, the quartz-potassium feldspar-plagioclase ratios of

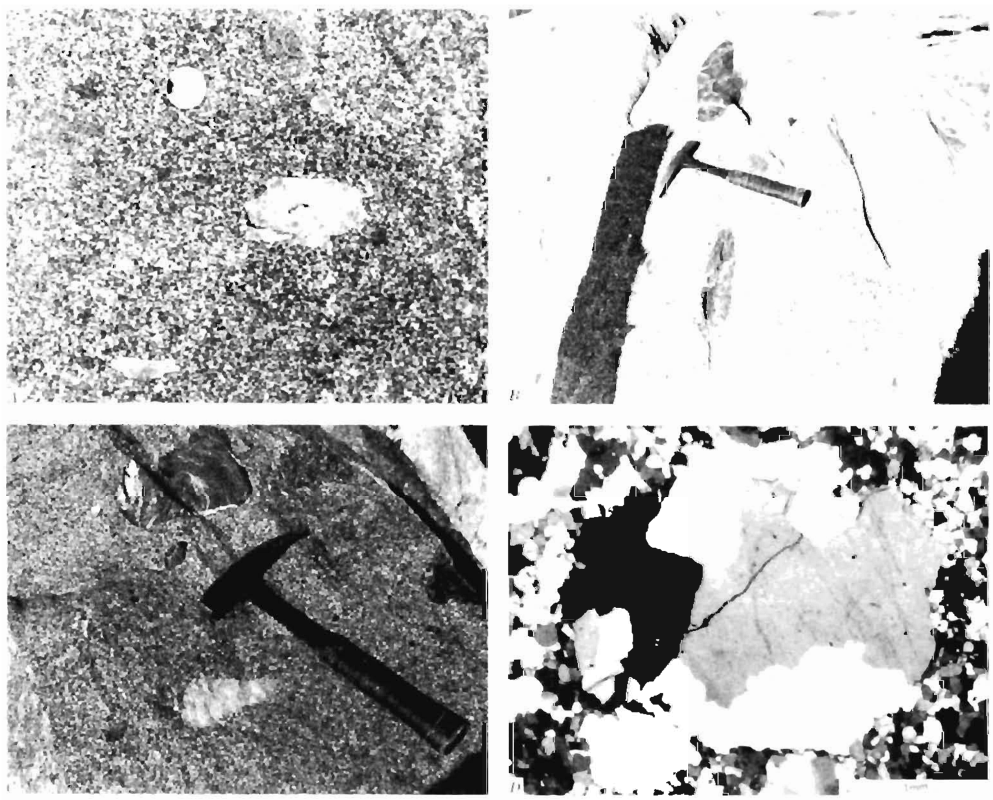


Figure 11. Norbeck gneiss, and Relay Quartz Diorite (of former usage). A, quartz lump and rock fragments in Norbeck gneiss at small stream crossing Layhill Road 2,000 ft southwest of Norbeck Road, Kensington quadrangle, Maryland. At top center is a granitic inclusion with indistinct borders; small granules of fine-grained quartzite, schist, and mafic rock are also visible. This outcrop is quite similar to the rock from which zircons were dated. The dated rock also contains a variety of inclusions. B, clasts in Norbeck gneiss. Note metagraywacke inclusion at upper right, lying at an angle to the two cobbles of mafic rock. Same locality as A. Large dark area to left of hammer is a shadow. C, pebble- and cobble-sized clasts in "pseudogranitic" matrix of Norbeck gneiss. Light colored clast below hammer is fine-grained quartzite. Outcrop at Bauer and Russet Streets, about one-half mile south of Norbeck Road, Kensington quadrangle, Maryland. D, photomicrograph showing relict, rounded quartz granule in metamorphosed volcanic-sedimentary rock from Relay Quartz Diorite (of former usage) about 500 ft southeast of Interstate Route 95 on south bank of Patapsco River, Howard County, Maryland.

some modal analyses of the Kensington plot above the 50 percent quartz line in the triangle (Hopson, 1964). Both the Norbeck and the Kensington have recrystallized metamorphic textures. Although Hopson emphasized the zoned plagioclase crystals in these rocks and interpreted them as evidence of magmatic origin, there is no reason to believe they could not just as well be of volcanic or very shallow hypabyssal origin as plutonic, especially in the Norbeck (Hopson, 1964, Pl. 33, fig. 1).

Chemistry. Analyses of the Norbeck and Kensington rocks (Table B) plot in the quartz field on a q-or-ab diagram (Fig. 12), although both rocks have less than 80 percent q + or + ab and the Norbeck has high normative an. On a q-or-ab + an diagram (Fig. 13), the Norbeck plots higher toward the quartz apex than do most magmatic rocks, but it also plots very close to the quartz-plagioclase side of the diagram, with volcanic and volcanic-sedimentary rocks (*also see* Hopson, 1964).

Origin. The Kensington may be a metamorphosed graywacke, perhaps deposited and partially homogenized by submarine sliding. Metamorphism and shearing may have further contributed to the homogeneous texture. If it was a graywacke, the material in its source area was considerably better sorted than that of other slump deposits in the Piedmont. More appealing, however, is the alternate interpretation that the Kensington was a shallow, or surface-breaking pluton, as suggested by its relict plagioclase crystals and texture, and also by regional considerations.

The evidence suggests that the Norbeck may represent an altered volcanic sediment with some material added from "normal" sedimentary sources. Because of the rounded quartz lumps and rock fragments, and its chemical similarity to other volcanic-sedimentary rocks, the Norbeck is tentatively considered a submarine slide deposit consisting mostly of volcanic or volcanic-epiclastic material. Similar rocks have been described by Schermerhorn and Stanton (1963) in the West Congo geosyncline and by Horne (1969) in Newfoundland.

Alternatively, the Norbeck may be a "complex," composed in part of shallow, surface-breaking "plutons" intimately associated with volcanic, volcaniclastic, and volcanic-epiclastic sediments, with the whole now metamorphosed so that slight original variations in texture and composition are almost indistinguishable.

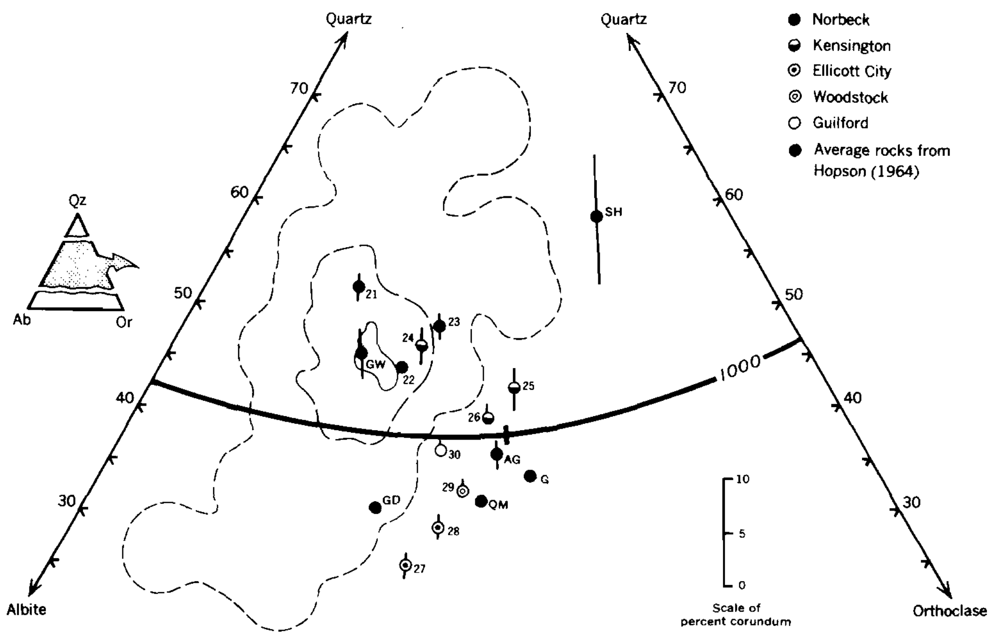


Figure 12. Normative quartz-orthoclase-albite ratios and corundum compositions of Norbeck and Kensington rocks and other Maryland Piedmont "granitic rocks." Lines through symbols indicate percent corundum. Plot and average rocks are the same as those of Figure 6. Analysis numbers correspond to those of Table B. Norbeck and Kensington rocks plot in the "sedimentary field."

Relay Quartz Diorite of Hopson

Hopson (1964, p. 160) thought the Relay differentiated from Baltimore Gabbro and was silicified and albitized by its own residual fluids. He included it in his "gabbroic series." He stated (1964, p. 160) that it "... was emplaced in its present position during regional deformation..." and (p. 155) that "the mass looks like a sill from the map pattern, but it may be crosscutting at depth." Several workers (Knopf and Jonas, 1929a; Herz, 1951; Hopson, 1964) have reported intrusive contacts between the Relay and the Baltimore Gabbro, but none have described the detailed nature of these contacts or given evidence to show which rock

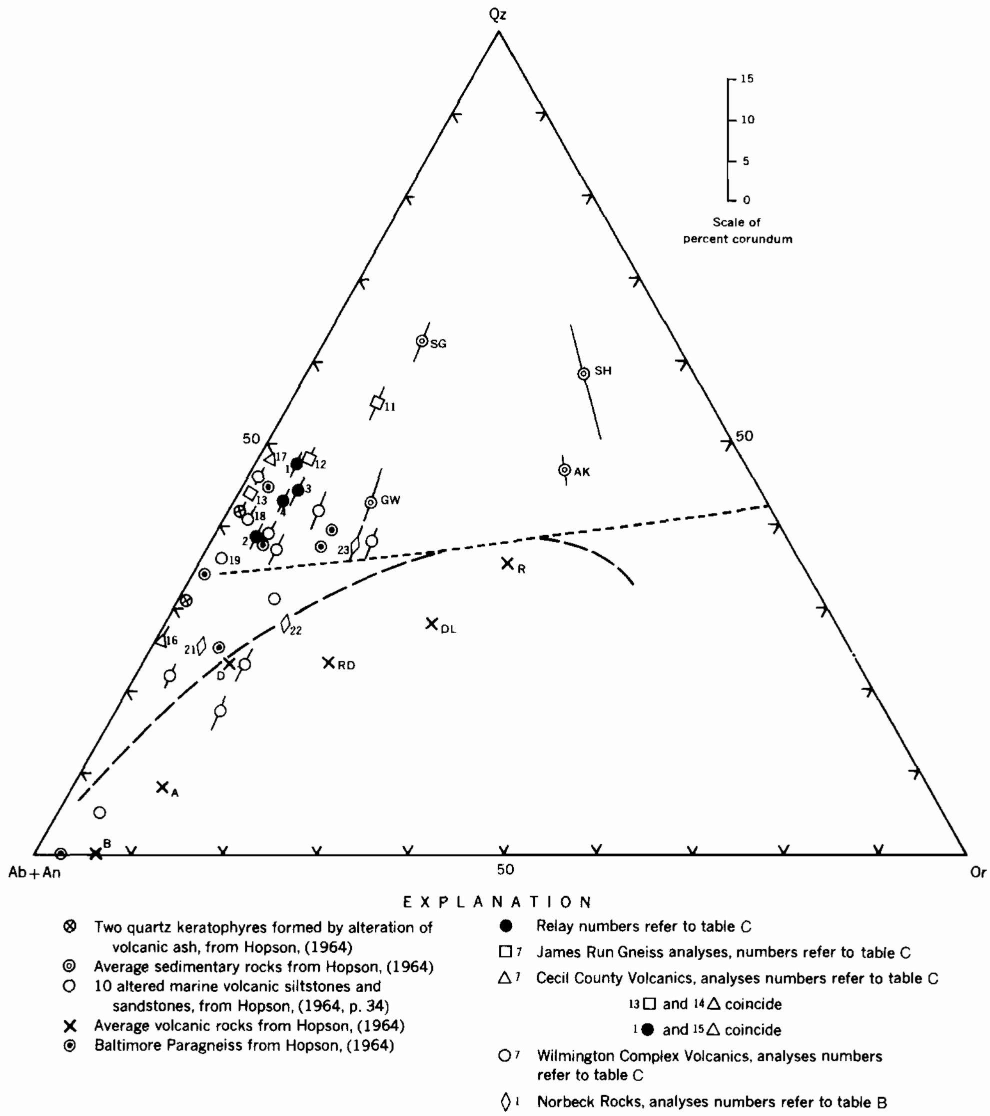


Figure 13. Normative quartz-orthoclase-albite + anorthite plot comparing the Relay rock, James Run Gneiss of Southwick and Fisher (1967), Cecil County metavolcanic rocks of the James Run Formation, and metavolcanic rocks of the Wilmington Complex of Ward (1959) with rocks from Hopson's (1964) "Baltimore paragneiss" and with altered marine volcanic rocks (Hopson, 1964). Lines through symbols indicate percent corundum. The average rocks are the same as those in Figure 8. Norbeck rocks are also plotted. For other details of the plot, see Figure 7.

intruded which. Reported dikes and veins of leucoquartz diorite in the gabbro are inconclusive evidence that the Relay intruded the gabbro because: (1) there is no evidence to physically connect them with the Relay; (2) they are identical with dikes and veins within the gabbro that formed from the gabbro (Hopson, 1964); and (3) identical dikes and veins are present in the gabbro far from any contact with the Relay (Hopson, 1964).

The structural position of the Relay argues against Hopson's (1964) tentative conclusion that it differentiated from Baltimore Gabbro. If Hopson's (1964) structural interpretations regarding his Baltimore Gabbro mass are correct, the Relay is at the bottom of the gabbro body. Siliceous and felsic (granophyric) differentiates of mafic bodies are generally found near the middle or top of the bodies.

A cross section of the Relay is well exposed along the Patapsco River. There, in contrast to most descriptions in the literature, the exposed rocks comprise a heterogeneous assemblage, and the contact with the gabbro is nearly impossible to pick. In the southeasternmost exposures of the Patapsco River valley, along the tracks of the B & O Railroad and along U.S. Highway 1, the rock looks like a fine-grained felsite with abundant blebs and grains of quartz; in appearance, it is strikingly similar to some of the metamorphosed tuffaceous sediments of the James Run Formation. Upstream to the west along the river, more mafic rocks appear and increase in percentage to the west; these might be called "quartz diorite." West of Rockburn Branch, gabbro is intercalated with the "quartz diorite," and it increases in percentage to the west until the more felsic and siliceous rocks are completely absent. Coarse-grained rocks containing abundant quartz grains are also part of the assemblage within the "quartz diorite" part of the Relay complex.

In general, the Relay rocks are quite similar to volcanic, volcaniclastic, and volcanic-epiclastic rocks of the James Run Formation exposed along the Susquehanna River south of Port Deposit in Cecil County, Maryland.

