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

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THE GEOLOGY OF CECIL COUNTY, MARYLAND

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by

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1990

COMMISSION OF THE MARYLAND GEOLOGICAL SURVEY

The Geology of Cecil County

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THE GEOLOGY

of

CECIL COUNTY,

MARYLAND

THE CRYSTALLINE ROCKS OF CECIL COUNTY[1]

by
Michael W. Higgins[2]

INTRODUCTION

In the eastern Maryland Piedmont, southeast of the extensive terrane of pelitic and psammitic rocks that have traditionally been assigned to the Wissahickon Formation, is a terrane of layered gneisses, massive but fine-grained granofels, and layered, massive, and pillowed amphibolites collectively called the James Run Formation. Interspersed with and locally grading into the James Run Rocks are coarser grained granitic plutons. The plutons and the James Run Rocks are believed to represent the roots, products, and debris of ancient volcanoes. There also is a large outcrop belt of ultramafic and mafic rocks belonging to the Baltimore Complex, called Baltimore Gabbro by earlier workers. The relations among the metasedimentary rocks, the James Run Formation and its associated plutons, and the Baltimore Complex are important to our understanding of the history of the central Appalachians. The James Run metavolcanic rocks and associated plutons are perhaps best exposed in Cecil County, the northeasternmost county in Maryland (fig. 1; pl. 1), where a small part of the sequence has long been called "the volcanic complex of Cecil County." Thick and diverse sections of the metasedimentary rocks also occur, as well as the most intact section known of the Baltimore Complex.

This paper gives descriptions of the rocks exposed in Cecil County, interpretations of the origins of these rocks, and interpretations of the geologic, structural, and tectonic history of the area. The terminology used herein is that of the U.S. Geological Survey and does not always conform to Maryland Geological Survey practice.

PREVIOUS WORK IN CECIL COUNTY

Although a geologic map of the area around Baltimore had been produced by Williams and Darton (1892), detailed and systematic areal geologic mapping in the central Appalachian Piedmont really began with Florence Bascom's pioneer work in Cecil County, Maryland. Here (Bascom, 1902; Bascom and others, 1902) she described the geology for the first geologic map of a Maryland county. Earlier, Grimsley (1894) and Leonard (1901) had done topical studies on some of the rock units in the County, but their publications included only geologic sketch maps of parts of the County. Later, students of Ernst Cloos at the Johns Hopkins University studied some of the metavolcanic rocks in Cecil County (Marshall, 1937) and the Port Deposit Gneiss (Hershey, 1937). Hopson (1960) examined some of the features of the Port Deposit Gneiss and suggested that part of what had previously been mapped as the Port Deposit might actually be metasedimentary.

A structural study was made along the Susquehanna River in Maryland by Cloos and Hershey (1936). A later study by Freedman and others (1964) included the rocks along the Susquehanna River in the northwest corner of the County. Lapham and McKague (1964) investigated the structure of some of the serpentinites, and Lapham and Bassett (1964) obtained

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[1] Publication approved by the Director of the U.S. Geological Survey.

[2] U.S. Geological Survey, Doraville, Georgia.

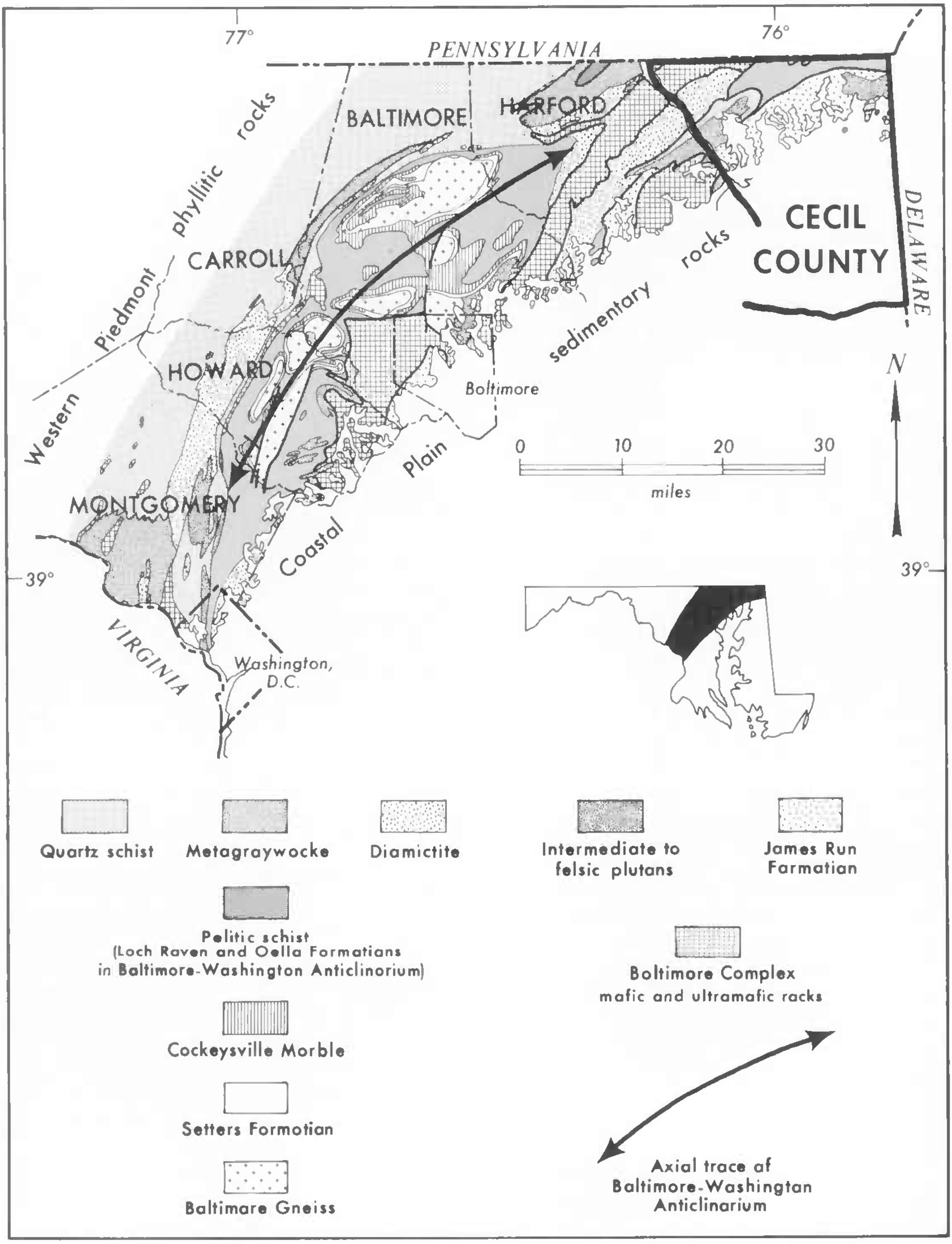

FIGURE 1: Lithologic map of the eastern Piedmont region of Maryland showing location of Cecil County.

K-Ar dates from some of the rocks in the northwestern part of the County. Steiger and Hopson (1965) dated zircons from the Port Deposit Gneiss, and Higgins and others (1971) dated zircons from some of the metavolcanic rocks and from the gneiss near Elkton.

Since 1971, several papers have been published that involve the geology of Cecil County (Higgins, 1971a, 1972, 1973, 1977a, 1977b; Higgins and Fisher, 1971; Crowley and others, 1971; Higgins and others, 1977; Southwick, 1979; Fisher and others, 1979; Lesser and Sinha, 1982).

METHODS

Geologic mapping was done on 1:24,000-scale topographic quadrangles and was compiled onto the 1:62,500-scale topographic base map of Cecil County (pl. 1). In most places, particularly in the flatter uplands of the north-central part of the County, exposures are very poor. Delineation of the rock units was based on float fragments and on differences in saprolite. Geologic control is much better near the Susquehanna River and along some of the major streams where bedrock is exposed. Many of the contacts are gradational. Because the rocks in Cecil County have been metamorphosed and have been folded at least four times (Higgins, 1972), stratigraphic thicknesses are difficult to determine and can only be approximated from the widths of the units on the geologic map.

ACKNOWLEDGEMENTS

I was privileged to work in the Maryland crystalline terrane at a time when geologic concepts about this area were being revised, and at a time when A.A. Drake, Jr., G.W. Fisher, B.A. Morgan, and the late W.P. Crowley were also working there. I am especially indebted to these men for their unselfish sharing of ideas. Any geologist who has worked in the central Appalachian Piedmont within the past two decades owes a great deal to C.A. Hopson, who was the first student of this area to look past the metamorphism and deformation into the origin of these ancient rocks. I am indebted to J.D. Pepper, W.P. Crowley, P.D. Muller, G.W. Fisher, David Gottfried, and in particular, A.A. Drake, Jr., for their constructive reviews of the manuscript. Drake's review resulted in a complete rewrite of the manuscript. I am also grateful to K.N. Weaver and the Maryland Geological Survey for the support of this work.

REGIONAL GEOLOGIC SETTING

The oldest rocks in the central Appalachian Piedmont are a complex of quartzofeldspathic gneisses, migmatites, gneissic granitic rocks, and sparse amphibolites collectively named the Baltimore Gneiss (Williams, 1892; Hopson, 1964; Crowley, 1976) and often referred to as the "basement complex." Baltimore Gneiss crops out in seven refolded "mantled gneiss domes" (Eskola, 1949; Hopson, 1964) in Maryland (fig. 1) and in similar occurrences in Pennsylvania and Delaware (Fisher and others, 1979). Radiometric age determinations indicate that the gneiss was strongly metamorphosed 1,000 to 1,300 m.y. ago (Tilton and others, 1958; Wetherill and others, 1966; Wetherill and others, 1968; Sinha and others, 1971; Grauert, 1972, 1974). Good descriptions of the gneiss and interpretations of its origin have been given by Hopson (1964), Southwick (1969), and Crowley (1976). The Baltimore Gneiss was uplifted sometime after the 1,000 to 1,300 m.y. event, eroded, submerged, and a sequence of rocks known as the Glenarm Group was deposited upon the old erosion surface. The gneiss was again metamorphosed and deformed during the Paleozoic, along with its cover rocks.

The Baltimore Gneiss is unconformably overlain by potassium-rich quartzite and quartz-rich schist of the Setters Formation (Hopson, 1964), which locally contains pelitic rocks and metaconglomerate (Fisher, 1971). The Setters is conformably overlain by the Cockeysville Marble (Choquette, 1960; Hopson, 1964; Crowley, 1976), a unit consisting of metalimestones and metadolostones that is divisible into several mappable members (Crowley and others, 1976). Conformably overlying the Cockeysville with gradational contact is a sequence of pelitic schist and lesser amounts of metagraywacke called "lower pelitic schist" by Southwick and Fisher (1967), Southwick and Owens (1968), and Southwick (1969). Crowley (1976) divided this unit into the Loch Raven Schist and Oella Formation. The Setters Formation, Cockeysville Marble, Loch Raven Schist, and Oella Formation constitute the Glenarm Group as presently defined, and are thought to represent an autochthonous shelf sequence (Setters and Cockeysville) transitional into a deeper water clastic sequence (Loch Raven and Oella) of probably Early Paleozoic age.

Most of the rocks that lie structurally above the Loch Raven Schist and Oella Formation are now considered allochthonous and thus are not part of the Glenarm Group. This thick sequence of metamorphosed clastic metasedimentary rocks was formerly considered to constitute the major part of the old Wissahickon Formation (or Wissahickon Group of Crowley, 1976). It is now believed to be a complex sequence of stacked thrust sheets and melanges (pl. 2), probably similar in age and origin to the Manhattan Schist and Taconic thrust slices in New York and New England (A.A. Drake, Jr., written communication, 1982; Drake and Morgan, 1981). In addition, the Baltimore Complex, which was considered to be intrusive before the work of Crowley (1976), is now regarded as allochthonous (Crowley, 1976; Fisher and others, 1979; Drake and Morgan, 1981), as are the rocks of the James Run Formation.

ROCKS EXPOSED IN CECIL COUNTY

Only rocks exposed in Cecil County are described in this paper. For descriptions of rocks elsewhere in the Maryland Piedmont, see Hopson (1964), Southwick and Owens (1968), Crowley (1976), Fisher and others (1979), and Drake and Morgan (1981).

METASEDIMENTARY ROCK SEQUENCE

The metasedimentary rock sequence in Cecil County, formerly termed the Wissahickon Formation (Southwick and Fisher, 1967; Cleaves and others, 1968; Higgins and Fisher, 1971; Higgins, 1972), contains three distinct lithofacies: pelitic rocks, diamictite, and metagraywacke. Each of these lithofacies is further divisible into two or more subfacies. Because of structural and stratigraphic complications, as well as uncertainty of correlation among different outcrop belts, these subfacies have not been assigned formal names.

PELITIC LITHOFACIES

Pelitic rocks underlie large areas in Cecil County (pl. 1). These rocks are similar to those described as part of the "eastern sequence" of the Wissahickon Formation by Hopson (1964), and as the "lower pelitic schist" by Southwick and Fisher (1967) and Southwick (1969). The pelitic schists in Cecil County can be traced around the flank of the Mill Creek dome of Baltimore Gneiss a few miles (few kilometers) to the northeast in Pennsylvania and Delaware (Higgins and others, 1973; Gohn and others, 1974). Because of this, they are thought to be correlative with the Loch Raven Schist and parts of the Oella Formation in the upper part of the Glenarm Group in Baltimore County, as revised by Crowley (1976), and are probably autochthonous. However, the Cecil County rocks are separated from the Loch Raven and Oella by the Baltimore Complex.

PELITIC SCHIST

The pelitic schist in north-central Cecil County (pl. 1) is very poorly exposed, and most exposures are of weathered rock. In the few relatively fresh outcrops, it is a strongly crinkled, brownish- to silvery-gray, fine- to medium-grained quartz-biotite-plagioclase-muscovite schist[3] with opaque minerals as sparse accessories (table 1). It weathers to a reddish clayey soil containing quartz grains and flakes of muscovite. To the northeast, the schist appears to grade over a wide interval into pelitic gneiss by increase in grain size, increase in quartzofeldspathic segregations, and increase in abundance of pegmatite dikes and veinlets. These changes probably reflect an increase in metamorphic grade, but may also involve changes in chemical composition.

To the north and northwest, the pelitic schist is in contact with the Baltimore Complex (Higgins, 1977a). This contact is never well exposed, but appears to be sharp. Crowley (1976), Morgan (1977), and Fisher and others (1979) proposed that the contact is a fault. To the west the schist is in contact with the Conowingo diamictite, but the contact is unexposed. To the southeast, the schist is in contact with pelitic schist containing scattered stringers of amphibolite and with the pelitic gneiss unit.

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[3] Mineral modifiers are listed in order of increasing abundance in this paper.

TABLE I
MODAL ANALYSES OF ROCKS OF THE PELITIC LITHOFACIES,
CECIL AND HARFORD COUNTIES

	PELITIC LITHOFACIES											
	"Lower pelitic schist," Harford Co.		"Upper pelitic schist," Harford Co.			Pelitic schist, Cecil Co.		Pelitic gneiss, Cecil Co.			Pelitic schist with amphibolite, Cecil Co.	
	1	2	3	4	5	6	7	8	9	10	11	12
quartz	35.9	37.2	35.6	22.9	11.1	15.6	14.9	38.4	34.9	37.5	19.0	3.1
plagioclase	23.4	27.6	14.6	12.9	17.0	17.7	20.0	23.0	23.6	28.1	17.7	35.4
k-feldspar	-	-	-	tr	-	-	-	3.1	1.1	-	-	-
hornblende	-	-	-	-	-	-	-	-	-	-	-	51.8
muscovite	24.5	16.6	27.4	44.9	51.7	54.7	49.2	21.3	17.1	15.9	51.6	-
biotite	13.9	13.7	-	-	-	7.2	9.0	13.0	21.3	13.9	7.4	-
chlorite	0.1	-	16.9	9.3	16.5	1.2	4.7	-	-	-	0.6	1.6
calcite	-	-	0.7*	0.2*	tr	0.3	-	-	-	-	-	2.9
garnet	0.1	1.3	-	-	-	0.2	tr	0.4	1.7	1.4	tr	-
epidote	0.1	0.1	1.0	4.4	1.0	tr	-	-	-	0.1	0.2	2.6
allanite	-	-	-	-	-	-	-	-	-	-	-	-
apatite	0.4	0.2	0.3	0.6	0.5	tr	-	-	tr	-	-	-
sphene	-	-	-	-	-	-	-	-	-	-	-	0.2
tourmaline	-	0.3	-	0.2	0.1	0.1	0.2	tr	-	0.2	tr	-
monazite	-	-	-	-	-	-	-	tr	-	-	-	-
zircon	0.1	0.1	tr	0.1	0.1	0.1	tr	-	-	0.1	tr	-
magnetite	1.6*	2.9*	3.0*	4.3*	1.8*	2.3	-	0.8	0.3	2.8	0.6	1.9
hematite	-	-	-	-	-	0.2	1.9	-	-	-	2.8	0.5
others	-	-	0.8	0.2	0.2	0.4	0.1	-	-	-	0.1	-
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Points	1,455	1,432	1,530	1,476	1,527	1,000	1,000	1,000	1,000	1,000	1,000	1,000

* Minerals identified by Southwick (1969, p. 30, table 7) as *opaques*, *carbonate*, and *rutile* have here been listed as *magnetite*, *calcite*, and *others*, respectively.

1. From cut along Maryland Rte. 23 about 0.3 mile (0.5 km) west of bridge over east branch of Winters Run, Harford County. Analysis no. 1 of Southwick (1969, p. 30, table 7).
2. From small quarry near powerline on Boggs Road about 0.4 mile (0.6 km) west of Graftons Shop Road, Harford County. Analysis no. 2 of Southwick (1969, p. 30, table 7).
3. From tributary to Deer Creek south of Urey Road about 0.5 mile (0.8 km) east of Maryland Rte. 23, Harford County. Analysis no. 9 of Southwick (1969, p. 30, table 7).
4. From Falling Branch at Kilgores Rocks, Harford County. Analysis no. 10 of Southwick (1969, p. 30, table 7).
5. From large outcrop opposite Amoss Mill on Island Branch about 2 miles (3 km) east of Norrisville, Harford County. Analysis no. 11 of Southwick (1969, p. 30, table 7).
6. Fresh chip of cuttings from water well in field on northwest side of Maryland Rte. 274 about 900 ft (275 m) northwest of Wilson Road, approximately 0.8 mile (1.3 km) north of Farmington, Cecil County.
7. Chip of cuttings from water well on north side of Maryland Rte. 273 about 2,500 ft (760 m) west of Sylmar Road, approximately 1.5 miles (2.4 km) east of Rising Sun, Cecil County.
8. From outcrop on east bank of Big Elk Creek about 1 mile (1.6 km) north of Maryland Rte. 273, approximately 1.5 miles (2.4 km) northwest of Appleton, Cecil County.
9. From outcrop on west bank of Big Elk Creek about 1.5 miles (2.4 km) north of Maryland Rte. 273, approximately 2 miles (3.2 km) northwest of Appleton, Cecil County.
10. From outcrop on southeast side of Indian Trail Road at Little Elk Creek, approximately 1.5 miles (2.4 km) northwest of Rock Church, Cecil County.
11. Schist from outcrop on southeast side of Crothers Road about 900 ft (275 m) west of Northeast Creek, approximately 1.25 miles (2 km) northeast of College Green, Cecil County.
12. Amphibolite from large piece of float about 150 ft (45 m) north of Pettyjohn Road and 3,000 ft (900 m) west of Northeast Creek, approximately 1 mile (1.6 km) northeast of College Green, Cecil County.

Fresh outcrops of pelitic schist are limited to the valley of Northeast Creek and to the fairly deep cut of the abandoned line of the old Pennsylvania Railroad south of Rising Sun (pl. 1). In all outcrops the schist is strongly crinkled. Most outcrops also show a crosscutting cleavage.

In thin section, the schist shows an unlayered, strongly schistose but wavy texture, in which brown biotite and muscovite weave around quartz grains and grains of sodic plagioclase ($An_{12\text{-}38}$)[4]. Scattered opaque minerals appear to be magnetite. Table 1 gives modal analyses of two fresh samples of the pelitic schist and other schists in Cecil and Harford Counties.

PELITIC SCHIST WITH AMPHIBOLITE

Pelitic schist, identical with the pelitic schist described above but containing scattered amphibolite stringers, bears similar contact relations with other facies of the metasedimentary sequence. In addition, it is in possible thrust contact with metagraywacke facies rocks to the southeast (pl. 2). Contacts with the James Run Formation are not well exposed.

The amphibolites in this unit are fine-grained quartz-plagioclase-hornblende amphibolites. Plagioclase generally ranges from albite to andesine ($An_{9\text{-}36}$), but most is oligoclase. Rare grains as calcic as An_{54} occur. The hornblende is dark green and the quartz occurs in irregularly shaped grains about the same size as the plagioclase. Hornblendes are aligned in two directions in a strongly lepidoblastic texture. Tiny grains of magnetite are scattered throughout the matrix. Table 1 gives modal analyses of the schist and amphibolite in this subfacies.

PELITIC GNEISS

Pelitic gneiss forms a southwestward-curving outcrop belt along the Pennsylvania border from Delaware to about 2 miles (3.2 km) southeast of the town of Calvert in north-central Cecil County (pl. 1). In fresh outcrops, the gneiss is a lustrous, brown, medium- to coarse-grained, layered, strongly schistose rock riddled with quartzofeldspathic and aplitic segregations and cut by numerous pegmatite veins and veinlets. It is generally a muscovite-biotite-quartz-plagioclase gneiss, but locally has abundant, dark-red, 1/8- to 1/4-inch (~3 to 5 mm) garnets. The gneiss commonly has two or more cleavages in addition to the strong schistosity and streaking. Bascom and Miller (1920) mapped this rock as Baltimore Gneiss, but it has since been shown to be part of the metasedimentary cover sequence (Higgins and others, 1973; Gohn and others, 1974). The gneiss weathers to a red-brown, clayey saprolite containing abundant vein quartz fragments and fairly abundant quartz grains.

In thin section, the pelitic gneiss shows lepidoblastic to granoblastic textures. Commonly, reddish-brown biotite laths and lesser amounts of muscovite laths weave in and out among elongate, interlocked grains of plagioclase and quartz. Plagioclase is generally oligoclase. In some sections, small grains of potassium feldspar, probably microcline, are scattered throughout the groundmass. Garnets appear to have been rolled, and some have helicitic textures. Tiny grains of magnetite are seen in some sections. Table 1 gives modal analyses of some fresh samples of the pelitic gneiss.

The contacts of the pelitic gneiss appear to be gradational with other units of the pelitic facies. The gneiss is apparently in sharp contact with Baltimore Complex rocks south of the town of Lombard (pl. 1), although the contact is not exposed. Fresh outcrops of the pelitic gneiss are fairly abundant along the several creeks that cross its outcrop belt, and particularly good outcrops are found along Big Elk Creek. The pelitic gneiss outcrop belt appears to widen to the east and northeast in Pennsylvania and Delaware. The metamorphic grade also becomes higher in that direction; kyanite crystals are locally present in the gneiss just across the state line in Pennsylvania.

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[4] Plagioclase compositions were determined optically unless otherwise stated.

DIAMICTITE LITHOFACIES

Diamictite crops out in two belts in Cecil County (pl. 1). In the northwestern corner of the County, diamictite forms a small, wedge-shaped outcrop belt that appears to be faulted out a short distance to the northeast in Pennsylvania. This outcrop belt is a continuation of the diamictite that defines the northeastern nose of the Baltimore-Washington anticlinorium in Harford County (Southwick and Owens, 1968; Southwick, 1969; fig. 1, this paper). This is probably the same unit that outlines and defines the anticlinorium to the southwest in Baltimore, Carroll, Howard, and Montgomery Counties, Maryland, and in northern Virginia, where it is called the Sykesville Formation (Hopson, 1964; Fisher, 1970; Higgins, 1972; Crowley, 1976; Fisher and others, 1979; Drake and Morgan, 1981). The diamictite in Howard, Carroll, and Montgomery Counties has been mistaken for granite and was called "Sykesville Granite" by Keyes (1895), Jonas (1928), Cloos and Broedel (1940), and Stose and Stose (1946). Cloos (Cloos and Cooke, 1953) became convinced of its sedimentary origin while mapping in Montgomery County and designated it the Sykesville Formation. Fisher (1963) and Hopson (1964) presented evidence for a sedimentary origin and added the Sykesville Formation to the Glenarm Series (now referred to as the Glenarm Group). Fisher (1963) also recognized that similar rocks in eastern Howard and Montgomery Counties, called Laurel Gneiss by Chapman (1942), are sedimentary in origin and correlated these rocks with the Sykesville. Hopson (1964, p. 112-114) renamed the eastern unit the Laurel Formation and considered the Sykesville and Laurel to be "...stratigraphic equivalents that outline the southward-plunging nose of the Baltimore-Washington anticlinorium." Southwick and Fisher (1967) demoted the Sykesville and Laurel Formations to a single lithofacies of the Wissahickon Formation, chiefly because of Southwick's mapping in Harford County (Southwick and Owens, 1968; Southwick, 1969), and suggested that not all the diamictite there is at the same stratigraphic level as the Sykesville and Laurel diamictite belts. Higgins and Fisher (1971) changed the name of Southwick and Fisher's (1967) "boulder gneiss lithofacies" to the diamictite facies of the Wissahickon, but followed the same concept as did Southwick and Fisher. Crowley (1976; Crowley and others, 1976) proposed that the name Sykesville Formation be readopted for the diamictites in the Sykesville and Laurel outcrop belts. Drake and Morgan (1981) followed Crowley and reinstated Sykesville Formation for the diamictites in northern Virginia as well as in Maryland. Therefore, Sykesville Formation is used in this paper for the northwesternmost belt of diamictite in Cecil County and for the diamictites along strike to the southwest in Maryland and Virginia.

The second belt of diamictite in Cecil County is located southeast of the Baltimore Complex from the vicinity of Conowingo Dam to just south of the town of Rising Sun (pl. 1), and is informally called the "Conowingo diamictite." The unit is well exposed on the northeast side of the Susquehanna River downstream from Conowingo Dam for approximately 3 miles (4.8 km) to the southeast. The most spectacular exposures are found along the river, under and around the large powerlines just downstream from the dam, but excellent exposures are also found along Octoraro Creek northeast of Rowlandsville. This belt of diamictite extends to the southwest into Harford County for several miles (several kilometers). Included in this unit is an unusual zone of quartz-bearing mafic rocks that were mapped as quartz gabbro and quartz diorite by most earlier workers, and which they associated with the mafic and ultramafic rocks that I have mapped as Baltimore Complex.

Like the diamictites to the southeast in the Maryland Piedmont, all the diamictites in Cecil County and adjacent Harford County had been mistaken for plutonic rocks (Grimsley, 1894; Leonard, 1901; Bascom, 1902; Hershey, 1936, 1937; Cloos and Hershey, 1936) and called Port Deposit Granite or Port Deposit Granodiorite. Hopson (1960, p. 31-32) suggested that some of these rocks along the Susquehanna River just below Conowingo Dam are sedimentary in origin. Later mapping by Southwick (Southwick and Owens, 1968) showed a thin belt of "boulder gneiss," about 1,300 ft (400 m) thick, just below the dam on the southwestern side of the Susquehanna in Harford County. Southwick (Southwick and Owens, 1968) also mapped the Sykesville Formation in Harford County as "boulder gneiss." My mapping has extended the

Sykesville Formation into Pennsylvania and has expanded the area underlain by Conowingo diamictite (pl. 1).

Hopson (1964, p. 101, 103) and Fisher (1970, p. 303) estimated the thickness of the Sykesville Formation in Montgomery County to be as much as 15,000 ft (4,600 m). About 7,000 ft (2,100 m) of Sykesville diamictite and as much as 13,000 ft (4,000 m) of Conowingo diamictite are exposed in Cecil County. Both diamictites have been divided into coarse-grained and fine-grained lithologies (pl. 1).

CONOWINGO DIAMICTITE

Coarse-grained

Called "boulder gneiss lithofacies" by Southwick and Fisher (1967), the spectacular coarse-grained part of the Conowingo diamictite superficially resembles a weakly foliated granite, but the unit contains abundant grains, granules, and scattered pebbles of quartz, as well as chips, blocks, and slabs of quartz, quartzite, granofels, gneiss, schist, graywacke, amphibolite, and calc-silicate rock (figs. 2-4). Locally, slabs as long as 325 ft (100 m) are present in the coarse-grained diamictite.

Many of the gneiss, granofels, and amphibolite clasts in the coarse-grained diamictite (fig. 3) are lithic matches of metavolcanic rocks in the James Run Formation (Fisher and others, 1979), and some of the granitic clasts appear to be of Port Deposit Gneiss. Most of the clasts in the diamictite, including clasts thought to be derived from the James Run Formation and Port Deposit Gneiss, appear to have been mildly metamorphosed and deformed before their incorporation in the diamictite (also see Hershey, 1936). Many of the quartz grains in the Conowingo are blue, and interestingly, many quartz grains in the James Run volcanic-epiclastic rocks are also blue.

The Conowingo diamictite is generally massive and poorly bedded. Over large areas, no bedding or layering are visible at all, but in a general way the exotic blocks appear to be concentrated along definite zones or lenses. The coarse-grained diamictite commonly forms good outcrops, even on hilltops. Where it is deeply weathered, it forms a gray, quartz-rich saprolite in which scattered, weathered fragments of the rock clasts are locally recognizable.

Mineralogically, the coarse-grained diamictite is very similar to the Sykesville and Laurel gneisses described by Hopson (1964, p. 107, 115) and to some of the diamictite in Harford County described by Southwick (1969, p. 34) as "boulder gneiss" and metagraywacke. The only difference is in the potassium feldspar content (table 2). The coarse-grained Conowingo diamictite has a relict clastic texture, in which quartz occurs as relict clastic grains, tiny matrix grains, and rounded aggregates of two or more grains. Hopson (1964, p. 106) stated of the diamictite in the Sykesville Formation:

> There is no difference, other than grain size, between the clastic quartz grains seen in thin section and the quartz "lumps" so conspicuous in outcrop. Moreover, there are all gradations in size between them. It is evident that the quartz lumps are relict pebbles and granules, in a partly sandy matrix.

Plagioclase in the diamictite shows three forms similar to those described by Hopson (1964) in the Sykesville Formation: (1) Relict, rounded, clastic grains that have few inclusions but are commonly clouded by sericite and tiny grains of epidote or clinozoisite. Zoning or twinning has been broken or rounded off in many of these grains, and some have new overgrowths on the old clastic grains. This relict plagioclase generally ranges from albite to oligoclase (An_{10-29}), but a few grains as calcic as An_{50} were seen. The overgrowths on relict grains are commonly albite. (2) Newly formed, commonly untwinned, unaltered and unclouded porphyroblasts of albite or sodic oligoclase (An_{7-17}) that are strongly sieved and have irregular, amoeba-form shapes with arms that project into the matrix. These are the least common. (3) Tiny, granoblastic grains in the matrix that range from albite to sodic oligoclase (An_{9-16}).

FIGURE 2: Conowingo diamictite, coarse-grained facies. The granular texture of the matrix is due chiefly to granules and rounded grains of quartz. Clasts of graywacke, pelitic rock, and quartzite are seen to the left of the hammer, and a quartz "lump" is above the pick-point. Black material on rock in lower left is asphalt. Outcrop along Octoraro Creek 1 mile (1.6 km) northeast of Rowlandsville and about 200 ft (60 m) downstream from the powerline crossing.

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

Polygranular aggregates of feldspar, quartz, or both are fairly common in the diamictite. These are granules of rounded rock fragments in what was a pelitic-psammitic matrix. Also present are tiny slab- and lens-shaped fragments of biotite schist and graywacke or of quartzite and biotite schist.

The micas in the diamictite are similar to those described by Hopson (1964, p. 108) and Southwick (1969, p. 34). Muscovite, in fine flakes and as sericite concentrations, is the most prevalent micaceous mineral (table 2), followed by clusters of biotite and chlorite.

Magnetite is the most common accessory mineral in the Conowingo diamictite and accounts for the high magnetic susceptibility of the unit (Fisher and others, 1979).

FIGURE 3: Conowingo diamictite, fine-grained facies. Some of the clasts are aligned parallel to the general fabric of the matrix, whereas others lie at an angle to it. Clasts above the hammer head are of interlayered granofels and amphibolite and are interpreted as having been derived from the James Run Formation. Outcrop about 50 ft (16 m) south of the locality of figure 2.

Fine-grained

The rocks mapped as the fine-grained part of the Conowingo diamictite are essentially similar to the coarse-grained diamictite, but have a finer grained matrix and markedly less abundant clasts of pebble size or larger.

There has been controversy about some of the rocks I mapped as fine-grained Conowingo diamictite southeast of the large lens of coarse-grained diamictite below Conowingo Dam. These rocks were considered plutonic, or metaplutonic, by Grimsley (1894), Bascom (1902), Bascom and others (1902), Hershey (1936, 1937), Cloos and Hershey (1936), Hopson (1960), and Southwick (1969; Southwick and Owens, 1968). I (Higgins, 1972; and pl. 1, this paper) considered all the rocks along the Susquehanna River between Conowingo Dam and Sterret Island to be metasedimentary, whereas Southwick (1969; Southwick and Owens, 1968) had mapped most of the "granitic" rocks across the Susquehanna River in Harford County as metaplutonic Port Deposit Gneiss. This conflict spurred Southwick to remap and restudy the rocks on both sides of the river (Southwick, 1979). The results of this new effort, reproduced here in figure 5, are in only partial agreement with the geologic map of Cecil County (pl. 1). We now agree that the rocks along the river from about 3,000 ft (900 m) northwest of Sterret

FIGURE 4: Calc-silicate inclusion in the Conowingo diamictite exposed along the railroad tracks of the CONRAIL System about 300 ft (90 m) south of Conowingo Dam.

Island, labeled **a** in fig. 5, are diamictites of one kind or another. The two belts of rocks labeled **b** and **c** in figure 5 are open to question.

Southwick (1979, p. 106) described his unit **b**, "medium-grained gneissic biotite quartz diorite," as follows:

> Somewhat metamorphosed biotite quartz diorite, locally with hornblende also, occurs in a belt about 1 km wide south of Shures Landing in Harford County. It contains less quartz and muscovite, and more plagioclase and biotite, than the quartz augen gneiss (unit c) which it otherwise resembles closely. Moreover, it possesses well-preserved hypidiomorphic-granular texture with subhedral zoned plagioclase, wedge-shaped volumes of interstitial quartz..., and scattered euhedral crystals of zoned allanite.... The southern contact of this material against diamictite is indistinct and difficult to map precisely with the available exposure.

Southwick goes on to describe his unit **c**, "quartz augen gneiss":

> Oval grains of blue-gray quartz on the order of 5-10 mm long constitute about 20-25% of this rock; the remainder is plagioclase, biotite, finer grained quartz, and muscovite together with variable small amounts of iron-poor epidote and garnet. Foliation ranges from strong to barely detectable. In well foliated rocks particularly the quartz grains resemble clastic granules; in less foliated rocks the hand specimen appearance is more "granitic."

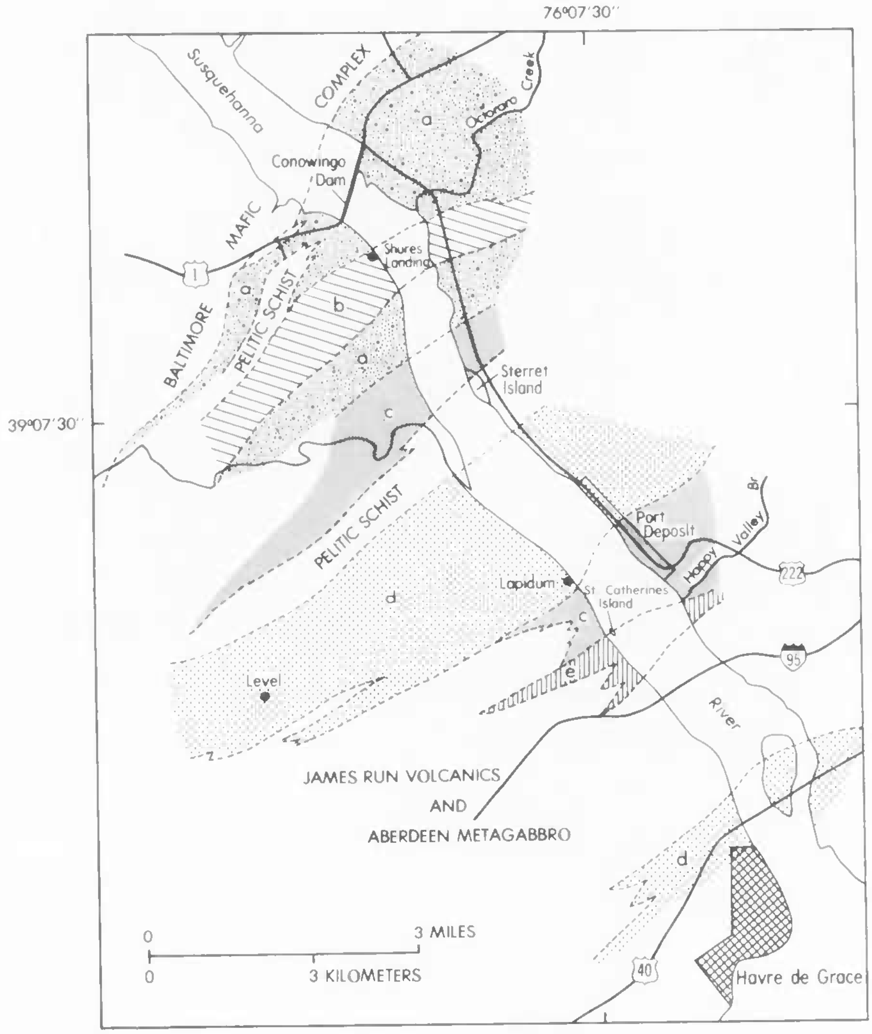

FIGURE 5: Distribution of rock types along the Susquehanna River in Cecil and Harford Counties, as reinterpreted by Southwick (1979).

a: diamictite
b: medium-grained, gneissic biotite-quartz diorite
c: quartz augen gneiss
d: coarse-grained, highly foliated biotite-quartz-plagioclase gneiss
e: massive porphyritic leucogneiss

Southwick (1969, p. 106, 115-116) concluded that his unit **b**, "biotite quartz diorite," is probably metaplutonic and (1979, p. 114-116) that the "quartz augen gneiss" of his unit **c** might be metamorphosed trondhjemite. His evidence for the biotite quartz diorite being metaplutonic consists of the following: (1) It is slightly different mineralogically and texturally from the diamictites on either side. (2) It has zoned, subhedral plagioclases with interstitial, wedge-shaped, polycrystalline masses of quartz. (3) It has scattered, euhedral crystals of zoned allanite. His evidence for the quartz augen gneiss being metaplutonic consists of its lithologic and chemical similarities to altered, metamorphosed, and deformed trondhjemites in Minnesota and New Mexico.

TABLE 2
MODAL ANALYSES OF ROCKS OF THE DIAMICTITE LITHOFACIES, CECIL AND HARFORD COUNTIES

	DIAMICTITE LITHOFACIES											
	1	2	3	4	5	6	7	8	9		10	
quartz	45.9	46.2	45.4	44.6	40.1	38.1	37.3	33.4	7.1	45.3	MATRIX	49.4
plagioclase	26.2	33.2	35.1	23.9	17.1*	17.9	20.8	26.5	41.7	34.3	QUARTZ GRANULES	18.8
k-feldspar	0.4	0.4	0.9	-	-	-	-	-	-	1.8	ROCK FRAGMENTS	15.7
muscovite	12.5	8.8	2.9	15.5	32.7	23.2	24.4	19.3	23.0	3.5	RELICT PLAGIOCLASE	16.1
biotite	8.2	6.9	10.3	5.6	6.1	-	11.2	7.1	0.6	12.1		
chlorite	5.3	3.0	-	7.2	2.1	15.2	4.1	7.5	16.9	1.4	Total	100.0
calcite	tr	-	tr	-	-	-	-	0.2*	-	-		
garnet	0.1	0.1	1.9	-	0.1	-	-	-	-	0.4	MATRIX FRACTION	
epidote	0.4	0.6	1.0	1.6	-	2.0	1.0	0.5	1.5	0.3	quartz	44.3
allanite	-	-	-	-	-	-	-	-	-	-	plagioclase	40.0
apatite	-	-	-	-	tr	0.1	-	0.1	0.3	-	new plagioclase	1.2
tourmaline	tr	-	-	-	-	0.1	-	0.1	-	-	(overgrowths on relict grains)	
monazite	-	-	-	-	-	-	-	-	-	-	biotite	11.8
zircon	-	tr	-	-	tr	tr	-	tr	tr	-	muscovite	2.7
magnetite	tr	tr	-	-	1.6*	3.4*	tr	5.1*	8.8*	-		
hematite	-	-	-	-	-*	-*	-	-*	-	-	RELICT PLAGIOCLASE	
clinozoisite	0.2	0.2	0.5	-	-	-	-	-	-	-	FRACTION	
others	0.8	0.6	2.0	1.6	0.2	-	1.2	0.2*	-	0.9	plagioclase	74.1
											muscovite and sericite	24.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	epidote	1.7
Points	1,500	1,000	1,440	1,254	1,493	1,391	1,000	1,511	1,577	1,609		

* Minerals identified by Southwick (1969, p. 30, table 7) as *opaques*, *carbonate*, and *rutile* have here been listed as *magnetite*, *calcite*, and *others*, respectively.
1. Average of 10 modal analyses of Conowingo diamictite from Cecil County, each with more than 1,500 points.
2. From outcrop beneath the powerline that crosses Octoraro Creek about 5,000 ft (1.5 km) northeast of Rowlandsville, Cecil County.
3. From outcrop along CONRAIL System about one mile (1.6 km) south of Octoraro Creek, Cecil County.
4. From Susquehanna River below Conowingo Dam, Cecil County; Peters Creek Formation analysis no. 4 of Hopson (1964, p. 118, table 30). Opaques listed here as magnetite.

(Continued next page, bottom)

I concede that some of the rocks along the Susquehanna River south of Octoraro Creek that I mapped as fine-grained diamictite (unit **b** of Southwick, 1979) may be partly of igneous origin. However, they may not be strictly plutonic. The zoned, subhedral plagioclases in these rocks (Southwick, 1979, fig. 3) are strikingly similar to plagioclase phenocrysts and broken phenocrysts in many of the James Run Formation metavolcanic, metavolcaniclastic, and metasubvolcanic rocks (Marshall, 1937; Higgins, 1972, p. 1000-1002, fig. 10) and to phenocrysts in volcanic and subvolcanic rocks elsewhere. Moreover, this "quartz diorite" as described by Southwick (1979) is similar in texture, mineralogy, and composition to other "quartz diorites" such as the Norbeck quartz diorite and related rocks to the southwest in the Maryland Piedmont (Hopson, 1964). Higgins (1972) and Crowley (1976) presented evidence that many of these rocks are either submarine slide deposits composed largely of volcanogenic debris or complexes of metasubvolcanic rocks, metavolcanic rocks, and shallow hypabyssal plutons genetically related to and of approximately the same age as the metavolcanic rocks. Perhaps this is also true for the "biotite quartz diorite" south of Octoraro Creek. Alternatively, these quartz diorites may be megaclasts, or "knockers," within the diamictite (see Drake and Morgan, 1981).

I must also concur with Southwick (1979) that many of the quartz augen gneisses in his unit c northwest of Sterret Island may indeed be metamorphosed plutonic rocks that were mistakenly identified as diamictite. However, some of the finer grained diamictites (including fine-grained diamictites within the coarse-grained diamictites), the metavolcanic and metasubvolcanic rocks, and the metaplutonic rocks are so similar in the field that, unless one had virtually continuous thin sections, the assignment of origin to these rocks is extremely difficult. Moreover, some of these rocks may be megaclasts within diamictites. I suspect that unit c contains more than one rock type.

Mafic zone

Some of the most perplexing rocks in the Piedmont of Cecil County are those I mapped as the mafic zone of the Conowingo diamictite (pl.1). This unit forms an outcrop belt about 700 ft (210 m) wide and 7.5 miles (12 km) long between Rising Sun and the Susquehanna River near Conowingo Dam, and occurs between the gabbroic rocks of the Baltimore Complex and the main mass of the Conowingo diamictite, including both the coarse-grained and fine-grained facies. The mafic zone consists of a heterogeneous mixture of quartz-bearing mafic rocks and rocks that appear to be intermediate between gabbroic igneous rocks and mafic metasedimentary rocks. In addition, occurrences of mafic breccia occur locally within the unit.

Rocks of the mafic zone of the Conowingo diamictite were considered to be associated with rocks of the Baltimore Complex by most previous workers. Leonard (1901) called them "quartz-mica-hornblende dioryte" or "tonalyte" and emphasized their quartz-rich character. Bascom and others (1902) referred to these rocks as "quartz-hornblende gabbro." Modal analyses of "quartz gabbros" and "quartz diorites" from Harford County (Southwick, 1970, p. 408, table 4) show that some of these rocks carry significant amounts of quartz, ranging up to as much as 20.2 percent. Blebs of blue quartz, which are very conspicuous in some of the

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(TABLE 2, continued)

5. From Susquehanna River below Conowingo Dam, Cecil County; Peters Creek Formation analysis no. 5 of Hopson (1964, p. 118, table 30). Opaques listed here as magnetite.
6. From outcrop on Maryland Rte. 623 about 0.5 mile (0.8 km) southeast of Broad Creek, Harford County; metagraywacke bed in Wissahickon boulder gneiss, analysis no. 3 of Southwick (1969, p. 30, table 7).
7. From roadcut on Prospect Road near Mill Green, Harford County; Wissahickon boulder gneiss analysis no. 4 of Southwick (1969, p. 30, table 7). Zoisite included here with epidote.
8. From outcrop near Walters Mill Road about 0.25 mile (0.4 km) northwest of Walters Mill, Harford County; Wissahickon boulder gneiss analysis no. 5 of Southwick (1969, p. 30, table 7). Zoisite included here with epidote.
9. From outcrop on Deer Creek about 0.65 mile (1.0 km) northwest of Sandy Hook, Harford County; Wissahickon boulder gneiss, highly contorted and plagioclase-rich, analysis no. 6 of Southwick (1969, p. 30, table 7).
10. Detailed modal analysis of Conowongo diamictite from railroad cut of CONRAIL System along the Susquehanna River about 1.5 mile (2.4 km) south of Octoraro Creek, Cecil County.

rocks of the mafic zone, appear identical to blue quartz blebs in the Conowingo diamictite at many localities in Cecil County. Moreover, in some mafic zone rocks these quartz blebs appear to be relict granules made up of more than one quartz grain. Many are rounded or subrounded like the quartz granules in the diamictites and are unlike the small, irregularly shaped interstitial quartz masses of many quartz gabbros (Southwick, 1970, p. 408). In other words, they appear to be relict detrital grains and rock fragments despite the mafic matrix.

Rocks similar to the mafic zone of the Conowingo diamictite have been mapped in the same tectonostratigraphic position in Harford County (Southwick and Owens, 1968) where they were called "quartz gabbro and quartz diorite gneiss." Southwick (Southwick and Owens, 1968) traced this unit southwest from the Susquehanna River for a distance of about 7 miles (11 km). This zone was described by Southwick (1969, p. 60-61) as follows:

> 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.... 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 injections of phases of 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.

In Cecil County, however, these rocks are in contact on the southeast with the Conowingo diamictite and not with the Port Deposit Gneiss (pl. 1, and fig. 5). This has been confirmed by the more recent work of Southwick (1979). The rocks of the mafic zone appear to grade into the Conowingo diamictite on the southeast, and approximately at the point where the diamictite pinches out in the vicinity of Rising Sun, the mafic zone also pinches out. An identical situation was mapped along strike to the southwest in Harford County by Southwick (Southwick and Owens, 1968). A long, narrow belt of "Wissahickon Formation, undivided" extends for 7.5 miles (12 km) from the Susquehanna River to just southeast of the village of Thomas Run along the southeastern side of the "quartz gabbro and quartz diorite gneiss," a rock unit that corresponds to the mafic zone of the Conowingo diamictite. Southwick (Southwick and Owens, 1968) described the "Wissahickon Formation, undivided" as "mica schist, chlorite schist, boulder gneiss, and micaceous quartzite occurring as septa between and inclusions within post-Glenarm igneous intrusions." He also mapped amphibolite lenses in this belt of rocks and lenses of "Wissahickon Formation, undivided" within the belt of "quartz gabbro and quartz diorite gneiss." My reconnaissance work in Harford County and Southwick's (1979) later work indicate that the rocks of the "Wissahickon Formation, undivided" belong to the Conowingo diamictite. Where this diamictite belt pinches out in Harford County, southeast of Thomas Run, the belt of "quartz gabbro and quartz diorite gneiss" also pinches out, just as it does near Rising Sun in Cecil County. This strongly suggests that these two belts of rock are related.

The two most difficult contacts of the Conowingo diamictite to define in Cecil County are the contact between the mafic zone and the main body of the diamictite to the southeast, and the contact between the mafic zone and the gabbro unit of the Baltimore Complex to the northwest. Near the contact with the diamictite in Cecil County, the mafic zone rocks contain as much as 35 percent quartz. In addition, rocks that clearly belong to the Conowingo diamictite along its northwestern contact with the mafic zone are more mafic than "normal" diamictites elsewhere in the Maryland Piedmont. Leonard (1901, p. 137, 141, 172-174) gave good descriptions of the transitional nature of both the northwestern and southeastern contacts of the mafic zone. Hershey (1937, p. 143) also noted the gradational contact between the Baltimore Complex and the Conowingo diamictite (which he mapped as Port Deposit granodiorite), and stated: "The hornblende content of the granodiorite, which in this locality appears to increase toward the contact, suggests a mixing of the two rock types." On the geologic map of Cecil County (pl. 1), the northwestern contact of the mafic zone was arbitrarily placed at the last appearance of quartz grains that are visible to the naked eye. The southeastern contact was placed where diamictite-appearing rocks have a greenish matrix in outcrop owing to abundant chlorite or amphibole.

Together, the mafic zone and the Conowingo diamictite have all the characteristics of a melange (Silver and Beutner, 1980; Drake and Morgan, 1981). All who have studied these rocks have noted that they are a heterogeneous mixture of a wide variety of rock types. In fact, this zone contains more clasts of different rock types than is known for any outcrop of diamictite of the Sykesville Formation in Maryland. Many of these clasts appear to have been derived from the James Run Formation.

Mafic breccia

Spectacular mafic breccias crop out locally within the mafic zone of the Conowingo diamictite (also see Hershey, 1937, p. 143). These breccias are composed of clasts of amphibolite and metagabbroic rocks that range in size from a few inches to several feet (few centimeters to several meters) in a matrix resembling slightly mafic diamictite. One particularly good exposure of mafic breccia is in the bluffs along the northeast side of Octoraro Creek just southwest of where U.S. Rte. 1 crosses the creek (pl. 1).

SYKESVILLE FORMATION

Like the Conowingo diamictite, diamictites of the Sykesville Formation in the relatively narrow, wedge-shaped area in northwestern Cecil County have also been divided into coarse-grained and fine-grained units (pl. 1). These rocks are essentially identical with the Conowingo diamictite, but with two important differences: (1) they are virtually devoid of potassium feldspar; and (2) they contain a fair amount of large and small size clasts of ultramafic rocks. Excellent descriptions of these rocks have been given by Hopson (1964), Southwick (1969), and Drake and Morgan (1981).

The diamictites of the Sykesville Formation have been interpreted as olistrostromes (Hopson, 1964; Southwick and Fisher, 1967; Southwick, 1969; Fisher, 1970; Higgins and Fisher, 1971; Higgins, 1972; Crowley, 1976; Fisher and others, 1979). More recently, they have been considered to be a precursory ophiolitic melange that is dominantly olistrostromal in aspect (Drake and Morgan, 1981, p. 492-493).

METAGRAYWACKE LITHOFACIES

METAGRAYWACKE

Interbedded pelitic schists, metasiltstones, and metagraywackes, hereafter collectively referred to simply as metagraywacke, crop out in two separate outcrop belts in Cecil County. One belt forms a narrow arc across the northeastern part of the County (pl. 1), and has been traced for about one mile (1.5 km) into Delaware. These rocks are best exposed in the valleys of streams that cut across their outcrop belt. The metagraywackes appear to have sharp contacts (possibly fault contacts) with pelitic gneiss and pelitic schist with amphibolite of the metasedimentary rock sequence to the north and against units of the James Run Formation to the south (pl. 2). The second belt of metagraywacke underlies the northwestern corner of Cecil County and extends along strike to the northeast into Pennsylvania (pl. 1). To the southwest in Harford County, these rocks have been mapped as the "metagraywacke facies of the Wissahickon Formation" (Southwick and Owens, 1968), and are shown as grading along strike into the "lower pelitic schist of the Wissahickon Formation" (Southwick and Owens, 1968;

Southwick, 1969). In Cecil County, this unit is best exposed in the railroad cuts along the gorge of the Susquehanna River and in its tributary stream valleys.

The metagraywacke sequences commonly consist of graded metagraywacke and metasiltstone beds, which range in thickness from about 1 ft (30 cm) to about 8 ft (2.5 m), and are interbedded with sections of approximately the same thickness of finely laminated pelitic schist. Many of the metagraywacke beds have sharp contacts with underlying pelitic sections, but grade upward with diffuse contacts into overlying pelitic beds (fig. 6, and see Hopson, 1964) and thus give good facing criteria. Flame structures are relatively common at the bases of the metagraywacke beds.

METAGRAYWACKE WITH AMPHIBOLITE

Metagraywackwe sequences containing thin stringers of amphibolite form an outcrop belt that wraps around the Port Deposit Gneiss (pl. 1). In this belt, psammitic beds of metamorphosed graywacke, subgraywacke, and quartzose graywacke are rhythmically interbedded with pelitic schist and quartzose pelitic schist sections. In most outcrops, beds of psammitic rocks and sections of pelitic schist are remarkably uniform in thickness, ranging from about 2 ft to 6 ft (~60 to 180 cm); laminae within schist sections are generally less than $^1/_{16}$ inch (1 mm) thick. These rocks display a wide variety of original sedimentary features, including spectacular pull-aparts and slump structures. Their most characteristic feature in Cecil County, however, is the ubiquitous presence of large crystals of staurolite, $^3/_4$ to $2^1/_2$ inches (~2 to 6 cm) long, that have been altered to sericitic "shimmer aggregates" and smaller crystals of green chloritoid, $^1/_8$ to $^5/_{16}$ inch (~3 to 8 mm) long. Garnets, as large as $^3/_8$ inch (~1 cm) with rims altered to chlorite, are also fairly common in the metagraywacke-with-amphibolite unit.

In addition to a well-developed bedding plane schistosity, the rocks of the metagraywacke-with-amphibolite unit display classic strain-slip cleavage (fig. 7). The best exposures of structural, sedimentary, and mineralogical features in the metagraywackes are along both sides of the bridge on the road leading south from Colora (pl. 1). The best examples of altered staurolite crystals are found in the valley of Basin Run, just south of Liberty Grove.

Both the metagraywacke layers and the pelitic layers in the metagraywacke-with-amphibolite unit show strong lepidoblastic textures in thin section. This is also true of the amphibolite stringers in the unit. The metagraywackes consist of quartz, plagioclase (generally oligoclase), muscovite, and large laths of bent and twisted green biotite (table 3). The pelitic layers are composed of biotite, muscovite, and quartz, and minor magnetite (table 3). The amphibolites are identical with amphibolites in the pelitic schist-with-amphibolite unit.

The contact of the metagraywacke-with-amphibolite unit with the Port Deposit Gneiss appears to be very sharp from the Susquehanna River to about Principio Creek. To the northeast, in the general vicinity of Cathers Corner (pl. 1), rocks identical with the Port Deposit Gneiss occurs as lenses within the metagraywacke as far as about 2,500 ft (760 m) east of the "main" contact between the metagraywacke-with-amphibolite unit and the Port Deposit. The metagraywacke-with-amphibolite unit appears to pinch out near Battle Swamp and is missing southeast of the Port Deposit Gneiss in the area between the Susquehanna River and the long tongue of upland gravel along Maryland Rte. 275.

In Harford County, directly along strike with the metagraywacke-with-amphibolite unit, Southwick (Southwick and Owens, 1968) mapped a unit of "Wissahickon Formation, undivided" that contains amphibolite. This belt of rocks appears to pinch out near Bramblewood, about 8 miles (13 km) southwest of the Susquehanna River.

MAFIC BRECCIA

A mafic breccia, completely surrounded by rocks of the metagraywackwe-with-amphibolite unit, crops out between Principio Road and Post Road, about half a mile (804 m) southwest of College Green (pl. 1). The breccia is composed of medium- to coarse-grained mafic rock fragments, some as large as 16 inches (40 cm) across, that appear to be similar to some of the

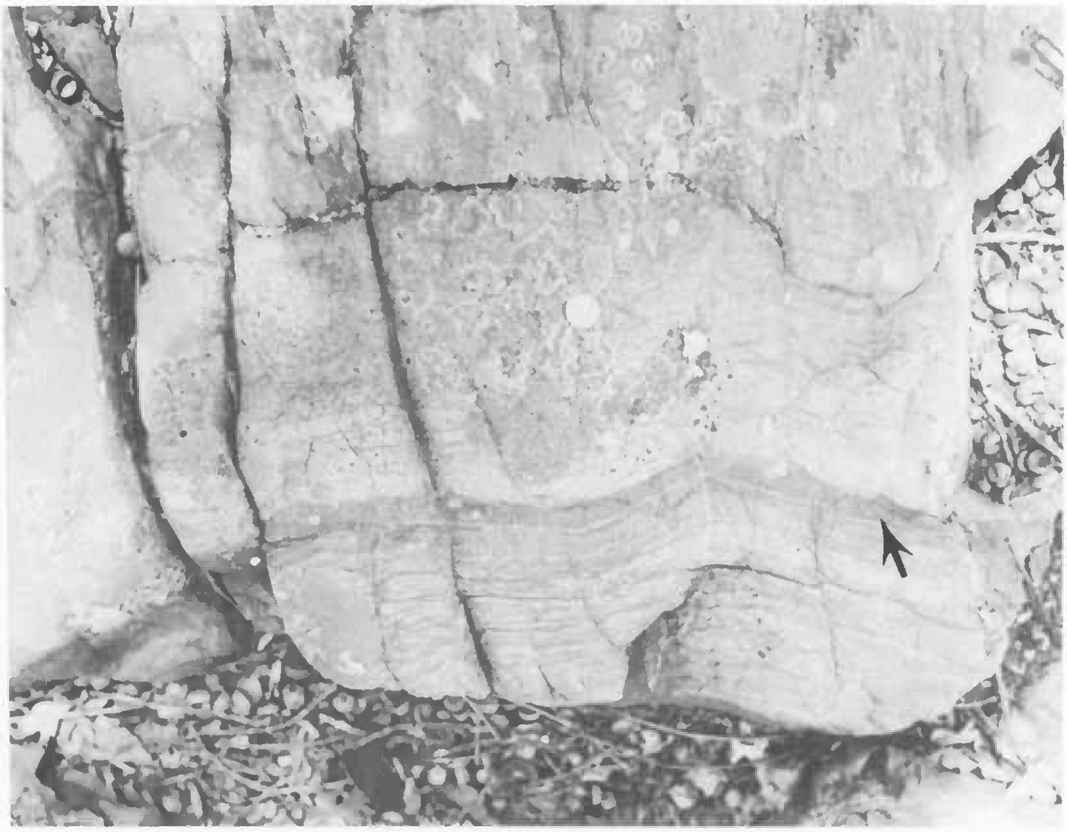

FIGURE 6: Metagraywacke, showing graded bedding. The sharp contact of the quartz-rich layer against the pelitic top of the underlying layer shows that stratigraphic tops are consistently toward the top of this photograph; dip of bedding is toward the viewer. Note flame structures (arrow) at base of graded bed. Coin is 3/4 inch (1.8 cm) in diameter. Outcrop along Basin Run.

gabbroic rocks in the Baltimore Complex; however, no thin sections or chemical analyses were made. An anastomosing matrix of granitic rock swirls around the mafic fragments, cutting through some of them as thin dikes (fig. 8).

METAVOLCANIC ROCKS

JAMES RUN FORMATION

Southwick and Fisher (1967) gave the name James Run Gneiss to interlayered quartz amphibolite and biotite-quartz-plagioclase gneiss that are well exposed along James Run in Harford County (Southwick and Owens, 1968), and suggested a volcanic and volcaniclastic origin for these rocks. Earlier, Hopson (1964, p. 31-35) had suggested a volcanic and volcaniclastic origin for similar rocks exposed in Baltimore City. Southwick (1969, p. 47-55) recognized the similarity among his James Run Gneiss, Hopson's (1964) "Baltimore paragneiss," parts of the "volcanic complex of Cecil County" (Marshall, 1937), and some of the rocks of the "Wilmington Complex" (Ward, 1959) in Delaware, and proposed that all of these rocks are correlative. Later, Southwick and others (1971) named similar rocks in northern Virginia the Chopawamsic Formation and suggested a possible connection with the James Run Gneiss and the other rocks of similar nature in Maryland and Virginia. In 1972, I changed the name of the

FIGURE 7: Metagraywacke, showing strain-slip axial-plane cleavage. Exposed along the Susquehanna River in Pennsylvania a few hundred yards (a few hundred meters) north of the Maryland state line.

Maryland rocks from James Run Gneiss to James Run Formation and proposed formal correlation with the Chopawamsic Formation in Virginia (Higgins, 1972).

The James Run Formation in Cecil County has been divided into seven formally named members: the Principio Furnace, Frenchtown, Little Northeast Creek, Gilpins Falls, Big Elk Creek, Principio Creek, and Happy Valley Branch Members (Higgins, 1971a, 1972, 1977b). In addition, one unnamed felsite lens of limited extent (Higgins, 1977b) has been mapped (pl. 1). Modal analyses of some of the James Run rocks are given in Table 4.

Principio Furnace Member

Interbedded, gray and light-gray to grayish-white, intermediate to felsic metavolcanic rocks and lesser amounts of diamictite composed partly of nonvolcanic sedimentary material were named the Principio Furnace Member of the James Run Formation for Principio Furnace on Principio Creek, Cecil County (Higgins, 1977b; and pl. 1, this paper). Exposures along Principio Creek, from just south of Maryland Rte. 7 to just north of U.S. Rte. 40, were designated the type section. The original thickness of the Principio Furnace Member cannot be determined because of subsequent deformation, but the present thickness is approximately 2,500 ft (760 m). The member is probably partly equivalent to the Little Northeast Creek Member. To the northeast, it interfingers with, and probably grades into, the biotite gneiss exposed at Rolling Mill (pl. 1). The Principio Furnace Member is apparently overlain with gradational contact by the Frenchtown Member.

TABLE 3
MODAL ANALYSES OF ROCKS OF THE METAGRAYWACKE LITHOFACIES, CECIL AND HARFORD COUNTIES

	METAGRAYWACKE LITHOFACIES							
	1	2	3	4	5	6	7	8
quartz	50.0	49.8	49.6	48.9	45.9	43.9	43.6	3.7
plagioclase	8.4	30.1	21.7	4.7	28.7	19.0	16.0	37.2
k-feldspar	-	tr	0.6	tr	-	-	-	-
hornblende	-	-	-	-	-	-	-	46.4
muscovite	36.4	6.7	22.4	29.3	15.6	20.3	25.9	-
biotite	0.9	4.0	1.8	-	0.1	1.1	-	0.4
chlorite	0.6	3.7	0.9	14.3	6.2	15.0	9.9	5.8
calcite	0.1	0.9	0.3	0.7*	0.3	0.4	2.0*	0.5
garnet	-	0.5	-	-	-	tr	-	-
epidote	-	0.2	tr	0.2	-	tr	0.3	3.9
allanite	-	-	-	-	-	-	-	-
apatite	tr	-	-	tr	-	-	tr	-
sphene	-	-	-	-	-	-	-	tr
tourmaline	-	0.1	-	0.1	-	-	tr	-
monazite	-	-	-	-	-	-	-	-
zircon	-	-	-	tr	tr	tr	tr	-
magnetite	3.1	3.8	2.1	1.8*	2.9	0.3	1.6*	2.0
hematite	tr	tr	-	-	-	-	-	-
others	0.4	0.2	0.6	-	0.3	-	0.7	0.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Points	1,000	1,000	1,000	1,000	1,000	1,000	1,466	1,000

* Minerals identified by Southwick (1969, p. 30, table 7) as *opaques*, *carbonate*, and *rutile* have here been listed as *magnetite*, *calcite*, and *others*, respectively.

1. From railroad cut of CONRAIL system along Susquehanna River about 0.5 mile (0.8 km) south of Peach Bottom, Lancaster County, Pennsylvania. Analysis of specimen 1191-A1 of Higgins and Fisher (1971, p. 773, table 2).
2. From railroad cut of CONRAIL system along Susquehanna River about 325 ft (100 m) southeast of the Pennsylvania-Maryland state line, Cecil County.
3. From railroad cut of CONRAIL system along Susquehanna River about 130 ft (40 m) southeast of tunnel at Wildcat Point, Cecil County.
4. From stream cut 0.65 mile (1.04 km) north-northwest of Prospect, Harford County. Analysis no. 8 of Southwick (1969, p. 30, table 7).
5. From fresh outcrop along Christina River about 3,200 ft (975 m) west of the Delaware-Maryland state line, Cecil County.
6. From railroad cut of CONRAIL system along Susquehanna River about 0.5 mile (0.8 km) south of the Pennsylvania-Maryland state line, Cecil County, and 1,000 ft (300 m) northwest of contact with the Sykesville Formation.
7. From north side of mouth of Broad Creek at Susquehanna River about 900 ft (275 m) west of powerline, Harford County. Analysis no. 7 of Southwick (1969, p. 30, table 7).
8. Amphibolite from outcrop of metagraywacke-with-amphibolite unit in Basin Run about 2,000 ft (610 m) southeast of Liberty Grove, Cecil County.

In fresh outcrops, the rocks of the Principio Furnace Member are gray, fine-grained, even-grained, intermediate granofels containing scattered blocky phenocrysts of plagioclase feldspar. The rocks are found in beds or layers, generally about 1 to 4 ft (0.3 to 1.2 m) thick, that alternate with light-gray, fine-grained, even-grained granofels containing scattered phenocrysts of plagioclase, green amphibole, and quartz, and with thin beds of gray, medium-grained, biotite-bearing epiclastic diamictite gneiss that contains abundant round to oblong grains and

TABLE 4
AVERAGE MODAL ANALYSES OF ROCKS OF THE JAMES RUN FORMATION, NORTHERN MARYLAND PIEDMONT

	JAMES RUN FORMATION															
	1		2		3		4		5		6		7		8	
	avg.	std. dev.	avg.	std. dev.	avg.	std. dev.	avg.	std. dev.	avg.	std. dev.	avg.	std. dev.	avg.	std. dev.	avg.	std. dev.
plagioclase	46.0	4.6	50.2	2.3	39.8	0.7	39.5	4.7	40.9	5.1	33.6	7.8	47.8	4.9	22.1	6.9
quartz	41.3	1.3	35.1	7.9	41.7	3.9	33.1	2.2	14.6	3.2	13.8	4.0	1.1	1.2	1.0	1.7
microcline	0.6	1.2	3.1	3.7	-	-	-	-	-	-	-	-	-	-	-	-
hornblende	4.2	4.5	6.9	8.5	9.7	1.1	17.2	3.1	29.5	4.7	48.0	11.0	18.1	4.7	4.5	3.2
cummingtonite	-	-	-	-	4.5	1.4	-	-	-	-	-	-	-	-	1.1	1.9
actinolite	-	-	-	-	-	-	tr	-	-	-	-	-	-	-	14.9	3.5
biotite	2.9	1.3	3.3	1.8	1.0	0.9	tr	-	0.4	0.3	0.3	0.5	0.3	1.0	-	-
muscovite	2.2	4.2	-	-	tr	-	-	-	0.5	1.0	-	-	-	-	-	-
chlorite	-	-	-	-	-	-	5.0	0.9	3.2	1.1	0.5	0.7	-	-	28.2	6.9
epidote	1.5	0.8	0.2	0.1	0.9	0.6	3.1	0.6	4.1	2.2	2.5	0.9	2.2	1.1	12.5	3.8
clinozoisite	-	-	-	-	-	-	tr	-	1.0	0.9	-	-	-	-	4.1	2.2
sphene	tr	-	0.3	0.3	-	-	-	-	0.3	1.2	tr	-	tr	-	-	-
garnet	0.5	-	0.1	0.16	-	-	-	-	0.8	1.4	-	-	-	-	-	-
calcite	-	-	-	-	-	-	tr	-	0.1	1.3	0.1	0.1	-	-	3.9	1.2
opaques	0.7	0.3	0.6	-	1.6	0.8	1.8	1.0	2.5	0.7	1.1	1.1	0.4	1.2	2.9	1.2
others	0.1	-	tr	-	0.8	0.4	0.3	1.4	2.1	2.5	0.1	0.1	0.1	0.3	4.8	2.3
Total	100.0	-	99.8	-	100.0	-	100.0	-	100.0	-	100.0	-	100.0	-	100.0	-

(More than 1,000 points counted for each specimen)

1. Five samples of felsic gneiss from the James Run Formation, Harford County (from Southwick, 1969, p. 48, table 9).
2. Five samples of gneiss and "granulite" from the "Baltimore paragneiss" (James Run Formation), Baltimore County and Baltimore City (from Hopson, 1964, p. 32, table 8).
3. Ten samples of quartz-rich granofels from the James Run Formation, Cecil County.
4. Twelve samples of felsic granofels and gneisses from the James Run Formation, Cecil County.
5. Eight samples of hornblendic granofels from the James Run Formation, Cecil County.
6. Seven samples of "hornblende-rich" rocks from the James Run Formation, Harford County (from Southwick, 1969, p. 48, table 9).

(continued next page, bottom)

FIGURE 8: Mafic breccia. Outcrop in field between Principio Road and Post Road, about 0.5 mile (804 m) west of College Green.

blebs of quartz (fig. 9). Locally, foreign rock fragments are also found in the diamictite gneiss (fig. 9). The light-gray granofels generally occurs in beds or lenses of about the same thickness as the gray granofels, but the diamictite gneiss generally occurs in beds or lenses from about 2 to 15 ft (0.6 to 4.6 m) thick. Volcaniclastic features and mafic rocks are rare in the Principio Furnace Member, and this helps differentiate it from the overlying Frenchtown Member.

In thin section, the light-gray granofels generally shows granoblastic to weakly lepidoblastic textures comprised of a matrix of fine- to medium-grained quartz and plagioclase, in which are set euhedral and broken phenocrysts of plagioclase as much as $^1/_4$ inch (~5 mm) long and large crystals of bluish-green amphibole as much as $^5/_{16}$ inch (~8 mm) long. The plagioclase phenocrysts are commonly zoned and range in composition from albite to oligoclase. The gray, intermediate granofels has similar textures and mineral composition, but the large plagioclase crystals generally range from oligoclase to andesine and are not as abundant as the large plagioclase crystals in the light-gray granofels. Most of the groundmass plagioclase in both types of granofels is albite. Chemically, some of these rocks are keratophyres (table 8) that may originally have been dacites and rhyolites.

