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THE GEOLOGY OF HARFORD COUNTY, MARYLAND

1969

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STATE OF MARYLAND
DEPARTMENT OF NATURAL RESOURCES
MARYLAND GEOLOGICAL SURVEY
KENNETH N. WEAVER, *Director*

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COMMISSION OF MARYLAND GEOLOGICAL SURVEY

Preface

The geologic map of Harford County published in 1968 replaced the one published in 1904. It represents completely new mapping accomplished through a cooperative program with the U. S. Geological Survey. David L. Southwick of the U.S.G.S. (now at MacAlester College) mapped the Piedmont portion, while James A. Owens of the U.S.G.S. mapped the Coastal Plain part of Harford County. This report describes in detail the geology of the County as discovered by the mapping and research program. Jonathan Edwards, Jr., of the Maryland Geological Survey, wrote the Section on the Mineral Resources of Harford County.

This investigation is the first complete geologic mapping of a Maryland County since the Allegany County geologic map was published in 1956. The last county report to be published was the Howard and Montgomery County Report in 1966. The geologic mapping of Howard and Montgomery Counties considerably predated the report. The Howard County map was published in 1940 and the Montgomery County map in 1953.

Dr. Southwick refers extensively to the work by C. A. Hopson in the Howard and Montgomery County Report. The serious student of Piedmont geology will probably want to use these publications as companion volumes.

Kenneth N. Weaver
Director

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CRYSTALLINE ROCKS OF HARFORD COUNTY

By

DAVID L. SOUTHWICK

GEOGRAPHY

Harford County, Maryland (see index map inset on Plate 1), is bounded on the southeast by Chesapeake Bay, on the northeast by the Susquehanna River, and on the north by York County, Pennsylvania, along the Mason-Dixon Line. Little Gunpowder Falls forms the longest segment of boundary against Baltimore County to the west. The County contains about 448 square miles of land which ranges in character from flat lowlands of the Coastal Plain near Chesapeake Bay to rolling, dissected Piedmont uplands in the northern areas.

From 1659 until 1773, Harford County was part of Baltimore County, and for a while a small but thriving village on Bush River, variously called Baltimore Town, Bush, and Harford Town, served as the County Seat. Only a few foundations mark the site today. In 1773, Harford County was separated from Baltimore County by Act of Assembly, and its boundaries have not been changed significantly since then.

The southern part of the County is crossed by the main transportation routes between Baltimore and the Wilmington-Philadelphia area and is rapidly becoming urbanized; the "upper County" is chiefly farmland. A network of good roads makes all areas readily accessible.

PREVIOUS WORK

The previous geologic work in Harford County is difficult to summarize because most of it has been incidental or peripheral to studies that were focused elsewhere. Mapping of the crystalline rocks by Mathews and Johannsen in the geologic map of the County (Maryland Geol. Survey, 1904) was the first geologic research dealing specifically with Harford County. Before that, the geology of the area was known only from scattered references in the early Pennsylvania Surveys (for example, Frazer, 1880) and the early Maryland Geological reports (Ducatel, 1838; Tyson, 1860, 1862).

Harford County localities were discussed by Knopf (1921) in her summary of the chromite deposits of Pennsylvania and Maryland, and again by Pearre and Heyl (1960) in their treatment of the same subject. It is virtually certain that Harford County exposures of the Glenarm Series were studied by Knopf and Jonas (1923, 1929a, 1929b), but most of their work was concentrated in nearby areas. The commercial slate quarries of the Peach Bottom Slate were discussed briefly by Behre (1933), and a geologic sketch map of the Peach Bottom syncline was presented by Stose and Jonas (1939).

The serpentinites and related rocks of Harford County were discussed in detail by Johannsen (1928), and in a companion article the gabbros of the area were described by Insley (1928). A detailed structural-petrologic study of the Port Deposit Gneiss in Cecil and Harford Counties, including a good small-scale geologic map, was published by Hershey in 1937. A companion paper on the volcanic complex of Cecil County by Marshall (1937) gives some information on Harford County occurrences, but focuses on Cecil County. The detailed work by Agron (1950) on the Peach Bottom syncline gives much structural data on the Harford County part of the fold, but the most thoroughly studied areas are in Pennsylvania.

By far the most important contribution to the geology of this area is the excellent report on the crystalline rocks of Howard and Montgomery Counties, Maryland, by C. A. Hopson (1964). Hopson has set forth many of the fundamental geologic relationships of the Maryland Piedmont and has described in detail many rocks that occur in Harford County as well as in south-central Maryland. An effort has been made in the present report to supplement rather than duplicate Hopson's descriptions, discussions, and conclusions, but some duplication has been unavoidable. In fact, the references to Hopson (1964) are so numerous that a copy of the Howard and Montgomery Counties report is nearly as essential to the reader as a copy of the Harford County geologic map.

SUMMARY OF STRATIGRAPHY

This summary is intended to give only the outlines of stratigraphy in the crystalline rocks of Harford County. Additional details and more complete citations of the literature are given in the section on description of rocks where each unit is discussed in turn.

The oldest rock in Harford County is the Baltimore Gneiss of Precambrian (1,100 m.y.) age, which forms the core of the Phoenix gneiss dome and of a tight anticline along Bynum Run (Plate 1). It is a medium- to coarse-grained microcline-biotite-plagioclase-quartz rock that ranges in texture and structure from uniform granitic gneiss to strongly segregated and deformed migmatite. Streakily banded veined gneiss is widespread in the Phoenix dome, whereas porphyritic gneiss of probable anatectic origin predominates in the Bynum Run area.

Unconformably overlying the Baltimore Gneiss is the Glenarm Series of metamorphosed sedimentary rocks, consisting of the Setters Formation at the base, the Cockeysville Marble, and the Wissahickon Formation at the top. The age of these rocks has been debated for years. Radiometric ages of about 525 m.y. on plutonic rocks that cut the Wissahickon, however, indicate that the Glenarm Series is no younger than Cambrian and very likely is late Precambrian in age (Davis and others, 1965).

The Setters Formation consists of quartzite, muscovite quartzite, microcline quartzite, microcline-rich mica gneiss, and mica schist; the Cockeysville Marble consists of calcite marble, metadolomite, and a variety of calc-silicate rocks. Both units vary markedly in thickness from place to place, owing partly to original thickness variation and partly to tectonic flowage. The total original thickness of both formations probably was about 1,500 to 2,000 feet.

In contrast to the relatively thin Setters-Cockeysville quartzite-carbonate sequence is the voluminous Wissahickon Formation. This vast complex of schist and associated arenaceous rocks, derived from rapidly deposited shales and graywackes, is at least 15,000 feet thick and may be much thicker. The Wissahickon Formation has been subdivided into five lithofacies, strictly on the basis of original sedimentary rock type (Southwick and Fisher, 1967). The lithofacies are strongly intergradational both vertically and laterally, and clearly are not time stratigraphic. At the base of the Wissahickon is the lower pelitic schist, which is overlain by boulder gneiss (equivalent to the Sykesville Formation as used by Hopson, 1964, and others), metagraywacke (in part equivalent to the Peters Creek Formation of Knopf and Jonas, 1929a, 1929b), and the upper pelitic schist. The fifth lithofacies is metaconglomerate, which forms a local lens within the much more voluminous metagraywacke lithofacies.

In southern Harford County, the Wissahickon Formation is overlain with apparent conformity by a sequence of interbedded quartz amphibolite and felsic biotite-hornblende-quartz-plagioclase gneiss that is termed the James Run Gneiss. In northern Harford County, at the Peach Bottom syncline, the Wissahickon is overlain with possible unconformity by the Cardiff Metaconglomerate, which in turn is overlain by the Peach Bottom Slate. The ages of the James Run, Cardiff, and Peach Bottom are uncertain. Recent interpretations of radiogenic ages (C. A. Hopson, unpub. data, 1967) indicate a late Precambrian to Cambrian age for the James Run, but more corroborative dates are needed. The Cardiff and Peach Bottom, on the other hand, are tentatively assigned to the Ordovician on the basis of questionable fossils and speculative lithologic correlation with known Ordovician rocks at Arvonia, Virginia.

The volcanic complex of Cecil County occupies small areas in the vicinity of Havre de Grace. These felsic to intermediate schists, for the most part in the upper greenschist or lower amphibolite facies of metamorphism, were derived from lava flows and volcanogenic sediments. They may be correlative with the more thoroughly metamorphosed James Run Gneiss, but they are surrounded by younger intrusive rocks and direct correlation is impossible.

Mafic intrusions were emplaced in the Glenarm Series, James Run Gneiss, and volcanic complex of Cecil County early in the cycle of deformation and metamorphism and were followed by syntectonic intrusions of granitic rocks. The mafic plutons (principally the Baltimore-State Line Gabbro-peridotite complex and the metagabbro near Aberdeen) have not been dated directly but are known to be older than 525 m.y.-old granitic rocks which invade them (Davis and others, 1965).

The largest mass of granitic rock in Harford County is moderately to strongly foliated quartz diorite and granodiorite; it is referred to as the Port Deposit Gneiss. A separate outcrop area of foliated quartz monzonite and granodiorite northwest of the Baltimore-State Line complex may or may not be connected at depth with the belt of Port Deposit Gneiss. Small bodies of alaskitic and pegmatitic rock near the Susquehanna River at Castleton are thought to be related to this northwest mass of quartz monzonite gneiss.

The youngest crystalline rock in Harford County is augite diabase, which forms dikes that range from a few feet to several tens of feet in thickness and range in length to one mile. It is assigned a Triassic age solely on the basis of lithologic similarity to known Triassic diabase in the Newark-Gettysburg basin.

STRUCTURAL GEOLOGY

STRUCTURAL SETTING

Harford County straddles the boundary between Cretaceous and younger, unconsolidated sedimentary rocks of the Atlantic Coastal Plain on the southeast and highly complex Precambrian to lower Paleozoic metamorphic and igneous rocks of the Appalachian Piedmont on the northwest. The Coastal Plain formations unconformably overlap the crystalline Piedmont rocks; they dip very gently seaward and also thicken in that direction. Except for gentle warping, the Coastal Plain rocks are undeformed. Bedding, cross-bedding, channeling, graded bedding, and other primary sedimentary features are well preserved, and fossils are locally abundant. Open domes and basins disturb the uniform seaward dip in parts of New Jersey and southern Maryland (Minard and Owens, 1966), but none occur in Harford County.

In contrast, the crystalline rocks of the Piedmont for the most part are intensely deformed schists and gneisses in which primary features are seldom well preserved. Original sedimentary and volcanic rocks have been intricately folded, faulted, metamorphosed, and intruded by mafic to granitic plutons. Many of the intrusions were emplaced early in the history of the area and have themselves been deformed along with the rocks they invaded.

MAJOR FOLDS

The principal folds in Harford County and contiguous parts of the Maryland-Pennsylvania Piedmont are the Baltimore-Washington anticlinorium, the Peach Bottom syncline, and the Tucquan arch. Their axes are shown on Plate 2.

Baltimore-Washington Anticlinorium

The Baltimore-Washington anticlinorium (Fisher, 1963; Hopson, 1964) extends in a gentle arc from Washington, D. C., to central Harford County. Along its axial zone are mantled gneiss domes (Broedel, 1937; Hopson, 1964, p. 28–30) which have cores of Baltimore Gneiss. Overlying the gneiss are metasedimentary rocks of the Glenarm Series, consisting of the Setters Formation, the Cockeysville Marble, and the Wissahickon Formation (Southwick and Fisher, 1967). In general the rocks along the Baltimore-Washington anticlinorium are of somewhat higher metamorphic grade than elsewhere in the region, and the grade generally increases towards the exposed cores of the domes.

The Baltimore Gneiss within the domes has some features that suggest it is an older basement rock unconformably mantled by younger strata and others that suggest it is a younger rock intrusive into its mantle (*see* Hopson, 1964, p. 30 for details). That the gneiss is a pre-Glenarm basement rock is indicated by (1) its extensive transformation and migmatization as compared with the Glenarm rocks which, though highly deformed, retain obvious bedding and some internal sedimentary structures, and (2) radiogenic dating, which shows that the gneiss recrystallized in the Precambrian (1,100 m.y. ago) and again in the Paleozoic (about 440 m.y.ago). The general concordance of foliation in the gneiss near the margins of the domes to the base of the mantling beds, and the local injections of gneiss into the mantle are interpreted by Hopson (1964) as having come about as the older basement was mobilized and squeezed upward into its own cover during the second metamorphic episode. This hypothesis was first proposed by Eskola (1949) to explain the features of similar mantled gneiss domes in Finland. The gneiss domes are interpreted as protuberances on the double plunging Baltimore-Washington anticlinorium. In general, the domes are steep limbed; overturning to the south and east can be demonstrated at some localities in Howard and Baltimore Counties (Broedel, 1937, pl. 27) and is indicated on the southeast limb of the Phoenix dome in Harford County where the Setters Formation dips northwestward under the Baltimore Gneiss.

Although the flanks of the individual domes are steep at the present level of exposure, there is some evidence that the basal contact of the Glenarm Series may be nearly horizontal (though highly irregular in detail) and fairly near the surface throughout the axial zone of the anticlinorium. The Wissahickon Formation in the structural saddles between exposed domes, is chiefly coarse-grained garnet-mica schist, but within a few thousand feet of the domes, kyanite is commonly developed (Hopson, 1964, p. 76). Kyanite-bearing schist was found to occupy a large oval area of western Harford County, roughly between Upper Crossroads, Fallston, and Little Gunpowder Falls, in which no Baltimore Gneiss is exposed (see fig. 7). Garnet-staurolite and staurolite-kyanite zone boundaries are more or less parallel around this area, which may be a dome of somewhat lower structural relief that has not been unroofed by erosion. Several ovoid anomalies suggestive of buried domes appear on aeromagnetic maps over interdome areas (Bromery and others, 1964), and one of these approximately coincides with the area outlined by the metamorphic zones.

The Baltimore-Washington anticlinorium is thought to have arisen primarily by vertically directed forces, chiefly because of the diapiric nature of the domes along its axis (Hopson, 1964).

Peach Bottom Syncline

The Peach Bottom syncline is a canoe-shaped fold outlined by the Cardiff Metaconglomerate and has as its center the Peach Bottom Slate. Its limbs are subvertical but there is a suggestion of slight overturning to the northwest. Agron's investigations (1950) provide much detail on the secondary structural elements of the area.

The extent to which formations stratigraphically beneath the Cardiff Metaglomerate are involved in the Peach Bottom syncline has been a matter of controversy, and interpretation of this fold has been deeply entangled with interpretations of stratigraphy in the Glenarm Series (Hopson, 1964, p. 54–56; Southwick and Fisher, 1967). Until 1963, the Peach Bottom syncline was considered by most geologists to be a major regional structure, affecting many thousands of feet of metasedimentary rocks, that extended from Pennsylvania to central Virginia (*see*, for example, Stose and Stose, 1948). Work in Montgomery and Howard Counties, Maryland, by Fisher (1963) and Hopson (1964) failed to reveal a syncline in rocks of the Wissahickon Formation and instead indicated a west-dipping homocline as the dominant structure of the area. Hopson (1964, p. 54–55) suggested that the Peach Bottom syncline might be a minor fold that did not influence the structure of rocks below the Cardiff to any appreciable extent. For reasons discussed elsewhere (Southwick and Fisher, 1967), the Peach Bottom syncline is here considered to be a second-order fold on the southeast flank of the Tucquan arch.

Synclinal structure cannot be demonstrated directly in rocks southwest of the trough outlined by Cardiff Metaconglomerate near Pylesville. A continuation of the synclinal axis between Pylesville and Little Deer Creek is postulated but not proved on the basis of tops determined from a few scattered graded beds and the form of a poorly demarcated anticline to the southeast. Near Little Deer Creek the syncline seems to be truncated by a probable fault zone that follows a string of lensoid serpentinite bodies southwestward from Cardiff (Plate 1). The same fault zone may account for the absence of the Cardiff Metaconglomerate on the northwest limb of the syncline, northeast of Delta, Pennsylvania (Agron, 1950). A more detailed map of the Peach Bottom syncline between Pylesville and the Susquehanna River is given in Plate 3, together with several cross sections.

Tucquan Arch

The axis of the Tucquan arch coincides with that of the Mine Ridge anticline in Lancaster County, Pennsylvania (Knopf and Jonas, 1929, p. 73; Stose and Stose, 1944, p. 65; Freedman and others, 1964, p. 622) and can be traced southwest at least as far as south-central York County, Pennsylvania. The aeromagnetic expression of this fold extends into northwestern Baltimore County, Maryland (R. W. Bromery, unpub. data), but to date the fold has not been demonstrated there on the ground. In the northwest corner of Harford County, 3 miles or less southeast of the axis, bedding schistosity on the southeast limb of the arch dips gently southeast. It gradually steepens as distance from the axial zone increases.

Recently the Tucquan arch has been studied along the Susquehanna River in Pennsylvania by Freedman and others (1964). They interpret it as a cleavage arch that formed by essentially vertical movement after an earlier episode of northwest-directed recumbent folding. Although full understanding awaits detailed mapping in York County southwest of the Susquehanna, it is plain that the Tucquan arch is a major structural element in the Maryland-Pennsylvania Piedmont.

FAULTS

The geologic map of Harford County (Plate 1) shows four regional faults. Two of these are shown as located approximately, and two are queried, indicating that their existence is open to debate. Faults almost certainly are abundant but are very difficult to prove in the poorly exposed, complex metamorphic rocks of the Maryland Piedmont. They can be easily postulated in various places; only rarely can they be demonstrated.

The most important faults are those extending across the central part of the County from a point near Macton to a point roughly 2 miles north of Jarrettsville, and the queried fault extending southwest from Cardiff along a row of serpentinite lenses. The first of these faults, termed the Mill Green fault, cuts across northwest-striking schistosity in the boulder gneiss lithofacies of the Wissahickon and brings boulder gneiss into sharp contact with the metagraywacke lithofacies west of Mill Green. It is not clear whether faulting preceded, followed, or coincided with emplacement of the ultramafic mass at Cherry Hill (Plate 1), but it would seem that the long northeast-trending tail of the ultramafic mass is fault controlled. The shape of the tail, in fact, suggests right-lateral strike-slip movement. This fault could not be traced to the Susquehanna River on the Harford County side. About half a mile north of Bald Friar on the Cecil County side, however, a zone of sheared grooved rock and quartz veins is approximately on strike with the Mill Green fault and may be an extension of it.

The fault through Cardiff is less definite and subject to extensive interpretation. Evidence for faulting includes:

(1) the shape and alignment of podiform, foliated, slickensided serpentinite bodies, which in other deformed belts are associated with faults;

(2) the absence of the Cardiff Metaconglomerate just north of Delta, Pennsylvania (*see* fig. 2; also, Agron, 1950);

(3) the pronounced linearity of magnetic anomalies along this zone in Harford County and southwest (Bromery and others, 1964; *also* Bromery, unpub. data).

Regionally this zone of serpentinites and linear geophysical anomalies can be traced as far south as the Potomac River, where it coincides with a zone in which the plunge direction of dominant lineation changes from northwest to northeast (Cloos and Cooke, 1953).

It is one thing to suggest that faulting is likely and another to prove actual displacement. The map pattern in the axial zone of the Peach Bottom syncline in York County, Pennsylvania (fig. 2), can be explained by a movement plan in which rocks north of the fault move either up *or* down. Agron (1950), reasoning from displacements on small faults in the Peach Bottom Slate, concludes that rocks north of the fault moved up. I tend to favor upward motion on the south, principally because the main tectonic transport in the area has been from southeast to northwest (Freedman and others, 1964). The problem probably could be solved by detailed structural mapping in York County.

A third fault apparently cuts out an anticline in folded Glenarm strata and James Run Gneiss in the lower course of Bynum Run (Plate 4) but is not exposed. The fourth fault is postulated along the west side of the Baltimore Gabbro of Cloos and Hershey (1936) near Little Gunpowder Falls (plate 1), chiefly because of the very straight gabbro-

Wissahickon contact here and in adjacent Baltimore County, and indirect evidence for faulting on this contact farther southwest (Hopson, 1964, p. 135).

Minor faults and dislocations, both pre- and postmetamorphic, are widespread in the County. These were not studied in detail.

SMALL-SCALE STRUCTURAL ELEMENTS

Classification and Description

In this discussion the usual division of structural elements into *primary* and *secondary* will be adopted. Cloos (1964, p. 223–224) has pointed out that such distinction is difficult or arbitrary in some instances, but in many cases inherited, pretectonic structures can be separated from imposed, tectonic ones. The practice of numbering secondary surfaces and lineations in order of formation (S_1, S_2, etc., L_1, L_2, L_3, etc.) will be used wherever the order is clear (Table 1).

Primary Structural Elements

Well to poorly preserved bedding in metasedimentary rocks of the Glenarm Series is the most widespread primary structure in the County. Relict grading is locally recognizable in metagraywacke beds of the Wissahickon Formation, but graded bedding and other sedimentary structures are generally less well preserved than in Montgomery County (Hopson, 1964, p. 88–93). Probable soft-sediment disruption of laminated siltstone layers within coarse arkosic layers was noted along Deer Creek south of Cherry Hill; small folds and faults probably related to pretectonic soft-sediment slumping were noted in a few laminate outcrops between Broad Creek and Michael Run.

Compositional layering almost certainly due to original stratification is characteristic of the James Run Gneiss and is present but less obvious in the volcanic complex of Cecil County. The scale of layering (less than 1 inch to more than 20 feet) is consistent with the scale of bedding observed in subaqueous pyroclastic rocks in Washington (State), Japan, Puerto Rico, and elsewhere (Fiske, 1963).

Primary structures in the intrusive rocks are not common. Primary compositional layering occurs locally in the Baltimore-State Line gabbro-peridotite complex in Harford County, but nowhere is it as extensive or as well preserved as in northwestern Baltimore City (Hopson, 1964). Foliation parallel to the walls of small, discordant dikelets of quartz diorite is clearly a primary flowage feature related to magma injection, but foliation within the main part of the Port Deposit Gneiss is largely secondary. This matter of primary vs. secondary foliation is discussed in detail in the section on the Port Deposit Gneiss.

Secondary Structural Elements

The foliations and lineations in the crystalline rocks of Harford County are similar to those described and catalogued by Ernst Cloos (1964, p. 227–254) in Howard and Montgomery Counties. The discussion that follows is an attempt to focus on several critical problems and is not a complete treatment of all structural elements in the area. Other structural problems of the area are dealt with by Agron (1950) and by Freedman and others (1964).

In metasedimentary rocks of the Glenarm Series, the dominant schistosity is parallel to bedding. This schistosity can be recognized even in deeply weathered rocks and is the principal structural element shown on the geologic map of Harford County. Its origin

TABLE 1

SEQUENCE AND NOTATION OF PLANAR STRUCTURAL ELEMENTS RECOGNIZED IN HARFORD COUNTY AND IN OTHER AREAS OF THE MARYLAND-PENNSYLVANIA PIEDMONT

Planar Element	Sequence and notation				Remarks on Development in Harford County	
	Cloos (1964) and Hopson (1964) in Howard and Montgomery Counties	Freedman and Others (1964) along the Susquehanna River	Harford County along Axial Zone of Baltimore-Washington Anticlinorium	Northern Harford County, Generally North of Mill Green Fault		
Bedding	S_1	S_0	S_0	S_1	Generally not observed independently of S_1.	
Bedding schistosity	$S_1 = S_2$	—	S_1	S_1(?)	Dominates in axial zone of Baltimore-Washington anticlinorium. Commonly closely folded *without* development of crosscutting axial-plane schistosity.	
Axial-plane schistosity to first folds	S_3	S_1	S_2	$S_1 \cong S_2$	Dominates in northern part of Harford County where first folds are isoclinal and steeply plunging. Physically indistinguishable from true bedding schistosity except in the noses of F_1 folds, which are not common. On regional basis, therefore, this element is parallel to bedding. Steep dips predominate.	
Axial-plane schistosity to second folds	—	S_2	—	S_{3a}	A second true schistosity, with extensive recrystallization of micas along it, that is developed in northwest part of County on flanks of Tucquan arch. Nearly parallel to first schistosity over wide areas, but locally is well separated from it.	Have not been observed in same outcrop; sequence of development uncertain.
Strain-slip cleavage	S_4	S_3	S_3	S_{3b}	Spaced cleavage with only minor recrystallization parallel to it. Moderate dips to northwest or northeast are common. Lies in axial plane of steplike shear folds in $S_1 \cong S_2$.	

with respect to the folding process has been interpreted in different ways. Hopson (1964, p. 75–76), describing the lower pelitic schist of the Wissahickon Formation in Howard and Montgomery Counties, states:

"... Where only one generation of schistosity is visible it almost invariably parallels the bedding, even around the crests of folds. Where the beds are strongly folded, however, a discordant axial plane cleavage is usually superimposed; this cleavage cross cuts and crinkles the earlier bedding schistosity. This cleavage first appears only in the pelitic layers, as widely spaced shear planes near the crests of folds. With more intense deformation the cleavage planes become more closely spaced and have newly recrystallized micas aligned along them. At this stage the discordant cleavage also appears in the interstratified psammitic beds, although here it is more widely spaced and less pervasive. With still further deformation and recrystallization a through-going axial-plane schistosity pervades all beds and nearly obliterates the original bedding schistosity.

"The bedding schistosity is commonly the dominant metamorphic structure, but there is little to indicate that deformation was necessary for its development. It appears to have preceded the strong deformation, for it is best shown in flat or weakly folded strata. Where the folds become tight a newer axial-plane cleavage has overprinted the bedding schistosity. *This structure is probably mimetic after bedding, not tectonic.*" (Italics added.)

In contrast to this interpretation, Freedman and others (1964, p. 627) think that the dominant schistosity is wholly of tectonic origin in rocks of the Wissahickon Formation along the Susquehanna River. They state:

"The F_1 fold pattern is characterized by isoclinal folding that involves flowage and the development of major schistosity. Locally, quartz lenses, layers, or pods follow S_1 [schistosity] and the isoclinally folded S_0 [bedding]. The S_1 includes the dominant schistosity of the region and is defined by major reorientation and recrystallization of the micas.... The entire mass of the rocks seems to have undergone flowage along planes parallel to S_1, a flowage that has transported most of the S_0 planes into parallelism with it."

In Harford County, the relations of bedding schistosity and axial-plane cleavage to folding as described by Hopson (quoted above) are well exposed in the lower pelitic schist lithofacies of the Wissahickon Formation along the axis of the Baltimore-Washington anticlinorium, south of Jarrettsville (table 1). In that area of medium- to coarse-grained mica schists, the schistosity is carried principally by oriented plates of muscovite and biotite, which wrap around the noses of minor folds (fig. 1*p*). Crosscutting axial-plane cleavage is well developed in some folds, but over wide areas it is lacking or weakly developed. Clearly the peak of metamorphism and recrystallization followed most of the folding in this region, for the trend lines of inclusions within garnet, staurolite, and kyanite porphyroblasts are straight or very weakly curved, and the porphyroblasts themselves are randomly oriented in the foliation planes.

The situation is different in the lower grade metasedimentary rocks north of the Phoenix dome and the Mill Green fault zone. Steeply plunging isoclinal folds with strongly developed axial-plane schistosity occur in that area (fig. 2). Although plainly discordant in the crests of folds, as shown in figure 5, the schistosity is virtually parallel to bedding on the limbs. Well-preserved isoclinal fold crests in bedding (the F_1 folds of Freedman and others, 1964) are relatively scarce, however, and without them it is very difficult to distinguish axial-plane schistosity from bedding schistosity as that term is used by Hopson (1964). One reason for the apparent scarcity of isoclinal fold crests is that the axes plunge steeply, in places almost directly down the dip of the axial surface, and therefore emerge only from subhorizontal outcrops (Freedman and others, 1964, p. 629). A second reason is that many crests have been sheared out by movement on the axial-plane schistosity. Many places show all stages in the production of "pseudo-bedding"

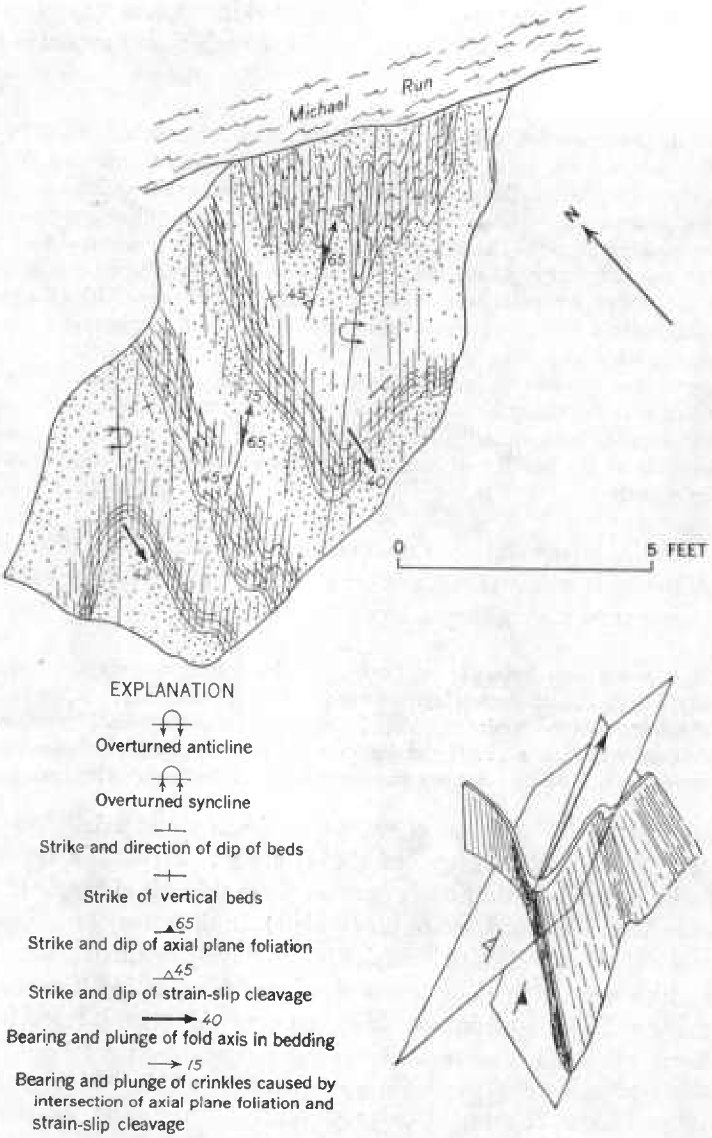

FIGURE 2. Sketch of subhorizontal outcrop of folded, interbedded metagraywacke and mica schist, metagraywacke lithofacies of the Wissahickon Formation. The metagraywacke beds are graded (heavy stipple at base); therefore anticlines and synclines may be distinguished. Axial-plane schistosity passes through the fold noses and is crinkled by intersection with strain-slip cleavage. The early fold axes plunge southward about 40°. Exposure about 1 mile above the mouth of Michael Run and 1,800 feet north of the Mason-Dixon Line in York County, Pennsylvania; visible only at very low water.

from sheared-out folds in relatively incompetent schist units (*cf.* Whitten, 1966, p. 179–196; fig. 174, p. 195). This movement partly accounts for the poor preservation of graded bedding in rocks along the Susquehanna River in contrast to the Potomac River gorge, where shearing parallel to bedding seems to have been less intense.

Folding and shearing seem to have coincided with and locally outlasted the main period of metamorphism in the northwest of the Mill Green Fault. The trend lines of inclusions within albite porphyroblasts are S-shaped, and rotation plainly occurred during crystal growth (fig. 3*p*). Garnet porphyroblasts locally have S-shaped trend lines also, and the porphyroblasts themselves may be flattened or spindle shaped (fig. 4*p*). Late shearing and the effects of retrograde metamorphism are widespread.

Evidence that bedding schistosity grades into or is obliterated by axial-plane schistosity in closely folded rocks has been put forward by Hopson (1964, p. 75–76) and Cloos (1964, p. 227–230). Such transitions occur in northern Harford County, but in most places axial-plane schistosity dominates. In southern Harford County, however, bedding schistosity in high-grade schists is prominent and intricately folded, and axial-plane schistosity is only locally developed.

This difference may be related to differences in the tectonic setting and metamorphic history of the two areas. The rocks along the crest of the Baltimore-Washington anticlinorium are thrown into crinklelike, close but not tightly appressed folds that are more or less upright to gently overturned. Regionally they are folded into broad domes and saddles. The grade of metamorphism has been moderate to high, and the schists are thoroughly recrystallized and coarse grained. It may be inferred from the diapiric character of the mantled gneiss domes (Broedel, 1937; Hopson, 1964; Cloos, 1964) that these rocks were deformed by a system in which vertical forces were dominant or at least very strong. In contrast, rocks farther north have been isoclinally folded and tightly appressed. The grade of metamorphism has been low to moderate, and relict sedimentary textures are locally preserved. There is no evidence that vertical forces were important in deforming these rocks, and indeed the pattern of early folds over the Tucquan arch and northward suggest strong horizontal compression and northwestward tectonic transport (Freedman and others, 1964).

It seems reasonable that deformation of argillaceous sedimentary rocks by vertical compression would stimulate mimetic recrystallization. New micas would tend to grow in bedding planes, parallel to primary fissility and subnormal to the main compressive stress. If the peak of metamorphism followed most of the movement, coarsely crystalline schists with strong bedding schistosity, feeble axial-plane cleavage, and slight rotation and alignment of porphyroblasts might result.

On the other hand, deformation of argillaceous sedimentary rocks by strong horizontal compression might tend to stimulate mica rotation and recrystallization in the direction normal to maximum stress, thereby forming steep axial-plane schistosity in the manner postulated by Leith (1905) and latter modified and refined by Kamb (1959). If the peak of deformation coincided with and locally outlasted the peak of regional low-grade metamorphism, schists with very well developed axial-plane schistosity and extensive porphyroblast rotation might result. This schistosity would erase earlier bedding schistosity that may have formed in an earlier stage of the deformation cycle.

Two kinds of tectonic surfaces younger than bedding schistosity have been recognized in the County (table 1). In rocks of the upper pelitic schist lithofacies of the Wissahickon, toward the axial zone of the Tucquan arch, a very strong, steeply dipping, younger schistosity (S_{3a}) cuts across and virtually obliterates earlier schistosity ($S_1 \cong S_2$). This younger element is a true schistosity with extensive recrystallization of mica along it, and it is exceedingly difficult to distinguish from the earlier schistosity because the two are nearly parallel over wide areas. There are a few outcrops, however, where they can be separated unequivocally. Because these two surfaces are difficult to separate over wide areas, especially in weathered outcrops, most of the schistosity symbols in the northwest corner of the County are hybrids and should be interpreted as giving the major "grain" of the rock rather than a specific tectonic element. The younger surfaces (S_{3a}) probably correspond to the S_2 of Freedman and others (1964, see table 1) who interpret them as axial-plane schistosity related to formation of the Tucquan arch. Movement on these surfaces during porphyroblast growth has produced S-shaped mineral trends within albite and, less commonly, within garnet.

Southeast of the queried fault that extends southwestward from Cardiff, strain-slip cleavage (S_{3b}, corresponding to the facture cleavage of Cloos, 1964) is widely developed in the rocks. In this area, the second schistosity, S_{3a}, described above, is missing or completely unrecognizable. The strain-slip cleavage strikes generally east-northeast to east southeast and dips at shallow angles northward (Plate 5). Its attitude is strongly dependent on lithology, and numerous examples of refraction occur in the sequence of interbedded metagraywacke and schist between Rocks Ridge and Slate Ridge. This structural element consists of discrete shear planes spaced less than 1 mm to several cm apart, along which mica recrystallization has been slight to moderate (fig. 5*p*). The planes are spaced more closely in pelitic rocks than in metagraywacke. Movement on these planes, which commonly are at high angles to steeply dipping bedding and bedding schistosity, has produced extreme crinkling of pelitic rocks and steplike slip folds in more competent sandy units (fig. 6*p*). The crinkles of intersection are by far the strongest and most common lineation in rocks of the metagraywacke lithofacies of the Wissahickon.

The relationship of the strain-slip cleavage to the overall tectonic history of the area is not well understood. Freedman and others (1964) conclude that the strain-slip cleavage (S_{3b} equals their S_3-south) is related to a deformation that followed the rise of the Tucquan arch. This may indeed be true, but more mapping is needed to establish the structural sequence. In many places, S_{3a} (equals S_2 of Freedman and others) cuts $S_1 \cong S_2$ and $S_3{}^b$ cuts $S_1 \cong S_2$, but I have found no outcrop where S_{3b} intersects positively identified S_{3a}. Moreover, there is inconclusive evidence for major faulting just northwest of the Peach Bottom syncline, between the areas where S_{3a} and S_{3b} are best developed. Plainly, there is much to be learned about the significance of these structures.

METAMORPHISM

Almost all the crystalline rocks in Harford County are metamorphic. Metamorphosed plutonic and volcanic rocks (Baltimore-State Line gabbro-peridotite complex, Port Deposit Gneiss, metagabbro near Aberdeen, James Run Gneiss) predominate in the southeast half of the County, whereas metamorphosed sedimentary rocks of the Glenarm Series, Cardiff Metaconglomerate, and Peach Bottom Slate predominate in the northwest half. Additional data on metamorphism may be found in descriptions of the crystalline rocks.

SOUTHEASTERN AREA

In general the metamorphosed igneous rocks of the southeastern area are of low to medium grade, ranging from upper greenschist to lower amphibolite facies. The most widespread rock of approximately basaltic composition contains blue-green hornblende, granular oligoclase, and epidote with or without quartz; this rock is therefore a typical example of the lower part of the amphibolite facies as defined by Turner and Verhoogen (1960). Albite-epidote-hornblende rocks occur locally near the Susquehanna River, and hornblende-andesine rocks are intermixed with the more common hornblende-oligoclase-epidote rocks throughout the County. Efforts to map isograds on the basis of these assemblages are hampered by: (1) bulk compositional variations, especially in the critical components Na_2O, CaO, and Al_2O_3; (2) the formidable task of separating and determining the widespread untwinned plagioclase; (3) limited exposure of fresh rock; and (4) obvious and widespread lack of chemical equilibrium. The evidence of disequilibrium is especially clear in the northeast end of the Baltimore-State Line complex, where irregular volumes of thoroughly recrystallized, partly recrystallized, and virtually fresh gabbro grade into one another in a blotchy manner for distances of a few feet or tens of feet. Probably this is partly because metamorphic water had considerable difficulty entering this massive, strong, and originally anhydrous rock mass.

Despite the difficulties in dealing with mineral assemblages in these rocks, structural and textural criteria indicate a general increase in metamorphic intensity from northeast to southwest. In a general way, the mafic rocks near the Susquehanna River are less well foliated and less completely recrystallized (in a textural sense) than they are from the center of the County southwestward. Relict minerals and textures have been obliterated in rocks in the southwest area, whereas they are locally well preserved northeast of Bel Air and north of Aberdeen.

A similar northeast to southwest transition occurs in the granitic rocks of the Port Deposit Gneiss. Original minerals and textures are obvious,though blurred by moderate shearing and recrystallization, between Level and the Susquehanna River. Secondary muscovite, epidote, garnet, and recrystallized sodic plagioclase tend to be concentrated along discrete foliation planes. The intensity of foliation (shearing) increases to the southwest, as does the degree of metamorphic recrystallization. It is not immediately obvious whether increased temperature to the southwest weakened these massive rocks so that shearing, grinding, and thorough chemical equilibration could proceed, or whether increased shearing simply improved the kinetics of metamorphic reactions.

NORTHWESTERN AREA

The metamorphosed sedimentary rocks of the northwestern half of the County range from fine-grained chlorite-albite-muscovite schists in the north and northeast areas to coarse-grained sillimanite-kyanite schists south of the Phoenix gneiss dome, southeast of Upper Crossroads (fig. 7).

The Wissahickon, Cardiff, and Peach Bottom Formations include a wide variety of original sedimentary rock types that have undergone varied regional metamorphism. Figure 7 is a map of metamorphic zone boundaries in Harford County, based on the "first appearance" of index minerals in the classical tradition of Barrow (1893, 1912) and Tilley (1925). Added to the map are the mineral assemblages observed in each zone. This map shows that the highest grade rocks are along the axis of the Baltimore-Washington anticlinorium and are spatially related to the gneiss domes. The lowest grade rocks are in the axial zone of the Peach Bottom syncline and south of it. The progression from high-grade to low-grade rocks is interrupted and confused by retrograde effects and probable faulting in a strip across the County from Mill Green west to the vicinity of Blackhorse, within which it is difficult to draw meaningful zone boundaries.

Fibrolitic sillimanite occurs in irregular patches south of the Phoenix dome and seems to be smeared across readily mapped staurolite and kyanite zones. The sillimanite forms fibrous bundles, randomly oriented for the most part, that are quite distinct texturally from the large, well-formed porphyroblasts of garnet, staurolite, and kyanite in the same rocks. They occur most commonly within muscovite, biotite, and quartz, but also replace kyanite, staurolite, and garnet (fig. 8*p*). Because sillimanite is smeared across zone boundaries and has clearly replaced large, well-formed crystals of earlier aluminous

TABLE 2

OPTICAL PROPERTIES OF SOME CHLORITES FROM THE WISSAHICKON FORMATION, HARFORD COUNTY

[Abbreviations: Lps, lower pelitic schist; Bg, boulder gneiss; Mg, metagraywacke; Ups, upper pelitic schist; Ky, kyanite; G, garnet; Chl, chlorite; Musc, muscovite; Ab, albite.]

No.	Sign	$\alpha \cong \beta$	γ	B	Ratios from Formulae, using Chidester (1962) [Al]^4/Si	Fe/(Fe + Mg)	Lithofacies and Rock Type
J-487	(+)	1.621	1.626	.005	.740	.450	Lps—retrograded Ky-G schist
F-299a	(+)	1.637	1.640	.003	.882	.610	Lps—retrograded G schist
D-246	(+)	1.626	1.629	.003	.667	.510	Bg—chl schist matrix of Bg
B-258	(+)	1.626	1.628	.002	.648	.510	Bg—chl schist matrix of Bg
C-132	(−)	1.636	1.637	.001	.510	.620	Bg—coarse metagraywacke
C-134	(+)	1.632	1.634	.002	.680	.575	Mg—thin bedded metagraywacke
D-237	(−)	1.636	1.637	.001	.510	.620	Mg—chlorite metagraywacke
D-255	(−)	1.634	1.635	.001	.510	.610	Mg—chl-musc. schist
D-252	(+)	1.625	1.627	.002	.591	.520	Bg—feldspathic metagraywacke
D-262	(+)	1.624	1.627	.003	.633	.490	Bg—feldspathic metagraywacke
F-474	(+)	1.630	1.633	.003	.702	.550	Mg—retrograded garnet schist
F-318	(−)	1.640	1.642	.002	.510	.660	Ups—retrograded garnet schist
N-418	(+)	1.627	1.632	.005	.835	.500	Ups—chl-ab schist
N-421	(+)	1.622	1.625	.003	.600	.480	Ups—chl-ab schist
F-422a	(+)	1.622	1.626	.004	.680	.470	Ups—laminated chl-ab schist (meta siltstone)
N-427	(+)	1.621	1.625	.004	.675	.465	Ups—garnet-chl-ab schist
N-510	(+)	1.635	1.639	.004	.970	.590	Ups-chl-ab schist
F-269	(+)	1.609	1.615	.006	.568	.320	Schist "chloritized" near ultramafic contact
F-274	(+)	1.620	1.625	.005	.707	.430	Do.
D-281	(+)	1.601	1.609	.008	.568	.250	Do.
D-325	(+)	1.607	1.613	.006	.551	.300	True chlorite blackwall
J-358	(+)	1.608	1.614	.006	.567	.320	Chl-actinolite-epidote schist

silicates, it seems to be related to an event that followed the peak of metamorphic recrystallization. This may have been simply a late reheating of the area. Another possibility is that sillimanite formed while the rocks were still hot, as tectonic pressure was released. As pressure decreased, possibly at the end of diapiric movement of the gneiss domes, the rocks passed from the kyanite stability field into the sillimanite field and remained there briefly, long enough for equilibrium to be established. A similar argument is put forward by Vejnar (1966) to explain kyanite-sillimanite relations in the southwestern Bohemian Massif in Czechoslovakia. There is no evidence that the fibrolite is related to pegmatite injection, as Hopson (1964, p. 98) has suggested for fibrolite on Bear Island in the Potomac.

Chlorite and Garnet in the Wissahickon Formation

Chlorite occurs in three geologically distinct environments in the metasedimentary rocks of Harford County. It is widespread in areas of low-grade metamorphism as an ordinary prograde mineral that crystallized in equilibrium with quartz, muscovite, and sodic plagioclase. It occurs as a retrograde mineral formed at the expense of the higher grade minerals biotite, garnet, and staurolite, and it occurs in zones around ultramafic masses where it has replaced earlier plagioclase and quartz of the wallrock schist and is

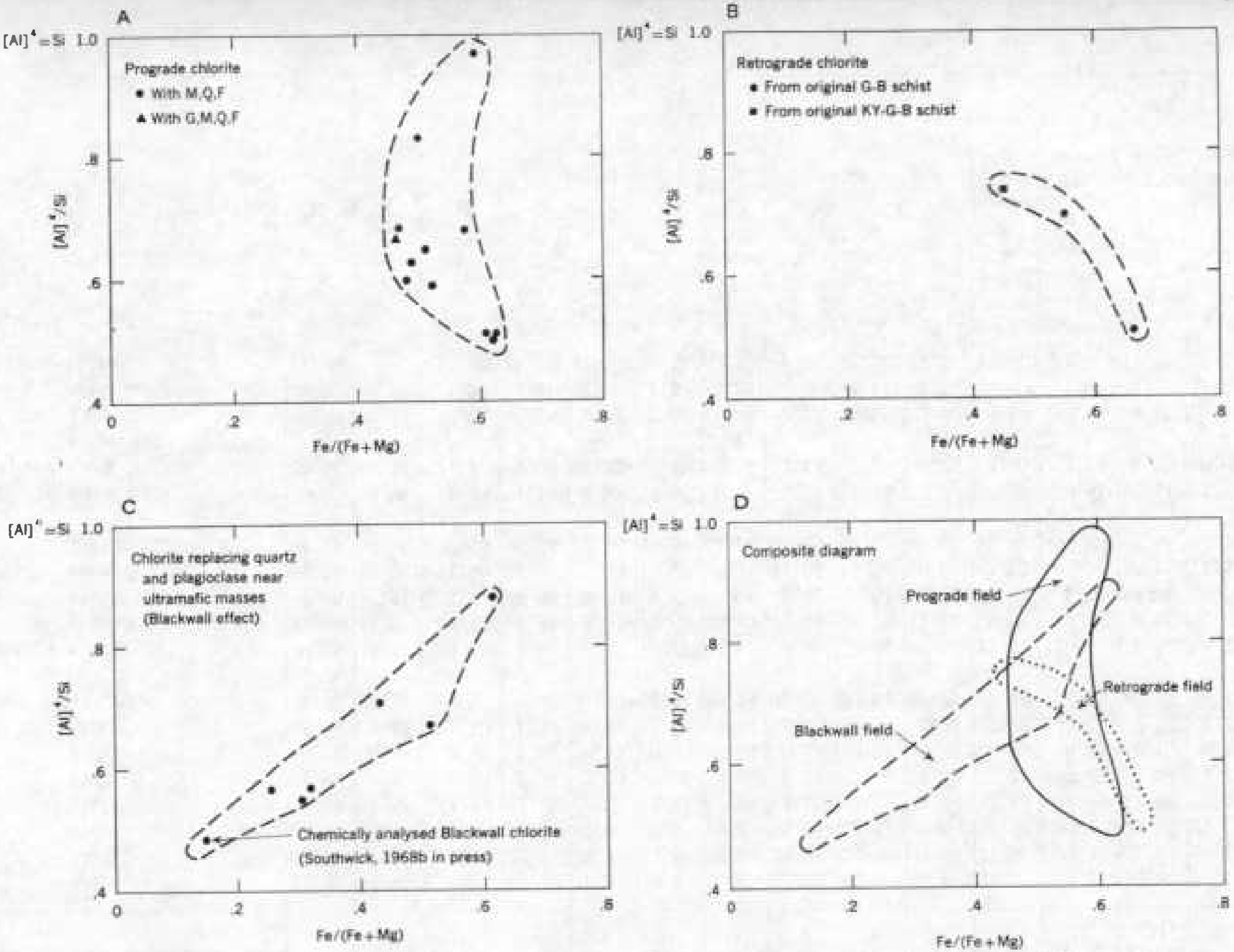

FIGURE 9. Diagram showing composition fields of chlorite in metasedimentary rocks of Harford County. Field boundaries enclose data points. Based on optical properties and Chidester's (1962) correlation diagram; subject to the usual limitations and inaccuracies of optical methods. A, prograde chlorites from ordinary chlorite-muscovite schists; B, chlorite from retrograded garnet-biotite and kyanite-garnet-biotite schists;, C chlorite replacing quartz and plagioclase near ultramafic masses (blackwall effect); D, composite diagram. Symbols: G, garnet; Ky, kyanite; B, biotite; M, muscovite; F, feldspar (sodic plagioclase); Q, quartz.

TABLE 3

PARTIAL CHEMICAL ANALYSES OF GARNET CONCENTRATES FROM PELITIC SCHISTS, HARFORD COUNTY

[Except for MgO, the analyses were made by quantitative X-ray fluorescence methods, Robena Brown, U. S. Geol. Survey, analyst; MgO determined by atomic absorption, Frank Cuttitta, U. S. Geol. Survey, analyst.]