Petrography. For convenience, the Relay rocks can be roughly divided into two main types: (1) those that look like quartz diorite in the field; and (2) those that look like felsites rich in quartz grains and granules. The latter correspond in part to what Hopson (1964) called "albite granite."

Relay Quartz Diorite corresponds to quartz diorite only on the classification diagrams. Modally it has quartz about equal to feldspar, and quartz and plagioclase together compose about 95 percent of the rock. This is also true of what Hopson called Relay Albite Granite (Hopson, 1964). Mineralogically the Relay Quartz Diorite differs from differentiates of mafic bodies. It has more quartz than granophyric differentiates, and the quartz is commonly in distinct lumps and grains, unlike the fine-grained granophyric quartz of gabbro differentiates (Wager and Brown, 1967; Walker and Poldervaart, 1949; Hotz, 1953; Best, 1963).

Metamorphic textures prevail in the Relay rocks, but the "large crystals of zoned and complexly twinned plagioclase" (Hopson, 1964) are volcanic relicts exactly like those in James Run volcanic and volcaniclastic rocks, and some of the quartz blebs seen in outcrop are clearly polygranular, relict quartz granules (Fig. 11D); other quartz blebs may be relict quartz phenocrysts or vesicle fillings.

Chemistry and Petrology. Hopson (1964, p. 159) listed the following characteristics of the Relay Quartz Diorite:

(1) It is very leucocratic; the color index is less than 5, whereas color indexes of the other quartz diorites range from about 10 to 50. (2) It is very siliceous; it contains about 78 percent SiO_2, more than even the granodiorites and quartz monzonites have. (3) It has exceptionally low K_2O and high Na_2O. (4) It grades into albite granite; the other quartz diorites show a close relation to granodiorite and quartz monzonite. (5) It is closely associated with the Baltimore Gabbro.

The high silica is of special interest. Many differentiated mafic intrusions—large complexes, dikes, and sills—have been investigated in detail (Wager and Brown, 1967, and references therein; Wilshire, 1967, and references therein). Many of these have what are considered extreme differentiates (*for examples, see* Wager and Brown, 1967; Best, 1963). However, none of these differentiates is as siliceous as the Relay (Table C)[4], and although many of the mafic bodies are much larger than the Baltimore Gabbro complex, none has

[4] Table C, consisting of 4 new chemical analyses and normative compositions, and 15 previously published chemical analyses and normative compositions of the Relay rock and other rocks of the James Run Formation is available by ordering NAPS Document 01720. See footnote 2.

granophyric differentiates that approach the Relay in volume. Differentiates that approach the Relay's silica content are generally thin dikes or sills or small granophyric bodies (Wager and Brown, 1967; Walker and Poldervaart, 1949), whereas those that approach or match the Relay's size are generally much lower in silica. Moreover, the siliceous differentiates of mafic bodies plot in the feldspar field on q-or-ab diagrams (Fig. 14). Wager and Brown (1967) and Hamilton (1963) have cast doubt on the legitimacy of some "differentiated" granophyres by showing that some of the Skaergaard granophyres may owe their high silica contents to incorporations of siliceous country rock.

At first consideration, it would seem that Hopson's (1964) theory that the Relay was silicified and albitized by its own residual fluids might account for some of the discrepancies, but this interpretation would still require that the silica differentiated from the gabbro. There is also the possibility that the Relay was silicified from an outside source and that it originally differentiated from the gabbro with a silica content comparable to large differentiates of gabbro bodies elsewhere (although this would involve a selective silicification of the Relay without affecting the rocks around it). If this were the case, the Relay should have high iron as the other differentiates have (Fig. 15), but the Relay is very low in iron.

Chemically, the Relay rocks are identical to James Run Formation volcanic and volcaniclastic sedimentary rocks, and to the volcanic sedimentary rocks which Hopson (1964) called Baltimore paragneiss (Fig. 13).

Origin and Reassignment. Field appearance, field relations, modal and chemical compositions, and petrographic evidence indicate that the Relay is an assemblage of metavolcanic, metavolcaniclastic, and metavolcanic-epiclastic rocks. These rocks are intruded by Baltimore Gabbro. The position of these rocks directly on strike with Hopson's volcanic Baltimore paragneiss and James Run rocks in Harford and Cecil Counties suggests correlation with the James Run Formation. Other evidence pre-

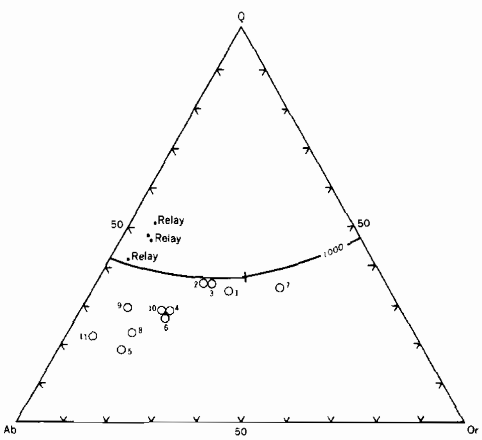


Figure 14. Quartz-orthoclase-albite plot comparing the Relay rock with "extreme" silicic differentiates of mafic bodies. Sources of data: 1, Best (1963, Table 5, no. 95); 2, Wager and Brown (1967, Table 9, no. 5259); 3, Wager and Brown (1967, Table 9, no. 3058); 4, Wager and Brown (1967, Table 9, no. 4489); 5, Wager and Brown (1967, Table 9, no. 4330); 6, Wager and Brown (1967, Table 9, no. 4332); 7, Walker and Poldervaart (1949, Table 15, no. 87); 8, Hriskevich (1968, Table 3, no. 7); 9, Hess (1960, Table 38, no. 1); 10, Hotz (1953, Table 4, no. 560); 11, Hotz (1953, Table 4, no. 601).

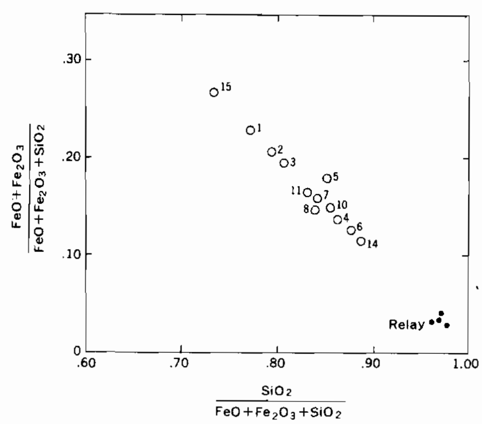


Figure 15. Plot comparing iron-silica ratios of 16 differentiates (mostly large) of mafic bodies with the Relay rock. The 16 rocks have silica contents from 52.2 to 66.04 percent and show a fairly even spread. Points 4 and 9, 7 and 12, 10 and 13, and 14 and 16 coincide. Data from: 1, Wager and Brown (1967, Table 9, no. 5264); 2, Wager and Brown (1967, Table 9, no. 3047); 3, Wager and Brown (1967, Table 9, no. 4332); 4, Wager and Brown (1967, Table 9, no. 4489); 5, Thayer (1963, no. 2); 6, Best (1963, Table 5, no. 86); 7, Best (1963, Table 5, no. 113); 8, McDougall (1962, Table 9, no. M336P); 9, McDougall (1962, Table 9, no. 384); 10, McDougall (1962, Table 9, no. M32); 11, Hriskevich (1968, Table 3, no. 7); 12, McDougall (1962, Table 9, no. M206); 13, Turner and Verhoogen (1960, Table 31, no. 5, Bushveld); 14, Hotz (1953, Table 6, no. 560); 15, Hess (1960, Table 38, no. 1); 16, Schwartz and Sandberg (1940, p. 1144).

sented in a later section further confirms this assignment. Therefore, I propose that the mass previously considered to be Relay Quartz Diorite (Hopson, 1964) be assigned to the James Run Formation. The name Relay mass can be used to distinguish these rocks from others when discussing regional aspects of the geology.

Baltimore Gabbro as Used by Hopson

Hopson's (1964) evidence for the "two comagmatic groups" of plutonic rocks in the Maryland Piedmont consisted of: (1) a quartz-plagioclase-potassium feldspar plot (p. 190, Fig. 46A) of the modal compositions of the gabbroic and granitic rocks, showing two separate "trends" based on his interpretations of "progressively younger rocks in each series"; (2) a plot of K_2O against total ferromagnesian constituents (p. 190, Fig. 46B), showing two separate "trends" based on his interpretations of the affiliations and age of the rocks; and (3) the close spatial relation between the Baltimore Gabbro and Relay Quartz Diorite. His addition of 50 m.y. to his interpretation of 500 m.y. as the minimum age of the Glenarm Series depended on the validity of separating the two comagmatic groups, and on his interpretation that the gabbro is older than all of the "granitic series" plutons.

The "trends" are probably not valid because: (1) the Baltimore Gabbro and the Relay are not directly related, (2) some of the "granitic series" rocks are supracrustal, and (3) Hopson's interpretations of the relative ages of the rocks are probably not correct. The Baltimore Gabbro is younger, not older, than some of the "granitic series" rocks. The relations of the gabbro to the Relay rocks have already been described; parts of the gabbro intrude parts of the Relay rocks. The only other "granitic pluton" with which the gabbro is supposed to be in contact is the Port Deposit. Nowhere in Cecil County is the Baltimore Gabbro in contact with Port Deposit Gneiss; the southeastern contact of the "Belair belt" of gabbro (Hopson 1964, Fig. 1) is a contact with Conowingo gneiss. The rocks that Southwick (Southwick and Owens, 1968) mapped in contact with the southeastern edge of the gabbro in Harford County are also metasedimentary and are considered correlative with Conowingo gneiss (Fig. 1). Although Southwick (1969) mentioned several localities where intrusive contacts were seen, he gave no evidence bearing on which rock intruded which, and at all the localities I have visited, the gabbro is in contact with metasedimentary rocks. In southwestern Cecil County, Aberdeen Metagabbro of Southwick and Owens (1968), which is probably correlative with Baltimore Gabbro (*also see* Southwick, 1969), intrudes rocks of the James Run Formation, and finer grained but chemically (Table B) and mineralogically identical gabbroic dikes intrude both the James Run Formation and Port Deposit Gneiss.

In Baltimore County, W. F. Crowley (1969, and also 1969, personal commun.) has found that many of the rocks formerly mapped as Baltimore Gabbro are actually supracrustal metavolcanic and metavolcaniclastic rocks. These amphibolites and layered gneisses belong to the James Run Formation (Fig. 1). The rocks formerly mapped as Port Deposit Gneiss in northeastern Baltimore County are chiefly metasedimentary pebble gneisses that occur in folds involving the James Run rocks.

Radiometric Ages

Zircon ages of the various so-called "granitic" rocks and the James Run Formation—including the James Run Gneiss of Southwick and Fisher (1967) and the Baltimore paragneiss of Hopson (1964)—fall into two groups (Table 1): (1) concordia ages about 500 to 600 m.y. (Pb_{207}/Pb_{206} ages about 470 to 550 m.y.), and (2) concordia ages 425 to 500 m.y. or younger (Pb_{207}/Pb_{206} ages about 410 to 450 m.y.). Wetherill and others (1966, p. 2145) interpreted the separation between the "plutonic" rocks as indicating an age separation of 100 to 150 m.y. between "early and late kinematic" intrusions. However, all the older ages from the so-called "plutonic" rocks are from rocks for which there is evidence of supracrustal origin, or evidence suggesting that they are shallow intrusive bodies contemporaneous with parts of the James Run Formation, and that they probably supplied volcanic material to the James Run rocks. The close agreement of the James Run Formation ages with those of the "plutonic" rocks of this older group supports these conclusions. If the ages of the Kensington, Norbeck, Relay, Port Deposit, and James Run rocks were obtained from volcanic and/or detrital volcanic zircons, they define a technical *maximum, not minimum* age of the Glenarm Series. Actually, they probably represent approximately "real" ages for parts of the Glenarm.

The magmatic younger granites, the Guilford and Woodstock Quartz Monozonites and the Ellicott City Granodiorite (Hopson, 1964), define the minimum age of the Glenarm Series at about 425 m.y. (Table 1). This is a technical minimum age; the actual minimum age must be older because rubidium-strontium dating of minerals from five pegmatite dikes that cut Glenarm rocks also gives ages of about 425 m.y. (Table 1; Wetherill and others, 1966). Thus the Glenarm Series must have been undergoing metamorphism and igneous intrusion about 425 m.y. ago.

Hopson (1964) and Wetherill and others (1966) interpreted the dated pegmatite dikes as essentially undeformed and unrecrystallized. Chiefly on this basis, they concluded that the major Piedmont plutonism, deformation, and metamorphism occurred prior to about 425 m.y. ago.

Regional Relations

Quantico and Arvonia Synclines. In the Quantico syncline[5] in northern Virginia (Fig. 1), Quantico Slate, which occupies the axial area of the fold, grades down into metavolcanic, metavolcaniclastic, and metavolcanic-epiclastic rocks, which in turn grade, through interlayering and decrease in volcanic material, into pebbly metasedimentary gneisses of the Wissahickon Formation. The synclinal nature of the fold is well documented by numerous graded beds of metasiltstone in the Quantico Slate. The metavolcanic, metavolcaniclastic, and metavolcanic-epiclastic rocks are identical to rocks of the James Run Formation: they are metatuffs, metamorphosed tuffaceous sedimentary rocks, metamorphosed basalt flows, tuffs, and breccias, and slump breccias consisting partially of volcanic material. Zircon ages from the Chopowamsic are the same as those from the James Run (Higgins and others, 1971). The pebbly gneisses are identical to parts of the Sykesville and Laurel gneisses of the diamictite facies of the Wissahickon Formation (Higgins and Fisher, 1971). Some of these pebbly gneisses contain fragments of the volcanic rocks, suggesting that some of the volcanic rocks are older than these correlatives of the Sykesville (J. C. Reed, Jr., 1969, written commun.). Recent mapping by members of the U.S. Geological Survey indicates that the sequence is completely conformable and without major faults. R. B. Mixon and J. C. Reed, Jr., have traced the metavolcanic rocks and the slate to within 7 mi of the Rappahannock River. I have traced both units to the Rappahannock, where the slate is a graphitic schist. The metavolcanic rocks trace southward directly into the metavolcanic sequence beneath Arvonia Slate in Arvonia syncline, although not exactly as shown on the geologic map of Virginia (Milici and others, 1963). Zircon ages from these metavolcanic rocks are the same as those from the Chopawamsic and James Run rocks (Higgins and others, 1971). My reconnaissance also suggests that the graphitic schist of Quantico Slate at the Rappahannock River is continuous into the schist of Arvonia Slate in Columbia syncline. Late Middle to Late Ordovician fossils are present in the Arvonia Slate (*see* Tillman, 1970, and references therein), and Ordovician fossils have been reported from the Quantico Slate as well (Watson and Powell, 1911). The Arvonia and Quantico Slates are correlative, and probably the same unit. The metavolcanic, metavolcaniclastic, and metavolcanic-epiclastic rocks beneath the Arvonia Slate may extend into the Carolina slate belt metavolcanic, metavolcaniclastic, and metavolcanic-epiclastic rocks in North Carolina (J. F. Conley, 1969, oral commun.).