(TABLE 4, continued)

7. Fourteen samples of amphibolite from the James Run Formation, Cecil County.
8. Three samples of metamorphosed pillow basalts (interiors) from the James Run Formation, Cecil County. Fine grain size makes analysis difficult; a high margin of error should be assigned to these analyses.

FIGURE 9: Epiclastic diamictite gneiss bed in the Principio Furnace Member of the James Run Formation. Note round to oblong blebs of quartz, and angular rock fragment above coin. Coin is $^3/_4$ inch (1.8 cm) in diameter. Outcrop along Principio Creek between U.S. Rte. 40 and Maryland Rte. 7.

Frenchtown Member

Interbedded dark-green mafic, gray intermediate, and light-gray to grayish-white metamorphosed felsic volcanic, volcaniclastic, and volcanic-epiclastic rocks (fig. 10) containing relict phenocrysts of plagioclase and (or) quartz (fig. 11), (or) amphibole, and locally, relict pumice lapilli, accretionary lapilli, and amygdules, were named the Frenchtown Member of the James Run Formation for good exposures around Frenchtown, Cecil County (Higgins, 1977b; pl. 1). The type section consists of the exposures in the gorge of the Susquehanna River, from just northwest of Interstate 95 to the village of Frenchtown. Most fresh exposures of the Frenchtown Member are found in creek valleys, but good exposures are also found in roadcuts along Interstate 95 just north of the Susquehanna River. The Frenchtown Member appears to stratigraphically overlie the Principio Furnace Member and is structurally overlain by the Gilpins Falls Member of the James Run Formation. It may be equivalent to part of the Little Northeast Creek Member.

In fresh outcrops, the rocks of the Frenchtown Member are fine-grained, schistose to massive, commonly amygdaloidal amphibolites; fine- to medium-grained, gray granofels with blocky plagioclase phenocrysts, minor amounts of amphibole phenocrysts, and quartz blebs; and light-gray to grayish-white granofels with blocky plagioclase phenocrysts and blebs. Volcaniclastic features are relatively common (fig. 11). Amphibolite layers are commonly about 1 to 11 ft (0.3 to 3.5 m) thick and weather to a green saprolite. The felsic rocks occur in layers between 4 and 30 ft (~1 and 9 m) thick and weather to gray saprolite containing sparse quartz grains and to a very light-gray saprolite with abundant quartz grains.

FIGURE 10: Volcanic-epiclastic rock in the Frenchtown Member of the James Run Formation, showing flame structures (arrow) at the base of the bed. Outcrop along the gorge of the Susquehanna River southeast of Frenchtown.

The amphibolites are composed of plagioclase, colorless cummingtonite, blackish-green sodic hornblende, epidote, accessory magnetite, and minor amounts of quartz (table 4). Most have lepidoblastic textures with medium to large amphiboles, $^1/_{16}$ to $^1/_4$ inch (~2 to 6 mm) long in a groundmass of plagioclase spotted with epidote and accessories. The plagioclase is generally albite to andesine (An_{8-33}). Southwick (1969, p. 57) noted the coexistence of two amphiboles in the rocks now assigned to the Frenchtown Member.

In thin section, the light-gray intermediate granofels shows granoblastic or weak lepidoblastic textures. Large, blocky, zoned phenocrysts of plagioclase, generally albite to andesine (An_{9-35}), are interspersed in a groundmass of feldspar, mostly albite to oligoclase, and quartz. Tiny grains of epidote and opaque minerals are seen in the groundmass in some thin sections. The very light gray to grayish-white granofels is composed almost entirely of quartz and plagioclase, although some thin sections show minor amounts of potassium feldspar (orthoclase?). This lithology generally has porphyritic granoblastic textures. Groundmass plagioclase is oligoclase to andesine (An_{11-39}). Large porphyritic plagioclase crystals are also oligoclase to andesine (An_{10-38}), with the most being about An_{25}. These are commonly zoned, and some have outer zones as sodic as An_7.

Chemically, the rocks of the Frenchtown Member are high in Na_2O and low in K_2O (table 8). They may originally have been basalts, andesites, dacites, and rhyolites.

Little Northeast Creek Member

Grayish-white to gray, fine- to medium-grained, massive granofels containing relict phenocrysts of plagioclase and quartz are best exposed along Little Northeast Creek in central

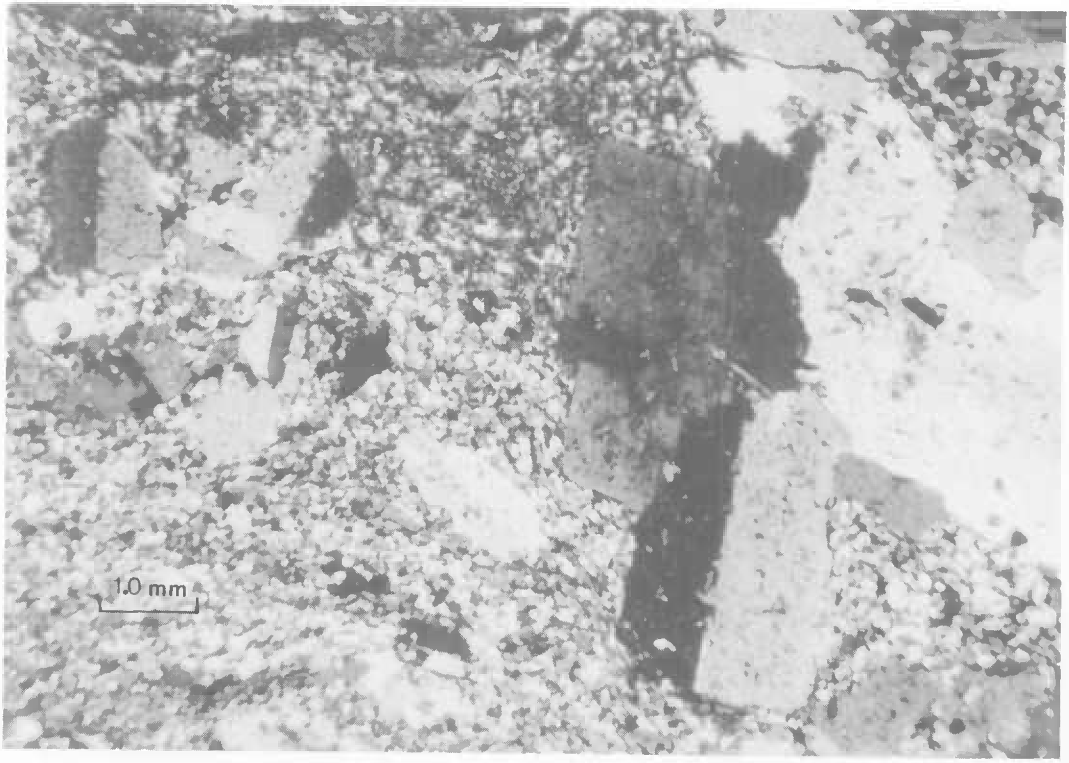

FIGURE 11: Photomicrograph (crossed polars) of felsic volcanic rock of the Frenchtown Member of the James Run Formation, showing blocky volcanic plagioclase phenocrysts and a large glomeroporphyritic clot. Outcrop along the Susquehanna River near Frenchtown.

Cecil County (pl. 1). These rocks were named the Little Northeast Creek Member of the James Run Formation (Higgins, 1977b). The type section was designated along Little Northeast Creek northeast of Bay View, between outcrop belts of the Gilpins Falls Member (pl. 1). The present thickness of the Little Northeast Creek Member is about 4,600 ft (1,400 m).

Little Northeast Creek rocks are generally well exposed in the valleys of creeks that flow southeastward across Cecil County. Where not covered by Coastal Plain sedimentary deposits on the interfluves between streams, rocks of this unit are generally deeply weathered to a grayish-colored saprolite with fairly abundant quartz grains.

In fresh outcrops, the rocks of the Little Northeast Creek Member are generally grayish-white to gray, fine- to medium-grained, massive granofels, with small blocky crystals of plagioclase, small blebs of quartz, and minor amounts of biotite and elongate amphibole crystals. Locally, however, the rocks have a slight foliation, and commonly more than one weakly developed cleavage. Hints of relict bedding are rare, but this may be due in part to the lack of large, continuous exposures. Very rare hornblende-plagioclase amphibolite layers in the Little Northeast Creek Member may have been basaltic dikes or sills.

In thin section, the granofels of the Little Northeast Creek Member show lepidoblastic to granoblastic textures. Amphibole crystals as long as 3/8 inch (8 mm) and biotite segregations about 1/4 inch (5 mm) across show alignments in more than one direction in a matrix of plagioclase and quartz. The alignment of the mafic minerals is generally weak. Crystals of plagioclase that are larger than the groundmass grains generally show no preferred alignment. Relict volcanic and volcaniclastic textures are fairly common (fig. 12). Glomerocrysts of blocky, zoned plagioclase are seen in many thin sections.

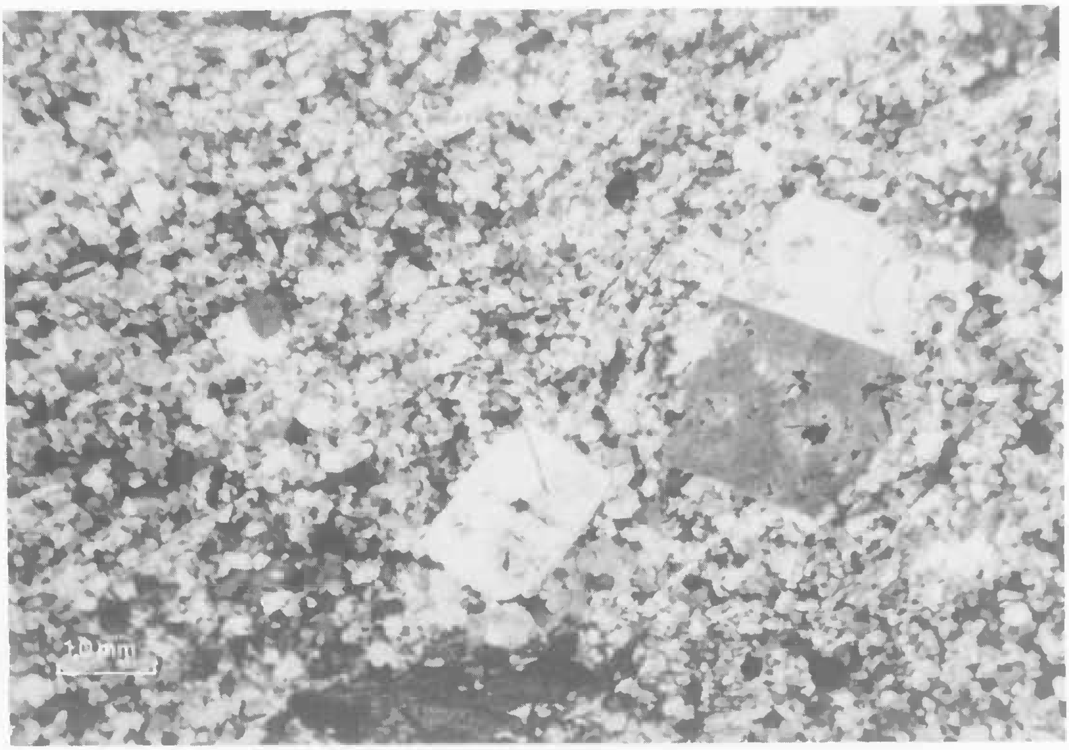

FIGURE 12: Photomicrograph (crossed polars) of massive volcanic rock of the Little Northeast Creek Member of the James Run Formation, showing blocky plagioclase phenocrysts. Outcrop along Little Northeast Creek.

The plagioclase in the groundmass of the Little Northeast Creek granofels is nearly all albite to oligoclase (An_{8-27}), most commonly about An_{22}, as are many of the large, blocky, zoned plagioclase crystals. However, the cores of some of the large crystals are as calcic as andesine (up to An_{46}). The amphiboles are mostly blue-green hornblende, and the biotite is commonly brown. Opaques, chiefly magnetite, and tiny specks of epidote are the principal accessory minerals (table 4).

Chemically, most of the rocks of the Little Northeast Creek Member appear to have been rhyolites (table 8). Like the felsic rocks of other units in the James Run Formation, they are high in Na_2O and low in K_2O.

The rocks of the Little Northeast Creek Member structurally overlie the Gilpins Falls Member. To the northeast, these rocks appear to grade into biotite gneiss of probable sedimentary origin. To the east they appear to grade into rocks of the Frenchtown Member.

Gilpins Falls Member

The Gilpins Falls Member of the James Run Formation is the most distinctive and readily mappable unit in Cecil County. It consists chiefly of greenschists and greenstones in the southwestern part of its outcrop belt and of amphibolites and amphibole schists in the northeastern part of the belt, although there is much variation along strike. The type locality is Gilpins Falls on Northeast Creek just south of Maryland Rte. 272, northeast of Bay View (Higgins, 1971a, p. 323; and pl. 1, this paper). The type section is well exposed along Northeast Creek for about 1,000 ft (300 m) north of Gilpins Falls and for about 6,000 ft (1,830 m) south of the falls.

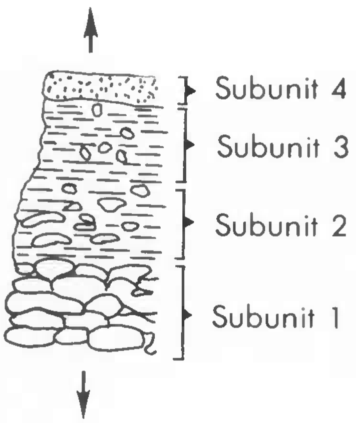

FIGURE 13: Schematic column showing four subunits of the Gilpins Falls Member of the James Run Formation.
Subunit 1: chiefly massive, close-packed pillow lavas with minor lenses of aquagene tuff.
Subunit 2: chiefly broken pillow breccia, isolated pillow breccia, and aquagene tuff.
Subunit 3: chiefly aquagene tuff with some isolated pillows.
Subunit 4: chiefly basalt flows.

The Gilpins Falls Member has been divided into four stratigraphic subunits (fig. 13). The lowermost of these is composed chiefly of metamorphosed massive, close-packed pillow lava (figs. 14 and 15), locally with thin chert beds near its top. The massive pillow lava grades upward very gradually into the second subunit composed of isolated pillow breccia (Carlisle, 1963) interlayered with thin beds of basaltic aquagene tuff (Carlisle, 1963). This second subunit grades upward into basaltic tuff containing isolated pillows and local lenses of broken pillow breccia (fig. 16). In places, this third subunit has a few thin, discontinuous beds of felsic tuff and of rocks that must have been mixtures of ash and nonvolcanic sedimentary detritus. Subunit three is overlain by massive coarse-grained metabasaltic rocks that were probably lava flows (fig. 17). Locally, this metabasalt contains fine-grained mafic volcaniclastic rocks. Not all of the subunits are present in every cross section through the member.

The rocks of the Gilpins Falls Member have been metamorphosed to the upper greenschist facies or to the amphibolite facies of regional metamorphism (Turner and Verhoogen, 1960; Turner, 1968), and locally the basaltic rocks have been sheared and recrystallized into amphibole schist or greenschist. It is not known whether the differences in the metamorphic grade within the Gilpins Falls are due to prograde or retrograde metamorphism, or to both. Mineralogically, the Gilpins Falls rocks are chiefly epidote-albite-chlorite schists and greenstones, plagioclase-hornblende schists, and hornblende-plagioclase amphibolites. Despite the metamorphism and deformation, however, primary structures and textures are generally well preserved and easily recognizable in the rocks of the Gilpins Falls Member.

The close-packed pillow lavas in the lower part of the Gilpins Falls Member range in shape from round to loaf-shaped to ellipsoidal, and in many outcrops the pillows are virtually undeformed (figs. 14 and 15). The pillows in this lower part of the Gilpins Falls generally range from about 1 ft (~30 cm) to about 3 ft (~90 cm) in diameter; most are about 2 ft (~60 cm) in diameter. They generally have well-preserved rims as much as $1^1/_2$ inches (~4 cm) thick; inward toward the center of the pillow is a zone of amygdules (figs. 14 and 15). Some pillows have a light greenish-gray central core that differs in color from the main green inner mass (fig. 14). Locally, overlying pillows are molded against those below and can be used as facing criteria (fig. 15). Isolated pillows in the aquagene tuffs higher in the Gilpins Falls are round and have poorly developed rims, or no rims at all. They are also commonly much smaller than the pillows in the close-packed lavas (fig. 16).

Amygdules are generally well preserved in the pillow lavas (fig. 14), even in outcrops where the pillows have been stretched 8:1 or more and where foliation is easily recognizable. The

FIGURE 14: Small, close-packed pillows in the Gilpins Falls Member of the James Run Formation. Outcrop along Gilpins Falls on Northeast Creek.

amygdules locally retain their round shapes even where the pillows have been stretched 4:1. Most of the amygdules are filled with subhedral and euhedral crystals of epidote (fig. 18), but some are filled with calcite or with calcite and epidote or clinozoisite, and some are filled with radiating clusters of acicular actinolite crystals. Locally, amygdules are filled with opaque minerals (chiefly magnetite). The size and percentage of amygdules suggest that the pillow basalts were emplaced in relatively shallow water (Higgins, 1971a).

Thin sections of the pillow lavas at Gilpins Falls show a variety of textures and a variety of mineral compositions. In general, these rocks have mineral assemblages characteristic of the greenschist facies. They are composed of various amounts of epidote, clinozoisite, chlorite, albite, actinolite, and tiny grains of magnetite (and lesser amounts of leucoxene). Textures vary greatly, not only from outcrop to outcrop and from pillow to pillow but also within individual pillows. The most common texture is a felted mesh of epidote and clinozoisite and tiny, irregularly shaped masses of albite, in which are scattered subhedral to euhedral crystals of plagioclase that range from albite to sodic oligoclase, and are probably pseudomorphic after calcic plagioclase. Probably the second most common texture consists of very weakly nematoblastic, acicular actinolite crystals set in a fine-grained matrix of clinozoisite, chlorite, epidote, and albite.

The mafic tuffs in the Gilpins Falls Member near Gilpins Falls are chiefly rocks that have lepidoblastic textures and are composed of chlorite, epidote, albite, and accessory magnetite. Epidosite clots are fairly common in these rocks.

Where the rocks of the Gilpins Falls Member are at amphibolite grade, as, for example, around Rock Church in the northeastern part of the county (pl. 1), they are nematoblastic hornblende-plagioclase and plagioclase-hornblende amphibolites with minor amounts of epidote.

FIGURE 15: Pillow basalts in the Gilpins Falls Member of the James Run Formation exposed at the upper end of Gilpins Falls on Northeast Creek. Coin is $^3/_4$ inch (1.8 cm) in diameter.

The hornblende is pale-green and the plagioclase is generally andesine (An_{40}). Most thin sections show minor amounts of quartz.

Over short distances all along the Gilpins Falls outcrop belt, the rocks vary from amphibolites or amphibole schists to greenschists or greenstones due to shearing. The best examples of this variation are in the outcrops around Rock Church. Outcrops 60 to 100 ft (~20 to 30 m) uphill from the church have almost undeformed pillows, but, in front of the church, amygdules can be traced from round (nearly undeformed) to long smeared streaks, and the only vestiges of pillows are distorted, flattened pieces of rims.

One of the major folds in the area, interpreted as a synformal anticline, is defined by the outcrop pattern of the Gilpins Falls Member as it crosses Cecil County. Amphibolites of the Gilpins Falls have been traced eastward for nearly 1.25 miles (~2 km) into Delaware, where they appear to grade into coarser grained rocks. Amphibole schists have also been traced to the southwest into Harford County for about a thousand feet (a few hundred meters).

Big Elk Creek Member

Interlayered amphibolites and felsites composed chiefly of plagioclase and quartz (but locally containing amphibole) were named the Big Elk Creek Member of the James Run Formation for exposures along Big Elk Creek approximately 0.3 to 0.4 miles (0.5 to 0.7 km) northwest from Maryland Rte. 273 (pl. 1). This section was also designated the type section (Higgins, 1977b). Fresh outcrops of the Big Elk Creek are confined to creek valleys. The mafic and felsic rocks of the Big Elk Creek Member are characterized by their occurrence in layers about 1 to 5 inches (~3 to 12 cm) thick, but early folds parallel to bedding are common. The rocks weather to a layered green and gray saprolite, but saprolite outcrops are rare.

FIGURE 16: Broken pillow breccia in the Gilpins Falls Member of the James Run Formation. Outcrop along Northeast Creek about 1,000 ft (300 m) downstream from Gilpins Falls.

The schistose and streaked, fine-grained, equigranular amphibolite layers in the Big Elk Creek Member have a strong lepidoblastic texture defined by well-aligned green hornblende and elongate grains of plagioclase. The plagioclase is oligoclase to andesine. Opaque minerals, epidote, and quartz are accessories. The felsites are fine grained and generally nonporphyritic, with granoblastic to lepidoblastic textures. They are composed chiefly of plagioclase (albite to andesine) and quartz, and locally contain amphibole. Opaque minerals are the main accessories. Locally, rounded quartzite fragments in these rocks suggest that they are volcanic-epiclastic with some contributions from nonvolcanic sources.

The Big Elk Creek Member structurally overlies the Gilpins Falls Member of the James Run Formation and appears to be partly equivalent to the Happy Valley Branch and Principio Creek Members (pl. 1). The present thickness of the unit is approximately 1,000 ft (300 m). This member pinches out about 1.2 miles (2 km) southwest of Little Northeast Creek. To the northeast, it has been followed into Delaware for over half a mile (about a kilometer).

Principio Creek Member

Biotite-plagioclase schist, characterized by abundant small, blocky plagioclase crystals, numerous blocky epidosite inclusions, and local layers of amphibolite, was named the Principio Creek Member of the James Run Formation (Higgins, 1977b). The exposures of this unit along Principio Creek northwest of Theodore Road in Cecil County were designated the type section. Fresh exposures of the Principio Creek Member occur only in the gorge of Principio Creek. Elsewhere, the rocks are weathered to a brownish-red saprolite that commonly contains small blocks of slightly weathered rock. The member pinches out about 1.2 miles (2 km) northeast of Northeast Creek, and is covered by Coastal Plain sedimentary deposits about 1 mile (1.6 km) southeast of Principio Creek (pl. 1).

FIGURE 17: Massive, coarse-grained amphibolite near the top of the Gilpins Falls Member of the James Run Formation. Interpreted as a metamorphosed basalt flow. Coin is 3/4 inch (1.8 cm) in diameter. Outcrop along Northeast Creek.

Fresh exposures of the Principio Creek Member are of a dark-gray, medium-grained schist speckled with abundant, well-aligned, small, lath-shaped plagioclase crystals that appear to be relict phenocrysts (fig. 19). Numerous blocky epidosite inclusions, as much as 11 inches (~30 cm) long and 8 inches (~20 cm) wide, are scattered throughout the schist. These are generally aligned with the foliation and some have reaction rims. In many outcrops, layers of fine-grained, equigranular amphibolite parallel the main schistosity.

The schist has an extremely strong lepidoblastic texture and could be mistaken for a mylonite except that the rounded colorless blebs in the rocks are probably not porphyroclasts because they are composed of quartz, not feldspar (Higgins, 1971b). In addition, the small crystals of plagioclase are zoned and have all the characteristics of plagioclase crystals found in volcanic rocks. These plagioclase crystals are generally oligoclase to andesine ($An_{12\text{-}39}$). The biotite is dark-brown, and the laths bend with the wavy foliation. Elongate, strained quartz also follows the foliation, but large quartz grains, as much as 1/4 inch (~6 mm) across, disrupt the foliation.

Happy Valley Branch Member

Chiefly gray to grayish-white, fine-grained, medium- to thin-bedded felsite and granofels containing relict, mostly broken phenocrysts of plagioclase, quartz, and locally of amphibole were named the Happy Valley Branch Member of the James Run Formation (Higgins, 1977b) for Happy Valley Branch, a tributary of the Susquehanna River in Cecil County (pl. 1). The type section consists of the series of exposures along the Susquehanna River from just north of Happy Valley Branch to the contact with the mafic rocks of the Gilpins Falls Member, about

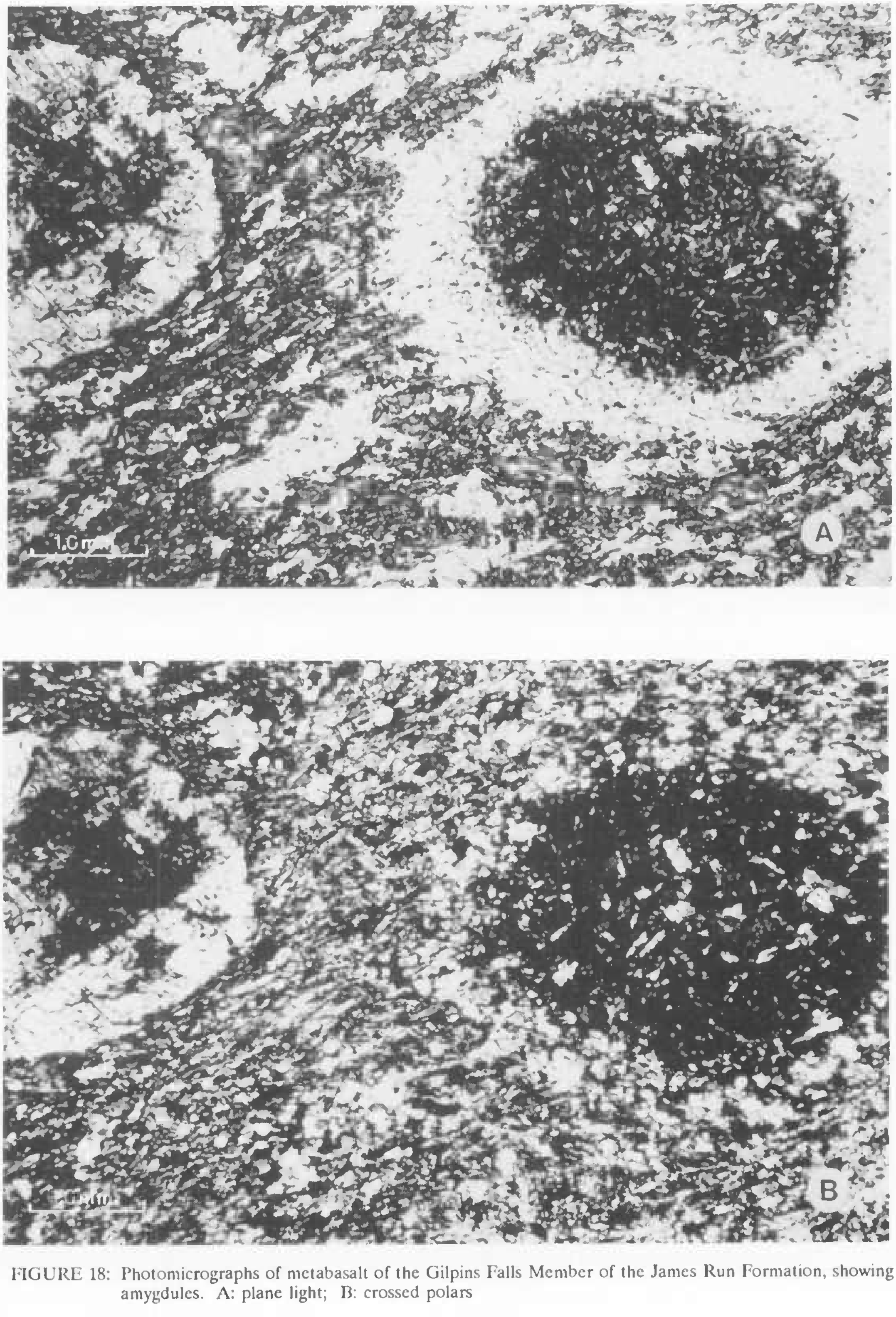

FIGURE 18: Photomicrographs of metabasalt of the Gilpins Falls Member of the James Run Formation, showing amygdules. A: plane light; B: crossed polars

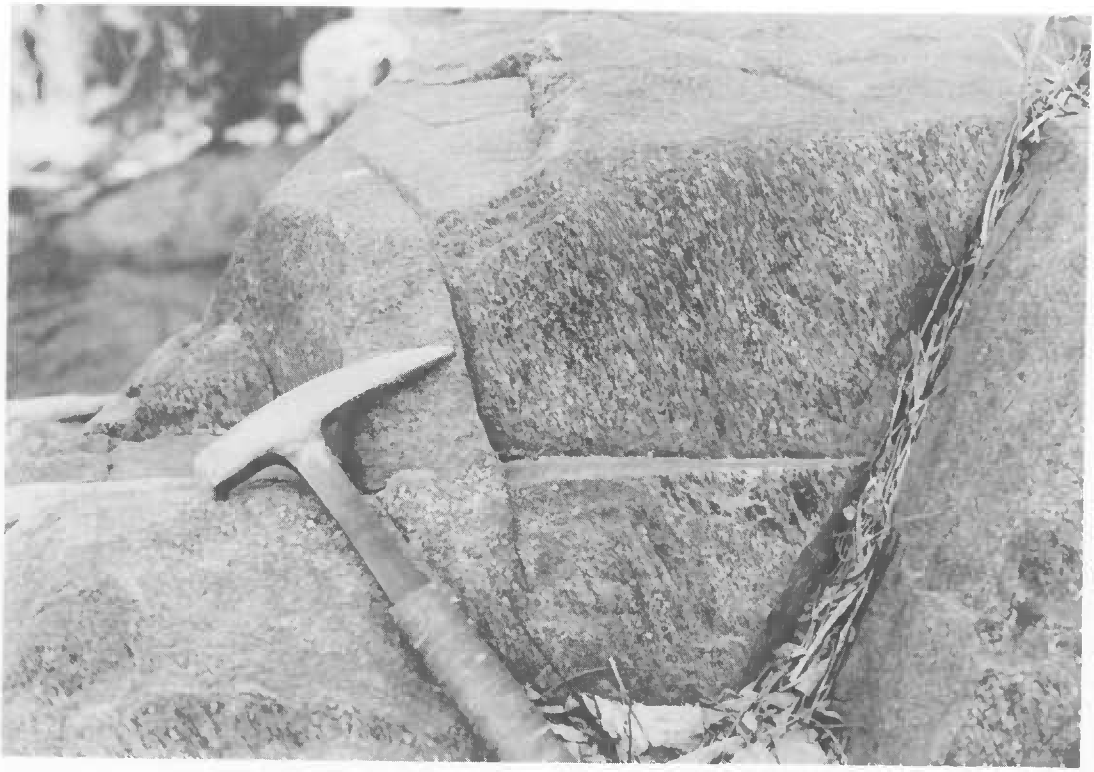

FIGURE 19: Dark gray schist of the Principio Creek Member of the James Run Formation. Note the strongly aligned plagioclase phenocrysts that are characteristic of this unit. Parent rock was probably an andesite. Outcrop along Principio Creek.

4,000 ft (1,200 m) northwest of Interstate 95. The thickness of the unit is approximately 3,000 ft (915 m).

Fresh exposures of the Happy Valley Branch Member occur in creeks and locally on relatively steep hillsides. Weathered rock consists of a grayish-white saprolite with numerous quartz grains. The unit can be traced for about a thousand feet (several hundred meters) into Harford County, but is then cut off or covered by the Aberdeen Metagabbro of Southwick and Owens (1968; Southwick, 1969).

The most common rock type in the Happy Valley Branch Member is a light-gray to white felsite containing abundant phenocrysts of plagioclase and blebs of quartz (fig. 20). Locally, wispy relict pumice lapilli are seen in some of these rocks. In thin section, this rock is seen to be a meshwork of tiny grains of plagioclase (albite to oligoclase) in which are set large, blocky plagioclase crystals about 1/4 inch (~6 mm) long, glomeroporphyritic clots of plagioclase crystals, and large grains of quartz (fig. 21). Opaque minerals, mostly magnetite, form a very small percentage of the rock, and trace amounts of epidote are present. Thin layers of hornblende-plagioclase amphibolite are the second most prevalent rock type.

The Happy Valley Branch Member structurally overlies the Gilpins Falls Member. It is apparently equivalent to parts of the Principio Creek Member. Contacts appear gradational with the fine-grained phase of Port Deposit Gneiss, but relatively sharp with other units. Southwick (1979) and I now agree on placement of this unit in the James Run Formation, but we still do not agree on the exact location of the northwestern contact and on the nature of some of the rocks northwest of that contact.

FIGURE 20: Typical porphyritic felsite of the Happy Valley Branch Member of the James Run Formation. Note blebs of quartz and dark, wispy pumice lapillus just below and to the left of the coin. Coin is 3/4 inch (1.8 cm) in diameter.

Unnamed felsite

The Principio Creek Member is overlain by an unnamed unit composed of light-gray to white, fine- to medium-grained felsite (pl. 1). In thin section, the felsite is seen to be composed chiefly of quartz and plagioclase (An_{10-40}), minor potassium feldspar, and rare biotite. There are very few outcrops of this unit, and its contacts are not exposed. It forms a featureless, light-gray, quartz-rich saprolite.

MAFIC PLUTONIC ROCKS

BALTIMORE COMPLEX

The Baltimore Complex (Higgins, 1977a) crops out across the northwest corner of Cecil County in a northeast-trending belt approximately 2.8 miles (4.6 km) wide and also in the noses of folds, which enter the north-central part of the county from Pennsylvania (pl. 1). Despite the fact that parts of the complex are exposed for a distance of about 60 miles (100 km) across the Piedmont of Maryland between Pennsylvania and southern Howard County just north of Laurel, and that the greatest areal extent of the unit is in the vicinity of Baltimore (Crowley and others, 1976), all workers in the area have agreed that the most intact section through the complex is along the Susquehanna River in Cecil County. At the river, the Baltimore Complex consists, from northwest to southeast, of a zone of mostly serpentinized, metamorphosed ultramafic rocks about 1,000 ft (305 m) wide and a zone of metagabbroic rocks with some ultramafic rocks about 2 miles (3.4 km) wide.

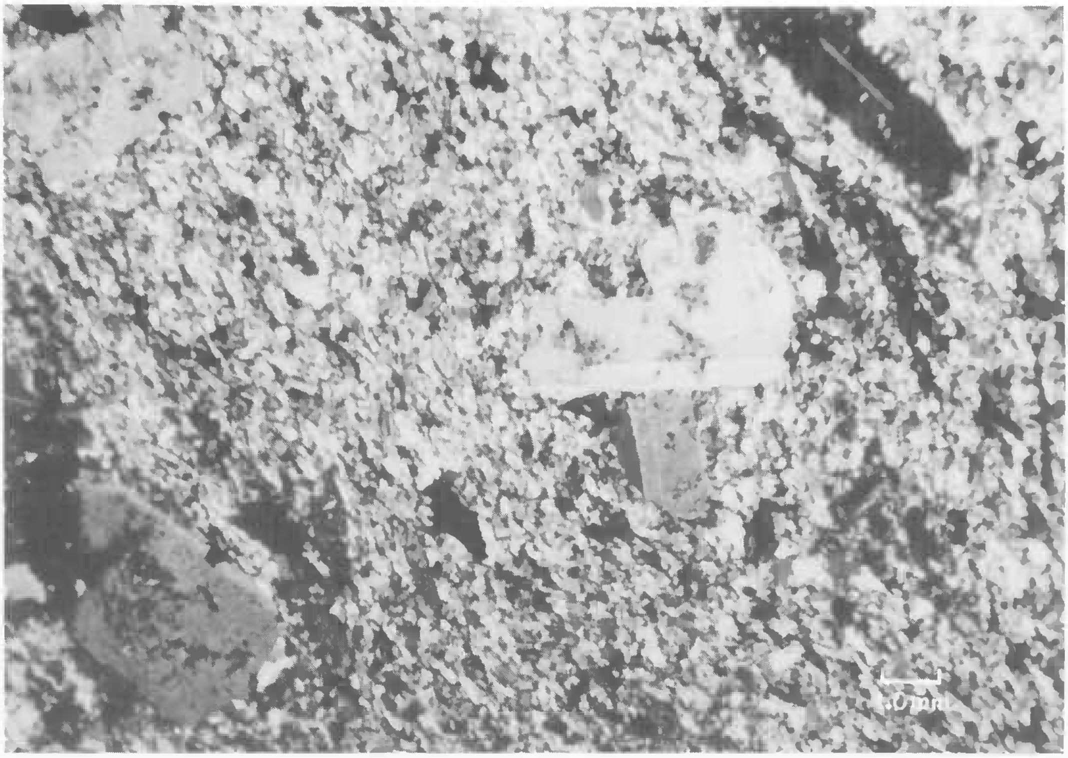

FIGURE 21: Photomicrograph (crossed polars) of the same rock as in figure 20. Note blocky plagioclase phenocrysts and glomeroporphyritic clot.

Bascom and others (1902) called the ultramafic part of the Baltimore Complex in Cecil County "serpentinite, peridotite, pyroxenite," and divided the remaining gabbroic part into two units: "hypersthene gabbro and norite" on the northwest, and "gabbro, metagabbro, and quartz-hornblende gabbro" on the southeast. Across the Susquehanna River in Harford County, Southwick (Southwick and Owens, 1968; Southwick, 1970, p. 400-401, fig. 2) showed six units within the outcrop area of his "Baltimore-State Line gabbro-peridotite complex" (Southwick, 1969, p. 59). Included with these in the southwestern part of the County was a unit of "...thoroughly recrystallized, lineated epidiorite and amphibolite; cut by numerous dikes and stringers of quartz-diorite gneiss..." which Crowley (Crowley, 1976; Crowley and others, 1976) considered to be metavolcanic rocks of the James Run Formation.

On the geologic map of Cecil County (pl. 1), the Baltimore Complex is divided into two major units: serpentinite and gabbro. However, each of these units contains significant amounts of other lithologies as well. The serpentinite has within it unserpentinized ultramafic rocks and locally some mafic rocks. The gabbro includes a wide variety of mafic rocks and locally contains ultramafic rocks. In addition, small areas consisting mainly of granitic rocks, and others of sheared talc schist with subordinate chlorite schist, also occur within the Baltimore Complex.

The northwestern contact of the Baltimore Complex is not exposed in Cecil County, but it appears to be sharp. Along the Susquehanna River, about 1,600 ft (500 m) southeast of Bald Friar (pl. 1), good exposures of highly sheared serpentinite and soapstone are separated from good exposures of diamictites of the Sykesville Formation by an interval of no exposure about 200 ft (60 m) wide. A small creek that enters the Susquehanna at this point appears to follow the contact. However, along and just southeast of the unpaved road that follows this narrow creek valley, float from these two units, as well as poorly exposed saprolite, indicates that the serpentinite and diamictite are in sharp contact. Outcrops of serpentinite and diamictite are within 50 ft (15 m) of each other along Conowingo Creek about 1,000 ft (300 m) due south of the Pennsylvania state line (pl. 1). Elsewhere, the contact was mapped on the basis of float and soils. Southwick (1970, p. 401) reported the contact to be a "highly sheared, badly weathered, subvertical concordant zone between talcose serpentinite and rocks of the Wissahickon Formation" about 0.6 mile (1 km) along strike to the southwest in Harford County. He also noted that the straight trace of the northwestern contact of the complex and the steep magnetic gradient across it, as shown by Bromery and others (1964), indicate a steep to vertical attitude for the contact. Pearre and Heyl (1960, p. 718) also reported steep southward dips on this contact in Pennsylvania.

Crowley (1976, p. 26-312) presented evidence that the northwestern contact of the Baltimore Complex is a thrust fault. He reasoned: (1) Where the complex is least deformed and most intact, from its northeastern terminus in southeastern Pennsylvania to near Scarboro, 4.5 miles (7 km) southwest of the Susquehanna River in Harford County, Maryland, it is bounded on the northwest by a continuous basal sheet of serpentinized ultramafic rocks. Near Scarboro, however, the basal sheet veers westward into clastic metasedimentary rocks, whereas the mafic part of the complex continues southwestward devoid of its ultramafic base. (2) The basal serpentinized ultramafic rocks in the complex from southeastern Pennsylvania to near Scarboro, Maryland, are hosts to podiform chromite deposits. Southwest of Scarboro, identical chromite deposits occur in the pods and lenses of serpentinized ultramafic rocks scattered through the lower part of the clastic metasedimentary sequence on the northwestern flank of the Baltimore-Washington anticlinorium (pl. 2). These ultramafic rocks are the remains of the sheared-off base of the Baltimore Complex. (3) Where the ultramafic base of the complex is missing, it can be found to the northwest within the clastic rocks. (4) The isolated ultramafic masses northwest of the main mafic belt of the complex are confined exclusively to the clastic sequence, at approximately the same stratigraphic horizon. If they were intrusive, similar ultramafic rocks should be found in the Baltimore Gneiss, Setters Formation, and Cockeysville Marble. (5) Some of the rocks previously considered plutonic in the basal parts of the mafic part of the complex are supracrustal metavolcanic rocks, whereas others are metaplutonic. If the base of the mafic part of the complex is occupied by supracrustal rocks in some places and by plutonic rocks in others, it must be a fault. (6) Internal units within the complex are truncated by the contact.

Fisher and others (1979, p. 33) stated:

> Crowley's mapping and our own reconnaissance clearly indicate that the contact between the Baltimore Complex and the underlying Wissahickon metasedimentary rocks is indeed a thrust fault, because it cuts major lithologic units within the Baltimore Mafic Complex as well as within the Wissahickon. This relation is particularly clear in the part of the complex between Baltimore and Conowingo, Maryland. Traced southward from Conowingo, the thrust cuts progressively up section from ultramafic rocks through gabbro to laminated metavolcanic rocks in the Baltimore Mafic Complex (the hanging wall) at the same time as it cuts down section from diamictite through Wissahickon pelite to Cockeysville Marble in the footwall.

In Cecil County, from the Susquehanna River northeastward to Pennsylvania, the thrust on the northwestern (basal) side of the Baltimore Complex cuts down section within the complex (the hanging wall). This accounts for the widening of the serpentinite unit outcrop belt to the northeast (pl. 1; Pearre and Heyl, 1960; Lapham and McKague, 1964).

Numerous workers have studied the petrography of rocks of the Baltimore Complex since the late 1880's (Williams, 1884, 1886, 1890; Leonard, 1901; Bascom, 1902; Knopf, 1921; Insley, 1928; Johannsen, 1928; Knopf and Jonas, 1929a; Herz, 1951; Hopson, 1964; Southwick, 1969, 1970; Hanan, 1976, 1980; Morgan, 1977). As Hopson (1964, p. 132) stated, Williams' (1886) study of the complex made it a classic example of uralitization and metamorphism of mafic igneous rocks. Excellent petrologic accounts of the complex have been given by Hopson (1964), Southwick (1970), and Morgan (1977), and the reader is referred to these papers for an overall petrologic description of the complex.

Serpentinite

Near the northwestern thrust contact of the serpentinite unit of the Baltimore Complex (pl. 1), the most common rock type is a lustrous, highly sheared and fractured, bluish-green, talcose serpentinite, or "soapstone," with no visible evidence of original texture or other original features. In thin section this rock is seen to be composed of serpentinite minerals with a mesh or felted-mat texture, cut by numerous shears and thin shear zones filled with antigorite. There are at least three prominent shear directions (also see Lapham and McKague, 1964) that cut across earlier textures. Minor amounts of sagenitic magnetite and (or) very small elongated masses of chromite are found in a few outcrops. The best exposure of this type of rock is the railroad cut along the northeast side of the Susquehanna River about 400 ft (120 m) southeast of the northwestern contact of the serpentinite unit (pl. 1). Sample S2-1 (table 11) is from this locality. Rocks of this type apparently form an outcrop belt along the northwestern side of the complex that is about 700 ft (210 m) wide, but the paucity of outcrops is such that other rock types may be present within this belt.

To the southeast, across strike and up section, the rocks of the serpentinite unit become more varied, although they are also generally sheared and fractured. Sagenitic magnetite and elongated masses of chromite gradually increase to the southeast, and palimpsest igneous textures are locally present. These rocks were originally dunite, peridotite, various pyroxene-bearing peridotites (see Williams and others, 1954, p. 78), olivine pyroxenite, and pyroxenite. Serpentinization of these rocks has been extensive, however, so that unaltered and even partially unaltered ultramafic rocks are rare. In thin section, most of these rocks show a mesh texture consisting of a felted mat of serpentine minerals cut by numerous thin shear zones that are filled with platy serpentine and (or) cross-fiber asbestos. Veinlets of carbonate are seen in most sections. Sagenitic magnetite is present in many sections, and locally, elongated, thin masses of chromite are present. Despite the deformation and alteration, some of these rocks can be identified with igneous, premetamorphic rocks by palimpsest textures and structures. Relict layering is locally present in these rocks and is generally contorted, as noted by Hopson (1964).

Perhaps the most distinguishing characteristic of the ultramafic rocks, as noted by Crowley (1976, p. 26-27), is that they commonly contain significant amounts of chromite, both as disseminated elongated grains and as massive podiform ore bodies (Pearre and Heyl, 1960; Thayer, 1960, 1967, 1970, 1971; Southwick, 1970). In the old "State Line Chromite District," which straddles the boundary between Cecil County, Maryland, and Chester County, Pennsylvania, the chromite deposits do not appear to mark a specific horizon or even the basal part of the serpentinite unit but occur throughout the major part of the unit (Pearre and Heyl, 1960). Nevertheless, the presence of significant amounts of chromite is confined to the serpentinite unit. Some of the smaller chromite grains are folded with the rest of the rocks and are cut by fractures filled with serpentine minerals. The fact that the serpentine-filled fractures are not axial planar to the folded chromite grains suggests that some of the serpentinization took place after one phase of folding and possibly during metamorphism.

Relict minerals, or cores of relict minerals with altered rims, are rare in the serpentinite unit, but Southwick (1970, p. 405) reported: "Relict olivine in the dunitic rocks is highly magnesian, having compositions of Fo_{86-92} ...." To the southwest, in Baltimore County, Herz (1951, p. 986) found that the relict olivine in the ultramafic rocks ranges from Fo_{70} to Fo_{96} (70 percent in the range Fo_{86-90}) and that orthopyroxenes in the ultramafic rocks (pyroxene-bearing peridotites and metapyroxenites) range from about En_{83} to En_{90}. In Harford County, Southwick (1970, p. 405) found that pyroxenes associated with the olivine-bearing rocks in the northwestern part of the complex carry orthopyroxene with a composition near En_{80}. Norms from two traverses across the Baltimore Complex in Cecil County (table 11) suggest that the orthopyroxenes in the ultramafic rocks are probably very high in enstatite, and that the olivines are probably high in forsterite. Optical measurements indicate enstatite and forsterite values more compatible with those reported by earlier workers, but only a few relict grains were measured.

Clinopyroxene appears to have been a very rare constituent of most of the metapyroxenites in Cecil County. However, according to Southwick (1970, p. 405): "Clinopyroxene, some of it zoned, forms a significant part of some pyroxenites and locally may be dominant." It is not known whether the pyroxenites to which he referred are in the serpentinite part of the complex or in the gabbroic part, but Herz (1951) reported significant amounts of clinopyroxene in rocks associated with the "ultramafic" part of the complex in Baltimore County. This was confirmed by Hopson (1964, p. 138-139, 144). However, Crowley (1976) presented evidence suggesting that the ultramafic rocks in the main mass of the complex around Baltimore City are not part of the basal chromite-bearing unit, and thus not at the same stratigraphic horizon, or same tectonostratigraphic horizon, as the serpentinite unit in Cecil County.

Locally, the serpentinite in Cecil County is cut by veins and veinlets of cross-fiber asbestos which range in width from a fraction of an inch (a few millimeters) to about 4 ft (1.2 m). Most of these veins strike roughly parallel with the dominant schistosity in the serpentinite, but the fact that some cut directly across it suggests that they formed late in the history of the complex. The asbestos veins are best exposed in the barren field northwest of Conowingo Creek, at the first curve northwest of the creek on the road between Oakwood and Pilot. Good exposures are also found in drainage ditches along this same road going uphill to Pilot. Lapham and McKague identified these veins as filling two sets of fractures, and stated (1964, p. 656): "The northeast striking gash fractures now containing chrysotile are younger than antigorite veinlets with the same orientation, but older than a period of shearing."

All previous geologic maps of Cecil County (Bascom and others, 1902; Pearre and Heyl, 1960) show a lens-shaped area of serpentinite extending into the northwest part of the county from Pennsylvania and underlying the area around St. Patricks Church (formerly called Grub Corner on old maps). Because no positive evidence to confirm the existence of this serpentinite lens, such as float, soils, outcrops, or vegetation differences, was found in this area, it has not been included on the present geologic map (pl. 1).

Gabbro

Within the gabbroic part of the Baltimore Complex in Harford County, Southwick (1970, p. 400, fig. 2) drew a boundary between rocks on the northwest, where relict orthopyroxene is more magnesian than En_{60}, and rocks to the southeast, where relict orthopyroxene is less magnesian than En_{60}. My mapping has extended this compositional boundary to the northeast through the thick gabbroic part of the complex in Cecil County, where it approximates the position of a contact drawn by Leonard (1901, pl. XV) between "gabbro and noryte" on the northwest and "dioryte" on the southeast.

Hypersthene gabbro[5] is by far the most common rock type in the gabbroic part of the Baltimore Complex in Cecil County, although uralitization has been extensive and most rock types described here are based largely on palimpsest textures, mineral forms, and relatively few unaltered or partly altered minerals. Although rocks classified as augite gabbro or norite are present within the complex in Harford County (Southwick, 1969, p. 60), most of the gabbros contain approximately equal amounts of hypersthene and augite. Southwick (1970, p. 405-407) referred to these rocks as hypersthene gabbro. In his description of the Baltimore Complex in Baltimore and Howard Counties, Hopson (1964, p. 142) also considered hypersthene gabbro to be the predominant type of rock.

The principal minerals of the hypersthene gabbro are hypersthene, augite (commonly "diallage"), and calcic plagioclase. The least altered hypersthene gabbros in Cecil County have allotriomorphic- or hypidiomorphic-granular textures. My few measurements of optic angles

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[5] **Hypersthene gabbro** in the terminology of Williams (1884, 1886, 1890), Hopson (1964), and Southwick (1970).

of clinopyroxene agree well with Southwick's (1970), and suggest that the pyroxene is a normal Ca-bearing variety. This was confirmed by microprobe analysis (Hanan, 1976, p. 28). Some thin sections of hypersthene gabbro have minor amounts of brown hornblende as an interprecipitate mineral (Hopson, 1964, p. 146). As Hopson stated (p. 146):

> The brown hornblende occurs as interstitial fillings between the peri-euhedral minerals or encloses them poikilitically. In each case, it is in sharp contact with the pyroxenes and has clearly grown *around* them. In contrast, the green uralitic hornblende eats into the pyroxenes along their margins, cleavages, and parting planes, gradually replacing them.

Olivine gabbros, for the most part completely uralitized, are very rare in the Cecil County part of the Baltimore Complex. Williams (1884, 1886, 1890), Herz (1951), and Hopson (1964) all described olivine gabbros in the gabbroic part of the complex in Baltimore County, although all stated that they are not common.

Feldspathic "net veins" are found in the gabbroic part of the Baltimore Complex in Cecil County, but most are less than 3 feet (~1 m) thick and cannot be shown on the geologic map. These veins are composed of large uralitized pyroxene crystals in a matrix of plagioclase crystals. I did no petrographic work on the veins, but Hopson (1964, p. 148) gave a petrographic description of the veins in Baltimore County. Both Hopson (1964, p. 140) and Southwick (1969, p. 61) stated that these veins are common in the gabbroic part of the complex elsewhere in Maryland.

Talc schist

Bodies of talc schist occur at several places within the gabbro unit of the Baltimore Complex (pl. 1). The largest of these, about 1 mile (1.6 km) long, is in the vicinity of Octoraro, on Octoraro Creek at the intersection of New Bridge Road and Horseshoe Road. Another is exposed along the Susquehanna River about 0.5 mile (0.8 km) northwest of Pilot Station, where Bell Manor Road turns northeast away from the river. The rock in these bodies is predominantly a fine-grained talc schist with lesser amounts of chlorite schist and shows the effects of strong shear deformation. Except for outcrops along stream banks, these talc schists are poorly exposed.

GRANITIC ROCKS

Small areas of quartz-rich granitic rocks, completely surrounded by gabbroic rocks of the Baltimore Complex, were mapped at several places in Cecil County (pl. 1). The largest of these areas is about 1,700 ft (500 m) east of Oakwood. Another is along the Susquehanna River about 1,300 ft (400 m) southeast of the mouth of Conowingo Creek. Contacts between the granitic rocks and the gabbros are not exposed. Because of their weathered condition and limited exposure, these granitic rocks were not studied in detail. The only good outcrop is on the east side of U.S. Rte. 222 south of Old Conowingo Road. The relations between the granitic and gabbroic rocks and the significance of the granitic rocks are unknown. The granitic rocks could be: (1) granitic intrusions into the Baltimore Complex, either before or after it was emplaced in its present position; (2) late-stage differentiates of the complex; or (3) antiformal exposures of the underlying lithology in windows through the Baltimore Complex thrust sheet.

GABBRO AND SERPENTINITE AT GRAYS HILL

Gabbroic rocks and lesser amounts of serpentinite occur in the valley of Big Elk Creek and its tributaries north of Elkton, in deep railroad cuts and small stream valleys near the Delaware State line northeast of Elkton, and on and around Grays Hill, east of Elkton (pl. 1). An additional very small outcrop area of gabbro is present along Little Elk Creek about 2.5 miles (4 km) northwest of Elkton. The gabbroic rocks are poorly exposed and generally deeply weathered, and range from extremely coarse-grained hypersthene metagabbro to finer grained, more equigranular metagabbro. The coarse-grained rocks are found as large boulders in and around the small stream that runs westward from Grays Hill. Finer grained metagabbro blocks are found as float on Grays Hill and in outcrops along Big Elk Creek. Deeply weathered serpentinite crops out along with gabbro in railroad cuts around Interstate 95 and in small stream valleys nearby. In this area, the rocks are commonly covered and coated with iron silicates and have a "honeycomb" texture. This material was mined for iron ore in the area of Chestnut Hill and Iron Hill in Delaware.

Mineralogically and chemically (table 11) some of the gabbroic rocks of the gabbro and serpentinite unit are similar to some of the rocks northeast of Havre de Grace, in Harford County, that Southwick (1969; Southwick and Owens, 1968) called "metagabbro at Aberdeen."

AMPHIBOLITE DIKES AND SILLS

Hundreds of greenish-black, fine- to medium-grained plagioclase-hornblende amphibolite dikes have intruded the Port Deposit Gneiss and some units of the James Run Formation along the Susquehanna River. These dikes cannot be traced far from the river, as all who have studied them have noted, although I found several thin, weathered ones in the James Run rocks as far as 2 miles (3.2 km) northeast of the river. Hershey (1936, p. 26-27; 1937, p. 118) counted more than 150 dikes along the Cecil County side of the Susquehanna (also see Bascom, 1902, p. 97-98). Only the thickest are shown on the geologic map (pl. 1).

The mafic dikes range in thickness from a few inches (a few centimeters) to about 20 ft (6 m). Many have well-developed, fine-grained chilled margins, and some have relict flow structures (fig. 22). Bascom (1902, p. 97-98) described the location of many of the larger dikes in detail, and correctly called them "hornblendic dikes." Hershey (1936, p. 26-27), however, stated: "Since hornblende is always present in large amounts, usually over 60%, these dark dikes are called hornblende lamprophyres." Southwick (1969, p. 70) followed Hershey and described the dikes as "lamprophyric dikes." Both Hershey (1936, p. 26) and Southwick (1969, p. 70) reported orthoclase in the dikes along the Susquehanna, but my sampling failed to find any potassium feldspar. Thus, there may be lamprophyre dikes along the Susquehanna, but most of the dikes are not lamprophyres, even though some are rich in hornblende. The mineralogy and composition (table 5) of these dikes indicates that they are metabasalt.

The mafic dikes have intruded the Port Deposit Gneiss and part of the James Run Formation, but have been metamorphosed along with the intruded rocks. The chilled margins on some of the dikes indicate that the host rocks, including the Port Deposit Gneiss, were relatively cool when the dikes were intruded. Because of this, and because the dikes cut at least one schistosity in the host rocks (also see Hershey, 1936, p. 27; Marshall, 1936, p. 119; Southwick, 1969, p. 70), a period of lowered temperatures between metamorphic and deformational events or phases is indicated. Thus, the evidence suggests that the James Run and Port Deposit rocks were deformed and metamorphosed before the dikes were intruded.

Perhaps the most significant thing about the amphibolite dikes is their limited distribution (also see Bascom, 1902; Hershey, 1936, p. 26). The dikes appear to be exclusively confined to the Port Deposit Gneiss and the James Run Formation and do not occur in any of the rocks northwest of Steel Island (pl. 1). This constitutes evidence that the Port Deposit Gneiss and some of the rocks of the James Run Formation are allochthonous. Crowley (1976) suggested that the James Run rocks in Baltimore and Harford Counties are in thrust contact with Baltimore Complex rocks, and this was supported by the work of Fisher and others (1979), but the evidence from the dikes indicates that the Port Deposit is also allochthonous along with the James Run rocks. If the dikes intruded into relatively cool, already deformed and metamorphosed rocks of the Port Deposit and James Run Formations, but are not present in the units which lie to the northwest, then the deformation, metamorphism, and intrusion must have occurred elsewhere, before these rocks were thrust into their present locations. That the James Run and Port Deposit were metamorphosed before being emplaced in their present positions is also supported by the fact that clasts of James Run rocks in the Sykesville and Conowingo diamictites were already metamorphosed and deformed before being deposited (Fisher and others, 1979, p. 32).

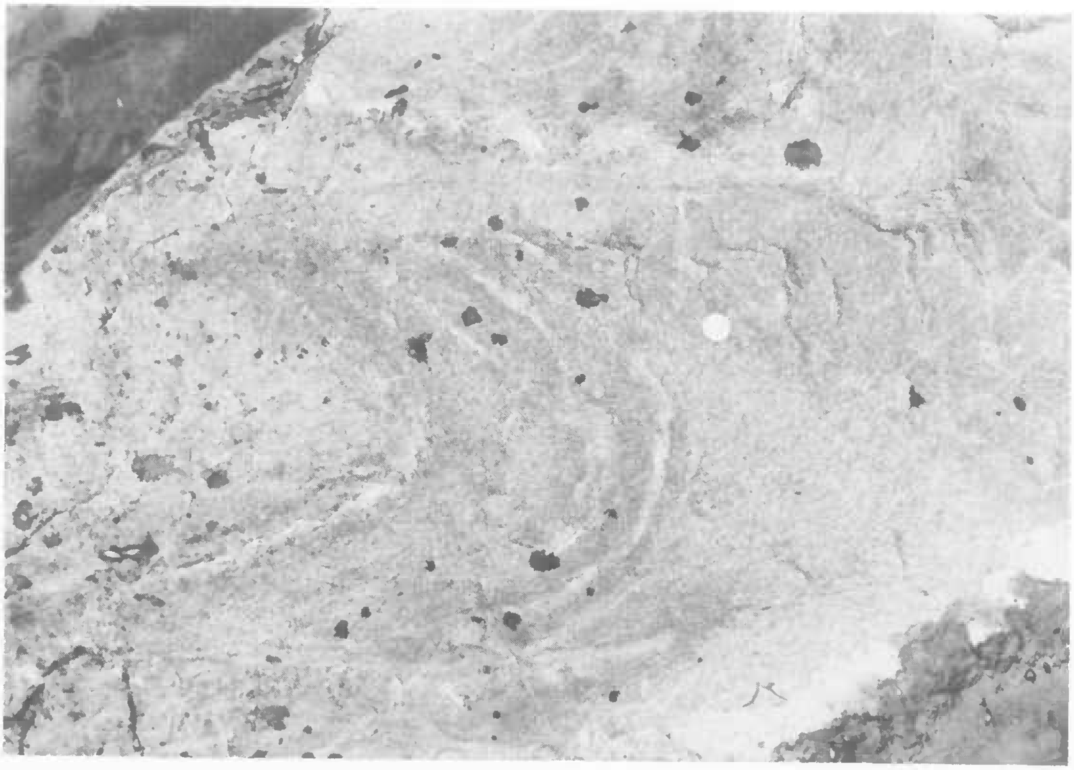

FIGURE 22: Hornblende amphibolite dike showing relict igneous flow banding. Coin is 1 inch (2.5 cm) in diameter. Outcrop along Rock Run.

DIABASE DIKES

Several northeast-trending Late Triassic or Early Jurassic dikes of equigranular, fine-grained, dark-grayish-black diabase are found in Cecil County (pl. 1). The largest of these dikes passes just southeast of Colora. Although I was able to follow it for about 1.7 miles (2.8 km), I was unable to locate several dikes mapped by Bascom (Bascom and Miller, 1920).

The diabase dikes have ophitic textures and are composed of augite, labradorite, opaques (chiefly magnetite), small amounts of brown biotite, and sparse accessories. Fisher (1964, p. 15-17) gave detailed petrographic descriptions of similar dikes farther southeast in Maryland.

One Cecil County diabase dike (table 6) is high in titanium and is quartz normative. It is chemically similar to the Mesozoic high-Ti, quartz-normative tholeiitic dikes of eastern North America (Weigand and Ragland, 1970).

FELSIC PLUTONIC ROCKS

PORT DEPOSIT GNEISS

A variety of plutonic and plutonic-appearing granitic rocks crop out along both sides of the Susquehanna River in northeastern Maryland and underlie large areas of Harford and Cecil Counties. Grimsley (1894) named these rocks the Port Deposit Granite for exposures in the quarry on the east side of Maryland Rte. 222, just north of the town of Port Deposit, Cecil County. At the same time he gave the name "Rowlandsville Granite," after the small community of Rowlandsville on Octoraro Creek in Cecil County, to the large outcrop belt of gneissic rocks northwest of his Port Deposit Granite. Bascom (1902) and Insley (1928)

TABLE 5
ANALYSES OF TWO HORNBLENDE AMPHIBOLITE DIKES IN CECIL COUNTY

Modal analyses			Chemical analyses					Normative analyses		
						Recalculated to 100% (water free)				
	1	2		1	2	1	2		1	2
quartz	3.2	2.9	SiO_2	52.6	48.0	53.57	50.40	QZ	6.83	-
plagioclase	38.2	35.0	Al_2O_3	14.9	14.2	15.15	14.64	OR	4.51	5.24
hornblende	56.0	58.1	Fe_2O_3	2.8	2.3	2.85	2.37	AB	22.51	13.96
cummingtonite	-	-	FeO	10.0	6.2	10.18	6.39	AN	27.26	29.92
actinolite	0.5	tr	MgO	4.2	11.2	4.28	11.65	CO	-	-
biotite	-	-	CaO	8.7	11.0	8.86	11.34	WO	6.47	10.83
muscovite	-	-	Na_2O	2.6	1.6	2.65	1.65	DI	12.98	20.77
chlorite	0.6	0.3	K_2O	0.75	0.86	0.76	0.89	EN	10.65	21.68
apidota	0.6	1.7	H_2O+	0.11	1.6	-	-	FS	15.18	7.00
clinozoisite	-	-	H_2O-	1.2	-	0.09	-	FO	-	5.14
garnet	-	-	TiO_2	1.1	0.43	1.12	0.44	FA	-	1.83
calcite	-	-	P_2O_5	0.18	0.03	0.18	0.04	MT	4.14	3.44
magnetite	0.7	0.8	MnO	0.36	0.17	0.37	0.18	IL	2.13	0.84
hematite	-	-	CO_2	0.05	0.02	-	0.02	AP	0.43	0.10
others	0.2	1.2						Other	-	0.05(cc)
Total	100.0	100.0	Total	99.6	98.7	100.0	100.0	Diff.In.	33.75	19.19
Points	1,000	1,000						SALIC	61.02	49.11
								FEMIC	39.00	50.90

1. From dike exposed in Rock Run about 3,000 ft (1,000 m) upstream from the Susquehanna River. Dike averages about 4 ft (1.2 m) in thickness and has relict flow structures.
2. From dike about 2 ft (0.6 m) thick exposed along the Susquehanna River in railroad cut of the CONRAIL system about 200 ft (60 m) southeast of the contact between the Port Deposit Gneiss and the Happy Valley Branch Member of the James Run Formation.

followed Grimsley. Hershey (1937) considered all the granitic and granitic-appearing rocks to be part of a single, large plutonic intrusive complex, which he named the Port Deposit Granodiorite complex. Southwick (1969) followed Hershey, but changed the name to Port Deposit Gneiss because the rocks are obviously foliated and metamorphosed.

My work has shown that much of the northwestern outcrop belt of granitic-appearing gneiss, which I (Higgins, 1972) informally called Conowingo gneiss, and now Conowingo diamictite, is mostly of sedimentary origin. In addition, large parts of the southern outcrop belt of granitic-appearing gneisses have been found to be metavolcanic and metasubvolcanic rocks that belong to the James Run Formation (pl. 1). Most of these rocks in Harford County were originally mapped by Southwick (Southwick and Owens, 1968) as Port Deposit Gneiss, but his later remapping (Southwick, 1979) showed us to be more in agreement (fig. 5) and has also provided some new insights into the origin of some of these rocks.

Coarse-grained phase

At its type locality, the Port Deposit quarry, the Port Deposit Gneiss is a coarse-grained, thoroughly recrystallized, doubly-foliated, even-textured, plutonic-appearing rock with the mineralogical composition of a quartz-rich biotite granodiorite (Hopson, 1960; Southwick, 1969, 1979; and table 7, this paper). Despite the thorough recrystallization and the lack of definitive plutonic textures in the Port Deposit, the uniformity and overall plutonic appearance of this rock have caused everyone who has studied it to conclude that it is plutonic in origin. I mapped this rock as the coarse-grained phase of the Port Deposit Gneiss (pl. 1).

Coarse-grained Port Deposit Gneiss crops out in a northeast-trending belt about 1.2 miles (2 km) wide and 5 miles (8 km) long in Cecil County (pl. 1). It extends at least 7.5 miles (12 km) southeastward into Harford County. To the northwest, the coarse-grained gneiss is in

TABLE 6
CHEMICAL AND NORMATIVE ANALYSES OF A MESOZOIC DIKE IN CECIL COUNTY

Sample REV-4				
Chemical Analysis			Normative Analysis	
		Recalculated to 100% (water free)		
SiO_2	52.1	53.02	QZ	4.87
Al_2O_3	14.2	14.45	OR	3.31
Fe_2O_3	1.3	1.32	AB	15.50
FeO	8.9	9.06	AN	29.55
MgO	7.4	7.53	CO	-
CaO	10.6	10.79	WO	9.62
Na_2O	1.8	1.83	DI	18.87
K_2O	0.55	0.56	EN	18.75
TiO_2	1.1	1.12	FS	14.03
P_2O_5	0.14	0.14	FO	-
MnO	0.18	0.18	FA	-
CO_2	<0.05	-	MT	1.92
H_2O+	0.87	n.a.	IL	2.13
H_2O-	0.53	n.a	AP	0.34
			Other	-
Total	99.7	100.00	Diff.I.	23.68
			SALIC	53.23
			FEMIC	46.78

sharp contact with the metagraywacke-with-amphibolite, and the gneiss appears to be folded with this unit. Beyond its northeastern contact, small occurrences of the gneiss are found within the metagraywacke-with-amphibolite unit. Part of the southeastern contact of the coarse-grained Port Deposit Gneiss is covered by Coastal Plain deposits, but for about 1.2 miles (~2 km) northeast and 1.8 miles (3 km) southwest of these deposits, the coarse-grained phase of the gneiss is in gradational contact with rocks that I mapped as fine-grained Port Deposit.

In thin section, the texture of the coarse-grained Port Deposit Gneiss is very similar to its texture in outcrop. Large ellipsoidal or lozenge-shaped pods of quartz and feldspar are outlined by biotite. These pods are formed by intersecting foliations. Locally, the gneiss has small amounts of microcline, chlorite, epidote, allanite, and garnet (Southwick, 1969, 1979; Higgins, 1972).

Fine-grained phase

As one follows the Susquehanna River southeastward from about the middle of the long, narrow town of Port Deposit, finer grained phases of Port Deposit Gneiss become more prevalent. Where exposed in the southern part of the town, coarse-grained Port Deposit Gneiss, although not generally as coarse as at the type locality, is intercalated with the fine-grained phase on a scale of tens to hundreds of feet (tens of meters). The finer grained gneisses and granofels increase in abundance and thickness through an interval of about 0.9 mile (1.3 km), until rocks of unquestionable subvolcanic and (or) volcanic parentage are present. The latter have blocky relict phenocrysts of plagioclase, relict volcanic or subvolcanic textures in thin section, and locally, relict pumice lapilli, accretionary lapilli, and amygdules. I assigned the metavolcanic and volcanic rocks to the James Run Formation and the mixed interval to the fine-grained phase of the Port Deposit Gneiss (pl. 1), even though some of the

TABLE 7
MODAL ANALYSES OF PORT DEPOSIT GNEISS, CECIL COUNTY

	PORT DEPOSIT GNEISS			
	1	2	3	4
quartz	39.8	47.5	46.4	38
plagioclase	39.9	40.5	40.1	32
k-feldspar	6.1	4.8	0.3	10
muscovite	1.5	0.4	5.2	2
biotite	9.3	3.3	5.6	10
chlorite	0.1	-	0.8	-
calcite	-	-	-	-
garnet	0.1	-	0.1	*
epidote	2.7	1.8	0.9	6
allanite	tr	-	tr	-
apatite	-	-	tr	-
tourmaline	-	-	tr	-
monazite	-	-	-	-
zircon	-	-	tr	-
magnetite	-	-	tr	-
hematite	-	-	-	-
clinozoisite	-	1.2	0.2	-
others	0.5	0.5	0.5	2
Total	100.0	100.0	100.0	100.0
Points	1,609	1,557	1,500	-

* Garnet included in *others* for this sample.

1. From northeast wall of Port Deposit quarry along U.S. Rte. 222 about 0.25 mile (0.4 km) northwest of Rock Run, Cecil County.
2. Siliceous layer in north wall of Port Deposit quarry along U.S. Rte. 222 about 0.25 mile (0.4 km) northwest of Rock Run, Cecil County.
3. Average modal composition of Port Deposit Gneiss, Cecil County.
4. Average modal composition of "Port Deposit Granodiorite," from Hopson (1960, p. 28).

finer grained rocks in this mixed interval are probably transitional between plutonic and subvolcanic. Still another type of rock mapped as fine-grained Port Deposit is the quartz augen gneiss described by Southwick (1979, p. 106). Mineralogically, many of the rocks in the fine-grained phase are similar to those of the coarse-grained phase.

Some of the rocks in the fine-grained phase of the Port Deposit Gneiss are similar to coarse-grained Port Deposit in thin section; others have textures similar to subvolcanic rocks like some of those depicted by Cater (1969) in his description of the Cloudy Pass batholith in Washington State, and the subvolcanic rocks into which it grades.

In summary, the fine-grained phase of the Port Deposit Gneiss is composed of interlayered rocks of probable plutonic and subvolcanic origin, and of rocks that appear to be transitional between plutonic and subvolcanic. These rocks are so intimately interlayered that it is virtually impossible to map them separately.