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	SiO_2	35.3	36.8	37.5	36.9	36.8	36.8	36.6	36.5	36.0	36.8	37.0	37.5	36.6	37.1	37.4
	Al_2O_3	20.7	21.8	21.9	22.3	21.2	21.4	21.2	22.0	20.9	21.6	21.3	22.4	21.2	20.8	22.5
	FeO	30.6	31.8	31.0	31.2	32.9	32.5	29.2	31.0	32.9	30.5	29.5	30.1	29.5	31.1	31.6
	MgO	1.49	1.65	1.36	2.10	1.86	2.43	2.69	1.60	2.05	2.53	2.70	2.50	1.99	2.40	2.31
	CaO	4.85	5.25	6.40	5.06	3.00	2.85	3.88	5.65	3.19	4.18	3.22	3.72	3.68	4.32	3.10
	TiO_2	0.70	0.43	0.20	0.16	0.12	0.05	0.38	0.23	0.55	0.40	0.30	0.38	0.10	0.28	0.10
	MnO	3.95	1.42	1.80	1.30	1.62	1.50	4.80	1.03	1.05	3.75	5.40	4.75	2.95	1.37	1.18
	TOTAL	97.59	99.15	100.16	99.02	97.50	97.53	98.75	98.01	96.64	99.76	99.42	101.35	96.02	98.37	98.19
Calculated wt. percent:	spessartite	9.10	3.31	4.19	3.01	3.77	3.49	11.17	2.29	2.44	8.73	12.57	11.06	6.87	3.20	2.73
	grossularite	12.99	14.05	17.13	13.55	8.03	7.62	10.40	15.13	8.55	11.20	8.61	9.96	9.86	11.57	8.29
	pyrope	4.96	5.51	4.54	7.00	6.20	9.12	8.96	5.33	6.84	8.43	9.01	8.34	6.64	8.01	7.71
	almandite	67.73	73.50	71.60	72.10	76.00	75.10	67.24	71.65	75.90	70.05	68.18	69.54	68.11	71.68	73.02
	TOTAL GARNET	94.78	96.37	97.46	95.66	94.00	95.33	97.77	94.40	93.73	98.41	98.37	98.90	91.48	94.46	91.75
Present in inclusions of quartz, muscovite, and opaque minerals	excess SiO_2	—	0.91	1.20	1.15	1.95	1.66	—	3.25	1.13	—	0.25	0.61	2.54	1.73	3.20
	excess Al_2O_3	0.71	1.56	1.30	2.05	1.43	0.41	0.50	3.13	1.23	0.75	0.50	1.46	1.90	0.90	3.14
	excess FeO	1.30	—	—	—	—	—	0.10	—	—	0.20	—	—	—	—	—
	TiO_2	0.70	0.43	0.20	0.16	0.12	0.05	0.38	0.23	0.55	0.40	0.30	0.38	0.10	0.28	0.10
	n(Na light)	1.805	1.808	1.806	1.810	1.809	1.809	1.807	1.806	1.811	1.808	1.809	1.810	1.809	1.804	1.805
	a(Ångstroms)	11.589		11.600	11.559	11.552	11.553	11.566	11.580	11.560	11.571	11.570	11.571	11.576	11.567	11.559
Associated minerals:																
quartz		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
muscovite		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
plagioclase		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
chlorite		X	X	X					X	X						
biotite					X	X	X	X			X	X	X	X	X	X
staurolite										X					X	X
kyanite						X	X									
sillimanite						X	X									

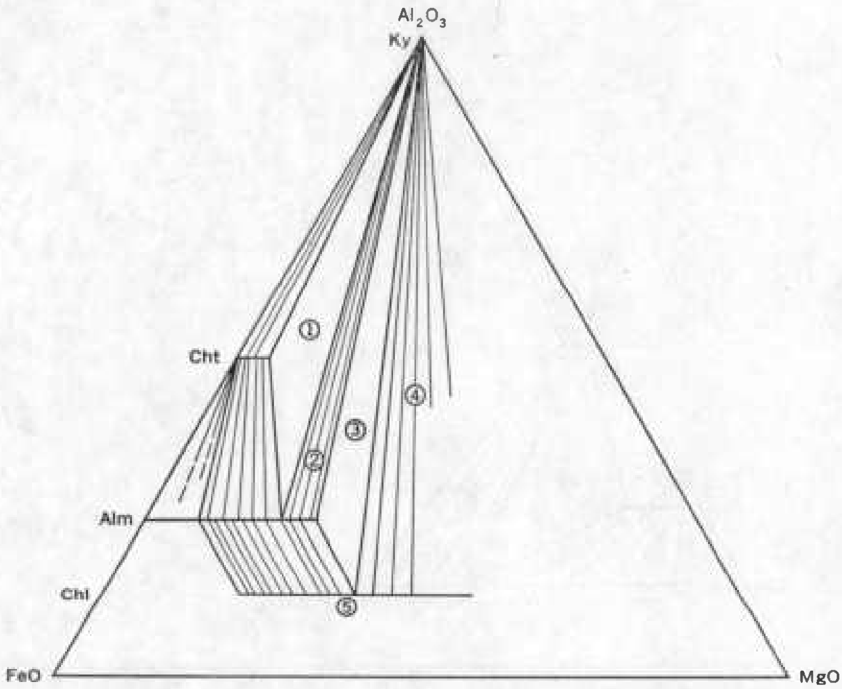

FIGURE 10. Schematic mol percent MgO-FeO-Al_2O_3 diagram showing mineral assemblages observed, together with quartz and muscovite in the metaconglomerate lithofacies of the Wissahickon Formation at Rocks Ridge. Symbols: Ky, kyanite; Cht, chloritoid; Alm, almandite; Chl, chlorite. Assemblages observed: in the central and west part, 1, Kyanite-chloritoid-almandite; 2 Kyanite-almandite; 3, Kyanite-almandite-chlorite; 4, Kyanite-chlorite; in the east part, 5, Chlorite.

plainly related to the steatization-blackwall formation process as discussed by Chidester (1962).

Optical data for some chlorites from all three environments are given in table 2, along with the compositions deduced from optical properties, using Chidester's (1962, p. 44–46) correlation diagram. These compositions are plotted in terms of $[Al]^4/Si$ vs. Fe/Fe + Mg on figure 9. It is plain from the diagrams that (1) most of the chlorite that formed by "chloritization" of schist near ultramafic bodies is more magnesian than the chlorite of normal prograde chlorite-muscovite schist, and (2) the composition field for chlorite formed from the retrogression of earlier, higher grade silicates is overlapped by the field for prograde chlorite-muscovite schist. The first relationship merely gives additional support to Chidester's (1962) conclusion that magnesium can and does migrate out of ultramafic masses during metamorphism and steatization. The second may mean (but of course does not prove) that retrograde metamorphism is nearly isochemical with respect to Fe, Mg, Si, and Al, for the same chlorites form as in prograde rocks of lower original grade.

Garnet is widespread in Harford County, occurring in all metamorphic zones. In order to establish compositional variations among garnets from different metamorphic zones and within the broad biotite + garnet zone, 15 samples were concentrated and partially analyzed by X-ray fluorescence methods. The results are summarized in table 3. Almandite is the dominant garnet end member; pyrope, grossularite, and spessartite

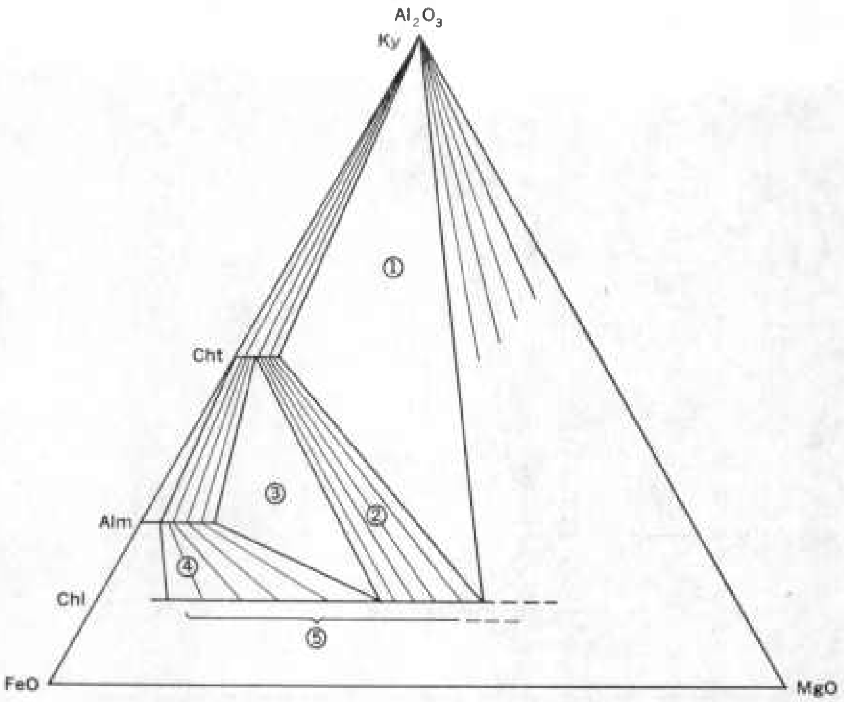

FIGURE 11. Schematic mol percent MgO-FeO-Al_2O_3 diagram showing mineral assemblages observed, together with quartz and muscovite, in the Peach Bottom Slate, Cardiff Metaconglomerate, and nearby Wissahickon Formation. Symbols: Ky, kyanite; Cht, chloritoid; Alm, almandite; Chl, chlorite. 1, Kyanite-chloritoid-chlorite (chlorite $n_\beta \approx 1.613$) 2, Chloritoid-chlorite (chlorite $n_\beta \approx 1.628$) 3, Chloritoid-almandite-chlorite (chlorite $n_\beta \approx 1.636$) 4, Almandite-chlorite (chlorite $n_\beta \approx 1.625$–1.640) 5, Chlorite (wide composition range). Assemblages 3 and 4 were seen only in retrograded rocks and may not represent equilibrium.

are all present in large enough quantities to invalidate the use of a 3-end member refractive index-cell edge diagram (Sriramadas, 1957) for determining composition.

The data show no simple, consistent pattern of variation in the composition of garnet. There seems to be a weak tendency for garnets from the staurolite and kyanite zones to contain slightly more almandite and less grossularite than garnets from the biotite + garnet zone, and for garnets from chlorite-bearing rocks to have the highest Al/Py ratios. The Al/Py ratios of garnets vary significantly within all zones, however, and seems to indicate that the composition of garnet was not fixed at any metamorphic grade.

Mineral Assemblages in Metaconglomerates

The metaconglomerate lithofacies of the Wissahickon formation and the Cardiff Metaconglomerate are schistose quartz pebble metaconglomerates containing 85 to 95 percent quartz, 3 to 10 percent muscovite, and small amounts of chlorite, kyanite, chloritoid, and sodic plagioclase. Garnet occurs only in the metaconglomerate lithofacies of the Wissahickon; the accessory minerals magnetite, rutile, ilmenite, pyrite, tourmaline, zircon, and epidote are common to both. Because the coexistence of kyanite with typical low-grade minerals such as chlorite and chloritoid is currently the subject of much petrologic interest (*see*, for example, Vrána, 1964; Albee, 1965), these rocks were studied in some detail.

Metamorphic mineral assemblages observed in the metaconglomerate lithofacies of the Wissahickon at Rocks Ridge are shown in figure 10. Rocks of the surrounding metagraywacke and boulder gneiss lithofacies are biotite-bearing adjacent to the central and west parts of the metaconglomerate lens and chlorite-bearing adjacent to the east part (fig. 7); the first appearance of garnet in the metaconglomerate corresponds roughly with the first appearance of biotite in surrounding rocks.

The assemblages observed in the lithologically similar Cardiff Metaconglomerate, as well as in closely associated Peach Bottom Slate and metagraywacke of the Wissahickon Formation, are shown in figure 11. Garnet was found only in the Wissahickon; it does not occur in the Cardiff or Peach Bottom. The assemblage kyanite-chloritoid-chlorite in the Cardiff is compatible with chloritoid-chlorite in the Peach Bottom (and also locally in the Cardiff). Chloritoid plus chlorite is a common assemblage in the chlorite or biotite zones of many metamorphic areas (for example, Harker, 1939, p. 213–214, 216); therefore, the Peach Bottom syncline is another in a growing list of places where kyanite and chloritoid coexist in low-grade metamorphic rocks (for example, Plas and others, 1958; Espenshade and Potter, 1960, p. 55–56; Vrána, 1964).

Because the pelitic rocks surrounding the Cardiff Metaconglomerate are chlorite-bearing and those surrounding the western two-thirds of the lens of metagraywacke in the Wissahickon at Rocks Ridge are biotite-bearing (fig. 7), the presence of garnet in the metaconglomerate at Rocks Ridge (fig. 7) may be the result of somewhat higher metamorphic grade. Inspection of figures 10 and 11 suggests that the assemblage chloritoid + chlorite of the Peach Bottom area has been replaced by kyanite + garnet at Rocks Ridge, the 3-phase fields changing accordingly. Whether this topological deduction has any basis in terms of chemical reactions remains to be demonstrated.

Chemical analyses of Peach Bottom Slate and Cardiff Metaconglomerate (table 4) show a high ratio of Al_2O_3 and total iron to MgO, a feature consistent with the occurrence of chloritoid in these rocks. An estimate of the chemical composition of the metaconglomerate matrix, shown in column 5a of table 4, was calculated from the bulk rock analysis by assuming spherical uniform quartz pebbles, hexagonal close packing, and no porosity in the parent gravel. The general chemical characteristics of this calculated matrix are remarkably similar to Peach Bottom Slate except for higher silica content (probably indicating that it was sandy) and higher total iron. The alkali to alumina ratio is nearly the same in both rocks (.156 in the Cardiff and .164 in the Peach Bottom); it does not seem, therefore, that kyanite is restricted to the metaconglomerate because of insufficient alkalis to form muscovite from all the available alumina.

Experimental work on the dry aluminosilicate system by Clark (1961) and Bell (1963) has shown that very high pressures ($\sim$7–10.5 kilobars) are required for the stable crystallization of kyanite in the probable temperature range of regional metamorphism. These pressures correspond to crustal depths of 25 to 35 km, close to the base of the continental crust. Such extreme depths seem unlikely for regional metamorphism; Clark (1961) postulated that tectonic overpressures of as much as 3.7 kilobars could be caused by orogenic forces and supported by the strength of the rocks. This would reduce considerably the depth required for kyanite crystallization. More recently, Newton (1966) has obtained results of hydrothermal experiments which indicate that kyanite is stable at pressures of 3 to 5 kilobars and temperatures of 450°–550°C, well within the probable field of regional metamorphism. These results, coupled with Clark's overpressure hypothesis (1961) may explain the widespread occurrence of kyanite in low- and medium-grade metamorphic terranes such as the axial zone of the Peach Bottom syncline.

TABLE 4

CHEMICAL ANALYSIS OF PEACH BOTTOM SLATE AND CARDIFF METACONGLOMERATE

	Peach Bottom Slate				Cardiff Metaconglomerate	
	1	2	3	4	5	5a
			Major Oxides			
SiO_2	56.6	55.88	58.37	60.32	90.6	64.90
Al_2O_3	21.8	21.85	21.99	23.10	3.9	15.2
Fe_2O_3	1.3	9.03	10.66	7.05	2.3	9.0
FeO	8.7				0.82	3.2
MgO	1.3	1.50	1.20	0.87	0.16	0.63
CaO	0.18	0.16	0.30	—	0.03	0.12
Na_2O	0.38	0.46		0.49	0.13	0.51
K_2O	3.2	3.64	1.93	3.83	0.48	1.9
H_2O+	4.2	3.39	4.03	4.08	0.75	2.9
H_2O-	0.29	—	—	—	0.02	0.08
TiO_2	1.2	1.27	tr	—	0.24	0.94
P_2O_5	0.23	—	—	—	0.06	0.23
MnO	0.09	0.58	tr	—	0.04	0.16
CO_2	<0.05	—	0.39	—	<0.05	—
C	—	1.79	0.93	—	—	—
SO_2	—	0.02	0.11	—	—	—
FeS_2	—	0.05	—	0.09	—	—
TOTAL	99.4(7)	99.62	99.91	99.83	99.5(3)	99.7(7)
			Trace Elements			
B	.005				<.003	
Ba	.07				.015	
Be	.0002				—	
Co	.0015				.001	
Cr	.015				.0015	
Cu	.003				.002	
Ga	.003				.0005	
Nb	.002				.001	
Ni	.005				—	
Pb	—				.002	
Sc	.002				—	
Sr	.007				.0007	
V	.01				.003	
Y	.005				—	
Yb	.0005				—	
Zr	.015				.01	

1. Peach Bottom Slate, dump of quarry just north of Maryland Route 136, Whiteford, Md. (**new analysis:** U. S. Geol. Survey rapid method).

2. Slate from Humphrey quarry, Delta, Pa.: Frazer, 1880, p. 270; A. S. McCreath, analyst.

3. Slate from York County, Pa.: U. S. Geol. Survey, 1899, p. 399, Booth, Garrett, and Blair, analysts.

4. Slate from Lancaster County, Pa.: Merrill, 1906, p. 119.

5. Cardiff Metaconglomerate, outcrop near jct. of Ridge Road and Bay Road, Harford County, Md. (**new analysis:** U. S. Geol. Survey rapid method).

5a. Approximate composition of metaconglomerate matrix *calculated from analysis 5*, assuming spherical, uniform quartz pebbles, hexagonal close packing, and no original porosity.

Another possible factor, difficult to assess, is the "piston effect" between relatively strong quartz pebbles under the influence of tectonic stress. It is conceivable that larger local overpressures could be maintained in conglomerates than in weaker pelitic rocks because of the strength and relative chemical inertness of the pebbles. Thus, kyanite may have formed in local high-pressure domains between opposed pebbles in the metaconglomerate units and did not form in adjacent pelitic units because the required overpressures could not develop.

DESCRIPTION OF THE CRYSTALLINE ROCKS

BALTIMORE GNEISS

Name and Stratigraphic Setting

The Baltimore Gneiss is the oldest rock in the Maryland Piedmont. It crops out in the cores of seven anticlinal domes in Baltimore, Howard, and Harford Counties and in a belt in Baltimore City that is overlapped by sedimentary rocks of the Coastal Plain (Hopson, 1964, p. 29, fig. 12). The gneiss in the domes lies unconformably beneath metamorphosed sedimentary rocks of the Glenarm Series and is cut by younger granitic rocks. It is a complex assemblage of granitic gneiss, veined gneiss, augen gneiss, amphibolite, and migmatite that is characterized at many places by contorted folds, ptygmatic veinlets, and other evidence of highly plastic deformation. Well-layered paragneiss occurs mainly in the belt along the Fall Line in Baltimore City, which does not seem to be within a mantled gneiss dome. This lithology occurs at the type area of Baltimore Gneiss along Jones Falls and Gwynns Falls (Williams, 1892; Hopson, 1964, p. 31). In this report the term "Baltimore paragneiss" is used informally for these well-layered rocks.

In Harford County, the Baltimore Gneiss underlies muscovite quartzite of the Setters Formation at the east end of the Phoenix dome in the neighborhood of Taylor and My Lady's Manor. The old geologic map (Maryland Geol. Survey, 1904) also shows a large area of Baltimore Gneiss in the southern part of the county, but my work indicates that most of this was incorrectly mapped. A small area of porphyritic biotite-microcline-quartz-plagioclase gneiss occurs along Bynum Run a short distance above the Fall Line (Plates 1 and 4). It is overlain by rocks lithologically like the upper member of the Setters Formation, which are in turn overlain by Wissahickon-like garnet schist. Because this porphyritic gneiss is beneath Setters-like rocks and seems to be confined to the core of a tight anticline (Plate 4), it is thought to be a phase of the Baltimore Gneiss that was remelted and emplaced during the formation of the gneiss domes.

The rest of the area shown as Baltimore Gneiss by Mathews and Johannsen (*in* Maryland Geol. Survey, 1904) is underlain by phases of the Port Deposit Gneiss complex, slivers of schistose rocks belonging to the Glenarm Series, and the James Run Gneiss. The James Run Gneiss is a well-layered paragneiss lithologically very similar to the Baltimore paragneiss, and in all likelihood it is this similarity that led Mathews and Johannsen (*in* Maryland Geol. Survey, 1904) to map the area as Baltimore Gneiss. The James Run Gneiss does not occur inside a dome; it seems to conformably overlie part of the Wissahickon Formation and may be part of the Glenarm Series. Quite possibly, James Run Gneiss is correlative with the paragneiss at Baltimore (or approximately so) and both are younger than the Baltimore Gneiss of the mantled gneiss domes. Detailed mapping between Baltimore and southern Harford County and more radiogenic dates are needed to clarify this matter fully.

Petrography

The various phases of the Baltimore Gneiss have been described by Hopson (1964, p 28–54), who discusses their petrogenesis in considerable detail. Nothing in Harford County conflicts with Hopson's interpretations, which are based on far better exposures in Baltimore and Howard Counties, and interested readers are urged to consult his work for a full treatment of the Baltimore Gneiss. Discussion is here restricted to brief descriptions of rocks that crop out in Harford County.

Veined gneiss grading towards migmatite forms two low outcrops in the Phoenix dome in a pasture near Turner Road about 0.7 mile south of Houcks Mill Road. Judging from float, similar rock underlies most of the area within the nose of the dome as outlined by the Setters Formation, but no other outcrops exist.

The rock is dark, medium-grained biotite-plagioclase-quartz gneiss that is streaked by layers or veins of quartz, microcline, and plagioclase. There is a complete gradation in scale between millimeter-size quartz-feldspar segregations and quartz-feldspar veins that reach a maximum of several inches in thickness and are more or less lenticular in shape. Contacts of the veins are essentially concordant and most are gradational.

Textural evidence indicates that the quartz-feldspar veins grew in the solid state by metasomatism or exudation. All stages can be seen in the development of veins by the coalescence of microcline porphyroblasts. In the earliest stages of the process, individual porphyroblasts were separated by "host" biotite gneiss. More and more porphyroblasts grew along certain favored planes and gradually joined together to form veins in which there are vague streaks and inclusions of biotite gneiss. It is difficult to tell whether the veins originated by exudation of material from the host rock or if they represent addition of material, notably potassium, from a remote source. There is no evidence that they are *lit-par-lit* injections of granitic magma.

Porphyritic biotite-microcline-quartz-plagioclase gneiss that crops out along Bynum Run near the bridge on Hookers Mill Road is a well-foliated, medium-grained rock spotted with sheared megacrysts of plagioclase as long as 2 cm. The plagioclase megacrysts originally were euhedral, but most of them now have mortared edges and a crudely lensoid shape due to shearing. The have weak compositional zoning, somewhat disturbed by shearing and incipient recrystallization, over the range An_{25} to An_{35}, and are well twinned on the carlsbad and albite-carlsbad laws. Some crystals are antiperthitic, having about 1 to 5 percent exsolved potassium feldspar in the form of small blebs and rods.

The large plagioclase crystals are set in a groundmass of quartz, deep-olive-brown biotite, plagioclase, and microcline that has been sheared and recrystallized to varying degrees. Microcline seems to have crystallized late. It extensively replaces earlier groundmass minerals, especially where they have been granulated, and locally invades the mortared edges of plagioclase megacrysts. It also forms sieved porphyroblasts as large as about 5 mm in diameter. Zoned epidote crystals with allanite cores are characteristic of this rock. Their external form has been modified by shearing, but many euhedral allanite cores have survived. Muscovite forms widely scattered sieved flakes, and granular sphene is a common accessory.

The large plagioclase euhedra and the zoned epidote-allanite crystals are interpreted as relicts from an igneous porphyritic granodiorite and formed early in the crystallization sequence. Following them in order of crystallization were biotite, quartz, and microcline. Microcline probably began in the late magmatic stage and continued to

TABLE 5
MODAL ANALYSES OF BALTIMORE GNEISS, HARFORD COUNTY

	1	2	3
Plagioclase	31.2	39.4	37.8
Quartz	30.0	26.1	28.6
Microcline	12.4	21.0	9.8
Biotite	23.3	10.3	18.3
Muscovite	1.1	1.8	1.4
Chlorite	—	0.1	tr
Opaques	0.2	0.1	0.3
Epidote	0.1	tr	2.1
Apatite	0.6	0.3	0.4
Sphene	0.8	—	0.9
Zircon	0.1	tr	tr
Tourmaline	—	0.1	tr
Allanite	tr	0.2	0.4
Carbonate	—	0.6	tr
Myrmekite	0.1	tr	tr
TOTAL (vol. percent)	99.9	100.0	100.0
No. of points	1416	1407	1393

1. Veined gneiss, Phoenix dome, near Turner road about 0.7 mile south of Houcks Mill road.
2. Porphyritic gneiss, lower Bynum Run, about 400 feet south of Hookers Mill road.
3. Porphyritic gneiss, lower Bynum Run, about 700 feet north of Hookers Mill road.

form as the rock solidified and underwent protoclasis. Residual potassium-rich fluids were channelled along granulated zones in the already crystallized rock and caused extensive replacement of earlier minerals by microcline.

The foliation of the gneiss is parallel to that of the overlying Setters Formation and suggests that emplacement of the porphyritic granodiorite was syntectonic. Probably magmatic flowage, protoclasis, and later regional shearing all graded into one another and occurred in response to the same tectonic forces.

There are numerous petrographic similarities between this rock and the Ellicott City Granodiorite of Hopson (1964, p. 168–175) in Baltimore and Howard Counties. Both have early-formed plagioclase, zoned epidote-allanite, and late-formed microcline of complex paragenesis. Modal compositions are also similar (table 5; see also Hopson, 1964, table 41, p. 172). Biotite- and hornblende-rich inclusions are abundant in the Ellicott City Granodiorite (Hopson, 1964, p. 168–169) and locally are fairly numerous in the Harford County rock. The abundance of mafic inclusions and the scarcity of schist inclusions even near contacts with schist led Hopson (1964, p. 169) to propose an anatectic origin for the Ellicott City pluton. He states (p. 169):

"A more reasonable explanation [for the scarcity of schist and the abundance of mafic inclusions] is that the granodiorite originated by anatexis of migmatitic basement, and the dark inclusions are unmelted remnants of the more refractory biotitic layers in the migmatite which have been disrupted and smeared out by flowage. Similar dark inclusions have originated in this way in the diapiric Gunpowder Granite, where anatexis can be demonstrated."

The porphyritic gneiss along Bynum Run is only a few miles from the east end of the Towson dome where Gunpowder Granite has formed by partial melting of Baltimore Gneiss. Because demonstrable anatexis did proceed nearby during the rise of the Balti-

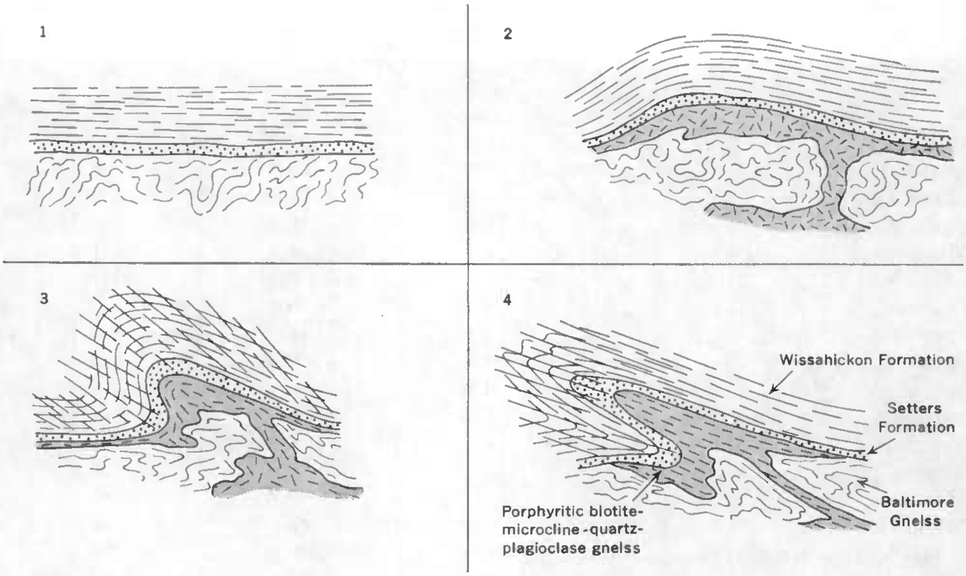

FIGURE 12. Schematic sequence of events leading to presence of rheomorphic facies of Baltimore Gneiss in core of tight anticline. 1, gneissic basement covered unconformably by sedimentary rocks. 2, deformation begins; basement gneiss heated and confined beneath cover as it becomes mobilized. 3 and 4, deformation intensifies and mobilized gneiss moves into core of anticline formed in cover.

more gneiss domes, it seems plausible to suggest that the gneiss on Bynum Run may also have formed by partial melting of Baltimore Gneiss.

There is no evidence along Bynum Run that the porphyritic gneiss actually intruded overlying metasedimentary rocks. It may have formed beneath the Setters Formation and moved into the core of a tight anticline as basement and overlying strata were deformed together, possibly as diagrammed in figure 12.

Age

Radiogenic dating of zircon and potassium feldspar (Tilton and others, 1958, 1960) indicates that migmatitic gneiss and related rocks in the cores of the domes underwent a period of crystallization about 1,100 m.y. ago and therefore are Precambrian in age. Zircons from layered gneiss at the type locality of Baltimore Gneiss, however, yield ages of about 600 m.y. (preliminary data, Bruce Doe, written commun., 1963), and this rock may not be equivalent to the more thoroughly transformed gneiss of the mantled domes, as formerly assumed. For the present, the layered gneiss is still considered to be part of the Baltimore Gneiss, but the need for careful restudy and possible redefinition is recognized.

SETTERS FORMATION

Name and Stratigraphic Setting

The Setters Quartz Schist was named by Williams and Darton (*in* Williams, 1892) for Setters Ridge near Towson, Baltimore County, where it is well exposed. Knopf and Jonas (1929b, p. 152–153) recognized that feldspathic schist and mica gneiss were significant members of the quartz-rich sequence and revised the name to Setters Formation.

The Setters Formation unconformably overlies the Baltimore Gneiss (see Hopson, 1964, p. 57 for a summary of the evidence for unconformity) and is overlain by the Cockeysville Marble. Its thickness is given by Choquette (1957, p. 5) as 0 to 750 feet. The irregular thickness and local absence of the Setters has been attributed to nondeposition and sedimentary overlap on an irregular basement surface (Knopf and Jonas, 1923, p. 45; Bascom and Stose, 1932, p. 10; Hopson, 1964, p. 59) and to tectonic stretching on the limbs of tight folds (McKinstry, 1961, p. 559–560). Both explanations probably are valid. At the nose of the Phoenix dome in Harford County the Setters seems to have been thickened by tectonic shearing, indicating that tectonic thinning may have occurred on the limbs.

Lithology

Three members of the Setters Formation are recognized in Baltimore County (Knopf and Jonas, 1929b, p. 153–155; Hopson, 1964, p. 59–61). The lower member is chiefly medium-grained feldspathic quartz-mica schist with thin beds of quartzite interstratified near the base. In places it is granitized near its contact with Baltimore Gneiss. The middle member consists of microcline quartzite and muscovite quartzite with a few interbeds of mica schist. The upper member is feldspathic mica schist with numerous beds of finer grained, more quartzose rock termed mica gneiss by Knopf and Jonas (1929b) and some thin quartzite beds. Schistose rocks of the lower and upper members contain quartz, muscovite, biotite, microcline, and plagioclase; microcline is an essential constituent and serves to distinguish schists of the Setters Formation from grossly similar but microcline-poor schists of the Wissahickon Formation (Hopson, 1964, p. 61–62).

Muscovite quartzite of the Setters Formation wraps around the nose of the Phoenix gneiss dome in western Harford County. Highly micaceous rocks are scarce, and neither an "upper" nor "lower" member can be distinguished. Along the lower courses of Bynum and Winters Runs, south of the main belt of Glenarm metasedimentary rocks, well-bedded microcline-mica schist and mica gneiss overlie porphyritic biotite-microcline quartz plagioclase gneiss (probably a phase of the Baltimore Gneiss) and underlie garnet-mica schist (probably Wissahickon). These rocks occupy the stratigraphic position of the Setters Formation and are lithologically like its upper member. Here the quartzitic middle member is absent.

Calcite marble containing a few percent quartz crops out in a bed as thick as 12 feet at the base of an old quarry face on the east bank of Winters Run about 0.8 mile upstream from Interstate Highway 95. The rock is a good quality, snow-white marble and is obviously the material that was sought in quarrying, even though it is overlain by about 40 feet of weathered and fresh Setters mica gneiss. The contacts of the marble bed are parallel to bedding foliation in the Setters, and the bed seems to be a lenticle in that formation. On the west side of Winters Run the marble is only about 4 feet thick, and Setters-like rocks occur on both sides of it.

Petrography

The Setters Foundation, where exposed around the nose of the Phoenix dome, is a muscovite quartzite (table 6). Quartz forms an interlocking, crystalloblastic mosaic; the muscovite is imperfectly oriented except on certain foliation planes spaced an inch to several inches apart. These planes are covered by well-oriented mica flakes and cause the rock to split easily into flags. Unlike the Setters quartzite near Baltimore, the Harford County rock contains little tourmaline. Opaque minerals, zircon, and rutile are the com-

TABLE 6

MODAL ANALYSES OF THE SETTERS FORMATION, HARFORD COUNTY

	1	2	3	4	5
Plagioclase	—	28.4	0.3	1.0	25.5
Quartz	87.5	36.4	40.4	29.2	32.5
Microcline	tr	14.0	42.1	40.4	4.4
Biotite	—	16.1	9.5	21.9	27.0
Muscovite	10.5	3.4	4.5	3.0	7.5
Garnet	—	—	—	1.7	—
Opaques	1.3	0.5	2.8	2.5	1.2
Epidote	tr	—	tr	—	tr
Apatite	—	0.2	0.1	tr	0.5
Sphene	tr	0.6	tr	tr	tr
Rutile	0.4	—	—	—	—
Zircon	0.3	tr	0.3	0.2	tr
Tourmaline	—	—	—	0.1	—
Allanite	—	—	tr	—	—
Clay minerals	—	0.4	—	—	—
Carbonate	—	—	—	—	1.4
TOTAL (vol. percent)	100.0	100.0	100.0	100.0	100.0
No. of points	1436	1368	1594	1654	1332

1. Muscovite quartzite, Phoenix dome, just north of Houcks Mill road about 0.5 mile northeast of Little Gunpowder Falls.

2. Granular mica gneiss, lower Bynum Run about 0.5 mile north of Hookers Mill road.

3. and 4. Mica gneiss, lower Winters Run about 0.9 mile upstream from Interstate Highway 95. Samples from adjacent 6-inch beds.

5. Mica gneiss 2 feet above marble bed, lower Winters Run about 0.8 mile upstream from the Interstate Highway 95.

monest accessory minerals. Slightly argillaceous quartz sandstone probably was the parent material from which the muscovite quartzite was derived.

Along lower Bynum Run and Winters Run the Setters Formation is microcline-mica schist and mica gneiss. Quartz, muscovite, biotite, microcline, and plagioclase are the chief minerals of these rocks (table 6). The micas are strongly aligned in the schistose rocks, and spindle-shaped grains of quartz and feldspar are elongated parallel to them. In the gneissic rocks are millimeter- to centimeter-thick laminae rich in feldspar, quartz, or feldspar and quartz, between which more mica-rich layers occur. Many of these have sharp contacts and are of large lateral extent relative to their thickness, perhaps indicating that they are relict sedimentary laminae of contrasting composition rather than the product of metamorphic segregation.

The schists and gneisses of the Setters Formation are readily distinguished from otherwise similar rocks of the Wissahickon Formation by the abundant microcline they contain. The modal analyses tabulated by Hopson (1964, p. 60, 78–80) show that microcline ranges from about 15–28 volume percent in the Setters; only 4 of 23 analyses of Wissahickon rocks report microcline at all, and the largest amount present is 3.8 percent. Plagioclase ranges from 1–8 percent in the Setters and from about 5–35 percent in the Wissahickon. No Setters rock analyzed by Hopson contains more plagioclase than microcline, and no Wissahickon rock contains more microcline than plagioclase.

Modal analyses of the rocks along lower Bynum and Winters Runs show that microcline is an important and ubiquitous constituent (table 6). However, not all the rocks have high microcline to plagioclase ratios, and rocks with more plagioclase than microcline are not rare.

If the unusually potassic composition of some Setters rocks is due to derivation from anomalously potassic parent sediments, as Hopson (1964, p. 64–66) quite reasonably suggests, then those rocks with lower K_2O/Na_2O ratios (as indicated by the microcline/plagioclase ratios) probably were derived from sediments with more nearly normal ratios of K_2O/Na_2O.

Mica gneiss of the Setters Formation within a few feet of the contact with underlying porphyritic biotite-microcline-quartz-plagioclase gneiss contains a few concordant pegmatitic lenticles that have formed along the bedding foliation. These have grown by replacement and probably are the result of small-scale potassium metasomatism from the subjacent anatectic Baltimore Gneiss.

Marble in the Winters Run quarry is chiefly calcite with a few percent quartz and traces of muscovite and phlogopite. The texture is completely crystalloblastic, and the calcite crystals have numerous twins and glide planes. The marble cropping out west of Winters Run contains phlogopite, tremolite, zoisite, microcline, and plagioclase in addition to calcite and quartz. The center of the bed is fairly pure calcite marble, but the edges are rich in silicate minerals. It is not certain whether this represents original composition or is the result of chemical migration during metamorphism across a carbonate-shale contact. Calcite marble and feldspathic mica gneiss are in sharp contact, showing no evidence of reaction, in the Winters Run quarry; this slightly favors original composition.

Evidence of former complex flow-folding is preserved in some quartz and microcline grains that have isoclinal folds marked out with opaque inclusions (fig. 13*p*).

COCKEYSVILLE MARBLE

The Cockeysville Marble was named by G. H. Williams (1892) for the town of Cockeysville, Baltimore County, where it has been extensively quarried for many years. It consists of metadolomite, calcite marble, and various calc-silicate rocks; of these, metadolomite and calcite marble are the most voluminous, and calcite marble is the most important commercially.

The Cockeysville Marble overlies the Setters Formation and is overlain by the Wissahickon Formation. Its breadth of outcrop in Baltimore and Howard Counties ranges from zero to several thousand feet, but this is not a measure of the stratigraphic thickness. Minor folding and tectonic flowage have greatly modified the original thickness, estimated by Choquette (1960, p. 1032) to be about 750 feet. Because it weathers and erodes easily, the marble underlies valleys, whereas the more resistant Setters and Wissahickon Formations hold up low ridges and gently rolling uplands. Thus, natural outcrops of marble are poor, and mapping depends in many places upon recognition of float and residual soil characteristics. In such manner, the Cockeysville Marble has been traced around the northeast end of the Phoenix dome in Harford County even though no outcrops exist.

A lensoid bed of marble about 12 feet in maximum thickness occurs interbedded in biotite-microcline-quartz gneiss on Winters Run about 0.8 mile upstream from Interstate Highway 95. This unit was mapped as the Cockeysville by Mathews and Johannsen (1904) and has been so considered by the marble industry ever since (oral communication, 1967, from geologists of Harry T. Campbell Sons' Corporation). The gneiss enclosing the marble is lithologically like the upper member of the Setters Formation. The marble, therefore, is here considered to be a local bed in the Setters and is discussed more fully in the section on the Setters Formation.

Because the Cockeysville Marble fails to produce a single solid outcrop in Harford County, its lithology there is impossible to describe. Small cobbles of yellowish metadolomite and honeycombed, highly leached nodules of tremolite rock occur scattered in red residual soil in the valley of Yellow Branch south of the Elkridge-Harford Hunt Club, but even these are rare. Interested readers are referred to the excellent paper by Choquette (1960) for structural and petrologic details of the Cockeysville Marble.

WISSAHICKON FORMATION

Name and Stratigraphic Setting

The Wissahickon Formation, first named by Bascom (1902) for Wissahickon Creek near Philadelphia, Pennsylvania, is a very thick sequence of metamorphosed sedimentary rocks that overlies the Cockeysville Marble. It is the uppermost and by far the most extensive formation in the Glenarm Series (Southwick and Fisher, 1967).

Because of its general uniformity over wide areas, the lensing, intertonguing habit of locally distinct lithologies within it, and its poor exposure, variable metamorphism, and structural complexity, this formation is troublesome to define and difficult to subdivide with precision. The evolution of terminology applied to these most confusing rocks has been summarized by Hopson (1964, p. 70–73) and Southwick and Fisher (1967).

The lithofacies nomenclature of Southwick and Fisher (1967) is followed here, in which the Wissahickon Formation is subdivided into five informal lithofacies, all of which complexly intertongue. They are: (1) *lower pelitic schist*, lithologically equivalent to the eastern sequence of the Wissahickon, as used by Hopson (1964); (2) *boulder gneiss*, lithologically equivalent to the Sykesville Formation as defined by Cloos and Cooke (1953); (3) *metaconglomerate*, lithologically equivalent to the Deer Creek Quartzite of Lesley (1892 v. 1, p. 130–132); (4) *metagraywacke*, lithologically equivalent to part of the Peters Creek Formation as used by Knopf and Jonas (1929a); and (5) *upper pelitic schist*, lithologically equivalent to the western sequence of the Wissahickon as used by Hopson (1964).

These units are not strictly stratigraphically equivalent. Isolated lenses of distinctive sedimentary facies (now metamorphosed) occur at different places in the section and along strike. Slumping and turbidity current activity apparently occurred from time to time along the deep submarine trough in which the original sedimentary rocks of the Wissahickon Formation were deposited. These episodes caused rapid and more or less local input of coarse clastic debris, whereas slower and more continuous deposition of finer material took place between and seaward from sites of slumping. There is no certainty, therefore, that lithologically similar rocks are everywhere stratigraphically equivalent.

Lower Pelitic Schist

The lower pelitic schist lithofacies of the Wissahickon Formation occurs along the axial zone of the Baltimore-Washington anticlinorium (Southwick and Fisher, 1967). It occupies a roughly triangular area in west-central Harford County, where it wraps around the northeast-plunging nose of the anticlinorium. It overlies the Cockeysville Marble on the northeast nose of the Phoenix dome; on the east and northeast it is cut off by intrusive rocks, and on the north it is in contact with the boulder gneiss, metagraywacke, and upper pelitic schist lithofacies of the Wissahickon. Part of the north contact is faulted, but where faults are absent the contacts with other Wissahickon lithofacies are gradational. A smaller area occurs south of the Baltimore Gabbro (Cloos and Hershey, 1936) and Port Deposit Gneiss, along lower Winters and Bynum Runs.

The thickness of the lower pelitic schist is difficult to estimate because of close folding and other structural complications. A minimum thickness of about 5,500 to 6,500 feet has been estimated for this unit on the flanks of the Woodstock and Mayfield domes in Howard County (Hopson, 1964, p. 74); this range is compatible with the apparent thickness north of the Phoenix dome in Harford County.

Most of the unit is medium- to coarse-grained pelitic schist that is interbedded with and gradational to less micaceous, more quartz-rich rock termed mica gneiss by Knopf and Jonas (1929b, p. 118–119) and semipelitic schist by Hopson (1964, p. 74–75). The pelitic schists are rich in muscovite and biotite; chlorite is abundant in retrograded zones. The micaceous minerals are generally well aligned and form a strong schistosity Garnet porphyroblasts are widespread and conspicuous; porphyroblastic staurolite and kyanite are developed in zones of appropriate metamorphic grade.

As mica decreases and quartz and feldspar content increases, the pelitic schists grade into semipelitic schists. The semipelites generally are finer grained than the pelites and show less segregation into mica-rich and quartz-rich laminae. They also are more competent and therefore less crinkled. As mica content and schistosity decrease, the semipelitic schists grade into psammitic granulite and quartzite. Hopson's observation (1964, p. 75) that psammitic rocks are more abundant toward the top of the section in south-central Maryland also holds for Harford County. The broad belt of Wissahickon southeast of the Phoenix dome is chiefly pelitic schist with local semipelitic zones and a few thin psammitic beds. Within about a mile of the gradational contact with the boulder gneiss lithofacies, the proportion of semipelitic and psammitic rock sharply increases.

Layers of amphibolite as thick as 50 feet occur locally, but comprise much less than one percent of the unit.

Bedding is prominent and easily seen where contrasting lithologies are intercalated but is not apparent in uniform pelitic schist. Bedding and schistosity generally are parallel, even around the noses of tight folds. The psammitic beds generally are thin, ranging in thickness from less than an inch to several feet. They are separated by intervals of micaceous schist, which may range from thin partings to sections several tens of feet or more in thickness. Graded bedding was not seen.

The rocks of this lithofacies are identical lithologically to those in Hopson's (1964) eastern sequence of the Wissahickon Formation. Inasmuch as Hopson has carefully and completely described the petrography of these rocks (Hopson, 1964, p. 76–87), their description here will be abbreviated.

Principal minerals in the pelitic schist are quartz, muscovite, plagioclase, biotite, and garnet. The commonest accessories are apatite, tourmaline, magnetite, ilmenite, and zircon; monazite, epidote, and allanite are less abundant. In the staurolite zone of regional metamorphism (fig. 7), porphyroblastic staurolite joins garnet; in the kyanite zone, kyanite also appears. Fibrolitic sillimanite is of spotty occurrence in rocks of both the staurolite and kyanite zones, but its distribution is so erratic that a separate sillimanite zone could not be mapped.

The semipelitic and psammitic rocks also contain quartz, plagioclase, muscovite,

TABLE 7

MODAL ANALYSES OF ROCKS FROM THE WISSAHICKON FORMATION, HARFORD COUNTY

	Lower pelitic schist		Boulder gneiss				Metagraywacke		Upper pelitic schist		
	1	2	3	4	5	6	7	8	9	10	11
Plagioclase	23.4	27.6	17.9	17.1*	26.5	41.7	16.0	4.7	14.6	12.9	17.0
Quartz	35.9	37.2	38.1	40.1	33.4	7.1	43.6	48.9	35.3	22.9	11.1
Microcline	—	—	—	—	—	—	—	tr	—	tr	—
Muscovite	24.5	16.6	23.2	32.7	19.3	23.0	25.9	29.3	27.4	44.9	51.7
Biotite	13.9	13.7	—	6.1	7.1	0.6	—	—	—	—	—
Chlorite	0.1	—	15.2	2.1	7.5	16.9	9.9	14.3	16.9	9.3	16.5
Garnet	0.1	1.3	—	0.1	—	—	—	—	—	—	—
Zoisite	—	—	—	0.2	0.2	—	—	—	—	—	—
Epidote	0.1	0.1	2.0	—	0.5	1.5	0.3	0.2	1.0	4.4	1.0
Opaques	1.6	2.9	3.4	1.6	5.1	8.8	1.6	1.8	3.0	4.3	1.8
Tourmaline	—	0.3	0.1	—	0.1	—	tr	0.1	—	0.2	0.1
Apatite	0.4	0.2	0.1	tr	0.1	0.3	tr	tr	0.3	0.6	0.5
Zircon	0.1	0.1	tr	tr	tr	tr	tr	tr	tr	0.1	0.1
Rutile	—	—	—	—	—	0.1	0.7	—	0.8	0.2	0.2
Carbonate	—	—	—	—	0.2	—	2.0	0.7	0.7	0.2	tr
TOTAL (vol. percent)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
No. of points	1455	1432	1391	1493	1511	1577	1466	1435	1530	1476	1527

* About 5 percent of plagioclase is antiperthitic.

1. Schist from cut on new Maryland Route 23 about 0.3 mile west of bridge over the East Branch of Winters Run.

2. Schist from small quarry near powerline on Boggs Road about 0.4 mile west of Graftons Shop Road.

3. Pebbly metagraywacke interbedded with lenses of coarser boulder gneiss, Maryland Route 623 about 0.5 mile southeast of Broad Creek.

4. Matrix of typical boulder gneiss, cut on Prospect Road at Mill Green.

5. Matrix of typical boulder gneiss, outcrop near Walters Mill Road about 0.25 mile northwest of Walters Mill.

6. Highly contorted, plagioclase-rich boulder gneiss, possibly feldspathized. Large outcrop on Deer Creek about 0.65 mile northwest of Sandy Hook.

7. Thin-bedded metagraywacke, north side of mouth of Broad Creek about 900 feet west of powerline.

8. Medium-grained base of metagraywacke bed, stream cut 0.65 mile north-northwest of Prospect.

9. Even-grained schist, tributary gulch to Deer Creek south of Urey Road about 0.5 mile east of Maryland Route 23.

10. Thinly laminated schist, probably in part derived from siltstone, Falling Branch at Kilgores Rocks.

11. Schist with prominent albite porphyroblasts, large outcrop opposite Amos Mill, south of Norrisville.

biotite, and garnet, but the proportion of quartz and feldspar to mica is higher than in the pelites. Because these rocks are less aluminous than the pelites, staurolite and kyanite are very rare in them and garnet is less abundant.

The plagioclase ranges in composition from An_{22} to An_{40} in this part of the Wissahickon. Potassium feldspar is very scarce, occurring only as a fine-grained alteration product of biotite.

In zones of retrograde metamorphism, the ferromagnesian silicates are partly to completely replaced by chlorite and white mica, and the aluminum silicates are converted to a shimmer aggregate of white mica. Locally, the plagioclase is replaced by clinozoisite plus a more albitic plagioclase, but more commonly it is sericitized.

Modal analyses of some typical schists are given in table 7. Hopson's data (1964, p. 78–81) should be consulted for a more complete picture of the mineralogy of this unit.

Original sedimentary textures have been completely eradicated. The texture is medium to coarse crystalloblastic, having strong parallelism of mica plates.

Two new chemical analyses of the lower pelitic schist lithofacies of the Wissahickon Formation from Harford County are given in table 8. They are essentially in agreement with analyses of schist calculated from modes by Hopson (1964, p. 78). Hopson (1964) has inferred from his calculated analyses that the schists originally were shales, the psammitic granulites were siltstones and fine graywackes, and the impure quartzites were siliceous shales or impure cherts.

I fully agree with Hopson's conclusion (1964, p. 86–87) that this part of the Wissahickon Formation was predominantly shale with numerous thin beds of siltstone and fine graywacke. Also present were some beds of siliceous shale, clean quartz sand, or chert, now represented by thin layers of granular quartzite, and widely separated layers of mafic rock (thin lava flows, sills, or tuffs) that now are amphibolite. The preponderance of originally shaly rocks, the thin even bedding of interstratified sandy rocks, and the absence of relict current structures indicate that deposition probably was marine, and in fairly deep water.

Boulder Gneiss

Stratigraphically above the lower pelitic schist is a sequence of gneisses and schists containing pebble- to boulder-sized detrital rock fragments. Some of these rocks are deceptively granitelike in appearance, but Hopson (1964, p. 108–112) has shown that they are metamorphosed conglomeratic sandstones, formed by the repeated slumping and mixing of still unconsolidated Wissahickon sediments. The detrital rock fragments include: 1) rounded granules and pebbles of quartz and quartz plus feldspar; 2) flattened fragments of mica schist ranging from micaceous blebs ½ inch long to slabs as thick as 3 feet and as long as 15 feet; 3) angular cobbles and irregular fragments of a wide variety of metamorphic rocks, chiefly metagraywacke, biotite-quartz gneiss, amphibolite, and calc-silicate schist. These are scattered through a remarkably uniform, poorly bedded matrix of granular garnet-oligoclase-mica-quartz gneiss, which has the chemical composition of a mixture of feldspathic graywacke and shale.

These rocks are lithologically equivalent to the Sykesville Formation as used by Cloos and Cooke (1953) and described and interpreted by Hopson (1964). Southwick and Fisher (1967) have discarded the formal name Sykesville Formation and consider these rocks to be a lithofacies within the Wissahickon Formation.