The metavolcanic, metavolcaniclastic, and metavolcanic-epiclastic rocks beneath the Quantico and Arvonia Slates are considered correlative with the James Run Formation along strike in Maryland. The Quantico is considered part of the Glenarm Series; it has the youngest rocks of the series and defines the Glenarm's minimum age as Late Ordovician.

Lynchburg Formation

Hopson (1964, p. 206–207) believed the Wissahickon Formation to be correlative with the Lynchburg Formation of Virginia, and he used this as supporting evidence for a late Precambrian age of the Glenarm Series. He based this correlation on lithologic similarities and used it to counter the argument that a late Precambrian age for the Glenarm is improbable because thick sedimentary strata are lacking beneath the known Lower Cambrian rocks in

[5] Many of my observations in the Quantico syncline area were made during guided trips by V. M. Seiders (Occoquan 7½′ quad., Virginia), and J. C. Reed, Jr. (Quantico, Joplin, and Stafford 7½′ quads., Virginia); the descriptions given here are my own, except where otherwise noted.

TABLE 1. RADIOMETRIC AGES FROM MARYLAND PIEDMONT ROCKS

Sample location (*N.G. = not given*)	Rock	Age in millions of years *Stratigraphic ages from Geol. Soc. London time scale (Harland and others, eds., 1964), and U.S. Geol. Survey time scale.* *L = Late M = Middle E = Early* *P = Pennsylvanian M = Mississippian D = Devonian S = Silurian O = Ordovician € = Cambrian P€ = Precambrian*							Interpreted age from Concordia Plot. See refs. B and I. **denotes interpretation without Concordia Plot; see ref. B.*	Chemical and modal analyses numbers	Reference	Best interpreted age from all data (*YT = younger than; OT = older than; ca. = about*)
		Mineral dated	Sr^{87}/Rb^{87}	A^{40}/K^{40}	Pb^{206}/U^{238}	Pb^{207}/U^{235}	Pb^{207}/Pb^{206}	Pb^{208}/Th^{232}				
N.G.	Relay quartz diorite	zircon			435 LO-ES	440 LO	470±50 MO-MS		550 ± 50 LP€-EO	1	A	YT 600 OT 500
1	Norbeck quartz diorite	zircon			497 EO	511 E€	565±20 LP€-E€	486 EO	500-600 LP€-EO	2,3	B	YT 600 OT 500
		hornblende		315±15 P						2,3	C	
2	Kensington quartz diorite	zircon (A)			366 MD	394 ED	540±20 E€-M€		500-600 LP€-EO	4	B	YT 600 OT 500
		biotite (A)	305 EP-MP	385 ED						4	B,D	
		zircon (B)			404 MS-LS	422 ES-LS	510±20 M€-EO	350 LD	500-600 LP€-EO	4	B	YT 600 OT 500
		biotite (B)		350 LD						4	B	
3	Ellicott City granodiorite	zircon			357 LD	370 MD	450±20 EO-ES	308 P	450-500 EO-MO	5,6	B	ca. 450
		biotite	290 M-LP	315 P						5,6	B,E	
		hornblende		300 M-LP						5,6	B	
4		2 pegmatites 3 feldspars 1 muscovite	346 LD								B	ca. 425
5	Woodstock quartz monzonite	zircon			331 M	342 M	410±20 ES-ED	315 M-P	450-500 EO-MO	7	B	ca. 450
		biotite	310 P	295 M-LP						7	B,E	
		whole rock	420±50						425* ES	7	B	ca. 450
N.G.	Gunpowder granite	zircon (A)			485 EO		690±60		550±50* LP€-EO		F	
		zircon (B)			320 M-P	355 LD	500±15 L€-EO		550±50* LP€-EO		F,A	
		zircon (A)			485 EO	510 L€	615±60 LP€-E€		550±50* LP€-EO		A	
		K-feldspar							440*		B	
6	Gunpowder gneiss	micro-cline	580±130 LP€-EO						550±50 LP€-EO		G	
7	Guilford quartz monzonite	biotite	295 MLP							8	E	
		muscovite	335 M							8	E	
		whole rock	420±50 EO-MO						425* ES	8	B	ca. 425
		pegmatite 2 feldspars	347 LD								B	ca. 425
		pegmatite muscovite	355 LD								E	ca. 425
8		pegmatite microcline	370 MD								E	ca. 425
9	Port Deposit quartz diorite	zircon					475±20 EO-MO		550±50* LP€-EO		F	YT 600 OT 500
		zircon			325 M-P	350 LD	525±20 E€-L€		550±50 LP€-EO		A	YT 600 OT 500
9	Port Deposit "granodiorite"	biotite		330±5 M							H	

TABLE 1 (continued)

Sample location (*N.G. = not given*)	Rock	Age in millions of years *Stratigraphic ages from Geol. Soc. London time scale (Harland and others, eds., 1964), and U.S. Geol. Survey time scale.* *L = Late M = Middle E = Early* *P = Pennsylvanian M = Mississippian D = Devonian S = Silurian O = Ordovician € = Cambrian P€ = Precambrian*							Interpreted age from Concordia Plot. See refs. B and I. **denotes interpretation without Concordia Plot; see ref. B.*	Chemical and modal analyses numbers	Reference	Best interpreted age from all data (*YT = younger than; OT = older than; ca. = about*)
		Mineral dated	Sr^{87}/Rb^{87}	A^{40}/K^{40}	Pb^{206}/U^{238}	Pb^{207}/U^{235}	Pb^{207}/Pb^{206}	Pb^{208}/Th^{232}				
10	*James Run* gneiss (metavolcaniclastic rock)	zircon			420 MS	435 ES	490 EO		550 E€		I	YT 600 OT 500
		zircon			325 M	355 LD	550 E€	420 E-MS	550 E€		I	
11	Setters quartzite	zircon			620 LP€	700 LP€	915 P€	615 LP€	1140 P€		I	YT 1300 OT 1000
12	Pegmatite in serpentite	muscovite		330±5 M							H	
13	Wissahickon metagraywacke	muscovite and biotite		355±5 LD							H	
14	"Baltimore paragneiss" (metavolcaniclastic rock)	zircon			575 LP€	570 E€	540 E-M€	530 M€	550 E€		I	YT 600 OT 500
		zircon			765 P€	735 P€	650 LP€		550 E€		I	YT 600 OT 500
		zircon			740 P€						I	
		hornblende		301 M-LP							B	
		hornblende		292 M-LP							B	
15	Baltimore Gneiss Towson dome	zircon			1040 P€	1070 P€	1120 P€	940 P€	1000-1100 P€		J	YT 1300 OT 1000
		biotite	300-305 E-MP	340 M					300* E-MP		B,J	
		feldspar		307 P							B	
16	Baltimore Gneiss Phoenix dome	zircon			960 P€	1020 P€	1120 P€	1100 P€	1000-1100 P€		J	YT 1300 OT 1000
		biotite	310-330 M-P	355 LD					330* LM-EP		B,J	
		micro-cline	1190 P€						1000-1100* P€		J	YT 1300 OT 1000
		micro-cline	1130 P€						1000-1100* P€		J	YT 1300 OT 1000
17	Baltimore Gneiss Woodstock dome	zircon			960 P€	1050 P€	1250 P€		1300* P€		I,J	YT 1300 OT 1000
18		biotite	300-305 E-MP	430 ES					330* LM-EP		B	
19		hornblende		367 MD							B	
19		diopside		328 M-P							B	
19		plagioclase		309 P							B	
see ref. K	Baltimore Gneiss (Hartley augen gneiss)	whole rock (5 samples)	1050±100 P€						1050* P€		K	YT 1300 OT 1000
		biotite and plagioclase	287 M-LP						290-300* M-LP		K	
		biotite and plagioclase	294 M-LP						290-300* M-LP		K	
20	Baltimore Gabbro	pyroxene		702† P€					†		B	†
		plagioclase		580† LP€					†		B	†
21		hornblende		372† MD					†		B	†

TABLE 1 (continued)

† *Ages are very probably too old. See statement p. 2148, reference B, and Hart and Dodd (1962).*

Sample locations:

(1) *Greenwood Knolls in Wheaton, Kensington quadrangle.*
(2) *Broad Branch Road, Washington, D.C.*
(3) *Quarry along River Road, 0.3 mi southeast of bridge at Ellicott City, Ellicott City quadrangle.*
(4) *Thistle, Ellicott City quadrangle.*
(5) *Sylvan Dell Quarry at Granite, Ellicott City quadrangle.*
(6) *Gunpowder Falls near Harford Road, Towson quadrangle.*
(7) *Middle Patuxent River, 1.5 mi southeast of Guilford, Savage quadrangle.*
(8) *Quarry along U.S. 29 at Atholton, Savage quadrangle.*
(9) *Port Deposit Quarry, east bank Susquehanna River, Aberdeen quadrangle.*
(10) *Gatch Quarry near Churchville, Edgewood quadrangle.*
(11) *Channel change along U.S. 111 (I83) 0.5 mi southwest of Verona.*
(12) *Conowingo Dam quadrangle; see ref. H.*
(13) *Conowingo Dam quadrangle; see ref. H.*
(14) *Cambell Corp. quarry, Gwynns Falls at W. Baltimore St., Baltimore.*
(15) *Roadcut on Charles Street Ave., Towson, between Malvern and Chesapeake Ave.*
(16) *Channel change on Piney Creek next to U.S. 111 (I83), 0.5 mi southwest of Verona.*
(17) *High rock bluff above Baltimore and Ohio Railroad tracks 200 yd west of Woodstock, 39°19.5'N., 76°52.5'W.*
(18) *Baltimore and Ohio Railroad cut 1/4 mi west of Woodstock.*
(19) *Same as (17).*
(20) *Maryland Rt. 102, 1.5 mi southeast of Ellicott City.*
(21) *Stream next to Thistle Road 200 m from Patapsco River northwest of Thistle.*

References:

(A) *Davis and others, 1965.*
(B) *Wetherill and others, 1966.*
(C) *Hart, 1961.*
(D) *Davis and others, 1958.*
(E) *Tilton and others, 1959.*
(F) *Steiger and Hopson, 1965.*
(G) *Tilton, 1960 from Hopson, 1964, p. 197.*
(H) *Lapham and Bassett, 1964.*
(I) *Tilton and others, 1970.*
(J) *Tilton and others, 1958.*
(K) *Wetherill and others, 1968.*

Pennsylvania and Maryland. He stated (1964, p. 207):

> A Precambrian age for the Glenarm Series cannot be excluded, therefore, on the grounds that known Precambrian strata are lacking. Upper Precambrian metasediments of comparable thickness and lithology occur in the Virginia Piedmont, approximately along strike, and for a long way to the south. . . . A more difficult problem arises if the Glenarm Series is Paleozoic: what then becomes of the section of Precambrian Lynchburg metasediments, 10,000–20,000 feet thick in Virginia, that strike directly into the Maryland Piedmont?

The relations stated by Hopson are not quite correct, however. The Lynchburg Formation occurs in the Blue Ridge–Catoctin Mountain anticlinorium (Reed, 1955; Bloomer and Werner, 1955; Brown, 1954, 1958). Its only known occurrence in the Piedmont is in the dome-like Sherwill anticline in south-central Virginia, more than 130 mi from Maryland (Brown, 1954), and the Blue Ridge–Catoctin Mountain belts of Lynchburg do not "strike directly into the Maryland Piedmont." To join the Wissahickon, the Lynchburg would have to branch and cut directly across strike (Fig. 1) and across the Catoctin Formation. The southward extension of the Wissahickon to the Rappahannock River, and the thin belt of rocks known as the Everona Formation of Early Cambrian(?) age of Mack (1957) and Milici and others (1963; *also see* Jonas, 1927), make physical connection of the Lynchburg with the Wissahickon impossible. Moreover, as Hopson stated (1964), a Precambrian age for the Glenarm necessitates a fault of relatively large displacement along the Martic line, but the Lynchburg outcrop belts in northern Virginia are west of this line, whereas the Wissahickon is east (Brown, 1954).

Recent radiometric age data also make correlation of a "late Precambrian" Wissahickon with a "late Precambrian" Lynchburg unlikely. Zircons from felsic volcanic rocks correlative with the Catoctin Formation which overlies the Lynchburg have concordia ages of approximately 820 m.y. (Rankin and others, 1969). Therefore, the Lynchburg is older than 820 m.y.

Peach Bottom Fold

Despite many detailed studies and much controversy, no one has presented any conclusive evidence that the Peach Bottom fold is a syncline. It was assumed to be a syncline because the Peach Bottom Slate was assumed to be less metamorphosed and younger than the Glenarm rocks, and because the slate was assumed correlative with the Quantico and Arvonia Slates. There is no real evidence that the fold is synclinal. As Southwick (1969) recognized, there is no difference in metamorphic grade between the Peach Bottom Slate, the Cardiff Metaconglomerate, and the Wissahickon rocks surrounding the Cardiff (the Wissahickon rocks were formerly called Peters Creek Quartzite). Nor is there any evidence that the Peach Bottom Slate is correlative with the Quantico and Arvonia Slates. Their only similarities are in color and in occurrence in narrow belts. The Peach Bottom and Quantico Slates are not even lithologically similar: the Peach Bottom is a fine-grained slate or locally a phyllite; the Quantico consists chiefly of rhythmically interbedded slate and coarser graded siltstone.

Structural evidence is equally inconclusive for determining the nature of the fold. Agron (1950, Pl. 6) shows bedding in the Cardiff defining a syncline at the southwest nose of the fold. Southwick's (1969, Pl. 3) map of the southwestern part of the fold shows axial-plane schistosity, but his explanation states that the symbols represent schistosity parallel to bedding "except where separate bedding symbols are shown"; no separate bedding symbols are shown. Bedding parallel to the axial plane would be inconsistent with the gross contacts of the formations, which clearly define a fold nose. Recognizable bedding is very rare in the Cardiff around the noses of the fold and cannot be used to show either synclinal or anticlinal structure. Bedding is rarely recognizable in the Peach Bottom Slate, and the contacts between the formations near and at the noses are not exposed. Southwick's (1969, Pl. 3) map is accurate for the schistosity, but this schistosity is not parallel to bedding in the area of the fold nose.