The intimate association of epizonal plutons with chemically similar volcanic rocks of approximately the same age has long been recognized in many different areas (for example: Fuller, 1925; Daly, 1933, p. 141-146; Buddington, 1959, p. 678, 685-694; Cater, 1969; Fiske and others, 1963; Hopson and others, 1966; Hamilton and Myers, 1967; Tabor and Crowder, 1969; Atherton and Brenchley, 1972; Myers, 1975; Elston and others, 1975; Taylor, 1976; Bussell and others, 1976; Bussell and McCourt, 1977; Pitcher, 1978; Thorpe and Francis, 1979; Atherton and others, 1979). In fact, this association is so common that it led Hamilton and Myers (1967, p. C1) to conclude that batholiths generally crystallize at relatively shallow depths, and that "many of them reach the surface and crystallize beneath a cover of their own volcanic ejecta."

There are numerous descriptions in the literature of epizonal plutons that broke through to the surface to feed volcanic eruptions, the products of which generally were intruded only slightly later by younger parts of the plutons. Each of these plutons has some characteristics that make it unique, but all the plutons have one characteristic in common: they are all closely associated in time and space with volcanic rocks whose chemical compositions either match or closely overlap those of the plutonic rocks. In addition, most of the plutons show some of the following characteristics: (1) They have some kind of finer grained border phase, or subvolcanic phase, representing the transition between plutonic and volcanic rocks. Such a border phase of subvolcanic rocks is well-displayed in the Late Cenozoic Cloudy Pass batholith in the northern Cascades of Washington State (Cater, 1969; Tabor and Crowder, 1969). Tabor and Crowder (1969, p. 22) stated: "The border complex is a broad zone of nonporphyritic to highly porphyritic andesite and dacite that occurs along the steep contact near Hart Lake. The chilled rock in this zone both grades into and is intruded by the main pluton." (2) They have intricate dike-and-sill complexes in which the dikes and sills have intruded the consanguineous volcanic rocks and in turn are intruded by the pluton. A good example of this is the dike-and-sill complex associated with the Cenozoic Tatoosh pluton in Mount Ranier National Park, Washington State, which Fiske and others (1963, p. 48) described as "an unbelievably complex assemblage of hypabyssal rocks." Fiske and others (1963, p. 48-52) described the hypabyssal complexes as follows:

> The Tatoosh pluton is bordered by complex swarms of sills and dikes, which are similar in composition to the rocks of the core but are even more varied in texture. *** ...sill is piled on sill until 50 to 90 percent of the rock is intrusive. Septa of wallrock between sills are thin or have been so shredded and mangled by crosscutting dikes and sills that in places an indescribable jumble of interpenetrating intrusive rocks replaces the orderly succession of superposed sills. *** ...larger sills are composite; two to five or more intrusions share a single chamber. Many of the younger sills cluster near the centers, or intrude along the edges of older sills; but some wander irregularly, breaking from one side to another, subdividing, or even turning abruptly upward and leaving the sill chamber as dikes. *** The intrusive rocks of the sill complexes are chiefly aphanitic to medium-grained porphyries, ranging in composition from diorite to quartz monzonite. Somewhat coarser sheetlike bodies of quartz diorite, quartz monzonite, and granodiorite occur within the tops of some of the larger stocks and show features that suggest huge "cedar-tree laccolith" complexes... These complexes appear to represent a transition between the main massive body of the stock and the surrounding complex of individual sills separated by septa of wallrock. *** The interrelations between pluton core and hypabyssal sheath are complicated in other ways... The pluton core only rarely grades upward and outward into sills; in most places it cuts them abruptly, or is separated from them by an intervening plutonic breccia composed of angular or rounded fragments of sill rock invaded by a coarser grained matrix. *** These contact relations seem to establish that the sills are at least slightly older than the main mass of the pluton, and in many places the pluton invades them. But on the other hand, there is equally good evidence that the sills were intruded after parts of the core had already solidified; the most striking evidence is afforded by inclusions that are thickly sprinkled through many sills and dikes. In general, the sill rocks have the same range in composition as the rocks from the main pluton and its roof zone, but they are finer grained and most of them are markedly porphyritic.

(3) The plutons locally broke through to the surface to feed volcaniclastic eruptions forming welded tuffs and tuff breccias that in places grade into highly vesicular and (or) amygdaloidal hypabyssal rocks (Fuller, 1925; Fiske and others, 1963, p. 52-59). (4) In many of the plutons it can be seen that the upper parts crystallized beneath a roof composed of their own volcanic ejecta (Hamilton and Myers, 1967). (5) The country rocks around and above many of the plutons show effects of contact metamorphism and metasomatism, and have been intruded by swarms of dikes that are late-stage differentiates of the pluton (Tabor and Crowder, 1969; Buddington, 1959). (6) There is a tendency for the younger parts of many of the plutons to be more silicic and more potassic than the older parts, the associated hypabyssal rocks, and the

associated volcanic rocks (Fiske and others, 1963; Cater, 1969; Tabor and Crowder, 1969; Atherton and others, 1979; Thorpe and Francis, 1979).

Despite the fact that it has been subjected to multiple deformation and metamorphism, the Port Deposit Gneiss preserves many of the characteristics of an epizonal, surface-breaking pluton: (1) Radiometric ages (Higgins and others, 1977; A.K. Sinha, oral communication, 1981) show that within experimental error it is contemporaneous with the metavolcanic rocks of the James Run Formation. (2) Its chemical composition overlaps that of some of the James Run rocks, but it is slightly richer in silica and slightly more potassic than many of the James Run rocks (see GEOCHEMISTRY section, and figs. 23 and 25). (3) It has a finer grained border phase that is probably subvolcanic and appears to grade into both the coarser grained plutonic rocks and the volcanic rocks. (4) Some of the James Run rocks are volcaniclastic, probably welded tuffs, and have broken phenocrysts like those in the volcaniclastic rocks associated with the Tatoosh pluton (Fiske and others, 1963, p. 52-59). (5) The complex, partly volcanic, partly hypabyssal, partly plutonic sequence exposed in the Susquehanna River gorge southeast of the town of Port Deposit is probably a dike-and-sill complex like those associated with the Tatoosh pluton. Therefore, I suggest that the Port Deposit Gneiss was an epizonal, surface-breaking pluton that fed the eruptions for some of the James Run Rocks. A similar origin is suggested for some of the other plutons associated with the James Run Formation.

GNEISS ON GARRETT ISLAND

A quartz-rich, "hobnail-textured" granitic gneiss crops out over the southeastern two-thirds of Garrett Island in the Susquehanna River (pl. 1) and on the adjacent mainland of Cecil County. Exposures are good along the southwestern shore of the island, but accessibility is limited. Southwick (1979; Southwick and Owens, 1968) considered this to be Port Deposit Gneiss, like that of the coarse-grained phase at the Port Deposit quarry. It is strikingly similar to rocks in the Virginia Piedmont that Pavlides (1981) considered trondhjemitic, but it also strongly resembles some gneisses in the James Run Formation.

GNEISS NEAR ELKTON

About 2,000 ft (600 m) south of Elk Mills is a medium-grained, plutonic-appearing gneiss (pl.1) that I earlier informally called "Elkton gneiss" (Higgins, 1973), or "gneiss in the vicinity of Elkton" (Higgins and others, 1977). This rock unit occurs in a band about half a mile (800 m) wide between the Frenchtown Member of the James Run Formation on the north and mafic rocks of the Grays Hill gabbro and serpentinite body to the south. This band extends for about a mile (1,600 m) west of Big Elk Creek; in the interfluvial divide areas to the east and west, this gneiss is covered by Coastal Plain deposits.

The gneiss crops out only along Big Elk Creek south of Elk Mills and in the large quarry of D.M. Stoltzfus and Son, Inc., on the east side of the creek. In this quarry, the rock is a homogeneous, well-foliated biotite granodiorite gneiss with a granoblastic texture. An important aspect of this gneiss is its close association with metavolcanic or (and) metasubvolcanic porphyritic felsites of the James Run Formation that crop out along Big Elk Creek just north of Elk Mills. This association is probably much the same as that between the Port Deposit Gneiss and the James Run metavolcanic rocks.

GNEISS AT ROLLING MILL

A biotite-plagioclase gneiss, commonly containing tiny garnets and magnetite crystals, underlies a large area in northeastern Cecil County between Little Elk Creek and the Delaware state line. The gneiss is well-exposed along Big Elk Creek (pl. 1), particularly around the site of Parks Rolling Mill where Jackson Hall Road formerly crossed the creek. The unit is everywhere surrounded by metavolcanic rocks of the James Run Formation, but the contacts are never exposed.

The gneiss at Rolling Mill is petrographically similar to the gneiss near Elkton, and it may be correlative because the two are separated by only a thin belt of James Run rocks.

PEGMATITE DIKES

Several large pegmatite dikes crop out in Cecil County, but most are weathered. They are most prevalent in the pelitic schist and pelitic gneiss units, and generally strike northeast, but cannot be traced very far. Some may be as much as 100 ft (~30 m) thick (Bascom, 1902, p. 101-103), although only those dikes that exceed about 20 ft (~6 m) in width have been shown on the geologic map (pl. 1). The locations, thicknesses, and compositions of these dikes were described in detail by Bascom (1902). Her map (Bascom and Miller, 1920) shows several pegmatite dikes that I was unable to locate.

The dikes are composed of large crystals of microcline, fairly large, irregularly-shaped quartz grains, and large books of muscovite. Some of the thicker dikes were mined in the last century for feldspar and muscovite (Singewald, 1928, p. 106-109).

QUARTZ VEINS

Small quartz veins, generally with tourmaline, are common in the rocks of Cecil County. Only those that more than 20 ft (~6 m) thick are shown on the geologic map (pl. 1), although several large quartz veins or dikes may be as much as 100 ft (30 m) thick. Most of the larger veins are composed of opaque, milky-white quartz, but many carry small amounts of yellow-stained muscovite and tourmaline. Some of the larger quartz veins appear to be associated with small shear zones.

GEOCHEMISTRY

All chemical analyses made in the course of this project were performed in the laboratories of the U.S. Geological Survey at Reston, Virginia. Major element oxides were determined by P. Elmore, H. Smith, J. Kelsey, and F. Brown, using the methods described by Shapiro (1975) supplemented by atomic-absorption spectrometry. Large-cation trace elements, minor ferromagnesian elements, and rare-earth elements were analyzed by L.J. Schwarz, using instrumental neutron activation (see Pavlides, 1981, p. A9 for details). Other elements were determined by N. Rait, using quantitative spectrographic analysis. Descriptions of the sample locations are on open file with the Maryland Geological Survey.

JAMES RUN GNEISS AND PORT DEPOSIT GNEISS

Except for scattered amphibolites and some of the rocks in the "volcanic complex of Cecil County" (Marshall, 1936, 1937), metavolcanic rocks were unknown in the eastern Maryland Piedmont until Hopson (1964) convincingly argued for a volcanic origin for a sequence of rocks in Baltimore City that he called the "Baltimore paragneiss." All previous workers had mapped these rocks as Baltimore Gneiss, and thus part of the approximately 1.1 b.y.-old "basement complex." In addition to field evidence and the striking resemblance of these rocks to unmetamorphosed volcaniclastic and epiclastic rocks in the Cascades and in Japan, Hopson (1964) used the chemical compositions of the rocks of his Baltimore paragneiss as evidence of their volcanogenic origin. He compared them with average sedimentary rocks, a series of average calc-alkaline lavas, altered marine volcanic siltstones, and quartz keratophyres formed by alteration of volcanic ash, and concluded (Hopson, 1964, p. 35) that the paragneiss represents "a thick sequence of rhyodacitic to basaltic sediments, which may have been albitized prior to high-grade metamorphism." These rocks are now considered to be part of the James Run Formation (Southwick, 1969; Southwick and others, 1971; Higgins, 1971a, 1972; Crowley, 1976; Crowley and others, 1976).

Southwick (1969, p. 47-50, 54, 57-59) studied the chemical characteristics of rocks of the James Run Formation in Harford County, and a few of these rocks in Cecil County. Like Hopson (1964), he noted (1969, p. 47) "the large excess of Na_2O over K_2O, even in very siliceous rocks, and the variable amounts of CaO in the mafic layers," and concurred with Hopson on the volcanic origin of the James Run Formation. Southwick (1969, p. 49) concluded that the James Run rocks had normal calc-alkaline compositions when erupted, but were altered after deposition either by reaction with resurgent connate water during diagenesis and incipient metamorphism accompanying deep burial, or by direct hydration of plagioclase to calcium zeolites followed by base exchange with sea water. He made a point of the uneven extent of diagenetic sodium enrichment (spilitization), citing the variable ratio of Na to Ca in James Run amphibolites. He further concluded (Southwick, 1969, p. 49) that adjustments in the distribution of Ca, Na, and K probably took place during metamorphism, but that the presence of different plagioclase feldspars in different beds a few meters apart indicates that the migration of Na and Ca was sluggish, and that there is no evidence of large-scale metasomatism of lime or alkalis during metamorphism. Hopson (1964, p. 32) had earlier concluded that "the high-grade metamorphism of the paragneiss was evidently isochemical."

Metavolcanic rocks of the Chopawamsic Formation and of Pavlides' (1981) Ta River Metamorphic Suite in northern Virginia have been tentatively correlated with the James Run Formation (Pavlides, 1981; Southwick and others, 1971; Higgins, 1972). Pavlides' (1981) extensive geochemical study shows that the rocks in his "central Virginia volcanic-plutonic belt" are geochemically similar to the rocks of the James Run Formation. Like Southwick (1969), Pavlides (1981, p. A9) favored alteration as the process by which some of the Virginia rocks

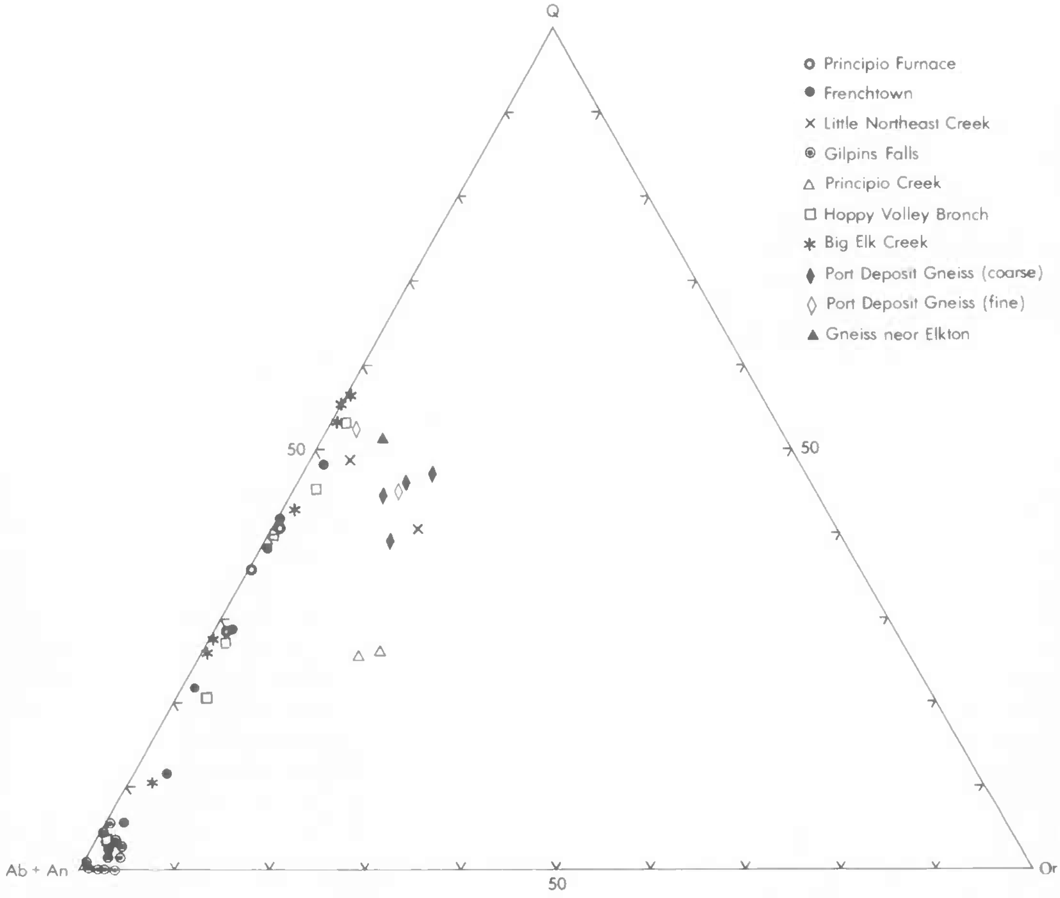

FIGURE 23: Plot of normative **Q - Or - Ab+An** for rocks of the James Run Formation, Port Deposit Gneiss, and the gneiss near Elkton.

became highly sodic. He (1981, p. A9-11) stated that the mobility of K_2O since the rocks were erupted "is demonstrated by the marked reversals of K_2O abundances in some of the metafelsites having about the same SiO_2 content."

MAJOR OXIDES

The major oxide compositions of rocks of the James Run Formation in Cecil County (table 8) are similar to those in Baltimore and Harford Counties. Most of these rocks could be called spilites, keratophyres, and quartz keratophyres. In a plot of normative quartz-orthoclase-albite + anorthite (fig. 23), most of the James Run rocks plot along the quartz-plagioclase side of the triangle. The three rocks that plot slightly more toward the orthoclase apex have high biotite contents, and thus are richer in K_2O. On this same plot, the Port Deposit Gneiss plots close to some of the more silicic units of the James Run, but generally slightly more toward the **Or** apex. In figure 24, rocks of the James Run Formation, including previously published analyses from Ward (1959), Hopson (1964), Southwick (1969), and Higgins (1972), are compared with altered marine volcanic rocks, average sedimentary rocks, and average calc-alkaline volcanic rocks. Figure 25 compares James Run rocks with metavolcanic rocks of Pavlides' (1981) "central Virginia volcanic-plutonic belt." The chemical similarity between the Virginia rocks and those of the James Run supports their geologic correlation.

TABLE 8
CHEMICAL AND NORMATIVE COMPOSITIONS OF ROCKS OF THE JAMES RUN FORMATION, PORT DEPOSIT GNEISS, AND GNEISS AT ROLLING MILL

		JAMES RUN FORMATION										
		Principio Furnace Member			Frenchtown Member							
		NE-6	HV-10V	HV-11V	6KC	6KM	HG-28	NE-39	BV-68	BV-71	HG-25	7K
CHEMICAL ANALYSIS	SiO_2	65.9	72.0	71.6	51.8	53.8	58.4	65.7	71.7	73.5	78.4	77.8
	Al_2O_3	14.8	13.1	12.8	16.3	15.7	14.8	13.8	14.2	13.2	12.7	11.7
	Fe_2O_3	4.0	2.3	2.5	3.0	2.4	5.3	1.7	1.6	1.5	0.36	0.78
	FeO	3.1	2.4	3.0	7.1	6.7	5.2	4.3	2.9	2.7	2.4	1.2
	MgO	1.1	1.1	1.0	5.8	6.5	2.8	3.9	0.83	0.60	0.41	0.51
	CaO	4.2	1.8	1.9	9.5	9.9	6.5	4.7	2.5	2.1	2.4	2.6
	Na_2O	5.2	5.2	5.7	3.1	2.4	4.3	4.4	5.0	5.0	3.8	4.2
	K_2O	0.16	0.13	0.13	0.20	0.31	0.16	0.15	0.12	0.08	0.63	0.19
	H_2O+	0.84	0.89	0.42	1.5	1.5	0.73	0.85	0.76	0.47	0.68	0.77
	H_2O-	0.28	0.11	0.05	0.28	0.22	0.02	0.04	0.09	0.14	0.0	0.11
	TiO_2	0.77	0.36	0.48	0.37	0.31	1.5	0.34	0.72	0.48	0.23	0.26
	P_2O_5	0.15	0.32	0.09	0.06	0.04	0.04	0.07	0.03	0.05	0.03	0.06
	MnO	0.15	0.26	0.06	0.0	0.10	0.08	0.14	0.09	0.03	0.03	0.09
	CO_2	<0.05	<0.05	<0.05	<0.05	0.05	>0.05	>0.05	<0.05	<0.05	<0.05	<0.05
	Total	100.0	100.0	99.8	99.1	99.9	99.9	100.1	99.9	99.9	100.1	100.1
CHEMICAL ANALYSIS RECALCULATED TO 100% (water free)	SiO_2	66.04	72.75	72.13	53.28	54.78	58.94	66.23	71.25	74.06	76.87	78.23
	Al_2O_3	14.94	13.24	12.90	16.76	15.99	14.92	13.91	14.33	13.30	12.78	11.80
	Fe_2O_3	4.04	2.32	2.52	3.09	2.44	5.35	1.71	1.61	1.51	0.36	0.79
	FeO	3.13	2.42	3.02	7.30	6.82	5.25	4.33	2.93	2.72	2.41	1.21
	MgO	1.11	1.11	1.01	5.97	6.62	2.83	3.93	0.84	0.60	0.41	0.51
	CaO	4.24	1.82	1.91	9.77	10.08	6.56	4.74	2.52	2.12	2.41	2.62
	Na_2O	5.25	5.25	5.74	3.19	2.44	4.34	4.44	5.05	5.04	3.82	4.23
	K_2O+	0.18	0.13	0.13	0.21	0.32	0.18	0.15	0.12	0.08	0.63	0.19
	TiO_2	0.78	0.36	0.48	0.38	0.32	1.51	0.34	0.73	0.48	0.23	0.26
	P_2O_5	0.15	0.32	0.09	0.06	0.04	0.04	0.07	0.03	0.05	0.03	0.06
	MnO	0.15	0.26	0.06	-	0.10	0.08	0.14	0.09	0.09	0.09	0.09
	CO_2	-	-	-	-	0.05	-	-	-	-	-	-
NORMATIVE ANALYSIS	OZ	24.64	35.94	31.62	3.35	7.34	16.10	22.37	34.00	87.79	44.77	48.06
	OR	0.96	0.78	0.77	1.22	1.87	0.95	0.89	0.72	0.48	3.75	1.13
	AB	44.43	44.46	48.59	26.98	20.68	36.72	37.53	42.70	42.63	32.35	35.83
	AN	16.73	6.91	8.90	30.82	31.72	20.80	17.60	12.32	10.17	11.78	12.61
	CO	-	1.92	0.04	-	-	-	-	1.38	1.20	1.48	-
	WO	0.39	-	-	7.20	7.39	4.79	2.27	-	-	-	-
	DI	2.69	-	-	14.10	14.42	9.25	4.44	-	-	-	-
	EN	2.77	2.77	2.51	14.86	18.48	7.04	9.79	2.09	1.51	1.03	1.28
	FS	1.41	2.42	2.76	10.23	10.18	2.87	6.24	3.01	3.01	3.81	1.31
	FO	-	-	-	-	-	-	-	-	-	-	-
	FA	-	-	-	-	-	-	-	-	-	-	-
	MT	5.86	3.37	3.65	4.47	3.54	7.76	2.49	2.34	2.19	0.53	1.14
	IL	1.48	0.69	0.92	0.72	0.60	2.88	0.65	1.38	0.92	0.44	0.50
	AP	0.36	0.77	0.22	0.15	0.10	0.10	0.17	0.07	0.12	0.07	0.14
	Other	-	-	-	-	0.12(cc)	-	-	-	-	-	-
	Diff.In.	70.03	81.18	80.98	31.55	29.58	53.78	60.80	77.41	80.90	80.86	83.02
	SALIC	86.76	90.01	89.93	62.37	61.10	74.58	78.40	91.11	92.26	94.13	95.64
	FEMIC	13.25	10.02	10.08	37.63	38.41	25.43	21.61	8.89	7.74	5.87	4.37

(continued next page)

TABLE 8 (continued)

		JAMES RUN FORMATION								
		Little Northeast Creek Member		Gilpins Falls Member						
		BV-85	NW-19R	P-1,c	P-1,v	P-1,r	PB-2,c	PB-2,t	PB-2,v	PB-2,r
CHEMICAL ANALYSIS	SiO_2	73.8	78.0	50.6	50.2	48.7	48.4	47.8	46.2	47.8
	Al_2O_3	13.8	13.1	10.2	10.4	18.1	15.8	18.5	13.4	17.5
	Fe_2O_3	1.7	0.61	2.1	2.5	5.8	4.5	5.3	4.8	55.3
	FeO	0.38	1.9	9.3	8.9	3.7	4.8	4.8	6.7	2.9
	MgO	0.91	0.70	9.7	9.6	4.5	8.7	6.0	8.5	4.7
	CaO	2.0	1.7	13.0	13.6	18.2	15.8	16.0	16.8	17.4
	Na_2O	3.7	4.0	1.7	1.8	1.8	2.4	1.5	0.64	1.9
	K_2O	2.4	0.74	0.19	0.12	0.06	0.06	0.09	0.09	0.8
	H_2O+	0.81	0.77	0.77	0.62	0.66	0.62	0.43	0.61	0.66
	H_2O-	0.14	0.03	0.11	0.09	0.17	0.15	0.23	0.11	0.11
	TiO_2	0.30	0.22	0.64	0.64	0.64	0.56	0.53	0.72	0.64
	P_2O_5	0.09	0.06	0.08	0.07	0.11	0.10	0.08	0.08	0.09
	MnO	0.16	0.06	0.11	0.14	0.06	0.11	0.11	0.14	0.06
	CO_2	<0.05	<0.05	0.04	0.02	0.02	0.02	0.04	0.02	0.08
	Total	100.0	99.9	98.5	98.5	100.3	99.8	99.0	98.8	99.0
CHEMICAL ANALYSIS RECALCULATED TO 100% (water free)	SiO_2	74.33	78.70	51.81	51.33	46.94	48.86	48.40	47.10	48.46
	Al_2O_3	13.94	13.22	18.19	15.95	18.78	13.66	17.82	-	-
	Fe_2O_3	1.72	0.62	2.15	2.56	5.63	4.54	5.39	4.89	5.40
	FeO	0.36	1.92	9.52	9.10	3.72	4.64	4.68	8.83	2.95
	MgO	0.92	0.71	9.93	9.82	4.52	8.76	6.10	8.67	4.78
	CaO	2.02	1.72	13.31	13.91	18.29	15.95	16.27	17.13	17.71
	Na_2O	3.74	4.04	1.74	1.64	1.81	2.42	1.53	0.65	1.93
	K_2O+	2.42	0.75	0.09	0.12	0.06	0.06	0.09	0.09	0.06
	TiO_2	0.30	0.22	0.66	0.65	0.64	0.57	0.54	0.73	0.65
	P_2O_5	0.09	0.06	0.08	0.07	0.11	0.10	0.08	0.08	0.09
	MnO	0.16	0.06	0.11	0.14	0.06	0.11	0.11	0.14	0.06
	CO_2	-	-	0.04	0.02	0.02	0.02	0.04	0.02	0.08
NORMATIVE ANALYSIS	QZ	37.83	44.55	0.95	1.06	0.54	-	2.90	1.03	2.52
	OR	14.32	4.41	1.15	0.73	0.36	0.36	0.54	0.54	0.36
	AB	31.62	34.16	14.73	13.85	15.31	19.82	12.91	5.52	16.37
	AN	9.43	8.12	20.11	21.31	41.34	32.47	38.66	34.06	39.75
	CO	1.71	2.80	-	-	-	-	-	-	-
	WO	-	-	18.85	19.66	20.28	19.18	17.23	20.97	19.63
	DI	-	-	36.74	38.25	26.61	36.52	32.81	40.30	25.71
	EN	2.29	1.76	24.74	24.45	11.27	13.20	15.19	21.58	11.92
	FS	-	2.76	14.84	13.79	1.23	3.36	3.46	7.55	-
	FO	-	-	-	-	-	1.20	-	-	-
	FA	-	-	-	-	-	0.53	-	-	-
	MT	0.82	0.89	3.12	3.71	8.16	6.59	7.81	7.10	7.82
	IL	0.58	0.42	1.25	1.24	1.22	1.07	1.02	1.39	1.24
	AP	0.22	0.14	0.19	0.17	0.26	0.24	0.19	0.19	0.22
	Other	-	-	0.09(cc)	0.05(cc)	0.05(cc)	0.46(cc)	0.09(cc) 0.37(ne)	0.05(cc)	0.19)cc)
	Diff.In.	83.82	83.12	16.83	15.63	16.20	20.55	-	7.09	-
	SALIC	94.96	94.03	36.94	36.94	57.55	53.02	-	41.17	-
	FEMIC	5.05	5.96	63.07	63.06	42.56	46.99	-	58.84	-

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TABLE 8 (continued)

		JAMES RUN FORMATION										
		Gilpins Falls Member						Happy Valley Branch Member				
		PB-3,c	PB-4	PB-5	RC-1	RC-3	RC-I	CCV-2	CCV-5	AK-4	HG-11	HG-13
CHEMICAL ANALYSIS	SiO_2	48.5	45.3	48.8	50.8	50.8	62.2	67.2	47.8	48.9	81.4	53.4
	Al_2O_3	10.9	15.2	9.6	14.1	15.5	22.8	14.4	13.1	14.2	11.2	15.8
	Fe_2O_3	3.0	5.8	2.4	2.7	2.8	0.24	1.1	2.9	2.3	0.16	2.1
	FeO	8.2	3.2	9.2	6.7	6.1	0.52	4.0	3.8	6.2	0.76	7.8
	MgO	10.0	5.6	11.6	10.0	8.4	0.70	2.1	5.5	11.3	-.15	5.1
	CaO	15.4	22.1	14.4	9.7	10.1	5.1	2.7	18.4	11.0	0.52	7.8
	Na_2O	1.0	0.56	1.1	3.2	3.3	7.6	6.5	3.4	1.6	4.8	4.4
	K_2O	0.12	0.17	0.18	0.17	0.16	0.12	0.12	0.86	0.21	0.32	0.22
	H_2O+	0.45	0.79	0.86	0.63	0.91	0.58	0.55	1.4	1.8	0.48	0.78
	H_2O-	0.15	0.10	0.05	0.08	0.09	0.09	0.02	0.08	0.09	0.0	0.02
	TiO_2	0.76	0.46	0.71	0.73	0.88	0.04	0.57	0.63	0.43	0.17	0.73
	P_2O_5	0.10	0.11	0.11	0.12	0.22	0.03	0.11	0.07	0.04	0.10	0.04
	MnO	0.11	0.03	0.09	0.15	0.17	0.0	0.17	0.05	0.17	0.02	0.03
	CO_2	0.04	<0.05	<0.05	<0.05	<0.05	0.02	<0.05	4.3	0.02	<0.05	<0.05
	Total	99.2	99.2	99.2	99.1	99.3	99.8	100.0	99.6	98.7	100.0	99.1
CHEMICAL ANALYSIS RECALCULATED TO 100% (water free)	SiO_2	49.42	-	49.70	51.64	51.72	62.72	67.65	48.74	50.40	81.82	54.31
	Al_2O_3	11.11	-	9.78	14.33	15.78	22.79	14.50	13.36	14.64	11.26	15.87
	Fe_2O_3	3.06	-	2.44	2.74	2.65	0.24	1.11	2.96	2.37	0.18	3.15
	FeO	8.36	-	9.37	6.81	8.21	0.52	4.03	3.87	6.39	0.76	7.93
	MgO	10.19	-	11.81	10.17	8.55	0.71	2.11	5.61	11.65	0.15	5.19
	CaO	15.9	-	14.67	9.88	10.28	5.14	2.72	16.72	11.34	0.52	7.93
	Na_2O	1.02	-	1.12	3.25	3.36	7.66	6.54	3.47	1.65	4.82	4.48
	K_2O+	0.12	-	0.18	0.17	0.16	0.12	0.49	0.12	0.89	0.21	0.33
	TiO_2	0.77	-	0.72	0.74	0.90	0.04	0.57	0.64	0.44	0.17	0.74
	P_2O_5	0.10	-	0.11	0.12	0.22	0.03	0.11	0.07	0.04	0.10	0.04
	MnO	0.11	-	0.09	0.15	0.17	-	0.17	0.05	0.18	0.02	0.03
	CO_2	0.04	-	-	-	-	0.02	-	4.38	0.02	-	-
NORMATIVE ANALYSIS	QZ	0.39	-	-	-	-	5.43	17.24	1.80	-	51.42	1.14
	OR	0.72	-	1.08	1.02	0.96	0.72	2.92	0.72	5.24	1.25	1.92
	AB	8.62	-	9.48	27.53	28.43	64.85	55.37	29.34	13.96	40.82	37.87
	AN	25.37	-	21.11	24.00	27.49	25.19	8.73	20.52	29.92	1.94	22.24
	CO	-	-	-	-	-	0.82	-	-	-	2.38	-
	WO	21.53	-	21.26	10.07	9.21	-	1.69	14.30	10.83	-	7.03
	DI	41.66	-	41.18	19.38	17.72	-	3.35	27.32	20.77	-	13.86
	EN	25.38	-	25.29	17.73	17.40	1.76	5.27	13.97	21.68	0.38	12.92
	FS	11.75	-	12.17	8.51	8.58	0.70	5.85	3.71	7.00	1.03	10.79
	FO	-	-	2.90	5.31	2.73	-	-	-	5.14	-	-
	FA	-	-	1.54	2.15	1.14	-	-	-	1.83	-	-
	MT	4.43	-	3.54	3.98	3.84	0.35	1.61	4.29	3.44	0.23	4.57
	IL	1.47	-	1.37	1.41	1.70	0.08	1.09	1.22	0.84	0.33	1.41
	AP	0.24	-	0.27	0.29	0.53	0.07	0.26	0.17	0.10	0.24	0.10
	Other	0.09(cc)	-	-	-	-	0.05	-	9.98(cc)	0.05(cc)	-	-
	Diff.In.	9.74	-	10.56	28.55	29.39	71.00	75.53	31.86	19.19	93.49	40.93
	SALIC	35.11	-	31.67	52.55	56.88	97.00	84.25	52.38	49.11	97.81	63.18
	FEMIC	64.89	-	68.34	47.46	43.13	3.00	15.76	47.62	50.90	2.20	36.83

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TABLE 8 (continued)

		JAMES RUN FORMATION									
		Happy valley Branch Member				Principio Creek Member		Big Elk Creek Member			
		HG-18	HG-18B	BV-91	RS-17	RS-16	RS-16B	NW-28,vd	NW-28,d	NW-28,dvd	NW-28,ld
CHEMICAL ANALYSIS	SiO_2	62.8	77.8	74.1	78.5	82.8	62.5	54.8	58.6	60.1	76.3
	Al_2O_3	14.1	12.4	13.0	11.7	15.9	16.0	12.9	15.8	15.4	12.1
	Fe_2O_3	3.1	0.73	1.8	0.78	2.2	2.7	2.4	4.3	3.4	1.7
	FeO	5.9	0.88	1.5	1.2	4.8	4.3	8.2	8.0	4.8	1.4
	MgO	1.9	0.48	0.99	0.24	1.8	1.7	8.8	2.9	3.9	0.51
	CaO	5.0	0.43	1.4	2.1	4.5	4.5	9.9	7.0	8.9	3.4
	Na_2O	4.5	5.8	5.4	4.0	3.0	3.1	2.7	2.9	3.9	3.1
	K_2O	-	0.35	0.13	0.27	2.8	2.4	0.22	0.12	0.12	0.09
	H_2O+	0.47	0.82	1.1	0.73	1.4	1.2	0.71	0.48	0.62	0.32
	H_2O-	0.04	0.06	0.0	0.07	0.25	0.17	0.07	0.06	0.18	0.06
	TiO_2	1.2	0.26	0.40	0.22	0.42	1.1	0.31	1.0	0.85	0.24
	P_2O_5	0.28	0.17	0.04	0.07	0.46	0.02	0.01	0.22	0.18	0.03
	MnO	0.04	0.17	0.08	0.18	0.10	0.15	0.17	0.11	0.11	0.0
	CO_2	< 0.05	< 0.05	< 0.05	< 0.05	0.05	0.05	0.02	0.02	0.02	0.04
	Total	99.6	100.0	100.0	100.1	99.7	99.9	99.0	99.5	100.0	99.3
CHEMICAL ANALYSIS RECALCULATED TO 100% (water free)	SiO_2	63.41	78.34	74.97	79.09	-	63.44	55.58	59.21	60.6	77.14
	Al_2O_3	14.24	12.52	13.15	11.79	-	16.24	13.13	15.96	15.53	12.23
	Fe_2O_3	3.13	0.74	1.82	0.79	-	2.74	2.44	4.34	3.43	1.72
	FeO	5.95	0.89	1.52	1.21	-	4.36	8.31	6.06	4.84	1.42
	MgO	1.92	0.46	1.00	0.24	-	1.73	8.96	2.93	3.93	0.52
	CaO	5.05	0.43	1.42	2.12	-	4.57	10.08	7.07	8.96	3.44
	Na_2O	4.54	5.65	5.46	4.03	-	3.15	2.75	2.93	3.43	3.13
	K_2O+	0.22	0.35	0.13	0.27	-	2.44	0.22	0.12	0.12	0.09
	TiO_2	1.21	0.26	0.41	0.22	-	1.12	0.32	1.01	0.86	0.24
	P_2O_5	0.28	0.17	0.04	0.07	-	0.02	0.01	0.22	0.18	0.03
	MnO	0.04	0.17	0.08	0.18	-	0.15	0.17	0.11	0.11	0.0
	CO_2	-	-	-	-	-	0.05	0.02	0.02	0.02	0.04
NORMATIVE ANALYSIS	OZ	21.49	42.56	37.93	49.21	21.26	21.74	5.43	20.84	19.21	50.27
	OR	1.31	2.09	0.78	1.61	51.40	14.40	1.32	0.72	0.72	0.54
	AB	38.45	47.84	46.23	24.01	25.44	26.63	23.26	24.79	29.01	26.52
	AN	17.80	1.03	6.76	10.04	19.36	22.21	22.83	30.05	26.62	16.60
	CO	-	2.46	1.54	1.19	1.07	0.29	-	-	-	0.90
	WO	2.26	-	-	-	-	-	11.26	1.44	2.75	-
	DI	4.52	-	-	-	-	-	21.73	2.85	5.33	-
	EN	4.78	1.18	2.50	0.60	4.49	4.30	22.31	7.30	9.79	1.28
	FS	6.43	0.91	0.77	1.54	6.50	4.19	9.37	6.08	4.85	0.78
	FO	-	-	-	-	-	-	-	-	-	-
	FA	-	-	-	-	-	-	-	-	-	-
	MT	4.54	1.07	2.65	1.14	3.20	3.97	3.54	6.30	4.97	2.49
	IL	2.30	0.50	0.77	0.42	0.80	2.12	0.60	1.92	1.63	0.46
	AP	0.67	0.41	0.10	0.17	1.09	0.05	0.02	0.53	0.43	0.07
	Other	-	-	-	-	-	0.12(cc)	0.05(cc)	0.05(cc)	0.05(cc)	0.09(cc)
	Diff.In.	61.25	92.48	84.93	84.91	-	62.76	30.01	46.35	48.93	77.33
	SALIC	79.04	95.97	93.24	96.13	82.54	85.26	52.85	76.40	75.55	94.82
	FEMIC	20.97	4.04	6.78	3.87	16.08	14.75	47.16	23.61	24.46	5.18

(continued next page)

TABLE 8 (continued)

		JAMES RUN FORMATION			PORT DEPOSIT GNEISS				GNEISS AT ROLLING MILL	
		Big Elk Creek Member			coarse-grained		fine-grained			
		NW-28,l	NW-28,al	NW-28,wl	PD-1	PD-100	HG-15	BV-43	NW-5	NW-17R
CHEMICAL ANALYSIS	SiO_2	76.9	70.2	76.3	72.6	76.2	76.5	77.6	78.7	78.6
	Al_2O_3	11.5	13.8	11.8	13.3	12.0	12.4	12.8	12.0	12.1
	Fe_2O_3	1.7	2.0	2.0	0.84	1.0	0.85	1.0	2.1	0.78
	FeO	1.3	2.9	1.1	2.6	1.7	1.5	2.0	1.8	1.2
	MgO	0.42	1.4	0.44	0.72	0.48	1.52	0.53	0.23	0.14
	CaO	3.4	5.2	3.2	3.4	1.8	1.4	0.74	2.1	1.6
	Na_2O	3.0	3.1	2.9	3.3	3.3	4.0	4.3	4.1	3.9
	K_2O	0.0	0.19	0.06	2.1	2.2	1.8	0.48	0.15	0.95
	H_2O+	0.41	0.51	0.57	0.48	0.77	0.67	0.89	0.64	0.29
	H_2O-	0.06	0.11	0.12	0.0	0.08	0.06	0.10	0.03	0.05
	TiO_2	0.26	0.81	0.27	0.35	0.27	0.27	0.30	0.20	0.13
	P_2O_5	0.02	0.22	0.03	0.10	0.03	0.05	0.05	0.904	0.08
	MnO	0.0	0.0	0.0	0.09	0.03	0.05	0.03	0.09	0.06
	CO_2	0.02	0.02	0.2	<0.05	0.05	<0.05	<0.05	<0.05	<0.05
	Total	99.0	100.5	98.6	99.9	99.9	100.1	100.9	100.0	99.9
CHEMICAL ANALYSIS RECALCULATED TO 100% (water free)	SiO_2	78.06	70.31	77.92	73.04	76.94	77.01	77.73	-	-
	Al_2O_3	11.67	13.82	11.85	13.38	12.12	12.48	12.82	-	-
	Fe_2O_3	1.73	2.00	2.04	0.85	1.01	0.86	1.00	-	-
	FeO	1.32	2.90	1.12	2.62	1.71	1.51	2.00	-	-
	MgO	0.43	1.40	0.45	0.72	0.48	0.52	0.53	-	-
	CaO	3.45	5.21	3.27	3.42	1.82	1.41	0.74	-	-
	Na_2O	3.05	3.10	2.96	3.32	3.33	4.03	4.31	-	-
	K_2O+	0.0	0.19	0.06	2.11	2.22	1.81	0.48	-	-
	TiO_2	0.26	0.81	0.28	0.35	0.27	0.27	0.30	-	-
	P_2O_5	0.02	0.22	0.03	0.10	0.03	0.05	0.05	-	-
	MnO	0.0	0.0	0.0	0.09	0.03	0.05	0.03	-	-
	CO_2	0.01	0.02	0.02	-	0.05	-	-	-	-
NORMATIVE ANALYSIS	QZ	52.17	38.11	52.93	36.04	43.82	42.22	47.50		-
	OR	-	1.13	0.36	12.48	13.13	10.71	2.84	-	-
	AB	25.77	26.27	25.06	28.09	28.19	34.07	36.45	-	-
	AN	18.86	23.22	15.88	15.37	8.50	6.66	3.35	-	-
	CO	0.48	-	1.09	-	1.17	1.46	3.99	-	-
	WO	-	0.44	-	0.39	-	-	-	-	-
	DI	-	0.86	-	0.80	-	-	-	-	-
	EN	1.06	3.48	1.12	1.80	1.16	1.30	1.32	-	-
	FS	0.56	2.34	-	3.69	1.92	1.71	2.41	-	-
	FO	-	-	-	-	-	-	-	-	-
	FA	-	-	-	-	-	-	-	-	-
	MT	2.50	2.90	2.82	1.23	1.46	1.24	1.45	-	-
	IL	0.50	1.54	0.52	0.67	0.52	0.52	0.57	-	-
	AP	0.05	0.52	0.07	1.24	0.07	0.12	0.12	-	-
	Other	0.05(cc)	0.05(cc)	0.05(cc)	-	0.12(cc)	-	-	-	-
	Diff.In.	77.94	65.51	78.35	76.62	85.14	87.0	86.70	-	-
	SALIC	95.28	88.73	95.32	91.48	94.75	95.11	94.13	-	-
	FEMIC	4.72	11.29	4.68	8.02	5.25	4.89	5.87	-	-

TABLE 8 (continued)
SAMPLE LOCATIONS:

NE-6:	From railroad cut of Chessie System about 2,100 ft (640 m) east of Stony Run and 3,150 ft (960 m) west of Maryland Rte. 272 at Leslie, Cecil County.
HV-10V:	From outcrop along Principio Creek about midway between U.S. Rte 40 and Maryland Rte. 7 at Principio Furnace, Cecil County.
HV-11V:	Same location as sample HV-10V.
6KC:	From roadcut along north side of Interstate 95 about 1,800 ft (550 m) northeast of Susquehanna River, Cecil County.
6KM:	Same location as sample 6KC.
HG-28:	From outcrop on hillside about 25 ft (7.6 m) from northwestern side of Frenchtown-Craigtown Road about 2,600 ft (610 m) northeast of Susquehanna River, Cecil County.
NE-39:	From outcrop along Stony Run about 1,000 ft (305 m) north of Chessie System railroad, approximately 1 mile (1.6 km) west of Leslie, Cecil County.
BV-68:	From outcrop along Northeast Creek about 900 ft (275 m) south of the bridge at Mechanic Valley, Cecil County.
BV-71:	From outcrop along Northeast Creek a few feet (few meters) north of Chessie System railroad, south of Mechanic Valley, Cecil County.
HG-25:	From outcrop on hillside in Frenchtown, Cecil County, about 700 ft (215 m) northeast of Susquehanna River.
7K:	From roadcut along north side of Interstate 95 about 1,100 ft (335 m) northeast of Susquehanna River, Cecil County.
BV-85:	From outcrop along tributary to Stony Run about 2,700 ft (825 m) west of Goosemar Road and about 1 mile (1.6 km) southeast of Theodore, Cecil County.
NW-19R:	From outcrop along Little Elk Creek about 5,000 ft (1.5 km) south of Providence Road at Providence, Cecil County.
P-1:	(core, vesicular zone, and rim of metamorphosed pillow) From outcrop along Northeast Creek about 400 ft (125 m) south of Maryland Rte. 272, east of Bay View, Cecil County.
PB-2:	(core, transition zone, vesicular zone, and rim of metamorphosed pillow) From outcrop along Northeast Creek about 250 ft (75 m) south of Maryland Rte. 272, east of Bay View, Cecil County.
PB-3:	From outcrop along Little Northeast Creek about 2,500 ft (760 m) south of Warburton Road between Bay View and Pleasant Hill, Cecil County.
PB-4:	From outcrop along Northeast Creek about 1,000 ft (305 m) south of Maryland Rte. 272, east of Bay View, Cecil County.
PB-5:	Form outcrop about 100 ft (30 m) northeast of Bouchelle Road approximately 1,400 ft (425 m) southeast of Maryland Rte. 272, east of Bay View, Cecil County.
RC-1:	From outcrop in front of Rock Church, intersection of Rock Church Road and Maryland Rte. 273, west of Fair Hill, Cecil County.
RC-3:	From outcrop about 200 ft (60 m) northeast of Rock Church, intersection of Rock Church Road and Maryland Rte. 273, west of Fair Hill, Cecil County.
RC-L:	Felsic layer from same outcrop as sample RC-1.
CCV-2:	From quarry of Little Northeast Creek about 3,000 ft (915 m) upstream from Mechanic Valley, Cecil County.
CCV-5:	Same location as sample CCV-2.
AK-4:	From railroad cut of CONRAIL system along Susquehanna River about 1,000 ft (305 m) southeast of Happy Valley Branch, Cecil County.
HG-11:	From railroad cut of CONRAIL system along Susquehanna River about 750 ft (230 m) southeast of Happy Valley Branch, Cecil County.
HG-13:	From railroad cut of CONRAIL system along Susquehanna River about 1,100 ft (335 m) southeast of Happy Valley Branch, Cecil County.
HG-18:	From railroad cut of CONRAIL system along Susquehanna River about 1,600 ft (500 m) southeast of Happy Valley Branch, Cecil County.
HG-18B:	Same location as sample HG-18.
BV-91:	From outcrop along Stony Run about 450 ft (135 m) north of Bailey Road, about 1 mile (1.6 km) southeast of Bay View, Cecil County.
RS-17:	From outcrop on Linton Road about 50 ft (15 m) south of intersection with Belvedere Road, along Principio Creek, Cecil County.
RS-16:	From outcrop about 110 ft (33 m) east of Belvedere Road along first tributary to Principio Creek south of Theodore Road, about 1.5 miles (2.4 km) east of Woodlawn, Cecil County.
RS-16B:	From outcrop about 100 ft (30 m) east of sample RS-16.

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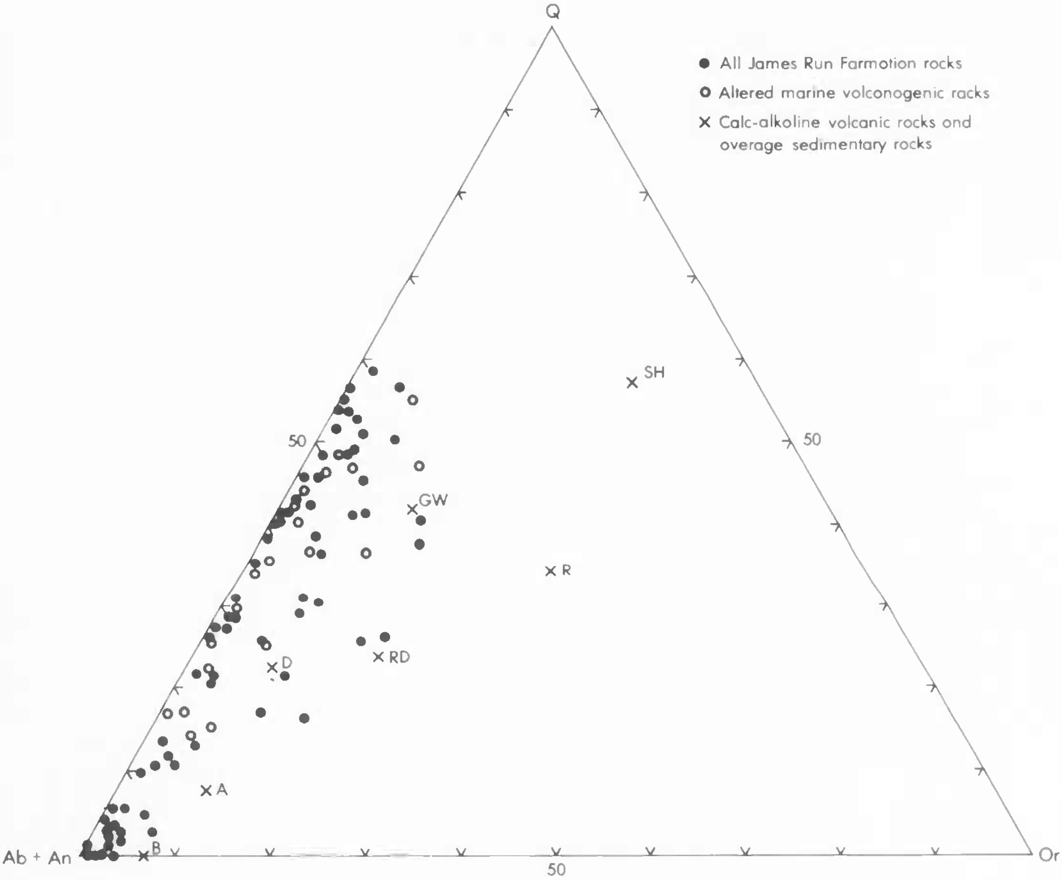

FIGURE 24: Plot of normative **Q - Or - Ab+An** for rocks of the James Run Formation, compared with altered marine volcanogenic rocks, average sedimentary rocks, and average calc-alkaline volcanic rocks (includes data from Ward, 1959; Hopson, 1964; Southwick, 1969; and Higgins, 1972).

(TABLE 8, continued)

NW-28: From outcrop along west side of Big Elk Creek about 2,300 ft (700 m) upstream from Maryland Rte. 273, approximately 1 mile (1.6 km) northwest of Appleton, Cecil County.

PD-1: From the Port Deposit quarry along U.S. Rte. 222 about 0.25 mile (0.4 km) northwest of Rock Run, Cecil County.

PD-100: From cliff outcrop in town of Port Deposit, Cecil County, about midway between intersections of U.S. Rte. 222 with Maryland Rtes. 269 and 276.

HG-15: From railroad cut of CONRAIL system along Susquehanna River about 1,100 ft (335 m) southeast of U.S. Rte. 222 at Port Deposit, Cecil County.

BV-43: From railroad cut of CONRAIL system along Susquehanna River about 1,300 ft (400 m) southeast of U.S. Rte. 222 at Port Deposit, Cecil County.

NW-5: From outcrop along Big Elk Creek about 3,900 ft (1.2 km) south of Maryland Rte. 273, approximately 1 mile (1.6 km) southwest of Appleton, Cecil County.

NW-17R: From outcrop along Gramies Run about 500 ft (150 m) upstream from Big Elk Creek and east of Booth Road, approximately 1 mile (1.6 km) north of Elk Mills, Cecil County.

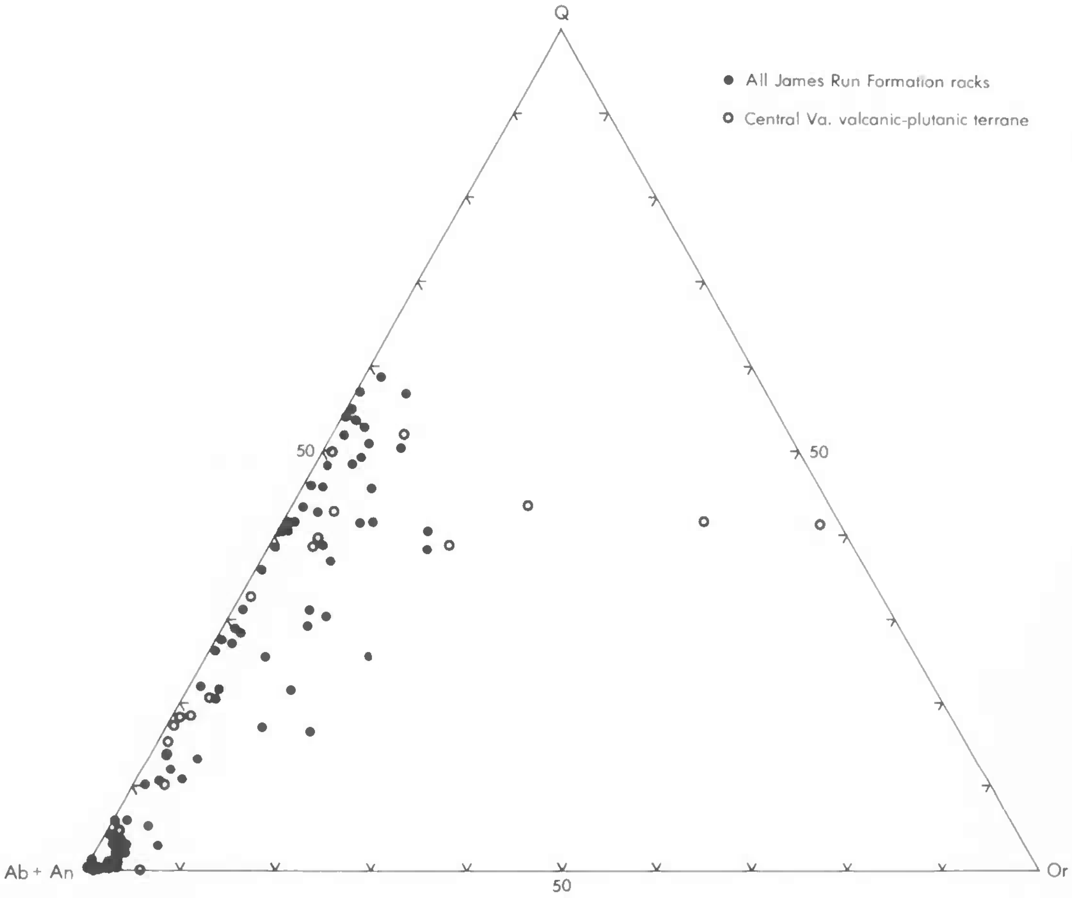

FIGURE 25: Plot of normative **Q - Or - Ab+An** for rocks of the James Run Formation, compared with volcanogenic rocks of the Chopawamsic Formation and Ta River amphibolites of the Central Virginia Piedmont (data from Pavlides, 1981).

The **Q - Or - Ab+An** plots suggest that some of the James Run rocks were altered marine volcanic rocks before metamorphism, as suggested by Hopson (1964), Southwick (1969), and Higgins (1972). However, some of the James Run rocks are almost certainly metamorphosed subvolcanic rocks, and parts of some members may be shallow metaplutonic rocks.

Figure 26 is a plot of normative orthoclase-albite-anorthite for James Run felsic rocks with silica contents greater than 55 percent and Port Deposit Gneiss, as well as some data from Southwick (1979). The volcanic and plutonic fields on the diagram are from O'Connor (1965). This figure clearly shows the apparent trondhjemitic affinities of some parts of the Port Deposit Gneiss and some of the probable metasubvolcanic rocks in the James Run Formation. It also illustrates the range in composition of the James Run felsic rocks, from somewhat **Or**-poor dacites to highly albitic quartz keratophyres.

Figure 27 is an **F'- M - A**[3] plot for the James Run metavolcanic and metasubvolcanic rocks. Considered as a suite, these rocks have a trend that is intermediate between the "Cascade trend" toward alkali enrichment with differentiation and the "Skaergaard trend" toward extreme iron enrichment. However, the scatter of points makes it difficult to define an exact trend. This scatter may be due to differences in alteration among the samples.

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[3] **F'** is total iron calculated as FeO.

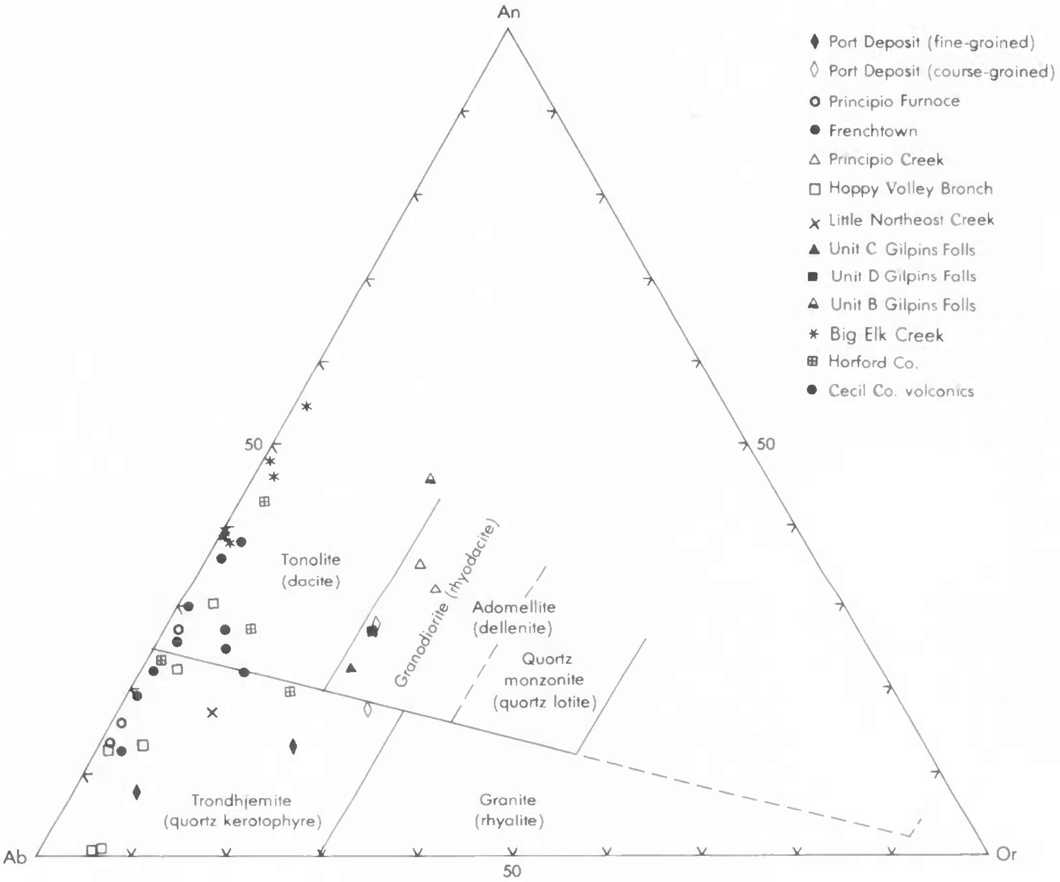

FIGURE 26: Plot of normative **Or - Ab - An** for rocks of the James Run Formation with greater than 55 percent SiO_2 and rocks of the Port Deposit Gneiss (includes data from Southwick, 1969). Field boundaries from O'Connor (1965).

ALTERATION

Of critical importance in classifying igneous rocks and igneous rock suites, and in making interpretations about their origins based on chemical compositions, particularly on major element compositions, are the types and degrees of alteration that have affected the rocks since eruption, deposition, or emplacement. Alteration processes can be divided generally into premetamorphic, metamorphic, and postmetamorphic, but these processes are commonly gradational from one category to another.

Some of the premetamorphic processes that alter igneous rocks are devitrification, deuteric alteration, diagenesis (including diagenetic zeolitization), weathering, hydrothermal alteration, hydrolysis, and halmyrolysis. These processes merge into low-grade metamorphic processes that include burial diagenesis, burial metamorphism, and metasomatism, which in turn merge into higher grades of regional metamorphism and metasomatism. Postmetamorphic processes that alter the rocks include hydrothermal alteration, weathering, and chemical exchange with ground water. Most igneous rocks have been subjected to more than one of these alteration processes.

Types and degrees of alteration are controlled by rock type and geologic environment. Specifically, alteration is controlled by such factors as grain size, texture, mineral composition,

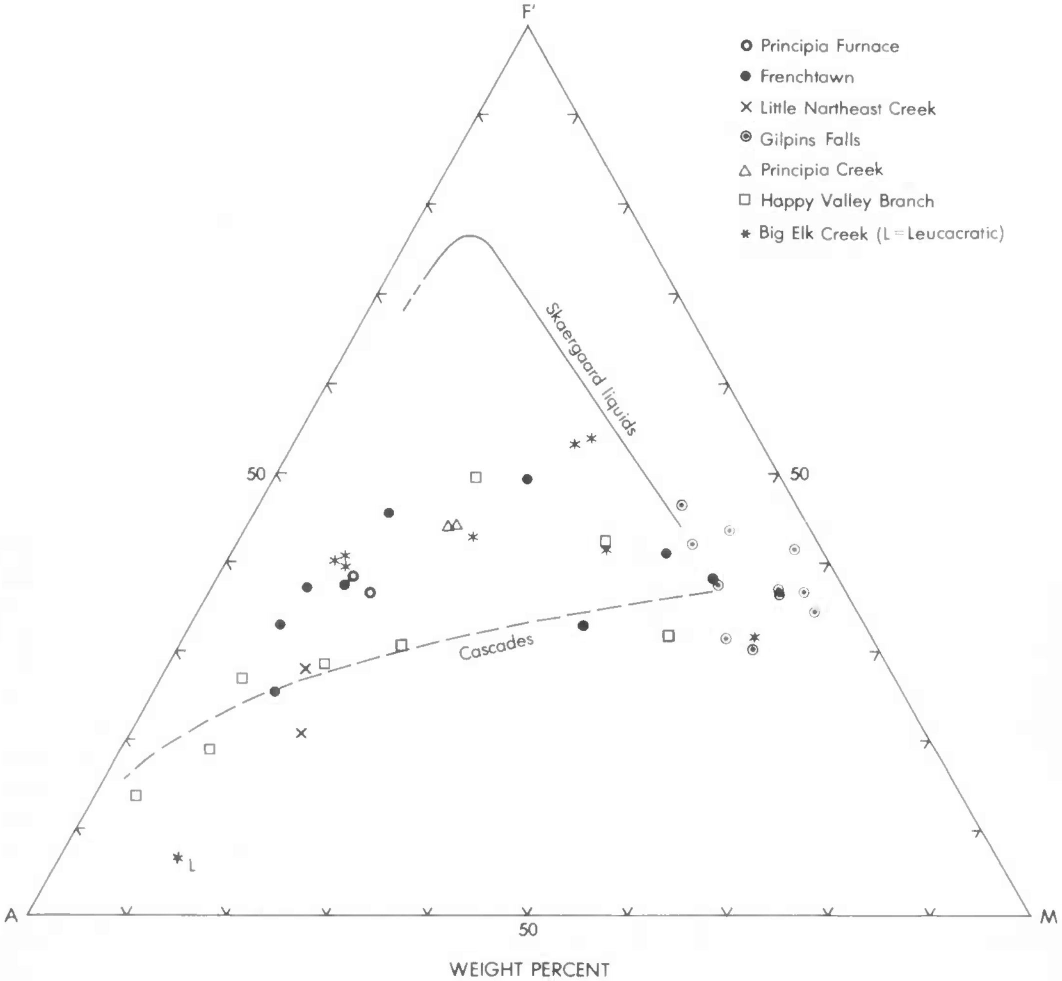

FIGURE 27: **F'- M - A** plot for analyses of rocks of the James Run Formation compared with the "Skaergaard" and "Cascade" trends.

and, probably most important, permeability. Plutonic rocks are generally less susceptible to alteration than volcanic rocks, particularly volcaniclastic rocks. Because volcanic rocks are erupted into air or water, they begin to be altered almost as soon as they leave the vent. Volcaniclastic rocks are by far the most readily and commonly altered igneous material, whether they are erupted subaerially or subaqueously, and whether mafic or felsic. Volcanic glass is extremely susceptible to devitrification, palagonitization, and zeolitization, subaerially, subaqueously, or with shallow burial (Bramlette and Posnjak, 1933; Ames and others, 1958; Deffeyes, 1959; Mumpton, 1960, 1977; Dickinson, 1962a, 1962b; Hay, 1962, 1963, 1966, 1977; Brown and Thayer, 1963; Fiske and others, 1963; Van Houten, 1964; Sheppard and Gude, 1965, 1968, 1973; Horne, 1968; Hay and Iijima, 1968; Surdam and Hall, 1968; Smith, 1968, 1969; Utada, 1971; Surdam, 1973, 1977; Murata and Whiteley, 1973; Galloway, 1974; Stewart, 1974; Walton, 1975; Boles and Coombs, 1975, 1977; Boles, 1977; Hay and Sheppard, 1977). Thick accumulations of altered (zeolitized, palagonitized, albitized) marine volcanic and volcaniclastic rocks are present in Japan (Sudo, 1950; Matsuda and Mizuno, 1955; Fiske and Matsuda, 1964; Utada, 1970, 1971; Iijima and Utada, 1972), in New Zealand (Coombs, 1954; Coombs and others, 1959; Boles, 1971, 1974; Boles and Coombs, 1975, 1977), in eastern

Australia (Smith, 1968, 1969), in the Indonesian region (Hamilton, 1979, and references therein), in Puerto Rico (Christman, 1953; Otálora, 1961; Glover, 1971), in the Virgin Islands (Donnelly, 1959a, 1959b, 1963, 1966), in the western United States (Wells and Waters, 1935; Warren and others, 1945; Waters, 1955; Dickinson, 1962a, 1962b; Fiske, 1963; Hamilton, 1963; Fiske and others, 1963; Brown and Thayer, 1963; Snavely and Wagner, 1964; Peck and others, 1964; Snavely and others, 1968), in western Canada (Carlisle, 1963; Surdam, 1973), and in the Aleutian Islands (Hamilton, 1963, and references therein).

The volcanic and volcaniclastic rocks of the James Run Formation are very similar lithologically and chemically to these altered marine volcanogenic rocks, even though the James Run Rocks have been metamorphosed to amphibolite facies grade of regional metamorphism and multiply deformed. So, in spite of the fact that caution must be exercised when interpreting chemical analyses of altered and metamorphosed rocks, chemical compositions can be used in a qualitative way to help decipher rock origins. It seems fairly certain that the James Run Formation rocks are mostly altered marine volcanic and volcaniclastic rocks, as proposed by Hopson (1964) and Southwick (1969).

I agree with Hopson (1964, p. 32) and Southwick (1969, p. 49) that the regional metamorphism of the James Run Formation was essentially isochemical. This is supported, as Southwick noted (1969, p. 49), by the presence of relict plagioclase phenocrysts of different compositions in closely spaced samples, and also by the fact that most of the James Run rocks plot identically with unmetamorphosed, but altered, submarine volcanic and volcaniclastic rocks (fig. 24). Ratios of Na_2O to CaO in the James Run rocks (fig. 28) are variable, as Southwick's (1969) limited number of analyses suggested. Much more impressive, however, are the extremely variable Na_2O to K_2O ratios (fig. 29); these ratios vary as much as 60 to 1 for rocks with essentially the same silica contents. On variation diagrams (fig. 30), oxides of the James Run rocks form relatively broad zones characteristic of altered submarine volcanogenic suites Hamilton, 1963, p. 70-71), but in contrast to the narrow zones of most subaerial volcanic suites. In the James Run rocks, CaO ranges downward from a maximum about equal to the normal amount in calc-alkaline rocks, and Na_2O varies upward from a minimum about equal to the normal amount in calc-alkaline rocks. This, too, is characteristic of most altered submarine volcanogenic sequences (Hamilton, 1963).

The erratic variations in the chemical compositions of the James Run Formation rocks are characteristic features of the "spilite-keratophyre association" of Turner and Verhoogen (1960), or the "andesite-keratophyre association" of Hamilton (1963), in which keratophyre, quartz keratophyre, and spilite are intercalated with calc-alkaline andesite, dacite, rhyodacite, and basalt, with trondhjemite a common plutonic rock type. The origin of the sodic rocks has been a source of controversy for many years; reviews and summaries were given by Gilluly (1935), Eskola (*in* Barth and others, 1939), Turner and Verhoogen (1960), and Hamilton (1963). As Hamilton (1963, p. 68) stated:

> Current theories explain these sodic rocks variously as formed from primary sodic magmas or from calc-alkaline rocks altered by sodium added from magmatic, geosynclinal, or sea water sources.