In Montgomery and Howard Counties, the term Sykesville Formation (equals boulder gneiss lithofacies) was applied only to the distinctive boulder gneiss lithology (Cloos and Cooke, 1953). In Harford County, however, a more liberal definition was found to be necessary. There, the boulder gneiss lithology occurs as discontinuous lenses from a few feet to more than a mile in legnth, scattered about in heavy-bedded metagraywacke. Numerous thin beds of fissile mica schist also are present, but metagraywacke is far more abundant. Because many of the boulder gneiss lenses are too small to map at 1:62,500, and because they are impossible to delineate except diagrammatically in areas

TABLE 8

CHEMICAL ANALYSES OF ROCKS FROM THE WISSAHICKON FORMATION, HARFORD COUNTY

	Lower pelitic schist lithofacies		Boulder gneiss lithofacies				Metagraywacke lithofacies			Upper pelitic schist lithofacies			
	1*	2*	3	4	5	6*	7	8	9*	10*	11*	12*	13*
							Major Oxides[a]						
SiO_2	65.1	65.1	70.39	66.43	71.45	71.1	73.00	72.25	51.2	66.3	58.9	65.5	60.3
Al_2O_3	14.8	14.1	14.00	16.78	14.36	13.6	10.55	11.98	25.0	15.8	19.5	17.1	18.4
Fe_2O_3	3.4	5.5	2.16	2.56	2.07	2.3	2.42	3.12	2.3	3.1	3.9	2.1	6.0
FeO	4.2	3.5	2.40	3.67	2.78	3.8	2.75	2.23	6.3	3.7	3.7	3.5	3.6
MgO	1.5	2.0	1.55	1.84	1.17	1.8	1.55	1.41	1.9	1.8	2.0	1.3	1.5
CaO	2.0	1.2	0.63	1.17	1.58	0.48	1.30	0.51	0.25	1.1	1.4	0.50	1.6
Na_2O	3.3	3.6	2.70	1.55	1.95	1.2	3.32	2.94	0.65	2.4	2.1	3.2	1.9
K_2O	2.2	1.9	3.70	2.61	3.28	2.7	2.10	2.58	5.6	2.2	4.5	2.6	2.2
H_2O+	0.94	1.0	1.65	1.95	—	2.1	2.01	2.41	4.1	2.3	2.2	2.0	2.1
H_2O-	0.06	0.05	0.04	0.05	—	0.06	—	0.15	0.22	0.04	0.03	0.06	0.00
TiO_2	1.6	1.1	0.46	0.80	—	0.80	0.90	0.83	1.6	0.60	0.97	1.2	1.1
P_2O_5	0.48	0.31	0.13	0.40	—	0.15	0.07	0.17	0.21	0.23	0.28	0.25	0.40
MnO	0.21	0.51	0.12	0.13	—	0.08	0.05	0.05	0.12	0.19	0.12	0.11	0.28
M_2O	—	—	—	—	1.30	—	—	—	—	—	—	—	—
CO_2	<0.05	<0.05	0.05	0.40	—	<0.05	0.25	0.00	<0.05	<0.05	<0.05	<0.05	<0.05
TOTAL	99.7(9)	99.8(7)	99.98	100.34	99.94	100.1(7)	100.27	100.63	94.4(5)	99.7(6)	99.6(0)	99.4(2)	99.3(8)
							Trace Elements[b]						
B	—	—				—			.005	—	—	<.003	<.003
Ba	.03	.03				.05			.07	.03	.05	.05	.03
Be	.0002	.00015				.0002			.0005	.0001	.00015	.001	.0001
Ce	.03	.03				—			.01	.01	.03	.01	.03
Co	.0015	.002				.002			.002	.0015	.002	.001	.0015
Cr	.007	.015				.007			.02	.02	.015	.01	.015
Cu	.015	.0003				.005			.001	.005	.003	.003	.007
Ga	.0015	.0015				.0015			.002	.0015	.002	.002	.002
La	.01	.01				—			—	.007	.01	.007	.01

	1	2	3	4	5	6	7	8	9	10	11	12	13
Nb	—	.001				.002			.002	.001	.001	.0015	.0015
Nd	.015	—				—			—	—	—	—	—
Ni	.003	.003				.015			.005	.003	.003	.003	.003
Pb	.0015	.0015				.0015			—	.0015	.0015	.001	.0015
Sc	.0015	.002				.0015			.002	.002	.005	.002	.005
Sr	.03	.03				.005			.02	.015	.03	.015	.015
V	.007	.015				.007			.01	.01	.015	.01	.015
Y	.01	.007				.003			.005	.005	.007	.003	.007
Yb	.001	.0007				.0003			.0005	.0005	.0007	.0003	.0007
Zr	.1	.02				.02			.015	.02	.02	.07	.07

[a] Analyses indicated by asterisk (*) are new and were done in the laboratories of the U. S. Geological Survey by methods similar to those described by Shapiro and Brannock (1962).

[b] Semiquantitative spectrographic analyses, U. S. Geological Survey.

1. Garnet-mica schist, roadcut on new Maryland Route 23 about 0.3 mile west of bridge over the East Branch of Winters Run, Harford County. Analyst: U. S. Geol. Survey rapid method, 1965.

2. Garnet-mica schist, small quarry near powerline on Boggs Road about 0.4 mile west of Graftons Shop Road, Harford County. Analyst: U. S. Geol. Survey rapid method, 1965.

3. Meta-arenite (M-251), Sykesville Formation (now termed boulder gneiss lithofacies of Wissahickon Formation). Maryland Route 97, 0.3 mile south of Glenwood, Howard County. Analyst: O. von Knorring *in* Hopson, 1964, p. 97.

4. Meta-arenite (M-133), Sykesville Formation (now termed boulder gneiss lithofacies of Wissachickon Formation). Seven Locks Road at Bells Mill Road (Batista Quarry), Montgomery County. Analyst: Penniman and Browne *in* Hopson, 1964, p. 97.

5. Meta-arenite from boulder gneiss lithofacies, Sykesville, Carroll County (originally called biotite granite). Analyst: W. F. Hillebrand *in* Williams, 1895, p. 672.

6. Pebbly metagraywacke interbedded with lenses of coarser boulder gneiss, Maryland Route 623 about 0.5 mile southeast of Broad Creek, Harford County. Analyst: U. S. Geol. Survey rapid method, 1963.

7. Peters Creek Schist (now termed metagraywacke lithofacies of Wissahickon formation), Benton, Lancaster County, Pa. Analyst: G. V. Brown *in* Knopf and Jonas, 1929a, p. 37.

8. Metagraywacke (M280-1), Maryland Route 117, 1.2 miles southeast of Boyds, Montgomery County. Analyst: H. B. Wiik *in* Hopson, 1964, p. 97.

9. Chlorite-muscovite phyllite from 1-foot bed interbedded with metagraywacke, Deep Run Road about 0.4 mile northeast of Cooper, Harford County. Analyst: U. S. Geol. Survey rapid method, 1964.

10. Even-grained albite-chlorite schist, tributary gulch to Deer Creek south of Urey Road about 0.5 mile east of Maryland Route 23, Harford County. Analyst: U. S. Geol. Survey rapid method, 1965.

11. Thinly laminated albite-chlorite schist, probably in part derived from siltstone, Falling Branch at Kilgores Rocks, Harford County. Analyst: U. S. Geol. Survey rapid method, 1965.

12. Albite-chlorite schist with prominent albite porphyroblasts, large outcrop opposite Amos Mill, south of Norrisville, Harford County. Analyst: U. S. Geol. Survey rapid method, 1965.

13. Sparingly garnetiferous albite-chlorite schist, Green Road near intersection of Long Corner Road, Harford County. Analyst: U. S. Geol. Survey rapid method, 1965.

of poor outcrop, it was decided that the metagraywacke in which these lenses occur had to be included to make a practical map unit. Therefore, the boulder gneiss lithofacies of the Wissahickon includes not only the boulder gneiss lithology *per se*, but also metagraywacke in which small lenses and tongues of boulder gneiss are scattered. As so defined, the unit outlines the northeast-plunging nose of the Baltimore-Washington anticlinorium in central Harford County, and forms a northeast-trending belt roughly from Kellogg Branch, south of Rocks Ridge, to the mouth of Broad Creek. Its contacts are gradational and difficult to place, especially in areas of poor exposure.

Quartz, plagioclase (principally sericitized or saussuritized oligoclase), and muscovite are present in all rocks of this lithofacies. Ferromagnesian assemblages vary with metamorphic grade. Northeast of a line passing roughly through Cherry Hill (indicated on Plate 1 and fig. 7 as the biotite + garnet—chlorite + garnet metamorphic zone boundary) the rocks contain chlorite + garnet, chlorite + biotite, or chlorite alone; southwest of it they contain biotite + garnet, biotite + chlorite + garnet, biotite + chlorite, or biotite alone. Scattered optical data indicate that chlorite from rocks in the chlorite + garnet zone is slightly more magnesian than chlorite in equilibrium with biotite in the biotite + garnet zone. Magnetite makes up as much as 5 percent of many rocks in this lithofacies, and they stand out as prominent positive anomalies on the aeromagnetic map of the county (Bromery and others, 1964). Epidote, tourmaline, sphene, apatite, and zircon are the principal minor accessories.

Quartz and plagioclase occur as relict sand grains in some of the less sheared, less recrystallized rocks, but in most specimens, recrystallization of sand-size material has been quite complete. Commonly only pebbles larger than about ¼ inch have survived as relicts from the sedimentary parent.

A few rocks contain muscovite in two textural forms—as fine, foliated aggregates braided among somewhat larger crystals of quartz and feldspar, and as large bent crystals diversely oriented with respect to schistosity. A similar texture in boulder gneiss from near serpentinites in southern Pennsylvania is described and figured by Lapham and Bassett (1964, p. 665), who interpret the large muscovite as a product of thermal metamorphism by the serpentinite, and the finer material as the result of later "... granitization that has destroyed pre-existing metamorphic foliation." They infer ages of about 460 m.y. for the coarse muscovite and about 330 m.y. for the fine, on the basis of potassium-argon determinations (Lapham and Bassett, 1964, p. 665). The fine muscovite unquestionably is younger than the coarse, but I see no reason to postulate "granitization." Instead, originally massive boulder gneiss has been sericitized during later shearing, which may have proceeded intermittently over a long period of time.

Modal analyses of some typical Harford County samples are given in table 7. These may be supplemented by Hopson's data (1964, p. 107) for a more complete picture of the mineralogy of the boulder gneiss. West and south of Sandy Hook, Harford County, the boulder gneiss is anomalously plagioclase-rich (table 7, col. 6). Possibly it has been feldspathized by the nearby intrusion of gneissic quartz monzonite, but proof of this is lacking.

Chemical analyses of the boulder gneiss are given in table 8, columns 3 to 6.

From its relations to other units in the Wissahickon Formation, its texture, and its composition, Hopson (1964) has concluded that the boulder gneiss in Howard and Montgomery Counties is a huge submarine slide mass formed by repeated sliding and remixing of still unconsolidated sediments. He states (Hopson, 1964, p. 112):

"Many of the features of the Sykesville could be accounted for by sliding and thorough mixing of

Wissahickon sediments alone. The Wissahickon consisted chiefly of graywacke and shale, which, if mixed together while still soft, might have yielded a sandy musdtone like the Sykesville sediment. Moreover, the vast majority of fragments found in the Sykesville could have come from disrupted Wissahickon beds. The three most abundant kinds of inclusions—metagraywacke and metasiltstone, pelitic schist chips, and calc-silicate slabs are closely matched in the Wissahickon by disrupted psammitic beds. disrupted pelite beds, and calcareous concretions. Some of the amphibolite fragments might also have come from ophiolitic beds or sills in the Wissahickon.

"Yet the Wissahickon could not have been the sole source of the fragmental material. The Sykesville also carries exotic inclusions—the quartz pebbles and fragments of gneissic basement rock—as well as abundant relict clastic quartz and feldspar grains that are much coarser than those found in the fine-grained Wissahickon sands. Furthermore, a thorough mixing of the Wissahickon—in which shale was 3 or 4 times more abundant than sandstone—would have led to a sediment considerably less sandy than the Sykesville.

"The Sykesville submarine sliding, therefore, appears to have involved not only the Wissahickon Flysch sediments but also large amounts of extraneous coarse sand, quartz gravel, and coarse fragmental debris from the basement. Such material was probably derived from a near-shore, shallow-water environment."

A similar mechanism, involving smaller scale, more local slumping, probably accounts for the local lenses of unstratified bouldery material within massive metagraywacke in Harford County.

Metaconglomerate

A highly deformed, schistose quartz pebble conglomerate underlies Rocks Ridge in central Harford County and is well exposed in large streamcuts along Deer Creek in Rocks State Park. It forms a curving wedge about 5 miles long that is about 1,200 feet thick at Deer Creek; it gradually thins to the northeast and pinches out altogether just northeast of Broad Creek. West of Deer Creek the metaconglomerate is of nearly constant thickness; its west end is blunt and probably has been faulted. The metaconglomerate wedge is conformable with rocks of the metagraywacke lithofacies of the Wissahickon formation along its north side and the eastern half of its south side. It is in probable fault contact with rocks of the boulder gneiss and lower pelitic schist lithofacies along the western part of its south boundary (*see* geologic map, plate 1).

Bedding and bedding schistosity are essentially vertical in this unit but have been thrown into step-like slip folds by movement on subhorizontal slip cleavage. Thick beds of granular to micaceous quartzite are interbedded with metaconglomerate. Within some thick beds, pebbly and sandy zones are mixed together in a manner suggesting rapid deposition, possibly in a deltaic environment. Relict festooned crossbedding was noted at one locality.

The pebbles in some metaconglomerate beds are closely packed together, and in others they are dispersed in a quartzitic to schistose matrix. Most of the pebbles are quartz. Fragments of black quartzite and mica schist occur but are decidedly rare. All pebbles show tectonic flattening to some degree. Locally they are smashed out to elongate wafers, barely recognizable as former pebbles, and having axial ratios as high as 10:1.

This unit corresponds to the Deer Creek Quartzite of Lesley (1892, p. 130–132), who noted its similarity to conglomeratic rocks (later named the Cardiff) that underlie the Peach Bottom Slate and suggested correlation. Correlation is definitely possible on the basis of lithologic similarity (both rocks contain small amounts of kyanite and chloritoid and have other petrographic characteristics in common), but no structural evidence for it has been found. Therefore the metaconglomerate at Rocks Ridge has been considered as a lithofacies of the Wissahickon Formation by Southwick and Fisher (1967). It seems to be a local conglomeratic lens interbedded in the much more voluminous flyschlike rocks of the metagraywacke lithofacies.

Quartz constitutes 85 to 95 per cent of the rocks in this lithofacies. The next most abundant mineral is muscovite, followed by chlorite, kyanite, chloritoid, garnet, and sodic plagioclase; accessory minerals include magnetite, rutile, tourmaline, zircon, epidote, ilmenite, and pyrite.

Quartz pebbles that are crushed and recrystallized to varying degrees are cemented by a quartz-rich micaceous matrix that probably was clayey sand. Sedimentary textures have been erased completely from the matrix.

Muscovite, chlorite, kyanite, garnet, and chloritoid occur in wispy, curvilinear clumps that wrap around granulated pebbles and define a weak to moderate foliation. The kyanite prisms are extensively bent and broken, indicating that movement on the foliation surfaces followed the end of kyanite crystallization.

Metamorphic mineral assemblages noted in the metaconglomerate are discussed in the section on metamorphism.

Metagraywacke

Metamorphosed psammitic rocks rhythmically interbedded with mica schist and phyllite crop out in a belt northwest of the boulder gneiss. Most of the sandy beds have the chemical composition of graywacke or subgraywacke (Hopson, 1964, p. 93; also table 4) and are called metagraywacke; inasmuch as quartz makes up less than 50 percent of many beds, metagraywacke is preferred to the alternative terms micaceous quartzite or feldspathic quartzite. The metagraywacke beds range from 1 inch to 10 feet in thickness, average about 12 inches, and have large lateral persistence with even inch-scale beds traceable for several tens of feet. Locally they are graded. In most cases, the grading is marked only by an upward diminution of quartz content and a corresponding darkening of color, but in a few beds an upward decrease in grain size is preserved. Graded bedding is better preserved and more widespread in metagraywacke sequences along the Potomac River (Hopson, 1964; Fisher, 1963) than it is in Harford County. Much of the grading in the Harford County rocks probably has been obliterated by extensive movement on schistosity parallel to bedding and further obscured by translation on closely spaced strain-slip cleavage surfaces across the bedding (fig. 5*p*). True quartzites occur from place to place in the sequence, but are uncommon.

The schists and phyllites interbedded with sandy rocks have the chemical composition of shale. The rhythmic intercalation of thin sandy and shaly beds, the relict graded bedding, and the composition of the individual beds all indicate that this sequence is a metamorphosed flysch-type deposit. Locally preserved ripple cross laminations, convolute bedding, and slump folds are also evidence of a flyschlike parent. Hopson (1964, p. 88–99) has already suggested that similar rocks in south-central Maryland were deposited from turbidity currents.

Southwick and Fisher (1967) assign to the metagraywacke lithofacies of the Wissahickon formation those sequences of rock that contain 25 percent or more of metamorphosed graywacke beds and 75 percent or less of intercalated pelitic schist. The metagraywacke lithofacies therefore grades into pelitic schist as the proportion of sandy beds decreases and grades into the boulder gneiss lithofacies as sandy beds increase and lenses of boulder gneiss appear. The broadly gradational relationships among these three rock units make their contacts difficult to map with precision, especially in areas of inferior outcrop.

In Harford County the metagraywacke is in fault contact on the southeast with the boulder gneiss, except near the Susquehanna River, where the units intergrade. Similarly, it is in probable fault contact on the northwest with rocks of the upper pelitic schist along the queried fault system extending southwestward from Cardiff. To the southwest it passes very gradually into mica schist of the lower pelitic unit. As so mapped, it corresponds to part of the Peters Creek Formation as defined by Knopf and Jonas (1923; 1929a) but differs from the Peters Creek by not including the less sandy rocks northwest of the axis of the Peach Bottom syncline. The rocks of that area, characterized by numerous thin beds of laminated metasiltstone intercalated with fine-grained mica schist, are considered to be part of the upper pelitic schist lithofacies, but their gradational relationship to the more sandy rocks of the metagraywacke lithofacies is recognized.

Most of the metagraywacke lithofacies in Harford County lies in the chlorite + garnet zone of regional metamorphism (Plate 1 and fig. 7). Biotite-bearing rocks occu-locally in that zone (just south of the trough of the Peach Bottom syncline, for example), but for the most part chlorite is the dominant ferromagnesian mineral. The psammitic rocks commonly are composed of quartz, plagioclase, muscovite, and chlorite, and widely scattered small garnets; accessory minerals include magnetite, zircon, sphene, apatite, and tourmaline. Some sandy beds contain relict sand grains of quartz and plagioclase in the oligoclase to andesine composition range. More commonly, however, the texture is wholly crystalloblastic, and plagioclase sand grains are reduced to a mosaic of recrystallized albite or sodic oligoclase, with or without associated clinozoisite.

Microcline is very rare over the unit as a whole, but one quartzite bed in the valley of Deer Creek contains several percent detrital microcline. Another pebbly quartzite bed in the same area contains small amounts of the iron-rich minerals siderite and stilpnomelane, neither of which are common in the rest of the unit. The anomalous compositions of these two beds suggest that their source was significantly different from that which supplied most of the detritus, and they may indicate catastrophic redeposition of a near-shore facies.

The pelitic interbeds commonly contain the same minerals as the associated sandy beds but in different proportions. Muscovite and chlorite are much more abundant, garnet is somewhat more common, and plagioclase is considerably diminished. Chloritoid occurs in rocks of the proper Fe- and Al-rich composition; chloritoid porphyroblasts as long as 7 mm occur in fine-grained schist near Pylesville, about 100 feet beneath the base of the Cardiff Metaconglomerate.

Within the biotite + garnet zone of the regional metamorphism, biotite becomes a major constituent of the rocks. Common assemblages, all with quartz and muscovite, are biotite, biotite + chlorite, biotite + chlorite + garnet, and biotite + garnet. At present, data are insufficient on the compositions of coexisting minerals to understand the reactions at the zone boundary. A compositional change in muscovite is suspected but has not been proved.

Modal analyses of a few typical rocks from the metagraywacke lithofacies of Harford County are given in table 7, cols. 7 and 8. Hopson (1964, p, 118, table 30, col. 3) gives a modal analysis of metagraywacke from the Susquehanna River at Broad Creek that contains 12.1 percent biotite. This must be a very local occurrence of biotite-rich rock, because all of my samples from that area contain chlorite, not biotite.

The former Peters Creek Formation and lithologically similar rocks in south-central Maryland have been interpreted by Hopson (1964, p. 118–120) as a turbidite facies within the large sedimentary complex that constitutes the Wissahickon. He states (1964, p. 120):

> "These turbidite sequences do not appear to have been continuous sheets but broad lenticular zones, occurring at different stratigraphic horizons. They grade laterally into chaotic slide deposits and into finer, more pelitic beds. Perhaps a close modern analogue are the deposits building up in the off-shore basins along the southern California coast (Gorsline and Emery, 1959). There, sand and chaotic slide debris form aprons along the base of the steep submarine slopes. Turbidity flows, emerging from the mouths of submarine canyons, move out across these aprons and spread broader fans of graded sands and silts farther out. Between and beyond the turbidite fans still finer silt and mud are accumulating. The lenticular turbidite zones within the Wissahickon, among which I include the Peters Creek Formation, may correspond to some of these fanlike deposits. This picture suggests that long-distance correlations with the Peters Creek Formation have little value."

The rhythmic metagraywacke-schist sequence of Harford County, though complicated by faulting, fits beautifully into a sedimentation pattern of the type proposed by Hopson, quoted above. It grades eastward into coarser chaotic slide deposits of the boulder gneiss lithofacies and westward into laminites and schists of the upper pelitic schist. The boulder gneiss probably represents chaotic slump deposits resulting from the same forces that triggered turbidity currents further seaward; the laminites represent the silt and fine sand deposited by the distal, low-energy ends of the turbidity flows far out in deep water.

Upper Pelitic Schist

The upper pelitic schist is above and northwest of the metagraywacke lithofacies in Harford County. Even though the units are in probable fault contact in this area, the gradational lithologic kinship between them is apparent. Where the metagraywacke is absent (as in the area north of Jarrettsville), the upper pelitic schist is in contact with the lower pelitic schist, from which it can be distinguished only in exceptional cases. In south-central Maryland the schist is in contact with boulder gneiss on the east. There, lenticular units of metagraywacke are intercalated in the schist (Fisher, 1963; Southwick and Fisher, 1967) and were considered to be an integral part of the unit, called the western sequence of the Wissahickon by Hopson (1964). The upper pelitic schist is very thick. Fisher (1963) estimates it to be no thinner than 14,000 feet along the Potomac, and its thickness in Harford County and adjacent parts of Pennsylvania is at least as great. Great structural complexity makes a precise estimate of thickness almost impossible.

Southwick and Fisher (1967) note that rocks of the upper pelitic unit range from albite-chlorite-muscovite-quartz schists to sillimanite-bearing migmatitic schists, depending on metamorphic grade. This is true of the unit as a whole, but the part in Harford County is of nearly uniform low grade and consists chiefly of albite-chlorite-muscovite-quartz rocks. Delicately laminated quartzose beds, originally impure fine sand and silt are fairly common. These laminites are not common in the lower pelitic schist and are about the only feature that can be used to distinguish the two sequences in the absence of intervening stratigraphic units. Rare calc-silicate schists (chiefly actinolite-quartz-epidote rock) and greenstones occur locally in the upper pelitic schist.

The rocks of the upper pelitic schist lithofacies in Harford County are thoroughly recrystallized, fine- to medium-grained schists, which, unlike their equivalents in Montgomery County, have no relict sedimentary textures (Hopson, 1964, p. 93). They are composed chiefly of quartz, muscovite, albite, and chlorite; garnet is sporadically developed and biotite is rare. X-ray analysis failed to detect paragonite. Accessory minerals include magnetite, pyrite, epidote, zircon, and tourmaline; the last is especially widespread, in the form of markedly zoned blue-green prisms. Modal analyses of some typical rocks are given in table 7.

Muscovite and chlorite are well aligned and impart a marked schistosity to the rock. There is evidence, however, of two generations of schistosity, the older one locally almost eradicated by translation and recrystallization parallel to the newer planes. Figure 14*p* shows the dominant schistosity wrapping around a small lens in which the micas are oriented nearly at right angles to the external trend. Examples of earlier schistosity ($S_1 \cong S_2$) transverse to and rotated by second schistosity (S_{3a}) are not numerous but are sufficiently abundant to suggest that the earlier planes ($S_1 \cong S_2$) may correspond to the S_1 observed by Freedman and others (1964) along the Susquehanna River, and the second planes (S_{3a}) to their S_2, related to the formation of the Tucquan arch. Petrofabric study of these rocks is needed to test this hypothesis, for the two sets of surfaces are very hard to distinguish in the field.

On the geologic map (Plate 1) a line across the upper pelitic schist separates rock with conspicuous albite porphyroblasts (on the northwest) from rock in which albite occurs in smaller crystals. The porphyroblastic rock can be traced northeast at least as far as Tucquan Creek in Lancaster County, Pennsylvania, and as far southwest as north-central Baltimore County (Cloos and Hietanen, 1941; Knopf and Jonas, 1929b). The albite porphyroblasts ($An_0 - An_3$) are as large as 8 mm in diameter, anhedral with crudely rounded or oval cross sections, and contain numerous inclusions of opaque material, mica, epidote, and rarely garnet that are aligned in trends transverse to the schistosity of the rock. These transverse trends were interpreted by Singewald (1932) as the result of porphyroblast growth across schistosity, followed by rotation of the porphyroblasts during subsequent deformation. This conclusion is substantiated by Freedman and others (1964, pl. 5, fig. 2, opp. p. 631) who present a photomicrograph of an albite porphyroblast in which the inclusions outline the nose of an earlier fold. Rotated albite from Harford County is shown in figure 3.

Four new chemical analyses of rocks from the upper pelitic schist sequence are given in table 8. These rocks are notably richer in Al_2O_3 and H_2O than are rocks from the lower pelitic schist, and this is reflected in their higher mica content. The high alumina content may indicate derivation from sediments generally more clay rich than those from which the lower pelitic schists were formed.

PEACH BOTTOM SLATE AND CARDIFF METACONGLOMERATE

Names and Previous Work

The Peach Bottom Slate is named for the small hamlet of Peach Bottom, Pennsylvania, on the west bank of the Susquehanna River in southeastern York County. "Peach Bottom black roofing slate" is a trade name dating back to the early days of quarrying and was adopted as a formation name by the first students of the area (Rogers, 1858; Frazer, 1879, 1880).

Underlying the slate is the Cardiff Conglomerate, a distinctive quartz pebble conglomerate and quartzite unit named by Mathews (1904, p. 143) for the village of Cardiff, Maryland. Because the conglomerate is everywhere schistose to gneissic (depending on the original content of pebbles) and contains a characteristic suite of metamorphic minerals, the name was changed to Cardiff Metaconglomerate (Southwick and Fisher, 1967).

At least six papers published between 1880 and 1914 emphasized the economic aspects of quarrying Peach Bottom Slate (*see* Behre, 1933, p. 359–360, for a summary and references). The first geologists to recognize that the slate was in the core of a fold where Mathews and Johannsen (1904) who mapped its southwestern part in Harford County, Maryland, and interpreted it as a syncline. T. Nelson Dale made the first petrographic study of the slate (1906, 1914) and attempted to work out detailed structure in several quarries. More thorough investigations of the area were made during the 1920's and 1930's by Knopf and Jonas (1929a), Behre (1933), and Stose and Jonas (1939). In 1950, Agron published the results of a detailed structural study of the syncline, and in 1964 Freedman, Wise, and Bentley reported on a study of fold patterns across a section of the Pennsylvania-Maryland Piedmont that includes the Peach Bottom synclinal axis.

Occurrence

Peach Bottom Slate crops out in the core of a long, narrow, northeast-trending syncline that extends about 16 miles from Pylesville, Harford County, Maryland, to a point half a mile north of Kings Bridge, Lancaster County, Pennsylvania. Approximately 3 miles of this length are in Maryland. The best outcrops of slate occur in Pennsylvania along both sides of the Susquehanna River and in the slate quarries clustered in the Cardiff-Delta area near the Mason-Dixon Line. In Harford and York Counties the slate holds up "Slate Ridge," a prominent hill about half a mile wide that stands some 150 feet above the surrounding country.

The Cardiff Metaconglomerate, which outlines the Peach Bottom syncline, underlies the slate and surrounds it except for a 9-mile gap on the northwest side of the fold northeast of Delta, Pennsylvania. In this area the slate is in contact with the upper pelitic schist of the Wissahickon Formation.

Thickness

Estimates of the thickness of the Peach Bottom Slate depend on the structural interpretation of the Peach Bottom syncline above the Cardiff basal contact. If the syncline is a simple fold, then a thickness of about 1,000 feet is required in the Whiteford-Cardiff-Delta area of Maryland-Pennsylvania. If the syncline is doublekeeled (see Plate 3), a thickness of 500 to 750 feet would be sufficient to explain the observed breadth of outcrop. The Cardiff Metaconglomerate ranges in apparent thickness from about 80 feet on the west bank of the Susquehanna River to 700 feet along Maryland Route 136 half a mile southeast of Whiteford. Still greater thicknesses are indicated near the end of the syncline northeast of Pylesville, Maryland, but here tectonic thickening has probably been appreciable.

Lithology

Silvery-white micaceous quartzite and quartz-pebble metaconglomerate make up the Cardiff Metaconglomerate. The commonest rock is a metaconglomerate with tectonically flattened quartz pebbles as much as 2 inches long set in a schistose matrix of sand-size quartz, muscovite, and chlorite (fig. 15*p*). Sufficient pyrite and ilmenite are present to impart a characteristic pinkish color to the weathered rock. Coarser beds with pebbles as long as 4 inches occur near the southwest end of the syncline; finer grained metaconglomerate and coarse micaceous quartzite are interbedded with coarser rocks almost everywhere but seem to be commonest where the formation is thin.

By far the greatest number of pebbles are quartz. Scattered pebbles of dark-gray chloritoid quartzite, black slate, and metagraywacke occur, but nowhere do these make up more than 5 percent of the pebbles and commonly they are lacking. All pebbles are strongly flattened by tectonic shearing. They lie with their intermediate and major axes in the foliation plane and their minor axes normal to it; the major axes are parallel to regional fold axes. Pebbles measured by Argon (1950, p. 1269) have axial ratios ranging from 2:2.4:1 to 10:18:1.

The contact between the metaconglomerate and the Peach Bottom Slate has been described by Agron (1950, p. 1269) and Behre (1933, p. 364) as a zone several feet thick of alternating thin quartzite and slate beds. This has been interpreted as a gradational zone between the formations, but in my opinion its gradational character has been overemphasized. On both banks of the Susquehanna River, along Ridge Road above Chestnut Street in Cardiff, and along the abandoned road that links Slate Ridge Road and Maryland Route 136 about ¾ mile southeast of Whiteford, typical pea-gravel metaconglomerates and coarse, light-colored quartzites of the Cardiff are in abrupt contact with interlayered slate and thin-bedded, dark-colored silty to sandy rocks of the Peach Bottom. Interbedded slate and fine sandy rocks are only in a narrow zone just above the Cardiff contact; they are fine-grained, black graphitic rocks that have little in common with the cleaner and coarser clastics of the Cardiff Metaconglomerate. In short, the contact is conformable but not notably gradational. The lithologic gradation at the Wissahickon-Cardiff contact is much more striking than that at the Cardiff-Peach Bottom contact.

Most of the Peach Bottom Slate is a hard, lustrous, blue-black slate having a crystallinity approaching phyllite. It is amazingly uniform in appearance and has virtually no sandy or silty beds away from a narrow zone next to the Cardiff Metaconglomerate. Subvertical slaty cleavage (S_2) is the dominant structure, but several transverse cleavages (S_3 , S_4 , . . . S_n) and related lineations of intersection are well developed (Agron, 1950). The commercial slate quarries are in areas where the crosscutting higher order cleavages are subordinate; elsewhere the slate is badly crinkled. Cutting the slate are narrow gnarled veins of quartz and mica pegmatite.

Petrography

The Cardiff Metaconglomerate consists chiefly of quartz. Quartz pebbles that are crushed and recrystallized to varying degrees are cemented by a quartz-rich micaceous matrix that probably originated as clayey sand. Muscovite is the next most abundant mineral, forming 5 to 10 percent of most rocks. Next in order of decreasing abundance are chlorite, chloritoid, kyanite, ilmenite, and sodic plagioclase, all of which are crystalloblastic and plainly grew under metamorphic conditions. Rounded zircon and tourmaline are common sedimentary relicts; less common are sphene, rutile, and xenotime. Epidote occurs both as rounded clasts and recrystallized aggregates. Dusty to granular ilmenite is widespread.

Muscovite, chlorite, kyanite, and chloritoid are oriented in curving foliation planes that wrap around elongate, granulated quartz pebbles. Movement on the foliation planes apparently continued after chloritoid and kyanite ceased to grow because both minerals are bent and locally pulled apart (fig. 16*p*).

The Peach Bottom Slate is composed chiefly of fine-grained quartz, muscovite, and chlorite. It is so fine grained that individual mineral grains cannot be resolved at magnifications much below 250x. The micaceous minerals are perfectly aligned in the slaty cleavage (S_2) so that a striking "mass extinction" is observed under crossed nicols.

Oriented graphite composes about 2 percent of most rocks but locally is much more abundant. Scraps of iron-rich biotite (stilpnomelane?) occur in places, but they are too small and scattered for precise optical determination. Dusty ilmenite and small cubes of pyrite are widespread. Tiny chloritoid porphyroblasts, rarely more than 0.1 mm long, are numerous and commonly oriented athwart the slaty cleavage (fig. 17*p*). No andalusite was observed; possibly T. N. Dale (1914) misidentified the small, rectangular chloritoid porphyroblasts as andalusite, which he reported as occurring in abundance.

Silty and fine sandy rocks from beds near the Cardiff contact contain deformed quartz and plagioclase sand grains, muscovite, chlorite, graphite, ilmenite, chloritoid, and a little biotite. Zircon, rutile, tourmaline, and epidote are the commonest relict accessories.

The mineral assemblages have been discussed further in the section on metamorphism.

Age

The age of the Cardiff Metaconglomerate and Peach Bottom Slate, although discussed for years, is still unknown. The problem is highly important because it bears on the larger questions of the age of the Glenarm Series, the Martic overthrust, and the position of the Precambrian-Paleozoic boundary in this part of the Piedmont.

The Cardiff Metaconglomerate and Peach Bottom Slate were included in the Precambrian Glenarm Series as originally defined by Knopf and Jonas (1923, p. 45). The Peach Bottom Slate was thought to be the youngest formation in the series and to lie in the center of a regional syncline that involved all other Glenarm rocks. However, Knopf and Jonas were troubled by the fact that the Cardiff looks like a basal conglomerate and raised the possibility that it and the Peach Bottom might be post-Glenarm in age. They later pointed out (1929a, p. 38) the lithologic similarity between the Cardiff-Peach Bottom sequence and the basal Cambrian Hellam Conglomerate Member of the Chickies Quartzite (which in York County, Pennsylvania, contains an upper slaty member) but reluctantly rejected the correlation, stating:

"In Pennsylvania there is no difference in trend between the Cardiff conglomerate and Peach Bottom slate and the underlying Peters Creek Formation, and there is an apparent gradation from fine pebbly sandstones in the upper beds of the Peters Creek Formation through coarser beds into the Cardiff conglomerate. Therefore, if a depositional break occurred between the two formations the field evidence indicates that it was not an angular unconformity. In the absence of any definite proof that it is Cambrian, the Cardiff conglomerate has been included in the pre-Cambrian Glenarm series."

Their doubt of this assignment is amplified as follows (1929a, p. 41):

"The Cardiff conglomerate occurs in a region where conditions subsequent to deposition have been favorable for molecular rearrangement which would have obliterated evidence for unconformity. Nevertheless it has been possible to prove an unconformity at the base of the Glenarm series where basal conglomerates are lacking, and it is somewhat surprising that an unconformity at the base of the Cardiff conglomerate cannot be demonstrated by field evidence."

Stose and Jonas (1939, p. 103–104) later proposed a probable Ordovician age for the Cardiff and Peach Bottom Formations based on the following rather involved argument:

"In Virginia there are two areas of fossiliferous slates of Cincinnatian age that are infolded with schist of the Glenarm series. . . . The slate of the western area, the Arvonia slate of Buckingham and Fluvanna Counties, lies along the axis of the Peach Bottom syncline. The Arvonia slate with a thin basal conglomerate overlies the Columbia granite of the Virginia Survey and the Peters Creek quartzite which that granite intrudes. Because the basal conglomerate lies on the bevelled edges of the Peters Creek and Columbia granite, it is evident that these underlying rocks are separated from the rocks of Cincinnatian age by an angular unconformity and they are both older than Cincinnatian for the Peters Creek quartzite was intruded by granite, was uplifted, and was eroded before the Arvonia slate was deposited. The Peters Creek quartzite is therefore considerably older than the Arvonia slate and is pre-Cincinnatian in age. . . .

"The Columbia granite of the Virginia Geological Survey extends northeastward in interrupted outcrop to Potomac River, in strike with the Sykesville granite of Maryland which crosses that river west of Washington. The Columbia granite and Sykesville granite are lithologically similar, they occur along the same strike, and both intrude the Peters Creek quartzite and are both younger than the diorite and metagabbro and serpentine which also intrude the Glenarm series in Pennsylvania, Maryland and Virginia. The Columbia granite and Sykesville granite therefore are regarded as equivalent. The Sykesville granite intrudes the Peters Creek quartzite and extends northeast across southern Maryland to east of North Branch of Patapsco River into Baltimore County. Along the same strike to the northeastward granite, probably of Sykesville age, intrudes both the Peters Creek quartzite and the Wissahickon formation. This granite has formed mixed rocks with schists of the Peters Creek in a belt that lies on the northwest side of the 'State line' serpentine belt. The 'granitized' schist of the Peters Creek quartzite enters Lancaster County near Texas where it forms only a small area and occurs on Susquehanna River a short distance south of York County. If the Sykesville granite is equivalent to the Columbia granite, it is older than the Cardiff conglomerate and Peach Bottom slate, although this assumption cannot be provided [sic] by the field relations in York or Lancaster County where Peters Creek adjoining the Cardiff conglomerate is not intruded by granite. . . ."

In conclusion they state (1939, p. 106):

"The Peach Bottom slate and Cardiff conglomerate occur in the same syncline as the Arvonia slate of Virginia and both slates overlie Peters Creek quartzite with a conglomerate at the base. The Peach Bottom and Arvonia slates are lithologically similar and are high-grade roofing slates. Both are underlain by quartz conglomerates, although the Cardiff conglomerate is thicker and more prominent than the conglomerate at the base of the Arvonia slate. Faunal evidence shows the Arvonia slate is of Cincinnatian age and it seems probable that the Peach Bottom slate also may be of Ordovician age and may be equivalent to the Arvonia slate. The writers therefore regard the Peach Bottom slate and Cardiff conglomerate as of probable Ordovician age and do not include them with the underlying rocks of the Glenarm series."

Stose and Stose (1948) changed the age of the Arvonia and Peach Bottom Slates to Silurian or younger (post-Taconic) and postulated that the syncline in which both supposedly lie extends more than 100 miles farther northeast to join the Green Pond Mountain syncline of New Jersey and New York. This extension is pointedly questioned by Agron (1950, p. 1279) who states:

"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 when they carry Maysville fossils."

Recent work in Virginia and southern Maryland has invalidated much of the reasoning used by Stose and Jonas in 1939 to correlate the Arvonia and Peach Bottom Slates. Geologic mapping in Fluvanna County, Virginia, by Smith and others (1964) casts doubt on the long-range correlation of rocks beneath the Arvonia Formation with the metagraywackes and schists of the Peters Creek Formation (of former usage) in Lancaster County, Pennsylvania. Besides the uncertainty caused by distance and discontinuous outcrop, the Virginia rocks ("metamorphosed volcanic and sedimentary rock unit" of Smith and others) include sizeable amounts of metamorphosed felsite porphyry, greenstone, and amphibole schist, whereas such metavolcanic rocks are uncommon in the Peters Creek section. Moreover, the metamorphosed volcanic and sedimentary rock unit of Smith and others is reported to grade upward into the Arvonia Slate without unconformity (Smith and others, 1964, p. 13–14). The Columbia Granite of Jonas (1928b), considered pre-Arvonia by earlier workers, is thought by Smith and others to be post-Arvonia and to have metamorphosed the slate near its contacts.

Studies in Howard and Montgomery Counties, Maryland, by Hopson (1963; 1964, p. 101–103) clearly show that the Sykesville "granite" is a large-scale sedimentary slump-breccia within the Wissahickon Formation; it is part of the Glenarm sedimentary sequence and not an igneous intrusion into it. Furthermore, the "granitized Peters Creek quartzite" occurring north of the State Line serpentinite district of Maryland and Pennsylvania is coarse-grained metagraywacke and pebbly metagraywacke similar to the Sykesville, and probably has not been "granitized" at all.

There seems to be no basis, therefore, for using relations to granite bodies as evidence for similar age of the Arvonia and Peach Bottom Slates, nor is there any other evidence for correlation except the striking lithologic similarity.

The absence of a demonstrable angular unconformity at the base of the Cardiff Metaconglomerate was pointed out and discussed by Knopf and Jonas (1929a, p. 38–39, 41). My observations substantially agree with theirs. Near Pylesville, rocks of the Wissahickon Formation seem to grade smoothly from quartzose chloritoid schist through pebbly micaceous quartzite to gneissic quartz pebble metaconglomerates of the Cardiff for a stratigraphic interval of about 75 feet. Gradational relations between the Cardiff and subjacent rocks also occur on both sides of the Susquehanna River. Bedding in both units is parallel wherever it can be seen. The detailed structural study made by Agron (1950) found the same number and kinds of structural elements, indicating a common deformational history, above and below the basal Cardiff contact. If elements derived from an earlier orogeny ever were developed in the Wissahickon they have been completely overprinted by tectonic events that followed the deposition of the Cardiff and Peach Bottom Formations.

There is no mineralogical or textural evidence to indicate that the metagraywacke lithofacies of the Wissahickon underwent a period of metamorphism and deformation that the Cardiff and Peach Bottom did not. The metamorphic grade of argillaceous beds above and below the Wissahickon-Cardiff contact is essentially the same. Phyllitic beds in the Wissahickon contain quartz, muscovite, and chlorite with or without albitic plagioclase, chloritoid, and widely scattered small garnets. The Peach Bottom Slate contains graphite in addition to the above assemblage and lacks any trace of garnet.

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.

The Glenarm Series was originally assigned to the Precambrian by Knopf and Jonas (1923, p. 45), but between 1935 and 1964, geologic opinion overwhelmingly favored an early Paleozoic age for it (Miller, 1935; Mackin, 1935; Cloos and Hietanen, 1941; Swartz, 1948; McKinstry, 1961). An age at least as old as Cambrian and probably late Precambrian, however, is indicated by the work of Hopson (1964, p. 204–207) who reasoned from radiogenic dates and stratigraphic considerations in the plutonic belt of the Maryland Piedmont. He finds that a long history of injection, deformation, and regional metamorphism of the Glenarm began with intrusion of gabbro at least 550 m.y. ago and culminated with the mobilization and rise of the Baltimore gneiss domes about 440 m.y. ago. At this time (late Ordovician) the Glenarm rocks, including the Wissahickon Formation, were undergoing deep-seated regional metamorphism. Emplacement of granitic rocks began early in the orogenic cycle, continued through its apex, and terminated in the waning stages of regional deformation about 370 m.y. ago.

The Cardiff Metaconglomerate and Peach Bottom Slate are intensely deformed rocks having structures and minerals indicating a metamorphic history essentially like that of nearby parts of the Wissahickon Formation. Therefore these rocks were probably undergoing metamorphism at the same time as the Wissahickon in late Ordovician time. The Cardiff Metaconglomerate contains kyanite, so there must have been enough time between deposition and metamorphism for burial to a depth compatible with the high-pressure stability field of kyanite. It seems likely, then, that the Cardiff and Peach Bottom are no younger than middle Ordovician and may be much older.

Enigmatic plant fossils were found on a quarry dump of Peach Bottom Slate near Delta, Pennsylvania, in 1876 (Agron, 1950, p. 1277) and now are in the paleobotanical collection of Princeton University. They were studied originally by Leo Lesquereux and James Hall; both thought they were algae of the genus *Buthotrephis*. Many years later the specimens were examined by R. S. Bassler and James Schopf; both thought they definitely were organic remains, and Schopf noted that they resembled algae of the species *Buthotrephis newlini* David White from the late Silurian eurypterid beds at Kokomo, Indiana (oral commun., cited in Agron, 1950, p. 1277).

Buthotrephis is not a good diagnostic fossil but is a useful form genus. The 20 forms assigned to this genus range in age from Canadian through Silurian (Bassler, 1915), and on this evidence it would seem that the Peach Bottom Slate is Ordovician or Silurian in age (Agron, 1950, p. 1277).

If one accepts (1) the Peach Bottom plant fossils as valid indicators of early Paleozoic age, (2) a conformable or paraconformable contact at the base of the Cardiff, and (3) a late Precambrian age for a large part of the Glenarm Series, one must conclude that sedimentation near the axis of the Peach Bottom syncline continued from late Precambrian into early Paleozoic time without major tectonic upheaval. Small shifts that produced diastems or low-angle unconformities cannot be ruled out, but no great disruption seems to have taken place. Work by Tilton, Hopson, and their colleagues indicates that much of the Glenarm Series had been deposited by Middle Cambrian time because it is cut by plutonic rocks of that age (*see* Davis and others, 1965; Hopson, 1964, p. 204–207). 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. Is it not possible that the Cardiff and Peach Bottom Formations are the last increment of sediment to be deposited in a geosyncline that started to develop and was largely filled during late Precambrian time, but continued to receive sediments in its downwarped axial zone well into the early Paleozoic?

JAMES RUN GNEISS

Name and Stratigraphic Setting

The James Run Gneiss is a strikingly layered rock composed of beds that range in composition from amphibolite to quartz-plagioclase leucogneiss. It is well exposed along the lower course of James Run, for which it is named (Southwick & Fisher, 1967). Gatch quarry, on James Run road about 2.3 miles south of Churchville, contains the longest continuous section and is designated the type locality.

The gneiss seems to overlie conformably a sequence of garnet-mica schists that probably are equivalent to part of the lower pelitic schist of the Wissahickon Formation. Thickness of the gneiss is unknown because its top is not exposed; however, a thickness of 2,000 to 5,000 feet seems reasonable from the structural pattern. A belt of younger intrusive rocks northwest of the James Run Gneiss separates it from the main belt of the Glenarm Series. A mass of metagabbro borders it on the east. Cretaceous and younger sedimentary formations of the Coastal Plain overlap it on the south, but similar layered gneisses probably equivalent to the James Run crop out in the deeper stream valleys at least as far south as Big Gunpowder Falls.

Lithology

Near perfect layering distinguishes the James Run Gneiss from other gneisses of generally similar bulk composition in the region (fig. 18*p*). Individual layers range from less than 1 inch to more than 20 feet in thickness; they have knife-sharp contacts, and even thin layers can be traced for several tens of feet before they gradually lense out. Although tilted from 20° to 80°, the strata lack small-scale flowage folds and other features indicative of highly plastic deformation. Most outcrops present a uniformly dipping sequence of layers that from a distance could be mistaken for unmetamorphosed sedimentary rocks. The formation can be divided crudely into two members on the basis of gross composition. The lower part (according to my structural interpretation) is more amphibolitic and thinner bedded, containing roughly 40 to 70 percent mafic beds 1 inch to 4 feet thick. The upper part contains felsic beds as thick as 20 feet and intervening, much thinner layers of amphibolite. Dark rocks make up no more than 20 percent of this member.

A nearly continuous range of compositions between amphibolite and biotite-poor quartz-oligoclase gneiss is represented in the individual layers. Many combinations and proportions of plagioclase, quartz, biotite, and hornblende occur, but quartz amphibolite and biotite-quartz-plagioclase gneiss are the commonest rocks.

A prominent foliation, carried chiefly by micas and to a lesser extent by hornblende, is parallel to layering throughout the formation. Probably it is parallel to the axial planes of northwest-overturned regional-scale folds (*see* Plate 4), but a direct demonstration of its relation to fold geometry cannot be made because of the surprising scarcity of small-scale folds. A second, far weaker subvertical foliation can be seen in some places; it is parallel to a strong foliation in the intrusive Port Deposit Gneiss and may have formed at the same time.

A very strong mineral lineation is especially prominent in hornblendic layers of the James Run Gneiss. It plunges northeastward and is approximately parallel to the plunging axes of the regional folds, as deduced from the map pattern. It is parallel to the plunge of crinkles in the less competent Wissahickon and Setters Formations, which have been folded together with the James Run.

Petrography

Both mafic and felsic layers of the James Run Gneiss are thoroughly recrystallized—there are no relict textures of any sort. Most light-colored layers consist of a medium-grained equigranular mosaic of quartz and plagioclase through which a few percent well-oriented biotite, muscovite, or hornblende grains carry the foliation. Epidote, apatite, zircon, sphene, and opaque minerals are common accessories, and chlorite derived from the breakdown of biotite is fairly widespread. A few layers contain a little garnet. Microcline is very rare. The dark layers consist chiefly of plagioclase, hornblende, and quartz, and variable but normally small amounts of biotite. The hornblende is very well oriented. Epidote makes up as much as 5 percent of some rocks; zircon, apatite, and opaque substances are the commonest accessories. Modal analyses of typical layers are given in table 9.

The plagioclase ranges in composition from An_{12} to An_{70}, the commonest values being near An_{25} for felsic rocks and An_{40} for mafic. As usual, thick mafic layers contain the most calcic plagioclase and thick, quartz-rich layers contain the most sodic. Sections of thinly interstratified light and dark beds 1 inch to 2 feet thick normally have the same plagioclase throughout. In this case diffusion seems to have been sufficient to permit equilibrium in a system of "averaged" bulk composition, even though adjacent beds differ markedly in bulk chemistry.

The hornblende is a typical dark-green variety that seems to be of normal calc-alkaline composition. The biotite is dark brown and has no anomalous characteristics. Optical properties of typical hornblendes and biotites are given in table 10.

Chemical Composition

"Rapid" chemical analyses of major oxides and semiquantitative determinations of trace elements in 7 layers of James Run Gneiss are given in table 11. Norms calculated from these analyses are also given. Important features of the analyses are the large excess of Na_2O over K_2O, even in very siliceous rocks, and the variable amounts of CaO in the mafic layers. In general, the analyses are more suggestive of volcanogenic rocks than any common type of normal clastic sediment.

Origin and History

There is a striking chemical similarity between the James Run Gneiss and the well-bedded Baltimore paragneiss described by Hopson (1964, p. 31–35). This is emphasized by comparing triangular plots of normative orthoclase, plagioclase, and quartz for the two units (fig. 19). Hopson noted that the Baltimore paragneisses plot in a field that lies roughly between the plagioclase-quartz side of the diagram and the field occupied by normal calc-alkali lavas; from this he concluded that normal lavas were not likely parent material for the paragneisses. He also noted that Pettijohn's average clastic graywacke plots within the paragneiss field, but cited the generally low level of normative corundum (excess Al_2O_3) in the paragneisses and the absence of interbedded shaly rocks as evidence against probable graywacke parentage. These arguments apply equally well to the James Run Gneiss.