The relations between schistosity, cleavage, and bedding do not resolve the nature of the fold either. Behre (1933, p. 365) stated that cleavage bedding relations show that the south limb of the fold is the south limb of a northward-overturned syncline. However, Behre's (1933, Fig. 85) map of the Susquehanna River area, where bedding is recognizable in the Cardiff and in the Wissahickon grits and quartzites ("Peters Creek"), shows clearly that bedding dips to the south less steeply than does cleavage or schistosity. This suggests that the south limb is the upright limb of an anticline. The evidence is inconclusive for either case, however, because, as Freedman and others (1964) recognized, there are four or more sets of planar features (S-planes) in these rocks.

Lineations throughout the fold and in the areas around both noses generally trend and plunge northeast, roughly parallel to the axial trace of the fold (Agron, 1950, Pl. 7; Southwick, 1969, Pl. 3, and Southwick and Owens, 1968; these show only the southwestern end of the fold). Long axes of stretched quartz pebbles in the Cardiff trend and plunge fairly uniformly to the northeast.

Minor fold axes in and around the Peach bottom fold also trend and plunge chiefly to to the northeast. Southwick (1969, Pl. 3) shows what he interpreted as "early fold axes" in the Cardiff and just southwest of the Cardiff in the Wissahickon rocks around the southwest nose of the fold; these fold axes are shown trending northeast at an angle to the axis of the Peach Bottom fold and plunging to the northeast at 18° to 55°. If these are early folds, they might be taken as evidence that the Peach Bottom fold is a syncline. However, (1) all these folds are located where Southwick's map shows "axial-plane bedding" (*see* above); and (2) identical folds with the same general trend and plunge occur at the northeastern nose of the fold. As Freedman and others (1964) noted, there are at least three generations of folds in these rocks. Their data and mine indicate that the fold axes mapped by Southwick are related to a different phase of deformation than that which folded the bedding in the Peach Bottom fold. In the area of the Peach Bottom fold along and near the Susquehanna River, particularly just north of the Peach Bottom Slate, I have found the early folds to be refolded, with almost vertical axes.

The evidence suggests that the Peach Bottom fold is anticlinal (Higgins, 1971b). In the grits and metagraywackes southeast of the Peach Bottom Slate, graded beds show tops predominantly to the southeast except for local minor reversals (*also see* Southwick, 1969, Pl. 3; Southwick and Owens, 1968; Freedman and others, 1964). Rare cross-beds in the quartzites of this same sequence corroborate the graded bedding evidence. Graded beds are not abundant in the area just northwest of the Peach Bottom Slate, but where I have seen them, they commonly show tops to the northwest. The few graded beds shown on Southwick's (1969, Pl. 3; Southwick and Owens, 1968) maps northwest of the slate are also more consistent with an anticlinal interpretation of the Peach Bottom fold. To interpret the fold as a syncline, one has to postulate an anticline of approximately the same wavelength as the Peach Bottom fold immediately southeast of the Peach Bottom "syncline" (Fig. 2). Having postulated such an anticline, one must also account for the absence of the slate and conglomerate across strike to the south. Southwick and Fisher (1967, p. 8) cited Freedman and others (1964) to support their contention that such a flanking anticline does exist. However, to quote Freedman and others (1964, p. 629): "For most of the distance from Peach Bottom to Bald Friar . . . graded bedding indicates stratigraphic tops to the south. Several local reversals of tops to the north occur for widths of a few hundred feet across strike. For example, the first tunnel south of Peach Bottom shows tops to the north. . . ." The first tunnel south of Peach Bottom is nearly 2 mi from the Peach Bottom Slate, and evidence of north-facing beds there cannot be used to support Southwick and Fisher's (1967, p. 6) postulated anticline immediately southeast of the slate. Moreover, northwest of this tunnel, near Peach Bottom (about a mile from the southeastern contact of the slate), the beds again show tops to the southeast, and a short distance southeast of the tunnel they also show tops to the southeast.

Drag folds, with wavelengths of a few inches, in bedding on both flanks of the Peach Bottom fold along the Susquehanna River indicate that the major fold is anticlinal, although these may not be directly related to the earliest phase of folding.

An anticlinal interpretation of the Peach Bottom fold is also most compatible with gross field relations. The Cardiff Metaconglomerate is merely the coarsest bed or group of beds of a sequence of coarse grits and fine-grained conglomerate beds belonging to the quartzite facies of the Wissahickon Formation (Higgins and Fisher, 1971). At the Pennsylvania-Maryland line, about 3 mi southeast across strike from the slate contact, the rocks are metagraywackes interbedded with fine-grained schists. To the northwest, toward Peach Bottom, the metagraywackes gradually give way to grits and the schist interbeds gradually became thinner and fewer. Quartzites (both orthoquartzites and protoquartzites) appear and increase toward Peach Bottom. About one-half mile south of Peach Bottom, the coarser beds of grit can properly be called fine-grained subgraywacke conglomerates. The conglomerate beds gradually become more quartzose to the northwest, and in the last hundred feet or so next to the Peach Bottom Slate, they contain granule to small-pebble-sized clasts. In addition, the percentage of quartzite beds increases to the northwest, and at Peters Creek, quartzite makes up more than half the sequence. The fining to the southeast, with the coarsest and sandiest beds being near the contact with Peach Bottom Slate, suggests that the coarsest (Cardiff Metaconglomerate) beds are the oldest. In fact, the Cardiff is probably a basal conglomerate of the Wissahickon quartzite facies.

As Southwick (1969) mentioned, the Cardiff contains numerous clasts of black slate identical with Peach Bottom Slate. This also suggests that the Peach Bottom is older than the Cardiff and the Wissahickon quartzite facies.

The contacts between the Wissahickon rocks (former Peters Creek Quartzite) and the Cardiff, and between the Cardiff and Peach Bottom Slate are conformable and gradational, just as Knopf and Jonas (1923) described them. Hopson's (1964) contention that the Peach Bottom fold is second order and that the Cardiff Metaconglomerate and Peach Bottom Slate were deposited unconformably upon a homoclinal, steeply westward-dipping sequence of folded Peters Creek and Wissahickon rocks does not fit with the gradational contacts, with the graded bedding evidence, or with the fact that all these rocks were metamorphosed together. Southwick and Fisher's (1967) modification of Hopson's picture of the fold is even more untenable. They (1967; *see* Fig. 2, C and D of this paper) show the Cardiff and Peach Bottom deposited unconformably over the steeply dipping contact between schist and metagraywacke of the Wissahickon Formation. It would be highly fortuitous for the contact to be everywhere directly under the syncline. Moreover, their postulation of a possible break between the Cardiff and Peach Bottom under those circumstances raises the question of why then should the Cardiff be present at all? Both interpretations violate the observed gradational contacts between all of the units.

The aeromagnetic map of the Harford County area (Bromery and others, 1964) lends support to the anticlinal interpretation of the Peach Bottom fold. The outcrop area of Peach Bottom Slate is marked by a magnetic low. Instead of terminating at the nose of the fold, where the slate outcrop terminates, this low makes a slight Z-shaped bend and continues to the southwest parallel with and only a short distance from the surface projection of the fold axis (Fig. 16). In this course, the anomaly coincides with an anticline mapped by Southwick in the Wissahickon rocks (Southwick and Owens, 1968). Southwick's map (Southwick and Owens, 1968) shows metagraywacke underlying the area of the anticlinal axis, but quartzites are locally present. These quartzites

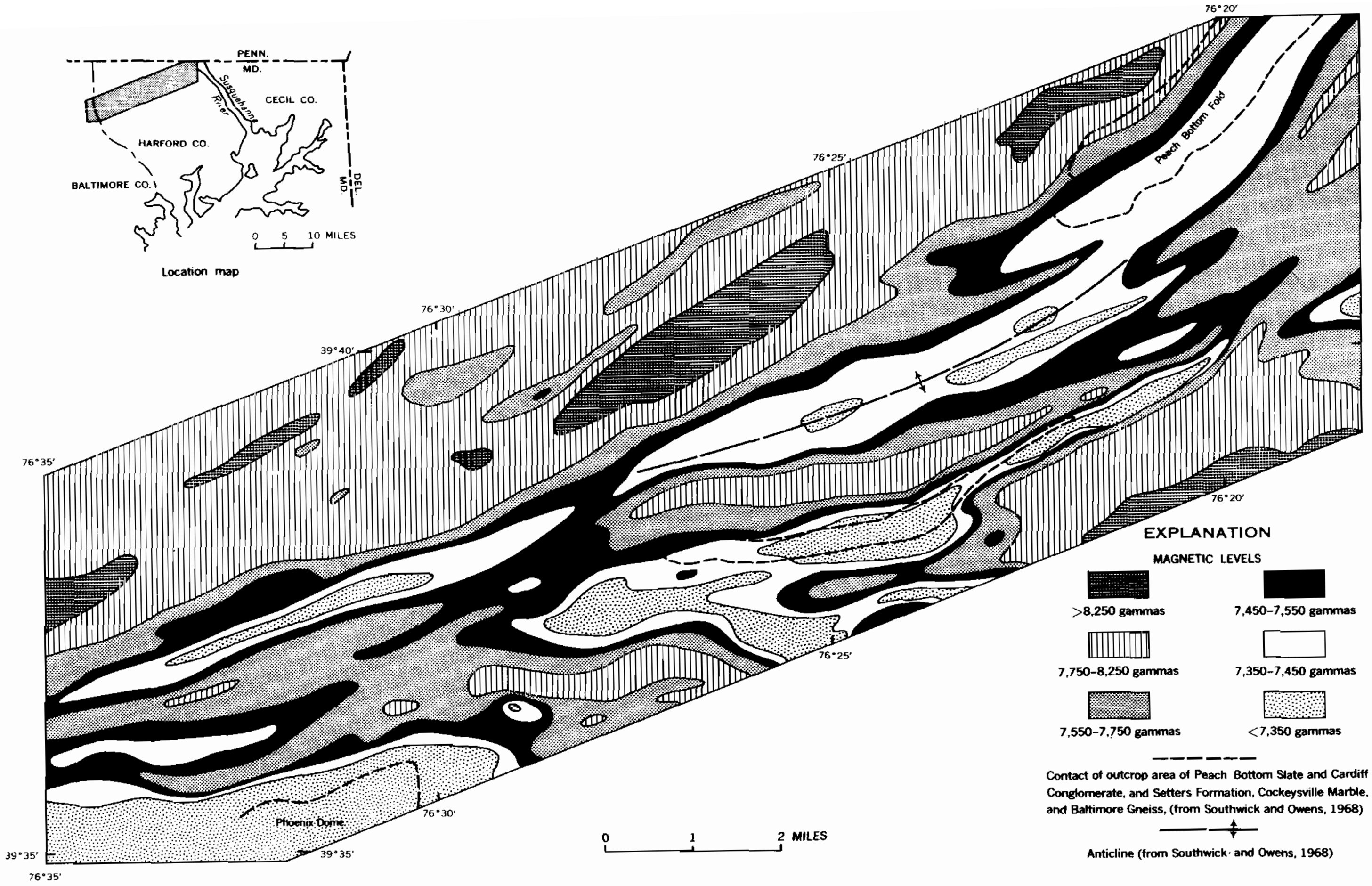


Figure 16. Aeromagnetic map of part of Harford County, Maryland (*from* Bromery and others, 1964). See text for explanation.

are quite similar to rocks of the quartzite facies of the Wissahickon (also mapped as metagraywacke by Southwick) on the flank of the Peach Bottom fold along the Susquehanna River. The magnetic anomaly is probably caused by the slate and conglomerate beneath the Wissahickon rocks.

It is interesting to note that this same anomaly continues to the southwest across Harford County, and finally blends into the lows around the Phoenix (Baltimore Gneiss) dome.

Martic Line

Northwest of the Martic line in southeastern Pennsylvania, the Cambrian and Ordovician sequence of the Hanover-York, Lancaster, and Chester Valleys occurs in five separated, roughly crescent-shaped features known as the Martic Hills (Fig. 17). In each of these features, the "axial" area of the crescent is occupied by the Antietam and Harpers Formations, and Vintage Dolomite crops out discontinuously around the flanks. Conestoga Limestone surrounds and separates the features. There is no metamorphic discontinuity at the Martic line; rocks north of the line are metamorphosed to the same degree as those south of the line. Nor is there any discontinuity in secondary structural features. Petrofabrics are essentially the same on both sides, and minor folds are identical on both sides for as much as 20 mi (Cloos and Hietanen, 1941; Wise, 1960). The same is true for cleavage and foliation. Normal and/or high-angle reverse faults of relatively small displacement can be demonstrated locally in the area, but there is no direct evidence of major thrusting, unless the Glenarm Series is assumed to be Precambrian.

The map of the Martic line and Martic Hills (Fig. 17) bears a striking resemblance to maps of areas where early folds have been refolded, and to theoretical and experimentally produced fold interference patterns (Ramsay, 1962, 1967). It is suggested here that the patterns shown in Figure 17 and the structural-stratigraphic relations are the result of superposition of two sets of folds. That there are at least two sets of folds is supported by minor structures in the immediate area and by minor and major structures elsewhere in this general region and along strike as far away as Carroll County, Maryland, 40 to 50 mi to the southwest. Small refolded folds are numerous in the Penn Central Railroad cut near New Providence, Pennsylvania (Fig. 18, A and B), and elaborate interference patterns and refolded folds are found in Conestoga Limestone south of Lancaster, Pennsylvania (Fig. 18, C and D). Multiple folding in the region has been noted by Agron (1950) and by Freedman and others (1964). McKinstry (1961) interpreted major structural features as refolded folds in Chester County, Pennsylvania, about 20 mi to the southeast. There are at least two generations of folds in Cecil County, Maryland, to the south. In Carroll County, Maryland, to the southwest, G. W. Fisher (unpub. data) has mapped large refolded folds and has shown excellent examples of minor refolded folds and interference patterns. Nappes and recumbent folds are well developed in the Great Valley of central Pennsylvania (Geyer and others, 1958; Sherwood, 1964; MacLachlan, 1967) and have been traced southward as far as the vicinity of Chickies anticline (Wise, 1958, 1970). Nappe structure and refolded folds are also present in the Reading Prong and Great Valley of eastern Pennsylvania and New Jersey (Drake, 1970).