The problems are as follows: (1) In most sequences, normal calc-alkaline rocks are intercalated with the sodic rocks, precluding theories of wholesale alteration of the entire volcanic pile by any method. Therefore, either the sodic rocks originated from sodic magmas erupted along with, or alternating with, normal calc-alkaline magmas, or parts of a calc-alkaline volcanic pile had to be selectively altered by enrichment in Na and depletion in Ca and K. (2) If the sodic rocks originated as sodic magmas, what is the origin of such magmas, and how could such magmas and normal calc-alkaline magmas have been erupted at virtually the same time and place? (3) In the same context, what is the origin of the trondhjemitic plutonic rocks that are commonly associated with the sequences of sodic and calc-alkaline volcanic rocks, and what relation do these plutonic rocks have to the volcanic rocks? (4) If, on

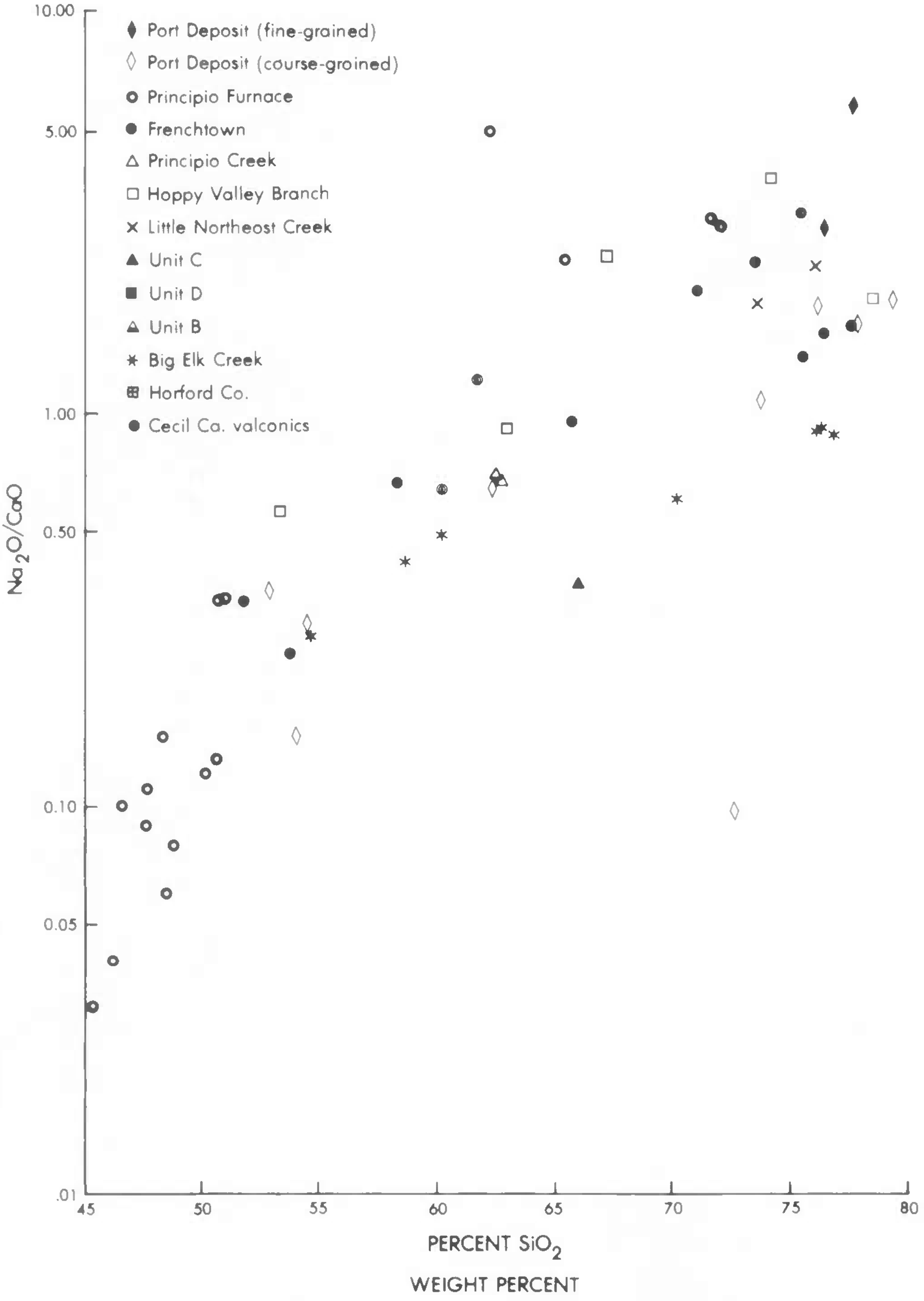

FIGURE 28: Plot of Na_2O/CaO versus percent SiO_2 for rocks of the James Run Formation.

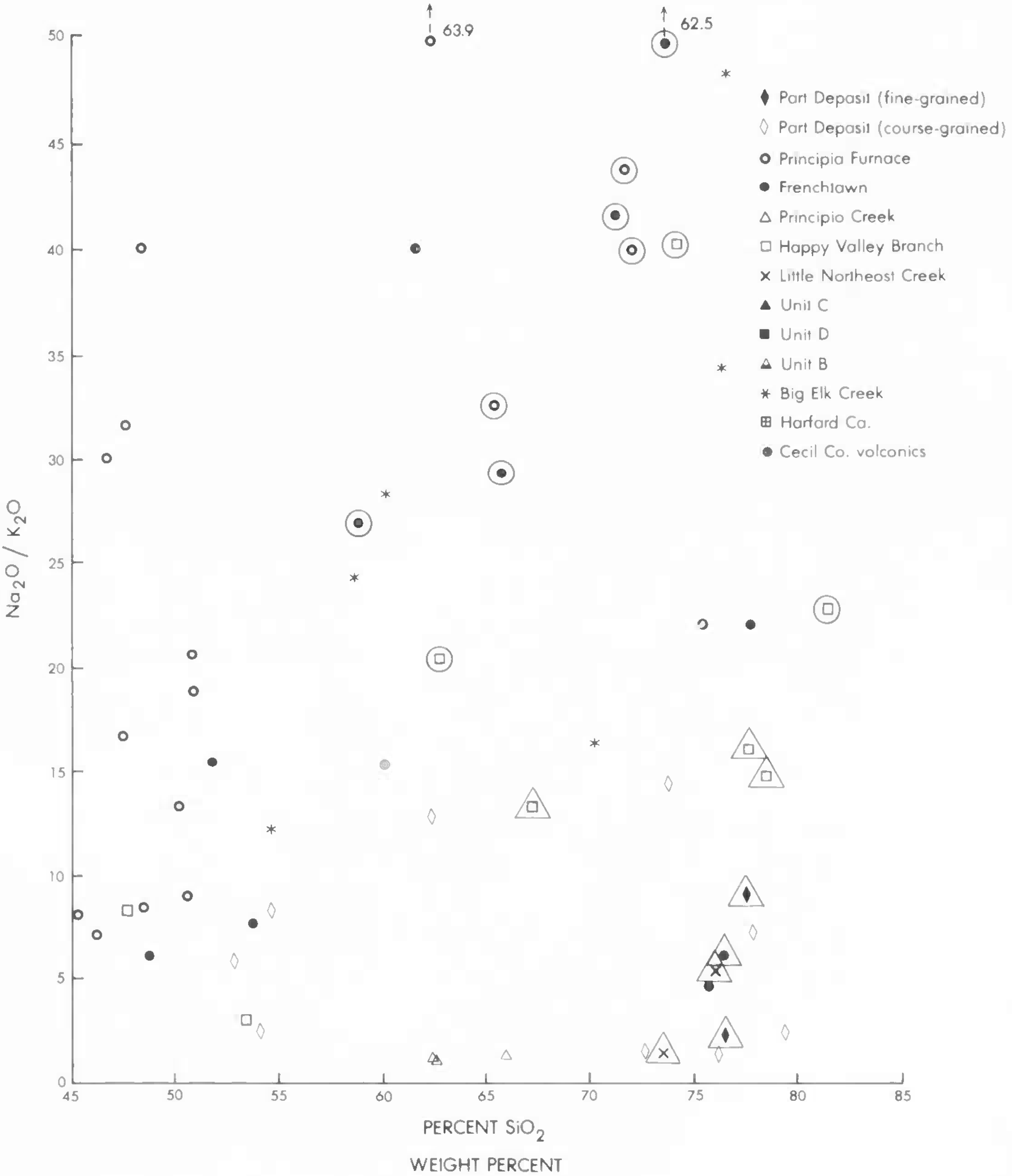

FIGURE 29: Plot of Na_2O/K_2O versus percent SiO_2 for rocks of the James Run Formation. Large circles indicate rocks with evidence of volcaniclastic origin; large triangles are flows or subvolcanic rocks.

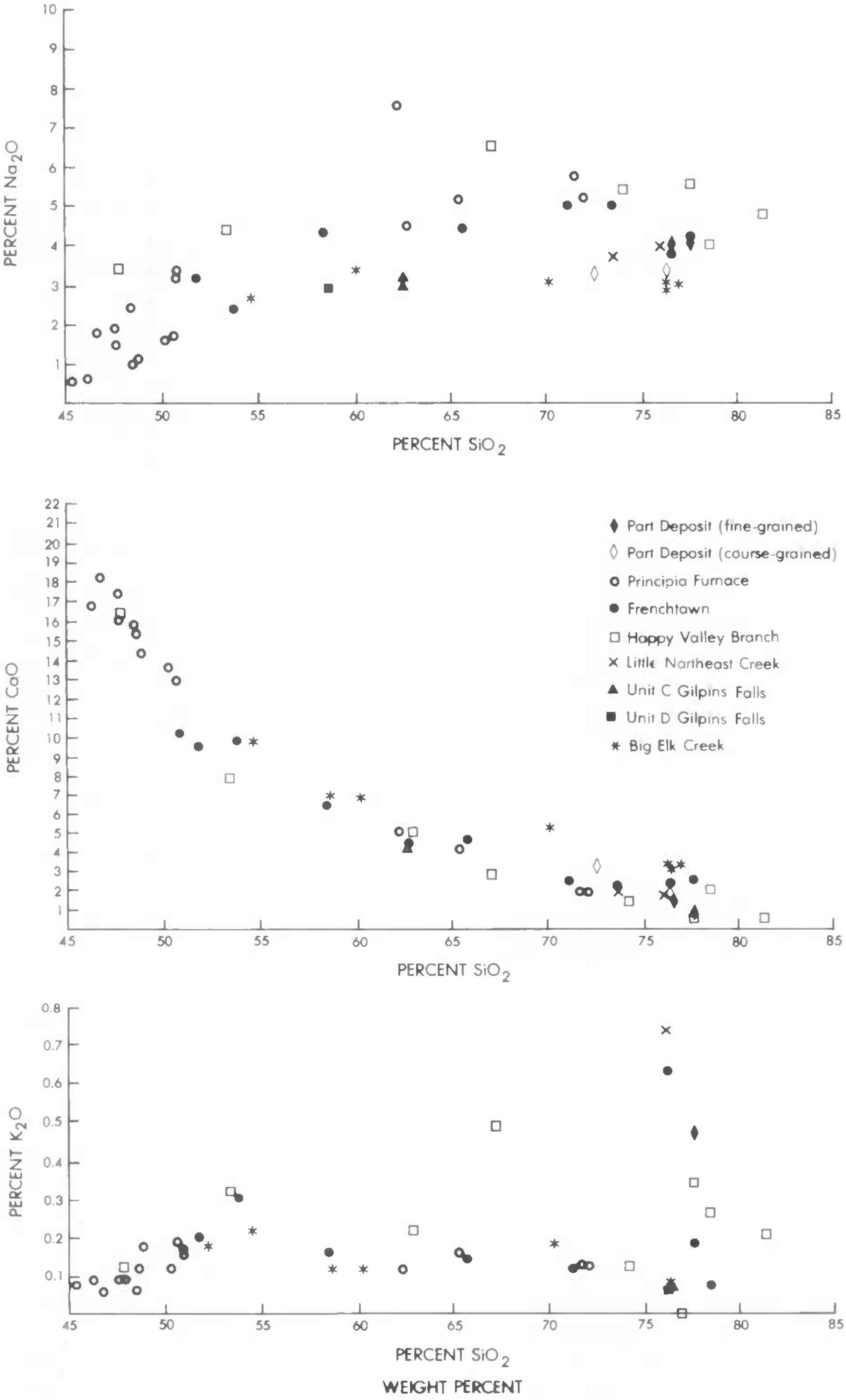

FIGURE 30: Variation diagrams for rocks of the James Run Formation.

the other hand, the sodic rocks were derived by selective alteration, what factors controlled the selectivity, and what was the mechanism of alteration? (5) If the sodic rocks were derived by alteration of calc-alkaline rocks, what was the medium for such alteration? Was it from a magma source, or by fluids expelled from older rocks being metamorphosed beneath the volcanic pile, or was it by interaction with sea water, either contemporaneously with eruption or after eruption?

Waters (1955, p. 707) noted that some dolerite sills, dikes, and subaerial flows in the Olympic Mountains and Oregon Coast Ranges are as thoroughly albitized as the pillowed flows, and that some thick masses of pillow lavas show little or no albitization. Following Gilluly (1935) he proposed (1955, p. 707) that:

> ...the alteration of the lavas to 'spilites' and greenstones, and the simultaneous albilization, silicification, and chloritization of the underlying sediments and intrusive bodies have been produced by water, alkalis, silica, and other easily removable constituents stewed from the slowly metamorphosing root of geosynclinal sediments as it was downbuckled to form a tectogene. Fluids expelled from this metamorphosing root rose along zones of mechanical deformation altering the overlying volcanics and sedimentary rocks.

Hamilton (1963, p. 722-74), on the other hand, emphasized the differences between what he called "the uncommon 'keratophyre'" in subaerial sequences and what he considered true keratophyres of island-arc sequences. He stated (1963, p. 73):

> The distinctive compositions of spilite and keratophyre must be due to post magmatic processes, and these processes seem somehow connected to the submarine environment in which these rocks almost exclusively occur. That diabase sills and other rocks intruded within the sequences are also albitized shows that the changes are not restricted to rocks that formed in direct contact with sea water.

Hamilton (1963) presented fairly conclusive evidence that: (1) all known rocks that should properly be called spilites and keratophyres were either erupted under sea water, or flowed into sea water, or were covered by sea water after eruption or deposition; (2) the sodic rocks were erupted as calc-alkaline magmas, and the albitized rocks owe their distinctive character to post-eruptive transformations; (3) "the sodium was introduced, and calcium removed, by the sea water in some sort of diagenetic process" (p. 73); (4) mineralogic capture of sea-water sodium is the most likely process. Hamilton (1963, p. 73-74) concluded:

> If bases in the volcanic rocks — and particularly in the porous and already partly water-laid tuffs — could be exchanged for bases in circulating water and the capture thus be diagenetic, the subsequent albitization could be explained easily.

and proposed that zeolitization is the process by which this is accomplished.

During the 1960's and 1970's tremendous advances were seen in our knowledge of zeolites, their mineralogy, chemistry, processes of formation, and their remarkable chemical-exchange capabilities. Hamilton (1963, p. 74) probably guessed right about zeolites being the chief culprits in the alteration processes that ultimately produce spilites and keratophyres. Nevertheless, zeolitization is an extremely complex process and commonly a multiphase process in which the first-formed zeolites are replaced by other zeolites, and so on, with changing diagenetic or low-grade metamorphic conditions.

In most volcanic rocks, and especially in volcaniclastic rocks, the first part of the rock to be affected is glass, which is rapidly transformed into, or replaced by, heulandite or (and) analcime (Gulbandsen and Cressman, 1960; Fiske and others, 1963; Hamilton, 1963; Boles, 1977, and references therein). With the increasing temperatures and pressures of burial, heulandite is converted to laumontite and analcime. Then, Ca-plagioclase is converted partly to laumontite and albite, and then laumontite is to pumpellyite and prehnite, which are finally converted to albite along with analcime, which goes to albite and quartz (see Boles, 1977, p. 127). This is simplistic, and many other minerals as well as other zeolites may be involved, depending upon rock type, geologic environment, and other factors, but it probably represents a general case in the complex transformation from calc-alkaline to sodic volcanic rocks, and could account for the gradual change from "normal" compositions to spilitic and keratophyric compositions.

Still a problem is the apparent selectivity of the chemical transformations from normal calc-alkaline rocks to sodic rocks. Even if Hamilton (1963) was right in his conclusion that subaerial rocks were unaffected by these transformations, we must still account for the fact that within the submarine volcanogenic sequences are "rocks that belong to both calc-alkaline and albitized series" (Hamilton, 1963, p. 71). How, then, can we account for the selective alteration of rocks within the submarine piles? This question must inevitably lead to its companion question about the origin of the trondhjemitic "plutonic" rocks within the sequences and how these sodic rocks relate to the sodic volcanic rocks.

Perhaps at least part of the answers to the questions lies in the recognition of subvolcanic rocks and shallow hypabyssal "plutonic" rocks. Although the pioneering works of Fuller (1925) and Buddington (1959) had foreseen the existence and importance of these classes of rocks, it was not until the 1960's that their widespread occurrence and importance became apparent.

In figure 29, which is one of the plots that is most demonstrative of sodic alteration, rocks that show clear lithologic and petrographic evidence of volcaniclastic origin (symbols within large circles) have much higher Na_2O/K_2O values for rocks in the same silica range than rocks that have lithologic and petrographic characteristics of flows or subvolcanic parentage (symbols within large triangles). Many of the other chemical plots also show this difference. This is a strong indication that premetamorphic alteration of the James Run volcanogenic rocks was largely dependent upon porosity and permeability, so that volcaniclastic rocks were preferentially altered over subvolcanic and plutonic rocks. Notable is the fact that one of the samples of fine-grained Port Deposit Gneiss in figure 29, which I consider to be subvolcanic and which Southwick (1979) considered to be probably a trondhjemite, could be just a somewhat altered calc-alkaline rock. This is supported by the fact that the "typical" plutonic Port Deposit samples plot close to normal calc-alkaline granodiorites in figures 26 and 29.

TRACE ELEMENTS

Despite the obvious limitations imposed by possible alteration and by metamorphism on the use of geochemistry to decipher the origins, and particularly the original tectonomagmatic setting, of the James Run Formation rocks, and despite the general objection to comparing metamorphosed rocks with unmetamorphosed rocks, it is generally accepted that some of the more immobile major and trace elements, and especially the rare-earth elements (REE), are useful to some extent for these purposes. Most of the geochemical schemes for determining the original tectonomagmatic setting of igneous rock suites are based on mafic rocks, chiefly basalts. Thus, the generally well-exposed, unweathered, metamorphosed pillow lavas and amygdaloidal amphibolites of the Gilpins Falls Member of the James Run Formation are perhaps as well suited for application of these geochemical schemes as any rocks in the central Appalachian Piedmont.

Comparison of the trace-element data for rocks in the James Run Formation (table 9) with that of basalts and metamorphosed basalts from a variety of tectonomagmatic settings (table 10), and with the average abundances in tholeiitic basalts given by Prinz (1967), shows that the Gilpins Falls metabasalts and an amphibolite from the Big Elk Creek Member of the James Run Formation are exceptionally rich in Ni and Cr. However, the abundance of Co in the Gilpins Falls is slightly lower than that in many of the rocks in table 10 and the average abundance in tholeiitic basalts. In addition, the Gilpins Falls metabasalts are somewhat enriched in V. The Gilpins Falls metabasalts are close to the Chopawamsic metabasalts in abundances of Zr, Sc, Hf, Th, Co, and Zn, but greatly exceed the Chopawamsic rocks in Ni

TABLE 9
TRACE-ELEMENT ABUNDANCES FOR ROCKS OF THE JAMES RUN FORMATION
(in parts per million)

	JAMES RUN FORMATION														
	Gilpins Falls Member														Big Elk Creek Member
	P-1,c	P-1,vz	P-1,r	PB-2,c	PB-22,t	PB-2,v	PB-2,r	PB-2,s	PB-3,c	PB-4	PB-5	RC-1	RC-3	RC-L	NW-28,vd
Rb	<38*	<34	<30*	<30*	<29*	-	<27*	-	-	<28*	<35*	<33	<32*	-	-
Ba	21	50	29	-	-	23	-	-	-	-	-	46	53	166	66
Sr	110	124	290	252	390	280	450	-	-	450	290	270	390	210	120
Zr	42	36	32	56	67	50	92	-	-	34	41	64	74	-	-
Sc	62	72	58	69	48	70	70	-	-	58	70	55	65	-	25
Hf	0.9*	0.9*	0.8*	0.85*	0.75*	-	0.95*	-	-	0.8*	1.2*	1.45*	1.4*	-	-
Th	0.9*	1.1*	0.8*	0.85*	0.65*	-	0.85*	-	-	0.5*	0.45*	0.9*	1.1*	-	-
Ni	92	470	150	235	228	98	155	-	-	165	920	360	245	17	224
Co	40	40	17	30	28	37	18	-	-	22	41	40	41	-	27
Cu	9	168	26	44	53	17	48	-	-	10	5	8	22	38	10
Cr	940	1040	1120	770	1020	880	600	-	-	990	1240	1000	740	20	1000
V	320	330	400	460	400	260	400	-	-	-	-	-	-	27	34
Zn	102*	77*	76*	66*	69*	-	67	-	-	80*	91*	79*	106*	-	-
Ga	10	12	24	18	22	15	23	-	-	22	12	16	20	12	12
Zr/Hf	46.7	40	40	65.9	89.3	-	96.8	-	-	42.5	34.2	44.1	52.9	-	-
Ni/Co	2.3	11.75	8.8	7.8	8.1	2.6	8.6	-	-	7.5	22.43	9	5.98	-	8.3
La	4.0	5.0	5.0	6.5	5.0	-	4.5	6.0	5.0	3.5	6.0	4.0	6.0	-	-
Ce	10	9	10	9	5	-	84.5	11	11	7	12	10.5	13	-	-
Nd	7	6	7	6	6	-	6	8	7.5	5	8	7.5	3	-	-
Sm	1.8	1.7	1.8	1.65	1.65	-	1.65	2.2	2.1	1.4	2.25	2.1	2.5	-	-
Eu	0.50	0.52	0.80	0.59	0.63	-	0.67	0.76	0.62	0.57	0.55	0.71	0.79	-	-
Cd	3.3	1.9	2.6	-	1.9	-	-	3.0	2.3	-	-	-	-	-	-
Tb	1.11	0.98	0.60	0.47	0.71	-	-	0.52	0.61	-	0.55	0.74	0.55	-	-
Tm	0.25	0.21	0.19	0.20	0.20	-	0.20	0.23	0.27	0.17	0.22	0.23	0.24	-	-
Yb	0.9	1.5	2.0	1.7	1.25	-	1.3	2.1	1.75	1.25	1.5	1.65	1.90	-	-
Lu	0.24	0.25	0.29	0.23	0.21	-	0.24	0.28	0.27	0.20	0.25	0.27	0.32	-	-

For locations of samples, see Table 8.

TABLE 10
COMPARISON OF TRACE-ELEMENT ABUNDANCES IN MAFIC ROCKS FROM A VARIETY OF TECTONIC SETTINGS, WORLDWIDE
(in parts per million)

	Gilpins Falls metabasalts	Big Elk Creek amphibolite	Chopawamsic metabasalts (9)	Ta River amphibolites (9)	Island-arc series (4)		Oceanic-ridge tholeiitic basalt (4,10)	Basic igneous complex of South America (2,3)			Nevada pillow basalts (15)	Ammonoosac metabasalts (1)	Pindos ophiolite (8)
					High-Al, calc-alkaline basalt	Tholeiitic basalt		Western Ecuador	Northwestern Colombia	Southeastern Panama			
Rb	<30	-	-	17.3	10	5	1	24.3	22.8	<15	-	<4	-
Ba	36	66	51.2	69	115	75	10	165	<50	<50	1439	-	-
Sr	300.6	120	134.5	324.7	375	200	135	282.4	174.75	153.6	310.4	159.1	-
Zr	53.45	-	54	54.2	100	52	95	115.8	95.9	92.75	169	98.1	-
Sc	33.15	25	38.6	41.4	-	-	-	-	-	-	29	-	
Hf	1.0	-	1.6	1.7	2.6	1.0	2.9	-	-	-	-	-	-
Th	0.89	-	1.3	1.04	1.1	0.5	0.18	-	-	-	-	-	-
Ni	283.45	244	22.4	104.6	25	12	97	65.8	141.6	95	138.9	70.1	140.5
Co	32.2	27	31.1	34.1	40	34	32	68.3	76.6	77.9	38.1	-	47
Cu	37.3	10	-	-	-	-	77	278.3	206.9	215.4	56	-	31.2
Cr	940	1000	71.45	209.8	-	50	297	141.6	251.6	192.9	263.6	53.	566
V	367	36	-	-	-	270	292	303.3	283.3	-	211.1	-	197.2
Zn	84.7	-	129.6	111.6	-	-	-	115	96.25	92.3	-	-	37.8
Ga	17.6	12	-	-	-	-	-	-	-	-	16.1	-	-
Zr/Hf	55.24	-	43	33	38	52	33	-	-	-	-	-	-
Ni/Co	8.62	9	0.7	3	0.63	0.4	3.0	0.96	1.8	1.2	3.6	-	2.99

	Archean Tholeiites Western Australia (6)	McKinney Basalt (7)	Canadian Shield basalt (6)	Cape Verde Islands (5)		Eastern North American Olivine-normative tholeiitic diabase (4,11,12,14)	Hillabee Greenstone (13)
				Suite A	Suite B		
Rb	7.4	16.6	-	22.6	43.7	8	12.7
Ba	-	380	-	205.5	329.5	100	79
Sr	108	321	465	408.2	596.7	115	198
Zr	64.9	278	110	-	-	50	71
Sc	-	31	-	-	-	-	-
Hf	-	5.8	-	-	-	1.1	-
Th	-	2.2	-	5.5	0.0	0.4	-
Ni	149.6	8.7	150	306.3	156.6	308	46.3
Co	57.25	51	48	0.0	57.0	65	37.7
Cu	78.9	-	100	86.7	78.4	108	185.3
Cr	363.6	215	200	563.7	271.6	766	144.7
V	302.3	-	250	-	-	-	217
Zn	106.9	-	100	0.0	87.3	84	95.7
Ga	-	-	-	0.0	16.8	-	-
Zr/Hf	-	47.9	-	-	-	45.4	-
Ni/Co	2.6	1.7	3.1	-	2.7	4.7	1.2

SOURCES OF DATA

1. Aleinikoff (1977)
2. Atherton and others (1979)
3. Goossens and others (1977)
4. Gottfried and others (1977)
5. Gunn and Watkins (1976)
6. Hallberg (1972)
7. Leeman and Vitaliano (1976)
8. Montigny and others (1973)
9. Pavlides (1981)
10. Pearce and Cann (1973)
11. Ragland and others (1968)
12. Smith and others (1975)
13. Tull and others (1978)
14. Weigand and Ragland (1970)
15. Wrucke and others (1978)

and Cr. Overall, except for the Chopawamsic metabasalts, the trace-element abundances of the Gilpins Falls appear closest to those of the tholeiitic basalts (low-K tholeiites) of the island-arc series (table 10; Pearce and Cann, 1973).

The low levels of Co and Zn and the very high levels of Ni, Cr, and V in the Gilpins Falls metabasalts are petrologically significant. Cu, although known to be mobile in many cases (David Gottfried, written communication, 1982), is low in the Gilpins Falls. Copper is generally enriched in the residual liquids during differentiation of basaltic magma until immiscible sulfides rich in Cu appear, at which point a severe decrease in Cu occurs (Wager and Mitchell, 1951; McDougall and Lovering, 1963; McDougall, 1964; Walker, 1969; Greenland and Lovering, 1966; Paster and others, 1974; Gottfried and others, 1977). Fleischer (1968) showed that the Ni/Co ratios in tholeiitic diabase-granophyre suites decrease systematically from approximately 3 to less than 1 during differentiation, and are useful as an index of fractionation. Paster and others (1974) showed that Ni and Cr are successfully removed from the liquid in a crystallizing basaltic magma by the early cumulus minerals. In the Gilpins Falls metabasalts, much of the chromium was probably removed by chrome spinel and (or) chromite. Gunn (1971), Henderson and Dale (1969/1970), and Paster and others (1974) found that the values for the distribution coefficients for Co and Zn entering olivine are greater than unity, and that values for Co entering clinopyroxene also exceed unity. However, Paster and others (1974) found that the agreement between the predicted concentrations based on the distribution coefficients and the observed concentrations of these elements is poor, and that liquid in middle stages of crystallization had higher concentrations than original liquid or cumulus stages. At any rate, Co, Zn, Cu, Ni, and Cr appear to be useful as qualitative indices of fractionation. All these relations and the elemental abundances in the Gilpins Falls suggest that the Gilpins Falls metabasalts are primitive and poorly fractionated, and probably represent part of the cumulus stage of crystallization. This is supported by the MgO contents of amygdaloidal amphibolites and interiors of pillows in the Gilpins Falls metabasalts which average 9.9 percent and range from 6.1 to 13.9 percent MgO (table 8); these values are significantly higher than for most basalts and metabasalts.

Rare-earth element (REE) abundances for 12 samples of the Gilpins Falls are given in table 9. The lack of significant differences in abundances of REE between samples of interiors of pillows and pillow rims suggests that neither possible alteration nor the amphibolite-grade metamorphism of these rocks caused any appreciable changes in the abundances or distribution of the REE. Chondrite-normalized (Haskin and others, 1968) REE patterns for the Gilpins Falls metabasalts (fig. 31) show slight enrichment of the light REE (La-Sm) relative to the heavy REE (Gd-Lu); slight Tb enrichment in four of the samples is probably an analytical problem. Figure 32 shows the average (mean) chondrite-normalized pattern and the field (range) of the Gilpins Falls metabasalts. Figure 33 compares the average REE pattern of the Gilpins Falls metabasalts with the average patterns of oceanic-ridge tholeiitic basalts, Charleston corehole basalts, and basalts from the Mesozoic eastern North America tholeiitic province. The fact that the light-REE depleted pattern of the oceanic-ridge tholeiitic basalts is in contrast to the slightly light-REE enriched and markedly heavy-REE depleted pattern of the Gilpins Falls metabasalts supports the trace element data described earlier, which suggests that the Gilpins Falls metabasalts are probably not normal ocean-floor basalts that originated in an oceanic-ridge system. By the same token, the pattern of the Gilpins Falls does not match the more light-REE enriched, less heavy-REE depleted patterns of the Mesozoic eastern North American quartz-normative dolerites, although the pattern of the Gilpins Falls is somewhat similar to the pattern of the primitive Mesozoic eastern North American olivine-normal diabases.

Figures 34 through 41 compare the average pattern and field of the Gilpins Falls metabasalts with those of the Chopawamsic metabasalts (Pavlides, 1981), the Ta River amphibolites (Pavlides, 1981), island-arc tholeiites (Jakeš and Gill, 1970), interarc-basin basalts from the Lau Basin (Gill, 1976), basalts from the FAMOUS (French-American Mid-Ocean Undersea Study) area (White and Bryan, 1977), Mesozoic olivine-normative tholeiitic diabases of eastern North America (Ragland and others, 1971), tholeiites from the Othris (Greece) ophiolite complex

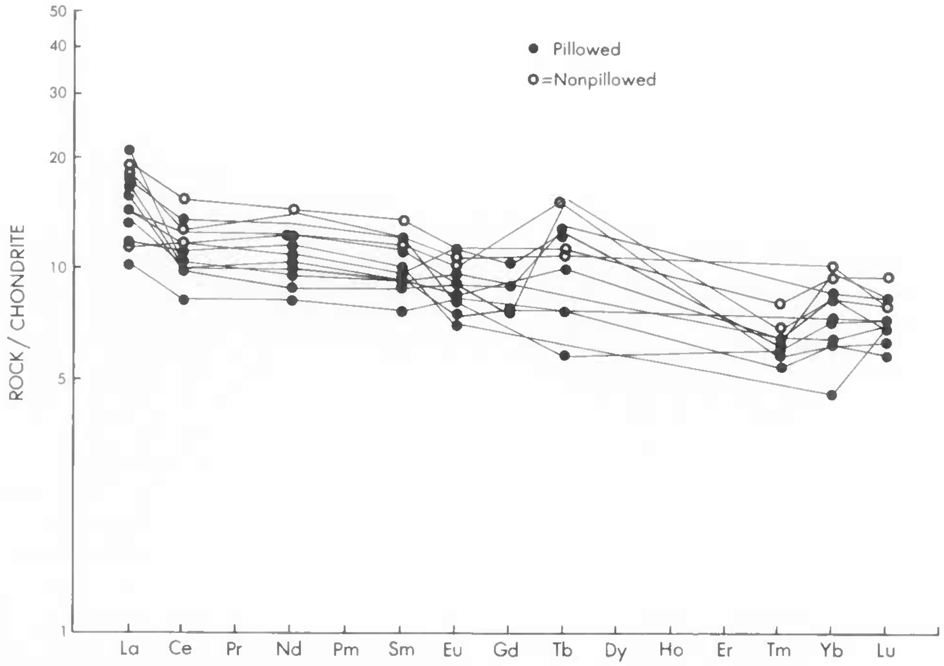

FIGURE 31: Plot of chondrite-normalized REE patterns for 12 samples of metabasalt from the Gilpins Falls Member of the James Run Formation.

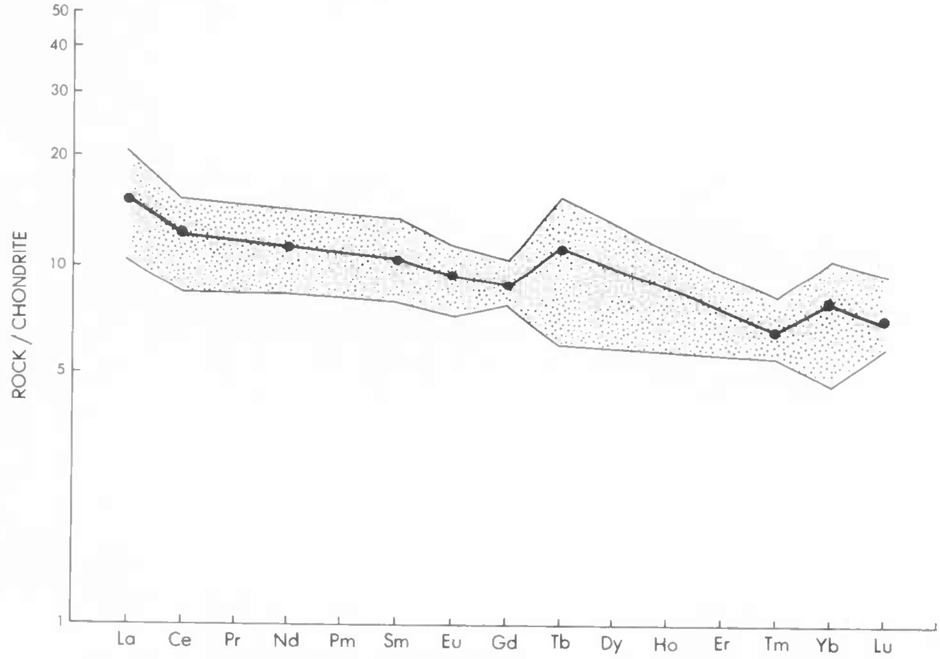

FIGURE 32: Average chondrite-normalized REE trend and field (stippled) for 12 samples of metabasalt from the Gilpins Falls Member of the James Run Formation.

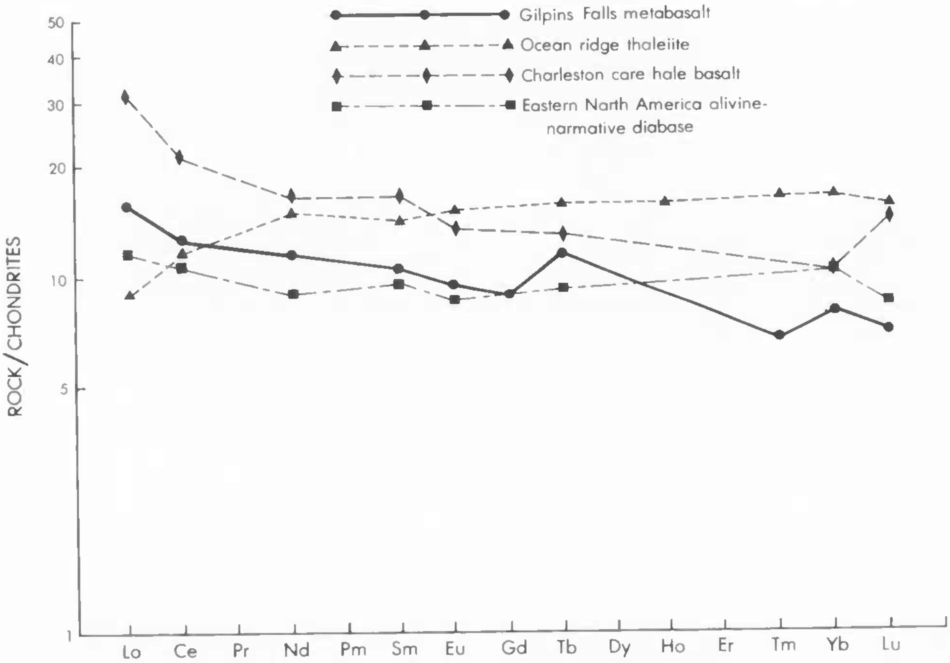

FIGURE 33: Average REE trend for metabasalts of the Gilpins Falls Member of the James Run Formation compared with the average REE trends of ocean ridge tholeiites, Charleston corehole basalts, and eastern North American olivine-normative diabases (data from Ragland and others, 1971; Schilling, 1971; and Gottfried and others, 1977).

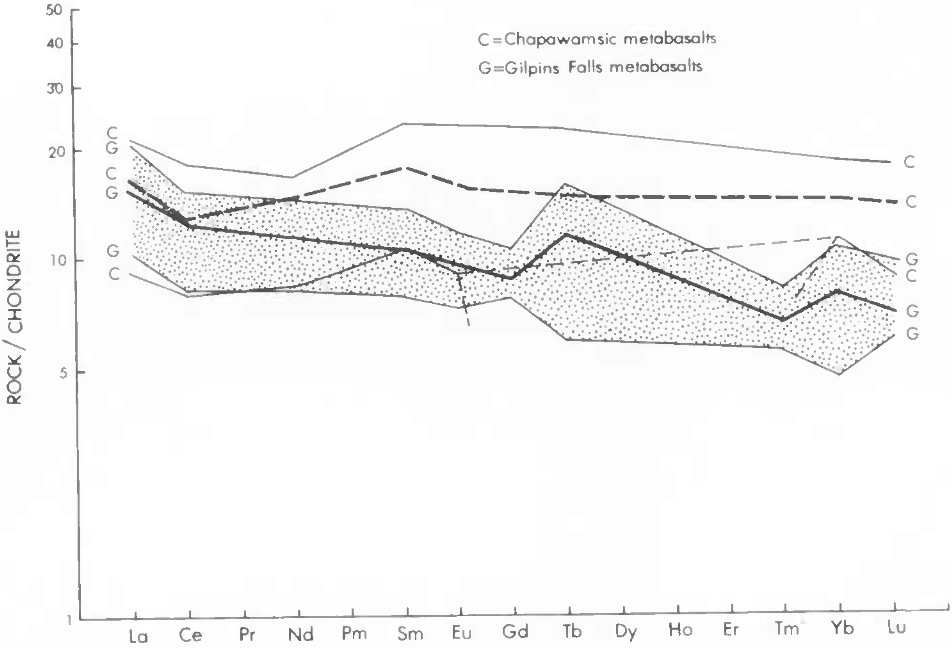

FIGURE 34: Field and trend of REE for metabasalts of the Gilpins Falls Member of the James Run Formation (stippled) compared with the field and trend of REE for metabasalts from the Chopawamsic Formation.

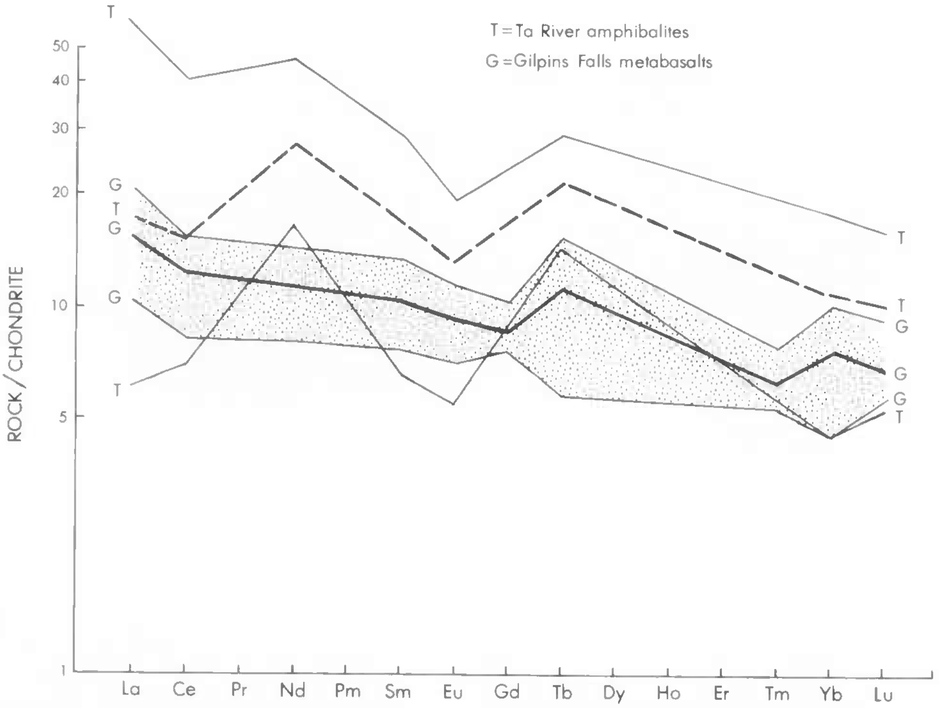

FIGURE 35: Field and trend of REE for metabasalts of the Gilpins Falls Member of the James Run Formation (stippled) compared with the field and trend of REE for the Ta River amphibolites.

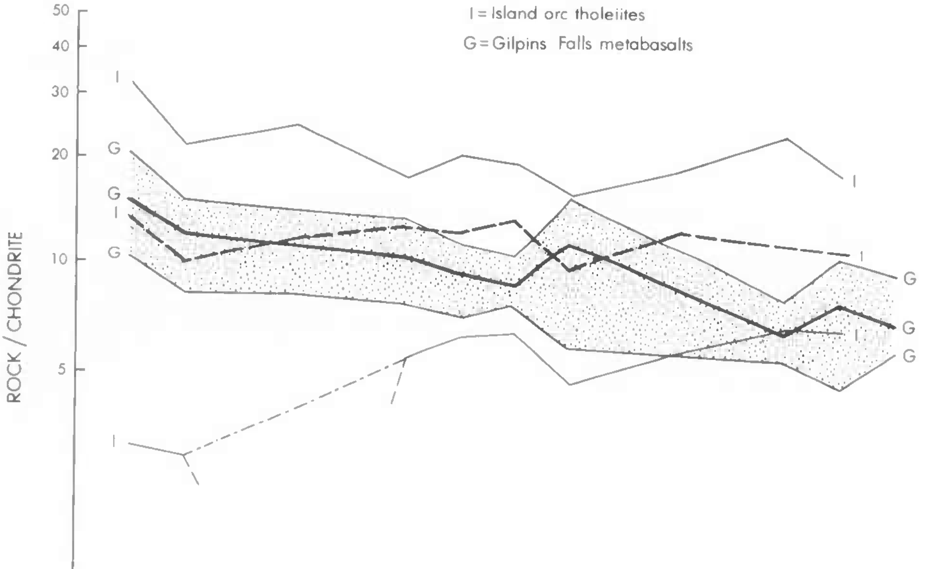

FIGURE 36: Field and trend of REE for metabasalts of the Gilpins Falls Member of the James Run Formation (stippled) compared with the field and trend of REE for island arc tholeiites (data from Jakeš and Gill, 1970).

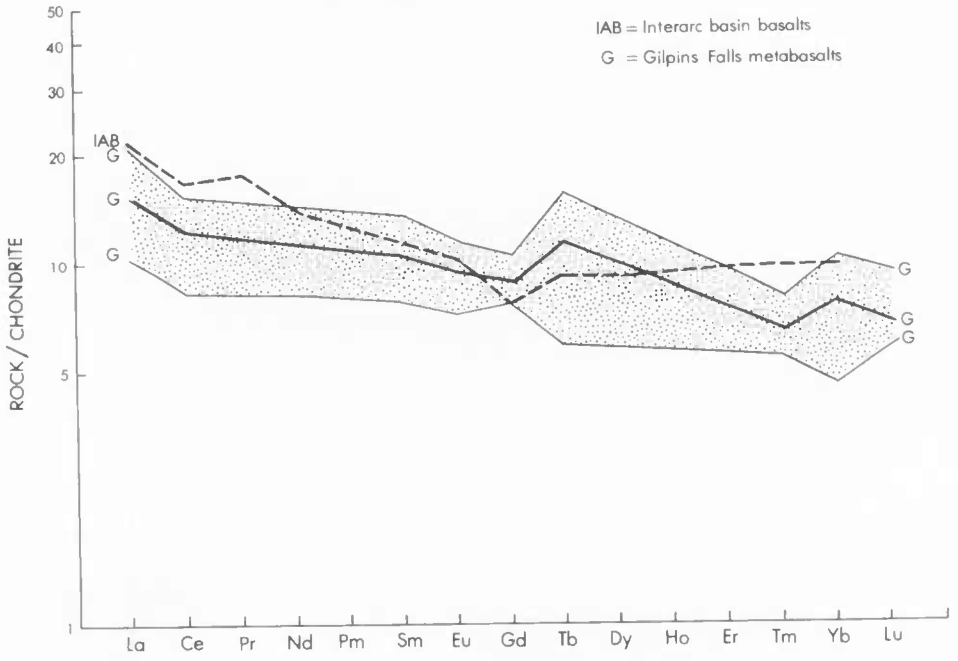

FIGURE 37: Field and trend of REE for metabasalts of the Gilpins Falls Member of the James Run Formation (stippled) compared with the trend of REE for interarc basin basalts from the Lau Basin (data from Gill, 1976).

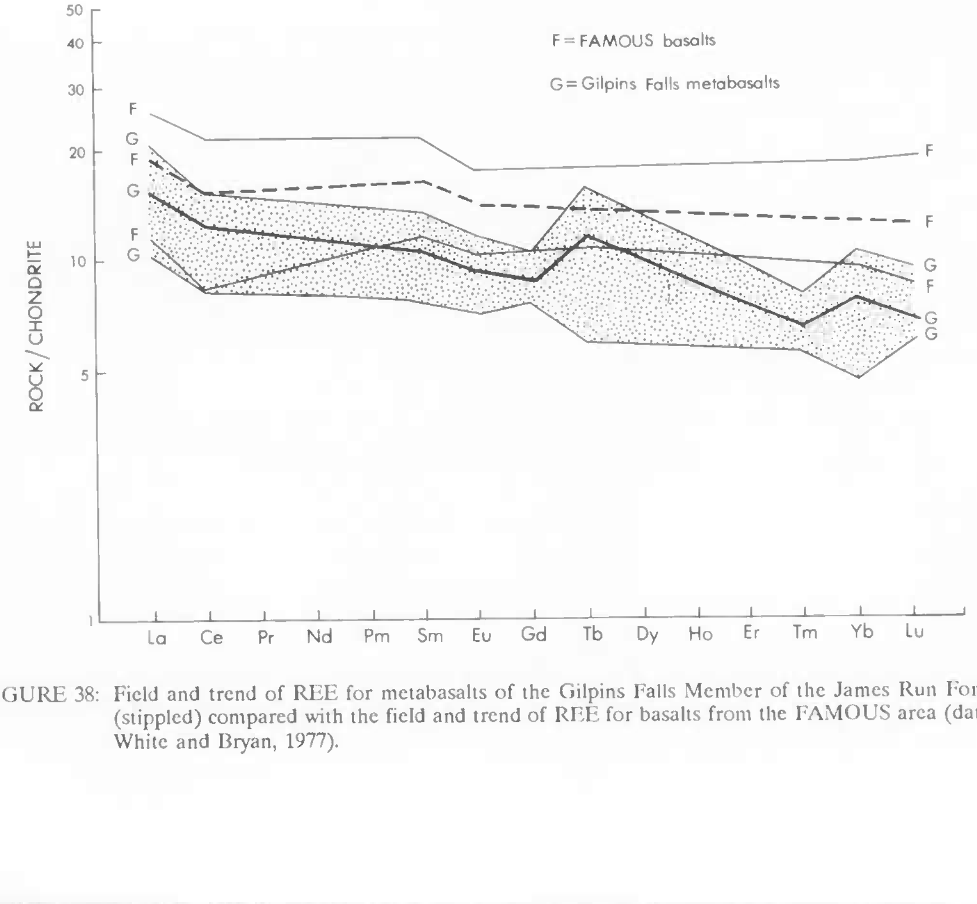

FIGURE 38: Field and trend of REE for metabasalts of the Gilpins Falls Member of the James Run Formation (stippled) compared with the field and trend of REE for basalts from the FAMOUS area (data from White and Bryan, 1977).

(Menzies, 1976), and Archean komatiites (Arth and others, 1977). The Chopawamsic metabasalts and the Ta River amphibolites are approximately along strike from the Gilpins Falls metabasalts to the southwest in Virginia, and the Chopawamsic Formation has been correlated with the James Run Formation on geologic grounds (Southwick and others, 1971; Higgins, 1972; Pavlides, 1976, 1980, 1981). The other rock suites were chosen either because they are from tectonic settings that might be similar to the original tectonic setting of the Gilpins Falls or because they have REE patterns in some way similar to those of the Gilpins Falls metabasalts. The fields for the Gilpins Falls metabasalts and the Chopawamsic metabasalts (fig. 34) overlap for the lighter REE from La through Nd, but from Nd through also have a slight, but consistent, Sm enrichment that is not seen in the Gilpins Falls. There is much less overlap between the Gilpins Falls metabasalts and the Ta River amphibolites Lu the Gilpins Falls metabasalts are more strongly depleted. The Chopawamsic metabasalts (fig. 35), but some of the Ta River data may be analytically poor (David Gottfried, written communication, 1982). The average REE pattern of the Gilpins Falls metabasalts lies almost completely within the broad field of island-arc tholeiites (fig. 36), but the field of the Gilpins Falls and the average Gilpins Falls pattern compared with the average island-arc tholeiite pattern, indicate greater depletion in the heavier REE in the Gilpins Falls. The average pattern of interarc-basin basalts has a similar trend to the Gilpins Falls trend, but is slightly more light-REE enriched and markedly less heavy-REE depleted than the Gilpins Falls field (fig. 37). The basalts from the FAMOUS area have about the same light-REE enrichment as the Gilpins Falls metabasalts (fig 38), but are markedly less depleted in heavy-REE. The Mesozoic olivine-normative tholeiitic diabases of eastern North America are less enriched in light-REE than the Gilpins Falls metabasalts (fig. 39), but less depleted in heavy-REE. Tholeiites from the Othris ophiolite complex define a REE field similar to that of the Gilpins Falls (fig. 40), but the field is based on sparse data. Archean komatiites are slightly less light-REE enriched than the Gilpins Falls metabasalts and are slightly less depleted in heavy-REE than the Gilpins Falls (fig. 41).

The most striking features of the REE in the Gilpins Falls metabasalts are the low-level abundances (table 9) and the depletion in heavy-REE (figs. 31 and 32). These features can be accounted for if the Gilpins Falls magmas were primitive and associated with a cumulus phase of crystallization, as suggested by the major and trace elements. Studies of REE in ultramafic rocks from ophiolite complexes and "alpine" ultramafic bodies (Frey and others, 1971; Menzies and others, 1975; Menzies, 1976) and layered mafic intrusions (Frey and others, 1971) show that these rocks are strongly depleted in REE relative to basalts. In figure 42, REE patterns of some representative ultramafic rocks and metamorphosed mafic rocks from the Soapstone Ridge Complex, Atlanta, Georgia (Higgins and others, 1980), are compared with the average REE pattern and field for the Gilpins Falls. Most of the ultramafic rocks are probably cumulates. The metamafic rocks of the Soapstone Ridge Complex are probably part of an ophiolite. There is an order of magnitude difference in abundance levels between the ultramafic rocks (fig. 42) and the Gilpins Falls metabasalts, but the trends of the patterns are similar. Menzies (1976, p. 649) stated:

> If a chondritic relative REE distribution is assumed for the parent, conventional ideas on REE distribution and partitioning imply that refractory peridotites are heavily depleted in REE because light REE are strongly partitioned into the liquid (Schilling, 1971).

The REE depletion that is generally associated with cumulates can be used to infer that the slightly depleted REE patterns of the Gilpins Falls metabasalts may result from their having crystallized during a late-stage cumulus phase. The similarity (fig. 40) between the REE patterns of the Gilpins Falls and those of "ophiolitic basalts" (Menzies, 1976) suggests that the Gilpins Falls metabasalts may be ophiolitic. In this regard, it is interesting to compare the REE pattern of the Gilpins Falls metabasalts with those of metatroctolites and metagabbros from the Soapstone Ridge Complex (fig. 42). The Soapstone Ridge metamorphosed mafic rocks are enriched in light-REE to about the same extent as the Gilpins Falls, but they are

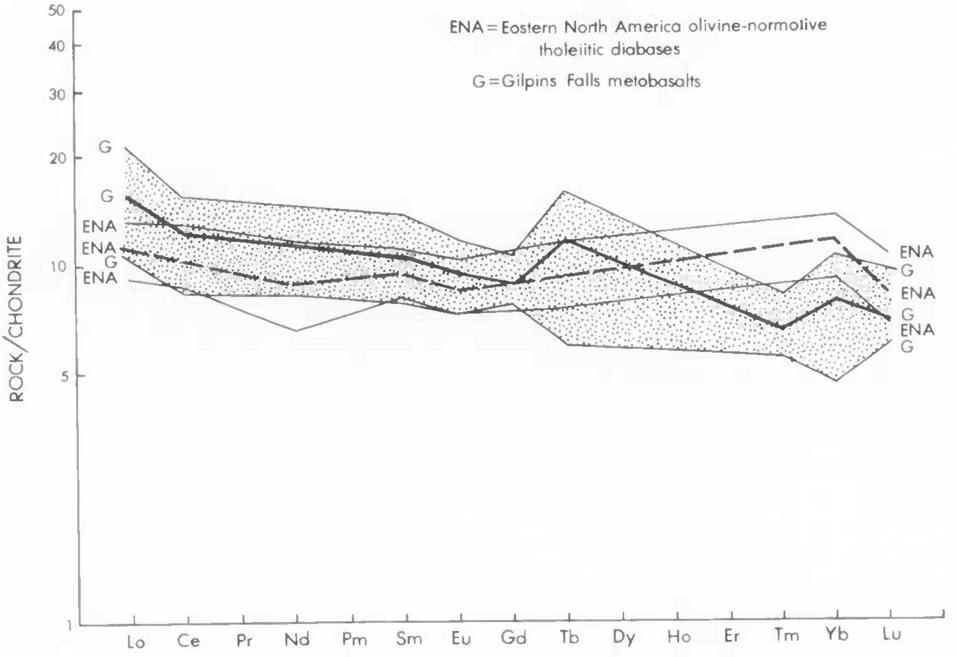

FIGURE 39: Field and trend of REE for metabasalts of the Gilpins Falls Member of the James Run Formation (stippled) compared with the field and trend of REE for eastern North American olivine-normative tholeiitic diabases (data from Ragland and others, 1971).

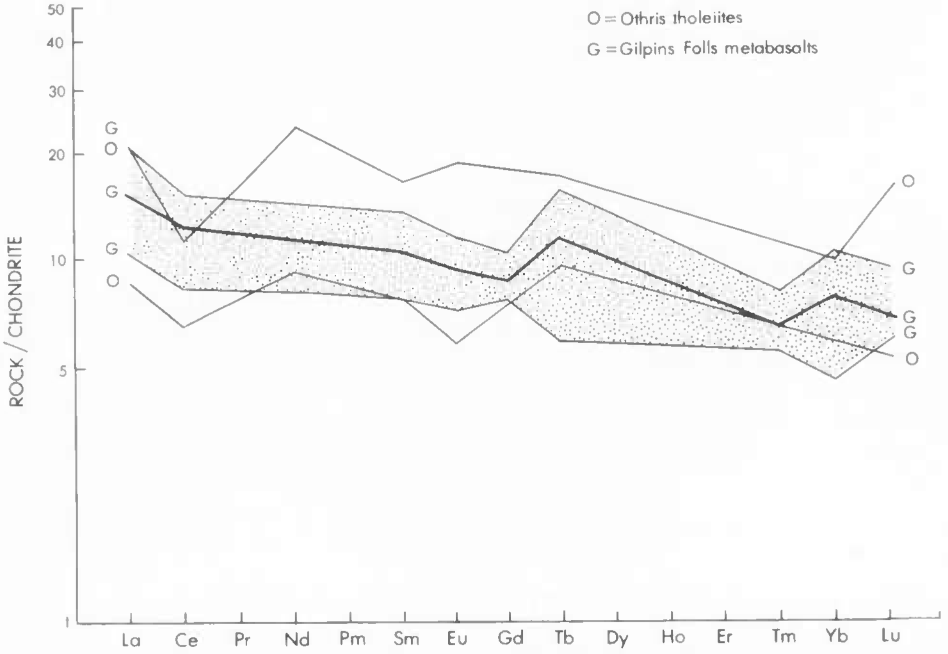

FIGURE 40: Field and trend of REE for metabasalts of the Gilpins Falls Member of the James Run Formation (stippled) compared with the field and trend of REE for the Othris tholeiites (data from Menzies, 1976).

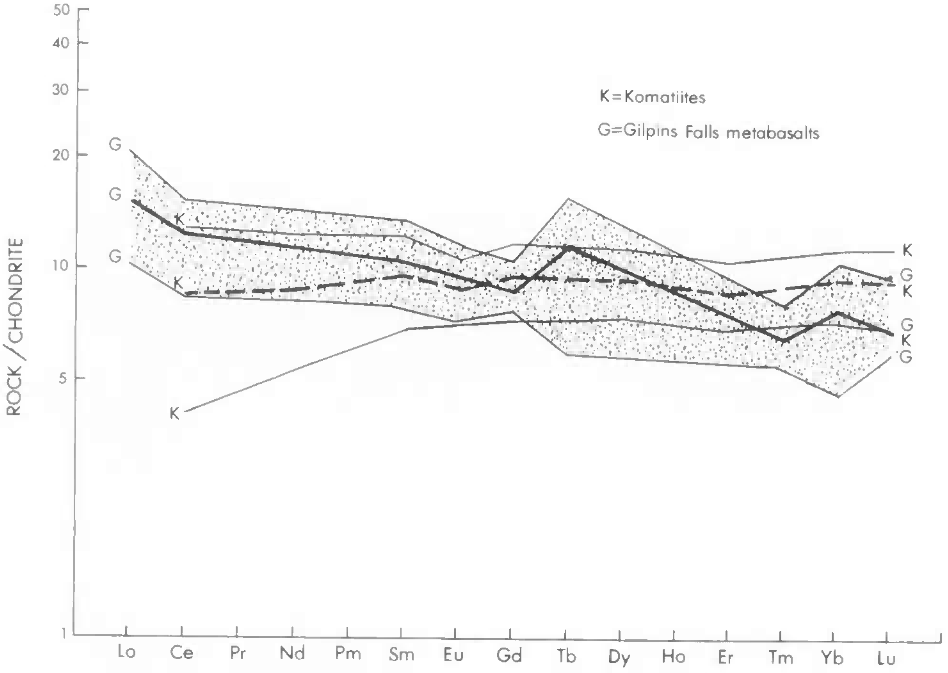

FIGURE 41: Field and trend of REE for metabasalts of the Gilpins Falls Member of the James Run Formation (stippled) compared with the field and trend of REE for komatiites from Ontario (data from Arth and others, 1977).

much more strongly depleted in heavy-REE, plotting between the Gilpins Falls and the ultramafic rocks. These relations would seem to support Menzies' (1976) and Schilling's (1971) model of light-REE enrichment through partitioning into the liquid, while leaving the heavy-REE depleted. The ophiolite with which the Gilpins Falls is associated would be the Baltimore Complex (Crowley, 1976; Morgan, 1977).

ORIGINAL TECTONOMAGMATIC SETTING

The original tectonomagmatic setting of mafic volcanic rocks is based on the relative motions of lithospheric plates. Therefore, these rocks are broadly divided into three categories (Pearce and Cann, 1973): (1) ocean-floor basalts formed at diverging plate margins; (2) low-K tholeiites and calc-alkaline basalts of the island arc series formed at converging plate margins; and (3) intraplate oceanic island and continental basalts formed within oceanic crust or within continental crust. Elements commonly used to distinguish these categories are Ti, Zr, Y, Nb, P, K, and Sr (Pearce and Cann, 1973; Floyd and Winchester, 1975; Winchester and Floyd, 1976; Pearce and others, 1975). The discrimination diagrams most widely used for unaltered, unmetamorphosed volcanic rocks are the **Ti-Zr**, **Ti-Zr-Y**, and **Ti-Zr-Sr** diagrams of Pearce and Cann (1973). Despite the fact that these diagrams were originally devised to distinguish the tectonic settings of unaltered, unmetamorphosed rocks, many workers have used them to investigate past environments of metamorphosed mafic rocks (for example: Pearce and Cann, 1971; Bickle and Nisbet, 1972; Seidel, 1974; Pearce, 1975; Smewing and others, 1975; Kay and Senechal, 1976; Menzies, 1976; Aleinikoff, 1977; Tull and others, 1978; Wrucke and others, 1978).

On **Ti-Zr** and **Ti-Zr-Sr** diagrams (figs. 43 and 44), the fact that the Gilpins Falls metabasalts of "calc-alkaline basalt of the island-arc series" lends support to the field evidence and other

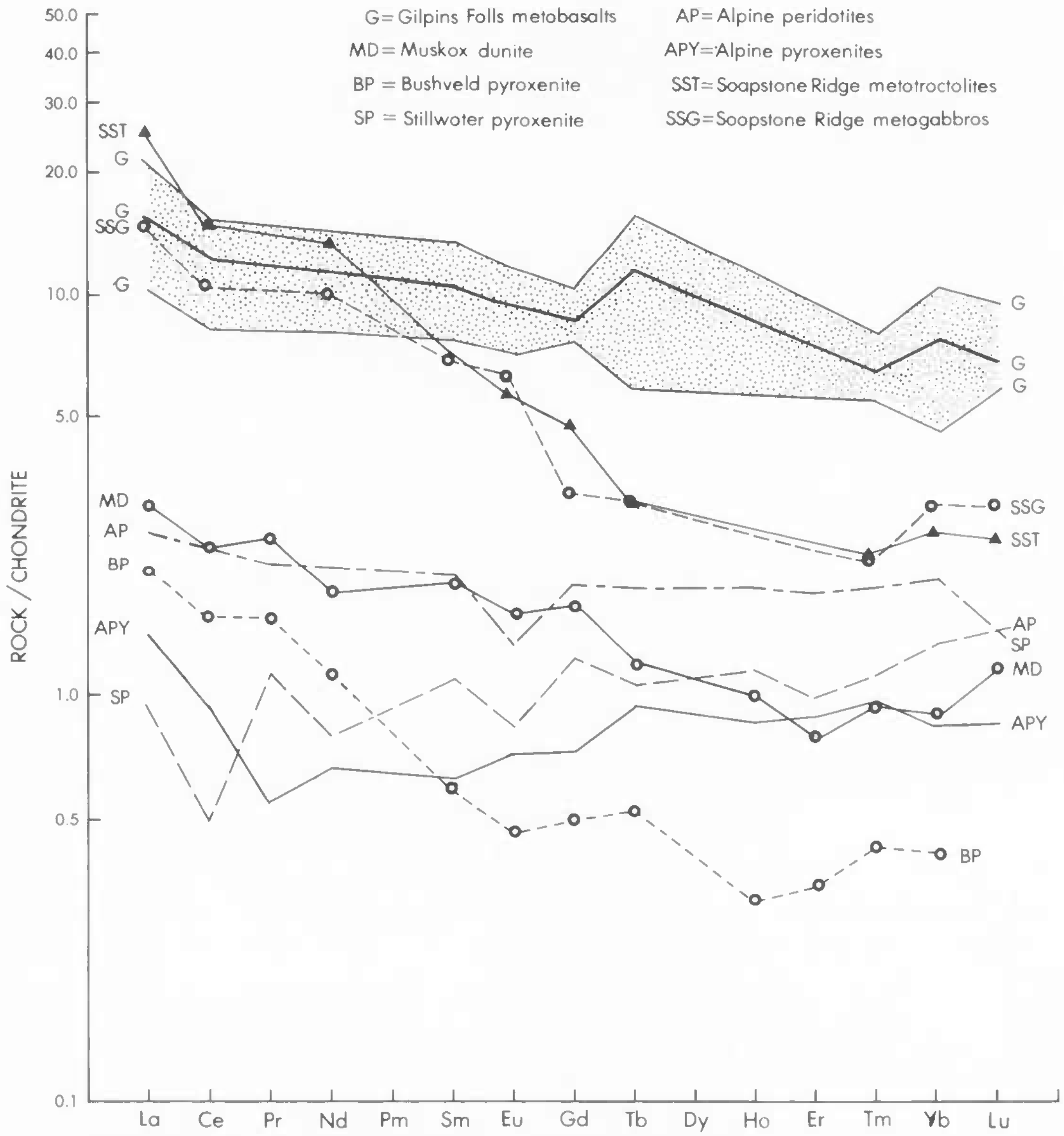

FIGURE 42: Field and trend of REE for metabasalts of the Gilpins Falls Member of the James Run Formation (stippled) compared with the average trends of REE for metatroctolites and metagabbros of the Soapstone Ridge Complex (Higgins and others, unpub. data), Muskox dunites, Bushveld pyroxenites, Stillwater pyroxenites, alpine peridotites, and alpine pyroxenites (data from Frey and others, 1971).

geochemical evidence suggesting that the James Run metavolcanic rocks formed in an island arc. Caution must be exercised in using these diagrams, however, because: (1) While Ti and plot in both the field of "low-potassium tholeiitic basalt of the island-arc series" and the field Zr are generally thought to be relatively immobile during alteration and metamorphism (Cann, 1970; Pearce and Cann, 1971, 1973; Pearce and others, 1975; Floyd and Winchester, 1975; Winchester and Floyd, 1976; Gottfried and others, 1977), Sr is generally considered mobile (Philpotts and others, 1969; Hart, 1971; Pearce and Cann, 1973; Hart and others, 1974; Gottfried and others, 1977); and (2) Gottfried and others (1977) have shown that the diagrams

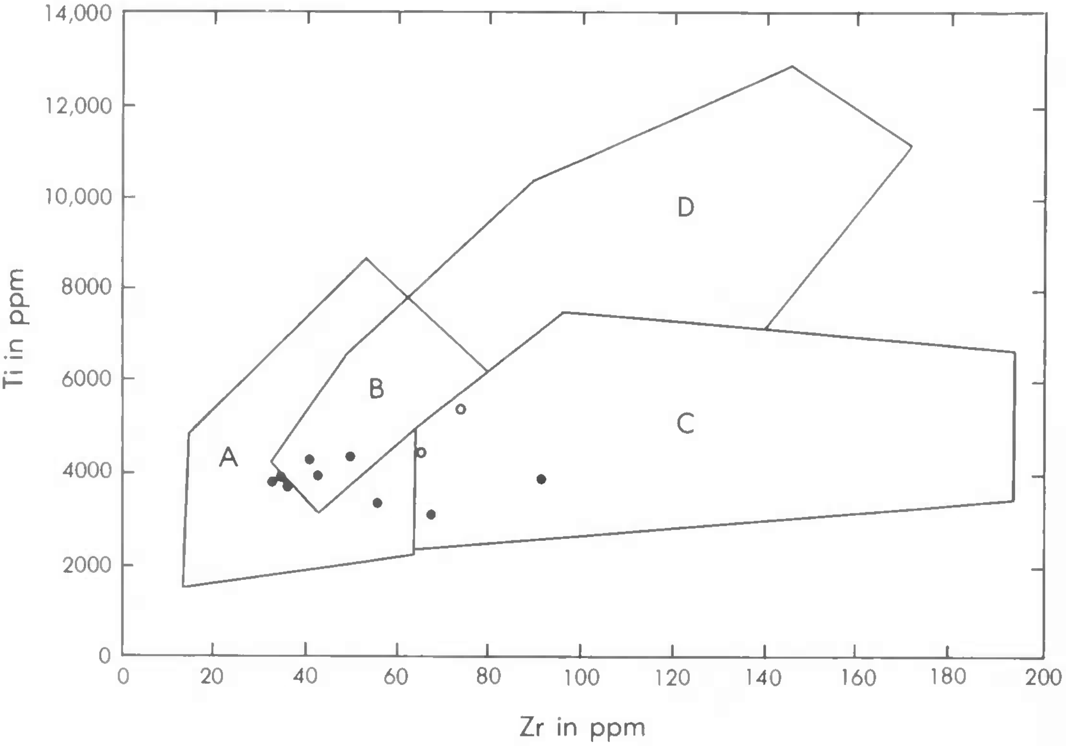

FIGURE 43: Ti - Zr plot for metabasalts of the Gilpins Falls Member of the James Run Formation (fields from Pearce and Cann, 1973).

A-B: Low-potassium tholeiitic basalt of the island arc series
B-C: Calc-alkaline basalt of the island arc series
B-D: Ocean-floor basalt

may be inappropriate for identification of the tectonomagmatic setting of some rock types, and stated (Gottfried and others, 1977, p. 110):

> ...no single group or pair of geochemically associated elements could be used alone for distinguishing magma type and tectonic setting of the corehole basalts from basalts of all the contrasting tectonic environments considered. This emphasizes the importance of using trace elements of widely different chemical properties and sizes for discrimination purposes.

The consistency of all the geochemical data from the James Run Formation suggests that these rocks originally formed in an island-arc setting.

BALTIMORE COMPLEX

The geochemistry of the Baltimore Complex has been studied by Herz (1951), Thayer (1960), Southwick (1969, 1970), and Hanan (1976). These workers all emphasized the differentiation trend toward iron enrichment shown on the **F' - M - A** diagrams for suites of rocks from the complex. However, both Southwick (1970) and Hanan (1976) recognized possible problems due to changes in the MgO/FeO ratios caused by alteration and metamorphism. Hanan (1976) also studied the Sr isotope geochemistry of the complex and concluded that greater equilibration through exchange with the "country rocks" during metamorphism had occurred in the vicinity of the Susquehanna River than in the vicinity of

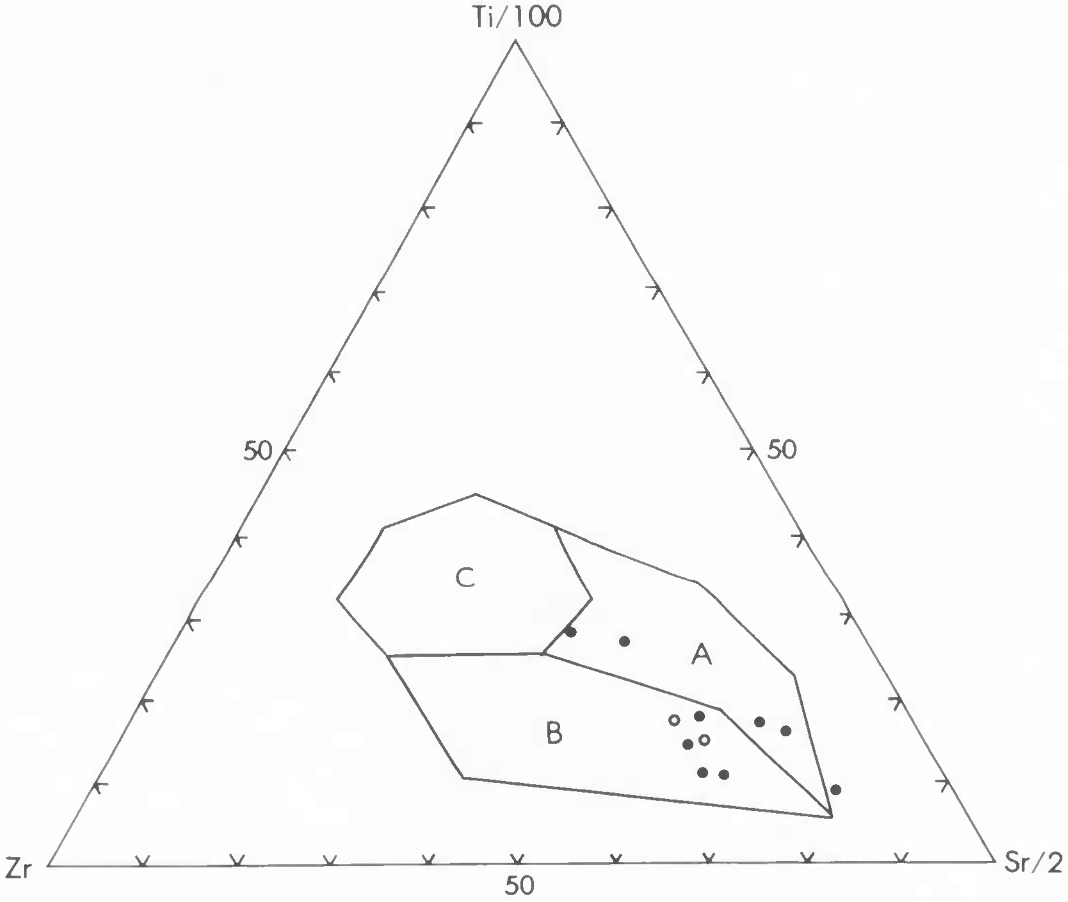

FIGURE 44: **Ti - Zr - Sr** plot for metabasalts of the Gilpins Falls Member of the James Run Formation (fields from Pearce and Cann, 1973).