Hopson goes on to state (1964, p. 35):

> "There is a class of altered marine volcanic sediments, however, whose chemical composition does closely match the Baltimore paragneiss. These are the albitized and zeolitized volcanic clastic rocks of intermediate to silicic composition. . . .
>
> "Such marine volcanic sediments commonly resemble the Baltimore paragneiss in structure as well as composition, forming massive to thin-bedded deposits with interstratified mafic material. . . ."

I think that altered marine volcanic rocks are also the most likely parent for the James Run Gneiss (also the volcanic complex of Cecil County, discussed later). The thin-bedded lower part of the formation may have been submarine andesitic tuffs deposited at some distance from the site of eruption; the thick-bedded upper part may represent submarine pyroclastic beds of essentially dacitic composition.

Thick piles of altered marine volcanic rocks (including clastic rocks and lava flows),

TABLE 9

MODAL ANALYSES OF JAMES RUN GNEISS, HARFORD COUNTY

I. *Felsic Layers*—Hornblende-Poor Rocks

	1	2	3	4	5
Plagioclase	38.9	50.3	48.4	48.4	44.2
Quartz	42.1	41.7	42.1	41.6	39.0
Microcline	2.7	0.2	tr	—	—
Hornblende	—		5.3	5.1	10.8
Biotite	3.3	4.7	3.0	1.9	0.8
Muscovite	9.7	1.0	—	tr	—
Chlorite	0.1		—	0.4	0.5
Epidote	2.8	1.3	0.8	1.5	1.1
Opaques	0.3	0.8	0.4	0.9	1.0
Sphene	tr	—	—		—
Zircon	0.1	tr	tr	tr	0.2
Apatite	tr	tr	tr	tr	tr
Allanite	—	—	tr	—	—
Garnet	—	—	tr	0.2	2.4
Carbonate	—			—	—
TOTAL (vol. percent)	100.0	100.0	100.0	100.0	100.0
Plag. An content	20	21	25	39	36
No. of points	1223	1251	1315	1288	1228

II. *Mafic Layers*—Hornblende-Rich Rocks

	6	7	8	9	10	11	12
Plagioclase	51.7	34.3	33.2	27.4	31.4	30.0	27.4
Quartz	16.8	13.3	8.8	14.9	20.5	14.6	8.0
Microcline	—	—	—	—	—	—	—
Hornblende	24.1	50.9	50.4	55.7	42.9	51.0	60.7
Biotite	—	—	0.3	—	0.2	1.4	—
Muscovite	—	—	—	—	tr	tr	—
Chlorite	2.0	—	0.5	tr	tr	0.6	0.1
Epidote	2.0	1.3	4.2	2.0	2.7	2.1	3.4
Opaques	2.8	0.2	2.2	tr	2.1	0.3	0.2
Sphene	0.2	—	tr	tr	—	—	tr
Zircon	tr	tr	—	—	—	—	0.1
Apatite	0.2	tr	0.1	tr	0.2	tr	0.1
Allanite	—	—	—	—	—	tr	—
Garnet	—	—	—	—	—	—	—
Carbonate	0.2	—	0.3	—	tr	—	—
TOTAL (vol. percent)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Plag. An content	40	40	34	70	40	38	75
No. of points	1229	1231	1155	1175	1290	1296	1467

1. Gatch Quarry, south of Churchville.
2. Gatch Quarry.
3. Interstate Highway 95 at Maryland Route 136.
4. Interstate Highway 95 about 1,000 feet northeast of Little Gunpowder Falls. Sample from felsic layer adjacent to mafic layer, col. 10.
5. Bynum Run about 1.5 miles east-southeast of Emmorton. Sample from felsic layer adjacent to mafic layer, col. 11.
6. Gatch Quarry.
7. Gatch Quarry.
8. Gatch Quarry.
9. Gatch Quarry.
10. Interstate Highway 95 about 1,000 feet northeast of Little Gunpowder Falls. Sample from mafic layer adjacent to felsic layer, col. 4.
11. Bynum Run about 1.5 miles east-southeast of Emmorton. Sample from mafic layer adjacent to felsic layer, col. 5.
12. Small tributary to Bynum Run about 0.7 mile west-southwest of Creswell.

TABLE 10

OPTICAL PROPERTIES OF HORNBLENDE AND BIOTITE FROM CHEMICALLY ANALYZED SAMPLES OF JAMES RUN GNEISS, HARFORD COUNTY

[Indices of refraction measured by standard immersion method using Na light; uncertainty ± .002· Optic angles measured on 4-axis universal stage by extinction method in white light; uncertainty ± 2–3°. β index for hornblendes *calculated*. All values are averages of 3 to 5 separate determinations.]

	α	β	γ	$2V_{\alpha}$	Composition of coexisting plagioclase
		Hornblende (blue-green)			
GA-3	1.661	(1.676)	1.681	62°	An_{40}
GA-4	1.660	(1.672)	1.678	68°	An_{40}
GA-5	1.662	(1.676)	1.679	59°	An_{34}
GA-6	1.649	(1.662)	1.669	74°	An_{70}
		Biotite (brown)			
GA-1	—	1.647	1.647	<5°	An_{20}
GA-2	—	1.646	1.646	<5°	An_{21}

chiefly of Mesozoic and Cenozoic age, occur in northeastern Oregon (Dickenson, 1962b; C. E. Brown, oral commun., 1966); in the Cascade Mountains and Coast Ranges of Oregon and Washington (*e.g.* Snavely and Wagner, 1964); in Japan (Fiske and Matsuda, 1964); in New Zealand (Coombs, 1954); and in Puerto Rico (Lynn Glover, oral commun., 1965), all areas of eventful sedimentary, volcanic, and tectonic history. Such rocks may also have been common in older orogenic belts, such as the Appalachian Piedmont, that have since been metamorphosed.

Presumably, when erupted, these rocks had normal calc-alkali compositions. After deposition they were altered, possibly by reaction with resurgent connate water during diagenesis and incipient metamorphism accompanying deep burial (Waters, 1955; Fiske, Hopson, and Waters, 1963) or by direct hydration of plagioclase to calcium zeolites, followed by base exchange with sea water (Hamilton, 1963, p. 74). Some tuffaceous rocks undoubtedly were first subjected to sedimentary processes that also modified their bulk compositions. In any case, the rocks were enriched in Na_2O with respect to K_2O, CaO, or both.

The uneven extent of diagenetic sodium enrichment (spilitization) has been emphasized by Hamilton (1963, p. 52–53, 72) who points out that the andesite-keratophyre suite normally includes all intermediates between calc-alkaline and keratophyric types in the same pile. The variable ratio of Na to Ca in quartz amphibolites of the James Run Gneiss is in accord with Hamilton's observations on less thoroughly metamorphosed rocks.

Further adjustments in the distribution of Ca, Na, and K probably took place during medium-grade metamorphism. The presence of different plagioclase feldspars in different beds a few yards apart, however, seems to indicate that the migration of Na and Ca was sluggish. Homogenization apparently occurred only in thinly interbedded sequences. There is no evidence for large-scale metasomatism of lime or alkalies during metamorphism

TABLE 11

CHEMICAL ANALYSES OF JAMES RUN GNEISS, HARFORD COUNTY

	Felsic Layers			Mafic Layers			
	1	2	3	4	5	6	7
				Major Oxides[a]			
SiO_2	79.3	77.8	73.7	62.4	54.5	52.8	54.0
Al_2O_3	11.2	12.0	13.0	14.8	15.2	14.8	15.7
Fe_2O_3	1.1	0.0	1.5	3.4	3.4	4.8	2.2
FeO	1.1	2.3	2.6	5.2	7.4	8.3	5.9
MgO	0.28	0.17	0.62	2.6	5.8	4.8	7.3
CaO	1.7	2.4	3.6	5.6	8.5	8.1	10.4
Na_2O	3.1	4.0	3.9	3.6	2.5	2.8	1.6
K_2O	1.2	0.55	0.27	0.28	0.30	0.47	0.65
H_2O+	0.68	0.46	0.58	0.73	0.91	0.92	0.68
H_2O-	0.07	0.06	0.09	0.17	0.42	0.13	0.32
TiO_2	0.18	0.31	0.36	0.80	0.68	1.1	0.28
P_2O_5	0.04	0.10	0.10	0.17	0.11	0.15	0.05
MnO	0.06	0.04	0.08	0.15	0.19	0.21	0.17
CO_2	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
TOTAL	100.0(1)	100.1(9)	100.4(0)	99.9(0)	99.9(1)	99.3(8)	99.2(5)
				Trace Elements[b]			
Ba	.05	.05	.01	.01	.007	.01	.007
Be	.0001	.0001	—	—	—	—	—
Ce	.05	.02	.0001	—	—	—	—
Co	—	—	—	.003	.005	.005	.003
Cr	.0005	.0003	—	—	.002	.0007	.02
Cu	.005	—	.0002	.07	.01	.003	.003
Ga	.001	.001	.0015	.0015	.0015	.0015	.001
La	.007	—	—	—	—	—	—
Nb	.001	.001	—	—	—	—	—
Ni	—	—	—	—	.002	—	.002
Pb	—	—	.0005	—	—	—	—
Sc	.001	.0015	.0015	.003	.005	.005	.005
Sr	.007	.01	.01	.015	.01	.015	.007
V	—	—	.003	.01	.02	.02	.015
Y	.003	.007	.003	.005	.003	.003	.002
Yb	.0003	.0005	.0003	.0003	.0002	.0003	.0002
Zr	.02	.015	.02	.015	.003	—	.005
				Norms			
Q	52.32	45.61	40.24	23.13	10.33	8.92	8.95
C	1.81	0.70	—	—	—	—	—
Or	7.09	3.25	1.60	1.65	1.77	2.78	3.84
Ab	26.22	33.83	32.98	30.45	21.14	23.68	13.53
An	8.17	11.25	17.18	23.40	29.37	26.43	33.74
Wo	—	—	0.01	1.36	5.04	5.33	7.31
En	0.70	0.42	1.54	6.47	14.44	11.95	18.17
Fs	0.92	3.78	3.09	5.70	10.01	9.85	8.87
Mt	1.60	—	2.18	4.93	4.93	6.96	3.19
Il	0.34	0.59	0.68	1.52	1.21	2.09	0.53
Ap	0.10	0.24	0.24	0.40	0.26	0.36	0.12
(H_2O)	0.75	0.52	0.67	0.90	1.33	1.05	1.00
TOTAL	100.02	100.19	100.41	99.91	99.83	99.40	99.25

Age

Geologic evidence favors including the James Run Gneiss in the Glenarm Series. It overlies and is folded together with Wissahickon-like schist which in turn overlies biotite-microcline quartzite and quartz schist that is identical with part of the Setters Formation (Hopson, 1964, p. 59–61). Sheared augen gneiss, probably a remobilized phase of the Baltimore Gneiss, underlies the Setters along a quasi-conformable contact in the core of a tight anticline exposed in Bynum Run.

Radiometric ages, however, do not give unequivocal support to this assignment. Ages on zircon from a thick bed of garnet-biotite-quartz-oligoclase gneiss near the center of the Gatch quarry determined by George Tilton of The Geophysical Laboratory, Carnegie Institute of Washington, are as follows:

Isotope ratio	*Age (m.y.)*
U_{238}/Pb_{206}	421
U_{235}/Pb_{207}	433
Pb_{207}/Pb_{206}	488

These are younger than the minimum 500 m.y. age of the Glenarm Series deduced by Hopson (1964, p. 203–207), but are plainly discordant. Regarding them, Tilton states (written commun., April, 1965):

> "The numbers are disappointingly low. . . . However, I could in no way rule out the possibility that the Churchville zircons [from Gatch quarry James Run Gneiss] are, say, 600 m.y. old and lost substantial fractions of lead during Appalachian metamorphism 350–450 m.y. ago."

Possibly the zircons of the James Run Gneiss were "reset" during the episode of intense shearing that accompanied and closely followed syntectonic emplacement of the Port Deposit Gneiss. Zircons from this rock also are about 450–525 m.y. old (Steiger and Hopson, 1965; Davis and others, 1965), and there is geologic evidence that the Port Deposit is intrusive into and therefore younger than the James Run.

Possible Regional Correlations

The great lithologic similarity between the James Run Gneiss and the Baltimore paragneiss has already been mentioned. Radiogenic age studies of the paragneiss by B. R. Doe (written commun., 1963) indicate that it may be much younger than the 1,100 m.y. old migmatitic gneiss of the mantled domes, and could be part of the cover instead of the basement. Correlation of the James Run Gneiss and Baltimore paragneiss is, therefore, possible. Scattered outcrops of layered gneiss occur along strike between mapped areas of these units, but no direct connection has yet been demonstrated.

To the northeast, metavolcanic rocks of the greenschist facies in Cecil County (Mar-

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TABLE 11—*Continued*

[a] Analyzed in the laboratories of the U. S. Geological Survey by methods similar to those described by Shapiro and Brannock (1962).

[b] Semiquantitative spectrographic analyses, U. S. Geological Survey.

1. Microcline-biotite-plagioclase-quartz gneiss, Gatch Quarry south of Churchville.
2. Biotite-quartz-plagioclase gneiss, Gatch Quarry.
3. Biotite-hornblende-quartz-plagioclase gneiss, Interstate Highway 95 at Maryland Route 136.
4. Quartz amphibolite, Gatch Quarry.
5. Quartz amphibolite, Gatch Quarry.
6. Quartz amphibolite (0.3 percent biotite), Gatch Quarry.
7. Quartz amphibolite, Gatch Quarry.

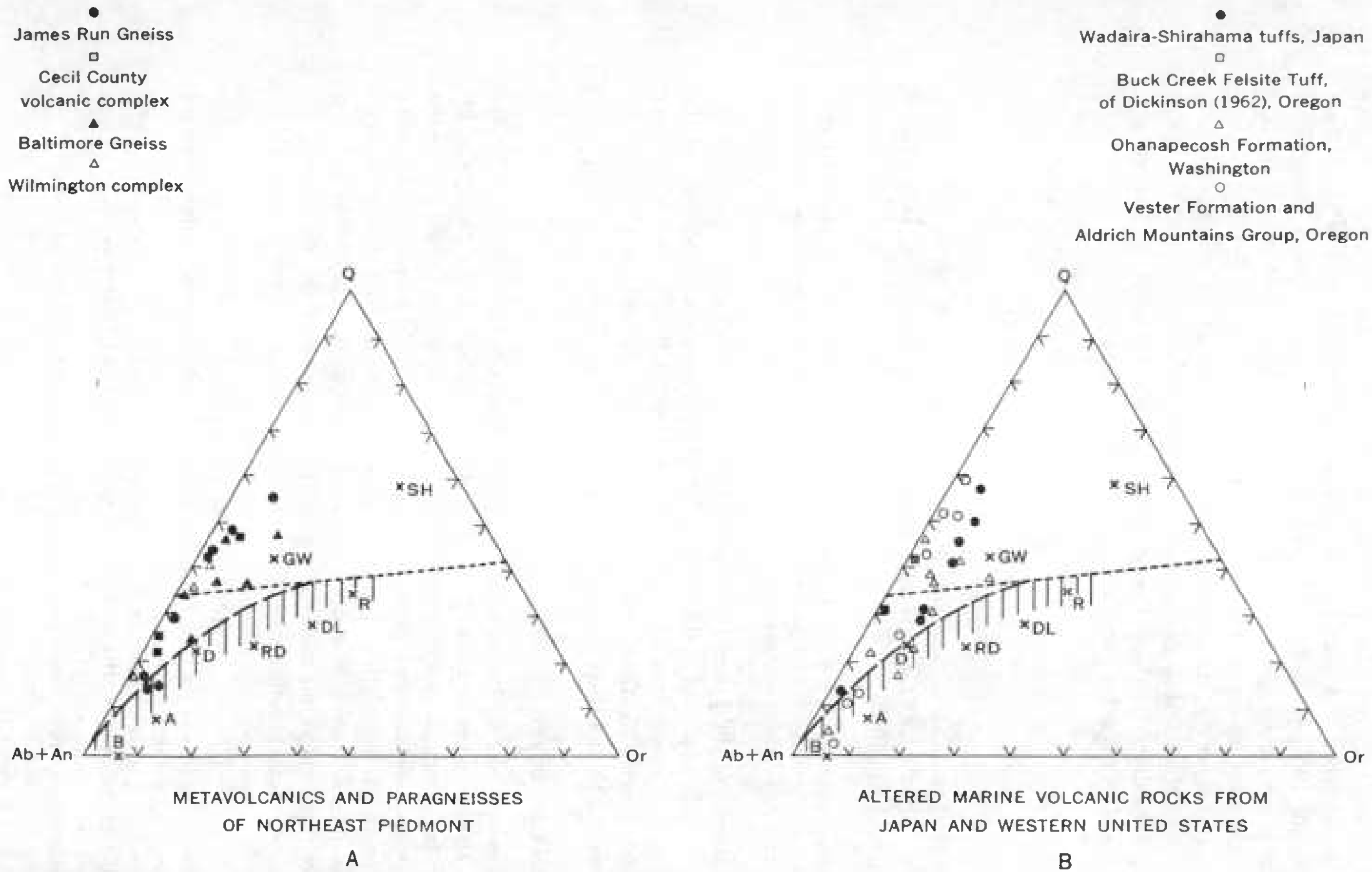

FIGURE 19. Plots comparing the normative compositions of layered rocks from the James Run Gneiss, volcanic complex of Cecil County, Baltimore paragneiss, and Wilmington complex with possible parent rocks and with submarine pyroclastic deposits from the western United States and Japan. The short dashed lines separate the fields of SiO_2 and alkali feldspar on the liquidus of the "dry" system Ab – Or – SiO_2. Unaltered volcanic rocks plot on the feldspar side: R, rhyolite; DL, dellenite; RD, rhyodacite; D, dacite; A, andesite; B, tholeiitic basalt (Bowen, 1937). Average shale, SH, and graywacke, GW, plot on the silica side. Altered marine volcanic rocks generally lie above the long-dashed line (diagram B), having a higher ratio of normative quartz and plagioclase to normative orthoclase than normal calc-alkaline lavas; the layered rocks of the Piedmont (diagram A) lie in the same area. Modified after Hopson, 1964, p. 34, fig. 13.

Data sources are: Piedmont rocks, this report (table 11); Wadaira-Shirahama Tuffs and Ohanapecosh Formation, unpublished data, R. S. Fiske, U. S. Geological Survey; Buck Creek Felsite Tuff of Dickinson (1962a), Vester Formation, and Aldrich Mountains Group, unpublished data, C. E. Brown and T. P. Thayer, U. S. Geological Survey.

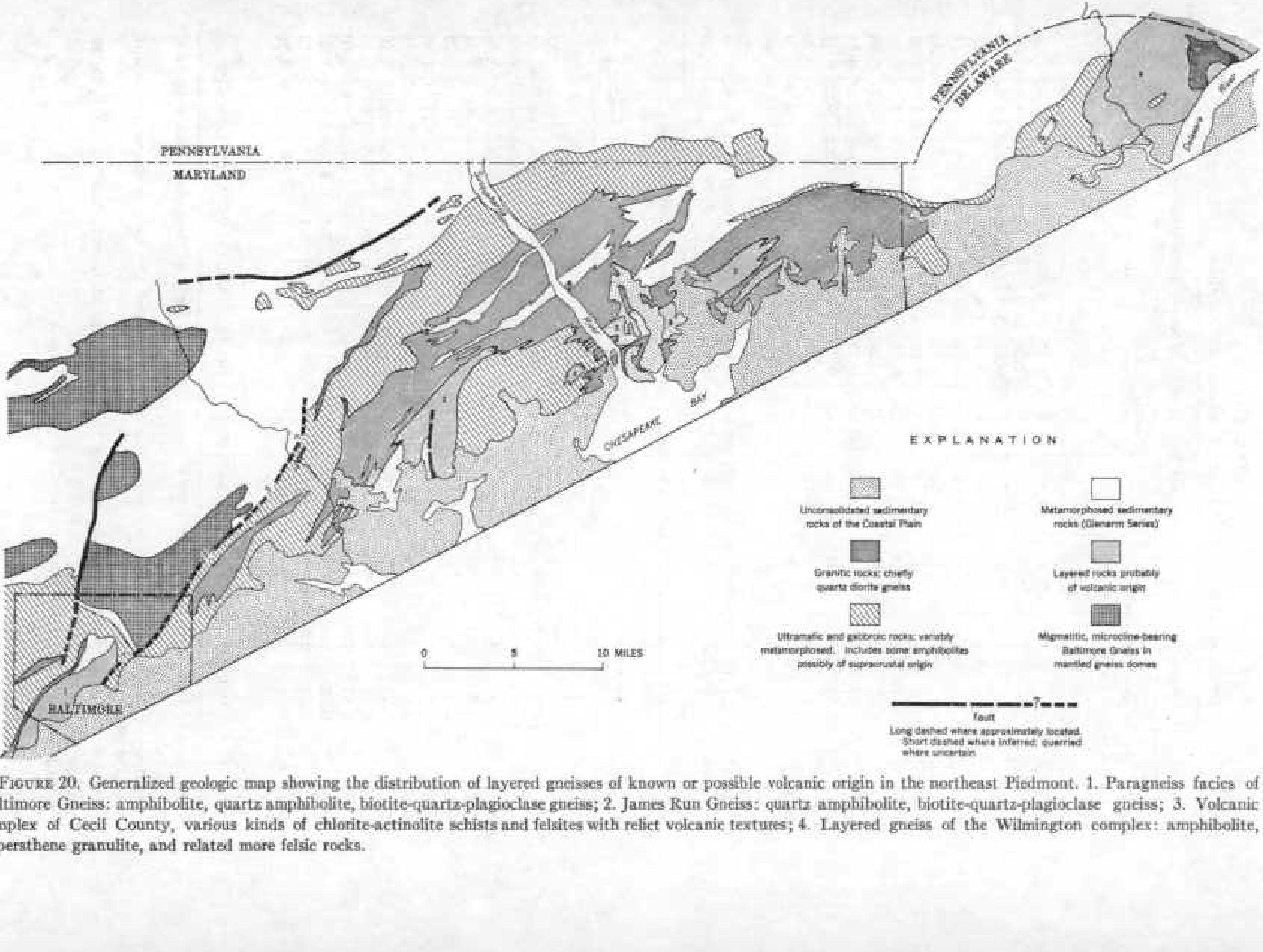

FIGURE 20. Generalized geologic map showing the distribution of layered gneisses of known or possible volcanic origin in the northeast Piedmont. 1. Paragneiss facies of Baltimore Gneiss: amphibolite, quartz amphibolite, biotite-quartz-plagioclase gneiss; 2. James Run Gneiss: quartz amphibolite, biotite-quartz-plagioclase gneiss; 3. Volcanic complex of Cecil County, various kinds of chlorite-actinolite schists and felsites with relict volcanic textures; 4. Layered gneiss of the Wilmington complex: amphibolite, hypersthene granulite, and related more felsic rocks.

TABLE 12

CHEMICAL ANALYSES OF LAYERED PARAGNEISSES, NORTHEAST PIEDMONT

I. *Felsic layers;* hornblende-poor rocks listed in order of decreasing SiO_2 for each group.

	James Run Gneiss[a]			Volcanic complex Cecil County[b]		Baltimore Gneiss[c]				Wilmington complex[d]	
	1	2	3	4	5	6	7	8	9	1	11
SiO_2	79.3	77.8	73.7	75.4	75.67	77.8	74.9	74.66	74.1	69.19	67.26
Al_2O_3	11.2	12.0	13.0	12.8	12.28	12.0	14.0	14.02	13.9	14.44	15.04
Fe_2O_3	1.1	0.0	1.5	1.2	0.85	1.1	0.3	0.37	1.0	1.89	2.13
FeO	1.1	2.3	2.6	1.4	2.59	1.4	1.3	1.44	1.9	3.34	3.53
MgO	0.28	0.17	0.62	0.70	0.37	0.3	0.3	0.17	0.4	1.89	1.74
CaO	1.7	2.4	3.6	1.7	2.65	2.4	2.5	2.08	2.7	4.71	5.36
Na_2O	3.1	4.0	3.9	5.3	3.63	4.3	4.3	4.20	4.7	3.09	3.29
K_2O	1.2	0.55	0.27	0.24	0.78	0.4	2.0	2.01	0.9	0.39	0.35
H_2O+	0.68	0.46	0.58	0.47	0.29	0.1	0.1	0.77	0.2	0.21	0.30
H_2O-	0.07	0.06	0.09	0.07	0.12	—	—	—	—	0.04	0.04
TiO_2	0.18	0.31	0.36	0.26	0.29	0.2	0.3	0.25	0.2	0.55	0.41
P_2O_5	0.04	0.10	0.10	0.30	0.05	tr	tr	0.09	tr	0.10	0.20
MnO	0.06	0.04	0.08	0.14	0.18	—	—	—	—	0.08	0.24
CO_2	<.05	<.05	<.05	<.05	tr	—	—	—	—	—	—
Other	—	—	—	—	0.18	—	—	—	—	—	—
TOTAL	100.0(1)	100.1(9)	100.4(0)	99.9(8)	99.93	100.0	100.0	100.06	100.0	99.92	99.89
Na_2O/K_2O	2.58	7.28	14.45	22.1	4.67	10.07	2.15	2.09	5.22	7.93	9.40

II. *Mafic layers;* hornblende-rich rocks listed in order of decreasing SiO_2 for each group.

	James Run Gneiss[a]				Volcanic complex, Cecil County[b]		Baltimore Gneiss[c]			Wilmington complex[d]		
	12	13	14	15	16	17	18	19	20	21	22	23
SiO_2	62.4	54.5	54.0	52.8	61.6	60.1	67.5	67.0	55.1	52.14	48.99	45.85
Al_2O_3	14.8	15.2	15.7	14.8	15.0	14.7	12.7	14.8	15.2	15.60	14.61	18.55
Fe_2O_3	3.4	3.4	2.2	4.8	4.2	3.2	2.8	0.8	1.8	0.23	1.79	3.62
FeO	5.2	7.4	5.9	8.3	6.0	6.7	3.1	2.5	5.3	10.84	8.62	9.34
MgO	2.6	5.8	7.3	4.8	2.0	2.9	3.1	2.9	7.5	9.27	10.89	6.72
CaO	5.6	8.5	10.4	8.1	4.0	6.3	5.4	5.2	8.6	8.78	12.58	11.96
Na_2O	3.6	2.5	1.6	2.8	4.8	4.0	4.3	4.7	4.6	0.55	1.36	1.64
K_2O	0.28	0.30	0.65	0.47	0.12	0.26	0.2	1.0	0.3	0.04	0.15	0.16
H_2O+	0.73	0.91	0.68	0.92	0.53	0.67	0.4	0.5	1.1	0.27	0.26	0.35
H_2O-	0.17	0.42	0.32	0.13	0.08	0.08	—	—	—	0.04	0.03	0.00
TiO_2	0.80	0.68	0.28	1.1	0.95	1.0	0.4	0.5	0.4	1.40	0.34	1.08
P_2O_5	0.17	0.11	0.05	0.15	0.27	0.26	0.1	0.1	0.1	0.13	0.02	0.12
MnO	0.15	0.19	0.17	0.21	0.18	0.23	—	—	—	0.16	0.20	0.21
CO_2	<.05	<.05	<.05	<.05	0.09	<.05	—	—	—	—	—	—
OTHER	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	99.9(0)	99.9(1)	99.2(5)	99.3(8)	99.8(2)	100.4(0)	100.0	100.0	100.0	99.45	99.84	99.60

[a] Analyses of James Run Gneiss from table 10; repeated here to facilitate comparison with analyses of other units.

[b] Analyses of volcanic complex of Cecil County from table 13; repeated here to facilitate comparison with analyses of other units.

[c] Analyses of Baltimore Gneiss (paragneiss) from Hopson, 1964, p. 32, table 8. Analyses 6, 7, 9, 18, 19, and 20 are calculated from modes.

[d] Analyses of Wilmington complex from Ward, 1959, p. 1448, table 14.

col. 10 = D4a of Ward
col. 11 = 28-74 Do.
col. 21 = G132 Do.
col. 22 = D4b Do.
col. 23 = 35-5 Do.

shall, 1937) have closely comparable bedding characteristics and chemical compositions, as do layered hypersthene granulites in northern Delaware (Ward, 1959).

These units are more or less on strike with one another and form a discontinuous belt just above the Fall Line from Wilmington, Delaware, to Baltimore (fig. 20). All contain beds of felsic and mafic rocks that are interlayered on all scales and have compositions compatible with a volcanic origin (table 12 and fig. 23); the Cecil County rocks have plainly recognizable relict volcanic textures. All units except the rocks of Cecil County are in apparent normal contact with Wissahickon Formation or its probable equivalents; the Cecil County volcanic rocks are wholly separated from schist by intrusive masses. All units have been intruded first by gabbroic and later by granitic rocks.

It seems likely that the layered rocks are more or less the same age, if not directly correlative, and represent a variably metamorphosed marine volcanic sequence that was deposited in the eastern part of the Glenarm geosyncline during middle to late stages of its history. Final correlation, however, awaits additional radiogenic dating and detailed geologic mapping between the areas for which structural and petrologic data are now available.

VOLCANIC COMPLEX OF CECIL COUNTY

Name and Previous Work

The informal name "volcanic complex of Cecil County" was applied by Marshall (1937) to a northeast-trending belt of metamorphosed volcanic rocks that extends along the Fall Line from the Susquehanna River to a point about 2 miles northeast of Bay View, Cecil County, Maryland. These rocks cross into Harford County near the southwest end of the bridge carrying Interstate Highway 95 over the Susquehanna but can be traced only about 1,500 feet southwest of the river before they are cut out by younger metagabbro. A small inlier or roof pendant surrounded by metagabbro is well exposed in Gasheys Creek, and inclusions, ranging from a few inches to tens of feet in size, are scattered through the metagabbro as far southwest as Robinhood Road.

The first geologists to study these rocks did not recognize their supracrustal origin. G. P. Grimsley (1894) called them diorite and thought they probably formed by the metamorphism of gabbro. They were mapped as metarhyolite by Bascom (1902), who thought they were intrusive dikes rather than flows or tuffs. In 1920, she decided that the term metadacite more correctly described their composition, but clung to her dike hypothesis (Bascom and Miller, 1920).

More detailed petrographic study by Marshall (1937) led to the recognition of relict amygdules in parts of the unit. He concluded that massive amygdaloid, sheared amygdaloid, and "schistose volcanics" all were derived by variable shearing and low-grade metamorphism of dacitic to andesitic lava flows.

Lithology

Apparently none of the earlier workers noted that the rocks in Frenchtown quarry in Cecil County or near Velvet Rock Run in Harford County are thin to medium bedded. Black to greenish-gray layers of fine-grained amphibole-rich rock are intercalated with bluish-gray to light-gray layers of very siliceous rock on a scale of a few inches to several feet. Some beds are amygdaloidal and therefore are thin flows; others contain oval blebs of greenish-black amphibole or chlorite in a felsic to chloritic matrix and seem to be metamorphosed tuffs with relict, flattened pumice fragments (fig. 21*p*). The bedded rock is split up by concordant apophyses of metagabbro. Michael Higgins of the U. S.

Geological Survey (personal commun., 1968) has recently discovered well-preserved pillow structure in metabasalt of this same unit along Northeast Creek in Cecil County.

In Harford County the volcanic rocks have a variably developed schistosity that is parallel to bedding and dips from 65° to 85° SE. A weak second cleavage transverse to bedding was noted in a few places but could not be measured accurately. Apophyses of metagabbro have worked their way along the bedding schistosity and have split the volcanic rocks into blocks and slivers. Both the volcanic rocks and the metagabbro have a pronounced lineation (chiefly of amphibole needles) that plunges about 60° NE. A similar lineation affects the Port Deposit Gneiss where it abuts the volcanic rocks in Cecil County.

The volcanic complex of Cecil County is completely surrounded by younger plutonic rocks, and its stratigraphic relationship to metasedimentary rocks of the Glenarm Series, therefore, is difficult to ascertain. Marshall tentatively concludes (1937, p. 212):

"The structure of the volcanics apparently indicates the trough of an isoclinally folded syncline remaining as a roof pendant in the surrounding Port Deposit granite complex. . . . Whatever the actual position may be there can be little doubt that the volcanics belong to the Glenarm Series and that they have been folded into their present position.

The intrusion of the Port Deposit complex has taken place after folding. . . ."

Petrography

Relict amygdules and plagioclase phenocrysts have survived low-grade metamorphism in parts of the complex, but no groundmass textures are preserved. As indicated by Marshall (1937), there is a clear gradation from rocks with well-preserved amygdules (and/or phenocrysts) to rocks from which all relict features have been obliterated by shearing and recrystallization. Actinolite- and chlorite-rich blebs that are probably smeared out pumice fragments in metamorphosed tuff can be recognized under the microscope as well as in hand specimen.

In terms of mineral composition, the rocks range from those containing chiefly quartz and untwinned sodic plagioclase and a few percent of amphibole, biotite, or chlorite to those containing chiefly amphibole and epidote with a few percent quartz and sodic plagioclase. Quartz and sodic plagioclase are common to all the observed mineral assemblages; colorless and green amphibole, biotite, chlorite, and epidote coexist with them in a variety of combinations and proportions (table 13). All the rocks are fine-grained and granoblastic with marked but variably developed foliation.

The commonest amygdule filler is epidote, which forms radial sheaves and granular aggregates. Quartz and albite amygdules also occur but these tend to recrystallize and become obliterated more easily than do epidote-filled ones. Zoned epidote-albite amygdules are described and figured by Marshall (1937, p. 193–196). Curious oval bodies consisting of epidote, pale-green amphibole, garnet, chlorite, magnetite, pyrite, sphalerite, and galena occur in a flinty, blue-black rock at the southwest end of the Interstate Highway 95 bridge over the Susquehanna River. Some of these definitely look like amygdules, whereas others are nondescript medium-grained patches with irregular boundaries (fig. 22*p*). They are probably amygdules that have been mineralized by hydrothermal solutions related to sulfide-carbonate-albite veins that crisscross the area. Carbonate-albite veins and a pyrite-rich shear zone occur directly on strike with this occurrence on the Cecil County side of the river.

Pale- to medium-green actinolitic hornblende is the commonest amphibole in the volcanic complex. In many felsic and intermediate beds, however, there are two am-

TABLE 13

VISUALLY ESTIMATED MODES OF ROCKS FROM THE VOLCANIC COMPLEX OF CECIL COUNTY, HARFORD AND CECIL COUNTIES

	1	2	3	4	5	6
Plagioclase	35	45	45	60	42	32
Quartz	45	40	43	20	15	5
Hornblende	—	—	3	12	35	50
Cummingtonite[a]	—	—	2	3	—	1
Biotite	10	10	2	—	—	7
Muscovite	10	—	—	—	—	—
Chlorite	tr	tr	3	tr	5	3
Epidote	tr	4	1	1	tr	tr
Opaques	tr	1	1	3	3	2
Carbonate	—	—	—	tr	—	—
Garnet	—	—	—	tr	—	—

[a] Identification based only on optical properties, which are not definitive; see text for details.

1. Face of abandoned quarry on Susquehanna River about 1,500 feet northwest of Interstate Highway 95, Harford County. Felsic bed in interbedded felsic and mafic sequence.
2. Face of abandoned quarry on Susquehanna River about 400 feet northwest of Interstate Highway 95, Harford County. From near center of 15-foot-thick felsic unit with relict amygdules.
3. Old Frenchtown Quarry just northwest of Interstate Highway 95, Cecil County.
4. Large cuts at southwest end of Interstate Highway 95 bridge over Susquehanna River, Harford County.
5. Outcrop in Gasheys Creek about 700 feet south of Chapel Road, Harford County.
6. Highly schistose rock near metagabbro contact, quarry on Susquehanna River about 1,000 feet northwest of Interstate Highway 95, Harford County.

phiboles—a colorless and a blue-green one—that commonly occur as zones or irregular patches of the same crystal (fig. 23*p*). In zoned crystals the colorless amphibole generally forms the cores and blue-green amphibole the rims; the contact between the two may be sharp or indistinct. Optic angle measurements indicate that the colorless amphibole may be cummingtonite and the blue-green one a soda-rich hornblende. No confirmatory optical or X-ray studies were undertaken, owing to difficulties of separation, but the problem deserves further work. Coexisting cummingtonite and hornblende have been reported in metagabbros and amphibolites from many areas (*e.g.* Eskola, 1950; Watters, 1959; Vernon, 1962) and the assemblage probably is much more common than presently realized.

Magnetite, which forms as much as 5 percent of many layers, is by far the commonest accessory in the rocks of the volcanic complex of Cecil County. Consequently, these rocks are sufficiently magnetic to produce marked positive anomalies on the aeromagnetic map, even against a background of metagabbro. Sphene, apatite, and garnet are less abundant but common accessories.

Chemical Composition

Chemical analyses of rocks in the volcanic complex of Cecil County (table 14) show ratios of Na_2O to K_2O that are much greater than normal for calc-alkali rhyolites, dacites, or andesites. The compositions are similar to volcanic rocks from the Pacific Northwest and elsewhere that were deposited under water and later were albitized and zeolitized. There is no evidence of large-scale alkali migration during low-grade metamorphism, but undoubtedly some local adjustments took place. The chemical similarity

TABLE 14

CHEMICAL ANALYSES AND NORMS OF ROCKS FROM THE VOLCANIC COMPLEX OF CECIL COUNTY, HARFORD AND CECIL COUNTIES

Major Oxides[a]					Trace Elements[b]					Norms				
	1	2	3	4		1	2	3	4		1	2	3	4
SiO_2	75.4	75.67	60.1	61.6	Ba	.007		.01	.005	Q	39.19	43.77	16.69	19.83
Al_2O_3	12.8	12.28	14.7	15.0	Ce	.007		—	.01	C	1.45	0.72	—	0.56
Fe_2O_3	1.2	0.85	3.2	4.2	Co	.0007		.002	.001	Or	1.42	4.61	1.54	0.71
FeO	1.4	2.59	6.7	6.0	Cr	—		.0007	—	Ab	44.82	30.70	33.83	40.59
MgO	0.70	0.37	2.9	2.0	Cu	.0002		.002	.0015	An	6.47	12.94	21.39	17.51
CaO	1.70	2.65	6.3	4.0	Ga	.001		.0015	.0015	Wo	—	—	3.41	—
Na_2O	5.3	3.63	4.0	4.8	La	.003		—	.005	En	1.74	0.92	7.22	4.98
K_2O	0.24	0.78	0.26	0.12	Mo	.0003		.0003	.0005	Fs	1.41	3.68	8.43	6.31
H_2O+	0.47	0.29	0.67	0.53	Nb	.001		—	.0007	Mt	1.74	1.23	4.64	6.09
H_2O-	0.07	0.12	0.08	0.08	Pb	.0003		—	.0015	Il	0.49	0.55	1.90	1.80
TiO_2	0.26	0.29	1.0	0.95	Sc	.001		.003	.003	Ap	0.71	0.12	0.62	0.64
P_2O_5	0.30	0.05	0.26	0.27	Sr	.01		.007	.02	Pr	—	0.21	—	—
MnO	0.14	0.18	0.23	0.18	V	.001		.015	.01	Cc	—	—	—	0.21
CO_2	<0.05	tr	<0.05	0.09	Y	.005		.003	.005	(H_2O)	0.54	0.41	0.75	0.61
Other	—	0.18	—	—	Yb	.0005		.0003	.0005	TOTAL	99.98	99.86	100.42	99.84
TOTAL	99.9(8)	99.93	100.4(0)	99.8(2)	Zr	.03		.01	.03					
					Zn	—		—	reported					

[a] Except for analysis 2, analyzed in the laboratories of the U. S. Geological Survey by methods similar to those described by Shapiro and Brannock (1962).

[b] Semiquantitative spectrographic analyses, U.S. Geological Survey; Zn detected qualitatively in concentrate of amygdule-filling minerals analysis 4.

1. Cummingtonite(?)-hornblende-plagioclase-quartz schist (schistose felsite), old Frenchtown quarry, Cecil County. Analyst: U. S. Geol. Survey rapid method, 1965. 2. "Acid dike-rock" (now considered to be volcanic), Cecil County. Analyst: W. F. Hildebrand *in* Bascom, 1902, p. 138. 3. Fine-grained quartz amphibolite from large inclusion in coarse metagabbro, Interstate Highway 95 about 2,150 feet southwest of Chapel Road, Harford County. Analyst: U. S. Geol. Survey rapid method, 1963. 4. Flinty, dark-gray felsite containing cummingtonite (?), hornblende, plagioclase, and quartz with amygdules of epidote, garnet, pyrite, galena, and sphalerite. Southwest end of Interstate Highway 95 bridge over Susquehanna River, Harford County. Analyst: U. S. Geol. Survey rapid method, 1965.

of the rocks of the volcanic complex to the higher grade James Run Gneiss already has been discussed (see p. 106, fig. 18*p*).

Origin and History

Relict textures and chemical data show that the volcanic complex of Cecil County originally was a sequence of thin lava flows and tuffs of intermediate to felsic composition. The sections of interbedded, thin and thick mafic and felsic layers are much like some less metamorphosed volcanic piles, such as the Ohanapecosh Formation of Washington (Fiske, 1963), that consist of intermediate to felsic flows and volcaniclastic rocks interlayered on all scales. Chemically, also, the rocks of the volcanic complex of Cecil County are closely akin to this class of volcanic material, which was probably deposited at least partly under water and albitized and zeolitized during diagenesis and deep burial (Fiske, Hopson, and Waters, 1963), or by base exchange with sea water (Hamilton, 1963, p. 74). In the case of the Cecil County rocks, this alteration was followed at an unknown later time by low-grade regional metamorphism.

Age

The volcanic complex of Cecil County is cut by metagabbro that probably is about the same age as Baltimore Gabbro of Cloos and Hershey (1963), and by Port Deposit Gneiss. Zircons from the Port Deposit have Pb_{207}-Pb_{206} ages in the range 475–525 $\pm$ 20 m.y. (Steiger and Hopson, 1965; Davis and others, 1965); therefore the volcanic rocks can be no younger than Cambrian and may be late Precambrian. They probably belong in the Glenarm Series even though they cannot be seen in contact with unequivocal Glenarm metasedimentary rocks.

BALTIMORE-STATE LINE GABBRO-PERIODOTITE COMPLEX

General Description

The Baltimore-State Line gabbro-peridotite complex, consisting of variably metamorphosed gabbro, ultramafic rock, quartz diorite, and albite granite, is the largest mafic pluton in the northeastern Piedmont (see Larrabee, 1966, sheet 3). It has been subidivided by Hopson (1964) into three parts, from west to east named the Soldiers Delight, Laurel, and Bel Air belts. Hopson's Bel Air belt crosses Harford County and is the subject of this discussion; it is here referred to simply as the Harford County segment of the Baltimore-State Line complex, following the informal usage suggested by T. P. Thayer (oral commun., 1967).

Inasmuch as a separate detailed paper on the Baltimore-State Line complex in Harford County has been written (Southwick, 1969), only a brief description of these rocks is given here. Readers are urged to consult earlier papers by Williams (1884, 1886, 1890), Cohen (1937), Herz (1951), and Hopson (1964) for additional petrologic and structural details on other parts of the complex.

At the Susquehanna River, the Baltimore-State Line gabbro-peridotite complex consists of a mile-wide zone of ultramafic rocks on the northwest, a zone of gabbro about 3 miles wide in the middle, and a zone of quartz gabbro and quartz diorite about 1.5 miles wide on the southeast (Plate 1). Contacts are broadly concordant with bedding schistosity in wall rocks of the Wissahickon Formation, and this, plus the rock sequence at the Susquehanna River, led Knopf (1921, p. 89) to postulate that the mass was a huge, upturned sheet, its gravity-differentiated floor phase on the northwest. A similar interpretation was made by Hopson (1964, p. 135).

This simple pattern does not extend far southwest of the river, however. Just north of Sandy Hook, ultramafic and mixed gabbroic and ultramafic rocks on the northwest side of the complex veer westward, forming a dikelike offshoot into the country rock. The northern part of this offshoot is chiefly serpentinized olivine-rich rock, whereas the southern part is a tangle of talc- and amphibole-rich rocks derived from intimately mixed pyroxenite and gabbro. Podlike bodies north of the offshoot are chiefly serpentinite and soapstone but also contain significant volumes of metamorphosed gabbro. Podiform masses of chromite have been mined from parts of the offshoot and several of the isolated ultramafic lenses (Pearre and Heyl, 1960).

Lithology

Between Bel Air and the Susquehanna River, the central gabbro zone is chiefly hypersthene gabbro that is slightly to completely uralitized and massive except for local shear zones. Virtually unaltered gabbro and uralitized rock are patchily intermixed in the manner described by Williams (1886, pl. 4, p. 72), and it is common to find all stages in the conversion of gabbro to uralite gabbro in a distance of a few feet. The parent rock consists of hypersthene, augite ("diallage"), and calcic plagioclase in varying proportions. Rocks properly classed as augite gabbro or norite are not rare, but most of the gabbros contain subequal amounts of hypersthene and augite and are conveniently termed hypersthene gabbro.

Farther southwest, between Bel Air and Little Gunpowder Falls, the commonest rock of the central zone is thoroughly recrystallized, lineated epidote amphibolite. It is cut by numerous small masses of gneissic quartz diorite and by a large apophysis in the valley of Winters Run. The amphibolite of this area was interpreted by Insley (1928, p. 321) as Baltimore Gneiss rather than Baltimore Gabbro (Cloos and Hershey, 1936) because it is lineated and at least partly quartz bearing. It is directly on strike with undoubted gabbro, however, and probably is metamorphosed gabbro and related diorite that have been locally modified by additions of water and perhaps silica from closely subjacent intrusive quartz diorite.

Pyroxenite and metapyroxenite form several small lenslike bodies near the northwest side of the gabbro belt, and an oval area about 1.5 miles long toward its center, southeast of Hickory. Most of these rocks are composed chiefly of pale-green, fibrous actinolite or talc plus actinolite; relict pyroxene is rare. They grade into metamorphosed gabbro on all sides.

Hypersthene gabbro grades southeastward into a belt of quartz gabbro and quartz diorite, which can be traced from Thomas Run to the vicinity of Conowingo Dam. It goes on into Cecil County, but its extent there is imperfectly known. The variable appearance and extremely poor exposure of these rocks have led to conflicting interpretations of them, but earlier workers all agree that they are somehow related to the gabbro complex (Maryland Geol. Survey, 1904; Insley, 1928, p. 310–315; Bascom, 1902, p. 121–124). Some rocks in this belt are dark, hornblende-rich, medium- to coarse-grained uralite gabbros having a few percent quartz; others are rather light biotite-hornblende quartz diorite. Commonly the dioritic rocks contain abundant dark inclusions that increase in abundance toward the northwest edge of the belt.

The southeast contact of the diorite belt is a complex zone that is confused by extensive shearing and by injection of phases of the Port Deposit Gneiss. A highly sheared zone of mixed rocks involving diorite, epidote amphibolite of uncertain affiliation, quartzite and boulder gneiss of the Wissahickon Formation, and aplite to quartz diorite phases of the Port Deposit Gneiss is exposed near the intake structure of the Baltimore-Susquehanna aqueduct of Conowingo Dam. A similar situation is inferred from a somewhat poorer outcrop along strike at Deer Creek.

Net veins, generally richer in plagioclase and somewhat coarser grained than the enclosing rock, are common in the gabbro. Some contain primary hornblende and are close to diorite in composition. Most veins are sharply bounded and unchilled. They pinch and swell, branch, and wander across all earlier structures; in many ways they resemble the subpegmatitic gabbro dikelets described by Baragar (1960) and are identical in appearance to veins in the Canyon Mountain complex of Oregon, figured by Thayer (1963, p. 59, fig. 10).

Petrography

The petrography and chemistry of rocks of the Baltimore-State Line gabbro-peridotite complex have been described in detail in another report (Southwick, 1969) and will be summarized only briefly here.

The ultramafic rocks are principally serpentinite that has been partly altered to talc or talc-carbonate rock, and various kinds of amphibole rocks after pyroxenite. Relict olivine and pyroxene are very scarce. The olivine is in the composition range Fo_{86-92}, and the orthopyroxene in the range En_{78-82}.

The hypersthene gabbro contains hypersthene, augite, very calcic, unzoned plagioclase (approx. An_{90}) and rarely primary brown hornblende. The hypersthene of the northwestern part of the gabbro zone is in the range En_{65}-En_{72}, whereas it is more iron rich in the southeast third of the zone, having compositions in the range En_{47}-En_{57}. Upon uralitization, fibrous green hornblende forms at the expense of pyroxene and some of the plagioclase, and the bytownite breaks down to clinozoisite or epidote plus a lesser calcic plagioclase.

The iron-rich gabbros seem to grade southeastward into quartz diorite. Traces of quartz and biotite appear and increase toward the quartz-diorite belt. The quartz diorite contains strongly zoned plagioclase (cores as calcic as An_{85}, rims as sodic as An_{45}) and quartz with various combinations of clinopyroxene, orthopyroxene, green hornblende, and biotite. Epidote and fibrous pale-green amphibole are widely developed, probably as the result of both deuteric alteration and metamorphism.

Origin

The Baltimore State Line gabbro-peridotite complex is the oldest intrusive pluton in the area. It invades the Wissahickon Formation and is cut by the Port Deposit Gneiss. It has been interpreted by Hopson (1964) as a stratiform sheet emplaced early in the tectonic history of the area and deformed as it cooled. I think the Harford County part of the mass was so strongly deformed that it actually was squeezed out of its original magma chamber and into higher levels of the crust (Southwick, 1969).