This interpretation of the Martic area involves correlation of the Wissahickon rocks south of the Martic line with the Antietam and Harpers rocks in the Martic Hills. There is no lithologic difference between the two (*also see* Cloos and Hietanen, 1941). Rocks mapped as Antietam-Harpers north of the line, because there is Vintage or Conestoga in contact with them, would be mapped as Wissahickon south of the line, and vice versa. Moreover, Antietam graywacke quartzite can be traced directly into Wissahickon near Quarryville, Pennsylvania (Fig. 17), and the same belt of Antietam-Harpers very probably joins the Antietam-Harpers in the westernmost of the Martic Hills (Cloos and Hietanen, 1941). Cloos hesitated to make these connections on the map in an attempt to make it completely objective and without interpretation, but he stated their probability in the text (Cloos and Hietanen, 1941, p. 15) and pointed them out in the field (E. Cloos, 1968, personal commun.).

There is a gradual facies change across the general area of the Martic line, but it does not involve any abrupt change from carbonates to pelitic and psammitic rocks. The rocks of the Antietam and Harpers Formations in the Martic Hills and of the Wissahickon Formation immediately south of the Martic line are graywacke quartzites, schistose siltstones, and pelitic schists. Graywacke quartzite beds alternate

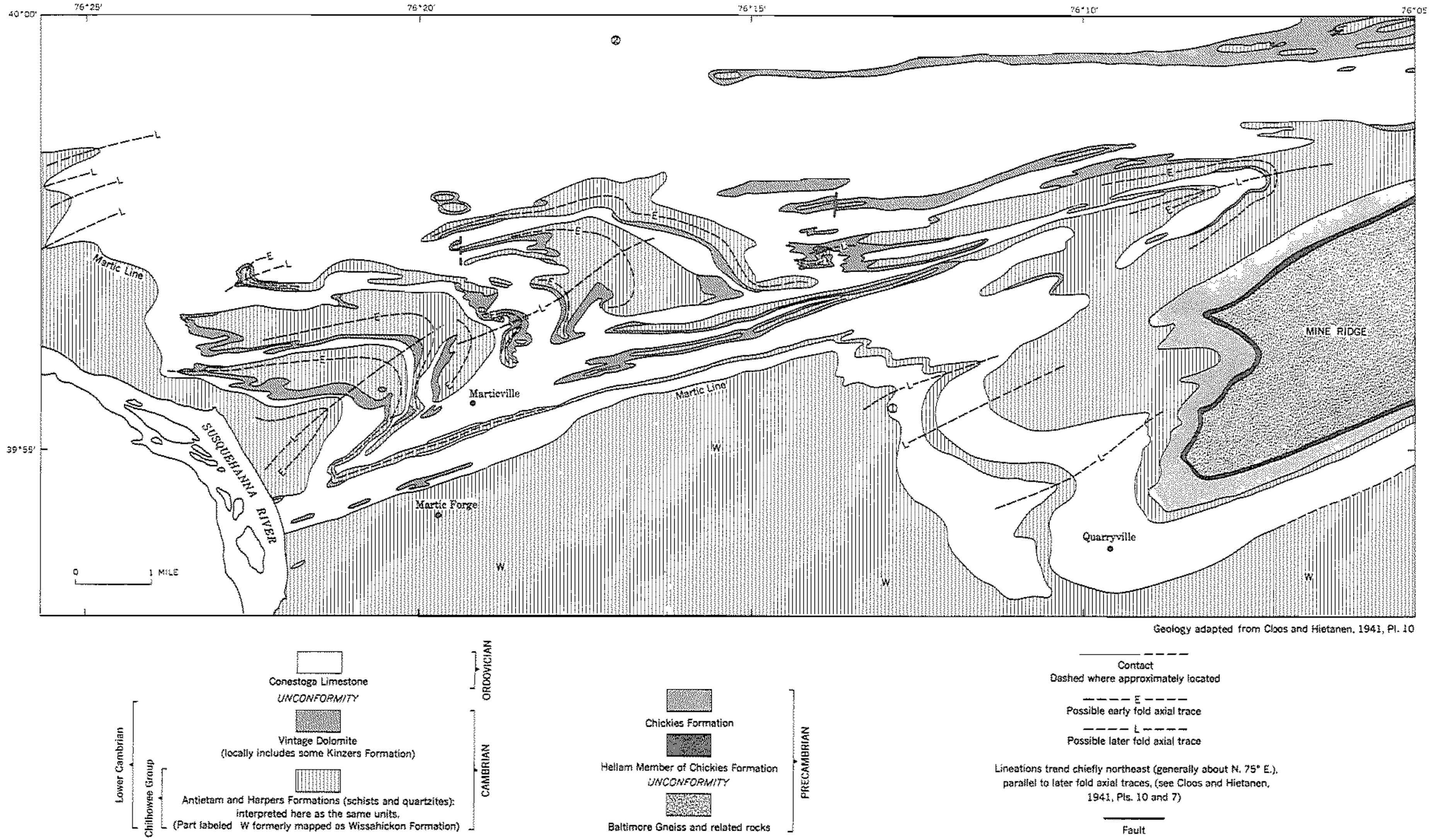


Figure 17. Geologic map of Martic line and Martic Hills area, Pennsylvania.

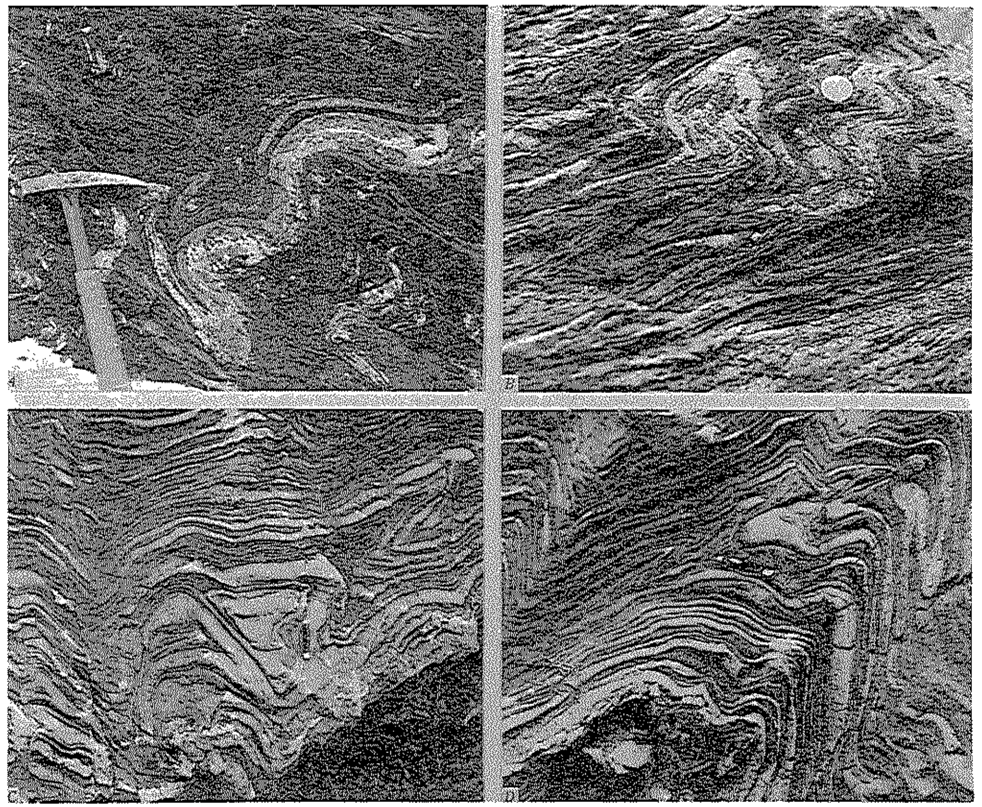


Figure 18. Folds in the Conestoga marble-siltstone. A and B, refolded folds along Penn Central Railroad cut near New Providence, Pennsylvania. C and D, interference patterns produced by superimposed folding in outcrop along U.S. Highway 222 one-quarter mile north of U.S. Highway 272, about 5 mi south of Lancaster, Pennsylvania. The pattern in D is similar to the map plan of the Martic Hills (Fig. 17).

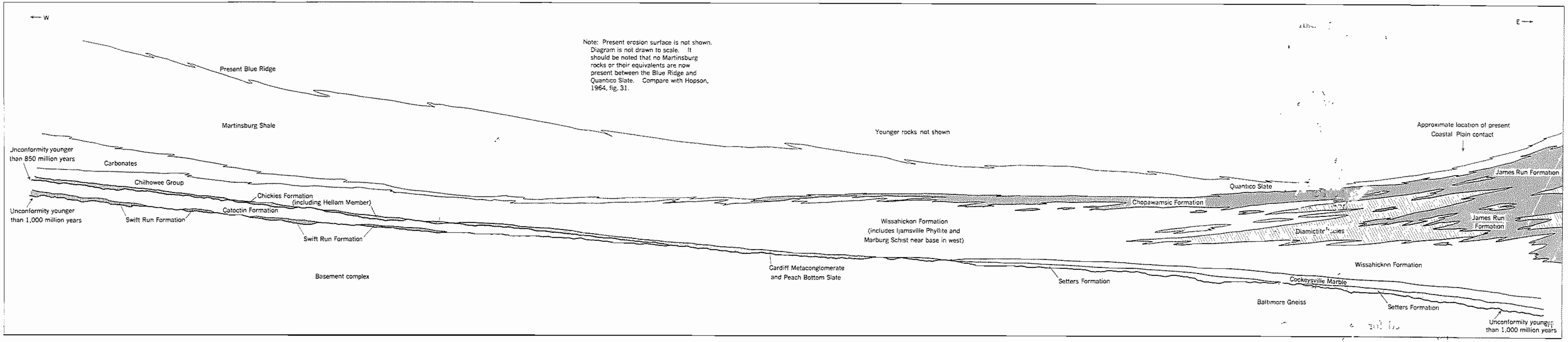


FIGURE 19. SCHEMATIC DIAGRAM SHOWING INFERRED STRATIGRAPHIC AND FACIES RELATIONS IN THE PIEDMONT AND BLUE RIDGE OF MARYLAND AND NORTHERN VIRGINIA BEFORE DEFORMATION AND EROSION.

with the schistose rocks in units generally measurable in inches or in feet. As one travels south, away from the Martic line, the thickness of individual units gradually increases, and the proportion of pelitic rocks gradually decreases. Four to six mi south of the Martic line, the units are measurable in tens or even hundreds of feet and the proportion of pelitic beds has decreased markedly. About 5 to 7 mi south of the line, one could draw a gradational contact with the rocks to the south mapped as Peters Creek by Knopf and Jonas (1923): these rocks should now be placed in the metagraywacke facies of the Wissahickon (Higgins and Fisher, 1971); they are quite similar to the rocks exposed along the Susquehanna River in northwesternmost Cecil County, Maryland.

The relations in the Martic area suggest that part of the Wissahickon Formation is correlative with part of the Chilhowee Group (Lower Cambrian) (King, 1950; Whitaker, 1955a; Nickelsen, 1956; Rodgers, 1956). This is in accord with the radiometric data which bracket the deposition of the Wissahickon between about 600 and 425 m.y. ago, and with other regional relations.

PROPOSED NOMENCLATURE, STRATIGRAPHY, AND CORRELATION

Baltimore Gneiss

No nomenclature changes are proposed for the Baltimore Gneiss. The term Baltimore Gneiss is synonymous with "basement complex" and includes a wide variety of rocks, probably of different ages and origin, which lie unconformably beneath the Glenarm Series (Hopson, 1964) or the Chilhowee Group. In Maryland, this Precambrian basement complex went through a period of crystallization about 1,000 to 1,300 m.y. ago (Tilton and others, 1958; Wetherill and others, 1966).

Glenarm Series

The Glenarm Series is retained as a provincial series (Hopson, 1964; Southwick and Fisher, 1967), composed of the Setters Formation, the Cockeysville Marble, the Peach Bottom Slate, the Cardiff Metaconglomerate, the Wissahickon Formation, the James Run Formation and the correlative Chopawamsic Formation (the volcanic rocks beneath the Quantico Slate in Virginia), and the Quantico Slate (Fig. 19). The Glenarm Series as defined here includes rocks which range in age from latest Precambrian (about 600 to 650 m.y.) to late Middle or Late Ordovician.

Setters Formation. No nomenclature changes are proposed for the Setters Formation. It is accepted as defined by Hopson (1964). The Setters is considered correlative with the lowermost Chilhowee rocks. Depending on which time chart is used, it is either latest Precambrian or Early Cambrian. It contains detrital zircons from the Baltimore Gneiss.

Cockeysville Marble. No nomenclature changes are proposed for the Cockeysville Marble. It is accepted as defined by Choquette (1960) and Hopson (1964). It is considered either latest Precambrian or Early Cambrian, depending on the time chart used.

Peach Bottom Slate. The name Peach Bottom Slate is retained for the black slate that crops out in the axial area of the Peach Bottom fold. The Peach Bottom fold is considered anticlinal and faulted on its northwestern side. The Peach Bottom Slate is considered older than the Cardiff Metaconglomerate. The Peach Bottom and the Cardiff are probably correlative with the Hellam Member of the Chickies Formation (Figs. 19 and 20). The Hellam, although often referred to simply as "conglomerate," consists of a basal black slate that grades up into quartz pebble conglomerate and quartzites (Stose and Jonas, 1939, p. 38–43; Jonas and Stose, 1930, p. 19). The black slate is identical with the Peach Bottom Slate, and the conglomerate has black slate clasts like those in the Cardiff (Stose and Jonas). The conglomerate in the Hellam grades upward into quartzites, arkosic quartzites, fine-grained conglomerates, and pelitic rocks very similar to the quartzite facies of the Wissahickon southeast of the axis of the Peach Bottom fold (Higgins and Fisher, 1971).

There is also a strong possibility that the Peach Bottom Slate and Cardiff Metaconglomerate, and the Hellam Member of the Chickies Formation, are correlative with the Setters Formation. G. W. Fisher (1971) has recently discovered pelitic rocks and conglomerates in the Setters around Phoenix dome in Baltimore County.

Cardiff Metaconglomerate. The Cardiff Metaconglomerate is retained as a formation, even though it has a gradational contact with fine-grained conglomerates of the Wissahickon quartzite facies, and even though it is very probably correlative with conglomerates of the Hellam Member of the Chickies Formation.