Baltimore. He attributed the difference to the greater water content of the metasedimentary rocks in contact with the complex along the Susquehanna, as opposed to the "dry" Baltimore Gneiss near the complex in the Baltimore area.

MAJOR OXIDES

Major oxide analyses of Baltimore Complex rocks from Cecil County are given in table 11; many of these analyses were also used by Hanan (1976). On an **F'- M - A** diagram (fig 45) most of these analyses plot along the **F' - M** side of the triangle, with a trend toward iron enrichment. However, several of the analyses plot farther toward the **F'- A** side of the triangle, and could be construed as marking the beginning of a trend "turning the corner" toward the alkali apex. Some of the analyses plot closer to the **M** apex of the triangle than previously known for the complex (compare with Southwick, 1970, p. 410). As noted by Southwick (1970), the scatter of points on the **F'- M - A** diagram suggests the possibility of changes in the ratios due to alteration and (or) metamorphism.

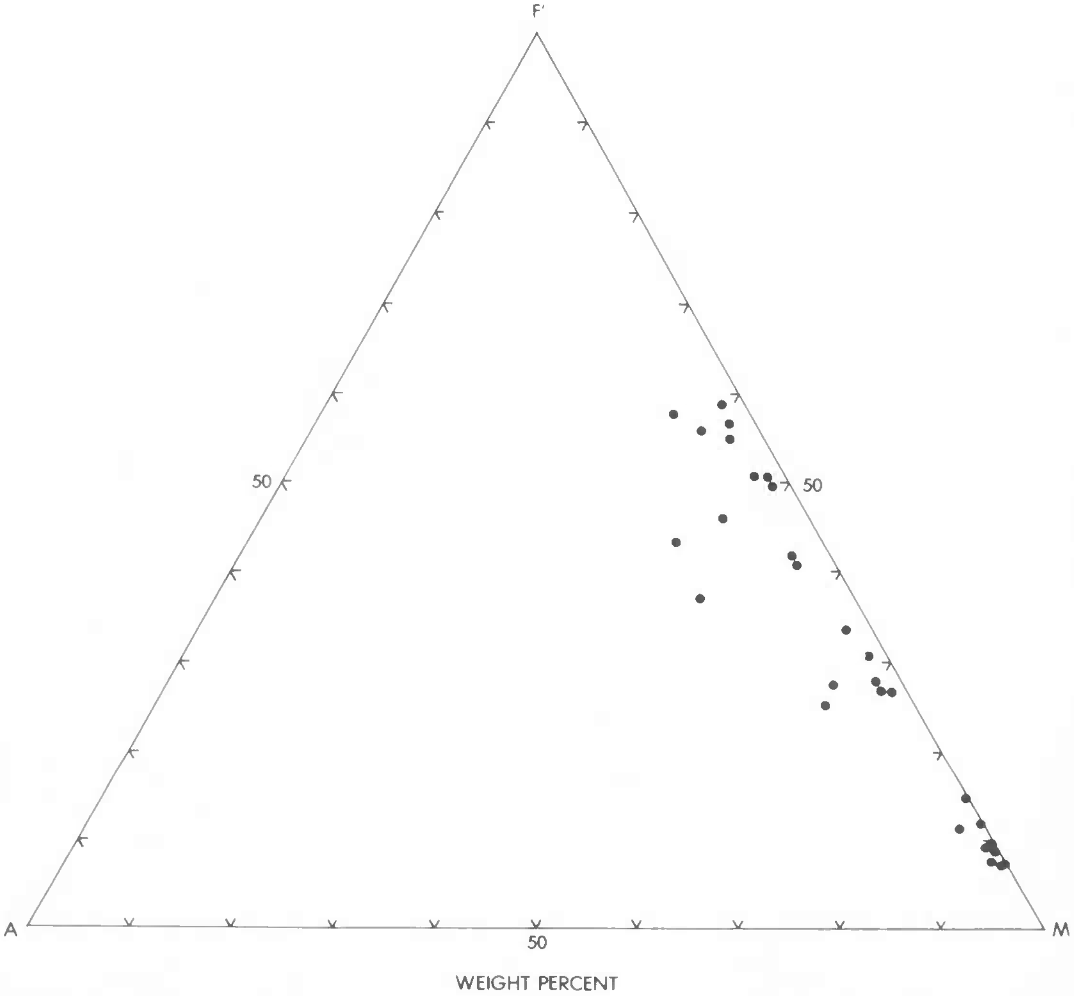

FIGURE 45: **F'- M - A** plot for analyses of rocks of the Baltimore Complex.

In figure 46, analyses of metavolcanogenic rocks of the James Run Formation from figure 27 are plotted along with the analyses of Baltimore Complex rocks from figure 45. Eight analyses by Southwick (1970, p. 412) of Baltimore Complex rocks from Harford County are included. Southwick's analyses 9 through 12 ("quartz-bearing metagabbro" and "dark quartz diorites") are not plotted in figure 46 because these rocks are now considered to belong to the mafic zone of the Conowingo diamictite. Analysis 8 of Southwick (1970, p. 412), shown in figure 46 by a separate symbol, may also be from the mafic zone near Rising Sun. Deletion of these analyses of probable metasedimentary rocks lowers the trend toward iron enrichment noted by previous workers. However, the points show so much scatter that an average trend is difficult to discern and may be meaningless because of alteration and (or) metamorphism. The overlap between the Baltimore Complex analyses and the analyses of mafic rocks from the James Run Formation on the **F'- M - A** diagram is evident, but the scatter of points in the area of overlap is so great that the overlap may not be significant.

In figure 47, the James Run and Baltimore Complex analyses are compared with several well-known differentiation trends. If the point scatter is ignored, and if the James Run rocks and the Baltimore Complex are genetically related, the differentiation trend would start with highly magnesian rocks, trend toward moderate iron enrichment like slightly iron-enriched,

TABLE 11
CHEMICAL ANALYSES OF ROCKS OF THE BALTIMORE COMPLEX, CECIL COUNTY

	Traverse #1												
	S-1-1	S-1-2	S-1-3	S-1-4	S-1-5	S-1-6	S-1-7	S-1-8	S-1-9	S-1-11	S-1-13	S-1-14	S-1-15
SiO_2	38.3	33.3	34.4	40.7	45.6	49.4	43.1	47.2	53.1	48.3	57.3	53.2	60.0
Al_2O_3	1.8	0.80	0.90	0.80	1.2	17.8	14.1	17.8	18.7	18.8	11.5	14.4	14.7
Fe_2O_3	5.6	3.2	2.3	7.8	1.0	2.8	5.0	1.7	3.5	4.1	1.2	2.4	3.0
FeO	1.8	2.6	3.6	1.2	5.2	4.0	10.8	4.8	6.7	6.7	8.2	5.4	4.8
MgO	37.8	38.0	38.4	36.4	35.8	7.8	8.5	9.8	3.4	8.1	11.1	10.5	4.1
CaO	0.23	1.1	0.33	0.09	0.29	11.4	11.8	14.1	9.8	11.8	7.5	9.5	7.4
Na_2O	0.05	0.07	0.06	0.03	0.02	3.1	0.43	0.33	1.1	0.30	1.7	1.5	2.0
K_2O	0.0	0.01	0.0	0.0	0.0	0.16	0.11	0.04	0.14	0.01	0.42	0.21	0.22
H_2O+	10.5	8.4	8.7	11.2	10.9	1.7	2.5	2.7	1.1	3.5	0.89	2.5	1.2
H_2O-	0.21	0.17	0.15	0.74	0.10	0.14	0.22	0.08	0.17	0.07	0.11	0.10	0.05
TiO_2	0.04	0.02	0.06	0.02	0.02	0.7	1.8	0.27	2.1	0.69	0.46	0.37	0.85
P_2O_5	0.01	0.01	0.01	0.01	0.01	0.10	0.02	0.01	0.50	0.46	0.16	0.11	0.27
MnO	0.05	0.08	0.15	0.08	0.03	0.07	0.19	0.08	0.14	0.20	0.11	0.11	0.08
CO_2	0.08	7.6	0.07	0.01	0.07	0.04	0.07	0.06	0.03	0.08	0.05	0.07	0.04
Ig.loss*	3.4	4.6	11.1	-	-	-	-	-	-	-	-	-	-
Total	99.5	100.0	100.2	99.1	100.2	98.9	98.6	98.8	98.5	98.9	98.7	100.4	98.5

	Traverse #2									
	S-2-1	S-2-2	S-2-3	S-2-4	S-2-5	S-2-6	S-2-7	S-2-8	S-3-1	S-3-2
SiO_2	44.4	42.3	47.6	43.2	48.9	40.4	40.5	47.2	50.7	47.2
Al_2O_3	2.2	0.70	17.8	18.1	16.4	18.3	17.8	16.8	11.7	19.2
Fe_2O_3	1.1	0.14	1.3	5.0	1.9	5.8	7.1	3.0	1.5	1.8
FeO	5.2	5.1	5.5	8.1	7.2	8.4	9.3	8.3	8.9	4.4
MgO	34.7	36.8	9.7	6.6	11.4	5.9	8.0	8.1	13.0	9.0
CaO	0.84	0.82	14.0	12.7	12.3	12.2	13.4	12.4	8.5	12.6
Na_2O	0.10	0.0	0.45	0.45	0.96	0.73	0.55	0.84	0.38	0.2
K_2O	0.0	0.0	0.10	0.37	0.01	0.03	0.04	0.02	0.12	0.23
H_2O+	10.9	11.2	1.9	3.2	0.75	3.0	1.8	0.54	3.3	3.5
H_2O-	0.16	0.07	0.09	0.13	0.05	0.08	0.05	0.05	0.14	0.07
TiO_2	0.09	0.02	0.20	1.0	0.38	2.3	1.8	1.1	0.70	0.22
P_2O_5	0.01	0.0	0.02	0.0	0.09	1.1	0.65	0.12	0.05	0.01
MnO	0.05	0.02	0.11	0.16	0.16	0.14	0.19	0.18	0.21	0.0
CO_2	0.04	1.0	0.06	0.02	0.03	0.08	0.08	0.04	0.07	0.03
Ig.loss*	-	-	-	-	-	-	-	-	-	-
Total	99.8	99.2	98.8	99.1	100.0	98.5	99.1	98.7	99.3	98.6

	Traverse #2, continued						Other samples			
	S-3-3	S-3-4	S-3-5	S-3-6	S-3-7	S-3-8	Z	CD-32	CD-71	Gabbro near Elkton EL-GAB
SiO_2	48.0	38.7	41.0	49.7	44.2	48.9	48.2	48.8	59.7	49.0
Al_2O_3	19.4	4.5	15.0	16.4	17.4	18.3	12.7	17.8	13.6	19.4
Fe_2O_3	1.6	10.0	6.4	4.3	4.6	2.4	7.4	0.90	2.9	1.0
FeO	6.2	5.9	9.8	7.4	8.9	7.5	7.4	7.0	5.6	5.4
MgO	8.5	31.0	8.3	4.5	5.3	5.5	11.9	10.7	5.1	8.6
CaO	13.5	2.3	13.0	9.4	10.5	10.5	9.7	12.1	6.9	14.4
Na_2O	0.47	0.0	0.49	0.87	0.70	0.27	0.54	0.60	2.3	1.0
K_2O	0.0	0.0	0.04	0.08	0.07	1.4	0.14	0.05	0.31	0.07
H_2O+	0.37	7.8	2.2	3.2	3.7	1.8	0.78	0.66	2.3	0.75
H_2O-	0.04	1.40	0.01	0.04	0.09	0.04	0.11	0.07	0.02	0.03
TiO_2	0.30	0.19	1.8	1.7	2.0	1.3	0.48	0.31	1.1	0.25
P_2O_5	0.03	0.02	0.02	0.69	0.86	0.44	0.22	0.13	0.10	0.0
MnO	0.12	0.15	0.17	0.18	0.17	0.17	0.18	0.17	0.14	0.12
CO_2	0.02	0.02	0.08	0.08	0.04	0.04	<0.05	<0.05	<0.05	<0.05
Ig.loss*	-	-	-	-	-	-	-	-	-	-
Total	98.6	101.0	98.3	98.5	98.5	98.8	99.8	99.3	100.1	100.1

* Ignition loss less CO_2 and H_2O.

(continued on next page)

TABLE 11 (continued)
Sample locations and descriptions
(** indicates location and description of sample not furnished by author)

TRAVERSE NO. 1: Boy Scout Camp Road section - Begins at horseshoe bend of Octoraro Creek in Cecil County, Maryland, just south of Camp Horseshoe Boy Scout Camp in Chester County, Pennsylvania, and follows the road eastward along the north side of the creek.

Sample	*Miles*	*Rock and description*
S-1-1	0.0	Serpentinite: serpentine + talc + opaques
S-1-2	0.0	Serpentinite: similar to S-1-1
S-1-3	0.09	Serpentinite: similar to S-1-1
S-1-4	0.15	Serpentinite: similar to S-1-1
S-1-5	0.19	Serpentinite: similar to S-1-1
S-1-6	**	**
S-1-7	0.43	Uralite gabbro: uralite + actinolite + epidote-zoisite + chlorite + opaques
S-1-8	0.56	Metagabbro: epidote-zoisite + plagioclase + chlorite + actinolite + quartz + opaques
S-1-9	0.71	Quartz metagabbro: quartz + plagioclase + uralite + chlorite + epidote-zoisite + actinolite + opaques
S-1-11	**	**
S-1-13	**	Epidiorite: quartz + plagioclase + actinolite + chlorite + biotite + muscovite + opaques (collected at the intersection of the Boy Scout Camp road and the first road east)
S-1-14	**	**
S-1-15	**	Quartz metagabbro: quartz + plagioclase + epidote-zoisite + uralite + actinolite + biotite + muscovite + opaques (collected on the east side of Octoraro Creek at the U.S. Rte. 1 bridge, about 0.25 mile (400 m) northeast of Richardsmere, Cecil County)

TRAVERSE NO. 2: Susquehanna traverse - Begins on the Susquehanna River 0.9 mile (1.5 km) northwest of Conowingo Creek, at the northwestern contact of the serpentinite, and continues southeast along the railroad tracks of the CONRAIL System for 1.3 miles (2 km) to the small pond beside the railroad about 0.5 mile (0.8 km) northwest of U.S. Rte 222.

Sample	*Miles*	*Rock and description*
S-2-1	0.0	Serpentinite: serpentine
S-2-2	0.15	Serpentinite: serpentine + talc + opaques
S-2-3	0.25	Metagabbro: orthopyroxene + clinopyroxene + plagioclase + epidote-zoisite + actinolite + muscovite + opaques + trace uralite
S-2-4	0.32	Uralitized gabbro: epidote-clinozoisite + chlorite + uralite + muscovite + biotite + actinolite + opaques
S-2-5	0.42	Metagabbro: orthopyroxene + clinopyroxene + plagioclase + actinolite + opaques + trace uralite
S-2-6	0.56	Uralitized gabbro: plagioclase + uralite + actinolite + epidote-zoisite + chlorite + sphene + opaques
S-2-7	0.70	Uralitized gabbro: uralite + actinolite + chlorite + epidote-zoisite + plagioclase + opaques
S-2-8	0.85	Metagabbro: orthopyroxene + clinopyroxene + plagioclase + opaques + trace uralite

The following samples were collected along the railroad tracks of the CONRAIL System, parallel to the Susquehanna River, between the south bank of Octoraro Creek and the small pond beside the railroad, about 0.5 mile (0.8 km) northwest of U.S. Rte. 222:

Sample	*Miles*	*Rock and description*
S-3-1	0.0	Quartz metagabbro: quartz + plagioclase + epidote-zoisite + uralite + chlorite + biotite + sphene + opaques
S-3-2	0.15	Metagabbro: epidote-zoisite + actinolite + chlorite + muscovite + trace uralite + opaques
S-3-3	0.30	Metagabbro: orthopyroxene + clinopyroxene + plagioclase + opaques + trace uralite
S-3-4	**	**
S-3-5	0.60	Uralite gabbro: uralite + actinolite + chlorite + epidote-zoisite + opaques
S-3-6	0.78	Quartz metagabbro: uralite + actinolite + chlorite + epidote-zoisite + opaques + plagiocalse + biotite
S-3-7	1.03	Quartz metagabbro: uralite + chlorite + epidote-zoisite + plagioclase + biotite + muscovite + apatite + quartz + opaques
S-3-8	1.30	Uralite gabbro: uralite + actinolite + plagioclase + biotite + muscovite + opaques

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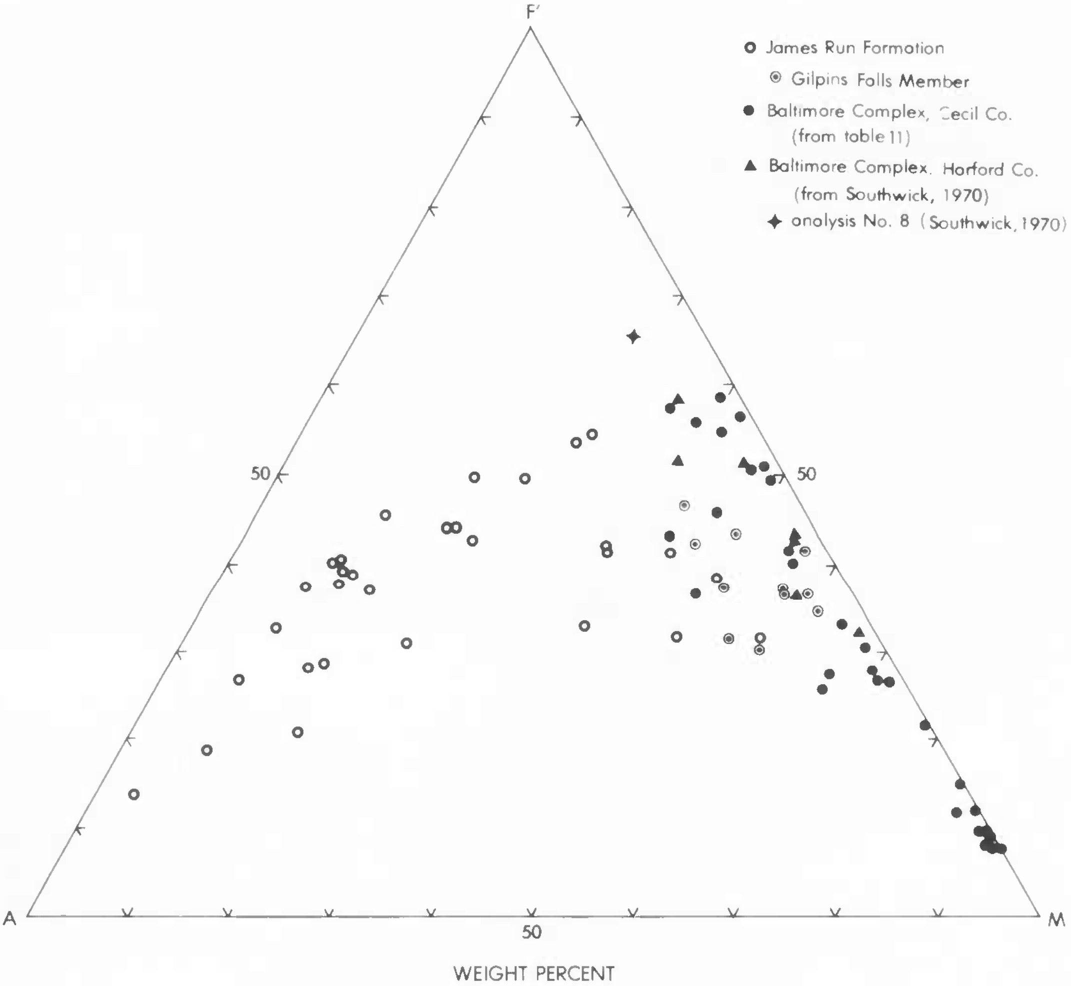

FIGURE 46: F'- M - A plot for analyses of rocks of the Baltimore Complex (including data from Southwick, 1970) compared with analyses of rocks of the James Run Formation.

TABLE 11 (continued)

Other rock samples:

Sample	*Miles*	*Rock and description*
CD-32	**	**
CD-71	**	**
EL-GAB	**	**

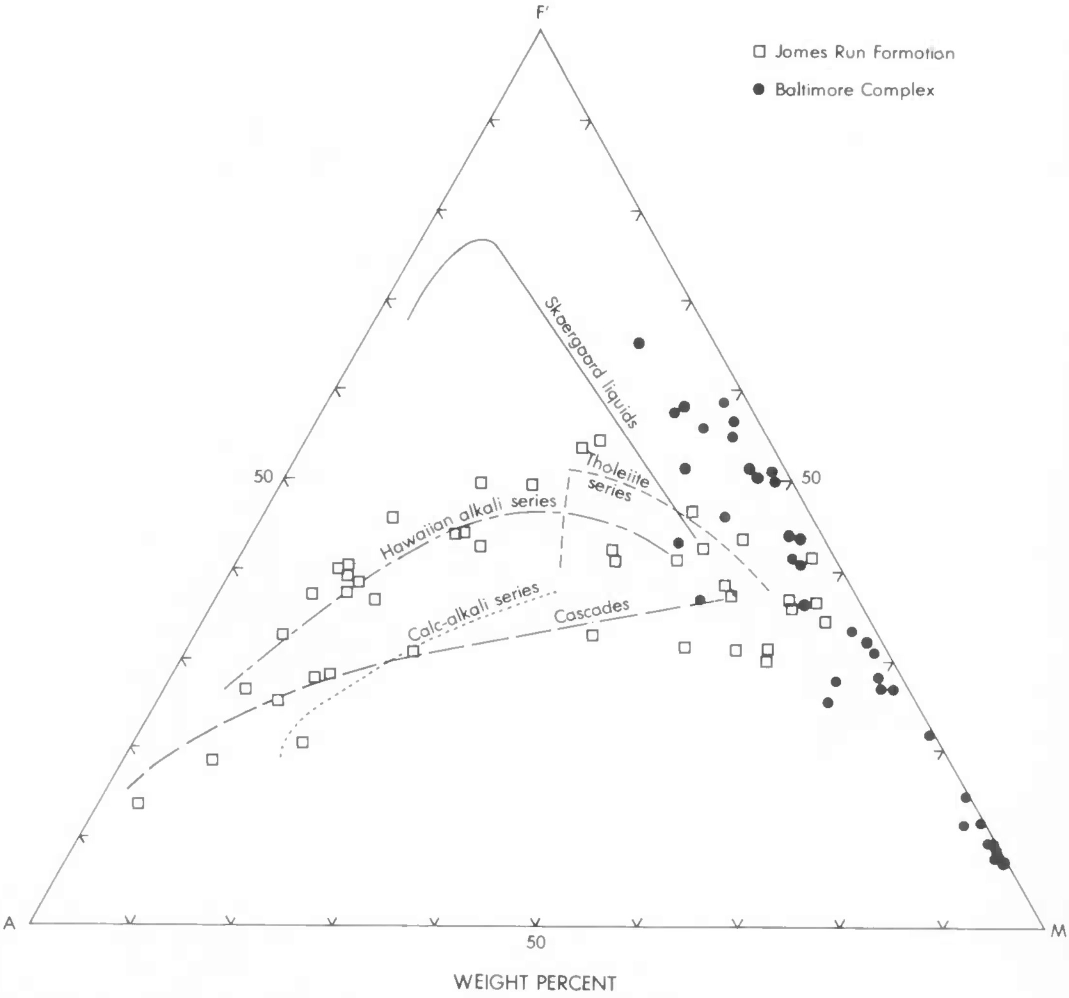

FIGURE 47: **F' - M - A** plot for analyses of rocks of the Baltimore Complex and the James Run Formation compared with trends of several well-known rock suites.

alkali-poor tholeiites, and end with a trend similar to the Hawaiian alkali series or the Cascade lavas. Both Crowley (1976) and Morgan (1977) interpreted the Baltimore Complex as at least a partial ophiolite. In figures 48 and 49, the combined field for rocks from the Baltimore Complex and the James Run Formation in figure 46 is compared with suites of analyses from three well-known ophiolite complexes. There is considerable overlap between the ophiolite suites and the Baltimore Complex-James Run field, but there is also a considerable scatter of points. Nevertheless, the fact that the three ophiolite suites are altered and metamorphosed (Moores and Vine, 1971; Montigny and others, 1973; Mendes, 1976) lends some credence to the comparison.

TRACE ELEMENTS

Perhaps the most important geochemical factors tying the James Run metavolcanic rocks genetically to the Baltimore Complex are the high Cr abundances in the James Run mafic rocks (table 9) and some of the rocks of the complex (Johannsen, 1928; Singewald, 1928; Mathews

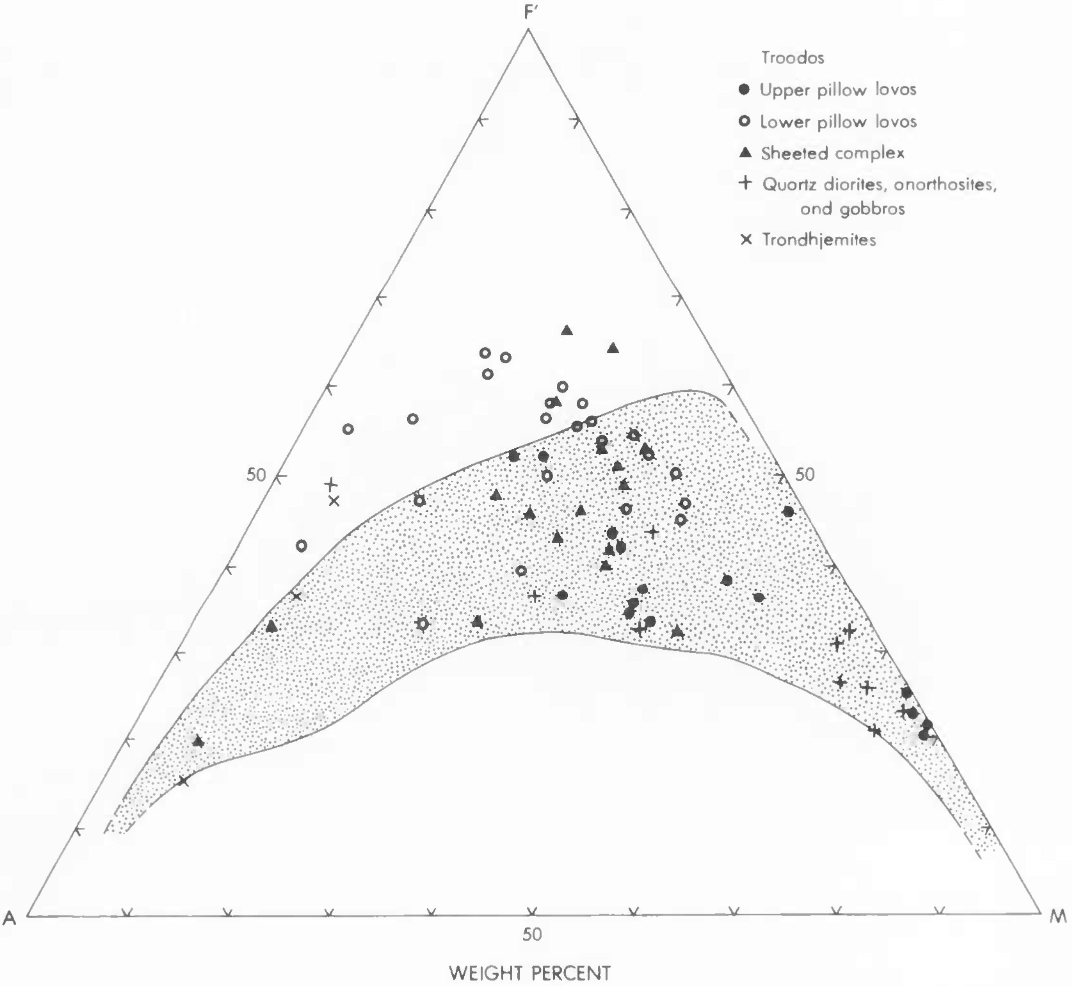

FIGURE 48: **F' - M - A** plot for analyses of rocks of the Troodos Complex compared with the field of the Baltimore Complex and James Run Formation from figure 46 (data from Moores and Vine, 1971).

and Watson, 1929; Pearre and Heyl, 1960). Nickel and vanadium are also in high abundance in some of the Baltimore Complex rocks (Johannsen, 1928; Southwick, 1970, p. 412) as they are in the James Run mafic rocks (table 9). Unfortunately no rare-earth element data are available from the Baltimore Complex rocks.

ORIGINAL TECTONOMAGMATIC SETTING

Although all the available geochemical data suggest that the mafic rocks of the James Run Formation are genetically linked to the Baltimore Complex, an apparent geochemical problem is also associated with the hypothesis of a genetic relation between these two rocks. The problem is the great volume of felsic and siliceous rocks in the James Run. I estimate that, taken as a whole throughout Maryland and Delaware, felsic and siliceous rocks make up at least 70 percent of the James Run Formation, not even including hypabyssal plutons. If the Baltimore Complex is interpreted to be an obducted slab of ancient ocean floor (oceanic crust and mantle), as inferred by Crowley (1976, p. 32-33), then the great volume of felsic and

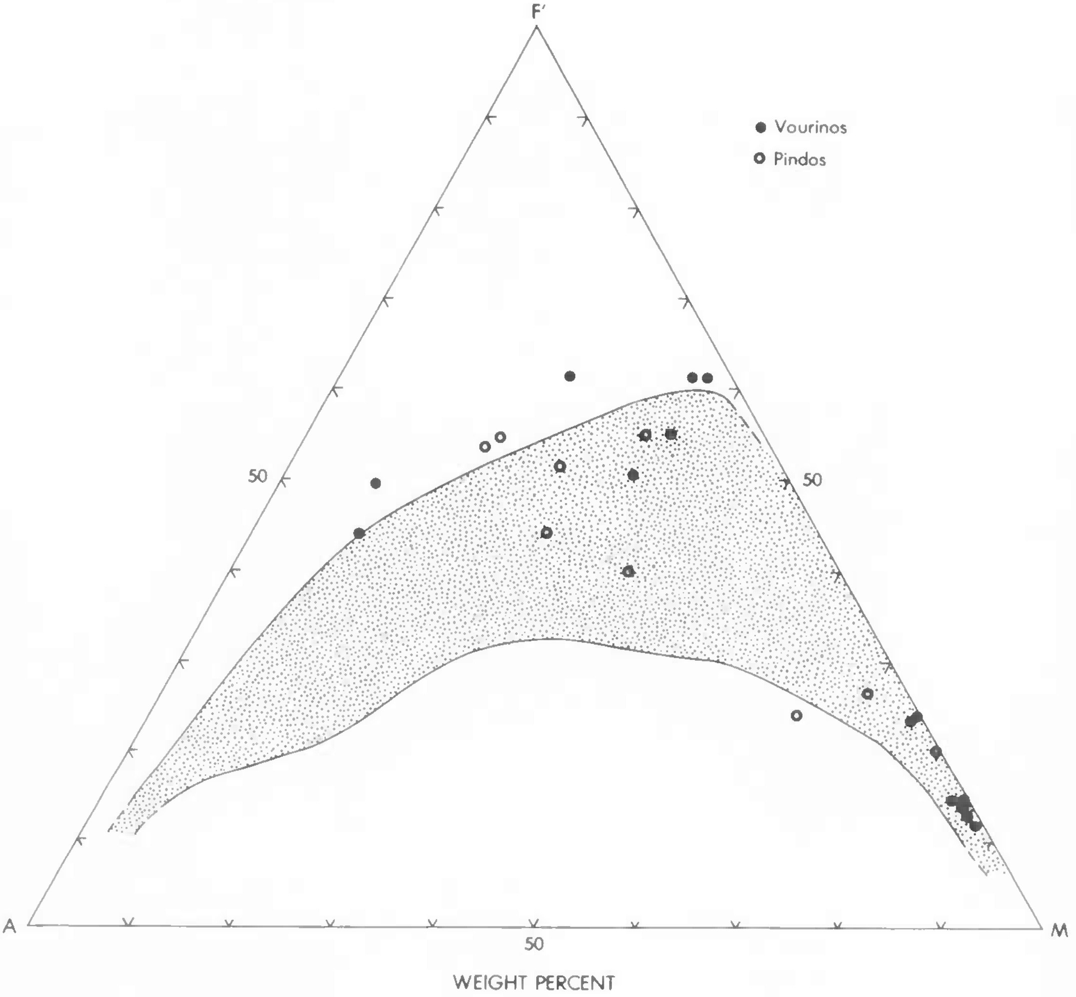

FIGURE 49: F'- M - A plot for analyses of rocks of the Vourinos and Pindos ophiolites compared with the field of the Baltimore Complex and James Run Formation from figure 46 (data from Montigny and others, 1973; and Mendes, 1976).

siliceous rocks in the James Run is anomalous. Moreover, abundant data indicate that some of the felsic rocks in the James Run were emplaced in relatively shallow water, and some of the more massive felsic rocks may even have been subaerial flows and subaerial pyroclastic deposits. This is incompatible with any hypothesis requiring both that the James Run rocks and the Baltimore Complex be genetically related and that the Baltimore Complex be obducted ocean floor. There is an alternative, however. All available evidence indicates that the James Run rocks were part of an island arc, and while there is good evidence that the Baltimore Complex was emplaced by thrusting (Crowley, 1976; Morgan, 1977; Fisher and others, 1979; Drake and Morgan, 1981), there is no real evidence that the complex was once oceanic crust. It may have been a pluton that was the remnant of the magma that produces the James Run volcanic rocks, or a piece of back-arc basin crust derived from the same magmas that produced the volcanic rocks.

STRUCTURE

The major regional structural feature of the eastern Maryland Piedmont is the Baltimore-Washington anticlinorium (Fisher, 1963, 1970; Hopson, 1964; Southwick, 1969; Crowley, 1976), a refolded, doubly plunging anticlinorium that extends from the vicinity of Washington, D.C., to central Harford County, Maryland (fig. 1). The anticlinorium is cored by complexly refolded "domes" and nappes (Fisher and others, 1979) of 1.1 b.y.-old Baltimore Gneiss. The northeastern end of the anticlinorium is complicated by faulting and by superimposed folding, so that there is no single axial trace or single nose for the major fold. In addition, throughout most of northeastern Baltimore County and southwestern Harford County the southeastern limb of the anticlinorium is covered by the Baltimore Complex thrust sheet (Southwick and Owens, 1968; Crowley and others, 1976; Fisher and others, 1979). Cecil County is located just northeast of the complicated northeastern end of the Baltimore-Washington anticlinorium.

The results of structural studies of the northeastern Maryland Piedmont and adjacent areas in southeastern Pennsylvania have been published by Cloos and Hershey (1936), Jonas (1937), Freedman and others (1964), Lapham and McKague (1964), Southwick (1969), Higgins (1973), and Amenta (1974). All these studies documented multiple deformation in this area. The reader is referred to Higgins (1973) for a description of the minor structural features in the northeastern Maryland Piedmont.

Plate 2 is a generalized geologic map with structural interpretations that has been modified from Southwick and Owens (1968), Crowley (1976, pl. 2), Fisher and others (1979), and plate 1 of this report. On this map, the Baltimore Complex is shown as having been thrust upon the diamictites of the Sykesville Formation following Crowley (1976), Morgan (1977), Fisher and others (1979), and Drake and Morgan (1981). The evidence for this interpretation, as summarized by Fisher and others (1979, p. 32-33), consists mainly of the fact that the northwestern contact of the Baltimore Complex places the complex in contact with different units throughout its course (cuts down section in the footwall) and places footwall rocks in contact with successively higher units of the complex (cuts up section in the hanging wall). The presence of clasts of Baltimore Complex rocks in the Sykesville diamictites shows that the complex is not intrusive. The interpretation shown in plate 2 differs from that of Crowley (1976) and Fisher and others (1979) in showing the belt of ultramafic and mafic-ultramafic rocks that veers westward from the rest of the complex in Harford County to be bounded on the south by a thrust. The same reasoning used to interpret the northern contact of this largely ultramafic mass as a thrust fault also applies to the southern contact because it also cuts different units within the mass and different units within the footwall (pl. 2; Southwick and Owens, 1968). In addition, the southeastern contact of the Baltimore Complex is shown as a thrust fault along which the James Run Formation, Conowingo diamictite, and pelitic schist units are thrust upon the complex (pl. 2). This thrust also cuts different units in the footwall (Baltimore Complex) and different units in the hanging wall.

The map patterns and other evidence in Cecil County (pl. 1) are compatible with the interpretation, shown in plate 2, that the James Run Formation and the Port Deposit Gneiss are thrust upon the Baltimore Complex, the Conowingo diamictite, the metagraywacke units, and the pelitic schist units of the Glenarm. This interpretation is supported by the following: (1) Some members of the James Run Formation appear to be truncated by this thrust in Cecil County (pls. 1 and 2), and different members of the James Run are in contact with the metagraywacke and pelitic schist units. (2) The Conowingo diamictite melange has sedimented clasts of James Run rocks and Port Deposit Gneiss. (3) The narrow outcrop belt of metagraywacke in northeastern Cecil County appears to have been overridden by the James Run Formation. (4) Amphibolite dikes and sills that have intruded the James Run Formation and the Port Deposit Gneiss along the Susquehanna River appear to be confined to these units.

Problems still remain in the assignment and nature of the metagraywacke units and the placement of the thrust faults: (1) Are the metagraywacke units (pl. 1) a melange beneath the James Run-Port Deposit thrust sheet, with the outliers of Port Deposit Gneiss in the metagraywacke northeast of the main Port Deposit body being sedimented debris rather than intrusive bodies? Or is the Port Deposit intrusive into the metagraywacke? (2) If the metagraywackes are a melange, are they part of the Conowingo diamictite melange, or a separate melange that overrode the Conowingo?

Several lines of evidence suggest that the metagraywacke units are a melange: (1) In addition to the outliers of Port Deposit Gneiss in the metagraywacke unit (pl. 1), the metagraywacke units contain what may be megaclasts of mafic breccia near College Green and mafic rocks in the northeastern corner of Cecil County near the Delaware state line (pls. 1 and 2). (2) Scattered amphibolites within the metagraywacke unit, and some of the pelitic schist unit as well, may be sedimented debris from the James Run Formation. (3) The Conowingo diamictite melange contains sedimented clasts of metagraywacke (fig. 2) that are lithic matches of the rocks in the metagraywacke units. These metagraywacke clasts were metamorphosed and deformed prior to incorporation in the melange. The diamictite melange also contains zircons that have yielded radiometric ages of approximately 1.1 b.y. (Sinha and others, 1971). If the metagraywacke clasts in the diamictite are derived from the metagraywacke units, as they appear to be, then the metagraywacke units must constitute a separate melange and thrust sheet that is structurally stacked above the Conowingo melange. A similar situation exists between the Peters Creek Schist and the Sykesville Formation in northern Virginia (Drake and Morgan, 1981).

Strongly lineated epidiorites and epidote amphibolites underlie a large area southeast of the James Run Formation and Port Deposit Gneiss in Harford County (Southwick and Owens, 1968; pl. 2, this report). Southwick (1969, p. 61-63) called these rocks "Metagabbro near Aberdeen," but they have more recently (Crowley, 1976; Morgan, 1977) been referred to as Aberdeen metagabbro. Crowley (1976, p. 32, and pl. 2) suggested that the Aberdeen metagabbro might be a thrust sheet. Such an interpretation is shown in plate 2, and the gabbro and serpentinite at Grays Hill are also included in this Aberdeen thrust sheet. With this interpretation, metavolcanic rocks of the James Run Formation that occur within the Aberdeen metagabbro outcrop area in Harford County (Southwick and Owens, 1968; pl. 2, this report) are considered to be exposed in windows. Alternatively, the "strongly lineated epidiorite and epidote amphibolite" (Southwick and Owens, 1968) may belong to the James Run Formation.

The bulk of the evidence in Cecil and Harford Counties supports the interpretation, given in plate 2, that there are several stacked thrust sheets in this area.

AGE RELATIONS

Interpretations of the ages of the rocks in the Maryland Piedmont (see review in Higgins, 1972) have been dependent upon: (1) correlations with upper Precambrian-lower Paleozoic rocks in the Blue Ridge at South Mountain and at Mine Ridge in southeastern Pennsylvania, with lower Paleozoic rocks in the Hanover-York, Lancaster, and Chester Valleys in southeastern Pennsylvania, with lower Paleozoic rocks in the Valley and Ridge province, and with upper Precambrian flysch sequences in Virginia (Lynchburg Formation) and in the southern Appalachians (Ocoee Supergroup); (2) radiometric ages and their interpretation; and (3) interpretations of the relations between the Maryland Piedmont rocks and the Quantico Formation (formerly Quantico Slate, see Pavlides, 1980) in the northern Virginia Piedmont.

CORRELATIONS

Basically, there have been two different views on the correlation and age of the Maryland Piedmont rocks: (1) The Maryland Piedmont rocks are Precambrian and are not correlative with uppermost Precambrian and (or) lower Paleozoic rocks in the Blue Ridge, on the flanks of the West Chester-Avondale-Woodville anticlinorium, in the Martic Hills, in the Hanover-York, Lancaster, and Chester Valleys, or in the Valley and Ridge province (Bascom and others, 1909; Bliss and Jonas, 1916; Bascom and Miller, 1920; Knopf and Jonas, 1922, 1923, 1929a, 1929b; Jonas, 1928, 1929; Jonas and Stose, 1930; Stose and Jonas, 1939; Stose and Stose, 1946, 1948; Hopson, 1964; Southwick, 1969; Fisher, 1970; Seiders and others, 1975; Rankin, 1975; Seiders, 1976a, 1976b), but are essentially correlative with the upper Precambrian Lynchburg Formation in Virginia and the Ocoee Supergroup in the southern Appalachians (Hopson, 1964); and (2) the Maryland Piedmont rocks are correlative with the uppermost Precambrian and lower Paleozoic rocks to the west (Mathews, 1905; Bascom, 1905; Mathews and Miller, 1905; Miller, 1935; Mackin, 1935; Cloos and Hietanen, 1941; Swartz, 1948; McKinstrey, 1961; Higgins, 1972, 1973, 1976a, 1976b; Fisher and others, 1979).

The recognition that many of the rocks in the Maryland Piedmont are allochthonous (Drake and Morgan, 1981, and references therein), including most of the units that make up what was formerly called the Wissahickon Formation, makes most previous correlations untenable. Emphasis must now be placed on the times of thrusting and on the interrelations between different thrust sheets.

RADIOMETRIC AGES

Numerous radiometric ages have been published from rocks in the Maryland and northern Virginia Piedmont. Compilations of most of the radiometric data published before 1977 were given by Higgins (1972) and Higgins and others (1977).

U-Pb zircon ages and Rb-Sr whole-rock and mineral ages showed that the Baltimore Gneiss went through a period of crystallization about 1 to 1.3 b.y. ago (Tilton and others, 1958; Wetherill and others, 1966, 1968; Tilton and others, 1970), thus defining a maximum age of tectonic emplacement for all of the rocks above the Baltimore Gneiss in the Maryland Piedmont. On the basis of U-Pb analyses, zircons from metavolcanic rocks of the James Run and Chopawamsic Formations were interpreted to be about 550 m.y. old (Tilton and others, 1970; Higgins and others, 1971), or between 500 and 600 m.y. old (Higgins, 1972). On the basis of U-Pb analyses, zircons from the supposed synkinematic granitic rocks were interpreted to be about 500 m.y. old (Davis and others, 1958; Tilton and others, 1959; Davis and others, 1960; Hopson, 1964; Davis and others, 1965; Wetherill and others, 1966), or between 500 and 600 m.y.

old (Higgins, 1972), and zircons from the "late-kinematic" plutons were interpreted to be about 425 to 450 m.y. old (Tilton and others, 1959; Hopson, 1964; Wetherill and others, 1966). This age was supported by a Rb-Sr whole-rock age for the Guilford Quartz Monzonite of Hopson (1964).

Since 1972, several radiometric ages have been published that bear on the ages of the rocks in the eastern Maryland Piedmont. Grauert (1973a) dated zircons from the Baltimore Gneiss and interpreted their pattern on a concordia diagram as indicating episodic lead loss about 450 m.y. ago. He also (Grauert, 1973b) dated zircons from the Gunpowder Granite, and found that the data have a lower intercept on a concordia diagram of about 330 m.y. He stated (1973b, p. 290):

> If Steiger and Hopson's method of interpretation were applied to the new data, the minimum age of crystallization for the euhedral zircons would be considerably lower, about 430 m.y. instead of 500 m.y. It is, however, striking that the age of 330 m.y., given by the lower intersection of the best-fit line with the concordia, nearly coincides with the ages of the Rb-Sr mineral isochrons (biotite, muscovite, feldspars) of three pegmatites determined by Wetherill *et al* (1966). It is therefore possible that a distinct thermal (and tectonic?) event took place 320-350 m.y. ago.

In another study, Grauert and Wagner (1975) found that detrital Precambrian zircons (about 1.5 b.y. old) in rocks of the Wilmington Complex in Delaware, which are probably correlative with part of the James Run Formation (Southwick, 1969; Higgins, 1972), have lower intercepts on a concordia diagram at 441 m.y. They suggested that 440±40 m.y. is the age of the granulite facies metamorphism in the Wilmington area. Seiders and others (1975) dated zircons from two granitic plutons in the northern Virginia Piedmont. One of these plutons, the Dale City Quartz Monzonite, was thought by Seiders and others (1975) to have intruded the Quantico Formation as well as the Chopawamsic Formation. The other pluton, the Occoquan Granite (Occoquan Adamellite of Seiders and others, 1975), was thought to have intruded the Chopawamsic and Sykesville Formations. Seiders and others (1975) interpreted the zircon ages as indicating an age of 560 m.y. for the two plutons.

The validity of most of the approximately 550 m.y. zircon ages in the Maryland and northern Virginia piedmont was questioned by Higgins and others (1977; see also Seiders, 1978, and Zartman, 1978), who showed that there is a possibility that the ages are too old because the zircons may have inherited a component of older radiogenic lead. Muth and others (1979) published the results of Rb-Sr dating of muscovites from two pegmatites in the Potomac River gorge near Washington, D.C. According to Muth and others (1979, p. 349), the pegmatites and associated small granitic bodies:

> ...intruded the Wissahickon during the climax of regional metamorphism just after formation of the major early folds and prior to formation of the latest folds and associated crenulation cleavage (Fisher, 1971).

They concluded (1979, p. 349):

> They show ages of 469±20 m.y. and 469±12 m.y. The ages may represent the time of intrusion or cooling of the rocks below about 500°C. The pegmatites crosscut the foliation of the Glenarm metasediments, and thus their age places a younger limit on the time of deposition of the series and of high-grade metamorphism in the area.

To the southwest in the Virginia Piedmont, Pavlides and others (1982) have interpreted U-Pb dates on zircons and Rb-Sr whole-rock and mineral dates as indicating ages of about 410 m.y. for early plutons and 300 to 325 m.y. for late plutons and dikes that crosscut the latest generation of folds in the area. More recently, A.K. Sinha (oral communication, 1981) has dated zircons from most of the granitic rocks and rocks of the James Run Formation in Maryland, many of which are the same rocks for which zircon dates were earlier interpreted as indicating ages of about 550 m.y., as well as from felsic differentiates of the Baltimore Complex. Mose and Nagel (1982) have published Rb-Sr ages for many of the plutonic rocks in the northern Virginia Piedmont. Sinha interprets the U-Pb zircon dates as indicating ages of 480 to 510 m.y. for the James Run metavolcanic rocks, the Port Deposit Gneiss, the Relay "quartz diorite," and the Baltimore Complex; about 430 m.y. for the gneiss near Elkton; and about 330 m.y. for the Gunpowder Granite (see also Sinha and others, 1979). Mose and Nagel (1982) reinterpreted published U-Pb zircon ages from the Occoquan and Dale City plutons as too old because of xenocrystic zircons, and interpreted their Rb-Sr dates as indicating ages of about 500 m.y. for both plutons.

QUANTICO FORMATION

In the eastern part of the northern Virginia Piedmont, the narrow Quantico syncline is cored with slate of the Quantico Formation and flanked by metavolcanic rocks of the Chopawamsic Formation and finally, on the west, by rocks of the Sykesville Formation (Mixon and others, 1972; Seiders and Mixon, 1980). To the southwest, the metamorphic grade of the Quantico increases and the slate has been transformed to a garnetiferous schist that locally contains staurolite, chloritoid, and sillimanite or kyanite (Pavlides, 1980; Pavlides and others, 1980). For many years, the Quantico was considered to be of Late Ordovician age on the basis of fossils reported by Watson and Powell (1911). Geologic mapping by D.L. Southwick, J.C. Reed, Jr., and R.B. Mixon (Southwick and others, 1971; Mixon and others, 1972; Higgins, 1972, p. 1009) suggested that the sequence from Sykesville diamictites up through the metavolcanic rocks of the Chopawamsic and through the Quantico Formation is conformable and without major faults (Southwick and others, 1971, p. D9). Southwick and others (1971) and Mixon and others (1972) accepted the Late Ordovician age for the Quantico Formation, and a late Precambrian age for the Sykesville diamictite (or "Wissahickon diamictite facies"), and assigned an age of Cambrian or Ordovician to the Chopawamsic Formation. I suggested (Higgins, 1972) that, in light of what appeared to be an unbroken, conformable sequence, the Quantico should be added to the Glenarm Group (as defined at that time), and would define a minimum age of Late Ordovician for the Glenarm.

Seiders and others (1975) disputed the Ordovician age of the Quantico Formation and the validity of the fossils on which that age was based. They contended that the Dale City Quartz Monzonite, which has a discordant zircon age that they interpreted as an intrusion age of about 560 m.y., intrudes the Quantico (Seiders and others, 1975, p. 492-495) as well as the Chopawamsic. Thus, they concluded that the Quantico predates the Dale City pluton and is no younger than Early Cambrian, thereby placing an Early Cambrian minimum age on the Glenarm Group. I argued (Higgins, 1976a, 1976b) on geologic grounds that such an assignment was erroneous.

Pavlides and others (1980) have shown through excavations of the contact between the Dale City pluton and the Quantico Formation that the Quantico is unconformable upon the Dale City, and that the Quantico was deposited on an erosional surface that had some topographic relief. They considered this unconformable contact to be the same as the unconformable contact that Pavlides (1973, 1976) had earlier shown to separate the Quantico from the underlying Chopawamsic Formation in the Fredericksburg, Virginia, area. Even more important, however, Pavlides and others (1980) discovered a suite of fossils in the Quantico Formation no more than 65 ft (20 m) above the basal unconformable contact of the Quantico with the Dale City pluton. These fossils indicate that the Quantico is Ordovician or younger (Pavlides and others, 1980, p. 290), probably Middle Ordovician or younger, and probably correlative with the well-dated Arvonia Slate (Higgins, 1972; Pavlides, 1980; Pavlides and others, 1980). Pavlides and others (1980, p. 290) suggested a Late Ordovician age for the Quantico Formation, as originally assigned by Watson and Powell (1911).

DISCUSSION

All of the available evidence indicates that the Baltimore Complex, the James Run Formation, and the plutons associated with the James Run are allochthonous. Moreover, these rocks supplied detritus to the Sykesville Formation melange. Therefore, the Sykesville Formation must be younger than the Baltimore Complex and the James Run Formation with its associated plutons. Earlier published U-Pb zircon dates were interpreted as indicating ages of about 550 m.y. for the James Run metavolcanic rocks and associated plutons (Tilton and others, 1970; Higgins and others, 1971; Higgins, 1972), but extensive re-analysis by A.K. Sinha (oral communication, 1981) indicates ages of 480 to 510 m.y. for the Baltimore Complex and James Run Formation and its associated plutons. Thus, the radiometric ages indicate that the Sykesville Formation is at least younger than about 550 m.y. and probably younger than 510 m.y.

Seiders and others (1975) published zircon ages from the Dale City and Occoquan plutons in northern Virginia, indicating intrusion ages of about 560 m.y. Both of these plutons appear to have intruded the Chopawamsic Formation, which has been interpreted as at least partly correlative with the James Run Formation (Southwick and others, 1971; Higgins, 1972; Seiders and others, 1975; Pavlides, 1976, 1980). The Dale City has intruded only the Chopawamsic Formation (Pavlides and others, 1980), but the Occoquan has intruded the Sykesville Formation as well (Drake and Morgan, 1981, p. 504; Drake, written communication, 1982). Therefore, the Chopawamsic must be older than the Dale City and Occoquan plutons, and the Sykesville must be older than the Occoquan. More recent radiometric dating of the Dale City and Occoquan plutons by Mose and Nagel (1981) indicates ages of about 500 m.y. for these rocks (494±14 m.y. for the Occoquan).

The radiometric ages and geologic relations in Maryland indicate that the Sykesville Formation is younger than 480 to 510 m.y., and that the James Run Formation is about 480 to 510 m.y. old, whereas radiometric ages and geologic relations in northern Virginia indicate that both the Sykesville and Chopawamsic Formations are older than about 495 m.y. Moreover, geologic relations in northern Virginia indicate that the Chopawamsic must be older than the Sykesville, and additionally, that the Chopawamsic rocks were metamorphosed and deformed before the Sykesville was deposited (Drake and Morgan, 1981; Drake and Lyttle, 1981; Drake, written communication, 1982). Therefore, one or both sets of radiometric data are wrong, or the Chopawamsic and James Run Formations are not strictly correlative, or the Chopawamsic and James Run are about 510 m.y. old, the Sykesville is about 500 m.y. old, and the Occoquan pluton is about 495 m.y. old. This last possibility would require that geologic events took place at a very rapid rate in the Piedmont of eastern Maryland and northern Virginia (see also Pavlides and others, 1980; and Mose and Nagel, 1982). If Sinha's 480 to 510 m.y. zircon ages for the James Run are correct and are crystallization ages rather than reset metamorphic ages, then the James Run would have to have been metamorphosed and deformed, and thrust along with the Baltimore Complex in the time period between about 510 and 500 m.y.

Confirmation of the Late Ordovician age of the Quantico Formation and documentation of its unconformable relation to the underlying rocks (Pavlides and others, 1980), coupled with the age determination of 469±20 m.y. for pegmatites associated with late granitic rocks that have intruded metasedimentary rocks in the Potomac River gorge (Muth and others, 1979), poses a real problem for interpretation of the times of metamorphism and deformation in the Maryland and northern Virginia Piedmont. Muth and others (1979, p. 350) concluded that "sillimanite-grade metamorphism and at least two episodes of deformation took place before 469±20 m.y. ago." Most time scales (Holmes, 1959; Geological Society of London Phanerozoic time scale, 1964; U.S. Geological Survey time scale, 1981[7]) indicate that 489 m.y. (469+20 m.y.) is Early Ordovician, or at about the boundary between Early and Middle Ordovician; 469 m.y. (no ±20) is Middle or early Late Ordovician, or at about the boundary between Middle and Late Ordovician; and 449 m.y. (469-20 m.y.) is Late Ordovician. However, the Upper Ordovician Quantico Formation has locally been metamorphosed to sillimanite-grade and folded into the major regional Quantico syncline that has been modified by subsequent folding (Southwick and others, 1971; Higgins, 1972, 1976a, 1976b; Mixon and others, 1972; Seiders and others, 1975; Pavlides, 1976, 1980, and oral communication, 1981; Pavlides and others, 1980).

The Late Ordovician age of the Quantico Formation is well established on the basis of faunal evidence and is in agreement with faunal ages from the correlative Arvonia Slate (Darton, 1892; Stose and Stose, 1948; Applegate, 1955; Tillman, 1970; Pavlides and others, 1980). Therefore, the possibilities are that the 469±20 m.y. age for the pegmatites is in error, or the time scales are incorrect for this part of the Paleozoic, or the interpretation that the pegmatites are related to the late granitic intrusives and postdate the sillimanite-grade metamorphism and deformation is in error. At any rate, the Upper Ordovician Quantico Formation has been metamorphosed to amphibolite-facies grades and folded at least twice. This is conclusive evidence that high-grade metamorphism and deformation occurred after Late Ordovician time in the northern Virginia Piedmont and probably in the Maryland Piedmont as well.

Pavlides and others (1982) obtained radiometric ages (U-Pb and Rb-Sr) of about 410 m.y. from a plutonic rock that had been metamorphosed and folded twice along with the Quantico Formation, and ages of about 330 m.y. from plutons that postdate folding and metamorphism. He concluded that the last major metamorphism and deformation in the area took place between 410 and 330 m.y. ago. These ages are virtually identical to ages from the Maryland and Delaware Piedmont. Both Grauert (1973b) and A.K. Sinha (oral communication, 1981) found zircon ages of about 330 m.y. from the Gunpowder Granite in Maryland, and Grauert (1973b) showed that published ages from undeformed pegmatites could be interpreted as indicating an event 320 to 350 m.y. ago (see also Higgins, 1973, p. 186-187). Grauert and Wagner (1975) found zircon ages suggesting that granulite facies metamorphism in Delaware took place about 440±40 m.y. ago, and A.K. Sinha (oral communication, 1981) found zircon ages of about 430 m.y. from the gneiss near Elkton. These ages are also similar to the 425 to 450 m.y. ages from "late-synkinematic" granitic plutons in the Maryland Piedmont (Tilton and others, 1959; Hopson, 1964; Wetherill and others, 1966). Thus, all available geologic and radiometric evidence indicates that the last metamorphism and deformation in the central Appalachian Piedmont took place between about 440 and 330. m.y. ago.

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[7] Since this report was written in 1981, three new time scales have been published: Harland and others (1982), Palmer (1983), and Salvadore (1985). None of these significantly differs with the ages used here.

SUMMARY AND CONCLUSIONS

In the Maryland Piedmont, an approximately 1.1 b.y.-old "basement complex," known as the Baltimore Gneiss, is unconformably overlain by the Setters Formation consisting of potassium-rich micaceous quartzite, quartz schist, and lesser amounts of pelitic rocks and metaconglomerate. Conformably overlying the Setters is a unit composed of a variety of metamorphosed carbonate rocks called the Cockeysville Marble. The Cockeysville is conformably overlain by a sequence of pelitic rocks that includes the Loch Raven Schist and much of the Oella Formation in Baltimore County, and unnamed schist and metagraywacke-schist sequences in Harford and Cecil Counties. The Setters Formation, Cockeysville Marble, and part of the pelitic sequence appear to be autochthonous and make up the redefined Glenarm Group.

Structurally above the autochthonous Glenarm Group is a sequence of allochthonous stacked thrust sheets and associated melanges. In Cecil County this sequence consists of, from lowest to highest, the Sykesville Formation melange, the Baltimore Complex thrust sheet, the Conowingo diamictite melange, an unnamed metagraywacke-schist melange, the James Run-Port Deposit thrust sheet, and the Aberdeen metagabbro thrust sheet.

The structurally lowest allochthonous rocks in Cecil County make up the Sykesville Formation melange, a thick sequence of diamictite with abundant sedimented clasts from the overlying Baltimore Complex thrust sheet and less abundant clasts from the James Run-Port Deposit thrust sheet. The Sykesville is interpreted as olistostromal, and the submarine slides may have been triggered by arrival of the structurally overlying stack of thrust sheets and melanges.

In northeastern Maryland, the Sykesville melange is structurally overlain by the Baltimore Complex thrust sheet. This sheet is composed almost entirely of the Baltimore Complex, a thick sequence of mafic and ultramafic rocks that has been interpreted as an ophiolite by some workers.

Another thick sequence of diamictite, the Conowingo diamictite, structurally overlies the Baltimore Complex thrust sheet in Cecil and Harford Counties, and includes the zone of mixed rocks (the "mixed zone" of this report), along with the "quartz gabbros and quartz diorites" that have previously been considered part of the Baltimore Complex. The Conowingo diamictite contains sedimented debris from all the structurally higher thrust sheets and melanges and is considered to be a precursory melange to the stack of higher sheets.

Locally, a unit of metagraywacke and schist is present structurally beneath the James Run-Port Deposit thrust sheet. This unit contain sparse detritus, which is interpreted as derived from the overlying thrust sheet which also may be melange.

In the James Run-Port Deposit thrust sheet, the James Run Formation consists of as much as 13,000 ft (4,000 m) of metavolcanic, metasubvolcanic, metavolcaniclastic, and metavolcanic-epiclastic rocks ranging in composition from basalt through rhyolite. Size and percentage of amygdules in pillow basalts and relict accretionary lapilli indicate that some of these rocks were deposited or emplaced in shallow water, whereas pumice lapilli and the massive character of other rocks in the sequence suggest subaerial deposition. All geologic evidence suggests that the James Run rocks formed in an island-arc environment.

Several metamorphosed granitic plutons, the largest of which is the Port Deposit Gneiss in Cecil and Harford Counties, Maryland, are closely associated with the James Run Formation. These plutons have radiometric ages that are the same as those of the James Run metavolcanic rocks, and their chemical compositions partly overlap those of the metavolcanic rocks. Moreover, they locally have finer-grained phases that appear to grade into James Run metavolcanic rocks. All available evidence indicates that the plutons are shallow, hypabyssal intrusives that were the sources for some of the James Run rocks.

The mafic rocks in the James Run Formation have geochemical characteristics of primitive magmas that probably crystallized during a late cumulus stage of differentiation. Trace-element abundances suggest that the James Run rocks are genetically linked with the Baltimore Complex. The Baltimore Complex was probably derived from a sub-arc magma.

Earlier radiometric ages of zircons from the Port Deposit Gneiss and metavolcanic rocks of the James Run Formation suggested ages of about 550 m.y., but extensive redating by A.K. Sinha suggests ages of about 480 to 510 m.y. for these rocks and the Baltimore Complex as well. Therefore, the structurally lower melanges, which contain sedimented debris from the James Run Formation, Port Deposit Gneiss, and Baltimore Complex, must be younger than about 510 m.y.

The highest thrust sheet exposed in Cecil and Harford Counties is composed of lineated epidiorite and epidote amphibolite, collectively called the Aberdeen metagabbro, and includes the gabbro and serpentinite at Grays Hill.

In northern Virginia, the Sykesville Formation and the Chopawamsic Formation, which are considered correlative with the James Run Formation, have both been intruded by the Occoquan Granite. Recent Rb-Sr age dating suggests that the Occoquan is about 495 m.y. old. If this age and the 480 to 510 m.y. ages from the James Run Formation, Port Deposit pluton, and the Baltimore Complex are correct, it means that deposition of the Sykesville Formation in northern Virginia took place between 510 and 495 m.y. ago, and that the James Run, Port Deposit Gneiss, and Baltimore Complex must have been metamorphosed, deformed, and thrust during this same short time period. Moreover, the Chopawamsic Formation in northern Virginia is unconformably overlain by the Quantico Formation, which has yielded Late Ordovician fossils, but has been multiply folded and locally metamorphosed to sillimanite grade. All available geologic and radiometric evidence indicates that the last metamorphism and deformation in the Maryland and northern Virginia Piedmont took place between about 440 and 330 m.y. ago.

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[8] The name of this agency was changed to the Maryland Geological Survey in June 1964.

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THE COASTAL PLAIN OF CECIL COUNTY[9]

by

Louis C. Conant[10]

INTRODUCTION

The southern 55 to 60 percent of Cecil County, roughly that part south of the Baltimore and Ohio Railroad and Interstate 95 (the John F. Kennedy Memorial Highway), is underlain by unconsolidated sediments of the Atlantic Coastal Plain (pl. 1, fig. 50). In contrast to the rocky terrane of northern Cecil County, the Coastal Plain is underlain chiefly by gravel, sand, and clay. Some of these deposits accumulated on the sea floor when much of the eastern and southern margins of the continent were covered by water; other materials accumulated on extensive deltas or tidal flats. Most of the older Coastal Plain strata dip gently southeast a few tens of feet per mile (few meters per kilometer). In much of the county, younger strata of gravel, sand, and silt cover those beds irregularly. The youngest sediments were deposited along rivers or near their mouths.

PREVIOUS WORK

Many geologic reports of various lengths have dealt wholly or in part with the geology of the Coastal Plain part of Cecil County. Chief among these was one by Shattuck (1902a), part of a report on the entire county published by the Maryland Geological Survey. This was accompanied by a geologic map prepared by several workers at the scale of 1:62,500 (Bascom and others, 1902). The southeast part of the county, east of Longitude 76°W and south of latitude 39°30'N, was also published in the Elkton-Wilmington Folio by Bascom and Miller (1920). Other reports are referred to throughout the following pages.

METHODS

The aim of this study was to identify the strata, map their distribution, describe the units, and note any materials of potential commercial value. Field work was done from late 1966 through 1970, chiefly during spring and fall, and was supplemented by some observations in 1971 and 1972.

Aerial photographs taken in the spring of 1952 and 1956 for use by the U.S. Geological Survey in the revision of their topographic maps were used to discover potential outcrops away from roads and to assist in projecting contacts between exposures. Photographs made in the summer of 1964 by the U.S. Department of Agriculture were used to identify some of the newer exposures, to make corrections in the road network, and to map the extent of some artificial excavations and fills. In general, the older photos, taken when the leaves were off the trees, were more useful for purposes of geologic mapping than were the newer photos which were made during the growing season.

The entire 100 miles (160 km) of coastline in the county were examined, much of it at least twice. Many of the outcrops were reached by boat, a method which greatly facilitated and

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[9] Publication approved by the Director of the U.S. Geological Survey.

[10] Retired. Formerly with U.S. Geological Survey, Reston, Virginia.

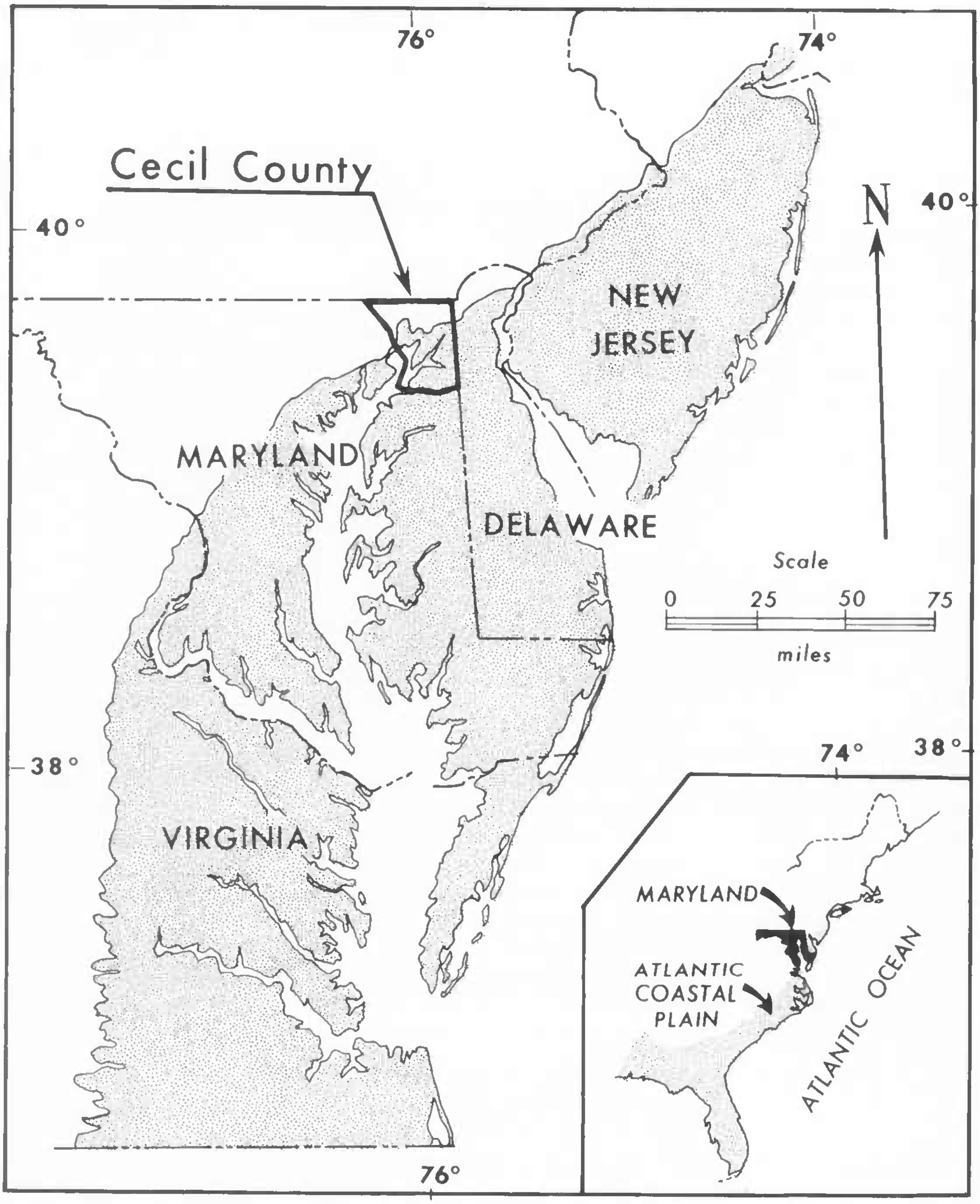

FIGURE 50: Location of Cecil County, Maryland, with respect to the Atlantic Coastal Plain of North America.

shortened the field work. Many creeks and their banks were searched, but few good exposures were found.

Besides the customary aim of examining all available surface exposures, 100 holes were drilled by power-auger and several hand-auger samples were taken. The power-auger holes had an average depth of 38 ft (~12 m) with the maximum being 176 ft (53.6 m), whereas hand-auger holes were 10 ft (~3 m) deep or less. Many samples from outcrops and auger holes were examined in the laboratory to determine their composition, chiefly as an aid in the identification of the formations from which they came.

Additional information was obtained from several water wells as they were being drilled and from the drillers' reports of older wells, the records of which are on file with the Maryland Geological Survey. Inquiries at many homes in the County regarding their dug or drilled wells also supplied some useful information.

Compilation of the geology was made chiefly on U.S Geological Survey 7.5-minute topographic quadrangles. The extent of such details as marshes, alluvium, borrow pits, fill, and spoil areas were taken from the aerial photographs. Most contacts between map units were drawn so as to be consistent with the contours, even though in some places the contours did not appear to depict the landforms accurately.

ACKNOWLEDGEMENTS

Many people and organizations aided in these investigations. Of the U.S. Geological Survey in Reston, Virginia, James P. Minard introduced the writer to the local stratigraphy in the nearby Betterton Quadrangle and in other scattered areas before the start of the Cecil County project, gave freely of advice in both field and office, and assisted in the augering. James P. Owens examined and took notes on many exposures in Cecil County, especially in some of the fresh cuts from Interstate 95 which was then under construction. He shared his information and consulted in both field and office. Nicholas Lampiris spent several weeks in the field assisting with boat trips along the shore, with augering, and in the examination of many outcrops. In the laboratory he prepared many samples for microscopic study and made X-ray determinations of several clay samples. Claire A. Richardson of the U.S. Geological Survey office in Baltimore supplied information from several water well records in that office.