METAGABBRO NEAR ABERDEEN

A large mass of medium- to coarse-grained epidote amphibolite and epidiorite occurs in the vicinity of Aberdeen (plate 1). It is weakly to strongly lineated but lacks layering of any sort. A gabbro parent for these rocks is indicated by (1) their massive, unstratified character; (2) rare but unmistakable relicts of gabbroic texture; (3) the common occurrence of small dikes and net veins of hornblende gabbro pegmatite; and (4) the local occurrence of ultramafic rocks. The metagabbro intrudes the James Run Gneiss and

TABLE 15

MODAL ANALYSES OF AMPHIBOLITES AND EPIDOTE AMPHIBOLITES FROM THE METAGABBRO MASS NEAR ABERDEEN

	1	2	3	4	5	6	7
Plagioclase	27.4	24.0	20.4	27.8	36.7	20.3	28.4
Quartz	0.3	—	—	—	1.5	4.7	0.1
Hornblende	66.5	75.2	78.5	69.8	58.3	68.7	59.6
Epidote	4.5	0.4	1.0	2.1	2.8	5.7	10.1
Chlorite	0.1	tr	tr	tr	0.3	tr	0.2
Sphene	0.8	—	tr	0.1	0.1	tr	1.0
Rutile	0.3	0.1	tr	—	0.1	—	—
Opaques	0.1	0.3	0.1	tr	0.2	0.6	0.6
Apatite	tr	tr	tr	—	—	tr	tr
Clay minerals	—	—	—	0.2	—	—	—
TOTAL (vol. percent)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
No. of points	1457	1452	1461	1470	1495	1452	1447

1. Amphibolite derived from gabbro, Interstate Highway 95 0.2 mile NE. of Maryland Route 492.
2. Amphibolite derived from gabbro, Interstate Highway 95 at Stepney Road.
3. Coarse epidote amphibolite with relict gabbroic texture. Interstate Highway 95 at Maryland House, 0.65 mile NE. of old Maryland Route 543.
4. Amphibolite, 5,930 feet from north portal of tunnel on Baltimore-Susquehanna aqueduct.
5. Amphibolite, Graftons lane at stream 0.75 mile W. of Maryland Route 22.
6. Amphibolite, knob in drainage of Mill Creek, approximately 600 feet S. of Maryland Route 155.
7. Amphibolite, gulch east of Cullum Road about 0.3 mile N. of Maryland Route 543.

TABLE 16

CHEMICAL ANALYSES OF ROCKS FROM THE METAGABBRO MASS NEAR ABERDEEN

Major Oxides[a]				Trace Elements[b]				Norms			
	1	2	3		1	2	3		1	2	3
SiO_2	46.7	45.9	48.3	Ba	.007	.01	.0005	Q	—	—	—
Al_2O_3	16.8	16.8	18.7	Co	.01	.01	.0015	C	—	—	—
Fe_2O_3	3.3	3.5	1.3	Cr	.05	.005	.03	Or	1.60	0.41	0.35
FeO	8.6	9.5	3.7	Cu	.07	.005	.07	Ab	15.22	6.77	5.24
MgO	8.2	9.0	9.4	Ga	.0015	.0015	.001	An	36.96	42.04	48.06
CaO	11.6	13.1	16.6	Mo	.0005	.0005	—	Wo	8.26	9.41	13.83
Na_2O	1.8	0.80	0.62	Ni	.02	.003	.005	En	14.38	18.14	23.38
K_2O	0.27	0.07	0.06	Pb	.0007	.0007	—	Fs	8.28	11.46	5.62
H_2O+	0.96	0.85	0.73	Sc	.003	.007	.002	Fo	4.23	2.99	0.01
H_2O-	0.10	0.08	0.10	Sr	.015	.01	.0003	Fa	2.68	2.08	0.03
TiO_2	1.0	0.50	0.17	V	.05	.02	.007	Mt	4.78	5.08	1.88
P_2O_5	0.12	0.06	0.02	Y	.001	—	—	Il	1.90	0.95	0.32
MnO	0.18	0.23	0.10	Yb	.0001	—	—	Ap	0.28	0.14	0.05
CO_2	<0.05	<0.05	0.16					Cc	—	—	0.36
TOTAL	99.6(3)	100.3(9)	99.9(6)					(H_2O)	1.06	0.93	0.83
								TOTAL	99.63	100.40	99.96

[a] Analyzed in laboratories of the U. S. Geological Survey by methods similar to those described by Shapiro and Brannock (1966).

[b] Semiquantitative spectrographic analyses, U. S. Geological Survey.

1. Amphibolite derived from gabbro, Interstate Highway 95, 0.2 mile northeast of Maryland Route 462.
2. Amphibolite derived from gabbro, Interstate Highway 95 at Stepney Road.
3. Coarse epidote amphibolite with relict gabbroic texture. Interstate Highway 95 at Maryland House, 0.65 mile northeast of old Maryland Route 543.

volcanic complex of Cecil County and is intruded by the Port Deposit Gneiss; its age, therefore, is in the same geologic bracket as the Baltimore Gabbro (Cloos and Hershey, 1936), but there is no field or radiogenic evidence that the two masses are strictly correlative.

Most of the rocks in the mass near Aberdeen are ordinary medium-grained epidote amphibolite, consisting of green hornblende, intermediate plagioclase, and epidote with traces of quartz. Accessory minerals include sphene, rutile, opaque oxides, pyrite, and apatite; secondary chlorite and montmorillonitic clay minerals are sparingly present. Modal analyses of some typical rocks are given in table 15, and chemical analyses are given in table 16.

The metagabbro locally weathers to a characteristic cellular red clay. The plagioclase is leached out completely during weathering, and a porous boxwork of montmorillonite derived from the amphibole remains. This cellular clay has densities ranging as low as 1.3 (C. B. Hunt, oral commun., 1963) and is extremely difficult to compact. Because of its lightness and resistance to compaction, residual clays developed on the Aberdeen metagabbro present engineering difficulties for heavy construction projects.

PORT DEPOSIT GNEISS

Name

The Port Deposit Gneiss is a plutonic complex of different kinds of gneissic granitic rocks that is southeast of the Baltimore-State Line gabbro-peridotite complex and extends from near Newark, Delaware, to northeastern Baltimore County, Maryland. It is named for the town of Port Deposit, Maryland, on the Susquehanna River, near which it has been extensively quarried. "Port Deposit" has been used as a formational term at least since 1894 (Grimsley, 1894, p. 112), but the rock type to which it applies has been changed several times. Thus, Grimsley referred to Port Deposit *Granite*, Bascom (1902, p. 117) to Port Deposit *Granite-gneiss*, Knopf and Jonas (1929b) to Port Deposit *Granite* and also Port Deposit *Gneiss*, and Hershey (1937) to the Port Deposit *Granodiorite Complex*. Bascom (1902) noted that rocks ranging in composition from hornblende quartz diorite to biotite quartz monzonite occur in the complex, and this was amplified by Hershey (1937). Hershey correctly points out that contacts between internal rock types are gradational and impossible to map with the available exposure. Because the complex is chiefly quartz diorite and microcline-poor granodiorite, and all of it is gneissic, quartz diorite gneiss is favored as a general lighologic name. For the sake of brevity, the formal name Port Deposit Gneiss, now used by the U.S. Geological Survey, is adopted here.

Regional Setting

The Port Deposit Gneiss intrudes the Baltimore-State Line Gabbro-peridotite complex, various metasedimentary rocks that probably belong to the Glenarm Series, the volcanic complex of Cecil County, the James Run Gneiss, and amphibolite of the Aberdeen metagabbro mass. It is cut by widely scattered, narrow dikes of diabase and by a small swarm of narrow hornblendic dikes in the Havre de Grace area that have been called lamprophyre by Hershey (1937, p. 118–119). Intrusive contacts of granodiorite gneiss into mafic and metasedimentary rocks may be seen near Conowingo Dam and at places along Little Gunpowder Falls, Winters Run, Bynum Run, and Deer Creek. Excavations for the Route 1 Bel Air bypass exposed metagabbro intricately diked by quartz diorite gneiss on the hills on both sides of Winters Run.

According to Hershey (1937, p. 148) "It is perfectly evident . . . that the Port Deposit pluton is not a batholith but consists of a large number of small concordant intrusions. These are structurally and petrographically independent of each other and represent a sequence of intrusions which followed each other at close intervals during one major period of deformation." This certainly appears to be true in Cecil County, where a number of small plutons have punched into schists of the Glenarm Series, and along the Susquehanna River where larger plutons are separated by long septa of schist, but is not evident farther southwest in Harford County where schist septa are rare and regional shearing of the plutonic rocks has been intense. In south-central Harford County, the Port Deposit includes wide areas of strongly gneissic or even schistose plutonic rocks that locally are difficult to tell from metamorphosed sediments without petrographic examination. These occur over much of the area mapped as Baltimore Gneiss by Mathews and Johannsen (Maryland Geol. Survey, 1904); they are shown, in generalized form, as sheared Port Deposit Gneiss on the geologic map of Harford County (plate 1).

Some of the more gneissic parts of the Port Deposit are exceedingly difficult to distinguish from felsic phases of the James Run Gneiss, especially in the southeastern part of the outcrop belt. It is possible and even likely that some of the rocks mapped as sheared Port Deposit Gneiss are really felsic James Run Gneiss.

It is also possible that some of the rock mapped as sheared Port Deposit Gneiss may be the boulder gneiss lithofacies of the Wissahickon Formation. The boulder gneiss is typically of granitic appearance (Hopson, 1964, p. 103; Southwick and Fisher, 1967, p. 12, and references therein), and where strongly foliated, it is not unlike sheared quartz diorite. Boulder gneiss, commonly associated with other lithofacies of the Wissahickon, occurs as large inclusions within the Port Deposit complex. The excellent exposures of boulder gneiss just below Conowingo Dam (Hershey, 1937, Hopson, 1964, p. 118) are such an occurrence. It is quite possible, therefore, that areas of boulder gneiss have been misinterpreted as plutonic rock in the poorly exposed terrane southeast of Bel Air.

Particularly open to question are highly foliated biotite-quartz-plagioclase gneisses, locally rich in fine-grained muscovite, chlorite and epidote, that contain conspicuous augen of blue-gray quartz as long as 10 mm. These augen strongly resemble quartz pebbles, but are equally plausible quartz prophyroclasts in a sheared, recrystallized granitoid rock. Their relatively uniform size and even distribution is not characteristic of the ubiquitous quartz "lumps" in undoubted boulder gneiss. Relict igneous textures, though scarce, support the metaigneous interpretation.

The Foliation Problem

All rocks of the Port Deposit complex are foliated to one degree or another, and the origin of the foliation has been the subject of controversy. Bascom (1902) and earlier workers noted its general concordance to schistosity in the wall rocks and apparently concluded that it was produced by deformation after emplacement. Hershey (1937, p. 131) attributed the foliation to magmatic flowage. He thought it formed as magma was injected under stress, before it completely crystallized. In support of this view, he cites the presence of oriented wall-rock inclusions, some of which have discordant internal structures; the mutual parallelism of minerals, mineral groups, inclusions, groups of inclusions, and schlieren; the parallelism of these to the contacts of the pluton, even where the contacts are discordant to wall-rock schistosity; and the general intensification of foliation toward the edges of the pluton. Stose and Stose (1944, p. 53) argue that the foliation is metamorphic and "was produced during the folding that affected both these intrusive rocks and the schists in which they are intruded."

Hershey's field observations are substantially correct. I did not find any place where foliation of the granitic rocks is discordant to wall-rock structure on a regional scale, but there are many places where dikelike offshoots, foliated parallel to their contacts, wander across wall-rock schistosity. In most areas, however, the evidence for secondary deformation is strong and unmistakable. In the vicinity of Level, Lapidum, Rocks Run, and Port Deposit, toward the center of the pluton, two foliations intersect at angles of 5° to 30°. Generally one direction is better developed than the other. Both sets cut across pods of quartz and aplite within granodiorite gneiss, and therefore formed after the mass was solid. Biotite, muscovite, epidote, and garnet have recrystallized along them. The intersecting foliations produce a characteristic braided pattern on surfaces normal to their intersection (fig. 24*p*).

There is a complete gradation from rocks having a measurable discordance between two foliations, as described above, and rocks having essentially one strongly developed shear surface that weaves around augen of quartz and feldspar. Recrystallization and development of new minerals, especially muscovite, has been extensive in these rocks, and there can be little doubt that the shearing took place after solidification. Petrographic evidence also supports the contention that shearing took place after consolidation.

Hopson (1960, p. 30–31) points out that this obvious deformation need not be ascribed to a completely postintrusion metamorphic episode. He suggests that the pluton may be syntectonic, "with magmatic flowage passing into protoclastic granulation, in turn passing indistinguishably into metamorphic deformation and recrystallization as the mass became sufficiently competent to transmit regional deforming stresses." I agree that this interpretation best fits the evidence available. It should be emphasized, however, that at many places the late-stage metamorphic shearing and recrystallization may have obliterated evidence of an earlier stage of magmatic flowage.

Petrography

The most voluminous rocks in the Port Deposit pluton are gneissic biotite quartz diorite, hornblende-biotite quartz diorite, and biotite granodiorite (table 17). Gneissic hornblende quartz diorite and biotite quartz monzonite were noted but seem to be fairly local. Dikes of pegmatite, aplite, and hornblende lamprophyre cut the plutonic rocks; dikes of granite porphyry are reported by Hershey (1937) but were not seen by me. In a very general way, the quartz diorite seems to lie toward the edges of the complex and the granodiorite toward the center.

Igneous texture is recognizable but never perfectly preserved. Some of the least sheared rocks are hypidiomorphic granular, having quartz and perthitic microcline (where present) moulded around euhedral to subhedral biotite, hornblende, and progressively zoned plagioclase, but this primary texture has been partly obliterated by granulation and recrystallization. During shearing of the protoclastic stage, when temperatures were still relatively high, the original plagioclase crystals were bent, broken, and partly replaced by unzoned granular oligoclase and epidote. Originally large quartz crystals were strained and commonly converted to mosaic aggregates of small grains. Biotite, epidote, and euhedral small garnets grew in shear zones transverse to the primary foliation. Continued shearing under lower temperature conditions produced muscovite

TABLE 17

MODAL ANALYSES OF PORT DEPOSIT GNEISS, HARFORD COUNTY

	1	2	3	4	5	6
Plagioclase	35.1	39.2	42.1	48.8	36.1	34.7
Quartz	29.7	27.1	29.7	37.6	37.3	44.5
Microcline	—	—	—	—	9.0	9.3
Myrmekite	—	—	—	—	0.1	0.3
Biotite	14.8	20.9	16.1	11.8	10.0	6.2
Hornblende	8.4	—	—	—	—	—
Epidote	10.5	11.1	10.7	0.8	4.0	3.2
Garnet	—	—	—	0.1	0.2	0.1
Chlorite	1.1	—	0.7	0.2	tr	—
Muscovite	tr	—	—	tr	3.0	1.4
Opaques	tr	1.5	0.5	0.4	tr	tr
Apatite	0.1	0.1	0.1	0.2	0.1	0.1
Allanite	—	—	tr	—	—	0.1
Zircon	0.1	0.1	tr	0.1	0.1	tr
Monazite	—	—	0.1	tr	—	—
Carbonate	—	—	—	—	—	tr
Sphene	0.2	tr	—	—	0.1	0.1
TOTAL (vol. percent)	100.0	100.0	100.0	100.0	100.0	100.0
No. of points	1513	1479	1514	1660	1615	1553

1. Hornblende-biotite quartz diorite gneiss, Deer Creek about 0.15 mile upstream from Maryland Route 161.
2. Biotite quartz diorite gneiss, Bel Air bypass (U. S. Route 1) about 0.4 mile north of Winters Run.
3. Biotite quartz diorite gneiss, west side of Susquehanna River, 1 mile southeast of Conowingo Dam.
4. Biotite quartz diorite gneiss, east side of Little Gunpowder Falls about 1,000 feet downstream from Franklinville.
5. Biotite granodiorite gneiss, small abandoned quarry behind houses, west end of Lapidum.
6. Light-colored biotite granodiorite gneiss, surge shaft on Baltimore-Susquehanna aqueduct, about 150 feet east of Rock Run Road, 0.75 mile northeast of Level.

and chlorite from biotite, and muscovite from feldspar. Nonperthitic granoblastic microcline formed from original perthite, and recrystallization of plagioclase continued. Hornblende was granulated and locally chloritized.

The most deformed rocks have lost all trace of primary igneous texture. They consist of pods and lenses of recrystallized quartz and feldspar interlaced with stringers of muscovite, chlorite, biotite, and epidote. Relict augen of euhedrally zoned plagioclase, the zones generally traced out by granular clinozoisite, are about the only clue that these mylonite gneisses are of igneous origin.

The accessory minerals sphene, apatite, and zircon commonly survive recrystallization. Euhedrally zoned allanite generally does not survive the protoclastic stage.

Chemical analyses of some typical Port Deposit gneisses are given in table 18, and the corresponding modes are listed in table 17. They are ordinary calc-alkaline granodiorites and quartz diorites with no anomalous chemical or mineralogic features.

Age

Zircons from granodiorite gneiss at the large quarry north of the town of Port Deposit have been dated by Rudolph Steiger of the Geophysical Laboratory, Carnegie Institute of Washington (Steiger and Hopson, 1965; Davis and others, 1965). The results are as

TABLE 18

CHEMICAL ANALYSES OF PORT DEPOSIT GNEISS, HARFORD AND CECIL COUNTIES

Major Oxides[a]

	1	2	3	4	5
SiO_2	66.0	65.7	66.68	75.1	61.9
Al_2O_3	13.4	14.3	14.93	12.8	19.9
Fe_2O_3	2.0	3.1	1.58	1.2	1.5
FeO	4.0	3.7	3.23	1.6	2.4
MgO	3.5	1.5	2.19	0.39	0.70
CaO	5.8	4.8	4.89	2.9	4.0
Na_2O	2.1	3.0	2.65	3.2	5.2
K_2O	1.6	1.4	2.05	2.0	2.9
H_2O+	1.0	0.64	1.09	0.65	0.84
H_2O-	0.02	0.07	0.16	0.04	0.10
TiO_2	0.46	0.81	0.50	0.24	0.34
P_2O_5	0.12	0.66	0.10	0.08	0.08
MnO	0.12	0.22	0.10	0.08	0.08
CO_2	<0.05	0.05	—	<0.05	0.08
Other	—	—	0.08	—	—
TOTAL	100.1 (2)	99.9 (5)	100.23	100.2 (8)	100.0 (2)

Trace Elements[b]

	1	2	3	4	5
Ba	.02	.05	r	.02	.05
Be	.0001	.0002	—	.0002	.0003
Ce	—	.015	—	—	.03
Co	.002	.0015	—	—	—
Cr	.015	.0005	—	.0007	.0003
Cu	.002	.0007	—	.002	.002
Ga	.001	.0015	—	.001	.002
La	—	.007	—	—	.015
Li	—	—	r	—	—
Mo	—	.0003	—	—	—
Nb	—	.001	—	—	.001
Nd	—	—	—	—	.05
Ni	.003	—	—	—	—
Pb	.0005	.0005	—	.0015	.002
Sc	.003	.005	—	.001	—
Sr	.007	.015	r	.007	.02
V	.015	.01	—	.015	.002
Y	.002	.01	—	.002	.005
Yb	.0002	.001	—	.0002	.0005
Zr	.01	.005	—	.05	.05

Norms

	1	2	3	4	5
Q	29.23	30.78	28.31	41.51	10.16
C	—	0.82	—	0.29	1.32
Or	9.45	8.27	12.11	11.82	17.13
Ab	17.76	25.37	22.41	27.06	43.98
An	22.41	19.18	22.79	13.86	18.81
Wo	2.32	—	0.40	—	—
En	8.71	3.73	5.45	0.97	1.74
FS	5.16	3.30	3.98	1.70	2.75
Mt	2.90	4.49	2.29	1.74	2.17
Il	0.87	1.54	0.95	0.46	0.65
Ap	0.28	1.56	0.24	0.19	0.19
Cc	—	0.11	—	—	0.18
(H_2O)	1.02	0.73	1.25	0.69	0.94
TOTAL	100.11	99.98	100.18	100.29	100.02

[a] Except for analysis 3, analyzed in the laboratories of the U. S. Geological Survey by methods similar to those described by Shapiro and Brannock (1962).

[b] Semiquantitative spectrographic analyses, U. S. Geological Survey.

1. Hornblende-biotite quartz diorite gneiss, Deer Creek about 0.15 mile upstream from Maryland Route 161, Harford County. Analyst: U. S. Geol. Survey rapid method, 1963. 2. Biotite quartz diorite gneiss, Bel Air bypass (U. S. Route 1) about 0.4 mile north of Winters Run, Harford County. Analyst: U. S. Geol. Survey rapid method, 1965. 3. Biotite granodiorite gneiss, Rowlandsville, Cecil County (termed "Rowlandsville granite" by Grimsley, 1894). Analyst: W. F. Hillebrand *in* Grimsley, 1894, p. 88. 4. Biotite granodiorite gneiss, small abandoned quarry behind houses, west end of Lapidum, Harford County. Analyst: U. S. Geol. Survey rapid method, 1963. 5. Composite sample of streaky light-gray to medium-gray biotite granodiorite gneiss, surge shaft on Baltimore-Susquehanna aqueduct about 150 feet east of Rock Run Road about 0.75 mile northeast of Level, Harford County. Analyst: U. S. Geol. Survey rapid method, 1963.

r. Element reported as oxide in standard analysis. Summed under "other," major oxides.

follows:

	$\frac{Pb^{206}}{U^{238}}$	$\frac{Pb^{207}}{U^{235}}$	$\frac{Pb^{207}}{Pb^{206}}$
Isotope ratio used			
Age (million years)	325	350	525 ± 20

The ages are discordant, suggesting some loss of lead during metamorphism, and the rather large error (±20 m.y.) in the Pb^{207}-Pb^{206} age is attributed in part to a rather high content of common lead (Davis and others, 1965, p. 175). The Pb^{207}-Pb^{206} age of 525 ± 20 m.y. (Cambrian) places the Port Deposit as an early member of the series of granitic plutons in the Maryland Piedmont, comparable to the Norbeck quartz diorite and Kensington quartz diorite of Howard and Montgomery Counties (Hopson, 1964, p. 197).

MUSCOVITE-QUARTZ MONZONITE GNEISS

Regional Setting

A belt of light-colored, medium-grained, muscovite-bearing quartz monzonite gneiss lies along the northwest edge of the Baltimore Gabbro (Cloos and Hershey, 1936) from a point about 0.5 mile southeast of Scarboro to a point about 1.5 miles southwest of Vale. It ranges in width from about 1 mile in the vicinity of Sandy Hook to somewhat less than 500 feet near its southwest end. A separate body of the same rock crops out on Little Gunpowder Falls at Harford Road and can be traced to within 2 miles of the main mass, with which it is on strike; the two probably join at depth. A body of pegmatoid to aplitic quartz monzonite gneiss crops out near Castleton on the Susquehanna River and can be followed at a short distance to the southwest. Large veins of quartz are associated with this rock and were the basis for a once-thriving "flint" industry at Castleton (Singewald, 1928, p. 140–141). Numerous quartz veins cut serpentinite, soapstone, and metagabbro in the area between Castleton and Sandy Hook, and at the quarry of the Maryland Lava Company near Scarboro at least one pegmatite dike cuts massive soapstone. The Castleton pegmatite-aplite, Scarboro pegmatite, and the quartz veins are all more or less on strike with the muscovite-quartz monzonite belt and may be offshoots from a still-concealed northeastward extension of it.

That the muscovite quartz monzonite gneiss is intrusive into Baltimore Gabbro (Cloos and Hershey, 1936) is suggested by the map pattern and confirmed by contact relations observed in pipeline excavations southwest of the U. S. Route 1 bridge over Deer Creek. There dikes of the gneiss have split the gabbro into a disrupted jumble of blocks (fig. 25). The contact of the gneiss against the Wissahickon formation is regionally conformable to foliation in the Wissahickon.

Lithology

In hand specimen the muscovite-quartz monzonite gneiss is characterized by prominent muscovite flakes as large as 2 mm in diameter and light in color (normally <5 percent biotite is present). In most places it is obviously foliated, recrystallized mica lying in millimeter-spaced shear planes. Locally, however, it is nearly massive (as at the race track on Sandy Hook road north of the Deer Creek bridge) or sheared out almost to schist (as near the bridge carrying Carrs Mill road over Bear Cabin Branch). In most places the rock is of uniform grain size, but a porphyritic phase occurs just east of the bridge carrying Sandy Hook road over Deer Creek. Veinlets of pegmatite and quartz are ubiquitous.

The muscovite quartz monzonite gneiss weathers more readily than surrounding rocks,

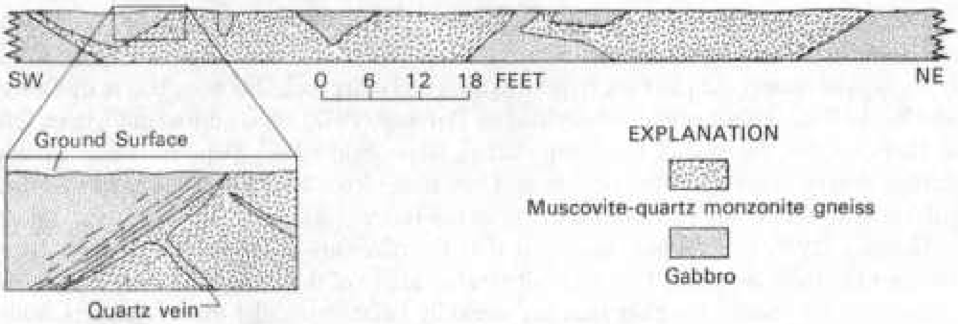

FIGURE 25. Contact relations between light-colored muscovite-quartz monzonite gneiss and gabbro of the Baltimore-State Line complex as exposed in excavation for pipeline on hill 0.5 mile SW. of U. S. Route 1 bridge over Deer Creek. Within the gneiss are many inclusions of gabbro that are too small to show at this scale. The enlarged area shows a quartz vein that cuts the muscovite quartz monzonite gneiss and follows a sheared gneiss-gabbro contact. This exposure is the wall of a 6-foot ditch dug in saprolite.

and the sandy saprolite derived from it is easily eroded. Consequently, most of the area underlain by this rock is topographically low.

Petrography

Plagioclase, microcline, and quartz together form about 90 percent of the rock; the remainder is principally muscovite and biotite. Commonly the amounts of plagioclase and microcline are subequal, but in some samples, plagioclase exceeds microcline by more than 2:1. In terms of igneous classification, therefore, the rock is chiefly quartz monzonite with some granodiorite. Apatite, garnet, epidote, clinozoisite, tourmaline, zircon, and magnetite are the principal accessories.

Plagioclase occurs as relict, inclusion-filled crystals of feebly zoned oligoclase and as granular aggregates of clear, recrystallized albite. Depending on the degree to which the rock has been sheared and recrystallized, either one form or the other may predominate.

Microcline forms large amoeboid crystals that enclose quartz and plagioclase, and also granular aggregates that are associated with recrystallized albite. Early formed phenocrysts of microcline were noted locally. Most of the large grains are slightly perthitic. Large lobes of myrmekite embay microcline in some of the less sheared rocks.

Muscovite forms large flakes that have been bent and warped by shearing, and also small, unbent flakes that, together with clinozoisite, have formed from the alteration of plagioclase. The large flakes plainly crystallized before deformation; moreover, they are sharply bounded against other minerals and locally are enclosed by quartz or microcline. This muscovite seems to be a pyrogenetic mineral, quite distinct from the obviously secondary muscovite derived from alteration of plagioclase. Its grain size and textural relations are similar to those of biotite in the same rock.

Textures of dynamic origin are prominent and in the most sheared rocks have obliterated all traces of primary igneous features. In most rocks, however, relict igneous texture is discernible, although blurred by the effects of shearing. Quartz is universally strained and commonly recrystallized; feldspar is mortared and partly recrystallized; primary mica is bent or broken; secondary mica is oriented in braided crush zones. This intrusion has undoubtedly participated in regional deformation, and in this respect it is different from the Guilford Quartz Monzonite of Howard County (Guilford Granite of Cloos & Broedel, 1940), to which it is otherwise similar (Hopson, 1964, p. 176–178).

LAMPROPHYRIC DIKES

Narrow mafic dikes consisting chiefly of hornblende, biotite, oligoclase, potassium feldspar, and quartz cut the Port Deposit Gneiss and older rocks between Havre de Grace and Rocks Run. They have been described by Hershey (1937) who counted more than 150 of them on the east side of the Susquehanna River below Port Deposit and 20 in the Bridge quarry north of Havre de Grace. They range from less than a foot to 15 feet in thickness and could not be traced away from the river.

Hershey (1937, p. 119) has concluded that the dikes are a late feature because they transect the foliation of the Port Deposit Gneiss. Many of the dikes have chilled margins and somewhat coarser interiors that are streakily foliated parallel to the contacts. This foliation is thought to be the result of primary flowage rather than tectonism, for it is commonly discordant to the regional foliation of the enclosing gneiss. Secondary epidote and chlorite are common in the centers of the dikes and probably are deuteric minerals that formed in the late stages of crystallization.

Boulders of a rather coarsely crystalline lamprophyre consisting of euhedral calcite, biotite, potassium feldspar, and quartz were found in the Maryland Lava Company quarry near Scarboro. This rock probably is related to pegmatites that cut the magnesian schists there and that are partly responsible for producing the massive talc rock that is commercially exploited (Pearre and Heyl, 1960, p. 797).

DIABASE DIKES

Dikes of even-textured to ophitic diabase that cut the Port Deposit Gneiss and all earlier rocks occur in various parts of the County (Plate 1). They consist of augite, labradorite, and opaque oxides; some contain a little pyrogenetic brown hornblende and biotite and traces of secondary epidote and chlorite. Metamorphic effects and foliation are completely lacking, and these dikes are plainly younger than the major periods of metamorphism and deformation in the area. They are generally considered to be of Triassic age (Knopf and Jonas, 1929b, p. 139).

CHRONOLOGIC SUMMARY

Geologic mapping and radiometric dating in Harford County and elsewhere in the eastern Piedmont of Maryland (Hopson, 1964; Cloos, 1964) indicate the following general history for the crystalline rocks:

(1) A strong orogeny and metamorphic episode in Precambrian time, about 1100 m.y. ago, transformed earlier rocks into gneiss and migmatite. These ancient rocks, called the Baltimore Gneiss, have been so thoroughly transformed that very little can be deduced about their pre-metamorphic condition.

(2) Extensive erosion of the Baltimore Gneiss terrane was followed by deposition of a thick sequence of sedimentary rocks. This sedimentary sequence was later metamorphosed to form the quartzites, marbles, and schists of the Glenarm Series. Most of the Glenarm Series probably was deposited in latest Precambrian time, but deposition may have carried over into the Early Paleozoic. The Setters Formation, the basal unit of the Glenarm, and the superjacent Cockeysville Marble appear to have been deposited in a stable tectonic setting. They are relatively thin, widespread units consisting chiefly of metamorphosed quartzite to feldspathic sandstones and carbonates, and represent a typical pre-tectonic platform-type sedimentary association. Overlying the Cockeysville is the Wissahickon Formation, a very thick sequence of metamorphosed shales, graywackes, and sedimentary slump deposits that is characterized by marked vertical and

lateral lithologic variations. The composition and stratigraphy of these rocks indicate deposition under tectonically active conditions, in contrast to the stable conditions represented by the earlier Setters and Cockeysville. The distribution of lithofacies within the Wissahickon Formation indicates that the principal source of detritus was to the east.

(3) During part and perhaps much of Wissahickon time volcanism was going on along the eastern edge of the depositional trough. Well-bedded tuffaceous rocks and thin flows of andesitic to dacitic composition, now metamorphosed to greenschists, amphibolites, and related felsic rocks, comprise the James Run Gneiss and volcanic complex of Cecil County. Similar rocks in Baltimore County, formerly thought to be Baltimore Gneiss, may also belong to this younger metavolcanic suite.

(4) The Baltimore-State Line gabbro-peridotite complex, a large, essentially sheetlike but highly deformed mafic pluton, was emplaced into Wissahickon rocks early in the main tectonic cycle. Crystallization of this mass may have begun locally before the onset of major tectonism, but most of the emplacement and crystallization history took place under dynamic stress. Tectonism continued beyond the magmatic stage and converted much of the pluton to well lineated amphibolite. Another early syntectonic mafic pluton exposed near Havre de Grace and Aberdeen, Harford County, may or may not be directly correlative with the Baltimore-State Line complex. Like the Baltimore-State Line complex, however, it antedates the emplacement of granitic plutons.

(5) Granitic magmatism began at least 520 m.y. ago (Middle Cambrian) and terminated about 370 m.y. ago (Devonian). The earliest plutons of the granitic magma series are quartz diorite (represented in Harford County by parts of the Port Deposit Gneiss); many plutons of intermediate age are granodiorite and the youngest are quartz monzonite. The early plutons are strongly gneissic and plainly early to middle syntectonic; the youngest ones (such as the 370 m.y.-old Woodstock quartz monzonite in Howard County lack a tectonic fabric and clearly are post-tectonic. The syntectonic members of this series cut mafic plutons that also are syntectonic. Thus, deformation involving mafic to granitic plutons and their Glenarm wall rocks began sometime prior to 520 m.y. (Middle Cambrian).

(6) Deformation apparently culminated with the formation of mantled gneiss domes. The Precambrian basement was remobilized and rose as anticlinal welts beneath its cover of Glenarm rocks. The doming, which locally involved incipient partial melting of the ancient basement, approximately coincided with strong syntectonic metamorphism of the mantling Glenarm Series. Deformation and metamorphism waned before the formation of pegmatites about 440 m.y. ago (Late Ordovician).

(7) Although orogeny and metamorphism culminated with gneiss doming in the Late Ordovician, there is abundant evidence that deformation both preceeded and followed this event. Radiogenic dates on syntectonic granitic plutons clearly show that orogenic forces were active as long ago as the Middle Cambrian. Also it is plain from lithofacies relationships within the Wissahickon Formation that sites of uplifts and downwarps shifted about as the Glenarm geosyncline was being filled. Indeed, it may be that conglomerate and black shale were being deposited in a restricted basin along the axis of the geosyncline as late as the Ordovician, at the same time that deep-seated deformation was underway farther east. Despite serious uncertainty about the stratigraphic age of the Cardiff Metaconglomerate and Peach Bottom Slate, it is clear that they were involved in main-stage deformation and later tectonic events. Multiple fold symmetries in the west-central Piedmont and the belts of retrogressively metamorphosed rocks in Harford County and elsewhere clearly show that repeated deformation, generally weaker and

more local than the main-phase folding, affected parts of the Piedmont after the peak of deformation and metamorphism had passed.

(8) Waning tectonic activity, punctuated by local episodes of shearing, may have continued into the Carboniferous. The broad scatter of K-A metamorphic mineral ages between 440 and 300 m.y. has been interpreted as evidence that temperatures were high enough during that period for radiogenic argon to diffuse from micas, feldspars, and hornblende (Tilton et al., 1959).

Much remains to be learned about the details of this generalized history. Current and future work undoubtedly will reveal much about the structure and stratigraphy of the western and west-central Piedmont. This information may give new insights to our understanding of events in the east, and may lead to reinterpretations that differ substantially from the outline presented here.

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COASTAL PLAIN ROCKS OF HARFORD COUNTY

By

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DISTRIBUTION AND PHYSIOGRAPHY

The southern third of Harford County is occupied by rocks of the Coastal Plain (Plate 1). These make up a southward thickening sheet of unconsolidated sediments which crop out from an elevation of over 400 feet in the north down to sea level along the southern boundary of the County. This sheet of sedimentary rocks is extensively dissected, particularly at the higher elevations in the north where many streams have downcut deeply through the Coastal Plain and have produced a very hilly topography. Numerous erosional remnants lie isolated from the main sheet in this region.

The southern part of the County is a broad lowland which rises gradually from sea level along Chesapeake Bay to about 90 feet near Aberdeen. Although this part of the Coastal Plain is less dissected than in the north, large estuaries, such as Bush and Bird Rivers form broad reentrants into this lowland.

Natural exposures of the Coastal Plain formations occur only along the actively eroding streams or in some of the bluffs along the larger bodies of water. For the most part, the sediments are poorly exposed because of their tendency to slump in freshly cut banks. Fortunately, the Coastal Plain formations are excavated for sand and gravel at a number of places and many fresh exposures were available for examination throughout the region. Additional outcrops, especially of the Coastal Plain-Piedmont contact, were seen during the construction of Interstate Highway 95 across Harford and Cecil Counties.

Much information was gathered from traverses across the high bluffs overlooking Chesapeake Bay on the west side of Elk Neck in Cecil County. These bluffs contain the best exposures of the Potomac Group in this region.

REGIONAL SETTING AND STRUCTURE

The Coastal Plain in Harford County forms part of the northern edge of the Atlantic Coastal Plain physiographic province. Unconsolidated Coastal Plain sediments rest unconformably on the much older crystalline rocks of the Piedmont physiographic province.

The Piedmont rocks, which are discussed in detail elsewhere in this report, are largely metamorphic rocks. They are typically finely crystalline, very micaceous (biotite, muscovite, and chlorite) and contain abundant quartz and albitic plagioclase. The presence of abundant muscovite and a large and varied suite of heavy minerals of metamorphic origin suggest that the pelitic metamorphic rocks were a major source for the Coastal Plain sediments. The absence of calcic plagioclase, hornblende, and pyroxene ih the sand-sized fraction of the Coastal Plain formations indicates that mafic rocks in the Piedmont supplied little detritus except as clay or silt. Apparently such minerals were unstable in the weathering environment to which they were subjected and were converted to clay minerals. The widespread occurrence of saprolite within the present-day Piedmont is an indication of the intensity of weathering.

The Coastal Plain sediments thicken rapidly southeastward from this region. The basement beneath the Coastal Plain in the Maryland-Delaware-Virginia area forms a deep east-southeast-plunging trough whose axis is approximately perpendicular to the existing Appalachian structural trend (fig. 26). This large downwarp, the Salisbury embayment, is one of the largest basement structures of this type beneath the Atlantic Coastal Plain. Sediments are thickest in this trough. The deepest well in the emerged northern Atlantic Coastal Plain east of Salisbury, Maryland, penetrated 7,710 feet of sediments, nearly all of which are clastic. The lower half of this section was assigned to the Potomac Group of Early Cretaceous age (Anderson, 1948).

The Potomac Group sediments crop out at the head of this embayment in an arcuate pattern (fig. 26). This upper Chesapeake Bay region is the only area in the Gulf and Atlantic Coastal Plains, except for southwest Arkansas, southeast Oklahoma and Texas, where

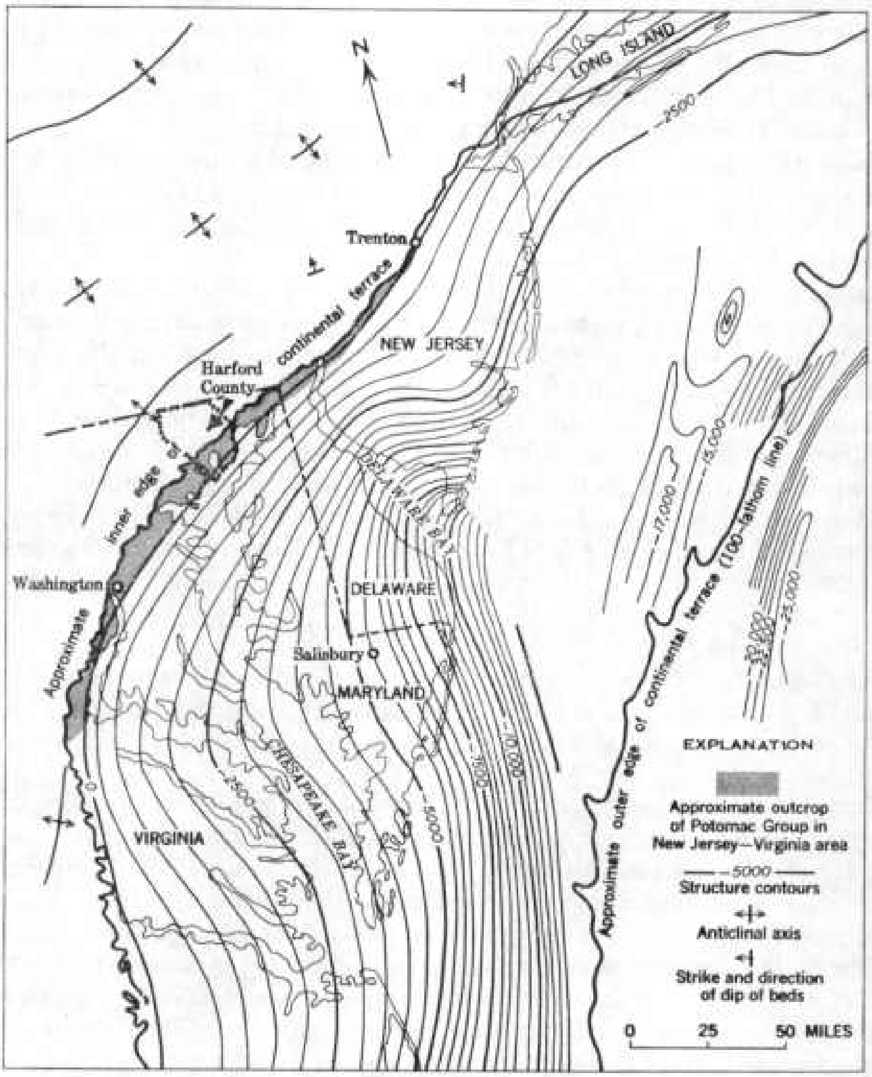

FIGURE 26. Contours drawn on the surface of basement rocks beneath the continental terrace showing the deep downwarp between the Delaware and Chesapeake Bays. This feature has been called the Salisbury embayment (modified from U. S. Geological Survey and Am. Assoc. Petroleum Geologists, 1961). Also shown is the outcrop belt of the Potomac Group and the location of Harford County. Contour interval 500 feet.

beds of Early Cretaceous age are known to reach the surface. Harford County is one of the better outcrop areas where these Lower Cretaceous beds can be studied in detail.

The Atlantic Coastal Plain was affected by large-scale epirogenic movements during Pliocene(?) to Quaternary time which lifted a part of the continental terrace above sea level (Doering, 1960). Subsequent extensive fluvial dissection of the emerged Coastal Plain produced the present topography of the region.

PHYSICAL STRATIGRAPHY

The stratigraphy of the Coastal Plain formations in Harford County is less complex than in nearby areas to the east and north. Only the Potomac Group of Early Cretaceous age, upland gravels of Pliocene(?) age, and the Talbot Formation of Pleistocene age are present. These formations are all clastics which were deposited in a continental environment. The Late Cretaceous through Late Tertiary interbedded marine-continental sequences, which are widespread east of Chesapeake Bay, do not crop out in Harford County.

CRETACEOUS ROCKS—POTOMAC GROUP

Previous Investigations

The Potomac Group of this report was originally named the Potomac Formation by McGee (1888). Clark (1897) later subdivided this formation into four formations: the Patuxent (oldest), Arundel, Patapsco, and Raritan (youngest); and established the general lithologic characteristics of each formation within the Group. The Patuxent Formation was termed an arkose in which most of the feldspar was kaolinized. The Arundel Formation comprised a series of large to small lenses of iron-ore-bearing dark clays, whereas the Patapsco Formation included highly colored and variegated clays with bands of cross—bedded sands containing much decomposed feldspar. The Raritan Formation included thick-bedded, light-colored locally gravelly sands and clay beds, usually light colored but locally red, at the base of the unit. These formations were ultimately raised to group status and it is thus shown on the old map of Harford County (Maryland Geol. Survey, 1904). Several other maps of the Maryland Coastal Plain were published in the first part of this century which showed the three formations of the Potomac Group and the Raritan Formation. In all of these, the units shown generally used Clark's lithologic descriptions for the formations. In recent years, however, there has been less agreement as to what constituted mappable units within this section of sediments. Darton (1947) and Cooke (1952) for example, mapped adjoining areas in the vicinity of Washington, D. C. Darton lumped the Patuxent, Arundel, and Patapsco Formations into a single unit (Potomac Group undifferentiated) and showed the Raritan as a separate formation. Cooke, on the other hand, mapped the Patuxent as a separate unit, lumped the Arundel and Patapsco as a single formation, and did not recognize the Raritan. Obviously, establishing well-defined rock units in this sequence of sediments is a problem, at least in this area.

The ages of the Patuxent, Arundel, Patapsco, and Raritan Formations have also been controversial. Early in this century, the Patuxent and Arundel were considered Jurassic and the Patapsco and Arundel Early Cretaceous (Maryland Geol. Survey, 1904). Berry (1910) studied the macroflora from these formations and concluded that the Patuxent, Arundel, and Patapsco were Early Cretaceous in age and the Raritan was Late Cretaceous. The Raritan was dropped from the Potomac Group at this time (Clark, 1910).

Lull (*in* Clark and others, 1911) examined the vertebrate remains collected from the Arundel Clay near Muirkirk, Maryland. He favored an Early Cretaceous age for these but Gilmore (1921) suggested a younger, perhaps Late Cretaceous age. Most workers in this area accepted this determination and the Arundel and Patapsco were considered Late Cretaceous. The Patuxent remained Early Cretaceous in age. Brenner (1963) re-opened the age controversy regarding the Patuxent, Arundel, and Patapsco. He studied the pollen and spores of these units and generally agreed with Berry's macroflora interpretation. These formations were again considered Early Cretaceous in age. This aspect will be discussed in more detail later in this report.

Few petrologic studies of the Potomac Group and the Raritan Formation have been made in Maryland. One notable exception is a study of the clays from these units in northeastern Maryland (Knechtel and others, 1961). Data from this report are used extensively to supplement the petrologic examination of the Potomac Group sediments for this report.

Distribution, Thickness, and Lithology

Detailed studies of the formations of the Potomac Group, as shown on the earlier geologic map of Harford County (Miller and Bibbins, *in* Maryland Geol. Survey, 1904) show that no consistent upper or lower boundaries of the formations can be established. Local diastems are numerous but are not persistent enough to constitute regional disconformities between the formations. For these reasons the Potomac Group is shown as a single map unit (Plate 1). The group status is retained because the three formations may be separate mappable units in their type areas near Baltimore.

The outcrop belt of the Potomac Group occupies the margin of the Salisbury embayment which extends into the southern part of Harford County. In cross section, the gross geometry of the Potomac Group is channel-form; the axis of the channel plunges east-southeast. The thickest known section in Harford County is in a well northeast of the embayment axis near Edgewood, Maryland (Bennett and Meyer, 1952). Deep channels, filled with unconsolidated Potomac Group sediments, separated by generally saprolitized bedrock interfluves were exposed at a number of locations during the construction of Interstate Highway 95. As much as 100 feet of relief was noted between the bottoms of channels and the tops of interfluves near the Harford Furnace School.

The Potomac Group is as much as 400 feet thick south of Edgewood (Bennett and Meyer, 1952). It was probably once much thicker in the southern part of the county, but here a large part of the section was removed by latest Tertiary and Quaternary erosion. The outcrop belt varies in width depending upon the amount of overlap by younger beds; the maximum width of outcrop is over 6 miles along the western boundary of the county.

The Potomac Group consists of interbedded light-colored sand, drab to variegated silty-clay and clayey-silt, and less commonly, very gravelly sand. The thickness and horizontal extent of each of these lithofacies varies widely. For example, clay-silt beds range in thickness from an inch to more than many tens of feet. According to the classification proposed by McKee (1957), these units are very thin to very thick bedded. This irregular thickness of bedding (rapid lensing) is characteristic of all lithofacies in the Potomac Group.

The clay-silt beds are typically massive, less commonly crudely stratified. They occur in a variety of colors (black, brown, yellow, or white) and locally some beds are mottled. The lighter colors, however, predominate. Lignitized plant and woody remains, some several feet in length and typically concentrated in thin beds, are abundant in the dark colored clays. Commonly, finely crystalline pyrite encrusts most of the larger lignitized pieces. Large rounded masses of dark-brown siderite, some as much as 2 feet in diameter, are locally abundant in the dark-colored beds near Edgewood.

The sandy beds are light colored, typically white or pale yellowish brown. These beds are thin to thick bedded and are commonly cross-stratified. As proposed by McKee and Weir (1953), the two major types of cross-strata are trough (fig. 27 *p.*) and planar (fig. 28 *p.*). Horizontal stratification (fig. 29 *p.*) is less common in the sandy beds.

The gravelly sand beds are typically confined to small well-defined channels (fig. 27 *p.*), and are not widespread. As in the sandy facies, the gravels are cross-stratified and light in color.

These lithofacies follow the general stratigraphic succession recognized by earlier workers. The deposits are gravelly at the base (Patuxent), clayey in the middle (Arundel), and sandy and clayey at the top (Patapsco). The gravelly sands of the Potomac Group in Harford County are most abundant in the updip areas, particularly north of Abingdon and on the north edge of Aberdeen, where they are exposed in numerous gravel and sand pits. Clays are generally more abundant near the central part of the outcrop belt as at Joppa (fig. 30 *p.*) and the sandy beds are very abundant in the south near Magnolia (fig. 29 *p.*). In detail, however, these lithic units do not persist laterally for great distances. The thick gravelly beds in the base of the formation, for example, commonly grade into clay beds along strike. In fact, thick beds of clay are widespread along the boundary between the Coastal Plain and the underlying bedrock at a number of places, as in the northeast part of the county just north of U.S. Route 40; along Interstate Highway 95 north of Clayton Station, and along Interstate Highway 95 just northeast of Aberdeen. Thick gravelly beds are exposed as far south as the mouth of Foster Branch west of Magnolia near the southern extremity of the county. Sand, although more common in the south, is ubiquitous throughout the entire outcrop area. Thick sections are common at Sewell, and in railroad cuts between Clayton Station and Joppa.

Although other investigators (Shattuck, 1902, and Miller *in* Bascom and Miller, 1920) indicate that a separation of the Patuxent, Patapsco, and Raritan Formations can be seen along the bluffs on the west shore of Elk Neck, Cecil County, no such separation based on lithic properties could be found. In fact, the lithic characteristics of these three formations are nearly identical throughout Cecil and Harford Counties.

Petrology

Within the Potomac Group in Harford County, sand is by far the major component. The Patuxent Formation was reported to be arkosic by Clark (1897) and if so should have a greater than 25 percent feldspar content. In Harford County, however, no fresh feldspar grains were observed in any of the Potomac Group sands. Small white opaque grains having a pearly luster are present and may be kaolinized feldspar. They make up, however, less than 10 percent of the sand fraction and in many samples less than 5 percent (table 19).

Quartz and muscovite are the major minerals in the sand. Nearly all the quartz is clear and colorless; translucent and colored varieties are present, but are of minor importance. A significant percentage of the quartz grains are polycrystalline and contain intergrowths of sericite and probably should be classed as rock fragments. They are, however, shown as polycrystalline quartz in table 19.

Muscovite is the only common mica, although large quantities of chlorite and biotite

TABLE 19

LIGHT-MINERAL (<2.80 SP. GR.; 0.149–.074 MM IN DIAMETER) DISTRIBUTION IN THE POTOMAC GROUP, UPLAND GRAVELS, AND TALBOT FORMATION IN HARFORD COUNTY, AND NEARBY AREAS IN PERCENT BY NUMBER

Unit and Sample Locality[1]	Common Quartz	Polycrystalline Quartz	Potassium Feldspar	Plagioclase	Rock Fragments
Talbot Formation					
Clay-silt facies:					
ED-20	66	32	1	1	—
Sandy facies:					
HG-8	40	56	1	1	2
HG-9	30	52	9	3	6
Tolchester Beach	16	74	7	—	3
Upland gravels					
RS-1	80	20	—	—	Tr
AB-4	97	3	—	—	—
ED-6	99	1	—	—	—
HG-1	100	—	—	—	—
Potomac Group					
Patuxent age					
Gravelly facies:					
PE-1	65	30	—	5*	—
HG-2	94	6	—	—	—
Sandy facies:					
ED-1B	94	6	—	—	—
ED-4A	79	18	—	3*	Tr
PE-3	85	13	—	2*	—
HG-5	81	18	—	1*	—
Patapsco age					
Sandy facies:					
ST-2	65	35	—	Tr	—
EA-2	62	38	—	Tr	—

[1] Collecting localities for samples given in appendix.