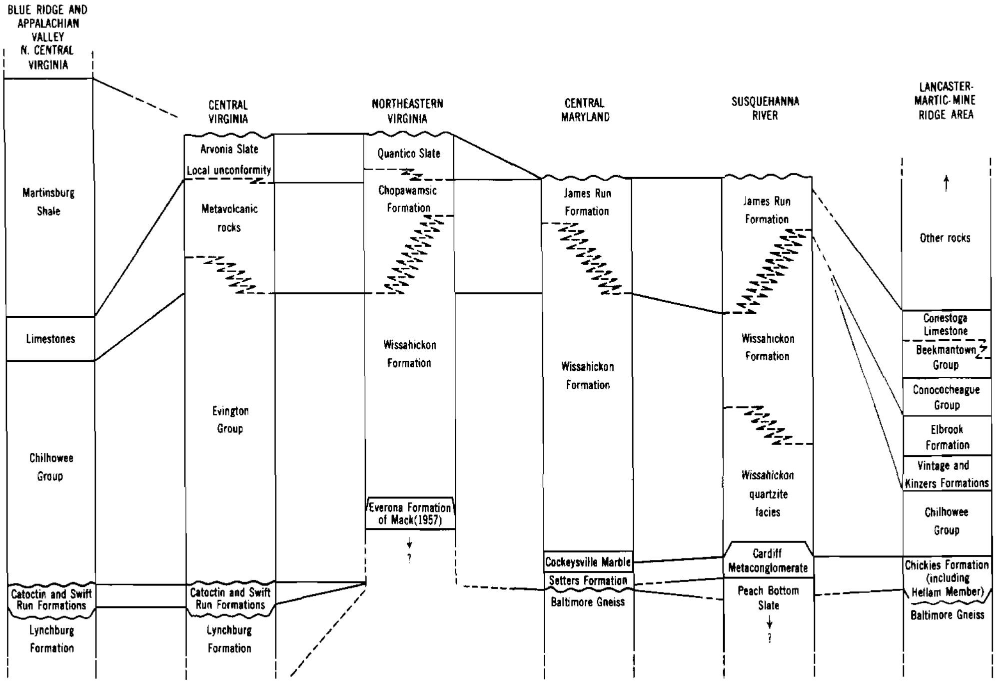


Figure 20. Correlation of stratigraphic units across the Piedmont to the Blue Ridge.

Metaconglomerates identical with the Cardiff crop out in a narrow belt southwest of the southwestern nose of the Peach Bottom fold in Harford County, Maryland. Southwick and Fisher (1967) named this rock the *metaconglomerate lithofacies of the Wissahickon* Formation (Southwick and Owens, 1968). Lesley (1892) and Southwick (1969) noted the complete similarity of these conglomerates to the Cardiff, and Lesley suggested correlation. I propose that the metaconglomerate facies of the Wissahickon be abandoned, and the rocks be correlated with and included in the Cardiff.

Wissahickon Formation. The terminology used in this paper for the Wissahickon Formation is that of Higgins and Fisher (1971), except as noted above.

Much of the Wissahickon is considered correlative with much of the Chilhowee. Most of the Wissahickon is early Paleozoic, chiefly Cambrian, although some of the oldest parts may be slightly older than the arbitrarily defined 570 m.y. base of the Cambrian (U.S. Geol. Survey, Geol. Names Committee, 1968), and some of the younger parts are possibly Ordovician (Fig. 21).

James Run Formation (Chopawamsic Formation in Virginia). The James Run Formation, defined earlier in this paper, is considered Cambrian and Ordovician (Higgins and others, 1971). It is partially correlative with much of the Wissahickon Formation, but many of the James Run rocks are younger than the Wissahickon. *It includes the former Relay Quartz* Diorite of Knopf and Jonas (1929b), the James Run Gneiss of Southwick and Fisher (1967), and the paragneiss of the Baltimore dome (the Baltimore paragneiss of Hopson, 1964). Correlative rocks beneath the Quantico Slate in Virginia have been named the Chopawamsic Formation by Southwick and others (1971). The James Run Formation also includes metavolcanic gneisses formerly considered as Baltimore Gabbro in eastern Baltimore and southwestern Harford Counties, Maryland.

Southwick (Southwick and Owens, 1968; Southwick and Fisher, 1967; Southwick, 1969) mapped and described what he considered a dome of Baltimore Gneiss, Setters mica gneiss, and Wissahickon lower pelitic schist surrounded by James Run Gneiss in southern Harford County, Maryland; on this basis, he tentatively considered the James Run rocks correlative with the older parts of the Wissahickon. I doubt the existence of this particular dome, and disagree with the tentative stratigraphic as-

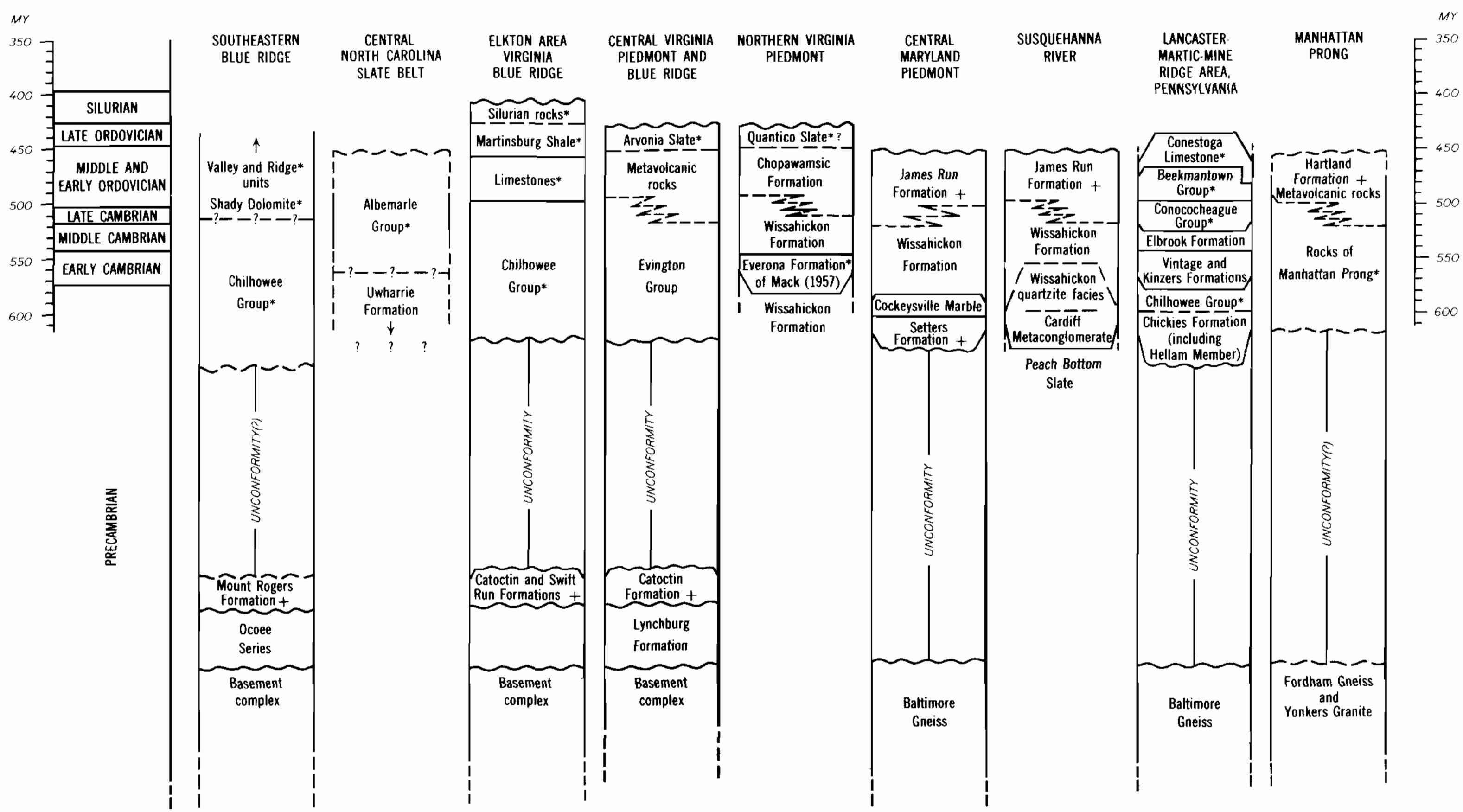


Figure 21. Interpreted age relations based on fossil data (*), radiometric determinations (+), and regional considerations. Unconformities are dashed where uncertain.

signment of the metavolcanic rocks. All other known Baltimore Gneiss domes in the Maryland Piedmont, even including those not yet exposed by erosion, have two prominent characteristics: (1) they appear on aeromagnetic maps as prominent and distinctive closed lows (Bromery, 1967; Bromery and others, 1964; J. W. Allingham, unpub. data); and (2) they appear on metamorphic isograd maps (Southwick and Owens, 1968; Cleaves and others, 1968; Hopson, 1964, p. 53) as high-grade metamorphic domes, their domical structure paralleled by successively lower isograds. Southwick's proposed dome is not distinctive on the aeromagnetic map (Bromery and others, 1964), being no different from the James Run rocks along strike; nor has it any effect on the metamorphic isograds (Southwick and Owens, 1968). Although Southwick (Southwick and Owens, 1968; Southwick, 1969) called the gneissic rock of his proposed dome Baltimore Gneiss, he recognized (1969) that it is different from most other Baltimore Gneiss in the Maryland Piedmont. The gneiss contains large, euhedral, zoned plagioclase crystals in a groundmass which Southwick described as "granulated" (p. 22). Over-all, the gneiss is quite similar to metamorphosed tuffs and tuffaceous sediments of the James Run Formation in Cecil County, Maryland, although in some respects it is also reminiscent of parts of Port Deposit Gneiss. I interpret it as either a shallow pluton, coeval and intimately connected in origin with the metavolcanic rocks, or a metavolcanic or metavolcaniclastic rock. In either case, I think it should be considered part of the James Run Formation. The rocks around the gneiss that Southwick assigned to the Setters Formation are also similar to tuffaceous sedimentary rocks in parts of the James Run Formation. The James Run Formation is thus not considered restricted to the older parts of the Wissahickon in age. The James Run rocks probably represent an eastern volcanic facies of the Wissahickon.

Southwick (1969) presented evidence that many of the layered gneisses of the Wilmington Complex of Ward (1959) are metavolcanic and metavolcaniclastic rocks probably correlative with rocks here considered part of the James Run Formation (James Run Gneiss of Southwick and Fisher, 1967). My reconnaissance in the Wilmington area suggests that the correlation is correct.

Quantico Slate. The Quantico Slate is considered upper Middle and Upper Ordovician and should be added to the Glenarm Series; it forms the uppermost unit of the series (Figs. 19 and 20).

REGIONAL SYNTHESIS

Much of the Glenarm is probably correlative with the Evington Group in the Virginia Piedmont (Espenshade, 1954; Brown, 1954), and with rocks in the Manhattan Prong (Hall, 1968; Scotford, 1956). The James Run Formation is considered correlative with the metavolcanic rocks of Quantico and Arvonia synclines and with part of the Carolina slate belt (Stromquist and Sundelius, 1969). It is also considered correlative with metavolcanic rocks in Delaware and with probable metavolcanic rocks of the Hartland Formation (Rodgers and others, 1959) in the Manhattan Prong (Hall, 1968).

A belt of roughly contemporaneous volcanism and rapid sedimentation, to which much volcaniclastic and volcanic-epiclastic material was added, probably existed in late Precambrian, Cambrian, and Ordovician time; it extended from central Georgia (Little River series of Crickmay, 1939, 1952) at least into southeastern New York, and probably through New England and eastern Canada. This "Atlantic Seaboard volcanic province" probably represents the remnants of a physiographic island arc. Ashfalls from eruptive centers in this belt probably supplied the material now found as bentonite beds and associated green cherts in the Ordovician rocks of the Valley and Ridge province (Kay, 1935) from Canada to Alabama.

In Maryland and adjacent areas, the Wissahickon rocks probably represent a deeper-water facies of the Chilhowee rocks. The Chilhowee rocks are largely beach and nearshore, shallow marine platform deposits, derived chiefly from the west (Whitaker, 1955b; Schwab, 1969, 1970). According to Schwab, the source for these sediments was a complex cratonic crystalline basement area in which there were also unmetamorphosed sediments. Paleocurrent data (Whitaker, 1955b; Schwab, 1969, 1970) indicate that the paleoslope was to the east, and that a deeper depositional basin was located east of the present Chilhowee outcrops. The Wissahickon was probably deposited in this basin between the "shelf" and the volcanic arc. Some of the Wissahickon sedimentary material (particularly in western Maryland) probably came from the west, from the same sources as the Chilhowee rocks, but as Hopson (1964) pointed out, most of it probably came from the east.

To the east, the Wissahickon grades into the volcanic and volcaniclastic rocks of the James Run Formation, largely deposited on the flanks of the island arc in shallower water than was most of the Wissahickon. This island arc differed from most modern arcs in several ways. Most modern arcs are situated relatively close to, and trend roughly parallel with, continental edges. They are commonly separated from the continent by relatively shallow seas, probably situated over relatively deep subsidence basins filled with sediments, and they separate these seas from the main ocean basins. The arcs are generally bordered on their ocean sides by deep submarine trenches. Crystalline basement rocks are rarely exposed in modern arcs, and most arcs are essentially devoid of nonvolcanic clastic sediments (Hamilton, 1969). If the shallow seas, with their thick sediments, and the arcs are considered analogs of parts of geosynclines, the nonvolcanic clastic sediments must have been derived from continental sources. However, the pre-continental-drift Appalachian geosyncline with the postulated "Atlantic Seaboard" island arc was probably not bordered on one side by an ocean basin, but by another part of the pre-Atlantic continent. This must have been a partly "landlocked" or "intracontinental" geosyncline, more akin in form and development to the Ural and Alpine geosynclines than to modern continental margin–island arc–ocean trench situations. The source for much of the Wissahickon was probably located in this eastern part of the pre-Atlantic continent ("Appalachia" of Schuchert, 1910), much as pictured by Hopson (1964, Fig. 29) except for the addition of a volcanic island chain at the edge of the eastern landmass. The volcanic island arc was probably a tectonically active area, where "crystalline basement" rocks were almost continuously exposed. These rocks also probably contributed material to the Wissahickon.

Metamorphism of the Glenarm rocks probably began in Late Ordovician, about 440 m.y. ago (U.S. Geol. Survey, Geol. Names Committee, 1968), soon after deposition, and in fact the older formations were possibly starting to be metamorphosed as the younger rocks were deposited. The climax of metamorphism was reached about 425 m.y. ago (Early Silurian), and was approximately coincident with intrusion of a late group of granitic plutons.