Dr. Earle B. Matthews of the Soil Conservation Service, U.S. Department of Agriculture, made available a draft manuscript report of a forthcoming soil survey of Cecil County. Mr. John Bailey, of the Soil Conservation Service Office in Elkton, gave advice on soils and told of various artificial exposures that were available for study.

The Maryland Geological Survey, which was supporting this study, followed the progress with interest, and various members of that organization visited the writer in the field one or more times. Mr. Abdul H. Tahir of the Maryland State Highway Administration and members of his staff made available engineering soil studies of the County. The Maryland State Police gave permission to study the road cuts along Interstate 95. Mr. David S. Moore, Sanitation Officer of the Cecil County Office of Environmental Health Services, and members of his staff gave much information on the water supply and sewage-disposal systems in the County.

The following companies and their officers kindly gave permission for the writer to visit their properties and also supplied him with helpful information on their operations and products: Mason-Dixon Division of York Building Products Company, Messrs. Robert H. Stewart, President, Nestor Kline, and Henry Couden, Jr.; the Arundel Corporation, Mr. Brian McCoy; The Maryland Sand, Gravel, and Stone Company; the Bacon Hill Sand Company; the Whittaker Iron Company, Mr. Jack Warrington; Georgetown Yacht Basin, Mr. Philip Parish, Service Manager; Lostens Marina, Mr. Losten; and the Galena Boat Yard, Mr. Robert Abel. Shore Well Drillers and Preston and Hamilton Well Drillers gave the writer information on various water wells.

The late Murray Cameron of North East, who had followed the activities of the clay industry since the late 19th century, went with the writer to many of the abandoned clay pits. He identified the ownership and supplied information on the types of clay that had been produced from these pits.

Land owners and managers were uniformly generous in granting permission to drill or to otherwise examine their properties and gave requested information regarding wells, pits, or other exposures on their lands.

To all these cooperators, thanks are due for their assistance which aided the writer substantially in his investigations.

REGIONAL GEOLOGIC SETTING

The Coastal Plain sediments of Cecil County are at the inner edge of a great mass of largely unconsolidated sediments that cover the Atlantic edge of much of the North American continent and continue eastward under the sea (fig. 50). In the continental United States, outcrops occur from Martha's Vineyard in Massachusetts southward to Mexico. In Cecil County, Maryland, these beds consist of gravel, sand, silt, and clay. Many of the sediments were deposited in the sea that from time to time covered this part of the continent, as is indicated by the presence of marine fossils and the mineral glauconite, a distinctive green mineral which forms in marine environments. Other sediments that show no evidence of marine origin were presumably deposited on vast low-lying mudflats and sandflats, in swamps, or along stream courses.

CRYSTALLINE ROCK FLOOR

The Coastal Plain sediments lie on a terrane of crystalline rocks similar to those that make up the Piedmont part of the county (see paper by M.W. Higgins, this volume). Some of the early reports on the regional geology (for example, Shattuck, 1902b, p. 72; Miller, *in* Bascom and Miller, 1920, p. 3) refer to the surface of the crystalline basement rocks as a peneplain, although marked topographic irregularities were known to be present. One of the most notable of these irregularities is Grays Hill just east of Elkton, a monadnock of gabbroic rock that protrudes through the Coastal Plain sediments. This hill stands about 165 ft (~50 m) above the surrounding sediments of the Potomac Group, but the steep slope of its contact with the sediments is known to continue beneath the Coastal Plain. The Holly Hall Utilities water well (fig. 51) south of U.S. Rte. 40 and only about three-quarters of a mile (1.2 km) south of the top of the hill, is 157 ft (47.8 m) deep and did not reach the crystalline rocks. It bottomed at 82 ft (24.9 m) below sea level, or 350 ft (106.7 m) below the top of Grays Hill. Another well, drilled in 1969 on the Ernest Cox property, about 0.6 mile (1.0 km) northeast of the top of Grays Hill, penetrated decomposed gabbro at a depth of 115 ft (~35 m), or about 45 ft (~14 m) below sea level, which is 313 ft (~95 m) below the top of the hill. The data on these two wells indicate local slopes at the rate of at least 465 ft per mile (~90 m/km) and about 520 ft per mile (~100 m/km) respectively. Other irregularities on the old surface are indicated by the isolated outcrops of gabbro amidst Coastal Plain strata in the small streams that drain the southwest slope of Grays Hill. On the south side of the hill, just east of the parking lot for two apartment houses, is a narrow north-trending line of large gabbro boulders, apparently the crest of a ridge that protrudes through the Coastal Plain. Two other similar hills, Chestnut Hill and Iron Hill, lie about 3 miles (~5 km) to the northeast, although they are no longer completely encircled by Coastal Plain sediments.

Deep industrial water wells in Delaware near the Chesapeake and Delaware Canal indicate irregularities on the basement floor on the order of 100 to 200 ft (~30 to 60 m) only a few miles (kilometers) east of Cecil County (Sundstrom and others, 1967, fig. 3). Similar irregularities probably occur in the subsurface of Cecil County although currently there is insufficient information.

An actual slope on the old crystalline floor can be seen in the deep railroad cut of the CONRAIL System where it is crossed by Interstate 95, near the eastern edge of the County. About 0.2 mile (0.3 km) southwest of the overpass, the cut shows about 40 ft (~12 m) of deeply weathered gabbro. Only a few hundred feet (tens of meters) farther southwest, Coastal Plain sediments overlie the gabbro only about 5 ft (~1.5 m) above ditch level, and to the northeast, 100 yards (~90 m) beyond the overpass, only Coastal Plain sediments were found. Similar undulations have resulted in irregularities of the Piedmont-Coastal Plain contact as mapped

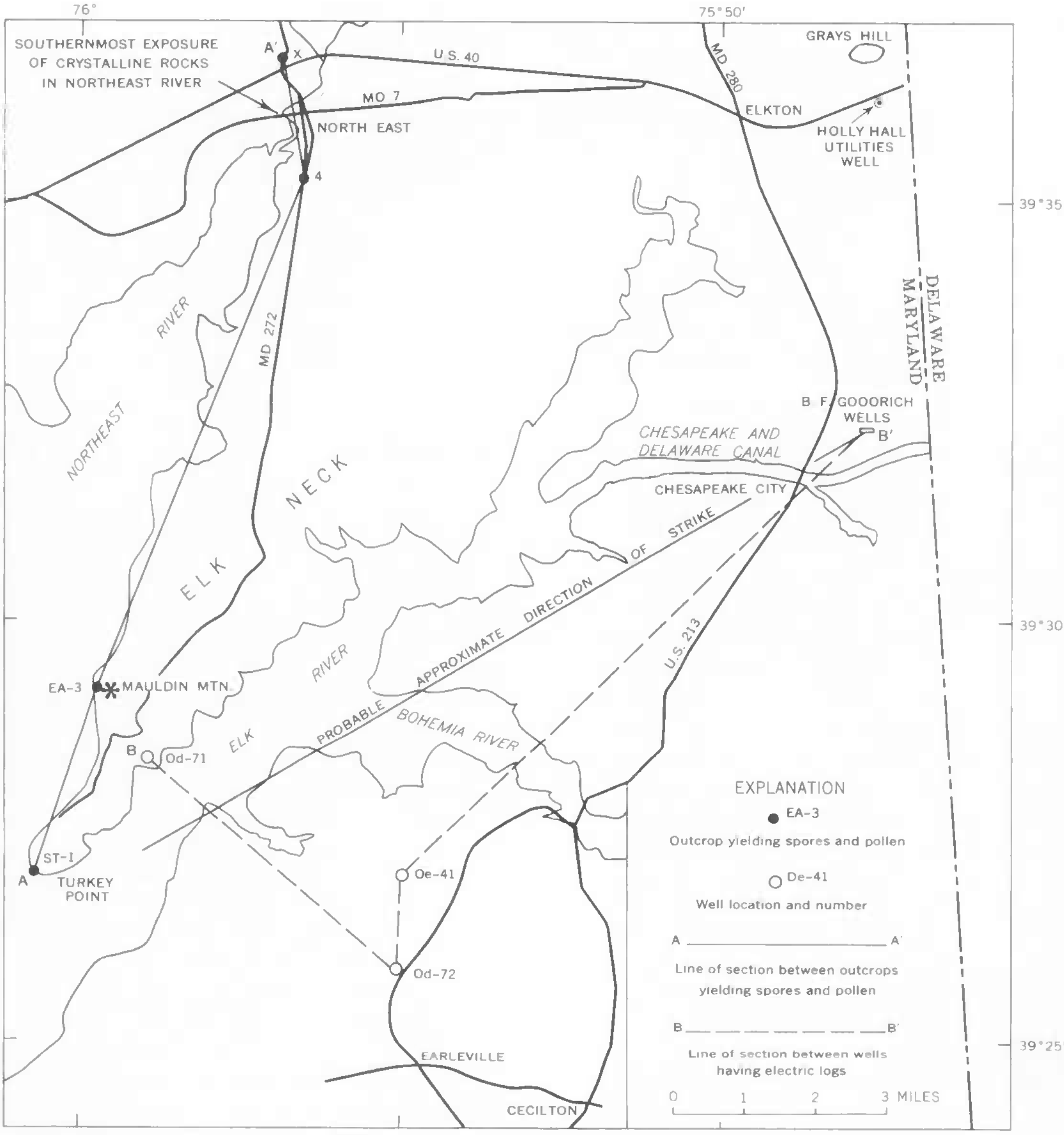

FIGURE 51: Location of outcrops and wells yielding data on the age and lithology of the Potomac Group.

by M. W. Higgins and this writer (pl. 1), but probably many others are undetected in areas of poor exposures.

Records of about 15 test holes for foundation specifications at the Firestone polyvinyl plant just east of Mill Creek in Perryville, on the south side of the railroad tracks of the CONRAIL System, show that rock was encountered at elevations of 20 ft (~6 m) or more above sea level. These records are interpreted by this writer as showing saprolite as high as 35 ft (~10 m) above sea level. Just to the west, scattered exposures of crystalline rocks can be seen for 100 to 200 yards (90 to 180 m) south of the railroad. The author, along with M.W. Higgins, could find no exposures of crystalline rock farther south along this creek while doing the field work for this project and the geologic map (pl. 1), although the original Cecil County geologic map of Bascom and others (1902) shows such rocks extending to the mouth of the creek.

In 1966, a deep test well for the B.F. Goodrich Chemical Company near North Chesapeake City (fig. 51) reached basement rock at about 585 ft (178 m) below sea level. This is some 615 ft (187.5 m) below the southernmost outcrop of the crystalline rocks in Little Elk Creek, 6.75 miles (10.8 km) to the north and about three-quarters of a mile (1.2 km) north of U.S. Rte. 40, and indicates an average slope of about 90 ft per mile (17 m/km) to the southeast on the crystalline floor between these two points. The lower beds of the Coastal Plain deposits that lie upon this surface dip at about the same rate. Successively higher strata in the Coastal Plain are inclined less and less, so that the youngest Tertiary marine beds in Cecil County dip only about 30 ft per mile (5.7 m/km). This implies that the crystalline floor was gradually tilted seaward through time as the sediments accumulated, causing the older beds to dip more steeply than the younger beds. No irregularities such as local steepening, flattening, or reversal of the dip of the Coastal Plain strata have been found in Cecil County which would indicate that there has been significant post-depositional tectonic movements.

A map and geologic cross section by Kraft and Maisano (1968) and a map by Sundstrom and others (1967, fig. 53) in nearby Delaware suggest that at the southeast corner of Cecil County the basement is about 1,700 ft (~520 m) below sea level. If the slope direction of the crystalline floor is about 30°SE, as believed, the gradient between the Goodrich well and the County corner is about 115 ft per mile (~22 m/km), which suggests a gradual steepening away from the outcrop. Local irregularities on the old basement surface may result in deviations from this average gradient.

STRATIGRAPHY

CRETACEOUS STRATA

POTOMAC GROUP

The basal beds of the Maryland Coastal Plain consist of a thick sequence of non-marine sands, silts, clays, and gravelly sands. W.J. McGee (1886, p. 19-21) named this sequence the Potomac Formation and later (McGee, 1888a p. 120-143) suggested that the upper part might be correlative with the Raritan Formation of New Jersey. Clark and Bibbins (1897, p. 481; Clark, 1897, p. 156, 189-193) raised the Potomac to the status of a Group and divided it into four formations: Patuxent (oldest), Arundel, Patapsco, and Raritan.

The Patuxent Formation has usually been described as an impure quartz sand containing considerable weathered feldspar and a substantial amount of clay. The Arundel Formation in the Baltimore-Washington area to the south is primarily a succession of dark clays with abundant lignitized wood and nodules of iron carbonate (siderite) that were once mined for iron ore. This unit is not well developed in the area of Cecil County. The Patapsco Formation consists chiefly of highly colored and varicolored clay associated with sand containing weathered feldspar.

On the original geologic map of Cecil County (Bascom and others, 1902) and in the accompanying geologic report (Shattuck, 1902a), this non-marine sequence was divided into the Patuxent and Patapsco Formations with an overlying Raritan Formation. Miller (*in* Bascom and Miller, 1920) attempted the same breakdown in the Elkton-Wilmington area. On the other hand, Darton (1939, 1947) mapped all beds below the Magothy Formation in eastern Maryland and the Washington, D.C., area as the Potomac Group, and did not recognize the Raritan. Cooke (1952; Cooke and Cloos, 1951) mapped the Patuxent as a separate formation, lumped the Arundel with the Patapsco as a single unit, and also did not recognize the Raritan.

Some recent workers with the subsurface parts of the Potomac Group believe that a satisfactory division of the sequence is possible in and near areas where others have not subdivided the outcropping continental beds. Sundstrom and others (1967), in a ground-water study in Delaware, recognized a crude threefold division of the Potomac through a combination of electric logs and hydrologic differences. Essentially this study showed upper and lower hydrologic zones of sands with clay beds separated by a somewhat more clayey interval. However, the authors did not relate these zones to the classical terminology. In another subsurface study Kraft and Maisano (1968) showed a division similar to that of Sundstrom and others (1967) for several miles (kilometers) down the dip, and on the logs of three deep oil-test wells south of Delaware on Maryland's Eastern Shore the classical Patuxent-Arundel-Patapsco-Raritan terminology was applied.

The Patuxent, Arundel and Patapsco units of the Potomac Group were traced in well records by Hansen (1969) for a few miles (few kilometers) down the dip from their outcrop in the Baltimore-Washington area. Any Raritan beds were included in the Patapsco. He pointed out that there is at present no certain correlation between the three deep oil-test wells on the chart of Kraft and Maisano (1968) and the Baltimore-Washington outcrop area.

After extensive study of the Potomac outcrops in Maryland, Delaware, and northern Virginia, Glaser (1969, p. 9) found that where the Arundel Clay is absent, differentiation between the Patuxent and Patapsco beds on the basis of lithology is difficult or impossible and stated (p. 17) that these four units "...are not lithologically distinct and cannot be mapped without recourse to paleontologic evidence." Glaser (1969) further suggested that the whole assemblage be called the Potomac Formation as originally considered by McGee (1886, p. 19-21), and that the names Patuxent, Arundel, Patapsco, and Raritan be used as stratigraphic facies terms. In neighboring Harford County, Cleaves (1968, p. 18-20) studied the excellent exposures of the Potomac Group during the construction of the Baltimore aqueduct. He could find no adequate basis for subdividing the unit although an attempt to do so had been made earlier by Mathews and others (1904). Owens (1969, p. 79, 81) likewise found it impracticable to subdivide the beds in Harford County into Patuxent, Patapsco, and "Raritan" and mapped the entire sequence as Potomac Group.

The so-called Raritan Formation was originally thought to be a southern continuation of the Raritan of northern New Jersey and thus to be of Early Cretaceous age (Clark, 1897). Some years later, Clark (1910, p. 647-648; and Clark and others, 1911, p. 29-30) pointed out that the Raritan is of Late Cretaceous age and that an unconformity probably separates it from the underlying units of Early Cretaceous age. In recent years, studies of the contained pollen and spores have shown that there is little, if any, time break between the beds in Maryland assigned to the Lower Cretaceous Patapsco and the Upper Cretaceous Raritan Formations (Wolfe and Pakiser, 1971) and that the so-called Raritan beds of Maryland (the "Elk Neck Beds" of Wolfe and Pakiser, 1971) are older than the Raritan of the type area in northern New Jersey.

Because of their lithologic similarity there is no adequate basis in most areas for distinguishing among the Patuxent, Patapsco, and Raritan Formations, except by study of their pollen and spores. Therefore, in this report the entire sequence is treated as the Potomac Group undifferentiated. The uppermost beds, part of which are known to contain plant fossils of Late Cretaceous age, are referred to informally as the "Raritan" of Maryland. This is discussed in more detail in the section on age, correlation, and stratigraphic relations.

Distribution and thickness

The basal contact of the Potomac strata with the crystalline rocks forms a highly irregular line that extends in an eastward direction across the county near the routes of Interstate 95 and the Baltimore and Ohio Railroad (pl. 1). This contact has been one of the more difficult contacts to map, except where it is exposed in artificial cuts such as along railroads and highways. On hillslopes, even where not concealed by forest, two factors have contributed to the problem: 1) the gravel and sand of the Potomac Group tends to creep down the slope for considerable distances; and 2) saprolite, the decomposed or "rotten" rock that overlies the solid crystalline rocks, may be many feet (meters) thick, thus affording no fresh exposure at the top of the crystalline sequence. At many places, however, the presence of angular quartz fragments in the soil of freshly plowed fields or in roadcuts indicates the presence of saprolite, and the relative abundance of gravel and rounded boulders is suggestive of the position of the basal part of the Potomac. During this study it was noted that aerial photographs, when viewed stereoscopically, show a slight but significant steepening of the hillslopes just above the contact, and many country roads also steepen in grade slightly above the contact. This criterion proved especially useful in extending the contact between the crystalline rocks and the Potomac across fields and through woods away from exposures where it can be observed directly. At some places, springs and seepage zones also suggested the probable position of the contact. Because of this spring line, or perhaps because of the different kinds of soil, the aerial photographs appear to show slight differences in the woodland vegetation along this contact.

In the rolling hill country of the Coastal Plain west of Elk River, the sediments of the Potomac Group are at the surface throughout most of the area, and outcrops are abundant in road and railway cuts as well as in other exposures. In some of the higher interfluvial areas, Potomac sediments extend 2 to 4 miles (~3 to 6 km) north of the highway, but in the intervening valleys these have been stripped off to expose crystalline basement along the stream courses for as much as 2 miles (~3 km) south of highway. From their northern edge, the Potomac sediments extend as a thickening wedge southward and southeastward to the vicinity of the Chesapeake and Delaware Canal. In most of the Eastern Shore area of Cecil south of Elkton, the Potomac strata are covered by much younger sediments but have been exposed in stream valleys and along the shoreline. They have also been found in wells and other excavations.

In 1966, a water well for the B.F. Goodrich Co. was drilled near Chesapeake City (fig. 51). The normal thickness of the Potomac sequence in that area is probably about 620 ft (~190 m), but the log for this well (fig. 52) indicated that about 540 ft (~165 m) of Potomac sediments were encountered. The uppermost 70 to 75 ft (~21 to 23 m) are missing, presumably because of a younger channel. Three deep oil-test wells in Wicomico and Worcester Counties on the Eastern Shore of Maryland encountered between 3,000 and 4,500 ft (~915 and 1,372 m) of Potomac Group sediments (Anderson, 1948); therefore indicating that the Potomac beds continue to thicken southeastward. A map and geologic profile of Delaware (Kraft and Maisano, 1968) estimated the Potomac Group near the southeast corner of Cecil County to be about 1,300 ft (~400 m) thick at depths of some 400 to 1,700 ft (~125 to 520 m) below sea level.

Quite certainly the Potomac and other Coastal Plain strata once extended farther inland than is shown by their present distribution. The relatively high ridge that extends north through Pleasant Hill, between Little Northeast Creek and Little Elk Creek, has exposures of Potomac Group sediments about 3 miles (~5 km) farther north than the somewhat lower terrain on either side. As these units may have been exposed to erosion since Early Cretaceous time, a period of some 100 million years or more, they must have been stripped off for considerable distances inland. Johnson (1931, p. 14-22) suggested that the Coastal Plain beds originally covered both the crystalline and folded Appalachians, although that hypothesis now has little following.

Lithology

In Cecil County the Potomac Group is made up of an irregular succession of lenses and layers of gravelly sand, sand, silt, and clay, as well as various intermediate mixtures of these that accumulated in a fluviatile environment. In the western part of the exposed section, gravelly sand and sand appear to predominate in the lower part, whereas clay and silt are more abundant in the upper part. This may also be true for some of the less well-exposed eastern part. Because of their fluviatile origin, the different types of materials are lenticular and have unpredictable distributions.

The pebbles and cobbles in the gravel are virtually all of quartz and quartzite. Most of the pebbles are less than 1 inch (~2.5 cm) in maximum dimension, although some as long as 3 inches (~7.5 cm) are common, and locally scattered cobbles 6 inches (~15 cm) or more in length may be present. Most of the pebbles and cobbles are well rounded, but some that occur near the base of the Potomac are only poorly rounded or subangular and doubtless are residual fragments from the nearby deeply weathered Piedmont surface. The gravelly lands in the western part of the county are well exposed along Belvidere Road between Interstate 95 and U.S. Rte. 40. Somewhat less gravelly sands are present farther south and are exposed in the former workings of the Muller-Thyme pits just south of the railroad track of the CONRAIL system, west of Mountain Hill Road. At the Russell clay pit on the north side of Interstate 95, 1.75 miles (2.8 km) northwest of U.S. Rte. 40 at North East, an exposure in a drainage ditch shows about 15 ft (~4.5 m) of a near-white micaceous sand and gravelly sand below the clay. The unit is irregularly cross-stratified with some beds dipping southeast 30° or more and others dipping north as much as 20°.

Early reports described the sand of the Potomac Group as arkosic, but Owens (1969, p. 81) in his report on Harford County pointed out that the sand grains in the unit are of quartz, some of which are polycrystalline, and feldspar is not generally present, although a small amount of kaolinized feldspar may be found. Brenner (1963, p. 50) and Sundstorm and others (1967, p. 17) also reported small amounts of feldspar. Muscovite mica is a common constituent and in places is conspicuous. Wherever the sand is well exposed, scattered lenses of clay of various colors and degrees of purity may be present. The sand beds commonly contain a significant amount of silt and clay impurities, and in places, clay balls may be found, probably having been reworked from nearby clay lenses. The gravelly sands of the western part of the county seem to grade eastward into sands that have very little gravel. Such sands are well exposed in the

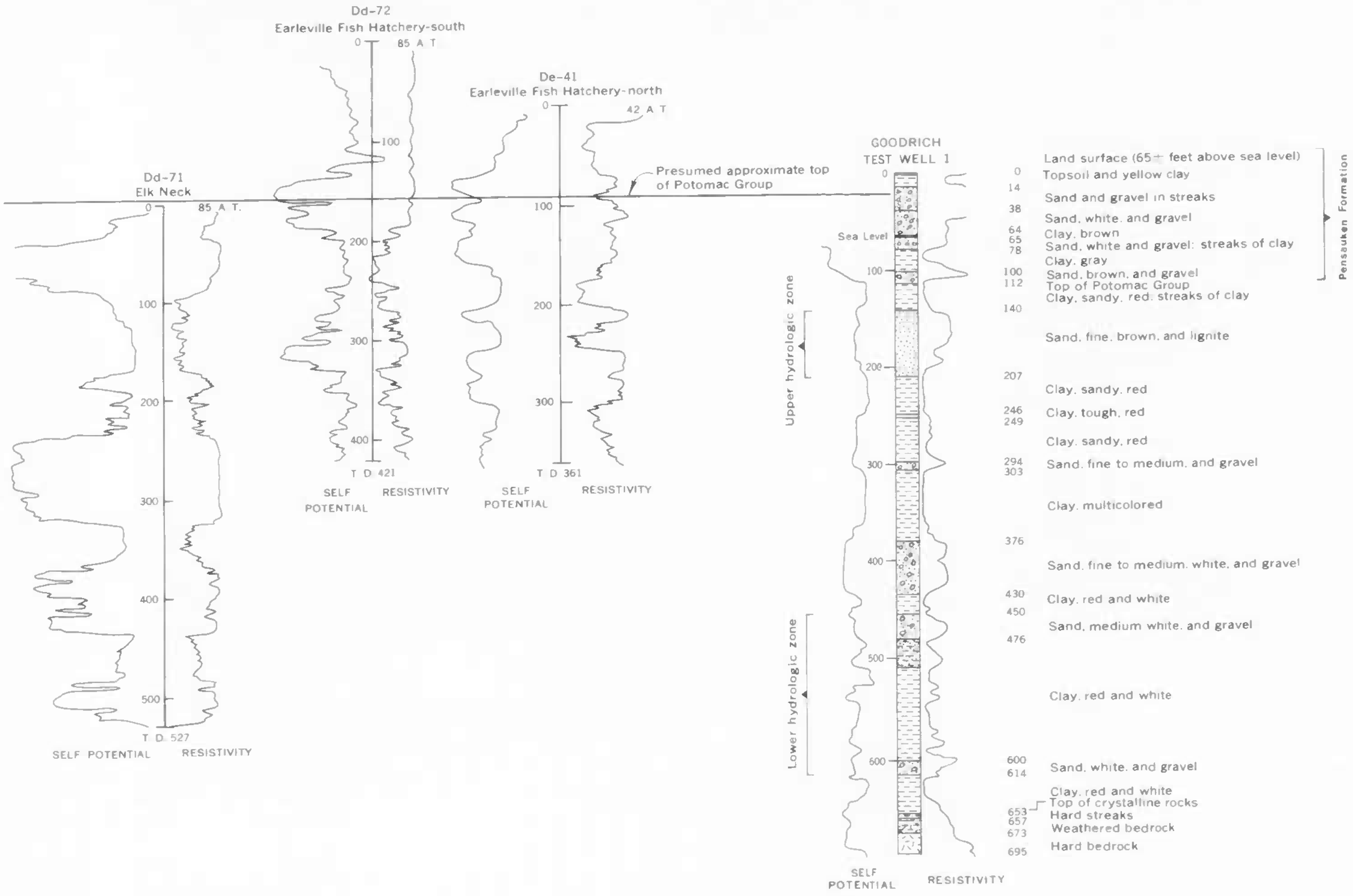

FIGURE 52: Electric logs of four deep wells in Cecil County. In general, the curves swing outward at sand beds and swing inward at clay beds. This figure illustrates the difficulty of correlating beds. In the two Earleville wells, the position of the top of the Potomac Group is uncertain because of the absence of nearby outcrops; in the Goodrich well it is assumed that the top of the Potomac has not been removed by the Pensauken channel. For locations, see figure 51.

vicinity of Bacon Hill, midway between North East and Elkton, in the pits of the MarylandSand, Gravel, and Stone Company north of U.S. Rte. 40, and in the Bacon Hill Sand Pit just north of Maryland Rte. 7. Gravel is more abundant in the lower part of the Potomac sequence, but some can be seen in higher beds. Clay, on the other hand, is more abundant in the upper part, but may occur in any part of the sequence.

Owens (1969, p. 83) called attention to studies in the subsurface and in other areas that have found different assemblages of heavy minerals in the Patuxent and Patapsco parts of the sequence. In Harford County he found that staurolite and kyanite are common in the outcropping beds of Patuxent age, whereas beds of probable Patapsco age contain a zircon-tourmaline-rutile assemblage. Groot (1955, p. 59, 62) had found similar assemblages in these units in Delaware. No study of the heavy minerals was made during the Cecil County project, but it is highly probable that similar relations exist there as the area lies between those studied by Owens (1969) and Groot (1955).

The clay beds of the Potomac Group are abundant and differ greatly in composition and color. Some are markedly plastic, whereas others are silty, sandy, and less plastic. Some black or dark gray clays contain fragments of lignitized wood and yield microscopic pollen and spores. Most of the clay beds are strongly colored in various shades of red, yellow, and purple, commonly as irregular splotches in a matrix of light-gray clay. Many deep-well records list red and white clays, colors that may have formed by weathering soon after deposition or subsequently by ground-water action. X-ray examination by Hosterman (*in* Knechtel and others, 1961, Table 1) of the clay fraction of the Potomac sediments from Cecil County, in samples obtained chiefly from drill holes, has shown that kaolinite is the most abundant clay mineral, together with considerable illite and a small amount of a mixed-layer clay. Most of the tested material was the clay fraction of impure sands and silts. The purer clays were chiefly kaolinite. X-ray examination by Lampiris (written commun., 1969) during the present project also showed kaolinite and illite to be the chief constituents of the Potomac clays. Like the quartz and quartzite grains of the coarser fractions, these clays are mature products of weathering processes that have caused the destruction or alteration of the less durable material. In the southern part of the area of Potomac exposures in Cecil County, and therefore higher in the outcropping sequence, clay beds are common and may be any of the colors that have been mentioned. Black sandy clay containing sticks and chips of lignite has been found at the base of the Potomac Group in two places along Interstate 95: at the east end of the tollgate cut near the Susquehanna River bridge, and about a quarter of a mile (400 m) east of Little Elk Creek where the lignite is present at the base of a gravel-filled channel that has cut a few feet into the saprolite. Lignitized logs have been seen at a few places, as at the top of the exposed part of the Potomac Group at the mouth of Bohemia River (see measured section of the Magothy Formation), where two flattened logs about 1 ft (~30 cm) across are present close to the top of the Potomac sequence.

In the eastern part of the county, especially northeast of Elkton along Interstate 95 and Maryland Rte. 279, an extensive blanket of impure reddish clay is at or near the base of the Coastal Plain sequence. Farther north, two cuts along the Baltimore and Ohio Railroad, just east of Maryland Rte. 316 near Barksdale, show red-stained gray clay on saprolite. However, the log of the 157-ft (48 m) Holly Hall Utilities water well east of Elkton (fig. 51), only 2.5 miles (4.0 km) south of Interstate 95, shows the lowest 32 ft (~10 m) to be predominantly fine to coarse sand with subordinate thin layers of red and white clay. As the well did not reach the crystalline basement, the bottom part of the section is unknown. The overlying beds of the Potomac, as logged, are predominantly clayey. The well yielded 700 gallons per minute (~2,650 liters per minute) on a pumping test; therefore it is apparent that these deep sand beds are extensive enough to be recharged, either at the surface of the ground or at the base of the Pensauken Formation, which overlies the Potomac Group in this area.

The many water wells drilled into the Potomac Group have penetrated no consistent correlatable succession of clay, silt, sand, or gravel. The electric log records of four wells near

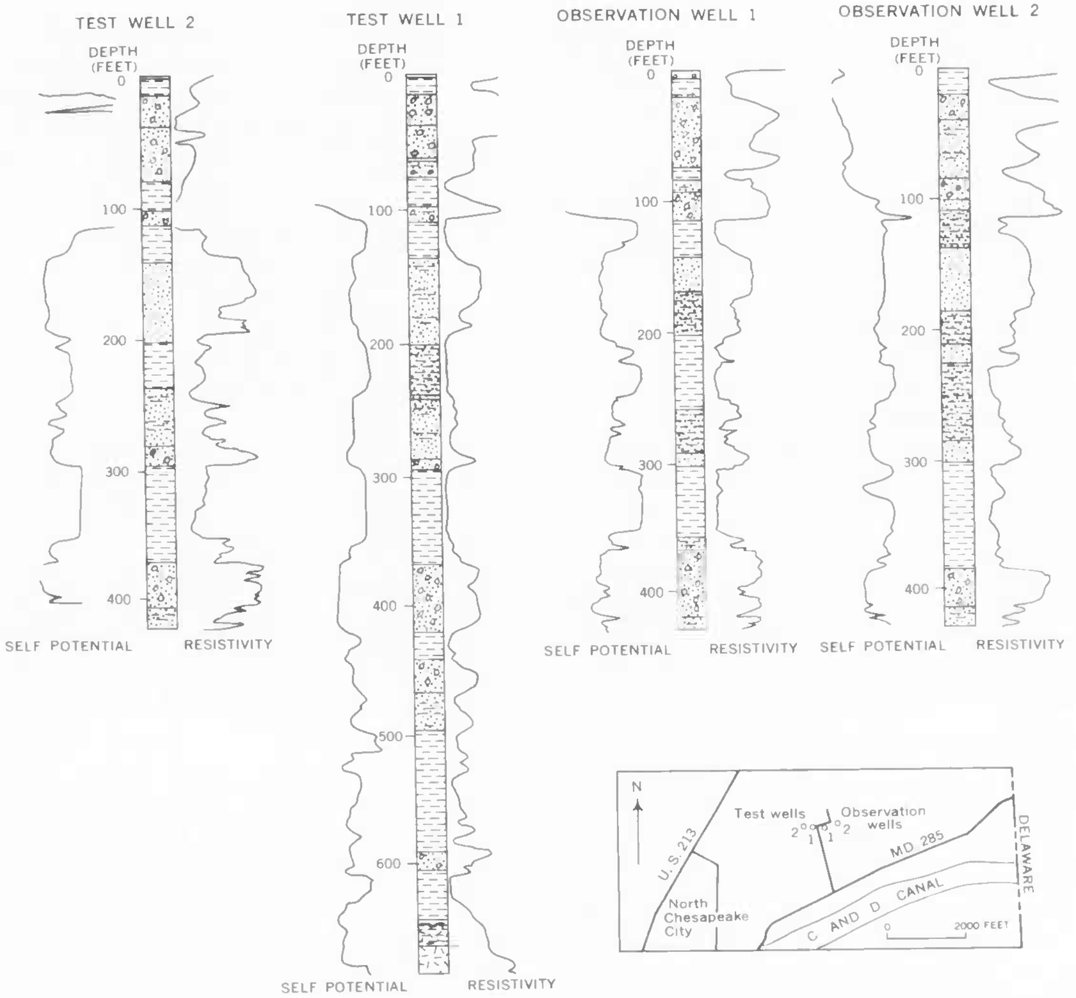

FIGURE 53: Electric logs of the four wells of the B.F. Goodrich Chemical Company near Chesapeake City. Logs courtesy of Geraghty and Miller, Port Washington, N.Y.

Chesapeake City (fig. 53), all drilled within 700 ft (~200 m) of each other, afford the best available information on the Potomac in Cecil County and show distinct differences in thicknesses of the individual beds. The log of the deep B.F. Goodrich well (fig. 52) shows about twice as much clay as sand, and all but 14 ft (~4.5 m) of the lowest 150 ft (~45 m) was logged as clay. The electric logs, however, suggest that a considerably greater proportion of sand is present. Hydrologists who have studied the water resources of the well recognized two hydrologic zones of interbedded water-bearing sands and clays, separated by a more clayey interval (Sundstrom and others, 1967, p. 20-21). The same report stated, concerning the Potomac Group in general (p. 18): "The inability ... to correlate sand bodies with reasonably good well control, suggests a randomness and indicates the lack of diagnostic features which might permit the identification of one sand over even short distances." It also states (p. 18) that whereas "Such clayey and sandy zones ... may be traced over short distances with certainty ... they require considerable generalization if they are extended over distances greater than one mile."

Well Dd-71, drilled at Elk Neck State Park about 11 miles (~18 km) west-southwest of the Goodrich wells (fig. 51), started near the top of the Potomac Group and reached a depth of 527 ft (160.6 m) without reaching basement (fig. 53). The electric log of the Elk Neck well, which is roughly along the probable strike of the Potomac from the Goodrich wells, shows distinct thick sand beds, but any correlation with beds in the Goodrich wells is questionable at best. Two wells drilled in 1967 and 1971 for a new fish hatchery north of Earleville (Dd-72 and De-41 on fig. 51) lie about a mile (1.6 km) apart and are 3 to 4 miles (~5 to 6.5 km) south and down dip from a line connecting the Goodrich and Elk Neck wells. These two wells are estimated to have penetrated the uppermost 250 ft (76 m) of the Potomac Group, but the electric logs (fig. 52) differ considerably from each other and show only questionable correlations with the Goodrich and Elk Neck wells. Detailed studies of many deep wells in the extensively drilled industrial areas a few miles (few kilometers) to the east along the Chesapeake and Delaware Canal in Delaware have shown that it is difficult to trace most individual beds over distances greater than a mile (approximately a kilometer) in the subsurface (Sundstrom and others, 1967, p. 18).

In spite of the large amount of sand and gravelly sand in the lower part of the outcropping section in central and western Cecil County, published water well logs (Overbeck and Slaughter, 1958) of many wells a short distance to the south in the vicinity of North East, Charlestown, and Carpenter Point show considerably more clay than sand and gravel. This leads to the speculation that the large outcropping mass of basal gravel and sand to the north may be a local fan type of deposit that does not extend much farther south.

Detailed study of the many deep wells in nearby parts of Delaware have shown (Sundstrom and others, 1967, p. 21, 24) that the lower beds of the Potomac Group tend to be sandier, as other writers have noted (for example, Clark and others, 1911, p. 58-60, 68-69).

Age, correlation, and stratigraphic relations

Early studies: The first assessment of the age of the Potomac Group, based on the fossil flora, was made by McGee (1888a, p. 137) who proposed a Late Jurassic to Middle Cretaceous age. Nine years later Clark (1897, p. 156, 189-191), following the work of Marsh (1888) on the dinosaur fossils in the Arundel, assigned the Patuxent and Arundel Formations to the Jurassic and the Patapsco and Raritan Formations to the Lower Cretaceous. Further studies of the flora by Berry (1911) and of the reptiles by Lull (1911; and Lull, *in* Lull and others, 1911) convinced Clark (Clark and others, 1911) that the Patuxent, Arundel, and Patapsco belonged in the Lower Cretaceous, and the Raritan in the Upper Cretaceous (Cenomanian). Berry's work focused on the disappearance of many primitive ferns, cycads, and conifers by the close of Arundel time, as well as the introduction into the Patapsco of a considerable variety of angiosperms. These early age assignments have remained firm through the first half of this century, despite some attempts to reassign parts of the Group (Arundel and Patapsco) to the Upper Cretaceous (Gilmore, 1921; Spangler and Peterson, 1950; Cooke, 1952). Dorf (1952), after thorough review of the paleobotanical evidence, reaffirmed the older age assignments.

Recent studies: The first modern palynological study of the Potomac Group was conducted by Brenner (1963), in which he established two major zones: Zone I to encompass the Patuxent and Arundel, and Zone II to equate with the Patapsco. The Early Cretaceous age assignment of the three units remained unchanged. Brenner (1963) further concluded that none of the disconformities within the Potomac Group, including that between the Arundel and Patapsco Formations, was a significant hiatus. A second, somewhat broader study of the microflora of these units by Wolfe and Pakiser (1971) reached similar conclusions.

Doyle (1969) found, as did Wolfe and Pakiser (1971), microfossils in some of the higher Potomac Group beds which, although Late Cretaceous in age, were older than the type Raritan in New Jersey. Thus, these strata were considered transitional between the Patapsco and the Raritan and are best grouped with the Patapsco. Because of this new age data, the Potomac Group is now considered to encompass both Lower and Upper Cretaceous beds. It seems likely, since no important disconformities have been identified in the section, that the entire sequence is essentially continuous, and is broken only by channeling and local non-deposition.

Correlation of Elk Neck strata: Owens (1969) reported pollen dates from Cecil County localities on or near Elk Neck. Exposures along the first 0.15 mile (240 m) on Maryland Rte. 272 north of the intersection with U.S Rte. 40 indicated that strata no more than 50 ft (~15 m) above the sediment-basement contact were Patuxent in age. A second sample, from a black lignitic clay on Maryland Rte. 272 about a mile (1.6 km) south of Maryland Rte. 7 in North East and about 175 ft (55 m) higher in the section, yielded a Patapsco age. The third pollen date, reported from strata outcropping on the west side of Mauldin Mountain about 50 ft (15 m) above the beach, indicated a Late Cretaceous age, but older than the Raritan Formation in New Jersey. These are the "transitional beds" here deemed to lie about 550 ft (168 m) above the crystalline basement. A black clay sample from near sea level at Turkey Point at the end of Elk Neck contained a pollen assemblage similar to that of the second sample collected at North East. However, since the stratigraphic position of the clay is uncertain with respect to basement, the pollen date obtained from it is not useful.

Origin

Deposition of the sediments of the Potomac Group was probably initiated by a rise of the Appalachian region and subsidence of what became the Coastal Plain (Clark and others, 1911, p. 80; Groot, 1955, p. 61; Sundstrom and others, 1967, p. 17; and Glaser, 1969. p. 74). Such crustal movements may be related to the opening of the North Atlantic Ocean, when North America migrated westward away from Europe and Africa by means of plate tectonics. Accelerated erosion of the uplifted hinterland, including part of the Piedmont, and rejuvenation of the streams resulted in an increase in transportation of sedimentary debris. These sediments apparently accumulated in non-marine environments such as river channels, flood plains, coalescing alluvial fans, swamps, and marshes. Groot (1955) has summarized evidence regarding the climate of the time, pointing out that the plant remains which abound in many of the clay beds indicate a warm, humid climate.

The sediments comprising the Potomac Group are chiefly a clay-silt mix with scattered sand lenses that represent elongate river channel deposits rather than broad, sheetlike bodies (Sundstrom and others, 1967, p. 18). It has already been pointed out that the gravelly sands exposed in the lower part of the Potomac Group from the western part of Cecil County grade eastward in the subsurface into extensive sand beds, but comparable gravel and sand beds are not apparent a few miles to the south as determined from water-well logs. There is little evidence of the continuity of the various beds either along strike or down the dip. The gravels and many of the sands probably accumulated in the beds of streams and in alluvial fans. Other sand bodies, together with silt, probably formed as overbank deposits on the flood plains, and many sands may have been deposited as point bars along meandering streams. The black clays presumably accumulated in swamps.

The sand beds are characteristically cross-bedded in an irregular manner. Festoon or trough cross-bedding is common (fig. 54), with the channel axes oriented in various directions. In places the sands show planar-type cross-bedding (fig. 55), which dips in virtually all directions, although a southerly dip prevails. Such diversity in type and direction of cross-bedding, and the fact that individual beds cannot be traced for any appreciable distance in the subsurface, would seem to indicate that the streams were meandering widely, perhaps with many distributary branches, over broad flood plains and alluvial fans.

Hansen (1969, p. 1930-1934) used electric logs to interpret the depositional environment of the subsurface Potomac Group in Southern Maryland. Citing the works of others, he pointed out that the deposits of meandering streams are coarse at the bottom and become finer toward the top. However, large braided streams, which have continually shifting channels, deposit channel-bed sediments that do not show a fining-upward sequence. On electric logs of wells

FIGURE 54: Festoon cross-bedding in the Potomac Group. Shovel handle is 21 inches (53 cm) long. Northeast wall of Bacon Hill Sand Company pit located on the north side of Maryland Rte. 7, 1.75 miles (2.8 km) west of Little Elk Creek.

in sediments of these differing types, the fining-upward sequence shows, by a gradual decrease in this resistivity curve, a gradation from coarse to fine sediments, whereas logs of the braided-stream sequence show a sequence of sediments having more-or-less uniform resistance.

If these criteria are applied to the electric logs of the B.F. Goodrich wells (fig. 53), there are suggestions of finding-upward sequences at a few places, which would seem to support in part the opinion expressed by Sundstrom and others (1967, p. 18) that the sand beds are elongate channel deposits. At other places, the electric logs indicate more massive-appearing sand beds, such as would have been deposited by a braided stream of higher velocity.

The abundance of gravelly sand and sand in the lower part of the exposed section in the western and central part of the county suggests the presence of an ancestral Susquehanna River in that area. However, the apparent absence of a massive sand body in nearby downdip wells near North East and Charlestown, as indicated by the well logs cited in Overbeck and Slaughter (1958), suggests that the sand body may have no appreciable subsurface extension. In the Elkton area, the abundant red and brown clay just northeast of the town and the predominance of red, multicolored, and lignitic clay in the Holly Hall Utilities well suggest that at the start of Potomac deposition the area was an extensive mud flat (perhaps lying between major drainages) for much of the time and was subject to intermittent floodings that brought in layers of silt and sand.

MAGOTHY FORMATION

The Magothy Formation, recognized as a distinct unit separated by unconformities from the beds below and above, was named by N. H. Darton (1893) for the good exposures along the Magothy River near Annapolis, in Anne Arundel County. He traced the unit from the Chesapeake and Delaware Canal near Chesapeake City in Cecil County to the vicinity of Bowie

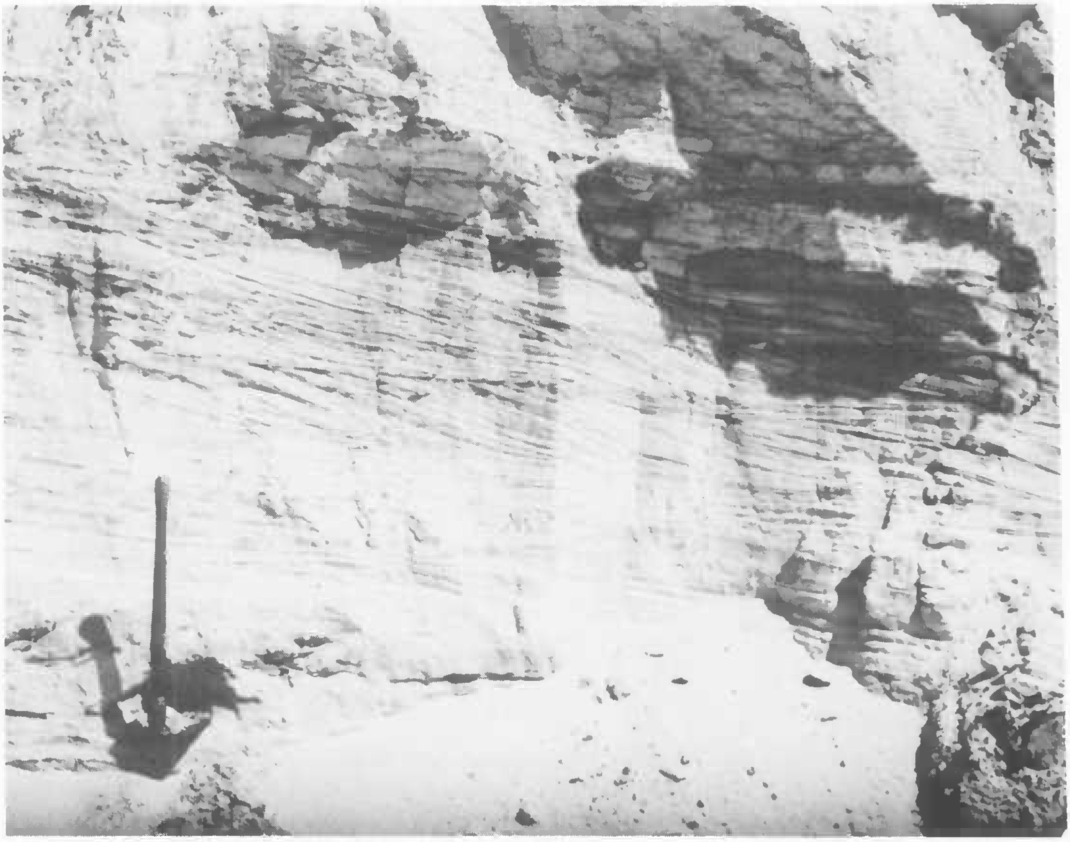

FIGURE 55: Planar cross-bedding in the Potomac Group. Overhanging beds probably contain a small amount of clay. Shovel handle is 21 inches (53 cm) long. North wall of Maryland Sand, Gravel, and Stone Co. pit located north of U.S. Rte. 40 and 2.25 miles (3.6 km) west of Little Elk Creek.

in Prince George's County, near Washington, D.C., and correctly surmised that it continued eastward across Delaware. A few years after Darton had identified the formation in Maryland, Clark (1904, p. 438) traced it from Chesapeake Bay to Raritan Bay, New Jersey. At its southern terminus the unit is overlapped by formations, and northward it has been reported on Long Island and in the New England islands (Clark, 1910, p. 648; Doyle, 1969, p. 18).

On the original geologic map of Cecil County (Bascom and others, 1902), the Magothy Formation was not shown as a separate unit but was included in the top of what was then called the Raritan Formation, now considered to be at the top of the Potomac Group. Miller (1906; Bascom and Miller, 1920), however, mapped it as a separate unit. This has been the general practice since.

Distribution and thickness

In a long, high bluff on the south shore of the Bohemia River near its mouth, Darton (1893, p. 411-412) described an exposure of the Magothy Formation (pl. 1) which showed an undulating contact with the underlying Potomac Group. This contact ranged from an elevation of about 30 ft (~9 m) at the west end to sea level a mile (1.6 km) to the east. Within the Magothy and near its top, Darton noted two "...elongated lenses of tough, laminated, gray clay," as much as 3 ft (~1 m) thick. In the eastern part of the exposure as much as 15 ft (~4.5 m) of overlying fine-grained and somewhat glauconitic sand beds were found. These are now known as the Merchantville Formation. Today the entire 3,000-ft (~900 m) length of the bluff west of Veazey Cove is largely overgrown, but scattered exposures show up to 35 ft (~10 m) of Magothy overlying 20 ft (~6 m) or less of the Potomac. None of the Merchantville was found by this writer. The base of the gravel cap undulates markedly, ranging from about 20 to 60 ft (~6 to 18 m) above sea level. The Magothy is also exposed on both sides of Battery Point, about 1.5 miles (~2.4 km) farther east on the south bank of the Bohemia River. Here it is locally cross-stratified.

Other good exposures of the Magothy Formation are on the northwest side of Grove Neck, just north of a western projection of Grove Neck Road, as also reported by Darton (1893). Here, in a nearly vertical bluff about 40 ft (~12 m) high (fig. 56), about 5 ft (~1.5 m) of the Magothy (white sand) can be seen beneath about 30 ft (~9 m) of the Merchantville Formation. To the northeast along the shore the contact rises gradually, but irregularly, because of the unconformable contact between the formations, until, about half a mile (0.8 km) from the first exposure, about 10 to 12 ft (~3 to 3.5 m) of the Magothy is present. Good but scattered exposures of the formation are present over a distance of about 1.25 mile (~2 km). At no point along Grove Neck, however, is the full thickness of the Magothy exposed, nor can the lowermost beds be seen.

No other good exposures of the formation were found in Cecil County. Darton (1893, p. 410) and Miller (1906, p. 3) reported the presence of Magothy high up on Mauldin Mountain at Elk Neck, but, as will be shown later, most of those beds are now interpreted differently, indicating that the unit is largely or entirely absent. According to Miller (1906, p. 3), about 16 ft (~5 m) of Magothy sands were exposed "...south of Reybold wharf..." which would be in the vicinity of Crystal Beach. However, no good exposures were seen by the writer. This area is now intensively developed and the bluff is covered with vegetation. Some dense, black plastic clay, probably of the Magothy, was seen at an excavation for a septic tank in a hillside trailer village about 0.4 mile (~0.6 km) inland.

Some of the best exposures of the Magothy Formation were made during a deepening and widening project of the Chesapeake and Delaware Canal from 1935 to 1937. Carter (1937, p. 248-250) studied the unit for a distance of 3.75 miles (6.0 km) from 4,000 ft (~1,200 m) east of Chesapeake City bridge to 1,900 ft (~580 m) west of Summit Bridge in Delaware.[3] Carter (1937, p. 249) did not report any place in the canal where the entire thickness of the formation was exposed, although he stated that the maximum observed thickness is about 34 ft (~10 m). About 10 ft (~3 m) of section was exposed near the Delaware state line. Minard and Owens (oral commun., 1971) measured 35 ft (10.7 m) of Magothy exposed along the canal while the banks were still bare, a short distance west of the relocated Summit Bridge in Delaware. Today these beds are largely concealed by landscaping and riprap.

Lithology

Darton (1893, p. 410-411) described the formation as consisting chiefly of moderately coarse white and buff sand, locally cross-bedded. Some lignitic lenses and pale-gray clay were also reported. However, Carter (1937), who saw it in nearly continuous fresh exposure during the widening of the Chesapeake and Delaware Canal in 1935-1937, observed three more or less distinct units of varied thicknesses. (1) A lower sand unit, nowhere more than 25 ft (7.6 m) thick, made up a little more than half the exposed section in the canal. This was described by Carter (1937, p. 248-249) as "...fine, yellow, iron-stained to buff, micaceous, compact and containing variable proportions of clay of the same color, plus additional small patches or lenses of black, sticky clay up to 1 ft in length and 1 inch in thickness". (2) The middle unit, not more than 18 ft (~5.5 m) thick, consisted of white sand and clay irregularly interbedded with clay, or grading into it; the distinctive nearly pure quartz sand that "... is coarse, sharp and sugary..." with a little mica, is easily recognized throughout the canal exposure. (3) The upper unit, up

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[3] Since the work of Carter (1937), the Chesapeake City bridge has been relocated about 600 ft (~180 m) to the west and the Summit bridge has been relocated about 3,500 ft (~1,100 m) to the west.

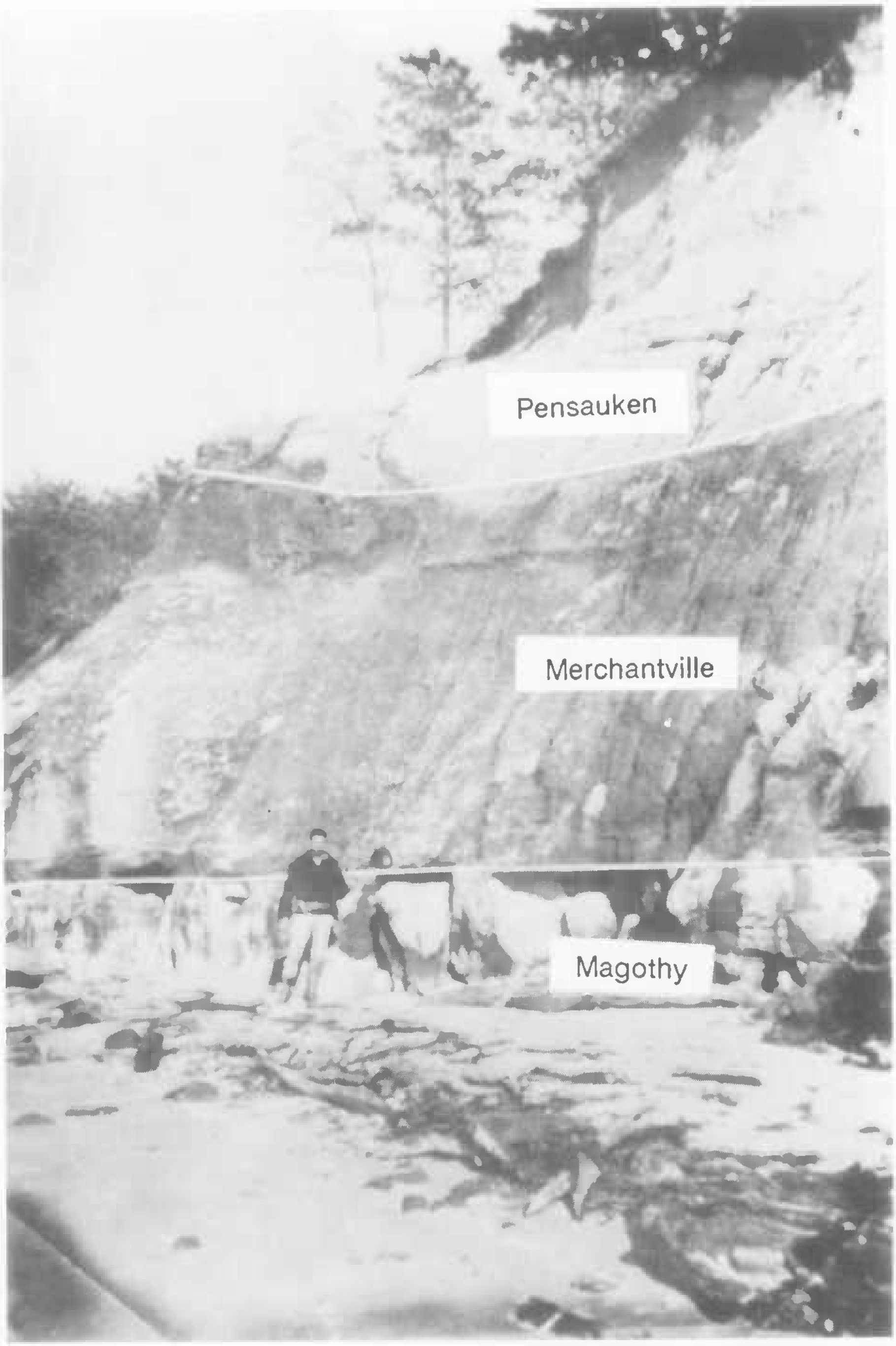

FIGURE 56: Magothy, Merchantville, and Pensauken Formations exposed in cliff on northwest side of Grove Neck. At the base about 5 ft (1.5 m) of white sand of the Magothy Formation is abruptly overlain by between 25 and 30 ft (7.5 and 9 m) of dark-colored, massive, fine-grained sediments of the Merchantville Formation. At the top is about 25 ft (7.5 m) or more of gravelly sand and sand of the Pensauken Formation.

to 15 ft (~5 m) thick, was a massive black clay containing "...much lignitized plant material and some grains of amber." Near the top were many siderite concretions as much as 15 inches (~40 cm) long. It now seems unlikely that clay beds in the formation can be traced for any appreciable distance, and the same may be true for other lithologic types. Improvement work on the canal in 1968-1969 exposed a few feet of the Magothy at about sea level on both sides of the canal along the first 500 yards (~460 m) west of the Delaware State line. The unit contained much lignitized material, including flattened logs as much as 12 inches (~0.3 m) across, and was associated with beds of coarse white granular sand and finely gravelly sand or black clay. At some places these materials lay directly upon an undulating surface of red-stained white clay of the Potomac.

Table 12 is a section of the Magothy Formation measured with the assistance of Mr. G.W. Hayes:

TABLE 12
MEASURED SECTION OF MAGOTHY FORMATION
Near mouth of Bohemia River
about 0.4 Mile (0.6 km) west of Veazey Cove

	Thickness	
	Feet	meters
MAGOTHY FORMATION:		
Sand, fine, of various colors, mostly white, yellow, and brown, with lenses of light-gray silty clay; upper 1 ft (30 cm) stained red. White sand has abundant fragments of lignite in some layers. Clay lenses 0.1 to 0.9 ft (3 cm to 27 cm) thick; one of which about 7 ft (2 m) below top at west edge of exposure wedges out completely within 4 ft (1.2 m)	21.5	6.5
Clay, black, silty, and sandy with laminae of very fine white sand. Noticeably lignitic; one lignite log about 1.5 x 1 ft (45 x 30 cm) in cross section has cavities lined with pyrite. About 2 ft (0.6 m) higher at west end of section. Thicknesses irregular, about .	2.5	0.8
Sand, fine to coarse; one layer of clayey silt about 1 ft (~30 cm) thick. A 2-inch (~5 cm) gravelly bed at the base has pebbles as much as 1 inch (2.5 cm) long. About	5.0	1.5
Sand, varicolored, interbedded with white and gray silty clay. Granule and pebble bed about 0.5 ft (~15 cm) thick at base. Basal contact slopes several feet (meters) About	5.5	1.6
Average total thickness of Magothy	35.0	10.7
POTOMAC GROUP:		
Clay, silty; upper part has medium-dark-gray clay with abundant chips of lignite and two somehat flattened logs about 1 ft (~30 cm) wide. Lower 2 ft (~0.6 m) red-stained. Doyle (letter of Feb. 20, 1972) identified black clay associated with logs as belonging to his Zone III of probable Late Cretaceous age. About	8.0	2.4

Especially well exposed outcrops of the Magothy Formation on the western and northwestern side of Grove Neck start about 140 yards (~130 m) south of the lane to the Chesapeake Haven Civic Association that leads past the Boy Scout camp at Snug Harbor to the beach. The outcrops continue northeast past several sea cliffs in which the formation is exposed intermittently for about 1.25 miles (2 km). At many places along this stretch of beach, cross-bedding can be seen dipping as much as 20° to 30° in various directions, including north, northeast, south, and southwest. The southernmost exposure of the Magothy shows about 5 ft

(~1.5 m) of clean, white, fine to very fine sand exposed beneath about 30 or 35 ft (~9 to 10 m) of dark, compact silt and very fine sand of the Merchantville Formation. The contact is knife-sharp wherever seen along the cliffs. A thin stratification and well-developed cross stratification in the Magothy are accentuated here by thin laminae of lignite grains (figs. 57 and 58). Some beds of gray clay contain fragments of lignite less than 1 inch (2.5 cm) long. Just south of the lane, the beds of the Magothy are markedly cross-bedded and the contact with the Merchantville undulates over a vertical interval of several feet (several meters), with the highest point being about 15 ft (~4.5 m) above the swash line. North of the lane are the excellent exposures illustrated in figures 57 and 58. Starting about 0.25 mile (~0.4 km) to the northeast, the uppermost 2 ft (0.6 m) of the Magothy is an indurated ferruginous sandstone, many blocks of which strew the beach. Some of the fallen boulders show that the base of the Merchantville contains a scattering of pebbles and lignite fragments, both commonly less than 1 inch (2.5 cm) in maximum dimensions. The Magothy in this area is commonly white to light-brown (5 YR 5/6)[12].

In good exposures the dark sediments of the Magothy can be readily distinguished from the varicolored clays of the Potomac Group on which they commonly lie. However, where sand of the Magothy lies on sand of the Potomac it is difficult to tell them apart. In drill cores, both the sands and clays of the Magothy Formation are dense black, but the sands become white with oxidation of the organic matter. Any black clays in the Magothy or Potomac would ordinarily be best distinguished by microscopic study of the spore and pollen content.

Age, correlation, and stratigraphic relations

Darton (1893, p. 418) was uncertain of the precise age of the Magothy in his original description of the formation but placed it in the Early Cretaceous. However, Clark (1904, p. 440) suggested that it is of Cenomanian (Late Cretaceous) age. As subsequent studies of the Potomac Group, already discussed, showed the underlying beds of the so-called Raritan Formation to be partly of Late Cretaceous age, it became apparent that the Magothy must be at least that young. Later, Clark (1916, p. 65) referred it to the Turonian, the next younger stage of the Upper Cretaceous. The correlation chart by Stephenson and others (1942) assigned it to the still younger Coniacian Stage. More recently, Doyle (1969, p. 20) assigned the Magothy to the Santonian on the basis of his studies of pollen and spores from the clays, and cited an ammonite identified by Sohl as verifying this age determination. More recently, Sohl (*in* Owens and others, 1970, p. 34) has assigned the Magothy to the Santonian and Early Campanian and also discussd (p. 33) some of this evolution in the dating of the Magothy, as well as that of the younger Cretaceous formations.

A sample from a 6-ft (~2 m) bed of black clay in the middle of the Magothy at the Chesapeake and Delaware Canal, about 100 to 150 yards (~90 to 140 m) east of the Delaware State line and about 12 to 18 ft (~3.5 to 5.5 m) above sea level, was submitted to J.A. Wolfe for study. He reported (written commun., 1969):

> The sample produced a rich and well preserved assemblage of pollen and spores. The occurrence of a rich Normapolles pollen flora, including a species of *Praebasopollis*, indicates an age no older than the Amboy Stoneware clay (middle Santonian). Three species of tricolpate pollen that occur in this sample have been previously found only in the Cliffwood beds of the New Jersey Magothy.... The available evidence indicates that your sample came from beds equivalent in age to the type Magothy and to the Cliffwood beds of the New Jersey Magothy; this age is presently considered to be earliest Campanian.

The pollen and spore flora indicate a considerable lapse of time between the deposition of the Potomac and Magothy Formations (Doyle, 1969, p. 18), which confirms the physical

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[12] Refers to color designations in Rock-Color Chart prepared by Goddard and others (1948).

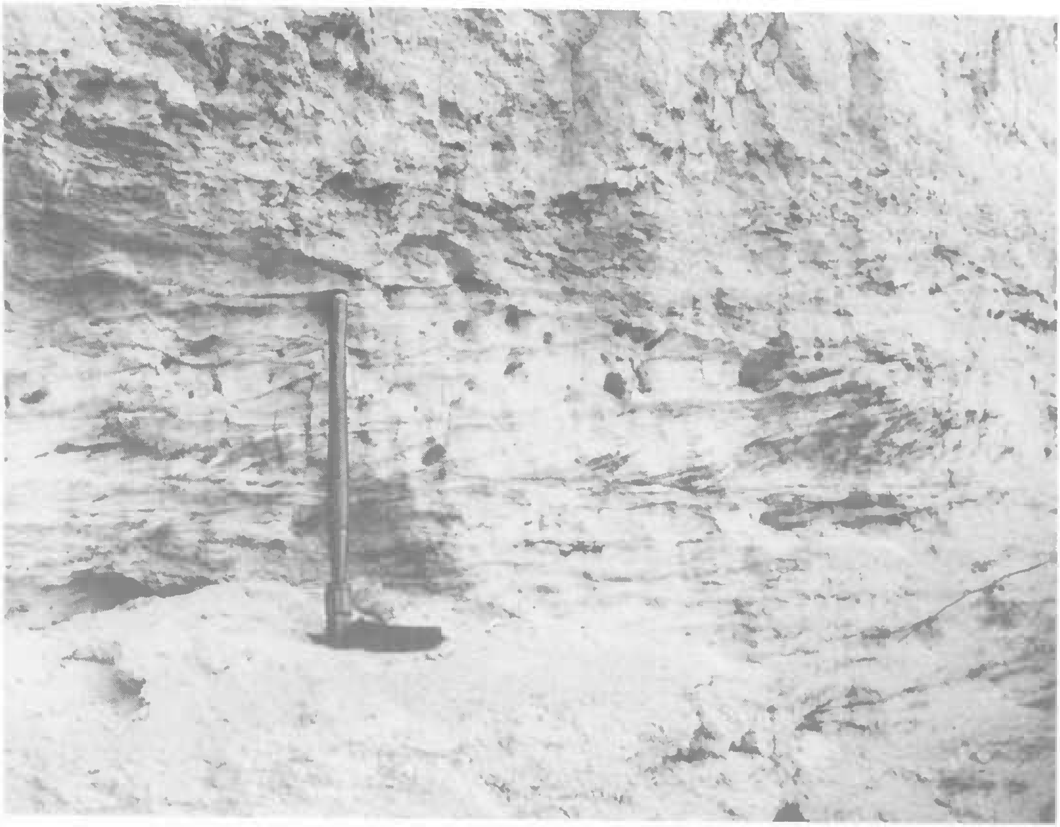

FIGURE 57: Planar cross-bedding in the Magothy Formation exposed in cliff face at west end of Grove Neck. Cross-beds dip north or northeast about 25° and sets are about 4 to 8 inches (10 to 20 cm) thick. Locality is about 75 ft (23 m) north of lane of Chesapeake Haven Civic Association.

observations of the outcrops by Darton (1893), Miller (1906, p. 4), and others that the formation lies unconformably on the older beds. The undulating basal contact of the Magothy Formation was well exposed in the canal, as reported by Carter (1937), and could be seen, at least locally, during this study both there and in the long bluff on the Bohemia River. As no beds of Turonian or Coniacian age have been found between beds of the Potomac Group and the Magothy (Sohl, *in* Owens and others, 1970, p. 35), it appears again that the unconformity between the two formations represents a considerable span of time.

Origin

According to Darton (1893, p. 419), the Magothy was laid down as a shoreline deposit "...when currents and beach action were sufficiently active to sort out moderately coarse sands and spread them in beds...," whereas clay lenses accumulated in slack-water areas. Deposition in a transitional environment between the nonmarine beds of the Potomac Group and the marine beds of the overlying strata was favored by Glaser (1969, p. 73-74). He suggested that estuaries, bays, and lagoons may have been important sites of accumulation. Owens (oral commun., 1971) believed that the material was deposited in the nearshore subaqueous part of a broad fluviodeltaic area along a once-extensive shoreline. At some places, numerous borings suggestive of marine organisms have been found in the sands, although none has been observed in the Canal exposures or in Cecil County. Coarse lignitic fragments and dark-gray organic pigmentation in the clays of the Magothy suggest some local closed-basin depositon and indicate lagoonal or estuarine conditions (Owens and Minard, 1960, p. 17).

FIGURE 58: Magothy and Merchantville Formations exposed in cliff face at west end of Grove Neck. About 3 ft (1 m) of well stratified, clayey, fine-grained sand beds of the Magothy Formation are overlain by massive beds of the Merchantville Formation. Shovel handle is 21 inches (53 cm) long. Locality is about 200 ft (60 m) north of lane of Chesapeake Haven Civic Association.

MATAWAN GROUP

The Matawan Formation was named by Clark (1894, p. 335-336) from Matawan Creek which flows into Raritan Bay in the northern New Jersey Coastal Plain. The strata originally included under the name were later subdivided, and today the term refers only to the lower part of the original unit. Clark (1916, p. 65-69) described the succession in Maryland, still referring to it as a formation but in its present restricted sense. G.N. Knapp, as reported by Salisbury (1899, p. 35-40), subdivided the New Jersey Matawan into five units called "beds," now known as formations, thereby raising the term Matawan to group status. Two of these units pinch out before reaching the southern end of New Jersey. The remaining three, the Merchantville (oldest), Englishtown, and Marshalltown, have been traced southward across New Jersey, into the area of the Chesapeake and Delaware Canal and into northeastern Maryland (Owens and others, 1970), where the combined thickness is about 80 ft (~25 m). Carter (1937, p. 245, 250-261) had previously made a similar identification of the Matawan beds exposed in the canal with the exception of using the more inclusive term Crosswicks Clay instead of Merchantville. Excellent exposures of all three formations may be seen in an abandoned section of the canal about 1.25 miles (2 km) east of the relocated highway bridge at Summit, Delaware (Owens and others, 1970, p. 20 and fig. 5c). Minard (1974, p. 3, 8-9) had recognized the three units a short distance southwest of Cecil County in the nearby Betterton Quadrangle in Kent County. Within Cecil County, a few good exposures of the Matawan formations have

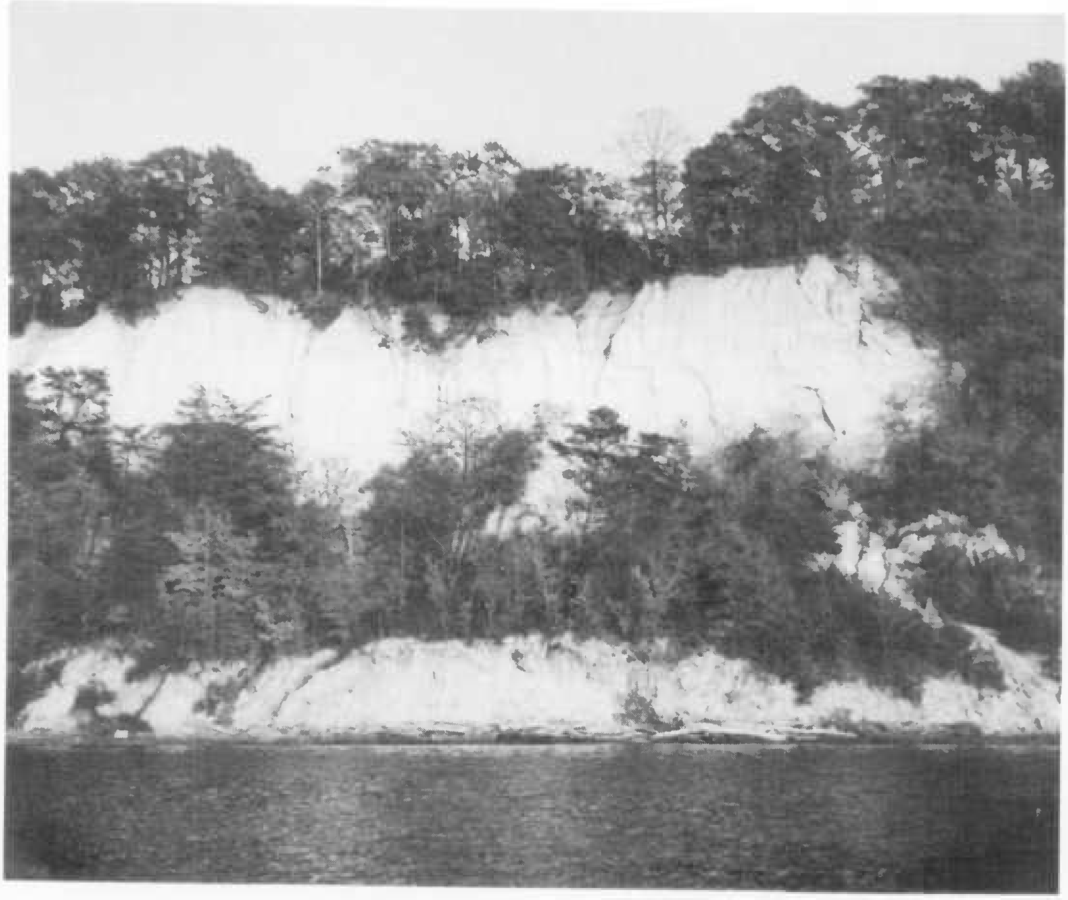

FIGURE 59: Exposure of Monmouth and Matawan Groups in cliff from landslide on west side of Mauldin Mountain. Top of bluff is about 225 ft (70 m) above sea level. About 70 ft (20 m) of strata near the top are interpreted as Monmouth Group and the Marshalltown, Englishtown, and Merchantville Formations of the underlying Matawan Group. Lowest 145 ft (45 m) is Potomac Group. North side of Elk Neck, about 2.5 miles (4 km) northeast of Turkey Point.

been seen along the Sassafras River, in the cliffs on Grove Neck, and along the Bohemia River. The beds have also been encountered in several auger holes. In contrast with the underlying formations, clear evidence of marine origin, such as fossils and the mineral glauconite, is present in all units of the Matawan Group. In the canal the thickness of the Merchantville is about 50 ft (~15 m), the Englishtown 14 ft (~4 m), and the Marshalltown also 14 ft (~4 m) (Owens and others, 1970, p. 12-15).