* All badly altered (kaolinized).

occur in the nearby metamorphic rocks. Most of the mica occurs as unaltered large flakes or small books.

The quartz-rich sands of the Potomac Group are nearly pure orthoquartzites, a very mature rock assemblage. Sand of this type is common in the Potomac Group in the New Jersey-Pennsylvania-Maryland area and possibly as far southwest as the District of Columbia. As the mica content increases, the chemical composition also changes and typically is similar to that of many protoquartzites. It is estimated from optical studies that the sands of the Potomac Group in Harford County have chemical compositions in the orthoquartzite-protoquartzite range, and hence, are very mature assemblages.

One of the most intensely studied components of the sands in the Potomac Group has been the heavy minerals. Anderson (1948) made the most comprehensive study of the heavy minerals from deep wells in the Eastern Shore of Maryland. He reported the following heavy-mineral zonations: (1) Patuxent Formation: garnet-staurolite-zircon zone, (2) Patapsco-Arundel Formations; epidote zone, and (3) Raritan: hornblende zone.

Bennett and Meyer (1952, tables 5 and 11) studied the heavy minerals in the sands from shallow wells in the vicinity of Baltimore and observed that the heavy minerals in the Patuxent are characterized by a staurolite-zircon-kyanite-sillimanite assemblage; garnet was notably absent. The Patapsco is notably deficient in epidote but has high concentrations of zircon, tourmaline, and rutile. Groot (1955, p. 59–61) found the same relationships in northern Delaware. Thus, to the east and west of Harford County, a vertical zonation of the sediments of the Potomac Group into two heavy-mineral assemblages (staurolite-kyanite and zircon-tourmaline-rutile) is possible. In Delaware, no physical break between the sediments containing these two heavy-mineral assemblages is recognizable (Jordan, 1962).

In Harford County, a similar heavy-mineral distribution can be demonstrated. Staurolite and kyanite are common in updip sections of Patuxent age sediments as shown in table 20 (PE-3 and HG-5), and also by Carroll (*in* Knechtel and others, 1961). In the southern part of the area (downdip) near Magnolia, the sands of probable Patapsco age contain a zircon-tourmaline-rutile heavy-mineral assemblage (table 20 ED-4A). At Turkey Point on Elk Neck (east shore of Chesapeake Bay), a zircon-rich assemblage was found in the Patapsco-age sands (table 20, ST-2 and EA-2). Apparently, the two-part zonation generally related to age can be applied over a wide area, but differs from the subsurface zonation proposed by Anderson (1948).

The difference in surface, shallow subsurface (Bennett and Meyer, 1952, for example), and deep subsurface heavy-mineral zonation (Anderson, 1948) for this general region may be the result of different source rocks, such that the sediments of the Potomac Group in northeastern Maryland and Delaware were derived from the north and those found in the deep subsurface from the west.

The gravels in the Potomac Group are a very mature suite (table 21), comprised of vein quartz and quartzite clasts only. Vein quartz is more abundant in the finer (<38 mm) fractions.

Knechtel and others (1961, table 2) examined the clay beds of the Potomac Group in Harford and nearby counties. They noted that the clay assemblage in these beds is mostly a kaolinite-illite mixture or, less commonly, nearly all kaolinite. Small to very large amounts of mixed-layer clays (montmorillonite-illite) are also present. In essence these are rather mature clay assemblages. A compatible association exists, therefore, between this mature clay suite and an equally mature sand suite (orthoquartzite-protoquartzite) in Harford County.

Two clay-silt samples from Cecil and Harford Counties (NE-5 and ED-5A) were analyzed chemically (table 22) and show a high silica and alumina content as well as a low total iron content. The stable compounds, SiO_2 and Al_2O_3, are thus concentrated in the clayey silts associated with the more mature quartz sands.

The results of several X-ray examinations of the 2-micron fraction from clays in Harford and Cecil Counties (fig. 31) were virtually the same as those obtained by Knechtel and others (1961), except for samples from the Arundel (?) Clay collected southwest of Baltimore. In this unit, in addition to major kaolinite and illite, a consistent 14 Å reflection is present. Unaffected by glycolitization, this peak collapses on prolonged heating at 300°C, which suggests vermiculite or nonswelling montmorillonite. Vermiculite, an alteration product of mica, seems the more likely mineral, in view of the great abundance of biotite and chlorite in the nearby metamorphic terrain. Similar clay assemblages are typical of the Potomac Group and Raritan (?) sediments from Trenton, New Jersey, to the District of Columbia. The clay mineralogy of the arkosic facies in Virginia, however,

TABLE 20

HEAVY MINERAL DISTRIBUTION (<2.80 SP.GR.; 0.177–.074 MM IN DIAMETER) IN THE POTOMAC GROUP, UPLAND GRAVELS, AND TALBOT FORMATION IN HARFORD COUNTY AND NEARBY AREAS IN PERCENT BY NUMBER

Unit and Sample locality[1]	Opaque[2]					Nonopaque[3]														
	Magnetite	Ilmenite	Brown Ilmenite	Hematite	Leucoxene	Zircon	Rutile	Tourmaline	Staurolite	Kyanite	Sillimanite	Garnet	Epidote	Chloritoid	Andalusite	Hornblende	Pyroxene	Chlorite	Biotite	Muscovite
Talbot Formation																				
Sand-gravel facies:																				
PE-6	90	—	9	—	1	55	9	6	Tr	1	13	3	12	Tr	Tr	1	Tr	—	—	—
Tolchester Beach	73	—	17	—	9	39	4	4	2	12	11	4	19	2	—	3	Tr	—	—	Tr
HG-8	84	—	—	5	11	11	2	1	—	1	—	34	23	3	1	10	7	5	2	—
HG-9	32	—	—	44	24	50	2	12	—	—	5	Tr	4	2	—	1	Tr	—	—	24
Clay-silt facies:																				
ED-20	14	—	13	42	31	10	2	4	15	7	—	—	16	Tr	—	44	2	Tr	Tr	Tr
Upland gravels																				
RS-1	—	25	2	—	73	86	5	6	3	—	—	—	—	—	—	—	—	—	Tr	—
AB-4	—	19	25	—	56	54	10	33	Tr	Tr	—	—	—	—	—	—	—	—	3	—
ED-6	—	9	60	—	31	2	11	13	13	4	—	—	—	—	—	—	—	—	2	55
HG-1	—	5	62	32	1	74	5	16	—	—	—	—	—	—	—	—	—	—	5	—
Potomac Group																				
Patuxent age																				
Gravelly facies:																				
AB-3	—	—	—	90	10	12	34	14	7	—	—	—	—	—	—	—	—	—	3	30
PE-1	—	—	32	53	15	3	15	6	57	6	1	1	—	—	—	—	—	—	1	10
HG-2	—	50	50	—	Tr	10	10	25	50	2	—	—	—	—	—	—	—	—	2	1
Sandy facies:																				
ED-1B	—	28	72	—	Tr	67	13	6	—	13	—	—	1	—	—	—	—	—	—	—
PE-3	—	1	66	—	33	10	4	16	43	6	—	—	—	—	—	—	—	—	—	21
ED-4A	—	35	34	—	31	7	18	22	3	Tr	—	—	—	—	—	—	—	—	Tr	50
HG-5	—	Tr	76	—	24	14	4	11	5	11	—	—	—	—	—	—	—	—	2(?)	7
Patapsco age																				
Sand facies																				
ST-2	—	18	9	—	73	73	9	15	—	2	—	—	—	1	—	—	—	—	Tr	Tr
EA-2	—	20	20	—	60	85	7	7	—	1	—	—	—	—	—	—	—	—	—	—

[1] Collecting localities for samples given in appendix.
[2] Percent of total opaque.
[3] Percent of total nonopaque.

is markedly different (fig. 31); montmorillinite (probably nontronite because of the high iron content) predominates and is associated with varying amounts of illite and kaolinite, an assemblage typical of relatively unaltered clay minerals. This immature clay assemblage is compatible with the immature sand of this facies (arkose).

Grain—size analyses were made of six sands, two clay-silt beds, and one gravel from the quartzose facies of the Potomac Group in Harford County (figs. 32 and 33). Collecting localities for the samples are listed in the appendix. The sands range from well to very poorly sorted ($\phi_I = .49$ to 2.55ϕ), using the formula proposed by Folk (1957). Most sorting is moderate. Skewness (S_{KI}) ranges from nearly symmetrical ($+ .013\phi$) to strongly

TABLE 21

DISTRIBUTION OF ROCK TYPES IN GRAVELS (17–44 MM) OF THE POTOMAC GROUP, UPLAND GRAVELS, AND TALBOT FORMATION IN HARFORD AND CECIL COUNTIES, IN PERCENT BY NUMBER

Unit and Sample Locality[1]	Quartz	Quartzite	Chert	White Sandstone	Brown Sandstone	Red Sandstone	Siltstone	Crystalline Rocks	Clay Galls
Talbot Formation									
PE-6	6	6	58	2	17	4	3	4	—
ED-9	96	4	—	—	—	—	—	—	—
Upland gravels									
ED-6	95	—	—	3	—	—	—	2	—
AB-15	64	34	1	1	—	—	—	—	—
AB-10	55	45	—	Tr	—	—	—	—	—
AB-4A	55	32	2	9	—	—	—	1	1
AB-4	42	40	4	11	—	—	—	1	2
HG-7	49	31	1	17	—	—	—	1	1
Potomac Group									
ED-10	62	38	—	—	—	—	—	—	—
PE-3	98	2	—	—	—	—	—	—	—
HG-5A	45	49	—	4	—	—	—	—	2
PE-1	90	10	—	—	—	—	—	—	—

[1] Collecting localities for samples given in appendix.

fine skewed ($+.48\phi$). Most of the samples are nearly symmetrical but all were positively skewed.

The sands in the Potomac Group of Harford County are extensively cross-stratified and probably accumulated in a high energy environment.

A sample of the gravelly sand (fig. 32, curve 3) is very poorly sorted ($\phi_I = 2.50\phi$) and bimodal. A sharp break in the size-distribution curve occurs between gravel and sand, a common situation in stream gravels (Wentworth, 1930). Two types of gravel are present, those having a high degree of angularity and those which are well rounded and commonly very fractured. The rounded gravel seems to have undergone extensive transport, whereas the angular clasts are of locally derivation. The sand in these beds is very angular and is probably a first cycle sediment.

The clay-silt beds are the most poorly sorted sediment in the Potomac Group. Two samples, thought to be fairly representative of the clayey strata in this region (fig. 33) are mainly very clayey silts. The clay-silt beds apparently were deposited in a very low energy environment, either in a swamp or as an overbank deposit (Allen, 1965).

Directional Properties

A systematic study of the widespread cross-stratification within the Potomac Group in Harford County was made employing the technique of Potter and Pettijohn (1963). Because of the uncertainty of the rock-stratigraphic relations within the group, and because of the small area sampled, the results are of only local application. If, however, there was a dominant regional paleoslope down which these sediments were transported, then the data may have more widespread applicability.

A "current rose diagram" (fig. 34) of all cross-stratification data shows a dominant east-southeast direction, thus suggesting sediment movement in this general direction. Such a general transport direction might be predicted from an examination of the large

TABLE 22

CHEMICAL AND X-RAY ANALYSES OF SAMPLES FROM THE CLAY-SILT FACIES OF THE POTOMAC GROUP IN HARFORD AND CECIL COUNTIES

Sample locality[2]	NE-5	ED-5A
Chemical Analyses[1]		
SiO_2	44.20	63.00
Al_2O_3	34.00	22.60
Fe_2O_3	4.30	1.20
FeO	.29	.72
MgO	.15	.25
CaO	.05	.20
Na_2O	.15	.32
K_2O	.04	1.90
H_2O-	14.90	.67
H_2O+	14.90	6.60
TiO_2	.46	2.10
P_2O_5	.34	.02
MnO	.01	.02
CO_2	.14	.05
Elemental sulfur	N.D.	.40
Acid soluble sulfur as SO_3	N.D.	.37
Estimated percentage of minerals (<2 microns) *determined from X-ray diffractometer traces*		
Quartz	—	26
Kaolinite	100	51
Illite	—	14
Montmorillonite	—	—
Vermiculite	—	—
Feldspar	—	9

[1] Rapid-rock analyses as described by Shapiro and Brannock (1962). Analysts Paul Elmore and others, U. S. Geological Survey. N.D. = not determined.

[2] Collecting localities for samples given in appendix.

downflexure centered about Delaware Bay (fig. 26). Apparently this structure had a strong influence on the dispersal pattern for sediment during the Early Cretaceous.

Age

As indicated earlier, the age of the Potomac Group has been controversial for many years. A basic conflict exists between age assignments based on vertebrate fossils and those based on paleobotanical remains. The paleobotanical dating method as outlined by Berry (1910) and enlarged by Brenner (1963) is followed in our study. Brenner noted two pollen zones in the Lower Cretaceous as shown below.

Series	Stage	Zone		Formation
Lower Cretaceous	Albian-Aptian (?)	2	B	
			A	Patapsco
	Neocomian	1		Arundel Patuxent

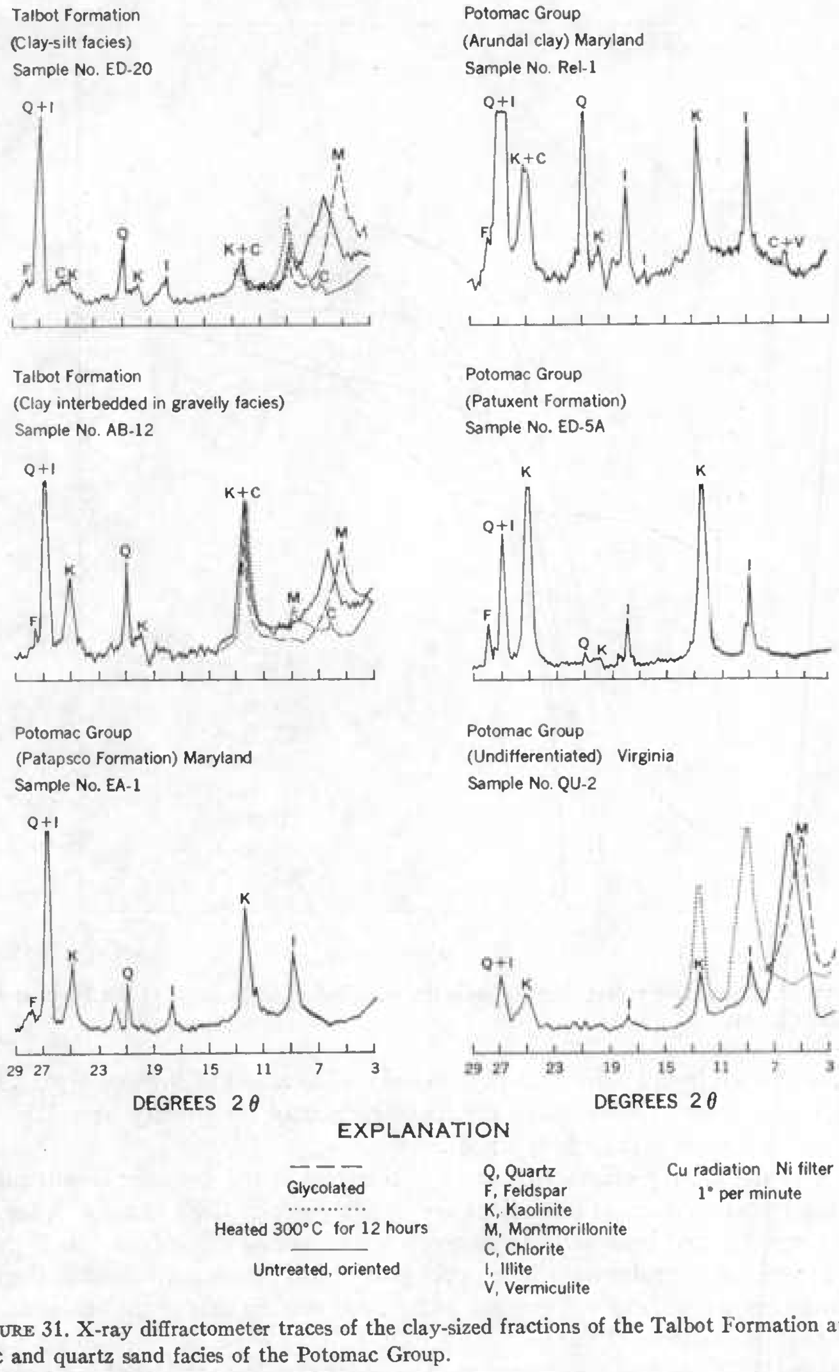

FIGURE 31. X-ray diffractometer traces of the clay-sized fractions of the Talbot Formation and the arkosic and quartz sand facies of the Potomac Group.

Zone 1 included the Patuxent and Arundel Formations of earlier investigators and zone 2, the Patapsco. Zone 2 was further divided into subzones A and B in which subzone B is stratigraphically higher than A. Zone 1 is roughly Neocomian in age and zone 2 is Aptian(?)-Albian. Pollen and spores from black clays were examined in connection with the present study (Wolfe, pers. com.) in the Potomac Group in Harford and Cecil Counties.

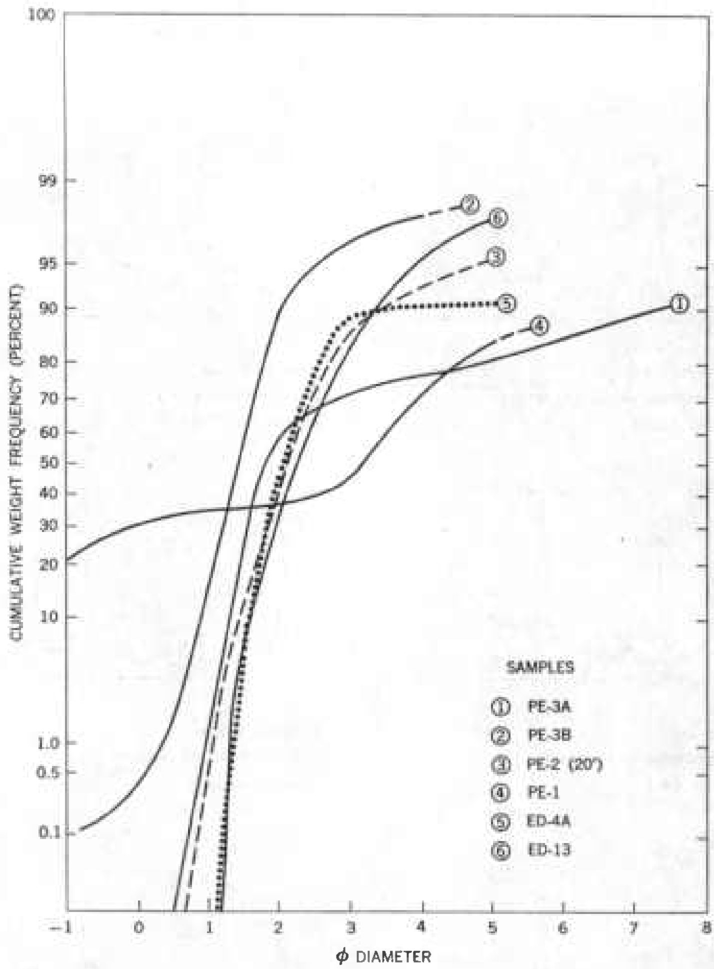

FIGURE 32. Cumulative curves showing grain-size distribution in six sands of the Potomac Group in Harford County.

All the samples from Harford County are assigned to zone 1 of Brenner (1963). However, no clays were examined from the southern part of the County near Edgewood Arsenal; thus the age of these beds is not known.

The best and most continuous outcrops of the clays of the Potomac Group and the overlying Upper Cretaceous formations are in Elk Neck in Cecil County. A series of samples was collected from north to south across the peninsula to determine if the deposits become younger downdip. The upper part of the Potomac Group and the overlying units are particularly well exposed in the southwestern part of the peninsula from Bull Mountain to Turkey Point.

Brenner (1963) assigned a Patuxent age to a black clay from the basal portion of the Potomac Group which crops out just north of the Elk Neck Peninsula on Maryland Route 272, 0.15 mile north of the junction with U. S. Route 40. The elevation of the clay bed is approximately 90 feet above sea level. A second black clay (sample locality NE-1) was collected along Maryland Route 272, 0.3 mile south of North East, Maryland or 1.6 miles south of the Patuxent-age locality at approximately 70 feet above sea level, or 10 feet above the road. This bed yielded a Patapsco-age flora from zone 2, subzone B,

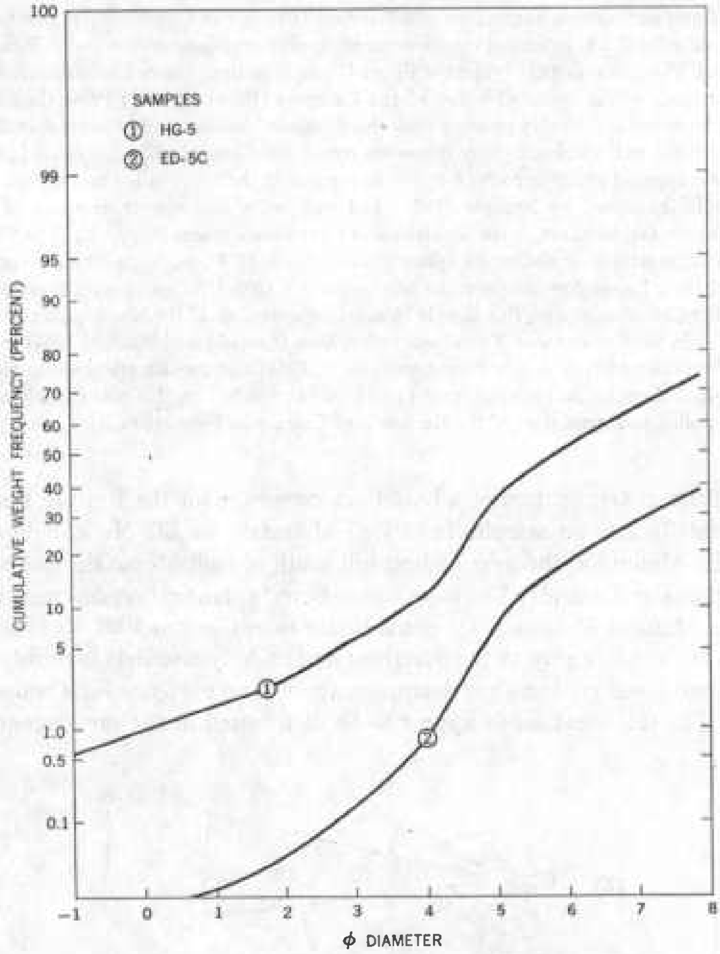

FIGURE 33. Cumulative curves showing grain-size distribution in two clay-silt beds in Harford and Cecil Counties.

as indicated by the occurrence of *Cicatricosisporites subrotundus* Brenner (fig. 35 *p.*, B and C). The pollen and spores in this sample are diverse and also include *C. patapscoensis* Brenner and *Apiculatisporsis babsae* Brenner. Dicotyledon pollen is poorly represented, and small tricolpate pollen accounts for less than 0.5 percent of the pollen and spore flora.

A third black clay sample from the base of the cliff (elevation 5 feet) near Turkey Point at the southern tip of Elk Neck Peninsula (sample locality ST-1) 5.5 miles southeast of NE-1 shows a similar flora, but pollen and spores are less abundant than in the sample from NE-1. Tricolpate grains of dicotyledons make up about 10 percent of the pollen and spores. The low frequency of dicotyledon pollen may indicate that ST-1 is stratigraphically lower than NE-1. Even though ST-1 is farther south and probably downdip from NE-1, its lower stratigraphic position may be explained by the much lower elevation at which it crops out.

An additional dark clay sample (EA-3), collected between sample localities ST-1 and NE-1 on the west side of Mauldin Mountain (approximately 50 feet above sea level), was reported upon by Wolfe (personal commun., 1967) as follows:

"... this sample contains an abundance and diversity of pollen and spores. That this sample can be no older than subzone B-2 is indicated by the occurrence of *Rugubivesiculties reductus* Pierce [fig. 35 *p.*, A of this report]. This genus is more typical of Upper Cretaceous than Lower Cretaceous flora (Tschudy, 1965), its occurrence in the uppermost part of the Patapsco (Brenner, 1963) being the oldest known. Sample EA-3, however, is probably younger than the Patapsco because of the dicotyledon flora. At least 10 different types of small tricolpate pollen grains are represented, four of which are figured [fig. 35 *p.*, I, J, K, and L]; these types of grains account for over 50 percent of the total pollen and spores. None of the Patapsco samples examined by Brenner (1963) had such an abundance or diversity of dicotyledon pollen. More important, however, is the occurrence of tetracoplate grains [fig. 35 *p.*, G and H] that have a complicated exine structure, and multicoplate grains [fig. 35 *p.*, F]. Such grains have not been previously recorded from Lower Cretaceous rocks and indicate a Late Cretaceous age. Presumably sample EA-3 is of earlier Cenomanian age; this sample lacks tricolpate grains of the Normapolles groups that are well represented in the Cenomanian Tuscaloosa pollen flora (Leopold and Pakiser, 1964). Samples from the Raritan Formation of New Jersey (Groot and others, 1961) also contain tricolporate pollen, lacking in sample EA-3. Although EA-3 is considered to be Cenomanian in age, it is also considered to predate any described pollen and spore flora of the Raritan and Tuscaloosa Formations."

Berry's (1910) determination of a Late Cretaceous age for the Raritan Formation in Maryland rests largely on samples from Bull Mountain on Elk Neck. Sample EA-3 is from Mauldin Mountain, the next highest hill south of Bull Mountain and presumably came from a similar black clay bed from which Berry's plant collections were made. The exposures on Mauldin Mountain are much better than those at Bull Mountain and the relationship of the black clay to the overlying and underlying sands is readily observed. Both upper and lower contacts are sharp, but there is no evidence for a widespread unconformity. The clays and sands appear to be distributed in the same general pattern

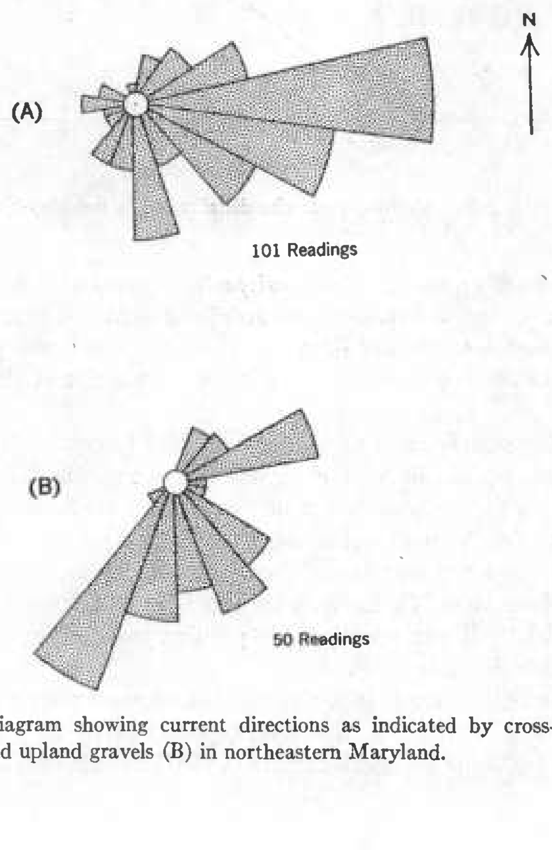

FIGURE 34. Rose diagram showing current directions as indicated by cross-stratification in the Potomac Group (A) and upland gravels (B) in northeastern Maryland.

commonly noted with clay and sand beds in the Potomac Group in northeastern Maryland. In this area of excellent exposures, it was not possible, lithologically, to separate the Potomac Group from the overlying Raritan Formation. Therefore, some fluviatile equivalent of the lower part of the Raritan was mapped with the Potomac Group. The Potomac Group as mapped in Harford County is, therefore, of Early and Late Cretaceous age.

The use of rock stratigraphic subdivisions within fluviatile beds of similar bedding characteristics and lithology is extremely difficult and probably impossible. Unless the Arundel Clay proves to be a mappable rock stratigraphic unit, the Potomac Group should probably be returned to formation status and only local members (arkosic sands, for example) mapped.

At the present time, there is no compelling evidence to support a tripartite division within the Potomac Group. It seems that a more logical lithic separation is along strike, between the arkosic facies in the south and the protoquartzite-orthoquartzite facies in the north. Until the Potomac Group is reexamined near the type localities of the Patuxent, Arundel, and Patapsco Formations, lithostratigraphy within this interval does not seem promising.

Origin

The Potomac Group in Harford County was apparently deposited in an alluvial (continental) environment. A number of subenvironments are represented; mostly fluviatile, channel fill, and overbank (Allen, 1965). Paludal deposits may also be present, although they do not constitute a large part of the sediments.

The fluviatile origin for these sediments is supported by: (1) the type, scale, and widespread character of the cross-stratification; (2) erratic distribution of lithofacies; (3) presence of channel-fill deposits (gravelly sands); and (4) wide range in bed thickness. Additional supporting evidence for this origin is indicated by the statistical parameters of the sands. Friedman (1961, p. 524) noted that medium-grained and finer sands of fluvial origin have sorting values greater than 0.5ϕ and are positively skewed. The sands of the Potomac Group have such characteristics.

The heavy mineral suites and abundance of muscovite indicate that the Piedmont rocks supplied large quantities of sediment to the Potomac Group. The absence of feldspar, biotite, and chlorite, needs explanation. Apparently, weathering conditions were rigorous enough in the source lands in Maryland to alter plagioclase and the iron-bearing micas.

TERTIARY(?) ROCKS—UPLAND GRAVELS

The Potomac Group, in the highest parts of the Coastal Plain in Harford County, is locally overlain by a coarse gravelly unit herein called the upland gravels. These gravels are restricted to the innermost part of the Coastal Plain and occur in a northeast-southwest-trending belt across the middle of the County. Whether the gravels once covered the southern part of the County is speculative because post-depositional erosion has apparently stripped away any high areas that were once present there.

Previous Investigations

The upland gravels were originally correlated with the Lafayette Formation of Mississippi by McGee (1891). They are so designated on the old map of Harford County

(Miller and Bibbins, *in* Maryland Geol. Survey 1904). Subsequently, when it was found that in the type area these gravels contained units with a wide range in age, Clark (1915) applied a local name (Brandywine) to the Maryland upland deposits. As later interpreted by Bascom and Miller (1920) and Bascom (1924), however, this unit was divided into an upper unit which they called the Bryn Mawr and a lower unit for which they retained the name Brandywine. Cooke (1931) introduced the concept of several marine terraces within which the Brandywine was designated as the highest terrace. Hack (1955) examined the higher terrace deposits near Brandywine and interpreted the upland gravels as a fluviatile rather than a marine deposit, thus disputing the multiple terrace hypothesis of Cooke (1931). Schlee (1957) examined the upland gravels over a wide area in the peninsula south of the District of Columbia. He agreed with the fluvial origin as suggested by Hack and examined the vectoral properties of these deposits in detail.

Because of the uncertainty of the relations of these gravels in northeastern Maryland to the gravelly deposits in the nearby areas, the name upland gravels rather than Brandywine is herein used until a detailed regional reexamination of these deposits has been made.

Distribution, thickness, and lithology

In Harford County, the upland gravels form a series of isolated patches capping the higher hills in parts of the Aberdeen, Bel Air, Edgewood, and Havre de Grace quadrangles. Locally, small areas of Potomac Group sediments occur beneath the protective cover of these gravels; in other areas the gravels rest on saprolite.

The upland gravels are particularly well exposed in pits near Webster and St. James Church (fig. 36 *p.*) in the Aberdeen quadrangle and at Mountain in the Edgewood quadrangle. They are best exposed, however, in the extremely large pits at Foys Hill (fig. 37 *p.*) in the Havre de Grace quadrangle in Cecil County.

The thickness of this unit is very difficult to determine because of the lithic similarity of the gravelly sands with parts of the underlying Potomac Group. Some coarse detritus in the upland gravels undoubtedly was derived from the underlying Potomac Group, thus producing similar-appearing beds on both sides of the contact. As a rule, the basal contact in such areas was drawn at the bottom of the lowest coarse (>3-inch maximum size) gravel bed. In other areas, the gravel overlies the deep-red silty clay of the Potomac Group, and less commonly rests directly on saprolite (as near Creswell in the Bel Air quadrangle). In both cases, the contact is easily established. In Harford County, the upland gravels appear to have a maximum thickness of 40 feet, although considerably thinner in most places.

The upland gravels vary widely in lithology both vertically and laterally. The unit is typically an intercalated gravel and sand sequence containing local thin discontinuous lenses of silt-clay. The upper 15 feet of the unit is deep red, but below is commonly white (fig. 37 *p.*). Because of the widespread red color, these gravels were referred to by many authors as the "red gravels." The beds are well stratified, and where largely gravel, they have a pronounced horizontal to slightly inclined stratification. In many respects these beds resemble extremely large-scale foreset beds (figs. 36 *p.* and 37 *p.*). Where the beds are predominantly sand, smaller scale cross-stratification is well developed, but not on the scale found in the older deposits.

The variable lithologic character of the upland gravels in Harford County is best demonstrated in a measured section in an abandoned gravel pit on the west side of State Route 152 at Mountain (elev. 397 ft.):

Thickness (Feet)	
6.5	Sand, gravelly, orange to orange-brown, thin-bedded. Weakly indurated with iron oxide.
3.0	Clay, very silty, soft, white, very micaceous. Massive bedded.
7.5	Gravelly sand and sand beds, reddish-brown, irregularly interbedded. Thin white silty clay beds common. Cross-stratification (trough type) well developed. Large irregular-shaped iron oxide-cemented blocks (as much as 8 feet long) are scattered throughout the middle of this interval. Thin layer of rounded white clay galls (2–3 inches average diameter) occurs at the base.
1.5	Sand, white, well-sorted, mostly medium-grained quartz; extensively cross-stratified.
20.0	Sand, white, very gravelly (as much as 50 percent of sediment). Pebbles average 1 inch in length and may be as much as 3 inches in length. Horizontally stratified. Underlain by red silty clay of Potomac Group.
38.5	Total measured thickness of upland gravels

Petrology

The upland gravels have a number of discrete lithofacies which are defined by textural variations. The major characteristic of the unit, however, is the abundance of gravel. Although these beds are similar to parts of the underlying Potomac Group, the general absence of thick dark-colored clayey beds is a conspicuous difference.

The gravel fraction of the upland gravels is mature, but contains many lithic types not found in the Cretaceous gravels. Chert (typically weathered), crystalline rocks (mainly fine grained micaceous metamorphic rocks), and especially sandstone occur in small amounts (table 21). These types are persistent in the high-level gravels in Harford and Cecil Counties.

The gravel is mostly rounded with pitted and extensively fractured surfaces. Numerous clasts in the gravel have very sharp edges indicating breakage during transport and deposition shortly thereafter.

Quartz and muscovite are the major sand-sized minerals in the upland gravels. No fresh feldspar was observed. The quartz is the common variety although polycrystalline grains constitute between 0 and 20 percent of the sand fractions (table 19). Most of the polycrystalline grains exhibit mortar or chalcedonic textures, whereas the common variety appears to be monocrystalline.

Heavy minerals in the upland gravels are variable from area to area but commonly have a high zircon, tourmaline, and rutile content (table 20). Typically such sands indicate derivation from highly weathered terrains. Large concentrations of leucoxene in samples RS-1 and AB-4, also suggest derivation from a deeply weathered source rock. Sample ED-6 at Mountain, where leucoxene is less abundant, also contains less stable nonopaque minerals such as staurolite suggesting a less weathered source rock. Muscovite, either in large flakes or books, is also very common in these beds. Locally many of the sands also contain finely divided muscovite in the matrix of the sand, imparting a silky sheen in outcrop. In general, the upland gravels heavy mineral-assemblages in Harford County, tend to be much more mature than those in the upland gravels south of Washington, D.C. (Schlee, 1957, p. 1382).

Beds of clay-silt are not common in the upland gravels of Harford County except near Mountain. Thin beds of clay, however, are very common at Foys Hill in Cecil County. The mature sand minerology suggests that the clay-silt fraction is dominated by the more stable clay minerals, kaolinite and illite. Mixed layering (illite-montmorillonite), however, is generally more abundant than in the Potomac Group. A similar relationship was found by Knechtel and others (1961). No chemical analyses of the sands or gravelly sands in this unit were made but the sands are undoubtedly highly siliceous, probably protoquartzites or orthoquartzites.

Several samples of the coarse gravelly facies from Harford and Cecil Counties were sieved for grain size analyses (fig. 38). Sorting in these samples is somewhat similar to that of gravelly sands of the Potomac Group, but they are not markedly bimodal. This nonbimodal character is typical of the upland gravels near Washington (Schlee, 1957, p. 1380). The sorting is poor to very poor (σ_I = 1.85 to 3.2ϕ). Most of the grains are very angular, but some are well rounded, suggesting that the sand was derived from two sources; mostly from the nearby metamorphic rocks (first cycle sediment) but the rest (well-rounded grains) apparently reworked from the underlying Potomac Group. It is probable, therefore, that only a small amount of sediment in the upland gravels is multicycle, and that there was no significant contribution of sand from the Potomac Group.

Directional Properties

The upland gravels appear to define distinct channel systems. Well-developed stratification has a strong southerly dip toward the present Chesapeake Bay basin (fig. 34B).

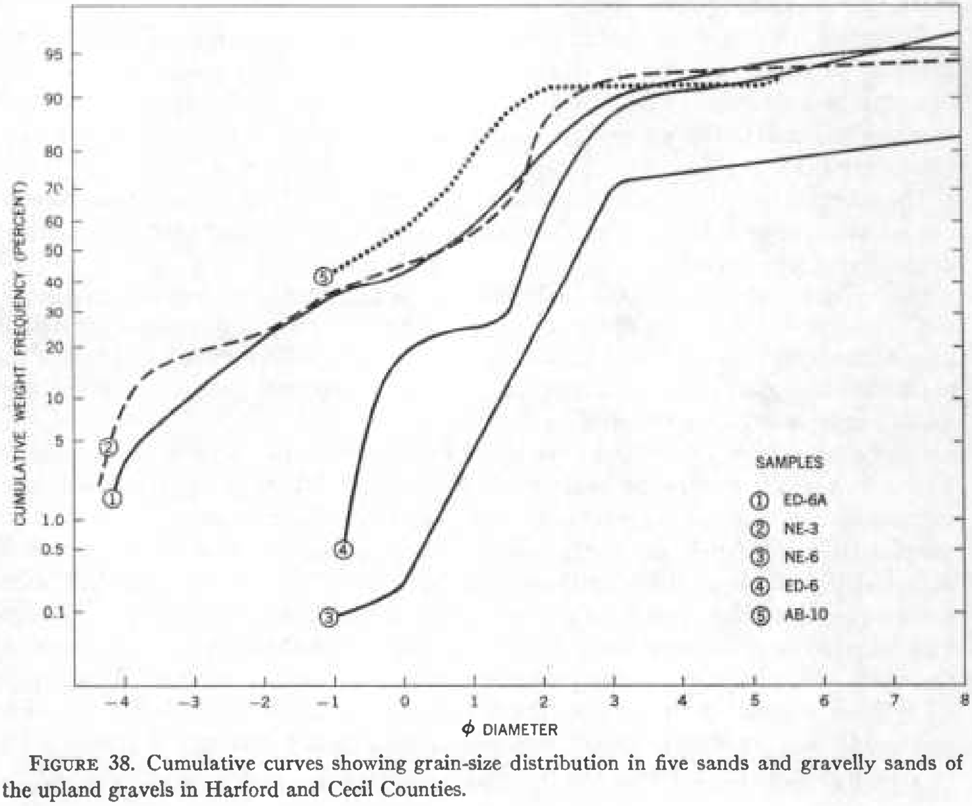

FIGURE 38. Cumulative curves showing grain-size distribution in five sands and gravelly sands of the upland gravels in Harford and Cecil Counties.

A considerable scatter in the dip azimuths was found, although this tendency was somewhat less pronounced than in the underlying Potomac Group. Comparison of this data with that of Schlee (1957, p. 1378) reveals a distinct shift in the direction of the vector mean in the upland gravels from an east-southeast direction near Washington to a southwest direction in Harford and Cecil Counties.

Age

No datable materials have ever been reported from the upland gravels even though good exposures have long been available at a number of places. The Pliocene(?) age is based in large part on the stratigraphic position of a gravel in the Brandywine area, Maryland. Here the upland gravels overlie the Chesapeake Group of Middle Miocene age (Hack, 1955). No datable beds overlie the gravels, so that their upper age limit is not known. In Harford County, where the gravels rest only on the Potomac Group, the age of the upland gravels is speculative. They have been provisionally assigned a Pliocene(?) age.

Origin

The upland gravels accumulated in a high-energy alluvial environment, judging from the abundance of coarse gravel and paucity of clay-sized sediment. Although the upland gravels are somewhat similar to the gravelly sand lithofacies of the underlying Potomac Group, there is a significant difference in the dominant type and scale of stratification. Horizontal to slightly inclined stratification is very common in the upland gravels, whereas it was not observed in the gravelly beds of the Potomac Group. The scale and persistence of this parallel bedding suggest an environment somewhat different from that of a typical point bar. It is possible that this type of stratification reflects deposition on an alluvial fan rather than on a floodplain, a hypothesis similar to one proposed by other workers (Wentworth, 1930; Campbell, 1931). Schlee (1957, p. 1396) argues against this interpretation citing several lines of evidence, such as the constant association of silt overlying sand in the upland gravels south of the District of Columbia, a typical stream phenomenon. The deposits in Harford County do not have this association. Also, he noted that the constant thickness of the deposit and its relatively flat basal contact with underlying beds are atypical of fans. Finally, the upland gravels south of Washington have the same stratification pattern found in the gravelly beds of the Potomac Group. It seems significant that the deposits in both areas have decidedly different stratification patterns and may, therefore, have been deposited in different environments. The upland gravels of northeastern Maryland are too well dissected to determine original thickness and distribution.

QUATERNARY ROCKS—TALBOT FORMATION

The youngest and most widespread Coastal Plain unit in Harford County is the Talbot Formation. This formation might be classed as lowland gravels because of its topographic position (less than 90 feet above sea level) and its very gravelly character. It is assigned a formational rank because of its widespread distribution fringing the upper Chesapeake Bay.

Previous Investigations

On the earlier map of Harford County (Miller and Bibbins *in* Maryland Geol. Survey, 1904) the deposits whose upper surface lie at an altitude of 40 feet or below were mapped as the Talbot Formation and those between an altitude of 40 and 100 feet were mapped as the Wicomico Formation. In the field, however, no distinct topographic or lithologic break exists between the 90-foot deposits and those below. In fact, these deposits grade from the higher elevations down to present bay level without any pronounced break. Because of this, all the terrace deposits at altitudes less than 90 feet in Harford County have been mapped as Talbot Formation.

Distribution, Thickness, and Lithology

The Talbot Formation in Harford County underlies an area approximately 5.5 miles wide and 16 miles long and crops out in the Spesutie, Havre de Grace, Aberdeen, Perryman, Hanesville, and Gunpowder Neck quadrangles. Much of the formation in Harford County lies within the Aberdeen Proving Grounds. Because of the limited access and very hazardous conditions within a large part of this military reservation, much of this area was unavailable for study and the data shown on the map are compiled from several other sources. Additional information regarding the composition of the unit was collected in two long traverses, one across the northern part of the area and the other in the bluffs along the Bush River. Some of the finest exposures of the Talbot Formation were observed to the north along the larger tributaries of Swan Creek.

The Talbot Formation, as defined in this report, is thin, although its maximum thickness is unknown. In the cut banks along Swan Creek and in the bluffs along Chesapeake Bay near Havre de Grace, as much as 40 feet of the formation is exposed. This is approximately the maximum thickness in this area because the underlying Potomac Group is exposed at a number of places in this area near the mouth of Swan Creek. A somewhat greater thickness, as much as 60 feet, may be present in the gullies north of High Point within the Aberdeen Proving Grounds. From this area northward, the terrace deposits thin rapidly and pinch out against the uplands of the Coastal Plain.

The Talbot Formation consists of two lithofacies in Harford County: a lower, thick bedded, cross-stratified gravelly sand facies (fig. 39 *p.*) and an upper massive to very thin bedded, very clayey silt or silty clay.

The gravelly sand facies is well exposed in the banks of gullies near High Point. The thickest known section, measured in gully 0.4 mile northwest of High Point is described below:

Thickness (feet)	
15	Yellow-brown to reddish-brown unconsolidated well-sorted sand containing thin stringers of gravel (clasts as much as 1 inch long), particularly in the middle and upper part of bed. Lower 3.5 feet mostly gravelly sand (10–20 percent gravel). Thin platelets of iron oxide developed in upper few feet.
10.0	Sand, light-yellow, unconsolidated, cross-stratified, typically medium to coarse grained. Gravel scattered throughout this interval.
7.0	Sand, light-yellow to white, unconsolidated, very gravelly (20–40 percent gravel). Extensively cross-stratified (trough type). Gravel typically 1 inch or less in diameter and well rounded.
32.0	Total section measured

On the east side of Swan Creek near Oakington, beds of dark-colored clay from a few inches to 10 feet thick are interbedded with the gravelly sands. Lignitized woody fragments and plant impressions are very common in the clay beds. Where these clays have been weathered they are green to bluish green. Shattuck (1902) noted the common occurrence of dark-colored clay in the Talbot Formation.

Another feature of the gravelly sand is the presence of very large boulders, some as much as 6 feet in length (fig. 39 *p*.). These boulders are the largest found within any of the Coastal Plain formations in Harford County. Where the terrace deposits have been eroded, these large boulders accumulate in the stream beds, such as Swan Creek, or along the beaches on Chesapeake Bay between Swan Creek and Havre de Grace. Large boulders are also common along the east side of Bush River particularly in the vicinity of Old Baltimore. The widespread distribution of these boulders along the periphery of the Talbot Formation indicates their abundance within this terrace. Some idea as to the concentration, size, and condition of these boulders can be seen in figure 39 *p*. Of particular note here is the weathered, saprolitic condition of the coarsely crystalline boulders. Although this particular pit lies near the highest part of the Talbot Formation (elevation 90 feet), the boulders at the lower elevations also exhibit saprolitization, indicating deep weathering throughout the entire formation.

The gravelly beds are capped nearly everywhere by a thin silt-clay unit. This unit overlies the gravelly sand facies irrespective of its altitude (from 90 feet to present sea level).

In outcrop, the silt-clay is massive and typically reddish brown near the surface and pale gray below. Thin reddish-orange oxidized zones extend along fractures into the gray clay. Locally, where weathering has been less intense, the lower part of the formation is drab brown or dark gray, probably the original color of the silt prior to subaerial oxidation.

This facies varies in thickness because of post-depositional erosion. In most areas, it is 6 to 10 feet thick, although as much as 20 feet was observed in the relatively undissected parts of the terrace along Gasheys Creek east of Aberdeen. A measured section of a typical exposure of the silt-clay facies in a small gully on the north side of Maryland Route 635, 1.5 miles east of Aberdeen, is given below:

Thickness (feet)	
6.3	Tan to reddish-brown clayey silt, very thin bedded. Fissile when dry.
4.9	Mottled white to brown very clayey silt, somewhat sandy. Scattered gravel randomly distributed throughout the silt.
1.8	Yellow-brown to white, cross-stratified, coarse-grained gravelly sand.
1.2	Bluish-gray to gray clayey silt. Bottom of cut.
14.2	Total section measured

In the deeper gullies nearby, the underlying gravelly sand facies was observed at a number of places, so it is assumed that the silt-clay beds are not much thicker than those described above.

Petrology

The Talbot Formation contains extremes in texture, from boulders to clay. Determination of an average composition of this unit is difficult because of the extreme lithic variability from area to area, but it is clear that it is much less mature than any other formation in this area. The gravel in the Talbot consists of a large number of rock types (table 21). This very heterogeneous immature suite is in marked contrast to the gravel assemblages in the other two Coastal Plain formations in Harford County. Large quantities of chert are very conspicuous (table 21). Fresh rock apparently was being eroded in the source area during Talbot time.

The sand in the Talbot Formation is variable depending to a large degree on the provenance. Where the underlying Coastal Plain formations served as a source, the Talbot is very quartzose, but where the nearby crystalline rocks contributed a large volume of sediment, such as from the Susquehanna River, the Talbot has a composition most nearly approximating that of an average graywacke.

A study of the heavy minerals shows the same general immature compositional trend as was observed in the other components in the formation (table 20). Many of the less stable heavy minerals, such as epidote, hornblende, and magnetite, are common constituents in these beds. A sample from the Talbot terrace at Tolchester Beach in Kent County across Chesapeake Bay, has an immature heavy-mineral suite similar to the Talbot beds in Harford County.

The clay minerals in both the clay-silt facies and in the clay beds of the gravelly sand facies are similar. Montmorillonite is a major species associated with kaolinite and illite (fig. 31). Montmorillonite was found in all the clay samples analyzed from this unit in the Chesapeake Bay region. The appearance of montmorillonite as a major clay mineral also points to the relative chemical and mineralogic immaturity of the sediments in the Talbot Formation.

Several samples of sand from the Talbot Formation were sieved for grain size analyses (fig. 40) and for the most part range from well to poorly sorted, ($\sigma_I = 1.25\phi$) and are bimodal, resembling the gravelly sands of the Potomac Group. In general, however, the sands of the Talbot Formation are better sorted than the other formations in Harford County.

No size analyses were made of the clays within the gravelly sand facies or from the upper silt-clay beds. Some samples of the upper beds, however, were washed and these contain a significant quantity of medium-grained sand. This suggests a relatively poorly sorted sediment.

The sand grains within these beds and from the underlying gravelly sand facies show much better rounding than those in the Potomac Group and upland gravels in Harford County. More than 50 percent of the grains exhibit some rounding; some of them are well rounded. The rest of the grains are angular so that the sand grains in the Talbot indicate mixing of sediment from two sources (first- and multicycle sands).

Directional Properties

Although the Talbot is a widespread unit, the material exhibiting directional properties (gravelly sand facies) is poorly exposed because of widespread cover by the overlying silty clay facies. Well-developed cross-stratification in the limited exposures of the gravelly sand facies indicates a strong component of current direction toward the south and southwest, essentially down Chesapeake Bay. This direction of sediment transport is markedly different from those associated with the Potomac Group and upland gravels.