For many years, the crystalline belt of the northern Appalachians, from New York north, has been considered different and separate from the crystalline belt of the central and southern Appalachians. If the interpretations, correlations, and regional picture proposed in this paper are correct, then the Appalachians are one continuous chain, with many similarities. The James Run and Wissahickon rocks are probably grossly correlative with the rocks described by Berry (1968) in New England and New Brunswick, where his "islands and volcanos belt" corresponds to the James Run, and his "shale belt" to part of the Wissahickon. A similar sequence of rocks in Newfoundland has recently been described by Horne (1969). His "Early Ordovician chaotic deposits" are very reminiscent of the diamictite facies of the Wissahickon, and the association of these deposits with chaotic deposits bearing volcanic material and with marine volcanic rocks compares closely with the James Run–Wissahickon association. Perhaps the "Port Deposit problem" is not unique either; Naylor's (1968) recent description and reinterpretation of the Oliverian domes in New Hampshire is reminiscent of the Port Deposit Gneiss with its gradational contact into James Run metavolcanic rocks.

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REFERENCES CITED

Agron, S. L., 1950, Structure and petrology of the Peach Bottom Slate, Pennsylvania and Maryland, and its environment: Geol. Soc. America Bull., v. 61, no. 11, p. 1265–1306.

Albers, J. P., 1964, Geology of the French Gulch quadrangle, Shasta and Trinity Counties, California: U.S. Geol. Survey Bull. 1141–J, 70 p.

American Association of Petroleum Geologists, 1944, Tectonic map of the United States, 1944: Tulsa, Okla., 2 sheets, scale 1:2,500,000.

Bascom, Florence, 1902, The geology of the crystalline rocks of Cecil County: Maryland Geol. Survey, Cecil County Rept., p. 83–148.

—— 1905, Piedmont district of Pennsylvania: Geol. Soc. America Bull., v. 16, p. 289–328.

Bascom, Florence, and Miller, B. L., 1920, Elkton-Wilmington, Maryland-Delaware: U.S. Geol. Survey, Geol. Atlas, Folio 211, 22 p.

Bascom, Florence, Clark, W. B., Darton, N. H., Kümmel, H. B., Salisbury, R. D., Miller, B. L., and Knapp, G. N., 1909, Philadelphia, Pennsylvania–New Jersey–Delaware: U.S. Geol. Survey, Geol. Atlas, Folio 162, 24 p.

Bateman, P. C., Clark, L. D., Huber, N. K., Moore, J. G., and Rinehart, C. D., 1963, The Sierra Nevada batholith—a synthesis of recent work across the central part: U.S. Geol. Survey Prof. Paper 414–D, 46 p.

Becraft, G. E., Pinckney, D. M., and Rosenblum, Sam, 1963, Geology and mineral deposits of the Jefferson City quadrangle, Jefferson and Lewis and Clark Counties, Montana: U.S. Geol. Survey Prof. Paper 428, 101 p.

Behre, C. H., 1933, Slate in Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. M 16, 400 p.

Berry, W.B.N., 1968, Ordovician paleogeography of New England and adjacent areas based on graptolites, *in* Zen, E-an, and others, eds., Studies of Appalachian geology—northern and maritime: New York, Interscience, p. 23–34.

Best, M. G., 1963, Petrology of the Guadalupe igneous complex, southwestern Sierra Nevada foothills, California: Jour. Petrology, v. 4, no. 2, p. 223–259.

Bliss, E. F., and Jonas, A. I., 1916, Relation of the Wissahickon mica gneiss to the Shenandoah limestone and Octoraro schist of the Doe Run and Avondale region, Chester County, Pennsylvania: U.S. Geol. Survey Prof. Paper 98–B, p. 9–34.

Bloomer, R. O., and Werner, H. J., 1955, Geology of the Blue Ridge region in central Virginia: Geol. Soc. America Bull., v. 66, no. 5, p. 579–606.

Bromery, R. W., 1967, Aeromagnetic map of Baltimore County and Baltimore City, Maryland: U.S. Geol. Survey Geophys. Inv. Map GP–613, scale 1:62,500.

Bromery, R. W., Petty, A. J., and Smith, C. W., 1964, Aeromagnetic map of Bel Air and vicinity, Harford, Baltimore, and Cecil Counties, Maryland: U.S. Geol. Survey Geophys. Inv. Map GP–482, scale 1:62,500.

Brown, W. R., 1954, Structural framework and mineral resources of the Virginia Piedmont: Kentucky Geol. Survey, ser. 9, Spec. Pub. no. 1, p. 88–111: Virginia Geol. Survey, reprint ser. no. 16, p. 88–111.

—— 1958, Geology and mineral resources of the Lynchburg quadrangle, Virginia: Virginia Div. Mineral Resources Bull. 74, 99 p.

Cady, W. M., Wallace, R. E., Hoare, J. M., and Webber, E. J., 1955, The central Kuskokwim region, Alaska: U.S. Geol. Survey Prof. Paper 268, 132 p.

Cater, F. W., 1969, The Cloudy Pass epizonal batholith and associated subvolcanic rocks: Geol. Soc. America Spec. Paper 116, 54 p.

Chapman, R. W., 1942, "Pseudomigmatite" in the Piedmont of Maryland: Geol. Soc. America Bull., v. 53, no. 9, p. 1299–1330.

Choquette, P. W., 1960, Petrology and structure of the Cockeysville Formation (pre-Silurian) near Baltimore, Maryland: Geol. Soc. America Bull., v. 71, no. 7, p. 1027–1052.

Cleaves, E. T., Edwards, Jonathan, Jr., and Glaser, J. D., compilers, 1968, Geologic map of Maryland: Baltimore, Maryland Geol. Survey, scale 1:250,000.

Cloos, Ernst, and Broedel, C. H., 1940, Geologic map of Howard and adjacent parts of Montgomery and Baltimore Counties: Baltimore, Maryland Geol. Survey, scale 1:62,500.

Cloos, Ernst, and Cooke, C. W., 1953, Geologic map of Montgomery County and the District of Columbia: Baltimore, Maryland Dept. Geology, Mines and Water Resources, scale 1:62,500.

Cloos, Ernst, and Hietanen, Anna, 1941, Geology of the "Martic overthrust" and the Glenarm Series in Pennsylvania and Maryland: Geol. Soc. America Spec. Paper 35, 207 p.

Crickmay, G. W., 1939, Geologic map of Georgia: Atlanta, Georgia Dept. Mines, Mining and Geology, scale 1:500,000.

—— 1952, Geology of the crystalline rocks of Georgia: Atlanta, Georgia Geol. Survey Bull. 58, 54 p.

Crowley, W. P., 1969, Stratigraphic evidence for a volcanic origin of part of the Bel Air belt of Baltimore Gabbro complex in Baltimore County, Maryland: Geol. Soc. America, Abs. with Programs for 1969, Pt. 1 (Northeastern Sec.), p. 10.

Davis, G. L., Tilton, G. R., Aldrich, L. T., and Wetherill, G. W., 1958, Age of the Baltimore gneiss [abs.]: Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1550–1551.

Davis, G. L., Tilton, G. R., Aldrich, L. T., Hart, S. R., and Steiger, R. H., 1965, The minimum age of the Glenarm Series, Baltimore, Maryland: Carnegie Inst. Washington Yearbook 64, 1964–1965, p. 174–177.

Dietrich, R. V., 1961, Petrology of the Mount

Airy "granite": Virginia Polytech. Inst. Bull., Eng. Expt. Sta. Ser. 144, v. 54, no. 6, 63 p.

Drake, A. A., Jr., 1970, Structural geology of the Reading Prong, *in* Fisher, G. W., and others, eds., Studies of Appalachian geology—central and southern: New York, Interscience, p. 271–291.

Espenshade, G. H., 1954, Geology and mineral deposits of the James River–Roanoke River manganese district, Virginia: U.S. Geol. Survey Bull. 1008, 155 p.

Fisher, G. W., 1963, The petrology and structure of the crystalline rocks along the Potomac River, near Washington, D.C. [Ph.D. dissert.]: Baltimore, Maryland, Johns Hopkins Univ.

—— 1971, Kyanite-, staurolite-, and garnet-bearing schists in the Setters Formation, Maryland Piedmont: Geol. Soc. America Bull., v. 82, no. 1, p. 229–232.

Fisher, I. S., 1962, Petrology and structure of the Bethel area, Maine: Geol. Soc. America Bull., v. 73, no. 11, p. 1395–1419.

Fiske, R. S., Hopson, C. A., and Waters, A. C., 1963, Geology of Mount Rainier National Park, Washington: U.S. Geol. Survey Prof. Paper 444, 93 p.

Folk, R. L., 1960, Petrology of sedimentary rocks: Austin, Texas, Hemphill's, 27 p.

Freedman, Jacob, Wise, D. U., and Bentley, R. D., 1964, Patterns of folded folds in the Appalachian Piedmont along Susquehanna River: Geol. Soc. America Bull., v. 75, no. 7, p. 621–638.

Fyles, J. T., 1955, Geology of the Cowichan Lake area, Vancouver Island, British Columbia: British Columbia Dept. Mines Bull. 37, 72 p.

Geyer, A. R., Gray, Carlyle, MacLaughlan, D. B., and Moseley, J. R., 1958, Geology of Lebanon quadrangle (Pennsylvania): Pennsylvania Geol. Survey, 4th ser., Atlas 167C, 1 sheet.

Grimsley, G. P., 1894, The granites of Cecil County, in northeastern Maryland: Cincinnati Soc. Nat. History Jour., v. 17, p. 59–67, 78–114.

Hall, L. M., 1968, Times of origin and deformation of bedrock in the Manhattan Prong, *in* Zen, E-an, and others, eds., Studies of Appalachian geology—northern and maritime: New York, Interscience, p. 117–127.

Hamilton, E. I., 1963, The isotopic composition of strontium in the Skaergaard intrusion, East Greenland: Jour. Petrology, v. 4, no. 3, p. 383–391.

Hamilton, Warren, 1969, Mesozoic California and the underflow of Pacific mantle: Geol. Soc. America Bull., v. 80, no. 12, p. 2409–2430.

Harland, W. B., Smith, A. G., and Wilcock, B., eds., 1964, The Phanerozoic time-scale; a symposium: Geol. Soc. London Quart. Jour., v. 120, supp., 458 p.

Hart, S. R., 1961, The use of hornblendes and pyroxenes for K-Ar dating: Jour. Geophys. Research, v. 66, no. 9, p. 2995–3001.

Hart, S. R., and Dodd, R. T., Jr., 1962, Excess radiogenic argon in pyroxenes: Jour. Geophys. Research, v. 67, no. 7, p. 2998–2999.

Haslam, H. W., 1968, The crystallization of intermediate and acid magmas at Ben Nevis, Scotland: Jour. Petrology, v. 9, p. 84–104.

Hershey, H. G., 1937, Structure and age of the Port Deposit granodiorite complex: Maryland Geol. Survey Rept. Inv., v. 13, p. 107–148.

Herz, Norman, 1951, Petrology of the Baltimore gabbro, Maryland: Geol. Soc. America Bull., v. 62, no. 9, p. 979–1016.

Hess, H. H., 1960, Stillwater igneous complex, Montana—a quantitative mineralogical study: Geol. Soc. America Mem. 80, 230 p.

Hietanen, Anna, 1963, Idaho batholith near Pierce and Bungalow, Clearwater County, Idaho: U.S. Geol. Survey Prof. Paper 344-D, 42 p.

Higgins, M. W., 1971a, Evidence for the Peach Bottom Anticline, southeastern Pennsylvania and northeastern Maryland: Geol. Soc. America, Abs. with Programs, Pt. 3, (Southeastern Sec.), p. 321.

—— 1971b, Cataclastic rocks: U.S. Geol. Survey Prof. Paper 687, 98 p.

Higgins, M. W., and Fisher, G. W., 1971, A further revision of the stratigraphic nomenclature of the Wissahickon Formation in Maryland: Geol. Soc. America Bull., v. 82, no. 3, p. 769–774.

Higgins, M. W., Sinha, A. K., Tilton, G. R., and Kirk, W. S., 1971, Correlation of metavolcanic rocks in the Maryland, Delaware, and Virginia Piedmont: Geol. Soc. America, Abs. with Programs, Pt. 3 (Southeastern Sec.), p. 320–321.

Hopson, C. A., 1960, The Port Deposit granodiorite complex (stop 1), and Conowingo contact zone, Port Deposit granodiorite (stop 2), *in* Wise, D. U., and Kauffman, M. E., eds., Some tectonic and structural problems of the Appalachian Piedmont along the Susquehanna River: Pennsylvania Geologists Guidebook, 25th Field Conf., Lancaster, 1960, p. 26–33.

—— 1964, The crystalline rocks of Howard and Montgomery Counties, *in* The geology of Howard and Montgomery Counties: Baltimore, Maryland Geol. Survey, p. 27–215.

Horne, G. S., 1969, Early Ordovician chaotic deposits in the central volcanic belt of northeastern Newfoundland: Geol. Soc. America Bull., v. 80, no. 12, p. 2451–2464.

Hotz, P. E., 1953, Petrology of granophyre in diabase near Dillsburg, Pennsylvania: Geol. Soc. America Bull., v. 64, no. 6, p. 675–704.

Hriskevich, M. E., 1968, Petrology of the Nipissing diabase sill of the Cobalt area, Ontario, Canada: Geol. Soc. America Bull., v. 79, no. 10, p. 1387–1404.

Hutchinson, R. M., 1956, Structure and petrology of Enchanted Rock batholith, Llano and Gillespie Counties, Texas: Geol. Soc. America Bull., v. 67, no. 6, p. 763–806.

Johannsen, Albert, 1931, A descriptive petrography of the igneous rocks; Vol. I, Introduction, textures, classifications, and glossary: Chicago, Univ. Chicago Press, 267 p.

Jonas, A. I., 1927, Geologic reconnaissance in the Piedmont of Virginia: Geol. Soc. America Bull., v. 38, no. 4, p. 837–846.

—— 1928, Geologic map of Carroll County, Maryland: Baltimore, Maryland Geol. Survey, scale 1:62,500.

—— 1929, Structure of the metamorphic belt of the central Appalachians: Geol. Soc. America Bull., v. 40, no. 2, p. 503–514.

—— 1932a, Structure of the metamorphic belt of the southern Appalachians: Am. Jour. Sci., 5th ser., v. 24, p. 228–243.

—— 1932b, Geology of the kyanite belt of Virginia: Virginia Geol. Survey Bull. 38, 38 p.

Jonas, A. I., and Stose, G. W., 1930, Geology and mineral resources of the Lancaster quadrangle, Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Atlas 168, 106 p.

Kay, G. M., 1935, Distribution of Ordovician altered volcanic materials and related clays: Geol. Soc. America Bull., v. 46, no. 2, p. 225–244.

Keyes, C. R., 1895, Origin and relations of central Maryland granites: U.S. Geol. Survey, 15th Ann. Rept., p. 685–740.

King, P. B., 1950, Geology of the Elkton area, Virginia: U.S. Geol. Survey Prof. Paper 230, 82 p.