The most interesting, yet puzzling, exposure of the Matawan sequence in Cecil County is in the high cliff on the west side of Mauldin Mountain on Elk Neck (fig. 59). This high outlier is especially interesting because it is 3.5 miles (~5.5 km) or more northwest of the nearest other places where the unit has been seen, and the beds show significant changes in composition and thicknesses. The writer, together with J.P. Minard, J.P. Owens, and Nicholas Lampiris have measured and provisionally identified a section of the Matawan Group (table 13), which appears to be thinner than expected.

TABLE 13

MEASURED SECTION OF MATAWAN GROUP

Exposure in the upper part of the high bluff
on the west side of Mauldin Mountain

	Thickness	
	Feet	meters
UPLAND GRAVELS:		
Gravel and gravelly sand; ferruginous conglomerate in lowest 6 to 12 inches (15 to 30 cm). About	4.0	1.2
MONMOUTH GROUP (MOUNT LAUREL SAND):		
Sand, generally loose and medium-grained with abundant granules in upper 12 ft (~3.5 m); ranges from various browns and yellows to white; slightly micaceous and somewhat glauconitic; scattered borings throughout	35.0	10.6
MATAWAN GROUP		
MARSHALLTOWN FORMATION:		
Sand, fine, dark-green, richly glauconitic	3.0	0.9
ENGLISHTOWN FORMATION:		
Sand, white, with orange splotches	3.0	0.9
Clay-silt, yellowish brown	4.0	1.2
Sand, white, micaceous	3.0	0.9
Total Englishtown	10.1	3.0
MERCHANTVILLE FORMATION:		
Sand, fine, micaceous, slighly glauconitic and lignitic; upper part weathered to various shades of pink, brown, and yellow; lower 6 to 8 ft (~2 to 2.5 m) chiefly dark gray (N 3-4) contains lignite fragments. 6-inch (15 cm) bed of 0.25 inch (~1 cm) pebbles at base	22.0	6.7
MERCHANTVILLE (?) or MAGOTHY (?) FORMATION, or POTOMAC GROUP (?):		
Clay, white, silty	6.0	1.8
POTOMAC GROUP:		
Poorly exposed or concealed on long wooded and slumped slope. A few feet (few meters) of red-stained, light-gray clay is present at top. At base, the toe of a slide exposes varicolored clay. Intervening interval described by Miller (1906, p. 3) as consisting chiefly of sand. To sea level	145.0	44.0

In the above measured section, many of the typical characteristics of the fresh material are recognizable, but the beds as identified are considerably thinner and are weathered. If the identifications given above are correct, most of the Marshalltown and part of the Englishtown are missing, as is about half of the Merchantville and most or all of the Magothy. In any case, if the Monmouth identification is correct, which seems certain, only about 40 ft (~12 m) of strata are left between that and the Potomac Group to represent all of the Magothy and Matawan beds which only a few miles down the dip have a combined thickness of about 115 ft (~35 m). The most likely implication of this is that the site of the Mauldin Mountain section was significantly closer to shoreline during the Cretaceous at the time of Matawan deposition. If in the Cecil County area the seas did not extend inland much farther than a few miles (few kilometers) beyond the present outcrops of the Matawan Group, there may have been occasional periods of non-deposition, or even periods of erosion in which some of the freshly deposited Matawan was removed during regressions of the sea.

The lithology, stratigraphy, and paleontology of the Matawan Group and the overlying Mount Laurel Sand in New Jersey, northern Delaware, and eastern Maryland have been described in detail by Owens and others (1970). The Merchantville and Englishtown Formations are considered to be of Early Campanian age and the Marshalltown to be of earliest Late Campanian age (Sohl, *in* Owens and others, 1970, fig. 23).

Near the south end of a landslide that has exposed the high bluffs on the west side of Mauldin Mountain, a 12- to 15-ft (~3.5 to 4.5 m) boulder on the shoreline (figs. 60 and 61) has a flat surface covered with marine *Ophiomorpha nodosa* borings (also known as *Halymenites major* (Lesquereux), commonly considered to be callianassid shrimp borings. The block may have fallen from either the Mount Laurel or the Englishtown, as both formations are known to contain local masses of borings. However, a search of the overgrown upper slopes by the writer revealed no place from which the block may have broken off.

MERCHANTVILLE FORMATION

The only good exposures of the Merchantville Formation in Cecil County are along the west and northwest sides of Grove Neck (pl. 1) where some of the sea cliffs are as much as 50 to 60 ft (~15 to 18 m) high. The maximum thickness of the exposed Merchantville is about 30 ft (~9 m), overlain by a cap of the Pensauken Formation and underlain by the Magothy Formation. Except for the enigmatic exposure on Mauldin Mountain, only the lower part of the formation is exposed; nowhere else in the County has its contact with the overlying Englishtown Formation been seen. On Grove Neck the basal contact with the Magothy undulates several feet in a distance of a few tens of yards (meters).

The Merchantville is essentially a fairly uniform and massive fine to medium clayey and silty sand that shows very little stratification. It is distinctly micaceous, has small scattered pieces of lignite, and contains a small amount of fine-grained glauconite that is discernable only with a hand lens. As noted by Owens and others (1970 p. 14), some of the glauconite grains have accordion shapes. Most of the cliff outcrops have been "case-hardened" enough to stand as vertical bluffs. Broken blocks from the base of the formation locally show scattered small pebbles and fragments of lignite. At the extreme west end of Grove Neck, near the base of the high bluff, is a zone several feet (meters) thick which contains many small siderite concretions that appear as thin plates commonly 1 to 3 inches (2.5 to 7.5 cm) in diameter. These have been weathered to moderate reddish brown (10 R 4/6) but are light gray on the inside. At places the siderite concretions are pebble size, as much as 1 to 3 inches (2.5 to 7.5 cm) thick, and 2 to 4 inches (~5 to 10 cm) long. Granules are scattered through the siderite zone, and elsewhere are present either as scattered grains or are locally concentrated into lenses. Commonly the beds range in color from medium gray (about N 5) to nearly black (about N 2). In the canal, the formation is about 50 ft (~15 m) thick (Owens and others, 1970, p. 14-15), but in southern Cecil County it probably thins somewhat, as Minard (1974, p. 8) found it to be only 20 to 40 ft (~6 to 12 m) thick in Betterton Quadrangle.

The contact of the Merchantville Formation with the underlying Magothy is irregular; therefore, it is clear that the units are separated by an erosional unconformity. As both formations are now believed to be of Early Campanian age, the time break was probably not great. This may be one reason why, in spite of its thinness, the Magothy is such a continuous unit.

The Merchantville Formation is the first outcropping Coastal Plain unit in the Maryland area to show clear evidence of a marine origin. In Cecil County this is indicated by the presence of glauconite, but the unit is less glauconitic than it is in New Jersey. This would seemingly be best attributed to an inner-shelf depositional environment. In the canal many kinds of marine fossils have been identified by Carter (1937, p. 253-255) and by Sohl (in Owens and others, 1970, p. 35-38).

Dorf and Fox (1957, p. 3-4) pointed out an alternation between deep-water and shallow-water sediments in the Coastal Plain succession of New Jersey. More recently Owens and Sohl (1969, p. 257-259) have stated that the Cretaceous and Tertiary Formations of New Jersey represent several cycles in the sedimentary history of the area. Ideally, each cycle

FIGURE 60: Large block of indurated sand, probably from the Englishtown Formation or possibly the Mount Laurel Sand. At base of cliff at south end of Mauldin Mountain.

commenced with the deposition of a glauconite-rich outer-shelf unit, succeeded by a predominently silty inner-shelf unit and overlain by a dominantly sandy nearshore or beach deposit. Some of the formations of the more complete New Jersey section are absent in Delaware and Maryland, where some of the cycles appear to have been interrupted.

ENGLISHTOWN FORMATION

The Englishtown Formation presumably extends across Cecil County from the vicinity of Back Creek to Grove Neck (pl. 1), but because of cover by younger strata it has been seen at only two places: in the Mauldin Mountain bluff and in the lower 10 to 15 ft (3 to 4.5 m) of a much overgrown and slumped high bluff just east of a large spoil area on the north side of the Sassafras River about 1.5 miles (~2.5 km) east of Grove Point. The formation is also exposed in the bluffs on the south shore of the Sassafras River at Betterton in Kent County, only about 1.25 miles (2 km) southwest of Grove Point, where it has been described by Minard (1974, p. 8-9). It has also been recognized in a few drill holes. In Delaware, the unit is present in the high bank on the north side of a recently abandoned part of the Chesapeake and Delaware Canal about 1.25 miles (2 km) east of the new Summit Bridge (Owens and others, 1970, p. 13).

The Englishtown Formation is a well-stratified, silty, fine to very fine sand that is micaceous and in some places slightly glauconitic. Lignite fragments are common. At Betterton it contains some layers of black, unctuous clay. When fresh the unit is nearly black because of abundant fine carbonaceous matter, but when weathered or washed the sand is almost snow white. In places, the lower 1 to 2 ft (30 to 60 cm) contains many siderite concretions and

FIGURE 61: *Ophiomorpha* borings exposed on large flat surface on left side of boulder shown in figure 60. Surface is almost 10 to 12 ft (3 to 3.6 m) across.

fragments of lignite as well as granule beds with pebbles as much as 1 inch (2.5 cm) in diameter. Carter (1937, p. 257) reported that the formation ranges in thickness from 6 to 16 ft (~2 to 5.0 m) in the exposures along the Chesapeake and Delaware Canal, and Owens and others (1970, p. 13) measured 14 ft (~4.5 m). In the Betterton area, Minard (1974, p. 8) found 15 to 18 ft (~4.5 to 5.5 m) of Englishtown. On the north side of the canal west of St. Georges Bridge, a former exposure of the Englishtown at water level, illustrated by Owens and others (1970, fig. 11) and by Pickett and others (1971, fig. 7), showed abundant *Ophiomorpha* borings.

By the cyclicity theory of Owens and Sohl (1969, p. 254), the extensively cross-stratified and only slightly glauconitic quartz sand of the Englishtown Formation can best be explained as a near shore or beach deposit that marks the end of a cycle. Sohl (in Owens and others, 1970, p. 33) assigned the Englishtown to the upper part of the Early Campanian.

MARSHALLTOWN FORMATION

The Marshalltown Formation is a glauconitic, greenish-gray clayey and silty fine sand, containing less mica than the two underlying formations. A complete section of this unit has not been found in Cecil County, but it is well-exposed along the Chesapeake and Delaware Canal in Delaware (Owens and others, 1970, p. 13) and also near Betterton in Kent County, a few miles (few kilometers) to the southwest (Minard, 1974, p. 9). The formation is unstratified and poorly sorted, with some granules and pebbles scattered throughout, especially near the base and top. Many of the glauconite grains have accordian shapes, in additon to the more usual botryoidal grains. Depending on the degree of weathering, the color ranges from

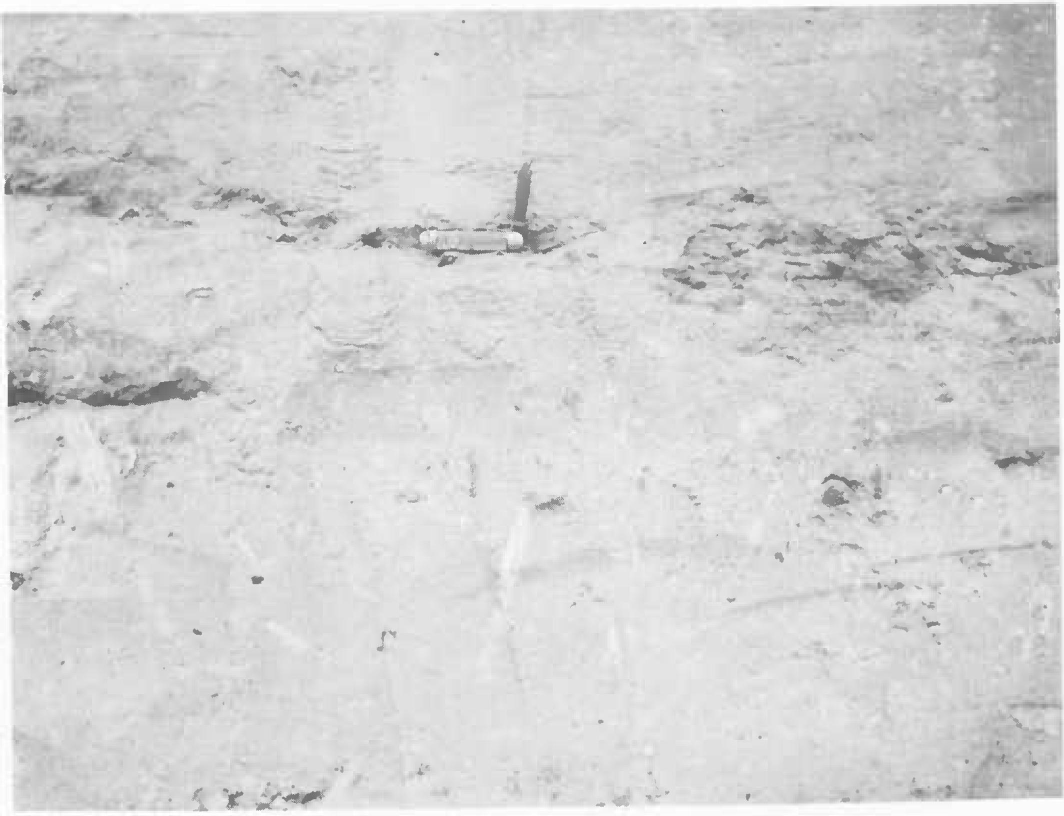

FIGURE 62: Fine-grained, glauconitic sand of the Marshalltown Formation showing extensive borings. Lower half of a 5-ft (1.5 m) face of a small pit. On Pearce Neck, north side of Crystal Beach Road, about 1.8 miles (2.9 km) northwest of St. Stephens Church.

greenish-black (5 G 2/1) where fresh, through various greens and olive-gray (5 Y 3/2) to moderate yellow (5 Y 7/6). Many fossils have been found in the exposures along the canal (Carter, 1937, p. 260-261; Sohl and Mello, *in* Owens and others, 1970, p. 41-44, 51-53). Borings are common, particularly in the upper part of the unit.

A good exposure of a portion of partly weathered Marshalltown is present in a small sand and gravel pit on the north side of Crystal Beach Road at Pearce Neck, 1.8 miles (2.9 km) northwest of St. Stephens Church. About 7 ft (~2 m) of glauconitic sand of the Marshalltown Formation, containing many borings (fig. 62), is overlain by about 8 ft (~2.5 m) of surficial sand and gravel of the Pensanken Formation. The color of the Marshalltown at this locality is moderate yellow.

An outcrop of the Marshalltown Formation in the high bluff of Mauldin Mountain has already been described. An additional exposure of the unit was found in the northernmost bluff of Mauldin Mountain, about 75 ft (~25 m) south of a 60- to 70-ft (~20 m) near-vertical face composed chiefly of the Potomac Group. By digging away the vegetation 6 to 10 ft (~2 to 3 m) below the top of the steep slope, about 4 ft (1.2 m) of Marshalltown can be seen overlain by a light-colored sand that presumably is of the Monmouth Group. Just below the Marshalltown is a near-white sand, most likely the Englishtown Formation.

A 5-foot (1.5 m) exposure of the Marshalltown can be observed with difficulty about 9 to 14 ft (2.7 to 4.3 m) above sea level in a cut bank behind a small service house at the Bohemia Anchorage Marina, just west of the south end of the U.S. Rte. 213 bridge over Bohemia River. Between here and Free School Point, half a mile (0.8 km) to the southeast, are at least two

FIGURE 63: Gradational contact between dark-colored Marshalltown Formation and overlying lighter colored Mount Laurel Sand of the Monmouth Group. The Marshalltown contains many borings of *Ophiomorpha* and a few poorly preserved internal molds of shelled fossils. Trench shovel is 28 inches (70 cm) long. North shore of Sassafras River at first bluff west of Ordinary Point, which is in the background.

exposures of the unit at the base of 20- to 25-ft (~6 to 7.5 m) bluffs. At Free School Point, about 5 ft (1.5 m) of Marshalltown is exposed at the base of the bluffs and grades upward through an interval of 2 or 3 ft (0.6 to 0.9 m) into the overlying beds of the Monmouth Group. Another fresh exposure of the formation containing a few internal molds of fossils can be seen just west of Ordinary Point on the north bank of the Sassafras River at the extreme western edge of the Earleville Quadrangle (fig. 63). Here a bluff about 30 ft (~9 m) grades upward into the Mount Laurel sand of the Monmouth Group.

A small collection of fossils, collected about 1.5 ft (~0.5 m) above the swash line at Ordinary Point on the Sassafras River, was reported by Sohl (written commun., 1967) to contain unidentified species of *Turritella*, *Crassatella*, *Cardium*, *Ostrea*, and questionable *Cucullea*. Although not diagnostic of anything other than the Matawan Group, in comparison with the sequence exposed in the canal their mode of preservation and general taxonomic representation were reported to be consistent with the fauna of the Marshalltown Formation. Sohl (in Owens and others, 1970, p. 33) assigned the Marshalltown to the lower part of the upper Campanian. According to the cyclicity theory of Owens and Sohl (1969), the Marshalltown, because of its abundant glauconite, is believed to be a middle- or outer-shelf deposit. It probably accumulated somewhat farther offshore than did the Englishtown Formation.

MONMOUTH GROUP

Clark and others (1897, p. 331) proposed the name Monmouth Formation for exposures in Monmouth County, New Jersey. As several subdivisions were recognizable, the formation was divided into three members: Mount Laurel Sands (oldest), Navesink Marls, and Red Bank Sands. The Tinton Sand was later split off from the Red Bank as the topmost member of the formation. Later, these members were raised in rank to formations and the Monmouth raised to group status. In Maryland, where no subvdivisions of the unit were recognized, the term Monmouth Formation was retained. Later, Carter (1937, p. 262) recognized the Mount Laurel Sand in the Chesapeake and Delaware Canal. Detailed mapping in New Jersey in recent years (Minard, 1964; 1965; 1970) has shown that the upper formations of the Monmouth Group, present in the northern part of that State, disappear southward (Minard and others, 1969, p. H30). Only the Mount Laurel can be found at the southern edge of New Jersey where it is between 50 and 80 ft (~15 and 25 m) thick (Owens and Minard, *in* Minard, 1965). Thus it has been assumed that of all the units in the Monmouth Group only the Mount Laurel is present in Delaware and Maryland (Owens and Sohl, 1969, p. 238, fig. 4, and p. 249; Owens and Minard, *in* Owens and others, 1970, p. 22). As is pointed out in the section on age and correlation, however, it is now believed that some higher units of the Monmouth occur in and near Cecil County where a considerably greater thickness of the group exists. Until more information is available, it seems best to refer to the beds in Cecil County as the Monmouth Group, in the belief that other members may overlie the Mount Laurel Sand.

Distribution and thickness

The beds of the Monmouth Group (pl. 1) are exposed in many roadcuts and stream banks in the southeastern part of the county. Along the Delaware state line these beds presumably lie immediately beneath the surficial Pensauken Formation from the south bank of Back Creek, 1.5 miles (~2.5 km) south of the canal, to the vicinity of Warwick. Along the north shore of the Sassafras River, the Monmouth beds are exposed in many cut banks and tributary gullies westward from the vicinity of U.S. Rte. 301 to about a mile (1.6 km) east of Grove Point. At many places on the south side of the river in Kent County they are well exposed, especially from the high bluff near Kentmore Park almost to Betterton. One of the better roadcut exposures in Cecil County is on the south bank of Back Creek along the road near the Delaware state line. Here about 30 ft (~9 m) of the Monmouth lying above the Marshalltown is best exposed in a small sand pit west of the road at the foot of the hill. About 3 miles (~5 km) farther south on the southeast side of Great Bohemia Creek at Bohemia Mills, a richly-fossiliferous calcareous layer, 2 ft (0.6 m) thick, is exposed in a roadside ditch at the foot of the hill on Old Telegraph Road, 60 yards (~55 m) south of the center of an east-west road. *Exogyra cancellata* and *Belemnitella americana* (Minard and others, 1969, p. H18) have weathered out from the strata at this point, leaving well-preserved molds. About 2 ft (0.6 m) above this layer is the base of a 12-ft (3.6 m), richly glauconitic bed that may be easily mistaken for the Hornerstown Formation. Another roadcut on Old Telegraph Road about 0.4 mile (0.6 km) to the south exposes highly varied sands, including a 12-ft (3.6 m) bed containing about 50 percent glauconite. Much of the glauconite occurs as coarse aggregates as in the bed at Bohemia Mills, but this layer appears to be higher stratigraphically. If this is the same glauconite bed as the one at Bohemia Mills and can be correlated with the Hornerstown Formation, it would indicate that there is a reversal in dip great enough to produce a vertical difference of 100 ft (~90 m) across the area between these exposures. This would represent a major structural irregularity for this part of the Coastal Plain in Cecil County. Evidence presented below indicates that such a correlation with the Hornerstown is improbable.

South of Little Bohemia Creek, several good exposures of the Monmouth Group overlain by gravels and sands of the Pensauken Formation occur along Bohemia Church Road. About 2 miles (3.2 km) east of Cecilton where Wards Hill Road crosses Duffy Creek and its tributary to the west, the Monmouth, overlain by the green Hornerstown Formation, can be found by digging in the stream banks.

The thickness of the Monmouth Group in and near Cecil County was determined by a series of deep power-auger holes. Minard, Owens, and others (Minard, 1974, p. 21-22) drilled a 171-ft (52 m) hole in a small gravel pit half a mile (0.8 km) northwest of Odessa, Delaware, starting about 4 ft (1.2 m) below the well-exposed base of the overlying Hornerstown Formation. Near the bottom, about 10 to 15 ft (~3 to 4.5 m) of light-gray calcareous and fossiliferous, glauconitic clayey sand were recovered. This material is similar to that at the base of the Mount Laurel at the Biggs Farm locality on the Chesapeake and Delaware Canal (Owens and Minard, *in* Owens and others, 1970, p. 15-16). At the bottom of the hole, 1 ft (30 cm) of highly glauconitic sand, quite certainly of the Marshalltown Formation, was encountered. It is apparent that the thickness of the Monmouth here is about 175 ft (53 m).

During the course of this study, a hole was drilled to a depth of 176 ft (53.5 m) in a small gravel pit 2.7 miles (4.3 km) east of Cecilton. It started in 10 ft (~3 m) of Hornerstown and finished in 5 to 10 ft (1.5 to 3 m) of light-gray calcareous and fossiliferous clayey sand believed to be the basal Mount Laurel. At this locality, therefore, beds of the Monmouth Group are at least 165 ft (50 m) thick and may be as much as 170 ft (52 m), as at Odessa. Midway through the drilling of this hole, the discharge from the drill stem was a green, soupy mud containing about 50 percent glauconite, very likely from the same glauconite bed as the one exposed at Bohemia Mills. Another hole was drilled at Bohemia Mills, 5 miles (8 km) northeast of the hole near Cecilton and 5.5 miles (8.8 km) west of the Odessa hole. This 101-ft (30.8 m) hole started a few feet (meters) below the glauconite bed and was interpreted as showing 75 ft (22.8 m) of Mount Laurel, underlain by about 10 ft (~3 m) of Marshalltown and 15 ft (~4.5 m) of Englishtown. Therefore, at this location the exposed glauconite-rich bed is about 80 to 85 ft (~25 m) above the base of the Mount Laurel, and is presumably in the middle of the Monmouth Group. By contrast, a third hole drilled in a small gravel pit just west of the Betterton Quadrangle and 19 miles (30.5 km) west-southwest of the Cecilton hole started in the overlying Aquia and Hornerstown beds and showed only 60 ft (18.3 m) of Monmouth, which indicates a rapid thinning to the southwest (Minard, 1974, p. 10). Apparently in Delaware and eastern Maryland a local downwarping or embayment permitted the accumulation and preservation of about 80 to 90 ft (24 to 27 m) of additional sand. As explained in the section on age and correlation, this may represent Monmouth beds younger than the Mount Laurel that have not heretofore been recognized in Maryland.

Lithology

Exposures of beds of the Monmouth Group characteristically show indistinctly stratified, more-or-less iron-stained glauconitic quartz sand, although fresh exposures commonly show good stratification or cross-stratification in many of the beds. The sands range in color from near white to various shades of yellow, brown, and red depending on the amount of iron oxide and the degree of weathering. Locally, the iron oxide has cemented the sand to sandstone.

The sand is chiefly fine- to medium-grained, but granules are common at or just below the Bohemia Mills glauconite-rich bed. Goldman (1916, p. 163) reported the presence of considerable unweathered feldspar, and Owens and Minard (in Owens and others, 1970, Tables 2 and 3) showed the feldspar content in the upper part of the beds in Cecil County to be about 15 percent. The glauconite content of the formation ranges from a trace to 90 percent or more with the lower part less glauconitic than the upper part. Owens and Minard report (*in* Owens and others, 1970, p. 22, and Table 2) a sample in which they found 34 percent glauconite. Some of the relatively unweathered beds, such as one exposed near the top of the Monmouth on the west side of Ordinary Point, show a scattering of dark-green glauconite grains in a near-white matrix, which gives the sand a "salt-and-pepper" appearance. The richest glauconite bed, near the middle of the Monmouth at Bohemia Mills, has dusky- to grayish-green colors and understandably has been mistaken for the Hornerstown Formation (Minard and others, 1969, p. H18). However, much of the glauconite in this bed, in contrast to that of the Hornerstown Sand, is in coarse aggregates and some grains have accordion forms. The glauconite and quartz grains both reach the size of granules. A wedge of this glauconite bed, about 2 ft (0.6 m) thick, was seen just below the gravelly capping beds on the north side of Bohemia Church Road just south of Little Bohemia Creek, about half a mile east (0.8 km) of U.S. Rte. 213. The basal part of the Mount Laurel portion of the Monmouth Group, exposed in the Chesapeake and Delaware Canal near St. Georges Bridge and the Biggs Farm locality of Owens and Minard (*in* Owens and others, 1970, p. 15-16), is an unweathered pale-gray clayey and calcareous glauconite quartz sand. In an auger hole this unit was found to be about 16 ft (~5 m) thick. Similar material was encountered at the base of the Mount Laurel in three deep auger holes located at Bohemia Mills, a site 2.7 miles (4.3 km) east of Cecilton, and at Odessa, Delaware, but has not been seen elsewhere.

In a few places, sands of the Monmouth Group have been indurated to form resistant ledges. The best example in Cecil County is near the top of the Monmouth at Fredericktown, on both sides of U.S. Rte. 213. A tough, fossil-rich, ledge exposed in an excavation in the hillside for a restaurant and boat sales room on the west side of the highway, ranges in thickness between about 1 and 4 ft (0.3 and 1.2 m) over a horizontal distance of about 75 ft (~23 m). This layer is overlain by some 8 ft (2.4 m) of green sand consisting of about half glauconite, much of it as aggregates, and half quartz sand ranging from very fine to very coarse. Above this unit is the Hornerstown Formation. On the east side of the highway, the fossiliferous ledge is exposed behind some boat repair shops. A similar indurated, highly fossiliferous calcareous sandstone bed at Bohemia Mills near the middle of the Monmouth Group has already been described.

Siderite concretions are present locally and are best seen on beaches below some of the bluffs from which they have been eroded. On the west side of Ordinary Point, along the north bank of the Sassafras River, some of these concretions are up to 4 ft (1.2 m) in diameter and 1 ft (0.3 m) thick. Others are more nearly spherical and may be as much as 2 ft (0.6 m) or more in diameter. The succession of bluffs at this place also shows good horizontal stratification and trough-type cross-stratification. The sand, much of it sprinkled with glauconite, ranges in color from nearly black in the unweathered basal part through various shades of yellow and brown to light gray.

Borings are common throughout the Monmouth Group, many of them branching. They are especially abundant at the very top of the unit in a reddish-brown sand where the tubes have been filled with green sand from the overlying Hornerstown Formation (fig. 64). Most of the borings are about 1 inch (2.5 cm) in diameter and are either near-vertical or inclined, although some are essentially horizontal.

Age, correlation, and stratigraphic relations

On the basis of macrofossils, Sohl (in Owens and others, 1970, fig. 23) indicated that the Mount Laurel is of Late Campanian age. He pointed out that the Mount Laurel Formation in the Chesapeake and Delaware Canal is characterized by *Exogyra cancellata*, as is the Mount Laurel of New Jersey, whereas that fossil is not present in the higher Monmouth formations of New Jersey (Sohl, *in* Owens and others, 1970, p. 49, fig. 23, table 8). *Exogyra cancellata*, along with *Belemnitella americana* is present in the 2-ft (0.6 m) ledge of calcareous sandstone just below the glauconite-rich bed at Bohemia Mills (Minard and others, 1969, p. H13, H18). Mello (in Owens and others, 1970, p. 55) concluded on the basis of Foraminifera, that the Marshalltown and Mount Laurel are both of Late Campanian to Earliest Maestrichtian Age.

The gradational contact between the Marshalltown and the overlying Monmouth is well exposed in the first bluff west of Ordinary Point on the north shore of the Sassafras River (fig. 63). In New Jersey, the Wenonah Formation lies between the Marshalltown and Mount Laurel, but is absent in the Chesapeake and Delaware Canal and in Cecil County. The fact that the Marshalltown-Monmouth contact in Cecil County is gradational with no material missing indicates that the lower part of the Monmouth of Cecil County may be correlative with both

FIGURE 64: Contact between Hornerstown Formation and Monmouth Group (at pocket knife). The brown sand of the upper foot (30 cm) of the Monmouth (light-colored) has abundant borings filled with dark green sand of the overlying Hornerstown (dark-colored). Other borings in the base of the Hornerstown contain sand of the Monmouth. About 10 ft. (3 m) above sea level on east side of Wilson Point, south shore of Sassafras River, Kent County.

the Wenonah and Mount Laurel of New Jersey, as suggested by Mello (in Owens and others, 1970, p. 55). That is, the Wenonah grades laterally southward into the Mount Laurel lithology.

In western Delaware and in Cecil County, the Monmouth is abnormally thick, about 170 ft (52 m), as previously pointed out, in contrast to a thickness of 50 to 80 ft (~15 to 25 m) in the Woodstown area of southern New Jersey. About 80 ft (~25 m) is present just west of the Betterton Quadrangle in Kent County, Maryland. In the middle of the thick Monmouth section of the Betterton Quadrangle, Minard and Sohl (Minard, 1974, p. 23) found the ammonite *Sphenodiscus* and other fossils in a dark-gray, very silty sand. A short distance below this bed is a glauconite-rich sand very much like the one exposed at Bohemia Mills and also similar to one at the base of the Red Bank Sand in the Roosevelt Quadrangle of New Jersey described by Minard (1964). Below this are fossils of Mount Laurel affinity. In New Jersey, *Sphenodiscus*, a fossil of Maestrichtian age, is not found lower than the Navesink Formation, which overlies the Mount Laurel. It may be that in the areas of Cecil County, the Betterton Quadrangle, and nearby parts of Delaware, the glauconite-rich bed and the *Sphenodiscus* bed are at the base of a heretofore unrecognized unit overlying the Mount Laurel sand and correlative with the Red Bank of New Jersey, a sequence that has not been previously identified in Delaware or in Maryland. This would indicate that southern Cecil County was near the middle of an embayment in Maestrichtian time during which an additional 80 or 90 ft (~24 or 27 m) of glauconitic sand accumulated and may represent another cyclic sedimentation unit with a glauconite-rich basal bed overlain by silty and sandy units. Further investigations are desirable before it can be decided whether these newly recognized beds in eastern Maryland and Delaware are southern extensions of the Navesink and Red Bank Formations, with connections in the subsurface, or whether they are unconnected and should be given new names.

Origin

If the cyclic theory of sedimentation, as proposed by Owens and Sohl (1969, p. 257-259), is applied in Cecil County to the Monmouth beds, in which the glauconite content is variable, it appears that oscillations took place between shallow water of the inner shelf and deeper water of the outer shelf. The Mount Laurel Sand would represent a shallowing of the sea, followed by the onset of a new cycle represented by the Bohemia Mills glauconite bed. This in turn was followed by the overlying silty sand that carries *Sphenodiscus*, overlain by 50 ft (15 m) or more of a somewhat glauconitic quartz sand, thus completing another cycle. It must be recognized, however, that conditions favoring glauconite formation are not well understood, so factors other than depth of water may have been responsible for the variation in glauconite content. The presence of younger sediments of Monmouth age, that is the glauconite-rich bed at Bohemia Mills and the strata overlying it, may be explained in one of two ways. These sediments may represent accumulation in a separate embayment, or they may be remnants of a sequence that was once continuous with the Navesink and Red Bank Formations of New Jersey. In the latter case, their isolated presence in Cecil County may be due to local downwarping, which protected them from subsequent erosion as the intervening area was uplifted. There may be a connection in the subsurface between these beds and those in New Jersey, but detailed studies of well records will be necessary to establish that relationship.

TERTIARY STRATA

HORNERSTOWN FORMATION

This unit, originally termed the Sewell Marls (Clark and others, 1897, p. 338), was later named the Hornerstown Marl (Clark, 1907, p. 3) from the town of that name in New Jersey. As it is a sand, though composed almost wholly of glauconite, it was termed the Hornerstown Sand in New Jersey by Minard and Owens (1960, p. B184). The beds were not recognized as a separate unit in the early work in Cecil County by Shattuck (1902a, p. 164) and Miller (*in* Bascom and others, 1902), but were considered to be part of the Aquia Formation along with what is now included in the upper part of the Monmouth Group. Miller (1906) reported greensand at some places in Delaware, but mapped it as the Rancocas Formation, which is now commonly divided into the Hornerstown and Aquia (or Vincentown) Formations. Miller (*in* Bascom and others, 1902) did not recognize those beds in Cecil County but included their outcrop area in his Aquia Formation. The Delaware Geological Survey also does not recognize the Hornerstown and Aquia as separate formations, but calls these units the Rancocas Formation. They have been identified, however, by Minard and others (1969, p. H16, H18) at several places in Delaware and northeastern Maryland.

Distribution and thickness

The Hornerstown Formation is remarkable for its uniformity in composition and thickness over long distances. It has been traced from the vicinity of Raritan Bay, New Jersey, to eastern Maryland, and throughout this distance of about 125 miles (~200 km) the thickness does not vary much from 20 ft (~6 m). The northernmost exposures in Cecil County are in an abandoned gravel pit 0.3 mile (0.5 km) north of Wards Hill Road, 2.7 miles (4.3 km) east of the center of Cecilton, where the unit is exposed beneath the gravel cap (pl. 1). The deep auger hole at this locality that penetrated 165 ft (~50 m) of the Monmouth Group first encountered 10 ft (~3 m) of Hornerstown above it. On the west side of Duffy Creek along Wards Hill Road, the formation can be dug out of the overgrown cuts through a vertical interval of about 15 ft (~4.5 m) between the gravel cap above and the Monmouth below. In 1966, the best exposure of the Hornerstown Formation in Cecil County was seen in Fredericktown at the site of the newly built Georgetown Post Office. At this exposure the base of the Hornerstown Formation was 5.5 ft (1.7 m) above the ground-level concrete loading platform at the rear of the post office, and about 30 ft (~9 m) above river level. Although more-or-less concealed by vegetation, a good contact with the underlying brown sand of the Monmouth could be seen (fig. 65). The top of the Hornerstown had many borings filled with green sand of the Hornerstown. About 19 ft (5.8 m) higher a gradational contact with the Aquia Formation can be exposed by digging. A measured section at this locality follows:

TABLE 14
MEASURED SECTION OF HORNERSTOWN FORMATION
Beside Georgetown Post Office in Fredericktown, Cecil County
about 100 yards (~100 m) north of U.S. Rte. 213 bridge
over the Sassafras River

	Thickness	
	Feet	meters
AQUIA FORMATION:		
Sand, fine, fairly uniform, partly weathered with various shades of yellow and brown; estimated to contain 15 to 20 percent glauconite; base chosen at base of 3-inch (7.5 cm) indurated bed	11.0	3.3
HORNERSTOWN SAND:		
Glauconite sand, fine to medium, olive-gray (5Y3/2), contains about 80 percent glauconite; somewhat lighter color at top because of weathering; lower 2 ft (60 cm) has abundant nodules of goethite	19.0	5.8
MONMOUTH GROUP:		
Sand, medium, glauconitic, light-brown (5YR5/6) at top, but grades downward to various light shades of green and brown; glauconite-filled borings in upper part	6.0	1.8
Total thickness of section	36.0	11.0

The best locality in Cecil County to see the fresh Hornerstown associated with overlying formations is along the road to Skipjack Cove which turns west from U.S. Rte. 213 about 0.2 mile (0.3 km) north of the Georgetown Post Office. Near the top of the hill, a deep ditch on the south side of the road affords excellent exposures of the two lower units; however, no contact was seen. Farther up the hill the Aquia Formation is poorly exposed in a shallow ditch whereas lower down the hill excellent exposures of the sands of the upper Monmouth Group are present.

The best exposure known of the Hornerstown Formation in Maryland is just across the Sassafras River in Kent County. A deep cut for the road leading to the Gregg Neck boatyard, about 1 mile (1.6 km) up the river from the U.S. Rte. 13 bridge between Fredericktown and Georgetown, exposes about 20 ft (~6 m) of Hornerstown. The unit lies on about 10 ft (~3 m) of Monmouth and grades upward into the Aquia, of which about 5 ft (~1.5 m) is exposed.

Lithology

In much of New Jersey the Hornerstown Formation contains about 95 percent glauconite, and even the clay fraction has been found to be composed largely of glauconite (Minard 1970, p. 22). In Cecil County the glauconite content of the unit is somewhat less, on the order of 80 to 90 percent, with the remainder mostly quartz. The glauconite is poorly sorted and chiefly fine- to medium-grained, but contains materials ranging in size from clay to coarse particles. The grains are mostly smooth, rounded, and single, although a small fraction consists of compound grains, and there is a sparse scattering of accordion-shaped grains. This is in contrast with the glauconite-rich bed in the middle of the Monmouth Group at Bohemia Mills, which abounds in compound grains and has an appreciable number of accordion-shaped grains.

FIGURE 65: Contact between Hornerstown Formation and Monmouth Group (at crossbar of folding rule). Borings are present in both formations, as at the locality of figure 64, but do not show in this photograph. Rule is 2 ft (60 cm) long. North side of excavation during construction of Georgetown Post Office in Fredericktown. Contact is 5.5 ft above loading platform at rear of building.

X-ray studies by Lampiris have shown that the clay fraction of the Hornerstown in Cecil County is also rich in glauconite.

The Hornerstown Formation ranges in color from various shades of grayish and dusky green or olive-gray in the relatively unweathered state to a lighter green where it has been partly weathered.

Age, correlation, and stratigraphic relations

Studies of the foraminifera in the Hornerstown Formation by Loeblich and Tappan (1957, p. 176, and fig. 28) led them to conclude that the unit is of Late Paleocene (Landenian) age, and has a fauna distinctly different from the underlying beds. However, Mello (*in* Minard and others, 1969, p. H25-H26), also studied the foraminifera and concluded that the Hornerstown is of Early Paleocene (Danian) age. Both workers detected a marked faunal break between the Hornerstown and the underlying Cretaceous strata. The Hornerstown has sometimes been correlated (Richards and others, 1957) with the Brightseat Formation in Southern Maryland (Bennett and Collins, 1952), although Loeblich and Tappan (1957, fig. 27) believed the Brightseat to be of Danian Age, in contrast with their somewhat younger Landenian Age for the Hornerstown.

Minard and others (1969) have discussed the opinions of various previous workers on the stratigraphic relations between the Hornerstown and underlying beds. Their detailed field work and laboratory investigations have shown convincingly that an unconformity separates the two sequences. The contact of the Hornerstown with the overlying Aquia Formation is gradational through an interval of 1 to 2 ft (0.3 to 0.6 m).

Hazel (1969) presented paleontological evidence that the Brightseat and the overlying Aquia are separated by an unconformity, which he suggests may represent a time gap of about 3.6 million years. Lithologically the Brightseat, a dark-gray micaceous, sparingly glauconitic, sandy clay, is quite different from the glauconite sand that constitutes the Hornerstown. These paleontologic and lithologic differences support the belief that the Brightseat is a separate, somewhat older unit not correlative with the Hornerstown.

Origin

The Hornerstown, according to the cyclicity theory of Owens and Sohl (1969), is assumed to be the initial deposit of a new cycle. As such, it is rich in glauconite and is believed to have accumulated at a considerable distance from shore on the outer shelf, or at least far enough offshore to be relatively free of quartz and other debris of continental origin.

AQUIA FORMATION

The Aquia Formation, named by Clark and Martin (1901, p. 58-64) after Aquia Creek in northern Virginia, is a succession of calcareous greensand, marl, and limestone that is widespread in the Maryland Coastal Plain. The name Vincentown Formation was applied by Clark and others (1897, p. 338) to a unit of calcareous greensand recognized from northern New Jersey south to Delaware and easternmost Maryland. Clark and his co-workers originally thought the Vincentown to be Upper Cretaceous and the Aquia to be Eocene, but the best current evidence indicates that they are correlative. The name Aquia has seen much broader usage in Maryland and permeates the bulk of the Coastal Plain literature, and consequently is the preferred term.

Distribution and thickness

The Aquia Formation is present only in the southeastern part of Cecil County and is believed to underlie only a few square miles at most (pl. 1). A good exposure of the Aquia is located about half a mile (0.8 km) south-southwest of Ginns Corner, where several feet (meters) of sediment were seen on both sides of an unnamed creek along a road to some abandoned farm buildings. A washed sample indicated about 5 to 10 percent glauconite in a fine- to medium-grained, dusky-yellow (5 Y 6/4) quartz sand. Two other exposures were seen at the top of the Post Office cut in Fredericktown and on the road to Skipjack Cove Marina. At the Post Office cut, about 11 ft (~3.5 m) of Aquia was found at the top by digging through the vegetation covering what appeared to be an earlier cut. Near the top of the Skipjack Cove road, about 11 ft (~3.5 m) of the unit is poorly exposed between the top of the Hornerstown and the gravel cap. An auger hole 0.15 mile (240 m) north of the southeast corner of the county beside a public road on the Delaware side of the state line, at elevation 52 ft (15.8 m), showed about 5 ft (1.5 m) of cap underlain by 62 ft (18.9 m) of poorly sorted sand. Most of this sand showed only 5 percent or less glauconite, but the lowest few feet (meters) were green and the unit was first assumed to be the Hornerstown. However, washed samples from this bottom material showed only 10 to 15 percent glauconite similar to that seen in the outcrops of the basal Aquia. The entire thickness of sand is therefore considered to be Aquia, and the formation probably extends to a greater depth, somewhat more than 10 ft (~3 m) below sea level.

Lithology

The Aquia Formation is a somewhat glauconitic quartz sand. As already indicated by the 62-ft (18.9 m) section penetrated in an auger hole, the sand is poorly sorted and generally contains less than 5 percent glauconite, except for the basal few feet (meters) where there is 10 to 15 percent. This higher glauconite content at the base is believed to result from reworking of the underlying Hornerstown material (Minard, oral commun., 1972).

Age, correlation, and stratigraphic relations

Loeblich and Tappan (1957, p. 176, fig. 28) have stated that the Aquia Formation is of Late Paleocene age. The contact with the underlying Hornerstown is gradational over an interval of 1 or 2 ft (0.3 or 0.6 m), as shown in the Gregg Neck exposure.

Origin

As the Aquia is strongly glauconitic at the base and much less so above, it presumably resulted from deposition during a shallowing of the sea. Owens and Sohl (1969, p. 256-259) included this as one of their inner-shelf or near-shore deposits.

UPLAND GRAVEL

Throughout much of the Atlantic Coastal Plain are several levels of gravel, sand, and loam deposits. These have been described by some workers as marine terraces, but others have considered them to be fluvial deposits of the major rivers. Various names have been give to these different levels, but in Cecil County the ones that have been commonly applied are, from highest (oldest) to lowest (youngest): Bryn Mawr, Brandywine, Sunderland, Wicomico, and Talbot. The two highest levels were first called Lafayette and later Brandywine, whereas the lower three were originally grouped as the Columbia. Shattuck (1906, p. 65-74) considered these to be deposits on marine-cut terraces formed during higher stands of the sea. The terrace, which sloped off gradually seaward as do modern wave-cut benches, was assumed to have been bounded on the landward edge by a seaward-facing, wave-cut cliff. In the original report on the geology of Cecil County, Shattuck (1902a, p. 170-173; 1902b, p. 73-76) clearly interpreted a marine origin for these deposits. Other workers who studied these deposits (McGee, 1888a, p. 371-380; Darton, 1894, p. 3; Miller, *in* Bascom and Miller, 1920, p. 4, 12-13) also held similar views. Campbell (1931) marshalled several telling arguments against such a marine origin: (1) the main accumulations of the so-called Brandywine and Sunderland "terrace" deposits are present only near the major streams where they cross the Fall Line; (2) smaller deposits lie close to some of the lesser streams, but in the intervening areas no deposits are present; (3) if these deposits had been formed along a shoreline, some of the material would have been spread out laterally as a continuous sheet by waves and longshore currents, but no such deposits occur. Campbell (1931, p. 838-844) also found that the supposed Sunderland terrace in its type area cannot be differentiated from deposits assigned to the Brandywine. Cooke (1952, p. 38) thought that the Bryn Mawr gravel was deposited as a series of separate alluvial fans which formed where various rivers crossed the Fall Line, and that the Brandywine, at least in the Potomac River area, was deposited in much the same way (p. 40). Other Brandywine deposits were considered to have been formed in a similar manner.

The highest of these deposits have generally been attributed to the preglacial Pliocene Epoch, when the general elevation of the land must have been closer to sea level, and the lower deposits were attributed to the various stages of the Pleistocene. By this explanation, all but the highest deposits have resulted, at least in part, from high stands of the sea during the interglacial stages when less water was locked up in glaciers than today. Also, by this theory, each terrace would have formed as a more-or-less continuous shoreline feature.

Most workers now believe that all the Tertiary and Quaternary gravel deposits listed above, except for some of the Talbot, are of fluvial origin. This concept is supported by the complete absence of marine fossils, the concentration of the deposits near the present or past river courses, the absence of deltaic cross-bedding, the composition and texture of the sediments, and the absence of such shoreline features as cliffs, bars, beach ridges, and lagoons which are characteristic of present-day marine terraces. The supposed beach cliffs of Shattuck (1906) and other workers are believed to have been formed by normal subaerial processes. The Talbot Formation probably marks a higher stand of the sea during one of the interglacial stages, although the material in Cecil County is of fluviatile or estuarine origin rather than marine. Flint (1940, p. 758-770) summarized the many views that had been held concerning these deposits up to that time.

In this report, the higher gravels (Bryn Mawr, Brandywine, and Sunderland) are referred to collectively as the Upland Gravel, as was done by Cleaves and others (1968) and by Owens (1969, p. 91). The name Talbot is retained as a separate unit. Badly needed, especially in Maryland, is a thorough regional study of this whole "terrace" situation. Among the problems to be considered is the Upland Gravel, which is here treated as a single deposit but which may actually represent two generations of depositon. If, as indicated by Campbell (1931) and by Cooke (1952) and supported by this writer, the higher gravels are unconnected deposits along the lower courses of different streams, then it is questionable whether the names used for one river system should be applied to deposits of other rivers. The Sunderland of previous reports also needs a thorough review and perhaps should be recognized in some places as a separate unit as in the past, but with a new name. Serious consideration also needs to be given to the nomenclature of deposits formerly mapped as Wicomico Formation and here called the Pensauken.

Name

McGee (1888a, p. 130), in his description of the Potomac Formation, stated that: "Extensive outliers of gravel occur on both sides of the Susquehanna several miles from the body of the Formation, notably at Webster on the south and Woodlawn (or Battle Swamp) on the north of the river." Although he mistakenly assigned these gravels to the Potomac Group, it is clear that he was referring to the high-level upland gravels.

In the original report on the geology of Cecil County, Shattuck (1902a, p. 165-169) called these gravels the Lafayette Formation, and the County geologic map (Bascom and others, 1902) showed the distribution of these with considerable accuracy. Miller (1906, p. 5-6) also placed some of the gravels on Elk Neck in this unit. The Lafayette, named for a locality in Mississippi, has since been found to be an older unit, and the name has long since been abandoned in Maryland.

The term Brandywine Formation was applied by Clark (1915, p. 499-500) to the higher gravels that had been recognized at scattered localities from Pennsylvania to the Carolinas. At Brandywine in Prince George's County, the formation lies only about 200 ft (~60 m) above sea level, but the name has been applied to deposits which range between 400 and 500 ft (~120 and 150 m) above sea level farther up the Potomac River, as well as to similar high-level gravels near the Patapsco, Susquehanna, and other rivers.

Miller (*in* Bascom and Miller, 1920, p. 12) applied the name Brandywine in the Elkton-Wilmington area to the many scattered high-level hilltop gravel deposits formerly termed the Lafayette Formation. Two distinctly different levels were recognized, those on Elk Neck being somewhat lower than the ones north and west of the town of North East. The higher gravels were termed Early Brandywine and were provisionally assigned to the Pliocene; the lower gravels were designated Late Brandywine and were considered to be possibly of Early Pleistocene age. Later, Bascom (1924) proposed that the term Brandywine be restricted to the lower gravels of that sequence and the name Bryn Mawr, used earlier by Lewis (1880,

p. 269-271), be restored to the higher gravels. That usage was adopted by Overbeck and Slaughter (1958, p. 84-85) in their report on the water resources of Cecil, Kent, and Queen Anne's Counties. Darton (1939), in maps of the gravel deposits of eastern Maryland, referred to these higher deposits as "Gravel of High Plateau." In this report, they are named Upland Gravel and are considered to be of probable Miocene age.

During the course of this project in Cecil County, no detailed study was made of the the elevations and slopes of the basal contact of the high-level gravels, so the units have not been differentiated, if indeed it is possible to do so. However, many unchecked altimeter readings were taken on the base of the gravel and seem to indicate two things: (1) the floor on which the gravel was deposited was irregular in elevation with perhaps as much as 40 to 50 ft (~12 to 15 m) variance in short distances, especially in the area north of U.S. Rte. 40; and (2) the floor slopes at an average rate of about 25 to 35 ft per mile (~5 to 7 m/km) to the southeast, about the same as had been deduced by Shattuck (1902a, p. 169). This could well indicate a single episode of deposition as is discussed more fully in the section on origin.

Distribution and thickness

Most of the Upland Gravel deposits in Cecil County are concentrated in the western part within 6 or 8 miles (~10 or 13 km) of the present course of the Susquehanna River (pl. 1). A few much smaller deposits are as far as 12 miles (~20 km) distant from the river. In Harford County, the larger deposits are within 3 or 4 miles (~5 or 6 km) of the river, and scattered deposits occur at greater distances (Southwick and Owens, 1968). No high-level gravels are present in the eastern part of Cecil County, but in the area of Philadelphia, Pennsylvania, extensive patches of the "Bryn Mawr" gravel are reported along the Delaware River (Lewis, 1880, p. 269-271).

At most places the Upland Gravel overlies strata of the Potomac Group, but at the northernmost localities it lies on saprolite of the crystalline rocks. North of U.S. Rte. 40 as far as the vicinity of Woodlawn, Theodore, and Bay View, most of the high hills are capped with gravel ranging from only a few feet (meters) to some 75 ft (~25 m) in thickness. In this northern area the base of the gravel lies at about 400 ft (~120 m) elevation, but just north of U.S. Rte. 40, about 3 miles (~5 km) to the south, it occurs at about 300 ft (~90 m). On an unnamed hill about 0.25 mile (0.4 km) northwest of the Woodlawn lookout tower, marked on the map by the 480-ft contour, the gravel is probably about 50 ft (~15 m) thick, and similar thicknesses seem to prevail in much of the high area between there and Interstate 95. At the site of the large gravel operation of the Mason-Dixon Company in the Foys Hill area, just north of U.S. Rte. 40, the gravel has a maximum thickness of at least 70 to 75 ft (21 to 23 m). About 2 miles (~3 km) further north where this same company has its large Belvedere operation, an area of gravel traversed by Interstate 95 extends from near Belvedere to the vicinity of Theodore. The thickness of this gravel many be greater than 75 ft (23 m) (Fig. 66). On Elk Neck, some 8 miles (~13 km) southeast of the highest of the above-mentioned deposits, nearly every hill greater than 200 ft (~60 m) in elevation is capped by gravel. In the northern part of the peninsula, the base of the gravel is at about 250 ft (~75 m), but to the south on Bull and Mauldin Mountains, the base descends to around 200 ft (~60 m). The gravel in some of these areas is as much as 60 to 80 ft (~20 to 25 m) thick and in places is being intensively worked by the Mason-Dixon Company.

Lithology

The Upland Gravel consists primarily of gravel and varying amounts of sand with a little clay. The gravel is composed almost entirely of quartz and quartzite clasts, although scattered chert pebbles, many of which have been weathered to tripoli, may be found. Other rock types are scarce and probably constitute less than 1 percent of the gravel. Nearly all of the pebbles are less than 3 inches (7.5 cm) long, although a few cobbles as much as about 8 inches (~20 cm) long are present; larger ones are rare. Some sand and gravelly sand beds are

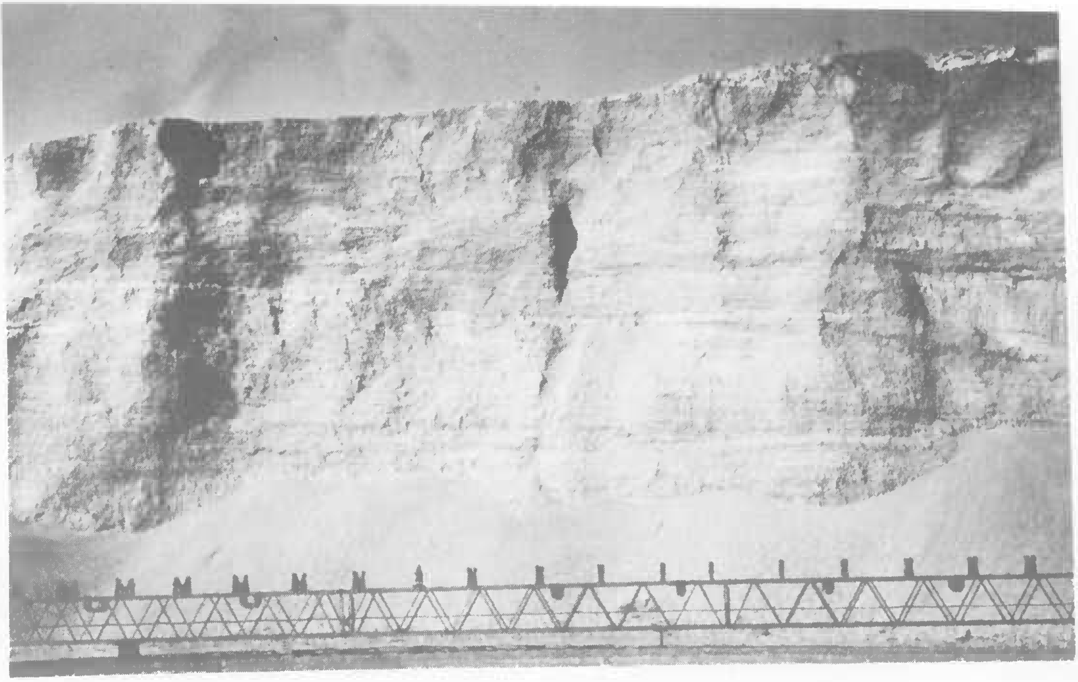

FIGURE 66: Upland Gravel exposed at Belvedere. Layering is essentially parallel with gentle easterly dip. North wall of gravel pit of the Mason-Dixon Company. Face is 40 to 50 ft (12 to 15 m) high.

interbedded with the gravel, and, locally, thin beds or lenses of white or light-gray silty clay occur. Locally, masses of this clay up to 2 or 3 ft (0.6 or 1.0 m) in diameter, may be present.

Where the Upland Gravel lies on the Potomac Group, which also consists of gravelly sand, sand, and clay, the two units ordinarily can be distinguished from each other by their relative amounts of gravel; the base of the Upland Gravel deposits is normally much more gravelly than are the deposits of the Potomac Group. Where gravel lies on clay of the Potomac Group or on saprolite and the contact is exposed, there is still the question of whether the gravel is of the Potomac or of the Upland Gravel. Normally the lack of lithologic diversity in the clasts of the Upland Gravel is the clue, but at some places the determination is uncertain. Generally, the beds are horizontally stratified, but at many places the material is crossbedded, notably in the sandier parts, with southerly dips common in the foresets. When fresh exposures were available for examination at the Rhodes Mountain gravel pits on Elk Neck, Owens (oral commun., 1972) noted especially well developed foreset beds.

Weathering of the gravels has resulted in concentration of iron oxide in the upper 10 to 15 ft (~3 to 4.5 m) of the gravel, which gives it a reddish-brown color in contrast to the lighter brown color of the underlying gravel. In some places this iron oxide has cemented the grains to produce a firm conglomerate that locally has been used as a foundation or fence stone. Such cemented gravel is present in the old pit reported by Miller (*in* Bascom and Miller, 1920, p. 12), 4.5 miles (7.2 km) north-northeast of the town of North East, and about 0.75 mile (1.2 km) west of Egg Hill. At several places on Elk Neck, such ironstone conglomerates seriously interfere with excavation in the gravel operations. Large slabs from the upper part of Bull Mountain are seattered over the steep western slope and on the nearby beach. It has long been realized (Lewis, 1880, p. 269-271; Miller, *in* Bascom and Miller, 1920, p. 12) that weathering for a long period of time has caused some of the more exposed pebbles in the Upland Gravel to disintegrate, so that a quartzite pebble may now shatter easily when hit with a hammer. This is especially true in the higher gravels to the north.

Some deposits mapped with this unit (shown with a stipple pattern on pl. 1) contain immature constituents such as igneous and metamorphic boulders. In some places, the cobbles and boulders, especially the immature ones, are appreciably weathered. A striking example of this occurs on the north side of the Mill Creek embayment just below its head at Perryville where a granite boulder 1.5 ft (~0.5 m) across has been completely saprolitized. Moreover, a gully exposure about 25 ft (7.6 m) above sea level at this location shows several saprolitized boulders of granite embedded in gravelly sand. Above this is a layer of gravel having abundant cobbles and boulders. The saprolitized boulders occur either at the base of the gravel unit or may be remnants of an earlier alluvial deposit. The shoreline in the area is strewn with many kinds of boulders that have obviously come from the gravel deposits in the eroding banks. Another good locality to see the contrast between these lower deposits of Upland Gravel and those of the Potomac Group is in a small, sporadically-worked gravel pit west of the road from Principio Furnace to the railroad tracks of the CONRAIL System where about 20 ft (~6 m) of gravel containing boulders of various igneous and metamorphic rocks as well as of red sandstone is exposed. Some of the boulders, which range up to 2 ft (0.6 m) in maximum dimension (fig. 67), are variably weathered. Good exposures of sand and gravelly sand of the Potomac Group are exposed in nearby gullies.

Upland Gravel overlies sediments of the Potomac Group in a pit just east of Mountain Hill Road between Maryland Rte. 7 and the railroad tracks of the CONRAIL System. This exposure shows the best example of the criteria used to distinguish these younger gravels from the gravelly sands of the Potomac. At the highest part of a 45- to 50-ft (~15 m) face, about 5 ft (1.5 m) of brownish gravel is present, and contains scattered cobbles ranging between 4 and 12 inches (~10 and 30 cm) in length. The basal contact of the Upland Gravel is sharp. Beneath it is gravelly sand of a much lighter color believed to be a unit of of the Potomac Group, in which most of the pebbles are less than 1 inch (2.5 cm) in size and are composed of white quartz and quartzite. Scattered pebbles and cobbles as much as 6 inches (15 cm) in maximum dimension are also present, including some subangular ones. The grounds for separating the upper unit from the lower one are the much greater proportion of gravel, the abundance of cobbles and boulders, the color differences, and the sharp basal contact. This gravel was probably deposited by the Principio Creek system at an earlier stage in its development. The lack of immature ingredients in the gravel may have resulted from reworking of the abundant nearby deposits of Upland Gravels and also from the absence of any nearby exposures of crystalline rocks when the stream was flowing at the higher level.

On the 1952 aerial photographs and on current topographic maps, a discontinuous ridge extends from this locality northeast across an area that has been completely mined out by the gravel quarrying operations. This ridge may have been capped by a few feet (few meters) of this same gravel deposit.

X-ray study of the clay fraction of these gravels by Lampiris (written commun., 1969) indicated that the clay minerals are kaolinite and illite. J.W. Hosterman (written commun., 1971) has confirmed this by later X-ray work, which also indicated the presence of gibbsite. Hosterman estimated that two samples from the upper 6 ft (1.8 m) exposed at the Julian gravel pit, east of Principio Road about 1.5 miles (2.4 km) northeast of the Interstate 95 toll gate, contained about 65 percent kaolinite, 5 to 10 percent illite, 20 to 25 percent gibbsite, and small amounts of mixed-layer clay and montmorillonite. Owens and Minard (oral commun., 1971) investigated the gibbsite content of the gravels in New Jersey and have found that the higher ones are richer in gibbsite, denoting more extensive alteration of the clay content.

Age, correlation, and stratigraphic relations

No fossils have been found in these gravels to indicate their age, but it commonly has been assumed that they are of Late Tertiary age. Several lines of evidence suggest that they are at least that old or older: the development of gibbsite; the degree of disintegration of the pebbles; and their height above the present nearby Susquehanna River, along the former course of which

FIGURE 67: Boulders of assorted lithologies in the Upland Gravel. Shovel handle is 21 inches (53 cm) long. Small pit west of the north-south road between Principio Furnace and the railroad tracks of the CONRAIL system.

they probably were deposited. The present writer believes that the Upland Gravel is probably Miocene or older in age.

Not enough is known about the various high-level gravels of the Atlantic and Gulf Coastal Plains to warrant reliable correlations. Hack (1955, p. 10) considered the supposedly correlative unit in the Brandywine area to be of Pliocene age, as have other workers, but in the absence of specific evidence he wrote: "...it may be in part Miocene in age and ... the field evidence justifies only the statement that it may be Miocene, Pliocene, or Pleistocene." The so-called Bryn Mawr Gravel at times has been correlated with the Citronelle Formation of the Gulf Coast, which has generally been considered to be of Pliocene age (Cooke and others, 1943), although some workers have considered it as Pleistocene. As already pointed out, the early concept of a continuous shoreline deposit of gravel, extending along the Atlantic Coastal Plain for hundreds of miles (hundreds of kilometers), has been rejected by most later workers. If the high-level gravels are the unconnected deposits of different river systems, such correlations over considerable distances, or even between adjacent river systems, may be questionable.

These gravels overlap the edge of the Coastal Plain deposits and lie partly upon the crystalline rocks of the Piedmont. Although the surface of contact is irregular, it is evident that no significant valley cutting in the crystalline rocks was taking place when deposition of the Upland Gravel began. The resistance of the thick gravel deposits to erosion protected many of the the underlying rock units while adjacent unprotected areas have been lowered. In other words, gravels that once accumulated in or near a former valley now stand high, indicating an inversion of the topography. The highest remnants of the Upland Gravel near Woodlawn are at about 480 ft (146 m), and the contact with crystalline rocks or saprolite is about 400 ft (~120 m). As the nearby river is now at sea level, it is apparent that it has had time to cut its valley into 400 ft (~120 m) of igneous and metamorphic rocks since the gravel was deposited. Even the much smaller Principio Creek has eroded nearly 200 ft (~60 m) of rock.

The contact at the base of the gravel is a major unconformity, as it rests on crystalline rocks of the Piedmont and on various lithic units of the Lower Cretaceous Potomac Group. At Mauldin Mountain the gravels lie on beds of the Monmouth Group, the youngest Upper Cretaceous unit in the area. The basal contact is irregular, indicating a rolling surface on which the sediments were deposited. The best example of this in Cecil County was seen during the construction of Maryland Rte. 275 northeast of the old Bainbridge Naval Training Center between Asbury Church and Highway Rte. 276 where the highway passes beneath a high-power transmission line. On the west side of the road, a 20-ft (~6 m) cut showed, within a horizontal distance of about 100 ft (~30 m), a low mound or hill of saprolite rising about 15 ft (~4.5 m) into the overlying gravel. The contact sloped to the south and disappeared beneath the gravel. On the east side of the highway, no saprolite was exposed in the bank of this roadcut. About 0.3 mile (0.5 km) to the south on this same road and about 50 ft (~15 m) lower in elevation is another exposure of the saprolite-gravel contact. About 30 ft (~9 m) of this difference in elevation can be attributed to regional slope, indicating a local topographic relief of 20 ft (~6 m). About 1.7 miles farther south on Maryland Rte. 275, just north of Mill Creek, a contact of gravel on saprolite was exposed on the east side of a deep cut during construction of the road. This locality was about 100 ft (~30 m) lower than the top of the saprolite hill exposed in the cut under the powerline 2 miles (3.2 km) to the north, indicating an average slope to the basement surface in this area of about 60 ft per mile (~11 m/km).

Origin

In his report on the geology of Prince George's County, Cooke (1952, p. 38) noted that: "Wherever the Bryn Mawr has been recognized it lies near the debouchure of a river from the Piedmont onto the Coastal Plain. The formation seems to have been deposited as a series of disconnected alluvial fans, one at each river, where the current slackened at the Fall Line." Where the ancestral Susquehanna passed from a steeper gradient on the crystalline rocks to a flatter one on the Coastal Plain, its velocity decreased, and gravel-sized material could no longer be transported. The river probably spread out widely as a braided stream over a large flood plain and left extensive gravel deposits, of which only scattered patches, both large and small, remain. Overbeck and Slaughter (1958, p. 84) gave a similar explanation for the origin of these gravels except for uncertainty as to whether the deposits accumulated on land or beneath the sea. Several small gravel deposits that occur more distant from the river, for example the one at Egg Hill, may have formed along the ancestors of smaller streams such as Northeast Creek or Little Elk Creek, or perhaps along streams whose courses have long since abandoned.

The high proportion of quartz and quartzite clasts and the almost complete absence of granitic, gneissic, and schistose rocks in the Upland Gravel suggests that during the Miocene Epoch the Piedmont, which probably supplied most of the material, was a deeply weathered region with little topographic relief. Only fragments of quartz and quartzite along with saprolite debris were available from that source, although some of the quartzite may have come from the folded Appalachians. As the Upland Gravel today is found lying upon on the landward edge of the Potomac Group as well as upon the the weathered crystalline rocks, only relatively small areas of the Potomac may have been subject to erosion and redeposition when the Upland Gravel was accumulating.

In this report, as already pointed out, the more northern patches of high-level gravel, the bases of which lie at elevations between 300 and 400 ft (~90 and 120 m) or more and whose tops reach 480 ft (~150 m), and the lower ones on Elk Neck whose bases are at about 200 ft (~60 m), are treated as parts of the same sequence. However, the apparent slope of these bases, about 25 to 35 ft to the mile (~5 to 7 m/km), seems to be excessive for a large, meandering stream that is building a broad flood plain. It may be that the land has been tilted seaward since the gravel accumulated. Detailed work on these deposits might reveal significant breaks in the slope of the basal contacts or of the upper surfaces to indicate that they are not parts of a once-continuous unit.

PENSAUKEN FORMATION

Shattuck (1901, p. 73-75) applied the name Wicomico Formation to the extensive surficial deposits along the lower reaches of the Potomac River in St. Mary's and Charles Counties, Maryland. The upper surface of the unit lies about 90 ft (~27 m) above sea level, and the base is between 40 and 50 ft (12 and 15 m). In Cecil County the term was applied to material underlying the extensive level surface that makes up the Eastern Shore part of the County (Shattuck, 1902a, p. 171-172), where elevations range mostly between 70 and 100 ft (~20 and 30 m). The base of the deposit was reported to be around 30 to 40 ft (~9 to 12 m) above sea level. The name Wicomico was also used in the Dover Folio (Miller, 1906, p. 6-7), which included some of southeastern Cecil County, as well as in the Elkton-Wilmington Folio (Bascom and Miller, 1920, p. 13-14), which included the remainder of eastern Cecil County. In both folios, a partial correlation was made with the Pensauken Formation, a similar gravel-sand-loam sequence in New Jersey named by Salisbury and others (1894, p. 57). In Delaware, these deposits are termed the Columbia Group. In this report they have been assigned to the Pensauken.

Salisbury and Knapp (1917, p. 67-159) described the Pensauken Formation and its origin in some detail and considered the unit to be deposits of the Pensauken River. This was an ancestral stage of the Delaware River, which may have also included the Hudson River and which flowed southwest along the inner edge of the Coastal Plain, as the Delaware now does, possibly as far south as the Chesapeake Bay area (Bowman and Lodding, 1969).