Age

A Pleistocene age for the Talbot is based upon its regional distribution and relations with nearby formations. Although the abundant floral remains in these beds might be diagnostic, they have not been studied. Samples of wood were collected from the very clayey beds within the lower gravelly sand beds near Oakington and these are greater

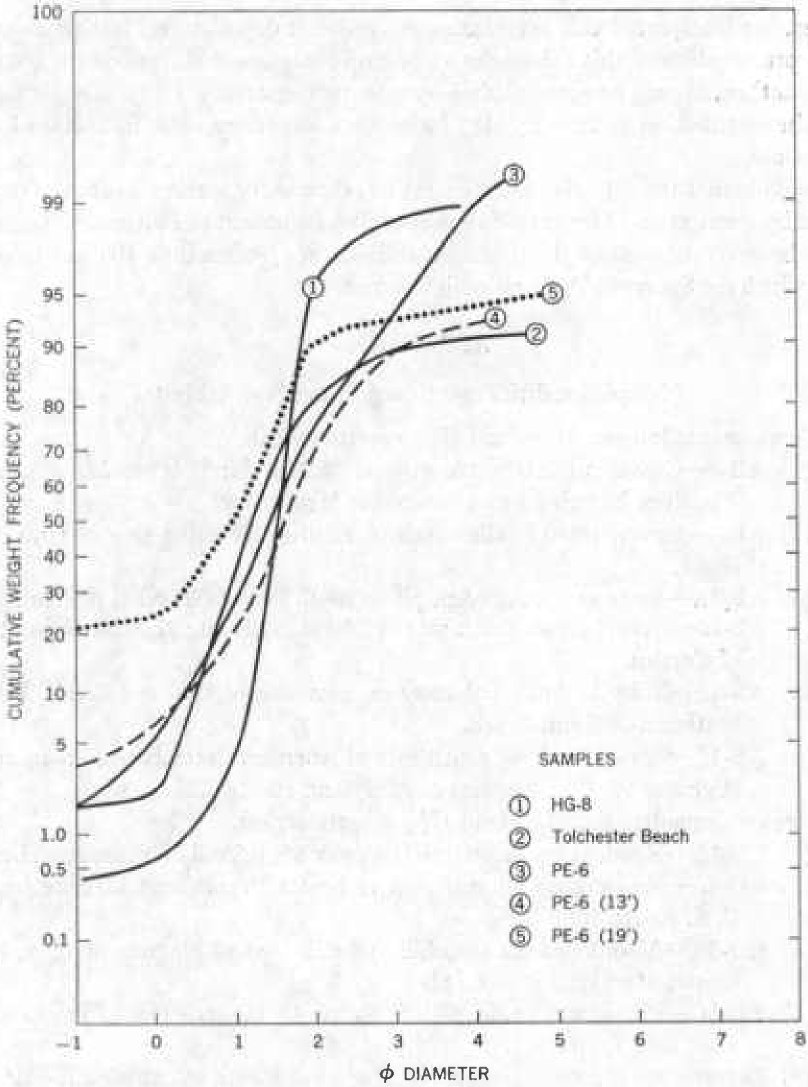

FIGURE 40. Cumulative curves showing grain-size distribution in the sands and gravelly sands of the Talbot Formation.

than 35,000 years old (determined in the laboratory of the U. S. Geological Survey, sample W-1799). The Talbot Formation thus may be pre-Wisconsin in age.

Origin

Shattuck (1902) and Cooke (1952) considered the Talbot a marine deposit. The Talbot in Harford County, however, does not have marine characteristics. The gravelly sand facies is clearly fluviatile. The gravel is restricted to distinct channels and extensive trough cross-stratification in both the sandy and gravelly beds are typical of channel-fill (point-bar) deposits.

The depositional environment of the overlying silty clay facies, however, is somewhat less certain. The distribution of this fine-grained lithofacies overlying gravels and sands is very similar to that described by Hack (1955) in the high-level gravels of the Brandywine area. He interpreted this silty facies as overbank deposits and further suggested that the preservation of this lithofacies at progressively lower elevations (in a steplike arrangement) could only be accomplished by a degrading stream. This mechanism might explain the distribution of the silty clay facies from elevations of 90 feet to sea level in Harford County.

It is possible that the silty clay facies might be estuarine or marine, as are the deposits described by Bennett and Meyer (1952) at Sparrows Point east of Baltimore. This seems unlikely, however, because of the thickness and depths (greater than 100 feet below sea level) at which the Sparrows Point clay-silt is found.

APPENDIX

(Sample localities mentioned in text and tables)

I. Aberdeen quadrangle, Maryland (7½ minute series).
  (1) AB-3—Gravel pit 500 feet northeast of Maryland Route 22, adjacent to Aberdeen interchange on Interstate Highway 95.
  (2) AB-4—Gravel pit 0.5 mile south of Earlton on north side of Gravel Hill Road.
  (3) AB-4A—Same as above except pit on south side of Gravel Hill Road.
  (4) AB-10—Gravel pit on south side of Maryland Route 22, 0.5 mile southeast of Carsins.
  (5) AB-12—Gully in small tributary on east side of Gasheys Creek, 1.0 mile southeast of Swan Creek.
  (6) AB-15—Gravel bank on south side of Aberdeen interchange on Interstate Highway 95, 0.2 mile west of Maryland Route 22.

II. Edgewood quadrangle, Maryland (7½ minute series).
  (1) ED-1B—Roadcut on Interstate Highway 95, 0.8 mile northeast of Bush.
  (2) ED-4A—Roadcut on hill adjacent to Foster Branch and 1.0 mile south of U. S. Route 40.
  (3) ED-5A—Abandoned pit atop hill, 0.8 mile east of junction of U. S. Route 40 and Maryland Route 152.
  (4) ED-5C—Pit on south side of U. S. Route 40, 0.5 mile east of junction with Maryland Route 408.
  (5) ED-6—Gravel pit on west side of Maryland Route 152 at Mountain.
  (6) ED-6A—Gravel pit 0.2 mile southeast of ED-6.
  (7) ED-9—Sand pit on north side of Baltimore and Ohio Railroad, 0.8 mile south of Abingdon.
  (8) ED-10—Sand pit 0.3 mile northwest of Sewell Station.
  (9) ED-13—Excavation for water main in Edgewood Heights, 0.3 mile east of Maryland Route 408.
  (10) ED-20—Railroad cut on north side of Pennsylvania Railroad 12 miles east of Edgewood.

III. Perryman quadrangle, Maryland (7½ minute series).
  (1) PE-1—Roadcut southeast side of junction of Interstate Highway 95 and Maryland Route 158.
  (2) PE-2—Pit on west side of Harford Furnace Road, 0.1 mile north of junction with Maryland Route 7.
  (3) PE-3—Sand pit west side of Maryland Route 158, 0.5 mile south of junction of Maryland Routes 7 and 158.

(4) PE-6—Gully on west side of Swan Creek, 0.35 mile north of High Point.

IV. Havre de Grace quadrangle, Maryland (7½ minute series).
   (1) HG-1—Roadcut on north side of Interstate Highway 95 at toll booth, 0.9 mile south of Craigtown.
   (2) HG-2—Roadcut on south side of Interstate Highway 95 at Blythedale.
   (3) HG-5—Abandoned pit, south of junction of U. S. Route 40 and Maryland Route 7 and 0.8 mile southwest of Foys Hill.
   (4) HG-5A—Pit 1.0 mile east of Principio Furnace, and 0.4 mile south of Maryland Route 7.
   (5) HG-7—Pit atop Foys Hill, Maryland.
   (6) HG-8—Cutbank on Chesapeake Bay at Bayside Park in Havre de Grace.
   (7) HG-9—Pit west side of U. S. Route 40, 0.5 mile southwest of junction of U. S. Route 40 and Maryland Route 157.

V. Spesutie quadrangle, Maryland (7½ minute series).
   (1) ST-1—Elk Neck State Park at Turkey Point, 5 feet above beach level.
   (2) ST-2—Elk Neck State Park at Turkey Point, 15 feet above beach level.

VI. North East quadrangle, Maryland (7½ minute series).
   (1) NE-1—Roadcut on west side of Maryland Route 272, 0.3 mile south of North East.
   (2) NE-3—Gravel pit west side of Bull Mountain, 1.7 miles southwest of Elk Neck.
   (3) NE-5—Shallow pit west side of Maryland Route 272, 0.1 mile north of junction of U. S. Route 40 and Maryland Route 272. Data from Carroll (1958).

VII. Earlville quadrangle, Maryland (7½ minute series).
   (1) EA-1—Base of bluff at Jacobs Nose on west side of Elk River.
   (2) EA-2—Base of bluff at Thackery Point on west side of Elk River.
   (3) EA-3—Bluff on Chesapeake Bay at Rocky Point (Mauldin Mountain), 50 feet above beach level. Raritan(?) Formation.

VIII. Rock Hall quadrangle, Maryland (7½ minute series).
   (1) Tolchester Beach—Pit south side of Maryland Route 21, at Tolchester Beach; sample from base of cutbank.

IX. Rising Sun quadrangle, Maryland-Pennsylvania (7½ minute series).
   (1) RS-1—Gravel pit, 0.9 mile northwest of Woodlawn.

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MINERAL RESOURCES OF HARFORD COUNTY

BY

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INTRODUCTION

Mineral commodities produced in Harford County include metallic and non-metallic minerals, building and decorative stone, crushed stone, sand and gravel, and clay. Many of these commodities, such as iron, chromite, feldspar, quartz, and asbestos are no longer produced, but are of historical interest. The principal mineral resources currently being produced are crushed stone and sand and gravel. These materials are connected with the building or construction industries and reflect the increasing degree of urban development in the County. Clay, talc, and serpentinite are also produced. In 1967, the value of mineral production in Harford County was $1,670,000 or 2 percent of the total value for Maryland.

This section on the mineral resources of Harford County has been compiled from the following sources: Darton (1939), Mathews (1898), Pearre and Heyl (1960), Singewald (1911), and Singewald (1928). For more detailed information regarding these mineral resources or for particular localities, see the references.

The localities of all known mines, quarries, pits, and prospects in the County have been indicated on the map (Plate 6). However, only operating localities and the more important abandoned sites have been identified by number.

CRUSHED STONE

Because of the location of Harford County in the eastern part of the Piedmont Province of Maryland, a region underlain by highly metamorphosed rocks, many of the bedrock formations are suitable for the production of crushed stone. At present, three operators are active. The Arundel Corporation operates a large quarry in the Port Deposit Gneiss on the west bank of the Susquehanna River about a mile north of Havre de Grace (loc. 1). A quarry in the James Run Gneiss is worked by the Gatch Crushed Stone Company two miles south of Churchville on James Run (loc. 2). A third quarry is operated by D. M. Stoltzfus and Son in metagabbro on Grays Run about three miles southeast of Churchville (loc. 3).

Several other formations may serve as excellent future sources of crushed stone. Suitable rock may occur in the Baltimore Gabbro, which strikes northeast across the entire County. The serpentinite bodies in the northern half of the County may also provide suitable stone. The Cockeysville Marble has been reasonably inferred to occur around the nose of the Phoenix dome in Harford County, although no outcrops have been found (Southwick, this volume). This formation is utilized for crushed stone in Baltimore and Howard Counties. A thin bed of marble within the Setters Formation is exposed in the small dome along Winters Run northwest of Edgewood (loc. 4). The last known use of this stone was in the 1860's when it was quarried for use as agricultural lime.

BUILDING STONE

Serpentinite and slate are the only rocks which have been widely used as building stone in Harford County. A quarry in the metaconglomerate member of the Wissahickon

Formation, located in the gorge of Deer Creek near Rocks (loc. 5), operated for a time in the early 1890's. Total production was small and consisted mainly of quartzite for foundation stones, sills, steps, and hearthstones. Small quarries in the Port Deposit Gneiss were located near Franklinville on the Little Gunpowder Falls and between Benson and Bel Air on Winters Run. The Setters Formation, which is quarried in Baltimore and Howard Counties for quartzite building stone, is a potential source of building stone in Harford County. It is possible that the more massive zones of the boulder gneiss member of the Wissahickon Formation may be suitable for building stone. This rock is currently being quarried in Montgomery County.

Serpentinite as building or decorative stone has been quarried from three localities in Harford County. The Broad Creek quarries near Macton (loc. 6) at the northeastern end of the Jarrettsville-Dublin serpentine district were worked during the 1870's and 1880's for both building and decorative stone. Most of the production was shipped to New York. The Protestant Episcopal Church in Darlington, Maryland, is the largest building constructed of serpentinite from the Broad Creek Quarries.

The other two quarries are in the extreme northern part of the County. The Whiteford quarry near Cambria (loc. 7) produced decorative stone for a short time during the 1890's. The only serpentinite quarry presently active is that of the Maryland Green Marble Company at Cardiff (loc. 8). Almost the total production from this quarry is aggregate chips for use in terrazzo flooring, but a small amount of the quarry output is, on demand, sawed into slabs of verde antique decorative stone. Perhaps the most famous use of this stone is in the Empire State Building in New York City. The deep emerald green color of the stone is streaked and mottled with light green and dark gray green, and cut by numerous white veinlets of calcite and dolomite. Quarrying of the severely deformed rock for dimension stone is difficult because of numerous seams and fractures; consequently the percentage of waste is high. The verde antique serpentinite competes with marble for use as interior trim and decorative stone and is therefore classified in the trade as marble.

Pearre and Heyl (1960) describe quarrying operations of the Maryland Green Marble Company as follows:

> "The verde antique is quarried from a channeled opening 247 feet deep, the present floor of which is 120 feet long and 60 feet wide. At a depth of 197 feet a platform leads from the quarry into extensive room-and-pillar workings, where the terrazzo stone is mined. The tunnels underground are about 35 feet wide and 40 feet high; roughly 40 percent of the total volume of rock is left as pillars. Two sets of joints in the serpentine—one dipping about 45° and the other dipping 10° to 15°—cause little trouble in mining or quarrying operations. Water accumulates slowly and is not a problem.
>
> The verde antique is removed from the quarry in 14-ton blocks, which are then sawed to various thicknesses, sized and polished. Serpentine for terrazzo aggregate is blasted out underground and then taken to the mill to be crushed and sized. The rock is not excessively hard, and therefore it crushes easily; capacity of the crusher is 120 tons per 8-hour day. Waste from the mill is 22 to 27 percent of the mill feed. The product is sized to $\frac{1}{4}$ inch, $\frac{5}{8}$ inch, and $\frac{3}{4}$ inch; a combination or Venetian size is also produced. The granules sell for as much as $27 a ton and are used in floors, with cement and water as a binder. The fines, which range in size from $\frac{3}{32}$ inch to dust are not currently used."

A number of quarries were worked in the Peach Bottom Slate near Cardiff and Whiteford, but at present the only quarry producing this stone is located in Pennsylvania, just north of the Harford County line. The output is crushed slate granules for composition roofing shingles.

According to local accounts, roofing slates were quarried in the area as early as 1750, but the first authenticated use of the Peach Bottom Slate was in the Slate Ridge Church, erected in 1805 and torn down in 1893. Slate from the Peach Bottom quarries has an unfading blue-black color with a slight micaceous sheen. The texture of the slate is characterized by a fibrous arrangement of the mineral components which renders the stone difficult to break evenly in a direction normal to the cleavage, and consequently sawing of the slate across the grain was necessary in dressing of the stone.

The weathered slate in the Peach Bottom area may be a possible future source of material for lightweight aggregate. However, samples of fresh slate collected by the Maryland Geological Survey and tested by the U. S. Bureau of Mines gave negative bloating test results.

SAND AND GRAVEL

Deposits of sand and gravel in Harford County occur in the Coastal Plain Potomac Group sediments (Cretaceous) and in the upland gravels (Late Tertiary–Early Quaternary). Those of the Patuxent Formation, the lowest unit of the Potomac Group, are preserved in the interstream divides along the western edge of the Coastal Plain. The upland gravels are found capping hills along or just west of the Fall Line, particularly near Mountain, Fairways, Carsins, and Webster. All of these deposits have been exploited for a number of years to supply fill material and aggregate to various construction projects in the County.

The Cretaceous deposits are currently being worked by Harford Sands, Incorporated, at Magnolia (loc. 9), by N. G. Spencer and Son at Abingdon (loc. 10), and by Joppa Sand and Gravel Company at Joppatowne (loc. 11). Stancill's, Incorporated, operates five pits in Cretaceous deposits near Aberdeen (loc. 12), Abingdon (locs. 13, 14), and Joppa (locs. 15, 16); and one pit in the upland gravels at Webster (loc. 17). W. Noble Hamilton and Son (loc. 18) and Harford Sand and Gravel Company (loc. 19) also produce from the upland gravels at Webster.

CLAY

In Harford County, massive clay occurs at various horizons within the sediments of the Potomac Group. These clay bodies have a wide range in thickness and irregular lateral distribution. The individual deposits may be used, depending upon their physical properties, for a number of products, such as building brick, fire brick, refractories, or terra cotta pipe and tile products (Knechtel, and others, 1961). At present, clay is dug for use in the production of building brick and vitrified sewer pipe by the Maryland Clay Company and by Stancill's, Incorporated, at McComas (loc. 20) and at Otter Point (loc. 13) near Abingdon.

TALC

Talc is associated with serpentinite in the northern part of Harford County. The deposits occur along the contacts with pegmatite dikes where the serpentinite has been hydrothermally altered. The talc is white to greenish-blue in color but becomes iron-stained upon weathering. In places the talc is contaminated by vermiculite, chlorite, magnesite, or small crystals of magnetite. Nodules of unaltered serpentinite may also be present within the deposits. Amphibole asbestos commonly occurs in sheared zones.

Five quarries have been worked by the Harford Talc Company in the Scarboro-Dublin area since 1916 for block steatite and for ground or powdered talc. A special grade of talc is machined into shaped articles and is then fired to a hard ceramic by the Maryland Lava Company, an affiliate of the Harford Talc Company. In the 1850's and 1860's soapstone slabs were produced from the main deposit at Dublin (loc. 21). This deposit was probably worked by the Indians in pre-Colonial times, as fragments of soapstone utensils have been found in the area. Another talc deposit southwest of Cherry Hill near Rocks (loc. 22) was worked by the Harford Talc Company during the 1920's.

IRON

Iron ore occurs in both the Coastal Plain sediments and in the Piedmont rocks of Harford County. Four iron works were located in the County: the Rough and Ready Furnaces in Havre de Grace, the Harford Furnace (or Bush Fiver Furnace) on Bush River, the LaGrange Furnace near Rocks, and Sarah Furnace near Jarrettsville. All ceased operations by the 1870's.

Limonite ore, a weathering product of siderite in the Arundel Clay, was mined in the area between the Gunpowder and Bush Rivers, principally south of the old town of Joppa, now the site of Joppatowne. Other pits were located along Otter Point Creek and Bush River. Mining probably began prior to 1754 as Harford Furnace was in operation by that date. Fourteen inactive ore banks were located in the area by Singewald in 1911; no subsequent mining activity has occurred.

Limonite also occurs in residual clay deposits overlying Cockeysville Marble at the east end of the Phoenix dome. Three pits, two of which remain today as ponds several acres in size, were worked in the mid-1800's.

Magnetite has been mined at several localities in the Piedmont. Near Shawsville (loc. 23) the ore occurs in a probable fault zone in the Wissahickon Formation. The ore body may lie in an extension of the Sykesville-Finksburg copper and iron district of Carroll County (Heyl and Pearre, 1965). The deposit is small and of low grade. It was worked on a minor scale in 1857 and prospected again in 1867. Magnetite ore is also associated with serpentinite in the area between Jarrettsville and Dublin. One mine was one-half mile east of Cherry Hill (loc. 24), another was somewhere in the Deer Creek area, and a third was somewhere north of the serpentinite quarries along Broad Creek northeast of Macton (loc. 25). Several other mines and prospects have been worked along the serpentinite belt. All of these ores contained some titanium which caused problems in smelting operations.

CHROMITE

Chromite ore was first discovered in the United States at Bare Hills in Baltimore County, by Isaac Tyson, Jr., around 1810. In Harford County, chromite ore was mined in the western part of the Jarrettsville-Dublin serpentine district, particularly in the serpentinite bodies near Jarrettsville, Chrome Hill, and Cherry Hill. Mining activity began in 1822 from boulders of massive chromite found in the soil. In 1827, Tyson discovered a large deposit of chromite boulders on what was then the Reed farm; this culminated in the development of the Reed mine (loc. 26), the second largest chromite mine in the United States at that time. The ore bodies in this mine were a series of westerly-plunging pods or lenses aligned *en echelon* in a northwest direction. Other less important mines in the district were the Birdseye (loc. 27), the Wilkins (loc. 28), the Ayers (loc. 29), and the Cherry Hill (loc. 30) mines. All of the mines produced both massive vein chromite ore and the lower grade "birdseye" or disseminated ore. Some placer chromite ore was also mined from alluvial stream gravels, notably at loc. 31 east of Chrome Hill. Most of the Maryland chromite production was used in the manufacture of chemical compounds, pigments, and dyes.

The district was most productive during the 1870's; mining activity ceased in the

1880's due to a number of causes, particularly competition from the more easily mined deposits in California. The Reed mine was dewatered in 1922 and limited production was reported until 1928. Since that time there has been no significant activity except for intermittent prospecting by industry and governmental organizations.

Chemical analysis of a grab sample of massive ore from the dump of the Reed mine and of a cleaned concentrate of the ore are given below (Pearre and Heyl, 1960):

	Massive Sample	Cleaned Concentrate
Cr_2O_3	46.1	58.0
Al_2O_3	8.6	9.1
FeO	17.3	23.4
MgO	15.9	8.6 (MgO + CaO)
CaO	.0	
TiO_2	.13	.08
SiO_2	8.1	.70
H_2O	2.2	.17
CO_2	.0	—
	98.33	100.05

TITANIUM

The Dinning rutile prospect was discovered in 1925 about two and one-half miles west of Pylesville (loc. 32). The deposit consists mainly of rutile and magnetite in pockets along the north side of a narrow, northeast-trending body of serpentinite. In the 1930's a shaft was sunk in the deposit and several trenches were cut along the hillside. Drilling tests found ore to a depth of 58 feet. The deposit was never commercially worked. Southwick (1968) presents a detailed discussion of the mineralogy of this deposit.

FELDSPAR

Only one small quarry, about two miles northwest of Castleton (loc. 33), was operated in Harford County for the extraction of feldspar. A few carloads were mined by H. Clay Whiteford and Company in 1909 and again in 1917. The mineral, a sodium feldspar, occurs in a podlike dike in serpentinite. There is no quartz associated with the feldspar and practically no mica.

QUARTZ

The quartz deposits of Harford County occur as veins, dikes, and lenticular masses or pods within the Piedmont rocks. Some of the largest known deposits of quartz in Maryland are in Harford County. Singewald (1928) reported that some of the openings of the Indian Rock Flint Company and of H. Clay Whiteford and Company were operating when he visited the sites in 1917, but most of the quarries have been inactive since the turn of the century. There has been no production of quartz from the County for a number of years.

The most productive district in the County was north of Castleton (loc. 34), where the deposits occur in quartz monzonite gneiss and alaskite gneiss. The Indian Rock Flint Company operated six large quarries in the area and H. Clay Whiteford and Company operated two quarries. Three quarries were operated east of Kalmia in a less productive district in gabbro. Quartz deposits in serpentinite were worked near Scarboro west of Dublin, and near Cherry Hill.

ASBESTOS

The asbestos deposits of Maryland are all slip-fiber amphibole asbestos and contain both the anthophyllite and tremolite varieties of amphibole. In Harford County, the asbestos deposits occur in veins associated with the ultramafic rocks in the northern part of the County. The best fibers came from sheared zones in the deposits. Only the weathered material was used because the fibers were more easily separated from a decomposed bedrock matrix.

Records of asbestos mining prior to 1917 are meagre, but as early as 1837, asbestos fibers were mined in Harford County. Production apparently came from the deposit later known as the Jenkins mine. The First World War created a shortage of imported asbestos and stimulated the reopening of many old workings. The largest asbestos mine in Maryland was the Jenkins mine (loc. 35) near Pylesville, which was worked from 1917 to 1941. The Neikirk mine (loc. 36) was worked for high-grade fiber in 1917 and again in 1923. Some anthophyllite asbestos has been separated and collected at the talc quarries of the Harford Talc Company at Dublin (loc. 21). Small deposits of asbestos near Rocks and Coopstown were also worked. Several other small unlocated deposits in the northern and western parts of the County furnished small amounts of asbestos.

MAGNESITE

Magnesite (magnesium carbonate), was mined in Harford County in 1838 from veins in a serpentinite body near Coopstown, southeast of Jarrettsville. The location of the deposit is unknown. The magnesite was ground and used in the manufacture of epsom salt.

FUTURE OUTLOOK

The outlook for future use of the mineral resources of Harford County indicates an increasing demand for construction minerals. The County lies on the periphery of the Baltimore metropolitan area and has already begun to experience urban development, especially in the southeastern part along the major highway and rail corridors. Population projections through 1980 made by the Maryland State Planning Department suggest that the population of Harford County will double in the period 1960–1980 (fig. 41). The trend in the value of mineral production in Harford County from 1952 to 1967 is shown in Figure 42. The curve reflects fluctuations in the demand for sand and gravel and for crushed stone by the building and construction industries. The influence of construction of the John F. Kennedy Memorial Highway (Interstate Highway 95) through the County is shown by the strong upward trend in the early 1960's. Since completion of the road the value of mineral production has declined. However, the projected increases in the population of the County suggest a long-term upward trend in the value of mineral production.

Available areas of suitable sand and gravel deposits, both of Cretaceous and Tertiary age, are not extensive and in many places are rapidly being preempted by other land uses. Consequently there is a limited future for this resource. The remainder of the Coastal Plain in Harford County is underlain by sands, clays, and silts of Quaternary age which do not contain economic deposits of gravel. Moreover, most of this land is already occupied by Federal military installations—Aberdeen Proving Ground and Edgewood Arsenal. Therefore, the future demand for aggregate in the County will have to be met by crushed stone, by manufactured aggregates such as lightweight aggregate, or by sand and gravel and crushed stone sources outside of Harford County.

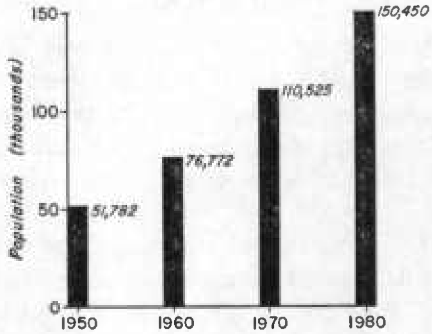

FIGURE 41. Population projections through 1980 for Harford County. (Source: Maryland population projections to 1980: Maryland State Dept. of Planning Newsletter, v. 20, no 4, July 1967.)

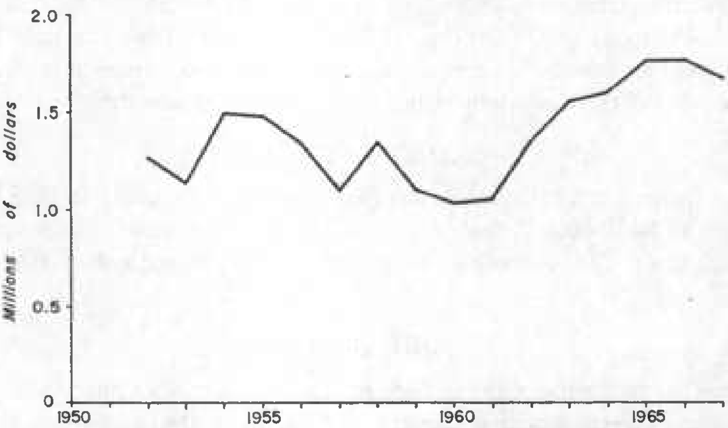

FIGURE 42. Value of mineral production in Harford County, 1952 to 1967. (Source: U. S. Bureau of Mines, Minerals Yearbook, for years 1952 to 1967.)

The best sources of crushed stone in the southeastern part of the County are the James Run Gneiss and the metagabbro near Aberdeen, both of which are currently being quarried, and the Baltimore Gabbro. The serpentinite bodies in the northern part of the county may also be a future source of crushed stone; they occur in an area which is in no immediate danger of development. However, this advantage is offset by a longer distance of transport for the aggregate.

A rational method for the conservation of prime areas for mineral resource development must be sought. Planning and zoning agencies are becoming increasingly aware of the preemption of mineral resources by other types of development. Because crushed stone and sand and gravel are bulk products with low unit value, the location of deposits close to the consumer is essential. Cost of transportation of these products from sites far removed from the market would significantly increase their cost and consequently add an incremental increase to all construction.

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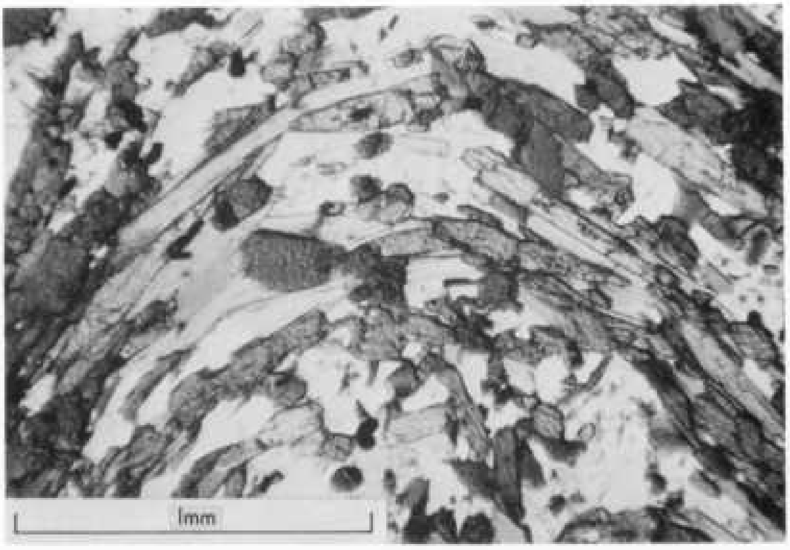

FIGURE 1. Photomicrograph showing minor fold without axial-plane schistosity. Hornblende and biotite are arched over the fold crest completely undisturbed by crosscutting axial-plane elements. Similar relations may be seen in folds of hand specimen to outcrop size in the axial area of the Baltimore-Washington anticlinorium. Specimen comes from a mineralogically atypical 10-foot bed of hornblende-biotite schist interbedded with staurolite-garnet schist of the Wissahickon Formation, lower pelitic schist lithofacies, on Little Gunpowder Falls about 0.9 mile upstream from Laurel Brook. Plane light.

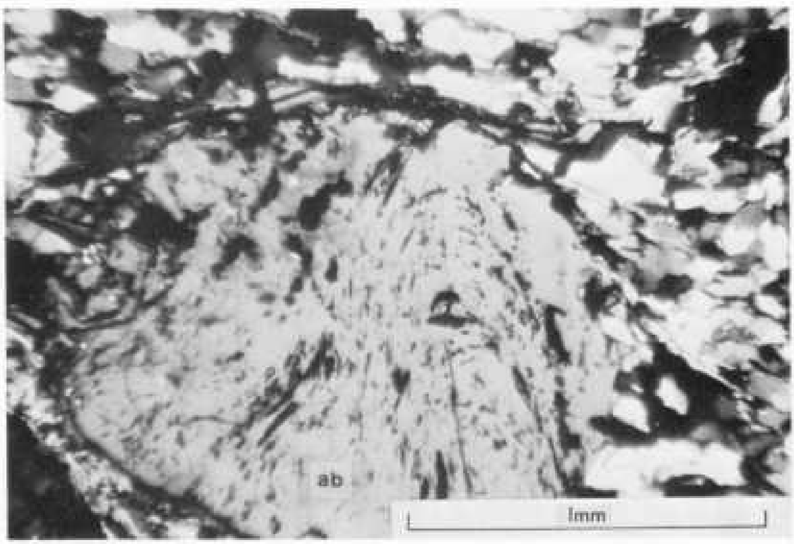

FIGURE 3. Photomicrograph of an albite porphyroblast within which inclusions of epidote, muscovite, and opaque material mark out a fold oriented across the schistosity. From Wissahickon Formation outcrop, upper pelitic schist lithofacies, in valley of small stream about 1,110 feet northwest of intersection of Drybranch Road and Jolly Acres Road. Plane light.

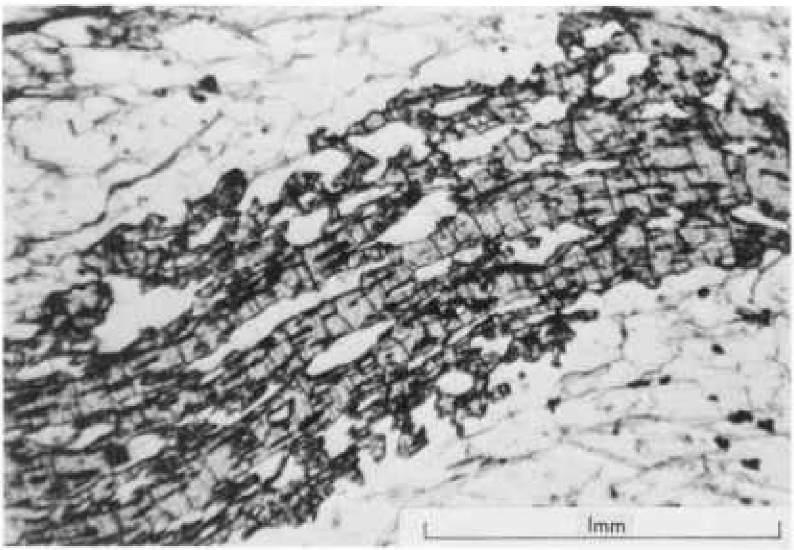

FIGURE 4. Photomicrograph of an elongate, sieved garnet porphyroblast that has been tectonically deformed into an S-shape. Wissahickon Formation, lower pelitic schist lithofacies (sheared and retrograded zone), Rock Hollow Branch about 1,000 feet west southwest of Old North Harford Church. Plane light.

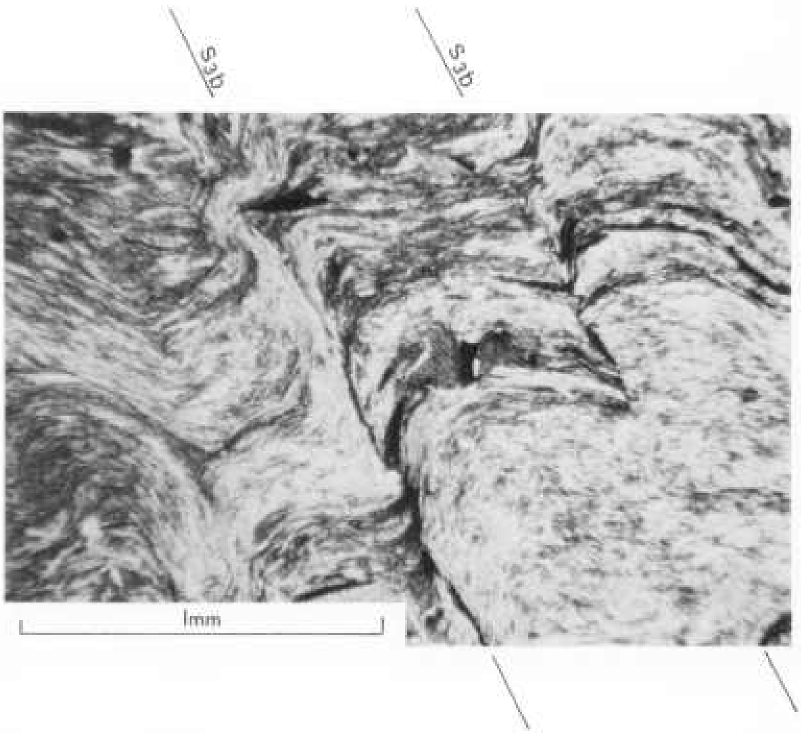

FIGURE 5. Photomicrograph showing strain-slip cleavage (S_{3b}) intersecting schistosity parallel to bedding ($S_1 \cong S_2$), throwing it into sharp crinkles. Recrystallization parallel to the cleavage is slight. Chlorite-muscovite schist, Wissahickon Formation, metagraywacke lithofacies, Broad Creek about 0.6 mile southeast of Heaps Road. Plane light.

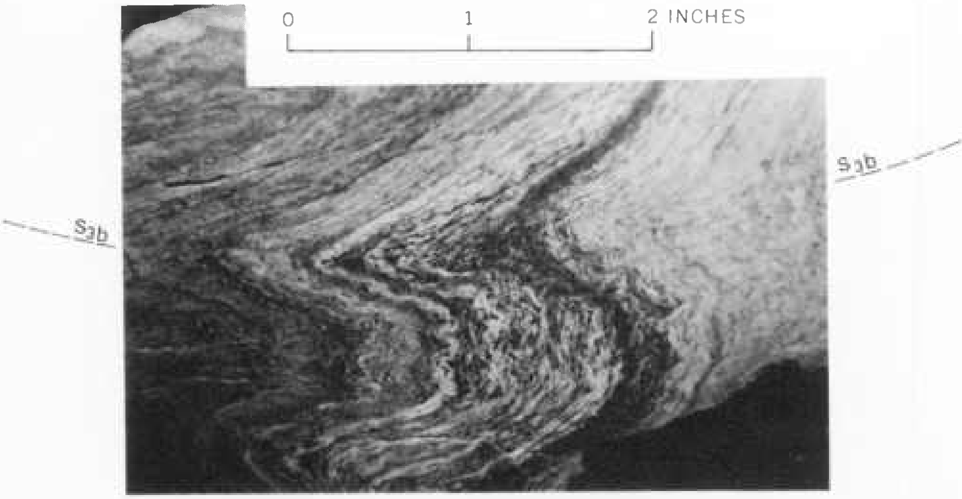

FIGURE 6. Photograph of a slab of thin-bedded chlorite-muscovite schist and metasiltstone showing intense deformation by translation parallel to strain-slip cleavage (S_{3b}). Wissahickon Formation, metagraywacke lithofacies, between Burkins Road and Emory Church Road about 1 mile southeast of Highland Road.

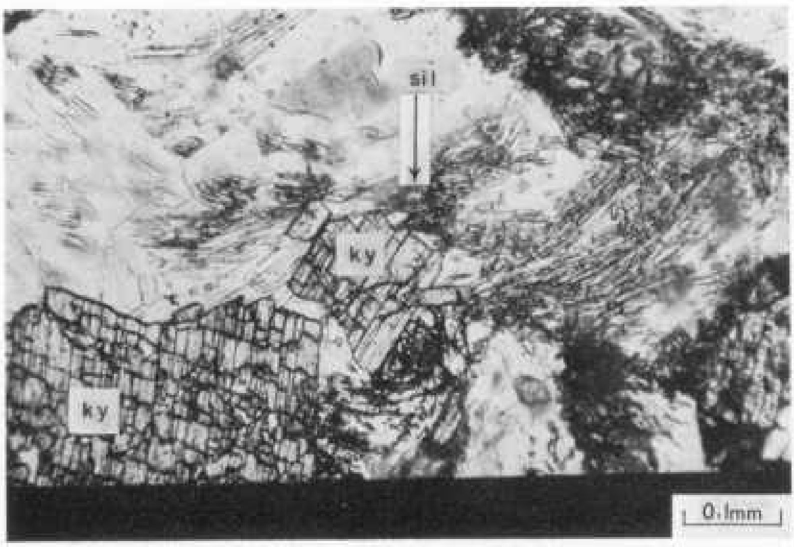

FIGURE 8. Photomicrograph showing fibrolitic sillimanite (sil) surrounding and replacing kyanite (ky). Wissahickon Formation, lower pelitic schist lithofacies, Little Gunpowder Falls about 1,000 feet north of the Pleasantville Road Bridge. Plane light.

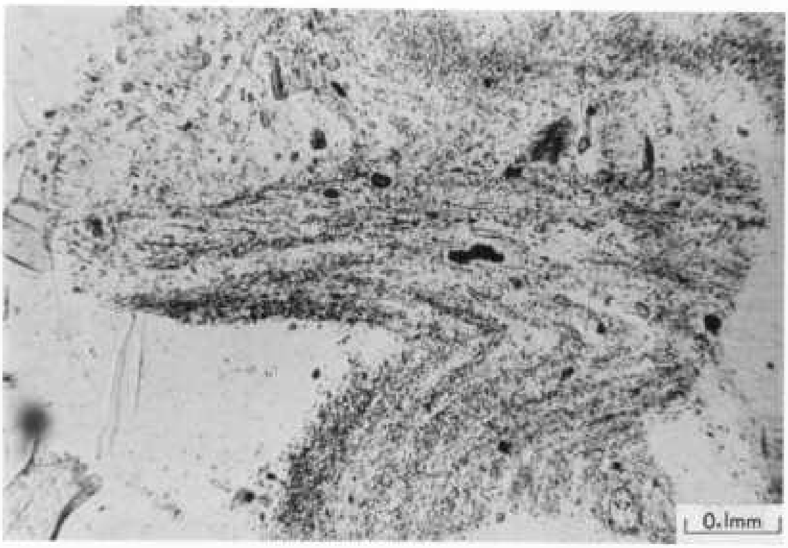

FIGURE 13. Photomicrograph showing folds traced out by opaque inclusions in microcline in impure marble, mica gneiss member of the Setters Formation. Winters Run Road 0.8 mile north of Interstate Highway 95. Plane light.

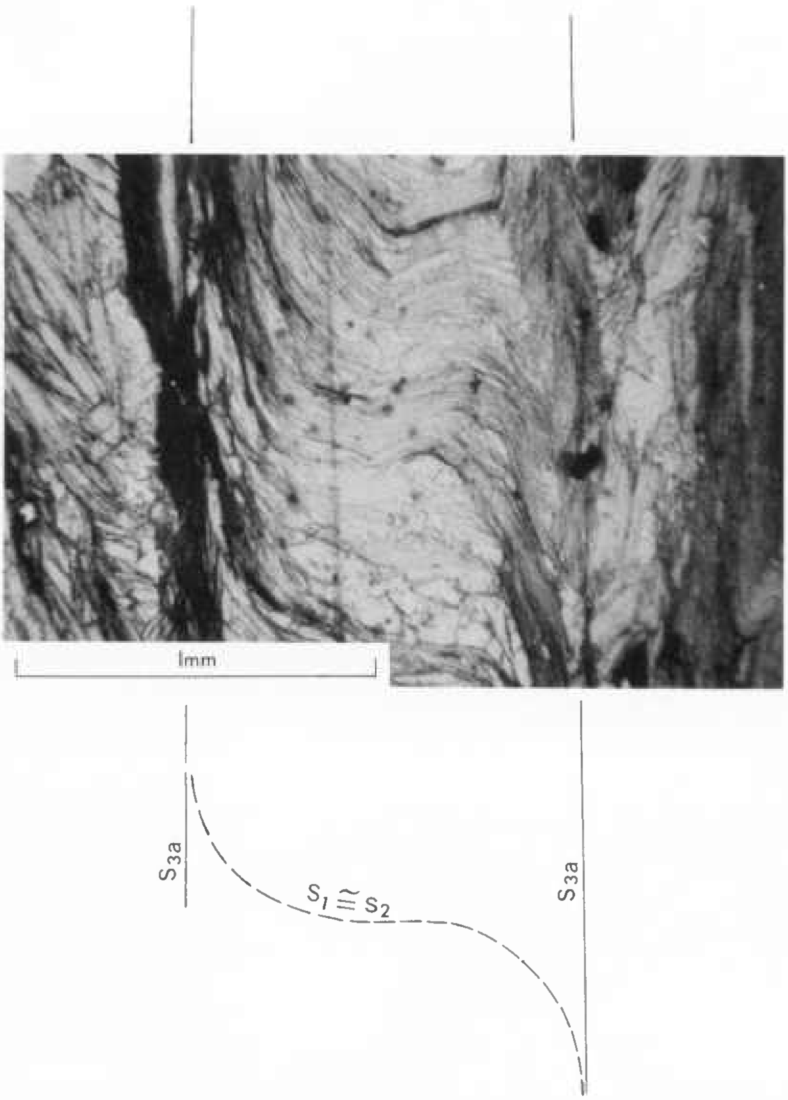

FIGURE 14. Photomicrograph showing earlier schistosity ($S_1 \cong S_2$) crosscut and dragged by movement on second schistosity (S_{3a}), along which there has been extensive mica recrystallization. Wissahickon Formation, upper pelitic schist lithofacies, 0.3 mile southeast of Constitution. Plane light.

FIGURE 15. Example of typical Cardiff Metaconglomerate lithology. White quartz pebbles as long as 2 inches are flattened parallel to schistosity, approximately parallel to hammer handle. Large boulder in pasture near intersection of Heaps School Road with Ridge Road, about 1 mile east of Pylesville.

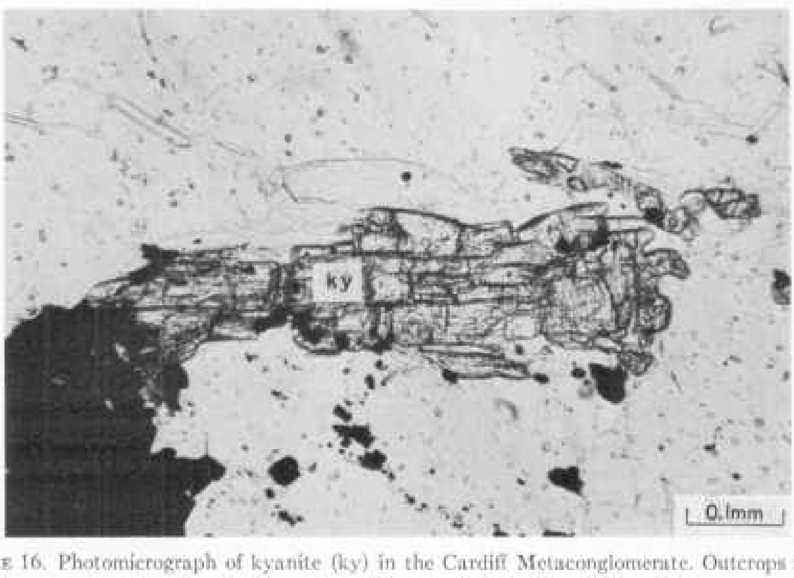

FIGURE 16. Photomicrograph of kyanite (ky) in the Cardiff Metaconglomerate. Outcrops in woods about 400 feet north of junction of Heaps School Road and Ridge Road. Plane light.

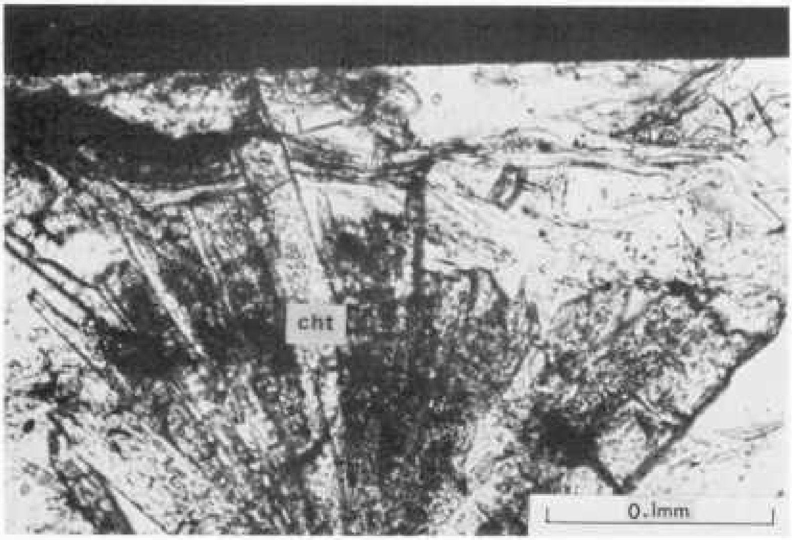

FIGURE 17. Photomicrograph of chloritoid (cht) in somewhat silty Peach Bottom Slate. Chloritoid also occurs in more typical finer grained slates, but in crystals that are hard to distinguish in a black and white photograph. Outcrops along abandoned road about 1,000 feet west of intersection of Ridge Road with Maryland Route 136. Plane light.

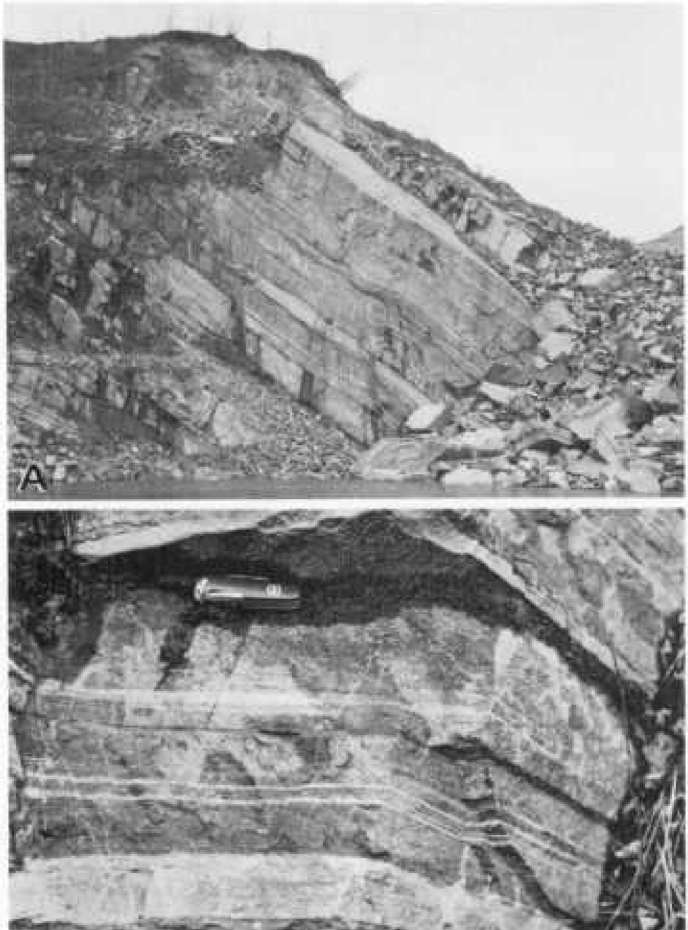

FIGURE 18. Layering in the James Run Gneiss and possible antecedent rock type. A. Layered James Run Gneiss, west end of old pit, Gatch Quarry. Layers range roughly from 1 to 6 feet in thickness. B. Closeup view of thin layering in James Run Gneiss, east end of old pit, Gatch Quarry. Dark layers are quartz amphibolite; light layers are quartz-plagioclase gneiss. C. Bedded dacite and andesite submarine tuff, Fudojiri Tuff (Miocene), Tanyawa Mountains, southwest of Tokyo, Japan. Thin-bedded sequence below; thick-bedded sequence above. Hammer gives scale. Pyroclastic rocks of this general type are believed to be likely antecedents of the James Run Gneiss. Photograph by R. S. Fiske, 1966.