Knopf, E. B., and Jonas, A. I., 1922, Stratigraphy of the crystalline schists of Pennsylvania and Maryland [abs.]: Geol. Soc. America Bull., v. 33, no. 1, p. 110–111.

—— 1923, Stratigraphy of the crystalline schists of Pennsylvania and Maryland: Am. Jour. Sci., 5th ser., v. 5, p. 40–62.

—— 1929a, Geology of the crystalline rocks: Maryland Geol. Survey, Baltimore County, p. 97–199.

—— 1929b, Geology of the McCalls Ferry–Quarryville district, Pennsylvania: U.S. Geol. Survey Bull. 799, 156 p.

Kretz, R., 1967, Granite and pegmatite studies at Northern Indian Lake, Manitoba: Canada Geol. Survey Bull. 148, 42 p.

Lapham, D. M., and Bassett, W. A., 1964, K-Ar dating of rocks and tectonic events in the Piedmont of southeastern Pennsylvania: Geol. Soc. America Bull., v. 75, no. 7, p. 661–668.

Larsen, E. S., Jr., and Cross, Whitman, 1956, Geology and petrology of the San Juan region, southwestern Colorado: U.S. Geol. Survey Prof. Paper 258, 303 p.

Larsen, E. S., Jr., and Schmidt, R. G., 1958, A reconnaissance of the Idaho batholith and comparison with the southern California batholith: U.S. Geol. Survey Bull. 1070–A, 33 p.

Lesley, J. P., 1892, A summary description of the geology of Pennsylvania: Harrisburg, Pennsylvania Geol. Survey, 2d, Final Rept., 3v., 2588 p.

Mack, Tinsley, 1957, Geology of the Everona Formation [M.A. thesis]: Charlottesville, Univ. Virginia.

Mackin, J. H., 1935, The problem of the Martic overthrust and the age of the Glenarm series in southeastern Pennsylvania: Jour. Geology, v. 43, no. 4, p. 356–380.

MacLachlan, D. B., 1967, Structure and stratigraphy of the limestones and dolomites of Dauphin County, Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Rept. G–44, 168 p.

Marshall, John, 1937, The structures and age of the volcanic complex of Cecil County, Maryland: Maryland Geol. Survey Rept. Inv., v. 13, p. 191–213.

Mathews, E. B., 1904, The structure of the Piedmont Plateau as shown in Maryland: Am. Jour. Sci., 4th ser., v. 17, p. 141–159.

—— 1905, Correlation of Maryland and Pennsylvania Piedmont formations: Geol. Soc. America Bull., v. 16, p. 329–346.

—— 1907, Anticlinal domes in the Piedmont of Maryland: Johns Hopkins Univ. Circ. 26, no. 199, p. 615–622.

Mathews, E. B., and Johannsen, Albert, 1904, Geologic map of Harford County: Baltimore, Maryland Geol. Survey, scale 1:62,500.

Mathews, E. B., and Miller, W. J., 1905, Cockeysville marble: Geol. Soc. America Bull., v. 16, p. 347–366.

McDougall, Ian, 1962, Differentiation of the Tasmanian dolerites; Red Hill dolerite-granophyre association: Geol. Soc. America Bull., v. 73, no. 3, p. 279–316.

McKinstry, H. E., 1961, Structure of the Glenarm Series in Chester County, Pennsylvania: Geol. Soc. America Bull., v. 72, no. 4, p. 557–578.

Milici, E. C., Spiker, C. T., Jr., and Wilson, J. M., compilers, 1963, Geologic map of Virginia: Charlottesville, Virginia Div. Mineral Resources, scale 1:500,000.

Miller, B. L., 1935, Age of the schists of the South Valley Hills, Pennsylvania: Geol. Soc. America Bull., v. 46, no. 5, p. 715–756.

Naylor, R. S., 1968, Origin and regional relationships of the core-rocks of the Oliverian domes, *in* Zen, E-an, and others, eds., Studies of Appalachian geology—northern and maritime: New York, Interscience, p. 231–240.

Nickelsen, R. P., 1956, Geology of the Blue Ridge near Harpers Ferry, West Virginia: Geol. Soc. America Bull., v. 67, no. 3, p. 239–270.

Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks: Geol. Soc. America Bull., v. 65, no. 10, p. 1007–1032.

Parker, R. L., and Calkins, J. A., 1964, Geology of the Curlew quadrangle, Ferry County, Washington: U.S. Geol. Survey Bull. 1169, 95 p.

Ramsay, J. G., 1962, Interference patterns produced by the superposition of folds of "similar" type: Jour. Geology, v. 70, no. 4, p. 466–481.

—— 1967, Folding and fracturing of rocks: New York, McGraw-Hill, 568 p.

Rankin, D. W., Stern, T. W., Reed, J. C., Jr., and Newell, M. F., 1969, Zircon ages of felsic volcanic rocks in the upper Precambrian of the Blue Ridge, Appalachian Mountains: Science, v. 166, p. 741–744.

Reed, J. C., Jr., 1955, Catoctin Formation near Luray, Virginia: Geol. Soc. America Bull., v. 66, no. 7, p. 871–896.

Rodgers, John, 1956, The clastic sequence basal to the Cambrian System in the central and southern Appalachians: Internat. Geol. Cong., 20th, Mexico, 1956, El sistema Cámbrico, su paleogeografia y el problema de su base—symposium, pt. 2, p. 385–413.

Rodgers, John, Gates, R. M., and Rosenfeld, J. L., 1959, Explanatory text for preliminary geological map of Connecticut, 1956: Connecticut State Geol. and Nat. History Survey Bull. 84, 64 p.

Schermerhorn, L.J.G., and Stanton, W. I., 1963, Tilloids in the west Congo geosyncline: Geol. Soc. London Quart. Jour., v. 119, pt. 2, no. 474, p. 201–241.

Schuchert, Charles, 1910, Paleogeography of North America: Geol. Soc. America Bull., v. 20, p. 427–606.

Schwab, F. L., 1969, Petrology, paleocurrents, and depositional environment of the Antietam Formation in the central Appalachians: Geol. Soc. America, Abs. with Programs for 1969, Pt. 7 (Ann. Mtg.), p. 201–202.

—— 1970, Petrology, paleocurrents, and depositional environments of the Harpers Formation in the central Appalachians: Geol. Soc. America, Abs. with Programs (Ann. Mtg.), v. 2, no. 1, p. 35.

Schwartz, G. M., and Sandberg, A. E., 1940, Rock series in diabase sills at Duluth, Minnesota: Geol. Soc. America Bull., v. 51, no. 8, p. 1135–1172.

Scotford, D. M., 1956, Metamorphism and axial-plane folding in the Pound Ridge area, New York: Geol. Soc. America Bull., v. 67, no. 9, p. 1155–1198.

Shapiro, Leonard, and Brannock, W. W., 1962, Rapid analysis of silicate, carbonate and phosphate rocks: U.S. Geol. Survey Bull. 1144–A, 56 p.

Sherwood, W. C., 1964, Structure of the Jacksonburg Formation in Northampton and Lehigh Counties, Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Rept. G–45, 64 p.

Southwick, D. L., 1969, Crystalline rocks, *in* Maryland Geol. Survey, Geology of Harford County, Maryland: Baltimore, Maryland Geol. Survey, p. 1–76.

Southwick, D. L., and Fisher, G. W., 1967, Revision of stratigraphic nomenclature of the Glenarm Series in Maryland. Maryland Geol. Survey Rept. Inv. 6, 19 p.

Southwick, D. L., and Owens, J. P., 1968, Geologic map of Harford County: Baltimore, Maryland Geol. Survey, scale 1:62,500.

Southwick, D. L., Reed, J. C., Jr., and Mixon, R. B., 1971, The Chopawamsic Formation—a new stratigraphic unit in the Piedmont of northeastern Virginia: U.S. Geol. Survey Bull. 1324-D, p. D-1–D-11.

Steiger, R. H., and Hopson, C. A., 1965, Minimum age of the Glenarm Series, Baltimore, Maryland: Geol. Soc. America, Abs. for 1964, Spec. Paper 82, p. 194–195.

Stose, A. J., and Stose, G. W., 1946, Geology of Carroll and Frederick Counties (Maryland): Maryland Dept. Geology, Mines, and Water Resources, Carroll and Frederick Counties Rept., p. 11–131.

Stose, G. W., and Jonas, A. I., 1939, Geology and mineral resources of York County, Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. C–67, 199 p.

Stose, G. W., and Stose, A. J., 1948, Stratigraphy of the Arvonia Slate, Virginia: Am. Jour. Sci., v. 246, no. 7, p. 393–412.

Stromquist, A. A., and Sundelius, H. W., 1969, Stratigraphy of the Albemarle Group of the Carolina slate belt in central North Carolina: U.S. Geol. Survey Bull. 1274–B, 22 p.

Swartz, F. M., 1948, Trenton and sub-Trenton of outcrop areas in New York, Pennsylvania, and Maryland: Am. Assoc. Petroleum Geologists Bull., v. 32, no. 8, p. 1493–1595.

Thayer, T. P., 1963, The Canyon Mountain Complex, Oregon, and the alpine mafic magma stem: U.S. Geol. Survey Prof. Paper 475–C, p. C82–C85.

Tillman, C. G., 1970, Metamorphosed trilobites from Arvonia, Virginia: Geol. Soc. America Bull., v. 81, no. 4, p. 1189–1200.

Tilton, G. R., Wetherill, G. W., Davis, G. L., and Hopson, C. A., 1958, Ages of minerals from the Baltimore Gneiss near Baltimore, Maryland: Geol. Soc. America Bull., v. 69, no. 11, p. 1469–1474.

Tilton, G. R., Davis, G. L., Wetherill, G. W., Aldrich, L. T., and Jäger, E., 1959, Mineral ages in the Maryland Piedmont: Carnegie Inst. Washington Yearbook 58, p. 171–174.

Tilton, G. R., Doe, B. R., and Hopson, C. A., 1970, Zircon age measurements in the Maryland Piedmont, with special reference to Baltimore Gneiss problems, *in* Fisher, G. W., and others, eds., Studies of Appalachian geology—central and southern: New York, Interscience, p. 429–434.

Turner, F. J., and Verhoogen, John, 1960, Igneous

and metamorphic petrology (2d ed.): New York, McGraw-Hill, 694 p.
Tuttle, O. F., and Bowen, N. L., 1958, Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O: Geol. Soc. America Mem. 74, 153 p.
U.S. Geological Survey, Geologic Names Committee, 1968, Major stratigraphic and time divisions in use by the U.S. Geological Survey: Washington, D.C., U.S. Geol. Survey, 1 p.
Wager, L. R., and Brown, G. M., 1967, Layered igneous rocks: San Francisco, W. H. Freeman and Co., 588 p.
Walker, Frederick, and Poldervaart, Arie, 1949, Karroo dolerites of the Union of South Africa: Geol. Soc. America Bull., v. 60, no. 4, p. 591–701.
Ward, R. F., 1959, Petrology and metamorphism of the Wilmington complex, Delaware, Pennsylvania, and Maryland: Geol. Soc. America Bull., v. 70, no. 11, p. 1425–1458.
Washington, H. S., 1917, Chemical analyses of igneous rocks published from 1884 to 1913, inclusive . . . : U.S. Geol. Survey Prof. Paper 99, 1201 p.
Watson, T. L., and Powell, S. L., 1911, Fossil evidence of the age of the Virginia Piedmont slates: Am. Jour. Sci., 4th ser., v. 31, p. 33–44.
Wetherill, G. W., Tilton, G. R., Davis, G. L., Hart, S. R., and Hopson, C. A., 1966, Age measurements in the Maryland Piedmont: Jour. Geophys. Research, v. 71, no. 8, p. 2139–2155.
Wetherill, G. W., Davis, G. L., and Lee-Hu, C., 1968, Rb-Sr measurements on whole rocks and separated minerals from the Baltimore Gneiss, Maryland: Geol. Soc. America Bull., v. 79, no. 6, p. 757–762.
Wheeler, E. P., II, 1955, Adamellite intrusive north of Davis Inlet, Labrador: Geol. Soc. America Bull., v. 66, no. 8, p. 1031–1059.
—— 1960, Anorthosite-adamellite complex of Nain, Labrador: Geol. Soc. America Bull., v. 71, no. 12, pt. 1, p. 1755–1762.
Whitaker, J. C., 1955a, Geology of Catoctin Mountain, Maryland and Virginia: Geol. Soc. America Bull., v. 66, no. 4, p. 435–462.
—— 1955b, Direction of current flow in some Lower Cambrian clastics in Maryland: Geol. Soc. America Bull., v. 66, no. 6, p. 763–766.
Williams, G. H., 1891a, The petrography and structure of the Piedmont Plateau in Maryland: Geol. Soc. America Bull., v. 2, p. 301–318.
—— 1891b, Crystalline rocks of Washington, *in* Guide to Washington . . . : Internat. Geol. Cong., 5th, Washington, D.C., 1891, Comptes rendus, p. 219–251.
—— 1892, Guide to Baltimore, with an account of the geology of its environs: Am. Inst. Mining Engineers, Baltimore meeting, 1892, Baltimore, J. Murphy & Co., 139 p.
Williams, G. H., and Clark, W. B., 1893, Geology (of Maryland), *in* Maryland, its resources, industries, and institutions, prepared for the Board of World's Fair (Chicago, 1893) Managers . . . : Baltimore, p. 89–153.
Williams, G. H., and Darton, N. H., 1892, Map of Baltimore and vicinity (to accompany "Guide to Baltimore" prepared for meeting of Am. Inst. Mining Engineers, 1892): U.S. Geol. Survey.
Wilshire, H. G., 1967, The Prospect alkaline diabase-picrite intrusion, New South Wales, Australia: Jour. Petrology, v. 8, p. 97–163.
Winkler, H.G.F., and Platen, H. von, 1961, Experimentelle Gesteinsmetamorphose: V. Experimentelle anatektische Schmelzen und ihre petrogenetische Bedeutung: Geochim. et Cosmochim. Acta, v. 24, no. 3–4, p. 250–259.
Wise, D. U., 1958, An example of recumbent folding south of the Great Valley of Pennsylvania: Pennsylvania Acad. Sci. Proc., v. 32, p. 172–176.
—— 1960, The Martic problem and the New Providence Railroad cut (stop 4), *in* Wise, D. U., and Kauffman, M. E., eds., Some tectonic and structural problems of the Appalachian Piedmont along the Susquehanna River: Pennsylvania Geologists Guidebook, 25th Field Conf., Lancaster, 1960, p. 38–47.
—— 1970, Multiple deformation, geosynclinal transitions, and the Martic problem in Pennsylvania, *in* Fisher, G. W., and others, eds., Studies of Appalachian geology—central and southern: New York, Interscience, p. 317–333.

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