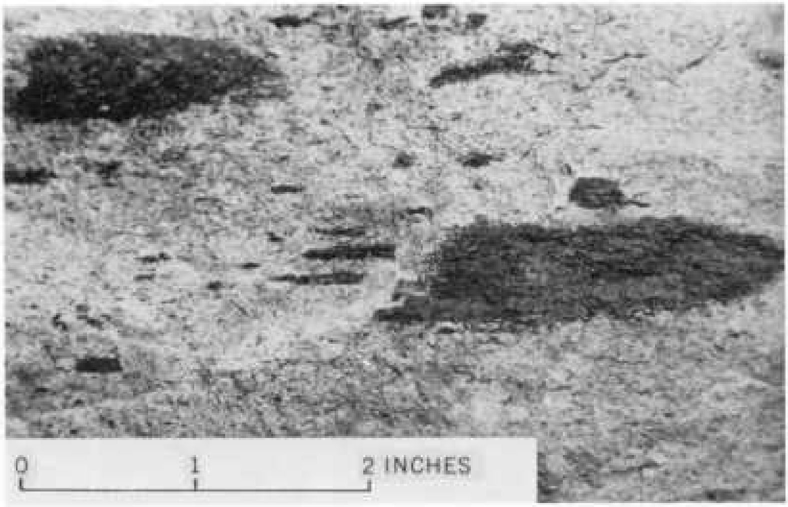

FIGURE 21. Photograph of slab of schistose quartz-plagioclase felsite with oval blebs of actinolite and chlorite smeared out on the schistosity surfaces. These blebs are interpreted as relict pumice fragments in a metamorphosed dacite tuff. Volcanic complex of Cecil County, old Frenchtown Quarry just north of Interstate Highway 95 bridge over the Susquehanna River, Cecil County.

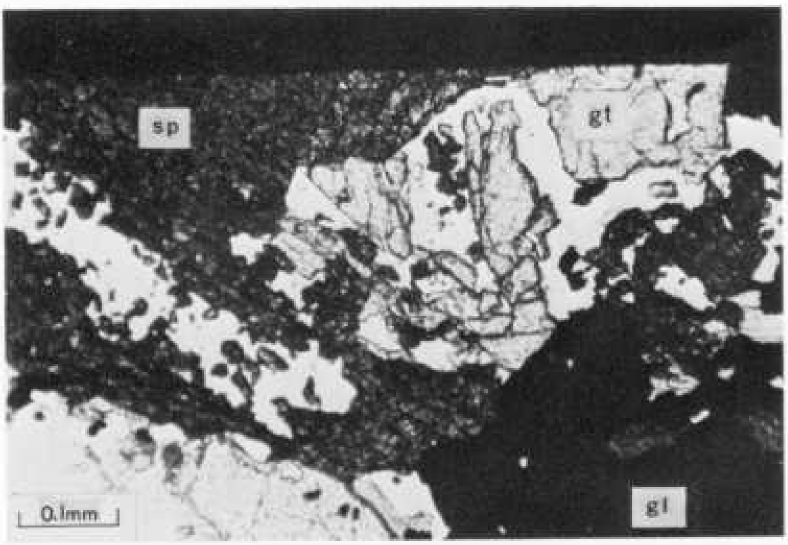

FIGURE 22. Photomicrograph showing aggregates of garnet (gt) sphalerite (sp) and galena (gl) in hornblende felsite of the volcanic complex of Cecil County. Large outcrops at southwest end of Interstate Highway 95 bridge over the Susquehanna River. Plane light.

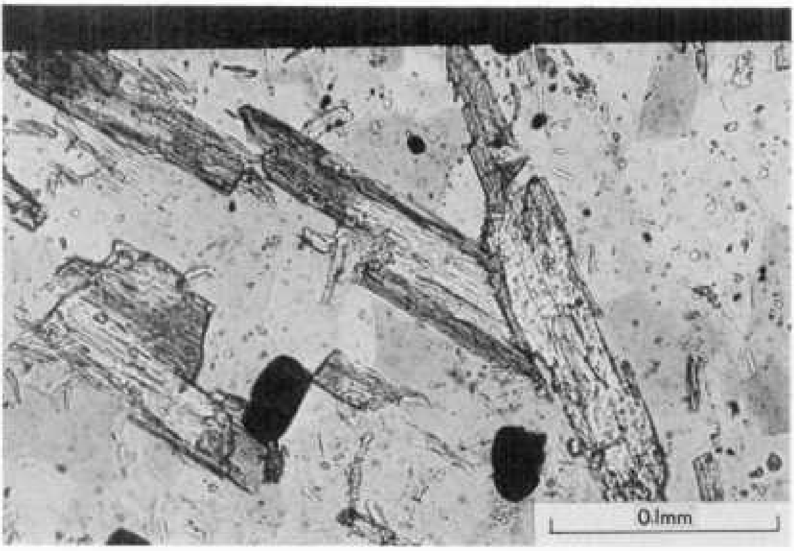

FIGURE 23. Photomicrograph of compositionally zoned amphibole in felsic metavolcanic rock, volcanic complex of Cecil County. Central part of crystal is colorless to pale amber and has the optical properties of cummingtonite; the rim is blue-green and appears to be a normal calc-hornblende. Specimen from Frenchtown Quarry, Cecil County. Nicols at 40°.

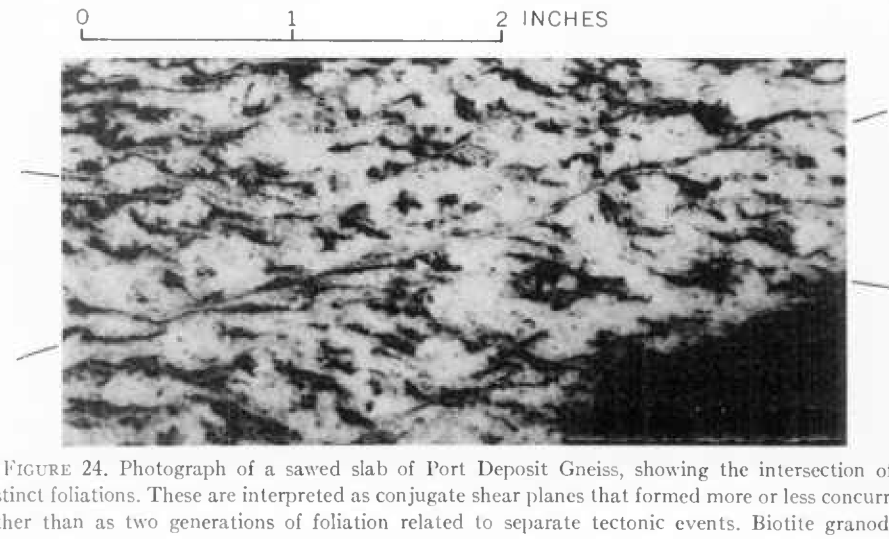

FIGURE 24. Photograph of a sawed slab of Port Deposit Gneiss, showing the intersection of two distinct foliations. These are interpreted as conjugate shear planes that formed more or less concurrently rather than as two generations of foliation related to separate tectonic events. Biotite granodiorite gneiss, Port Deposit quarry, Cecil County.

Figure 27. Well-developed trough cross-stratification in the gravelly sand facies of the Potomac Group, 4 miles northeast of Havre de Grace in Cecil County.

Figure 28. Planar cross-stratification in the sandy facies of the Potomac Group in railroad cut, 0.5 mile west of Sewell Station.

FIGURE 29. Horizontally stratified sands of the Potomac Group exposed in sand pit at Magnolia. Stratification of this type is the least common in the sandy deposits. Bank is approximately 18 feet high.

FIGURE 30. Dark clay bed in the Potomac Group exposed in pit on south side of U. S. Route 40, 0.5 mile west of junction with Maryland Route 24 at McComas. Approximately 12 feet of clay is exposed in this cut. Some of the masses at the base of the bank are siderite concretions.

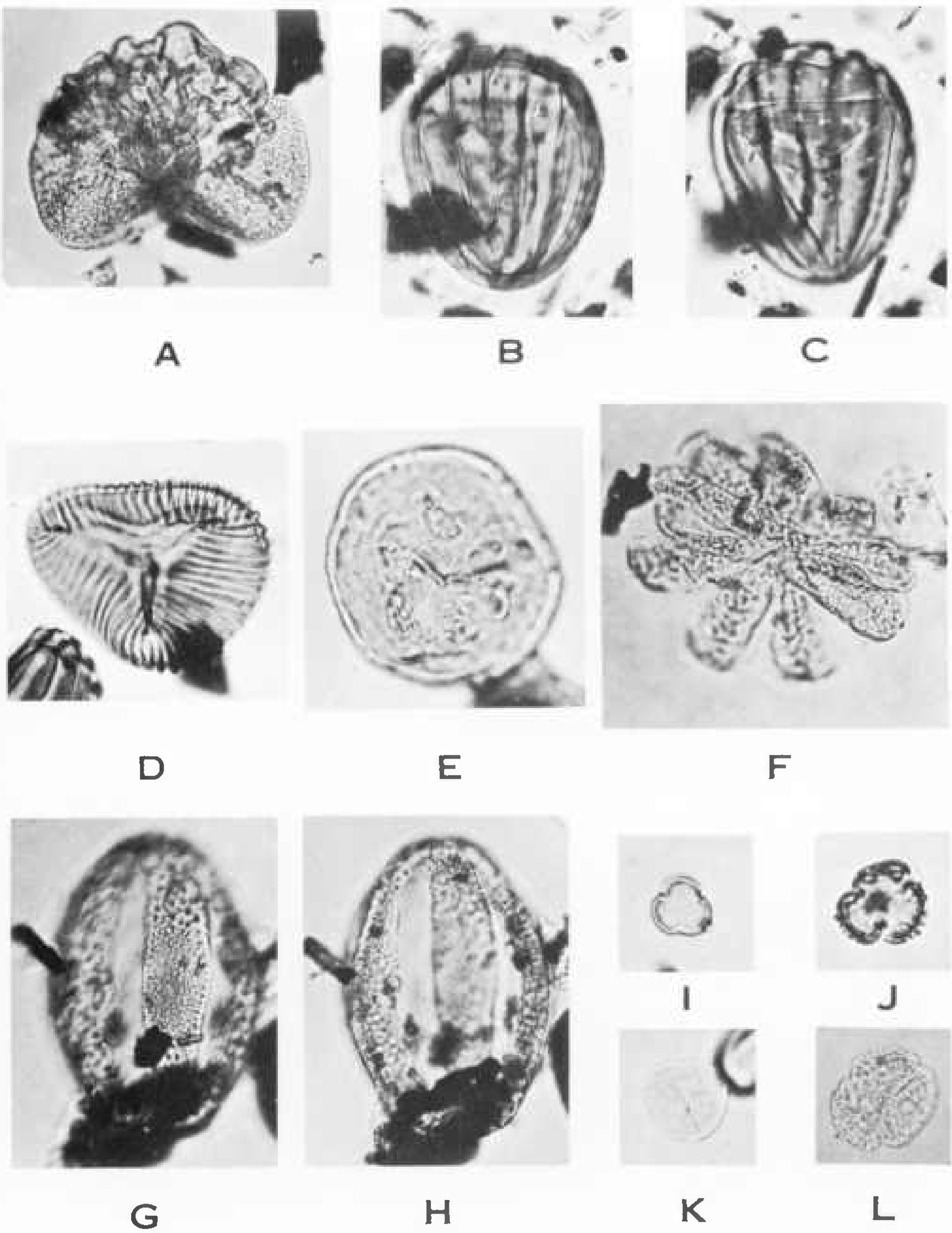

FIGURE 35. Selected pollen and spores from the Potomac Group and Raritan(?) Formation in northeastern Maryland. A, *Rugubivesiculties reductus* Pierce, Raritan(?) Formation, × 500. B, C, *Cicatricosisporties subrotundus* Brenner, Patapsco age, × 650. D, *Cicatricosisporites dorogensis* Pont and Gell, Patuxent age, × 650. E, *Kuylisporites lunaris* Cookson and Dettman, Patuxent age, × 650. F, Dicotyledonae, genus undetermined, Raritan(?) Formation, × 650. G, H, Dicotyledonae, genus undetermined, Raritan(?) Formation, × 650. I–L, *Tricolpopollenites* spp., Raritan(?) Formation, × 1000.

FIGURE 36. Upland gravels at Webster and St. James Church in Harford County, view looking north. Inclined parallel stratification of large foreset(?) beds is apparent in the gravelly beds beneath the automobiles. Gravel in this pit is abundant and typically coarse (1.5–3.0 inches common). The irregular contact between the dark-colored, iron oxide-stained upper beds and the lower light-colored beds within the upland gravels is also well exposed.

FIGURE 37. Upland gravels exposed in a pit atop Foys Hill, on north side of U. S. Route 40, 4.4 miles north of Perryville in Cecil County. Note the pronounced parallel stratification and gravelly nature typical of this deposit. The pit wall is approximately 30 feet high; the maximum size of gravel observed is 11 inches.

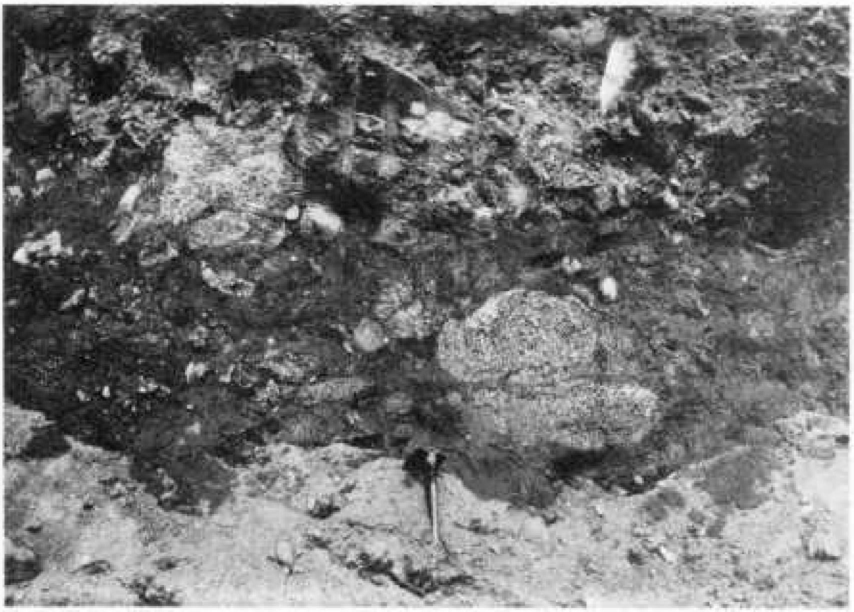

FIGURE 39. Poorly sorted, very gravelly sand facies of the Talbot Formation in pit on north side of U. S. Route 40, 0.3 mile southwest of junction with Maryland Route 157 at Havre de Grace. Note saprolitization and extremely large size of the crystalline rock boulders in this deposit. Several boulders are so weathered that a shovel cuts directly through them.

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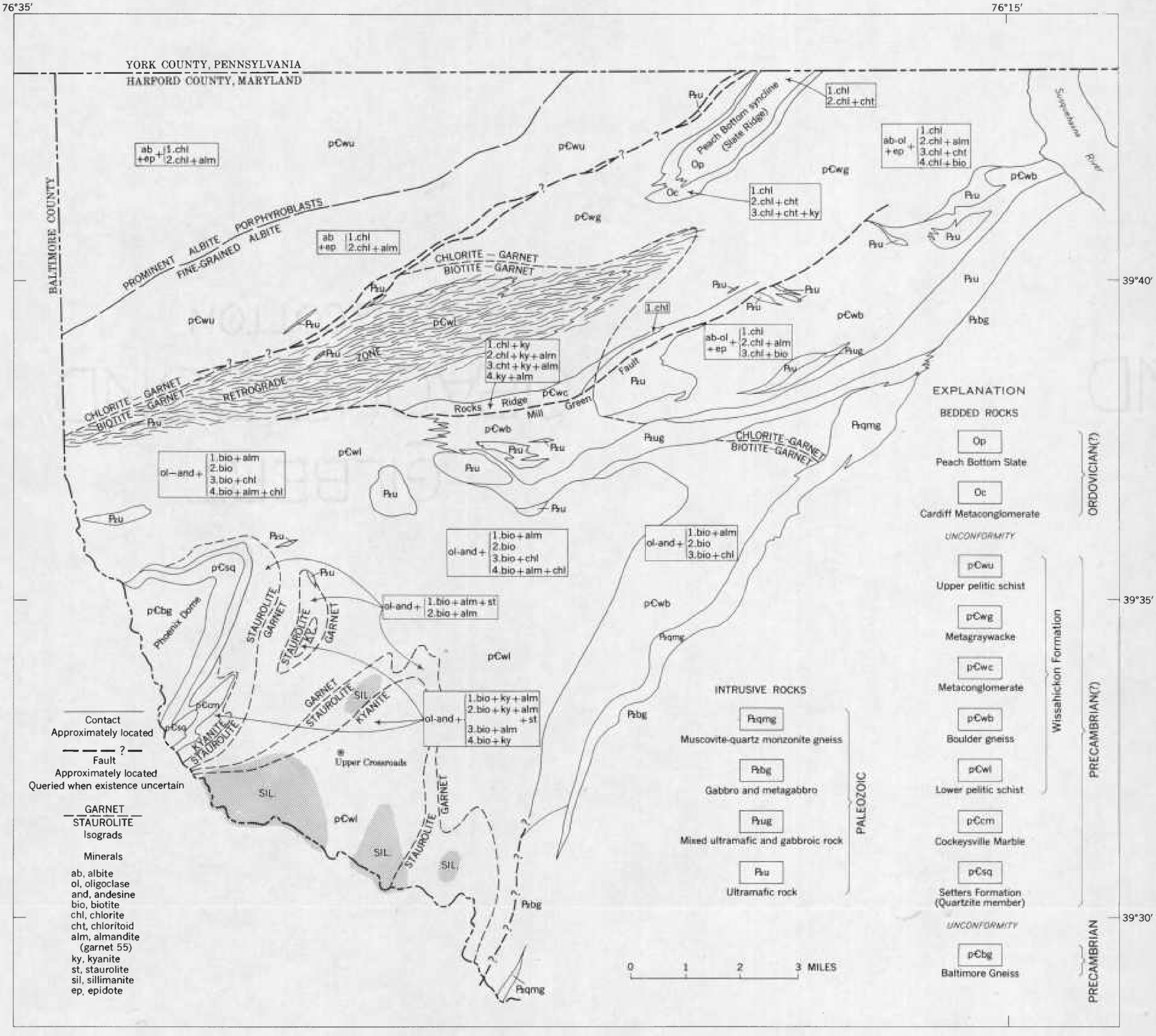
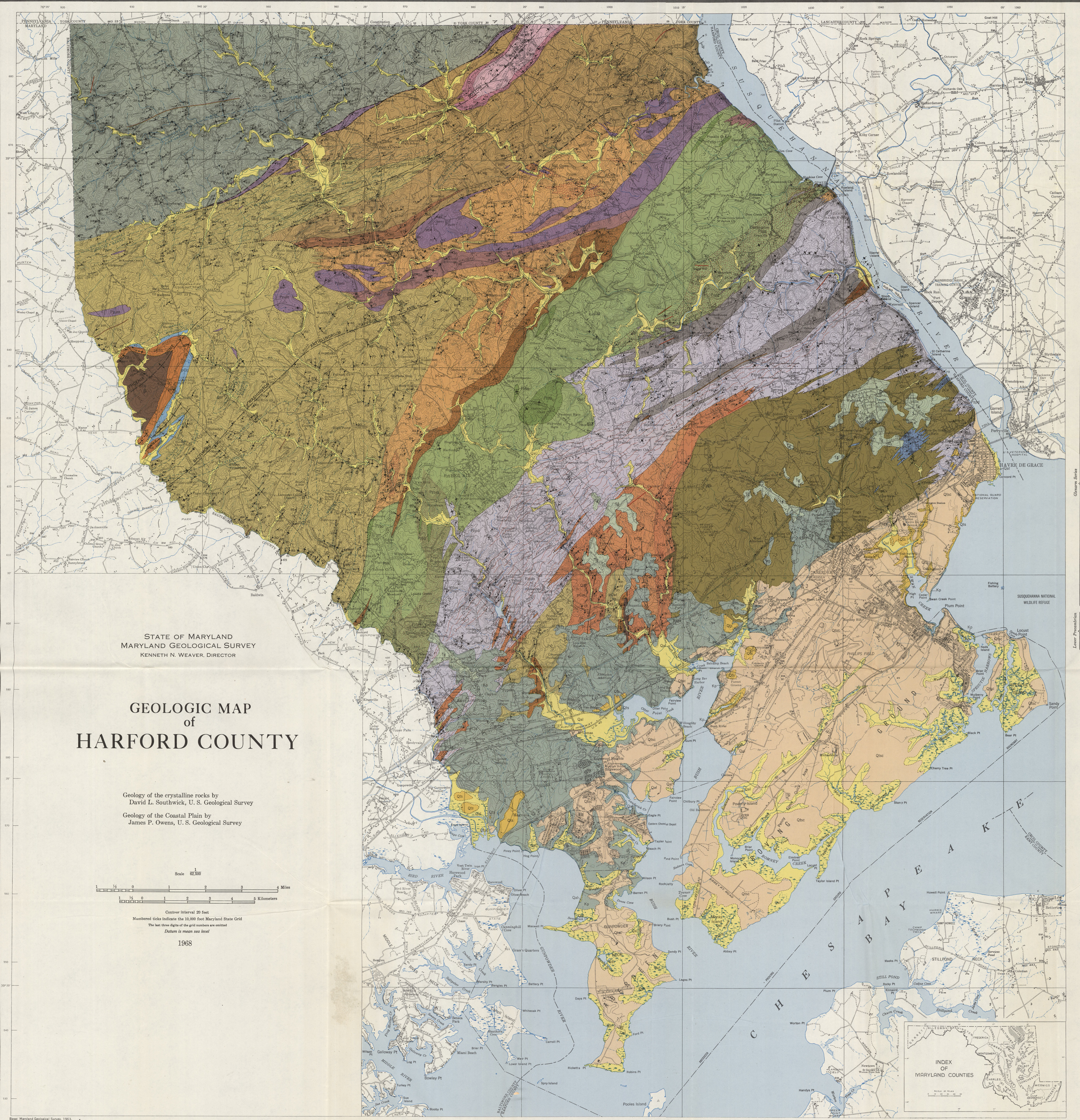


FIGURE 7. Map of northern Harford County showing metamorphic zonation and observed metamorphic mineral assemblages in rocks of the Wissahickon Formation, Cardiff Metaconglomerate, and Peach Bottom Slate.



STATE OF MARYLAND
MARYLAND GEOLOGICAL SURVEY
KENNETH N. WEAVER, DIRECTOR

GEOLOGIC MAP of HARFORD COUNTY

Geology of the crystalline rocks by
David L. Southwick, U. S. Geological Survey

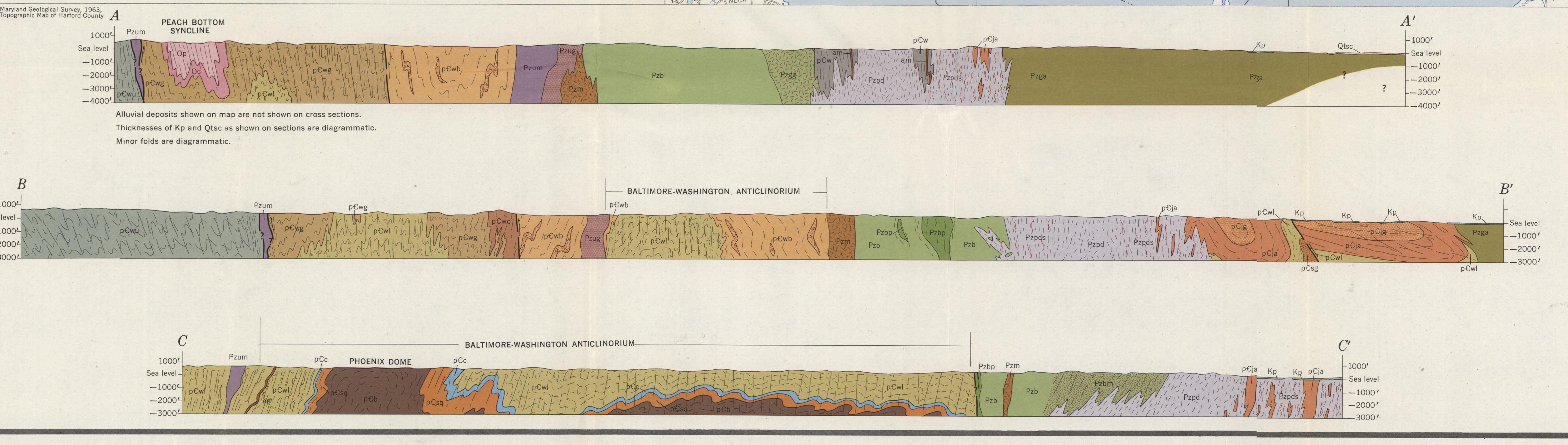
Geology of the Coastal Plain by
James P. Owens, U. S. Geological Survey

Scale $\frac{1}{62,500}$

Contour interval 20 feet
Numbered ticks indicate the 10,000 foot Maryland State Grid
The last three digits of the grid numbers are omitted
Datum is mean sea level

1968

Base: Maryland Geological Survey, 1963, Topographic Map of Harford County



Alluvial deposits shown on map are not shown on cross sections.
Thicknesses of Kp and Qtsc as shown on sections are diagrammatic.
Minor folds are diagrammatic.

EXPLANATION

The distribution of outcrops may be inferred in general from the distribution of structure symbols on the map. Most natural outcrops occur along streams. Roadcuts and other works of man provide exposures on the divides. Extensive use was made of temporary exposures provided by highway construction, pipelines, and housing developments

BEDDED ROCKS

Qal
Alluvium
Chiefly micaceous silt and clayey sand. Alluvium and colluvium in flood plain and valley fill deposits. In the north, deposits reflect bedrock composition; in the south, deposits consist of reworked Coastal Plain sediments

Qtsc / Qts
Talbot Formation
Qtsc, *pale- to moderate-gray silt, dark-brown where less weathered; contains abundant clay and some fine sand. Iron oxide staining and weak cementation common. Crudely stratified to massive*

Qts, *pale-gray- to dark-gray-brown graywacke sand interbedded with thick lenses of locally bouldery gravel. Pebbles of metamorphic rocks abundant in gravel. Crossbedding irregularly developed. Locally contains thick beds of massive dark-gray very clayey silt which weather pale greenish gray; leaf impressions common*

UNCONFORMITY

Tg
Upland Gravels
Pale-gray to white, intercalated thin to thick beds of gravel, sand, and silt; dark brown (illuviated?) near surface. Horizontal bedding prominent; locally contains conspicuous large-scale cross-stratification. Sand and silt principally orthoquartzitic but locally very micaceous, especially near the base. Gravel predominantly quartz and quartzite. Unit occurs as large channel-fill deposits

UNCONFORMITY

Kp
Potomac Group
White to pale-gray quartz sand, locally stained orange brown; gravel common in updip areas. Small-scale trough and planar cross-stratification well-developed in coarse beds. Contains thick lenses of dark-gray, massive, very lignitic and silty clay, and bright red and yellow clay. Large spheroidal to discoidal masses of dark-brown to pale-gray siderite occur locally in the dark clays. Lignitized plant and tree remains, some several feet long, common

UNCONFORMITY

Op
Peach Bottom Slate
Blue-black hard graphitic slate approaching phyllite in crystallinity. Locally contains abundant chloritoid porphyroblasts. Thin beds of fine-grained black quartzite near base. Slate of commercial quality near center of outcrop belt

Oc
Cardiff Metaconglomerate
Silver-gray, schistose, micaceous quartz-pebble metaconglomerate and quartzite; contains small amounts of chlorite, chloritoid, and kyanite

UNCONFORMITY(?)

pЄwu, pЄwg, pЄwc, pЄwb, pЄwl, gs, am
Wissahickon Formation
pЄwu, upper pelitic schist, *chiefly albite-chlorite-muscovite-quartz schist with a few thin beds of fine-grained, laminated metagraywacke. Albite porphyroblasts as large as 5 mm are common and especially prominent in northwest part of county. Biotite and garnet, commonly chloritized, occur locally.* gs greenstone

pЄwg, metagraywacke, *rhythmically interbedded metagraywacke and fine-grained pelitic schist. Composed chiefly of chlorite, muscovite, sodic plagioclase, and quartz; locally contains biotite, garnet, and chloritoid. Graded bedding locally preserved in metagraywacke.*

pЄw, am
Wissahickon Formation, undivided
Mica schist, chlorite schist, boulder gneiss, and micaceous quartzite occurring as septa between and inclusions within post-Glenarm igneous plutons. am, *amphibolite*

Volcanic Complex of Cecil County

James Run Gneiss

Cockeysville Marble

Setters Formation

Baltimore Gneiss

INTRUSIVE ROCKS

Diabase dikes

Pegmatitic quartz monzonite gneiss and alaskite gneiss

Muscovite quartz monzonite gneiss

Port Deposit Gneiss

Quartz gabbro and quartz diorite gneiss

Baltimore Gabbro of Cloos and Hershey (1936)

Metagabbro and amphibolite

Ultramafic and gabbroic rocks

Ultramafic rocks

CONTACT

FAULT

PLANAR FEATURES

LINEAR FEATURES

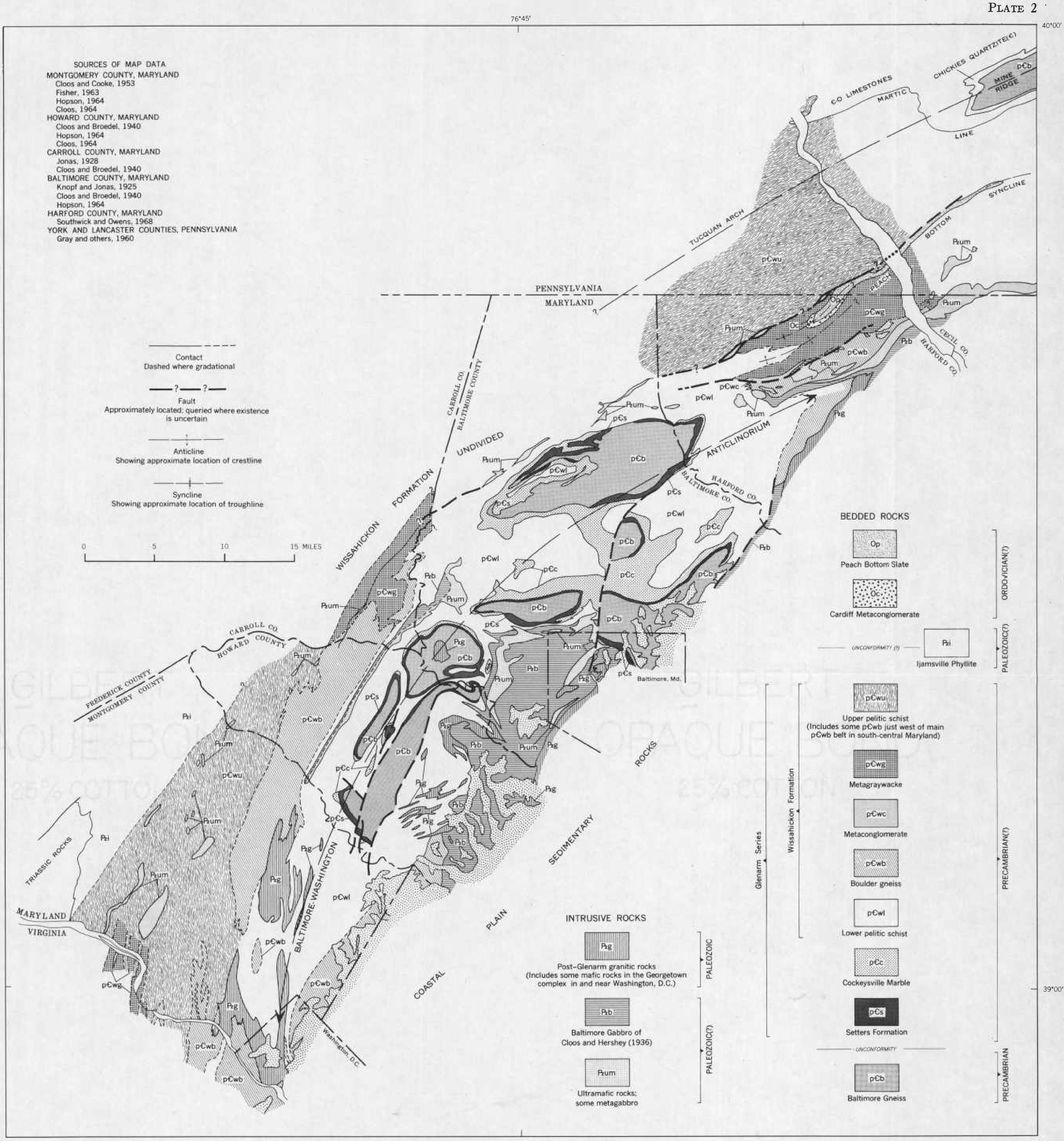
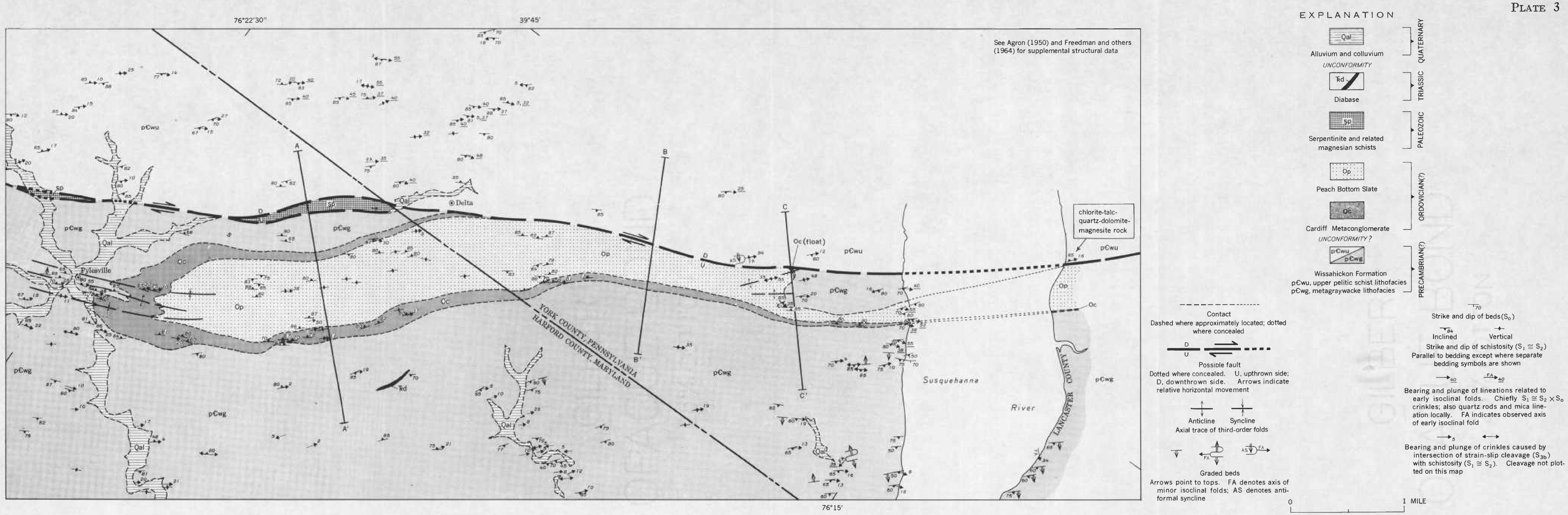


PLATE 2. Geologic sketch map showing the major structural axes of the east-central part of the Maryland Piedmont and contiguous parts of Pennsylvania. Modified from Southwick and Fisher, 1967, fig. 1.



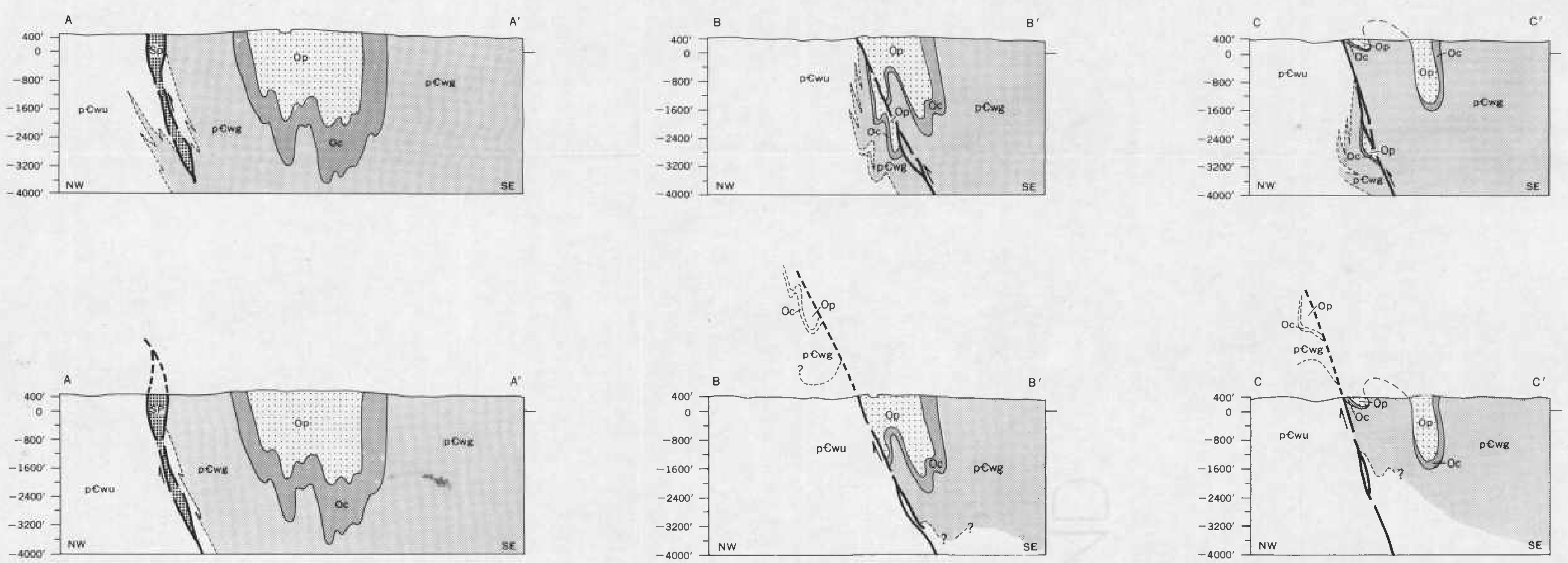


PLATE 3. Geologic sketch map of the axial zone of the Peach Bottom syncline between Pylesville, Md., and the Susquehanna River. Alternative structural interpretations are given in the cross sections. The carbonate rock mapped on the east side of the Susquehanna is a dikelike body about 20 feet thick composed chiefly of magnesite, dolomite, and quartz and small amounts of talc and chlorite. This mineral assemblage is readily obtained by the reaction of serpentine and tremolite with CO_2; therefore, the carbonate rock is thought to be derived from an ultramafic body related to those along strike in Maryland (plate 2).

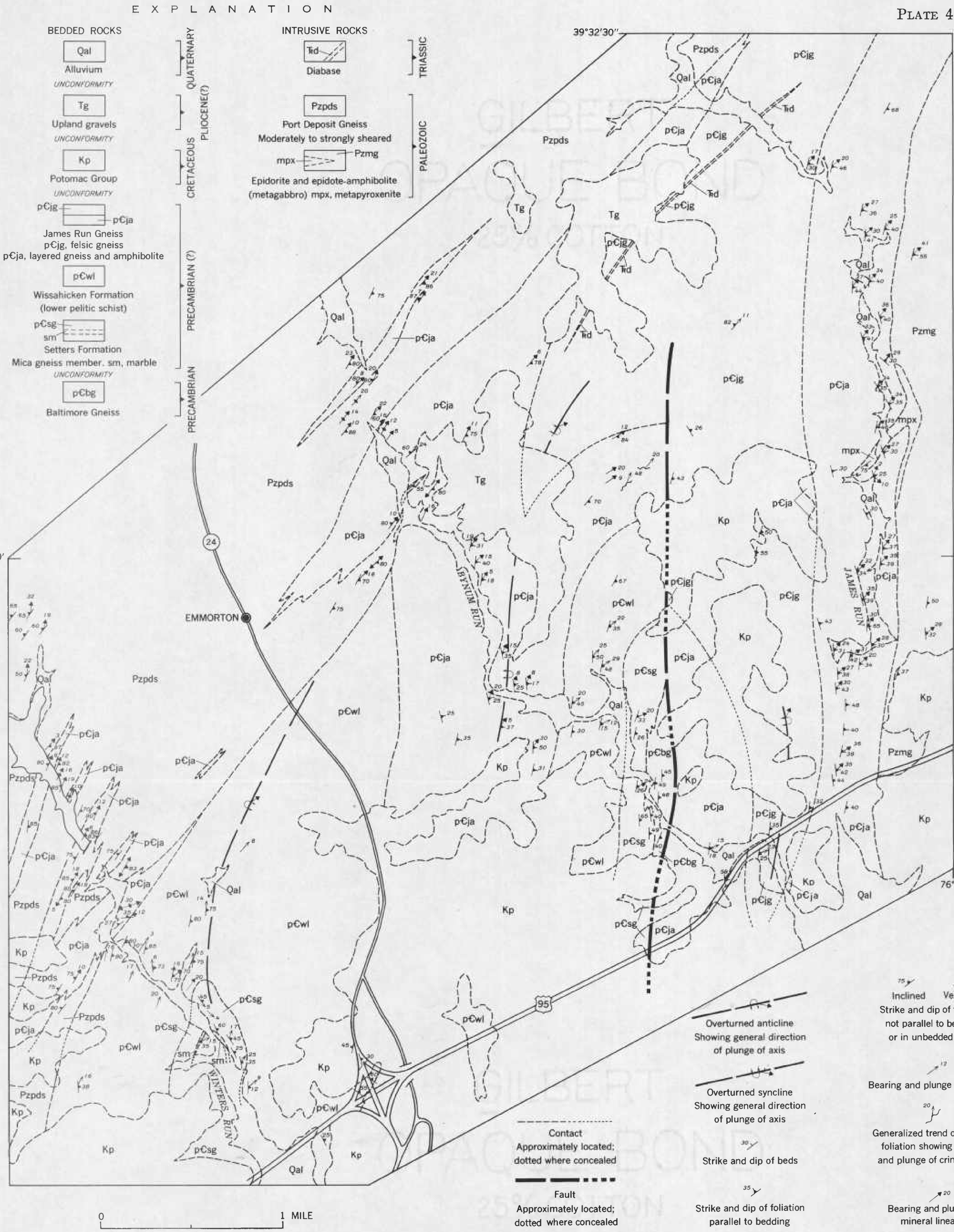


PLATE 4. Geologic map of the area around Emmorton, southeastern Harford County

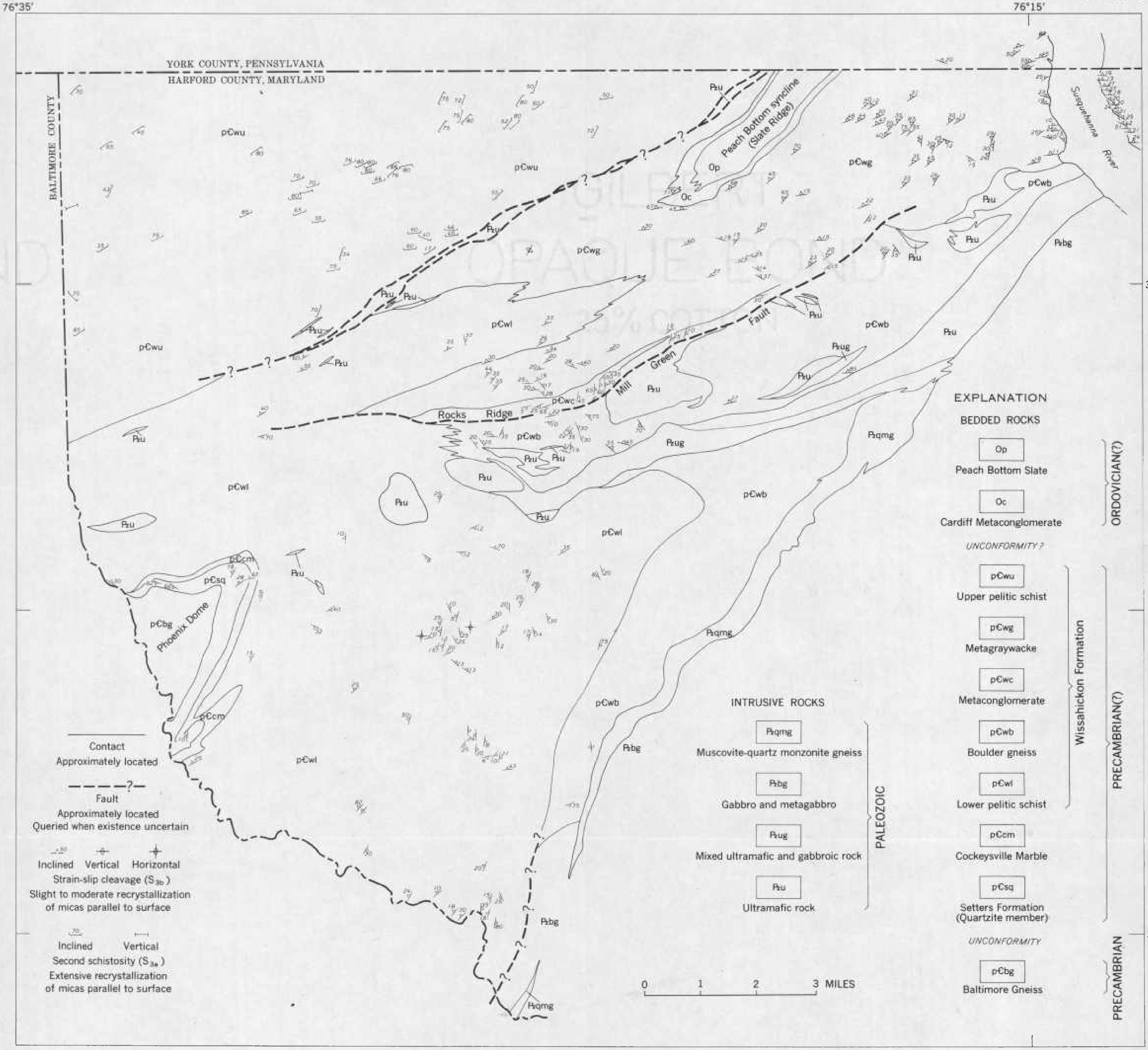


PLATE 5. Map of northern Harford County showing the attitudes of planar elements that cut the dominant schistosity. In the northwest part of the area the crosscutting element is a second, steeply dipping schistosity (S_{3a}) along which there has been extensive mineral recrystallization; in the southeast it is chiefly a strain-slip cleavage (S_{3b}) that dips gently to steeply.

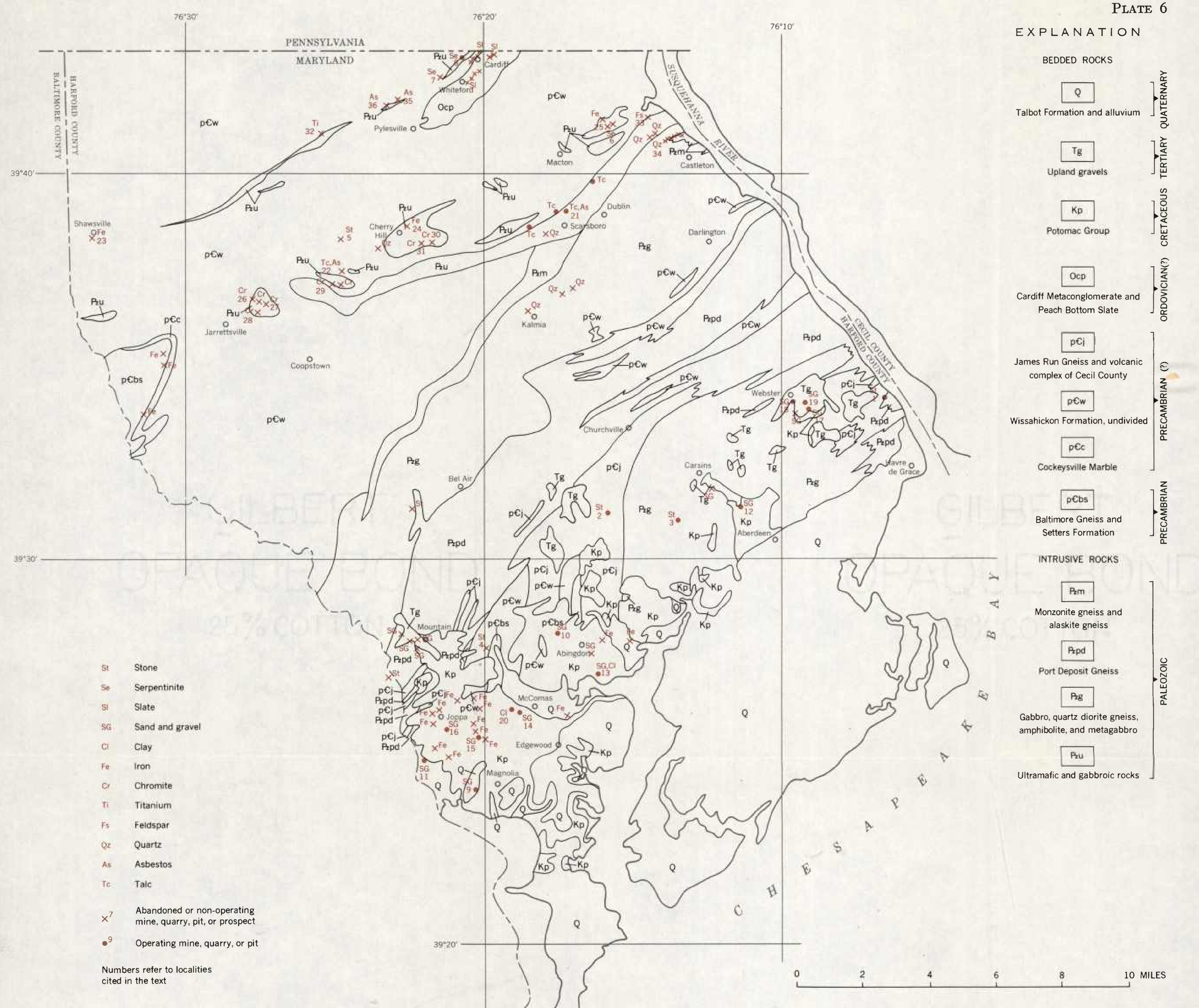


PLATE 6. Mineral Resources of Harford County, Maryland

THE GEOLOGY OF HARFORD COUNTY, MARYLAND 1969