On the east side of Elk Neck, deposits of gravel that were formerly mapped as Sunderland Formation are here included in the Pensauken. These deposits occur at somewhat higher elevations than the Pensauken, generally between 80 and 160 ft (~25 and 50 m), but lie close to several areas of undisputed Pensauken. In some places, the difference in elevation between the two levels is as much as 10 to 20 ft (~3 to 6 m) and they are distinctly separate, but in other places they appear to grade into one another. In this report the Sunderland deposits of earlier reports have been combined with the Pensauken for the following reasons: (1) the doubtful validity of the term Sunderland, as pointed out by both Campbell (1931) and Hack (1955); (2) the proximity of the "Sunderland" deposits to the lower ones of the Pensauken in Cecil County; and (3) the difficulty in some places of distinguishing between the deposits. In many other places, material that was formerly shown as Sunderland (Bascom and others, 1902; Bascom and Miller, 1920) is here considered to be of the Potomac Group, although the lack of good exposures makes it difficult to determine exactly how the material should be classified.

Distribution and thickness

The upper surface of the Pensauken Formation forms the relatively flat surface of the Eastern Shore part of Cecil County, east of the Elk River and mostly south of U.S. Rte. 40 (pl. 1). This surface is at an altitude of about 100 ft (~30 m) along the south and east sides of Grays Hill, just north of U.S. Rte. 40, but decreases in elevation gradually to the south so that in the vicinity of Warwick the average height is about 70 ft (~20 m). This surface slopes eastward across the southern part of the county from a high of 99 ft (30.1 m) just south of Pearce Creek on Pond Neck to about 75 or 80 ft (~23 or 24 m) at Cecilton, to the 70-ft (21 m) level at Warwick, and continues its gradual downward slope into Delaware. Along the east side of Elk Neck, a series of terraces whose present high points are at about 80 ft (24 m) have also been assigned to this unit. Near the mouth of the Susquehanna River, comparable deposits have also been mapped a Pensauken Formation.

The base of the Pensauken Formation is irregular, but in most places where the base can be seen, such as in roadcuts, valley slopes, and scattered small gravel pits, it is 40 to 60 ft (~12 to 18 m) above sea level. In areas where there is no exposure of the actual contact, its elevation has been estimated to lie at about 50 ft (~15 m). In places along the shores of the Elk and Sassafras Rivers, the base of the gravel ranges markedly from 40 to 50 ft (12 to 15 m) above sea level down to or near sea level within a horizontal distance of only a few hundred yards (few hundred meters). At Turkey Point, at the south end of Elk Neck, a magnificent exposure in a 90-ft (27.4 m) sea cliff shows Pensauken sediments within about 5 ft (1.5 m) of sea level. These sediments rest with irregular contact on clay and sand of the Potomac Group. Quite likely, this is a common deposit of the ancestral Susquehanna and Delaware Rivers at their junction.

At two places in the county, the presence of channels cut into the older units and filled with Pensauken sediments is suggested by drill-hole information. One of these channels is just north of the Chesapeake and Delaware Canal and east of U.S. Rte. 213. Pickett and Spoljaric (*in* Sundstrom and others, 1967, p. 50), examined cuttings from the deep water well of the B.F. Goodrich Company and found 112 ft (34.1 m) of Pensauken Formation to a depth of 47 ft (14.3 m) below sea level (fig. 52). However, in the observed exposures along and south of the canal it is difficult to see where such a deep channel would cross the canal and continue to the South. A channel extending to about sea level could probably be accommodated, and the author's mapping on the north side of the canal assumes such a depth. A 31-ft (9.4 m) power-auger hole located 0.3 mile (0.5 km) northeast of the Goodrich well on Knights Corner Road encountered chiefly nonlignitic sand, suspected to be channel-fill material, to about 22 ft (6.7 m) above sea level, but did not penetrate any Magothy sediments as anticipated, nor any of the characteristic clays of the Potomac Group such as is exposed nearby on a hillslope to the northwest and about 23 ft (7.0 m) below the hole location. Another hole on this same road, about half a mile to the southeast, was drilled to a depth of 50 ft (15.2 m). It penetrated apparent Pensauken material to sea level, then went into 1 ft (0.3 m) of probable Potomac. Two other drill holes and several outcrops along the upper mile (1.6 km) of the valley of Long Branch all show sediments believed to be of the Pensauken Formation rather than of the Potomac or Magothy. The channel may have a southwesterly trend here, but no outcrops or additional drill holes exist which would indicate its location more precisely. South of the canal, contacts have been drawn as though there was no channel in the area.

The second place where a buried channel may be present is near the southeastern corner of Cecil County (fig. 68). The base of the Pensauken Formation was encountered in four auger holes, D-10, D-11, D-12, and D-16, at elevations between 25 and 54 ft (7.6 and 16.6 m) above sea level. However, two additional auger holes, D-19 and D-20, centrally located with respect to the other four, penetrated Pensauken sediments at elevations of 10 to 12 ft (3.0 to 3.6 m) above sea level. If, indeed, there actually are buried channels at these two localities in Cecil County, they presumably connect in some way with buried channels in nearby Delaware (Spoljaric, 1967), although evidence for such a connection has not yet been found.

Much smaller areas of Pensauken Formation are shown between Perryville and Carpenter Point on the present geologic map (pl. 1) than were shown as occupied by the Wicomico Formation, as it was formerly called, on the geologic map of Bascom and others (1902). The writer found no deposits that he could assign to the Pensauken except at the top of the sea cliff. Behind the cliff the land is considerably higher, with no evidence of Pensauken. The topography resembles that underlain by the Potomac Group much more than any other area in the county. Consequently, the Pensauken is here shown as occurring in a narrow strip, in the belief that it is only a small remnant of a formerly more extensive terrace deposit.

Lithology

The lower part of the Pensauken Formation is typically a gravel or gravelly sand and is overlain by sand and loam. However, the composition varies considerably from place to place and the gravel layers range greatly in thickness. Exposures along the north shore of the Sassafras River and the east shore of the Elk River, as well as a few gravel pits at scattered locations inland, show about 10 ft (~3 m) of gravel or gravelly sand overlain by finer material. In most of the eastern part of the county, very little gravel was found in pits, roadcuts, or drill holes; therefore, the gravelly lower part of the unit appears to be much thinner in most of that area except for the two possible channels already mentioned. Pensauken gravel, unlike that of the Upland Gravel, contains in addition to the dominant quartz and quartzite clasts a liberal scattering of assorted igneous, sedimentary, and metamorphic rock types including granite,

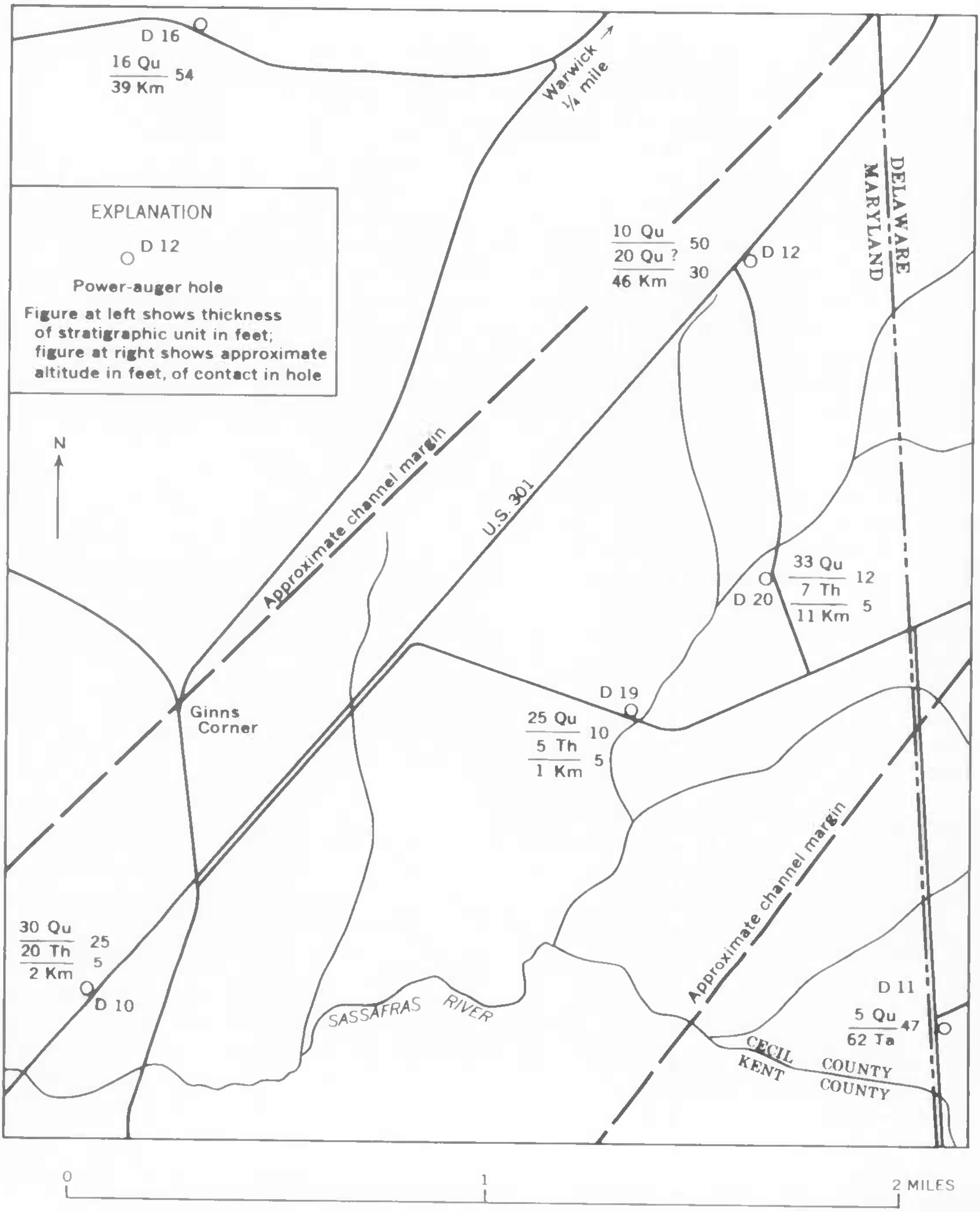

FIGURE 68: Location of possible channel filled with Pensauken sediments, southeastern corner of Cecil County.

gabbro, conglomeratic quartzite, schist, gneiss, and sandstone. The gravel has a much greater size range than that of the Upland Gravel, but most of the clasts are less than 3 inches (7.5 cm) in greatest dimension. Larger cobbles and boulders are not uncommon, including boulders having maximum dimensions as great as 6 ft (1.8 m). These large boulders are most often seen on the beaches below sea cliffs in which the gravel is exposed (fig. 69), but one or more large ones can also seen on the floors of most gravel pits (fig. 70). Piles of weathered cobbles and boulders are common at the lower edges of cultivated fields along valley sides. At Grove Point, McGee (1888b, p. 585) reported seeing an angular boulder of gabbro 3 by 6 by 9 ft (0.9 x 1.8 x 2.7 m) and a quartzite boulder 4 by 6 by 7 ft (1.2 x 1.8 x 2.1 m). On the modern beach, these boulders are now missing, which indicates that erosion of the bank over the past 80 years has proceeded so far that the boulders may now be some distance offshore and well below present water level. The basal gravelly portion of these deposits is commonly overlain by sand, which is pebbly in places, and then by several feet (several meters) of loam. The whole sequence seems to be that of a typical river flood plain.

No detailed study of the composition of the Pensauken Formation was undertaken during this project, but it is well known that the sands are feldspathic and clayey and contain various other minerals. In Delaware, Jordan (1964, p. 22-24) examined both the coarse constituents and the sand of the Columbia Group. He found that the gravel fraction contained about 14 percent chert, 2 percent crystalline rocks, and 2 percent shales, and the medium to very fine sand fraction averaged 80.4 percent quartz and 18.4 percent feldspar. The heavy-mineral suite showed a wide assortment, notably zircon, epidote, amphibole, sillimanite, and opaque minerals. In Cecil County, Owens (oral commun., 1967) called attention to a significant amount of feldspar in the sands and of chert in the gravels. At Turkey Point he found as much as 40 percent feldspar in some of the beds. Much of the plagioclase feldspar in the Pensauken is weathered, but the potassic feldspar tends to be fresh (Owens, written commun., 1972). Most of the chert has been weathered to tripoli.

The gravels of the Pensauken Formation on the east side of Elk Neck that were previously considered to belong to the Sunderland terrace deposits appear to be composed of nearly pure quartz and quartzite debris, although there is limited exposure of the material. These deposits were most likely derived from nearby occurrences of Upland Gravel. At the north end of this line of Pensauken deposits, an abandoned gravel pit used as a landfill by the town of Elkton contained highly feldspathic material (Owens, oral commun., 1971). This suggests, as does the mica content, that the material at this place was derived from a Piedmont source rather than from the nearby Tertiary Upland Gravel deposits.

Age, correlation, and stratigraphic relations

The age of the Pensauken Formation is not precisely known. In northern New Jersey, the correlative unit is overlain by both Wisconsin and pre-Wisconsin terminal moraines (Berry and Hawkins, 1935, p. 246; Bowman and Lodding, 1969), which indicates an age at least older than Illinoian. Owens and Minard (1979, p. D29) proposed a late Miocene age for the Pensauken, based on the pollen assemblage present in the distal portion of the unit in the southern Delmarva Peninsula.

Origin

In all of the early reports (Shattuck, 1901; 1902a; Miller, 1906; Bascom and Miller, 1920), the Wicomico was considered to be a marine terrace that formed at or just below the shoreline. Most recent workers as well as several earlier ones consider the deposits to be remnants of ancient alluvial fans or flood plains (see summary by Flint, 1940, p. 767-770). A portion of the Pensauken Formation of Cecil County probably formed along the course of the ancient Pensauken River, which flowed near the inner edge of the New Jersey Coastal Plain and presumably continued across northern Delaware and Cecil County, Maryland, into the Chesapeake Bay area. The typical succession of materials — gravel overlain by sand and loam — is characteristic of a stream that shifts back and forth over a broad flood plain.

The presence of scattered boulders of many lithologic types, including igneous and metamorphic rocks and possibly Tuscarora Quartzite from the Appalachian Mountains, has often been interpreted to imply that these were ice-rafted during the severe climate of the glacial period (McGee, 1888b, p. 604-605). However, a lowered sea level during a glacial stage would not cause deposition at the location of the sediments in question. It is well known that

FIGURE 69: Quartzite boulder, fallen from gravel of Pensauken Formation and lying on beach at Grove Point. Dimensions are 5 x 3 x 2 ft (1.5 x 1 x 0.6 m). The Pensauken Formation is exposed in the bluff at Grove Point where it unconformably overlies the Merchantville Formation. Also on beach are boulders of limonite-encrusted conglomerate from the base of the Pensauken. Same location as figure 56.

during severe floods, streams can transport boulders of considerable size, and it may be that the boulders in the Pensauken Formation reached their destinations in this manner. Although many exceptions could be cited, McGee (1888b, p. 600-601) noted that the coarse constituents of the unit decrease in abundance and angularity away from the mouth of the Susquehanna, and the same could probably be said for deposits extending from the old Pensauken River.

It has already been noted that Pensauken deposits on the east side of Elk Neck are strikingly similar in composition to the nearby but higher Upland Gravel deposits. Owens has suggested (oral commun., 1971) that these sediments were washed down from the nearby Upland Gravel and have merged into the lower deposits. The presence of nearby small streams that flow from the area of the higher gravels supports this. Nearer to the Susquehanna River, however, some deposits of Upland Gravel do contain a liberal scattering of immature constituents, such as the weathered boulders in the gravel pit west of the road from Principio Furnace to the railroad tracks of the CONRAIL System (fig. 67). This mass of alluvial material is believed to be a fan deposit at a former level of the mouth of the Susquehanna.

QUATERNARY STRATA

TALBOT FORMATION

The Talbot Formation was named by Shattuck (1901, p. 73-75) for terrace deposits in Talbot County, Maryland. The term has been applied throughout much of the Maryland Coastal Plain to a terrace, the upper surface of which lies about 40 ft (12 m) above sea level.

FIGURE 70: Quartzite boulder in gravel of the Pensauken Formation. Dimensions are 4.5 x 1.5 x 1.0 ft (1.3 x 0.5 x 0.3 m). Small pit beside road leading to Ches-Haven on the south shore of Grove Neck.

Distribution and thickness

As here mapped, the Talbot is everywhere adjacent or close to the present shoreline (pl. 1). Exceptions to this are in the valleys of Big and Little Elk Creeks where alluvial deposits as much as 4.75 miles (7.6 km) inland have been assigned to the Talbot, and along Back Creek south of Chesapeake City. At one time the unit may have been widespread along the shore, but at most places it has been destroyed by subsequent wave erosion. Small patches of the formation were identified by Owens (oral commun., 1971) at the base of Bull Mountain near Camp Rodney on Elk Neck, and at Lostens Marina at Hacks Point on the Bohemia River, although these are too small to be shown on the map. Much of the town of Elkton lies on a terrace of the Elk River that is here considered to be the Talbot. Much of the area around North East has also been mapped as the Talbot, although it is somewhat lower in elevation. It may in part be a recent delta and flood plain of Northeast Creek or it may be a Talbot terrace that has been partly eroded. The area of the nearby Veterans Hospital south of the CONRAIL System railroad and part of the town of Perryville is interpreted as being on a Talbot terrace. Many low terraces along the estuaries of Elk and Bohemia Rivers and along Back Creek are also shown as Talbot Formation.

Lithology

Some of the best exposures of apparent Talbot material were found in the town of Elkton during excavations for a 13-ft (~4 m) deep water-line trench and for an addition to the hospital. These lie on a probable delta and flood plain complex of Elk Creek at one of the heads of Chesapeake Bay. These two exposures show the upper part of the unit to range in thickness

FIGURE 71: Boulders of assorted lithologies from the Talbot Formation at Stump Point near the mouth of the Susquehanna River. Boulders in this area have dimensions as much as 8 ft (2.4 m). Shovel at right is 28 inches (70 cm) long. On grounds of the U.S. Veterans Hospital.

from about 7 to 15 ft (2.1 to 4.5 m) and to consist of loam, clay, silt, and sand. The sand is complexly cross-bedded, apparently a mixture of festoon and planar types. In places it is highly micaceous, with individual flakes as much as 0.5 inch (~12 mm) across. At both exposures, gravel underlies the upper part. Most of the pebbles are less than 1 inch (2.5 cm) maximum diameter, although a few are as large as 3 inches (7.5 cm). Mica in the sand and a mica-bearing boulder indicate a Piedmont source for much of the material, as would be expected, although some has been reworked from the Potomac Group.

In the vicinity of Stump Point, just east of the the U.S. Veterans Hospital at Perryville, the beach is strewn with large boulders (fig. 71). Many of these are angular with maximum dimensions as great as 8 ft (2.4 m); others can be seen embedded in the bank, which is obviously the source of those on the beach. Granite and gabbro predominate, but quartz, quartzite, and some others, including conglomerate, are also present. These boulders, as well as the deposit in which they occur, were presumably brought to their present location by floodwaters of the Susquehanna River. On the north side of Mill Creek, near the head of the tidal marsh just east of Perryville, the flat upper surface of the deposit has several different kinds of granitic boulders, some of which (fig. 72) have maximum dimensions as great as 7 or 8 ft (~2 or 2.4 m). These boulders also were probably carried and deposited during unusually large floods.

The exposures of the Talbot Formation at Lostens Marina and Bull Mountain consist essentially of laminated or stratified silt and sand with various amounts of clay, lignite, and heavy minerals. Glauconite grains in the deposit have doubtless been reworked from units in

FIGURE 72: Boulders on terrace of Talbot Formation east of Perryville. Maximum dimensions range up to 7 or 8 ft (2 or 2.5 m). North side of Mill Creek, near its mouth.

the nearby Monmouth Group or from other marine beds in the Upper Cretaceous. Other deposits of the Talbot doubtless differ in composition according to their sources.

Age, correlation, and stratigraphic relations

The Talbot terrace material appears to have accumulated along the shores of the Chesapeake Bay estuaries when sea level ranged up to 40 ft (12.1 m) higher than at present. It is generally assumed to have been deposited during an interglacial period when a warmer climate caused more polar ice to melt and sea level to be higher. For some distance to the south in Maryland, terraces at similar elevations have been referred to as the Talbot (Cooke and others, 1943).

The Talbot Formation unconformably overlies formations ranging from the Potomac Group to the Monmouth. To the north the unit rests upon crystalline rocks of the Piedmont.

Origin

At Perryville, North East, and Elkton the Talbot Formation is quite certainly of fluvial origin and is in the form of deltaic or flood plain deposits that have been subsequently modified by river erosion. At all of these places, much of the unit is considerably lower than 40 ft (12.1 m) in elevation, and may be a combination of sediments of Talbot age with Holocene alluvium. At other places, as at Lostens Marina and at the base of Bull Mountain where the sediments consist of laminated silts and sands, the Talbot Formation probably accumulated in estuaries somewhat like those of today.

ALLUVIUM AND TIDAL-MARSH DEPOSITS

Locally, deposits of alluvium are present on flood plains and in tidal marshes in both the Eastern Shore and Western Shore regions of the Coastal Plain in Cecil County. These are shown separately on the geologic map (pl. 1). The chief flood plain deposits occur along Big

Elk and Little Elk Creeks, at and upstream from the town of Elkton. Deltaic deposits subject to periodic tidal flooding are shown as tidal marshes and lie at the mouths of these and many of the smaller streams. Many of the smaller marshes are not extensions of significant flood plains but have formed where the lower ends of small valleys have been drowned and the streams lead directly into estuaries or into Chesapeake Bay. In a few places, swamps not subject to tidal flooding are present at or near the mouths of streams and have been mapped as alluvium. The largest of these is on the property of Boy Scout Camp Rodney, on the west side of Elk Neck just south of Red Point.

PHYSIOGRAPHY

The Coastal Plain portion of Cecil County consists of two strikingly different topographic types. That part east of the Elk River and south of Elkton, commonly known as the Eastern Shore, is essentially a low, nearly flat area with elevations ranging from about 60 to 100 ft (18 to 30 m); the remainder, which has been termed the Western Shore, is essentially a region of rolling and in some cases rugged topography, in many places reaching elevations of 400 to 480 ft (120 to 150 m). Elk Neck, though sometimes included in the Eastern Shore because it lies east of Chesapeake Bay, has the typical rugged terrain of the Western Shore, so that Shattuck (1902b, p. 64 and pl. 4) considered it to be associated with that physiographic unit, as does this author.

LANDFORMS

TERRACES

That part of the Coastal Plain in Cecil County that lies west and north of Chesapeake Bay is too rugged to allow extensive cultivation except near the mouths of the larger streams. Much of this region is underlain by easily erodible sand and gravelly sand of the Potomac Group, but many high areas are capped by younger gravel deposits, the remnants of an extensive high-level terrace that once covered much or all of the intervening area. Most of these terrace remnants lie north of U.S. Rte. 40 and the town of North East and range in elevation from 300 to 480 ft (~90 to 150 m). On Elk Neck, similar gravel-capped terrace remnants occur at elevations ranging from 250 to 300 ft (~75 to 90 m) and may have been part of the same high-level terrace present west of the bay.

The Eastern Shore owes its prevailing flatness to a widespread apron of ancient river deposits of the Pensauken River that covers most of the Delmarva Peninsula. This area, formerly referred to as the Wicomico Terrace or Wicomico Plain, is here termed the Upland Plain. Streams have cut many steep-sided and narrow valleys into this otherwise fairly smooth upland. Most of these small streams are fed by springs at the base of the terrace deposits which form the Upland Plain, but otherwise have no appreciable flow of water except after rains. On the Western Shore, some gravels and associated overlying materials that occur at elevations between 80 and 100 ft (24 and 30 m), formerly considered to be the Sunderland Terrace, are here included in the Upland Plain of the Pensauken.

Nearly all of the undissected part of the Upland Plain on the Eastern Shore has been cultivated or settled. The valleys remain mostly wooded except for some on their north sides and for a few small flood plains and low terraces.

Between the Upland Plain and the shoreline of Cecil County are local remnants of terrace deposits that range in elevation up to 40 ft (12 m) above sea level. These are commonly referred to as the Talbot Terrace and probably formed when sea level stood at approximately that elevation. Some lower terrace-like flats or gentle slopes have been given various names, but in this report they are included in the Talbot. The largest of these lower terrace remnants underlies the towns of Elkton and North East as well as the U.S. Veterans Hospital at Perryville. Remnants of Talbot sediments are also present at many places on the valley sides and estuary heads.

DEPRESSIONS

Throughout much of the Coastal Plain part of the county are undrained depressions. Most of these are too shallow to be depicted on the topographic maps, but they do appear on aerial photographs, in particular on the 1952 photographs which were taken when the leaves were off the trees.

In the western part of the county, most depressions lying within a few miles (few kilometers) of the old Principio Furnace are apparently places where charcoal was made for use in the iron furnaces. Such depressions are in the wooded area north and east of the intersection of Jackson Park Road and the Baltimore and Ohio Railroad, north of Principio Furnace. These pits are typically about 1 or 2 ft (0.3 or 0.6 m) deep, 100 ft (30 m) or less across, and commonly are surrounded by a low rim. For the production of charcoal, a wide, shallow pit is first scooped out of the ground. Wood is then stacked in the excavation, covered with the soil, and set afire. Burning of wood without sufficient oxygen for complete combustion results in the consumption of all the volatile components in the wood, leaving a carbon residue as charcoal. After burning, the cover of soil is thrown aside to recover the charcoal, which results in the raised rim to the pit. Excellent photographs of a charcoal pit in operation were published in Curran (1902, pl. 30).

Several more of these pits can be seen on Carpenter Point Neck east of Mountain Hill Road and south of the railroad tracks of the CONRAIL system. Some depressions that lie between Cayots and Courthouse Point in the Eastern Shore part of the county are also believed to have been old charcoal pits because of the topographic position of the depressions, the small diameters, usually on the order of 50 to 100 ft (~15 to 30 km), and their proximity to open water as a means of transportation.

Another type of depression in the surface of the Coastal Plain sediments appears to be the result of excavations for clay in the Potomac Group, either as prospects or for production. More than a dozen of these pits occur between a half-mile (0.8 km) and one mile (1.6 km) northwest of the CONRAIL System railroad crossing at the western edge of Charlestown.

A third type of depression, the origin of which is uncertain, occurs in many places throughout the eastern part of the county, chiefly on areas underlain by the Pensauken Formation (fig. 73). Abundant depressions lie south of Elkton in a wooded area of the Upland Plain bounded by U.S. Rte. 40, U.S. Rte. 213, Maloney Road, and Frenchtown Road. One of these, about 0.25 mile (0.4 km) west of Maloney road, is about 500 ft (~150 m) in diameter with a small swampy area in the center and is unusual in that is almost completely surrounded by a low rim. Several small rimless depressions also occur here. Other such depressions lie along the Delaware state line south of Maryland Rte. 281 for a distance of about 4 miles (~6.5 km). Depressions also occur on the Upland Plain in the area of Back Creek Neck west of U.S. Rte. 213. South of the Chesapeake and Delaware Canal, more depressions lie on the surface of the Upland Plain west of U.S. Rte. 213. After a rain, many of these shallow sinks retain water and are conspicuous in the open fields. Hundreds of similar depressions also occur in nearby parts of Delaware, many of which are of much larger size than those in Cecil County. About 2 miles (~3 km) northwest of the main highway crossing of U.S. Rtes. 40 and 213 in Elkton, a small area of depressions lies on sediments of the Potomac Group instead of the younger Pensauken.

In the western part of the county near Perryville, two small but well-developed depressions lie just west of a field road, some 500 yards (~450 m) east-northeast of the head of Mill Creek Bay. These are on a level surface typical of that developed on the Pensauken Formation. The origin of these depressions is unknown to the local people who suppose that they are meteorite craters, indicating that there is no knowledge of them as having been charcoal pits or clay pits. The true origin of these depressions is probably similar to that of the depressions in the eastern part of the county.

Wide, shallow depressions similar to those in Cecil County are abundant in many places on the Atlantic and Gulf Coastal Plains from New Jersey south to Mississippi and have been referred to as "Carolina Bays." Many explanations have been offered for such depressions, but none seems to be applicable to all of them. Among the many suggested explanations are meteorite scars, wind blowouts, washouts by artesian springs, gradual removal of underlying material by suspension and by solution, lodged icebergs or ice blocks during the glacial periods,

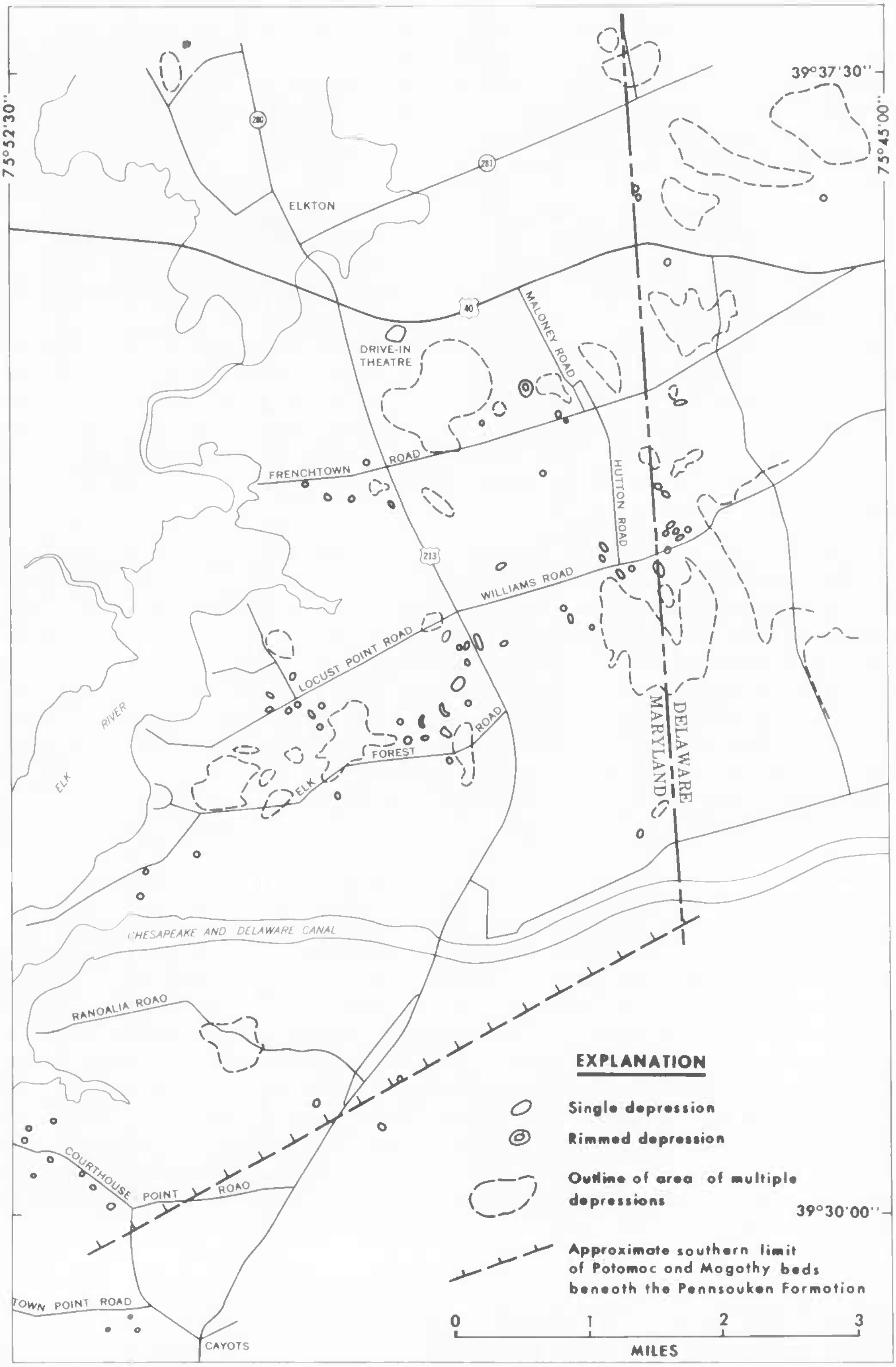

FIGURE 73: Distribution of shallow depressions of uncertain origin in Cecil County. These depressions lie chiefly on the surface of the Pensauken Formation.

frost action, scouring by eddy currents and turbulence due to fish schools (see review by Price, 1968). In Maryland, Rasmussen and Slaughter (1955, p. 26-28) called attention to some 1,500 such depressions, which they termed "Maryland Basins," in Somerset, Wicomico, and Worcester Counties. Unlike most of those in Cecil County, many of these were bordered by distinct rims. Those authors suggested that these depressions might mark places where blocks of floating ice or even icebergs had lodged during a high stand of the sea in the Pleistocene. A serious objection to this theory is that when icebergs would have been available during the colder climate of a glacial stage, sea level generally was lower and the area of the Coastal Plain would not have been submerged. Later, Ramussen (1958, 1959a, 1959b, 1965), on the basis of a study of these "bays" in Delaware, dismissed his earlier theory and explained them by an infiltration process. Wolfe (1953) described similar depressions in New Jersey and attributed them to seasonal frost and thaw action during one of the glacial stages.

In Cecil County most of the depressions are clustered in shallow valleys, although many lie on gentle slopes (fig. 74) and a few are in isolated low places on an otherwise smooth upland. In many areas, most of which are somewhat depressed and are forest covered, the ground is riddled with them. In some places, a succession of the depressions, some distinctly elongated, constitutes a drainage line. The suggestion is strong that they have been formed in some way by water seeping into the ground, as suggested by Rasmussen (1958, 1959a, 1959b) and still earlier by Smith (1931) in South Carolina.

According to the infiltration theory as proposed by Rasmussen (1958, p. 175-176), water collects in low spots on the original land surface. As it soaks through the underlying material the water removes enough clay and other fine particles as well as any soluble materials to lower the ground surface. The resulting depression holds water much of the time, and a swampy condition develops. It has also been speculated (Rasmussen, 1958, p. 178-181) that electrical currents in the ground resulting from different water levels might aid in some way in the removal of the particles. In summation, Rasmussen (1958, p. 178) stated that "These sinkholes are in part solution sinkholes, in part collapse sinkholes, and in part 'suspension' sinkholes." Such an infiltration explanation seems to this writer to be more applicable to the Cecil County depressions than any other theory that has been offered.

The field conditions in Cecil County suggest two possible adaptations of the infiltration theory of Rasmussen (1958). First, the areas of abundant depressions seem to have an apparent crude alignment of about N60°E, roughly parallel to the strike of the underlying beds (fig. 73). This suggests that the depressions have formed at places where the Pensauken Formation overlies permeable beds of the Potomac Group or of the Magothy Formation which permit rapid percolation of water. Second, as most of the depressions lie in shallow valleys, they may have formed in greater abundance where the relatively less-permeable semi-indurated Pensauken deposits have been partly removed by erosion, and water could seep easily into the more permeable unconsolidated material below. On the other hand, abundant development of the depressions may have caused the lowering of the ground surface to form a valley where conditions for seepage were most favorable. Where depressions have not formed, it may be that the Pensauken overlies impermeable clayey beds of the underlying formations. A similar explanation could be applied to the two depressions east of Perryville where the flat surface of the Upland Gravel has an unusually coarse gravelly base that could readily carry off any water that seeps down to it. A weakness in this theory is the virtual absence of such depressions where the Upland Gravel overlies permeable sands of the Monmouth Group.

Arguments against the infiltration theory were presented by Minard (oral commun., 1971) who found, in samples obtained from a series of power-auger holes across a similar feature in New Jersey, no apparent difference in grain size between material beneath the depression and that on either side of it. The present writer wonders, however, if such subtle differences in composition as would be expected could be detected in samples obtained in this manner.

Unlike the depressions in many other areas, the shape of individual depressions in Cecil County seem to show no preferred orientation of elongation. Many are essentially circular, and most of those that are elongated tend to be so in a downslope direction. Depressions that

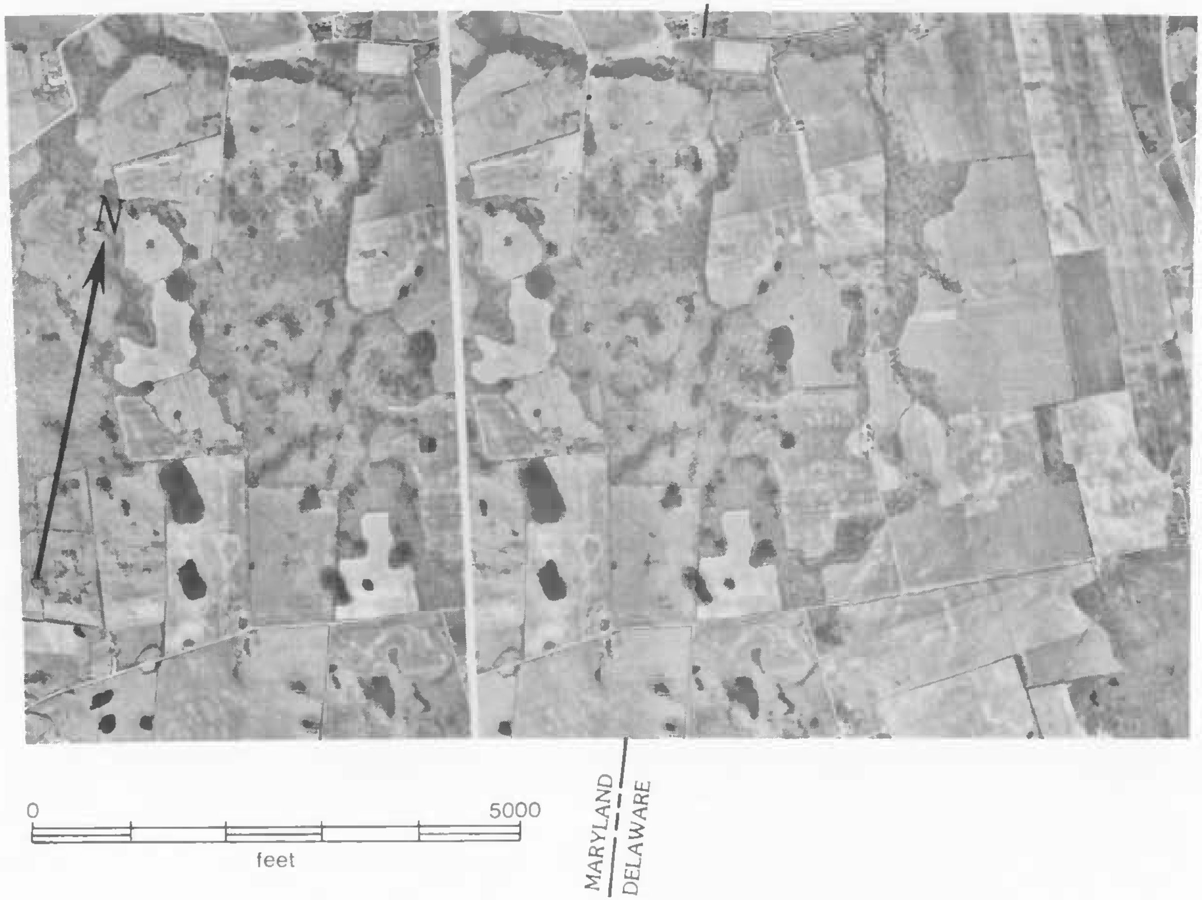

FIGURE 74: Stereo pair of aerial photographs showing depressions on the surface of the Pensauken Formation along the Maryland-Delaware state line. Locust Point Road crosses near the northern border of the picture and Woods Road crosses at the extreme southern border. U.S. Geological Survey aerial photographs GS-UI 1-04 and 1-05, April 10, 1952.

(In the absence of a suitable stereoscope, the viewer can achieve stereoscopic vision by holding a card vertically between the pictures and alternately close and open each eye until the images merge.

lie along the shallow drainage lines are commonly elongated in the direction of drainage. However, as stated before, in areas of abundant depressions, groups of them seem to be roughly aligned with the strike of the underlying beds.

ESTUARIES AND STREAMS

The Elk and Northeast Rivers, two prominent estuaries at the head of Chesapeake Bay, cut deeply into Cecil County. The Chesapeake Bay proper, a drowned continuation of the Susquehanna River, is a third estuary which forms the western boundary of the southern half of the county. The estuaries of the Bohemia River cut deeply into the south-central part of the county and a long estuary of the Sassafras River forms much of the southern boundary. The smaller estuary of Back Creek has been widened, deepened, and straightened to become part of the sea-level Chesapeake and Delaware Canal which crosses the eastern part of the county. Many of the smaller creeks and tributary streams also have estuaries, albeit they are considerably smaller and shorter than those mentioned above. These many estuaries result from the widening and deepening of the streams during the Pleistocene glacial epoch when sea level was lower. The subsequent melting of the glacial ice caused a rise in sea level that drowned the lower parts of these stream valleys. These estuaries are gradually being reduced in size and depth as the streams that feed into them deposit sediment, chiefly at their heads. This process is accelerating as man exposes the soil to erosion through cultivation and construction.

Some of the stream valleys on the Eastern Shore of Cecil County that flow westward into the Chesapeake Bay have steeper slopes on the south side than on the north. This suggests that even though the streams do not exactly follow the strike of the underlying strata, they have gradually migrated down the prevailing southerly dip of the more resistant underlying beds as their valleys were cut. This seems to be especially true for Great Bohemia and Little Bohemia Creeks.

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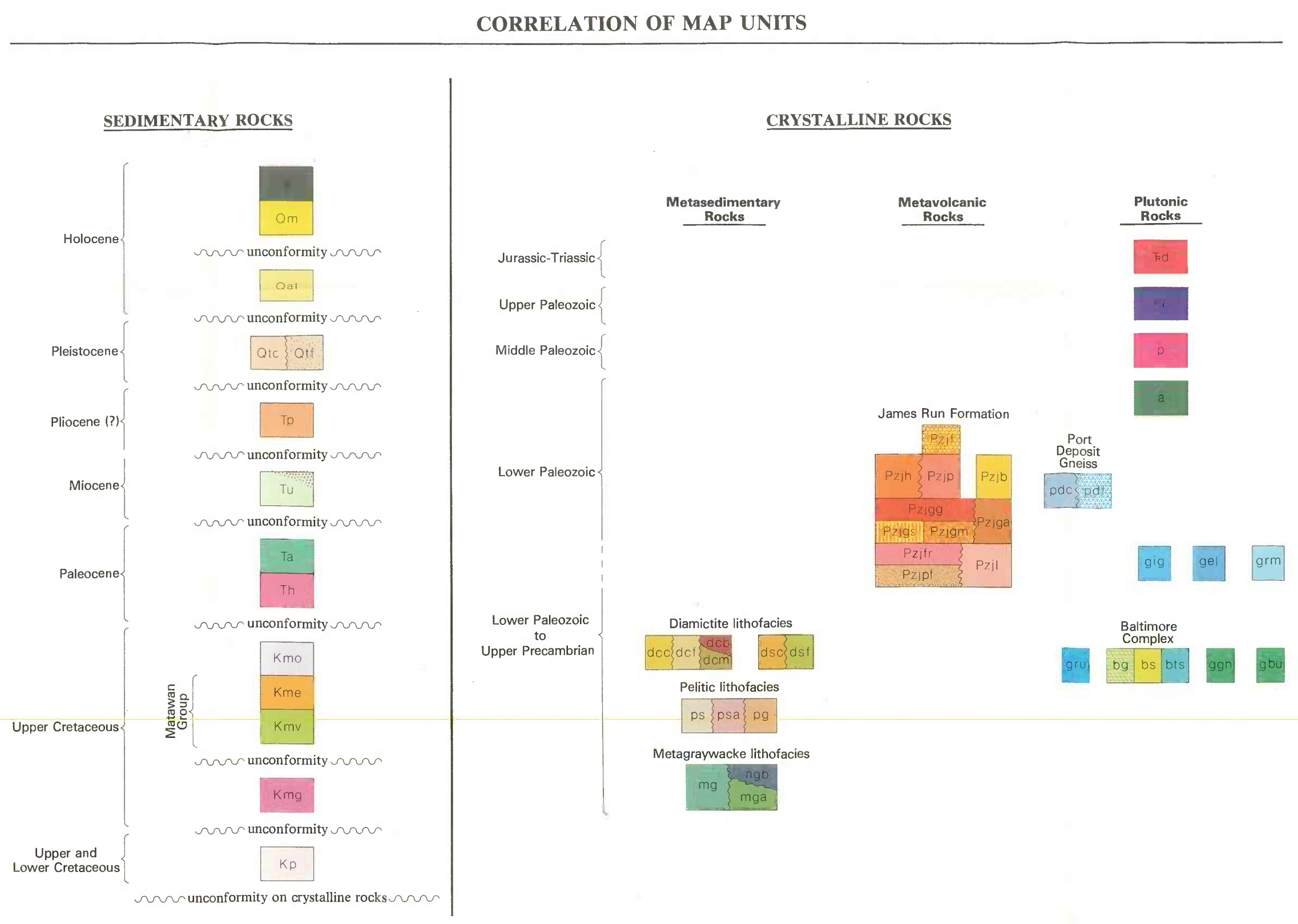
CORRELATION OF MAP UNITS



LITHOLOGIC DESCRIPTIONS OF MAP UNITS

SEDIMENTARY ROCKS

s **SPOIL** — Waste material consisting of unconsolidated or poorly consolidated mixtures of soil, sand, clay, gravel, and debris derived from local quarrying, dredging, and construction operations. Also, in places, contains rubble of crystalline rock fragments which range in size from pebbles to boulders. In areas adjacent to Chesapeake Bay and along some tidal rivers this unit contains mud, silt, shells, sand, and organic material with considerable water content. Thickness variable. Unit includes storage stockpiles, tailings ponds, and some areas of compacted fill such as landfills.

Qm **TIDAL-MARSH DEPOSITS** — Interbedded sand, silt, and clay rich in organic matter. Thickness generally less than 30 feet (9 m).

unconformity

Qal **ALLUVIUM** — Stream deposits consisting of sand, silt, clay, and gravel with some organic material. Locally contains boulders and includes some slope-wash and other colluvial deposits. Considerable range in thickness but generally less than 40 feet (12 m). Locally may include some tidal-marsh deposits.

unconformity

TALBOT FORMATION — Deltaic and flood-plain deposits consisting of lenses of micaceous sand and gravel interbedded with thin layers of silt and fine sand.

Qtc **Coarse-grained facies** — Coarse-grained and gravelly at base, finer-grained sand and loam in upper part. Clasts of crystalline rock in gravel range in size to boulders 8 feet (2.5 m) across. Thickness of unit ranges between 25 and 50 feet (7.5 and 15 m).

Qtf **Fine-grained facies** — Thin-bedded silt and fine sand, locally glauconitic. Thickness of unit ranges from 25 to 50 feet (7.5 to 15 m).

unconformity

Tp **PENSAUKEN FORMATION** — Polymict gravel overlain by arkosic sand and loam. Lower portion contains abundant poorly-sorted gravel with clasts generally less than 3 inches (7.6 cm) in diameter, but also with some boulders up to 6 feet (~2 m) across. Clasts of vein quartz are predominant but significant amounts of crystalline rock, conglomeratic quartzite, and red sandstone also occur. Sand contains as much as 40% feldspar, is commonly cross-bedded, and shows less oxidation than older, higher-level sand-gravel deposits. This unit is correlative with the Pensauken Formation of New Jersey and the northern Delmarva peninsula, and was probably deposited by the ancestral Delaware River during Late Tertiary time. Thickness ranges between 15 and 90 feet (4.6 to 27 m), but locally may be as much as 120 feet (36.6 m) in channels.

unconformity

Tu **UPLAND GRAVEL** — Quartz gravel with scattered lenses of cross-stratified quartzose sand and local lenses, slabs, and balls of light-gray clay. Upper portion has been oxidized to reddish-brown and in places has been cemented to ironstone conglomerate. Clasts are generally less than 3 inches (7.6 cm) in diameter, but cobbles and small boulders are locally present. Clasts in upper part, particularly those of chert, are commonly weathered and friable. These are probably Late Tertiary fluvial deposits of the ancestral Susquehanna River and of other smaller streams. No fossils are present to support this age assignment which is based on the degree of oxidation and the topographic position of these bodies. Thickness ranges up to 75 feet (23 m).

Stippled pattern indicates small areas of sand and gravel disjunct both laterally and vertically from other parts of this unit and also from the younger deposits of the Pensauken Formation. These bodies include a broad terrace of gravelly sand with boulders of saprolitized crystalline rock located east of Perryville at the mouth of the Susquehanna River, small patches near Leslie and west of Singerly, and a chain of mostly quartzose sand-gravel deposits on the eastern flank of Elk Neck which were probably derived from similar, older deposits exposed at higher elevations along the crest of the peninsula. All of these bodies are relatively thin, generally less than 20 feet (~6 m) in thickness.

unconformity

Ta **AQUIA FORMATION** — Glauconitic quartz sand, somewhat clayey, in various shades of light green and yellow. Fossils (*Oleneothyris, Gryphaea*) occur in lower part. Only the lowest 70 feet (21.3 m) are present in the southeast part of Cecil County. Basal contact is gradational.

Th **HORNERSTOWN FORMATION** — Dark green sand, about 90 percent glauconite as rounded grains. Interstitial clay is green and glauconitic as well. Generally unfossiliferous. Sharp basal contact. Generally about 20 feet (6 m) thick.

unconformity

Kmo **MONMOUTH GROUP** — Glauconitic quartz sand, locally cemented and crusted with iron oxide where weathered. Some calcareous zones are also present and locally contain shell fragments. Spherical and discoidal concretions of siderite up to 4 feet (1.2 m) in diameter occur sporadically. Sand layers are thick and structureless and locally contain borings of *Ophiomorpha*. Glauconite content ranges from trace amounts to abundant, with some beds resembling the Hornerstown Formation in glauconite content. Botryoidal grains are abundant and accordion forms also occur. Unit includes the Mount Laurel Sand, about 80 feet (24.4 m) thick, and an overlying unnamed member, also about 80 feet (24.4 m) thick. This upper member is composed of glauconite-rich sand grading up to dark-gray silty quartz sand and may be correlative with the Navesink and Red Bank Formations of New Jersey. Lower contact is gradational.

MATAWAN GROUP:

Kme **MARSHALLTOWN AND ENGLISHTOWN FORMATIONS, UNDIVIDED** —

Marshalltown Formation — Greenish-black, fine- to medium-grained, clayey and silty glauconitic quartz sand. Mottled greenish-gray color where weathered. Commonly unstratified. Many borings in upper and lower parts. Locally is richly fossiliferous.

Englishtown Formation — Dark gray to black, clayey, silty, and micaceous quartz sand with abundant grains of lignite. Slightly glauconitic. Brown, yellow, and white in color where weathered. Well-stratified with fine laminae. Layers of black, unctuous clay locally present. Poorly exposed in map area. Basal contact is sharp and conformable. Thickness is about 15 to 20 feet (4.6 to 6 m).

Kmv **MERCHANTVILLE FORMATION** — Black, very fine- to medium-grained silty and clayey micaceous and glauconitic quartz sand. Various shades of gray, yellow, and brown where weathered. Indistinctly stratified. A few thin beds of white sand and granule zones occur in places. Small pebbles and pieces of lignitic material are locally present at sharp basal contact. Siderite concretions are common in some zones as nodules 1 to 3 inches (2.5 to 7.6 cm) in diameter. A few small borings occur sporadically. Thickness is about 45 feet (13.7 m).

unconformity

Kmg **MAGOTHY FORMATION** — Black, dark gray, and white lignitic sand and clay, cross-stratified in places. Flattened and carbonized logs are present locally, chiefly near base. Thickness is about 35 feet (10.7 m).

unconformity

Kp **POTOMAC GROUP** — Quartzose sand, gravelly sand, silt, and clay, locally micaceous. Planar and trough-type cross-stratification is common. Gravel consists almost entirely of quartz and quartzite clasts, usually less than 3 inches (7.6 cm) in diameter, but some larger cobbles are present in lower part of unit. Clay layers are lenticular and are mottled red, purple, yellow, and white. Locally, clay is dark gray and lignitic and in places contains carbonized leaves and wood fragments that range in size from grains to flattened logs. Maximum thickness of unit is about 1,300 feet (396 m), but only about half of the formation is exposed in Cecil County.

unconformity on crystalline rocks

METASEDIMENTARY ROCKS

Diamictite lithofacies

CONOWINGO DIAMICTITE — Massive, medium-gray chlorite-biotite-muscovite-plagioclase-quartz gneiss and granofels with uniform matrix and included rock fragments. Contacts are gradational with other lithofacies of the metasedimentary rock sequence.

dcc **coarse-grained** — Ranges from medium- to coarse-grained and contains granule- to boulder-sized clasts, some in concentrations sufficient to constitute lenses of cobble and boulder gneiss. Clasts include pebbles of quartz, and feldspar as well as fragments of quartzite, metagraywacke, schist, quartz-biotite gneiss, amphibolite, and calc-schist. Larger sized fragments are angular and generally range up to 15 feet (4.6 m) long with some boulders attaining a length of 325 feet (100 m).

dcf **fine-grained** — Ranges from fine- to medium-grained, generally with smaller and less numerous clasts than in the coarse-grained diamictite. Clasts are primarily of quartzite, but all lithologies found in the coarse-grained diamictite also occur. Locally, rare lenses of cobble gneiss are present.

dcm **mafic zone** — Poorly defined zone of dark colored gneiss made up of mafic diamictite and gabbroic-appearing rocks that contain granules of blue quartz. Appears to be altered metasedimentary rocks of the diamictite lithofacies, but some rocks in the mafic zone may be of igneous origin (called quartz gabbro and quartz diorite by earlier workers). Contact with gabbro unit of the Baltimore Complex is drawn where quartz grains are discernable in outcrop. Gradational contact with the Conowingo Diamictite is placed where the diamictite matrix becomes greenish in color with abundant chlorite and/or amphibole.

dcb **mafic breccia** — Angular blocks and fragments of amphibolite and metagabbroic rocks, ranging up to about 10 feet (3 m) across, in an anastomosing matrix of felsic to mafic diamictite.

SYKESVILLE FORMATION — Massive, gray chlorite-biotite-muscovite-quartz gneiss and granofels similar to the Conowingo Diamictite except that a significant proportion of the included clasts are of ultramafic rock. A further difference is that the Sykesville Formation does not contain potash feldspar either in the matrix or in the clasts. The contact with the serpentinite unit of the Baltimore Complex is sharp.

dsc **coarse-grained**

dsf **fine-grained**

Pelitic lithofacies

ps **PELITIC SCHIST** — Strongly crinkled, silvery-gray to brownish-gray, fine- to medium-grained quartz-biotite-plagioclase-muscovite schist, locally garnetiferous. Poorly exposed, but contacts appear to be gradational with other units of the metasedimentary rock sequence.

psa **PELITIC SCHIST WITH AMPHIBOLITE** — Generally the same lithology as the pelitic schist but numerous thin layers of amphibolite occur throughout the unit. Contacts with other units of the metasedimentary rock sequence are gradational.

pg **PELITIC GNEISS** — Lustrous, brown, medium- to coarse-grained muscovite-biotite-quartz-plagioclase gneiss with sporadic potash feldspar and small, locally abundant red garnets. Unit has a streaked appearance due to thin quartzofeldspathic to pegmatitic layers, veins, and stringers. Contacts are gradational with other units of the metasedimentary rock sequence.

Metagraywacke lithofacies

mg **METAGRAYWACKE** — Interbedded tan to grayish-green chlorite-biotite-plagioclase-muscovite-quartz gneiss or metagraywacke and silvery-gray to grayish-green plagioclase-quartz-biotite-muscovite schist. Both lithologies generally contain magnetite, locally garnet and pyrite, and rarely chloritoid. Detrital grains of quartz and plagioclase as well as small rock fragments up to 1/4 inch (5 mm) long are present in the metagraywacke. Thickness of beds in the metagraywacke range from 6 inches (~15.2 cm) to 8 feet (~2.5 m). Layers in the schist are generally less than 1/16 inch (1 mm) thick and occur in sections up to 40 feet (12.2 m) thick. Contacts are gradational with units in the pelitic and diamictite lithofacies of the metasedimentary rock sequence and with the Big Elk Creek Member of the James Run Formation.

mga **METAGRAYWACKE WITH AMPHIBOLITE** — Rhythmically interbedded, light tan to dark greenish-gray metagraywacke and silvery brown to silvery gray-green schist with included thin layers and stringers of fine-grained amphibolite. Metagraywacke is a biotite-muscovite-plagioclase-quartz gneiss and occurs in beds that range in thickness from 3 inches (7.6 cm) to 2 feet (0.6 m). Graded bedding, pull-aparts, and flame structures are common. Schist is composed of quartz, biotite, and muscovite and occurs in laminae less than 1/16 inch (1 mm) thick which comprise sections with thicknesses comparable to the metagraywacke beds. Both lithologies contain porphyroblasts of chloritoid and garnet rimmed with chlorite. Large staurolite crystals up to 1.5 inches (~5 cm) long, retrograded to "shimmer aggregates" of sericite and quartz, are ubiquitous. Amphibolites are composed of quartz, plagioclase, and hornblende and exhibit relict volcanic textures and structures. Thickness of amphibolite layers range up to 150 feet (~50 m). Contacts of unit are gradational with units in the pelitic and diamictite lithofacies of the metasedimentary rock sequence, but are sharp with the Port Deposit Gneiss.

mgb **MAFIC BRECCIA** — Large masses or clasts of coarse-grained amphibolite, up to 1.5 feet (~0.5 m) long, enclosed in an anastomosing granitic matrix. Contact with surrounding metagraywacke lithofacies is gradational.

METAVOLCANIC ROCKS

JAMES RUN FORMATION:

Pzjf **felsite member** — Fine- to medium-grained, light gray to white plagioclase-quartz felsite with minor potash feldspar and rare biotite. Limited area of outcrop and contacts are not exposed. Textures and composition suggest that this unit is volcanic in origin.

Pzjh **Happy Valley Branch Member** — Fine-grained, light gray to grayish-white, medium- to thick-bedded, metamorphosed felsite and granofels. Contains relict, mostly broken, phenocrysts of plagioclase and quartz, and locally, phenocrysts of amphibole. Contact with Port Deposit Gneiss is gradational.

Pzjp **Principio Creek Member** — Medium-grained biotite-plagioclase schist with abundant small plagioclase phenocrysts and blocky inclusions of epidosite up to 1 foot (~30 cm) long. Layers of amphibolite occur locally. Contacts with other members of the James Run Formation and with units of the metasedimentary rock sequence are sharp. Member pinches out 1.2 miles (~2 km) northeast of Northeast Creek.

Pzjb **Big Elk Creek Member** — Interlayered, thin-bedded plagioclase-hornblende amphibolite and plagioclase-quartz felsite that locally contains rounded fragments of quartzite. Contact is gradational with the metagraywacke lithofacies of the metasedimentary rock sequence and locally is gradational with the Gilpins Falls Member of the James Run Formation.

Gilpins Falls Member

Pzjgg **greenstone** — Medium- to coarse-grained greenstone, locally amygdaloidal, with minor fine-grained greenschist. Unit occurs at top of pillow metabasalt.

Pzjgm **pillow metabasalt** — Massive metabasalt composed of close-packed basalt pillows and containing thin chert beds. Grades upward into greenstone and greenschist with pillow breccia and isolated basalt pillows. Metabasalt is composed of plagioclase, epidote, and chlorite in the southwest and of plagioclase and hornblende in the northeast. Pillow rims contain amygdules of epidote, calcite, magnetite, and also of radiating aggregates of actinolite. Greenstone and greenschist are believed to have been formed from basaltic tuff or tuffaceous material. Thin lenses of felsic rock are locally present. Contact with the Big Elk Creek Member of the James Run Formation is gradational over a short interval. Contacts with other units are sharp.

Pzjga **amphibolite** — Hornblende-plagioclase amphibolite, amphibole schist, and greenschist.

Pzjgs **chlorite schist** — Plagioclase-epidote-chlorite schist locally present beneath the metabasalt unit. Contacts are generally sharp with the metabasalt and with the Frenchtown Member of the James Run Formation.

Pzjl **Little Northeast Creek Member** — Grayish-white to gray, fine- to medium-grained, massive granofels with relict phenocrysts of plagioclase and quartz. Some crystals of amphibole and biotite. Locally, a weak foliation may be apparent and sporadic graded beds are present. Rare layers of hornblende-plagioclase amphibolite occur and may represent former basaltic dikes and sills.

Pzjfr **Frenchtown Member** — Interbedded, fine-grained, schistose to massive amphibolite and gray to light gray, fine- to medium-grained granofels. Amphibolites are composed of plagioclase, amphibole, and epidote with minor magnetite and quartz and occur in layers from 1 foot (0.3 m) to 11 feet (3.5 m) in thickness. Relict amygdules are present. Granofels are composed of feldspar and quartz with large, blocky phenocrysts of plagioclase and smaller ones of amphibole and of quartz. Layers range between 4 feet (1.2 m) and 30 feet (9 m) in thickness.

Pzjpf **Principio Furnace Member** — Interbedded gray to grayish-white granofels and gray diamictite. Granofels are fine grained and are composed of quartz and plagioclase with blocky phenocrysts of plagioclase and scattered crystals of amphibole. Some quartz phenocrysts are also present. Layers range in thickness from 1 foot (0.3 m) to 4 feet (1.2 m). Diamictites are medium grained biotite-quartz-plagioclase gneiss with locally-occurring rock fragments and round to oblong grains and blebs of quartz.

FELSIC PLUTONIC ROCKS

QUARTZ — Massive, pod-shaped veins of milky-white quartz up to 80 feet (24.4 m) thick. Locally contain small amounts of muscovite and a little tourmaline.

p **PEGMATITE** — Dikes up to 100 feet (30 m) thick composed of large crystals of microcline, quartz, and muscovite.

PORT DEPOSIT GNEISS:

pdc **coarse-grained phase** — Gray, coarse-grained, well-foliated, quartz-rich biotite granodiorite gneiss. Contact with the fine-grained phase is gradational, with both lithologies apparently interlayered throughout a broad interval. Believed to be the metamorphosed plutonic phase of a surface-breaking epizonal pluton. Contact with the metagraywacke lithofacies of the metasedimentary rock sequence is relatively sharp, but with much interfingering in the vicinity of Principio.

pdf **fine-grained phase** — Generally medium gray, fine- to medium-grained quartz-rich granofels and granodiorite gneiss composed of hornblende, biotite, and plagioclase, with phenocrysts of sodic plagioclase and quartz. Intercalated layers and lenses of the coarse-grained facies are common near the contact with that lithology, but are present elsewhere only locally. Relict volcanic textures increase across strike to southeast. Believed to represent the metamorphosed subvolcanic phase of a surface-breaking epizonal pluton. Contact with the Happy Valley Branch Member of the James Run Formation is gradational, and many rocks mapped in that unit may belong in the Port Deposit.

gig **GNEISS ON GARRETT ISLAND** — Well foliated, gray-tan, medium- to coarse-grained biotite-plagioclase-quartz gneiss. Very similar to the coarse-grained phase of the Port Deposit Gneiss. Poorly exposed except on Garrett Island. Contact with gabbroic rocks on Garrett Island is sharp. Contact with the Principio Furnace Member of the James Run Formation is not exposed.

gel **GNEISS NEAR ELKTON** — Well foliated, gray, medium- to coarse-grained biotite-quartz-plagioclase granodiorite gneiss with granoblastic texture. Contact with gabbro and serpentinite at Grays Hill is apparently sharp but is very poorly exposed. Contact with the Frenchtown Member of the James Run Formation is gradational over a short interval.

grm **GNEISS AT ROLLING MILL** — Medium gray, fine- to medium-grained biotite-quartz-plagioclase gneiss, commonly with crystals of magnetite and tiny garnets. Contacts are very poorly exposed but apparently are gradational and/or interfingering with units of the James Run Formation.

MAFIC PLUTONIC ROCKS

Ɍd **DIABASE** — Dikes of dark gray to greenish-black, fine- to medium-grained, equigranular augite diabase with ophitic texture. Unmetamorphosed.

a **AMPHIBOLITE DIKES AND SILLS** — Tabular bodies of very dark green to black, fine- to medium-grained plagioclase-hornblende amphibolite. May originally have been basalt or diabase dikes and sills. Many show relict chill margins and a few are locally amygdaloidal. Some amphibolites in the James Run Formation may have been basalt flows. Thickness ranges up to 60 feet (18 m), but only the largest bodies are shown.

BALTIMORE COMPLEX:

bg **gabbro** — Generally massive hypersthene gabbro in various stages of alteration to uralite gabbro but includes minor amounts of a wide variety of mafic and, locally, ultramafic rocks. Norite and augite gabbro are present in subordinate amounts. "Net veins" composed of large uralitized pyroxene crystals in a matrix of plagioclase, are locally present.

•••••••••• Approximate location of EN_{60} composition of orthopyroxenes

bs **serpentinite** — Highly sheared and fractured, bluish-green, talcose serpentinite and schistose soapstone, with minor amounts of unserpentinized ultramafic rocks and some mafic rocks. Original textures largely obliterated, but locally some highly contorted relict layering is present. Contains sporadic masses of chromite grains up to 3/16 inch (5 mm) across. Contact with units of the metasedimentary rock sequence is not well exposed, but appears to be sharp and may possibly be a fault.

bts **talc schist** — Fine-grained, sheared talc-actinolite schist and minor chlorite schist. Contacts with gabbro unit are gradational.

ggh **GABBRO AND SERPENTINITE AT GRAYS HILL** — Black to very dark green, coarse- to very coarse-grained, uralitized hypersthene gabbro and serpentinite. Poorly exposed and deeply weathered. Commonly mantled by iron-silicate cap with honeycomb structure. Relationship to rocks of the Baltimore Complex not known.

gbu **GABBROIC ROCKS, UNDIFFERENTIATED** — On Garrett Island, well-layered amphibolite representing a metamorphosed uralitized hypersthene gabbro with primary igneous layering. Probably correlative with the Aberdeen Metagabbro in Harford County. In northeast corner of county near Appleton, rock is a variably uralitized medium-grained hypersthene gabbro. Relationship to rocks of the Baltimore Complex not known.

gru **GRANITIC ROCKS, UNDIFFERENTIATED** — Small bodies of poorly exposed, quartz-rich granitic rock completely surrounded by rocks of the Baltimore Complex. Contacts not exposed.

GEOLOGIC SYMBOLS

Contact — Includes gradational contacts and inferred contacts

Thrust fault (generally inferred)
Teeth on upper plate

Axial trace — Big Elk generation fold
Approximate location
(Modified by Appleton generation folds)

Axial trace — Rock Church generation fold
Approximate location

Quarries — Active or intermittent pits

Planar Features

Axial planes with attending axial-plane S-surfaces	S-planes identifiable with a fold generation
22 Wildcat Point generation	15 Wildcat Point (S_cW)
70 Appleton generation	37 Appleton (S_cA)
83 Rock Church generation	50 Rock Church (S_cR)
40 Big Elk generation	60 Big Elk (S_cB)

23 S-planes not definitely identifiable with a fold (S_{sch})
(Most are S_sB or S_sR)

Doubled planar symbols indicate vertical dip.

Linear features

Bearing and plunge of fold axes

45 not perceptably folded

81 Folded, general bearing and plunge given

30 Bearing and plunge of very small folds, crenulations, and crinkles.
Many are folded (curved).

The above symbols may be used in conjunction with the axial plane symbols.

Bearing and plunge of lineations

12 Alignment of elongate minerals

54 Alignment of clasts, pebbles, amygdules, etc.

31 Alignment of elongate inclusions

Alignment of elongated pillows in metabasalt

Double-ended symbols indicate linear features are horizontal (no plunge).

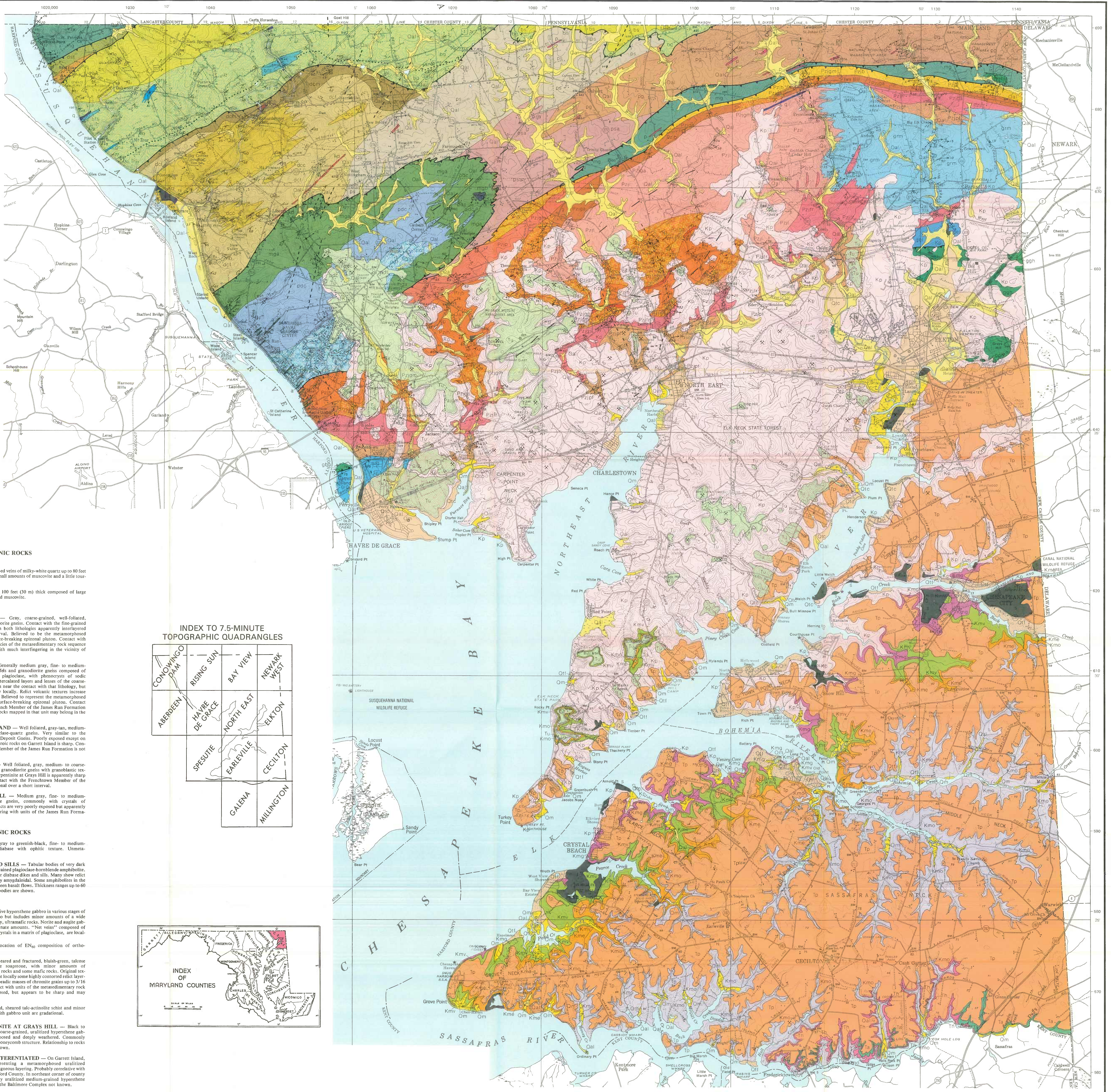
Other features

Sense of direction of small folds

Direction of rotation of inclusions

Stratigraphic top determined from graded bedding

Stratigraphic top determined from pillow structure in basalt

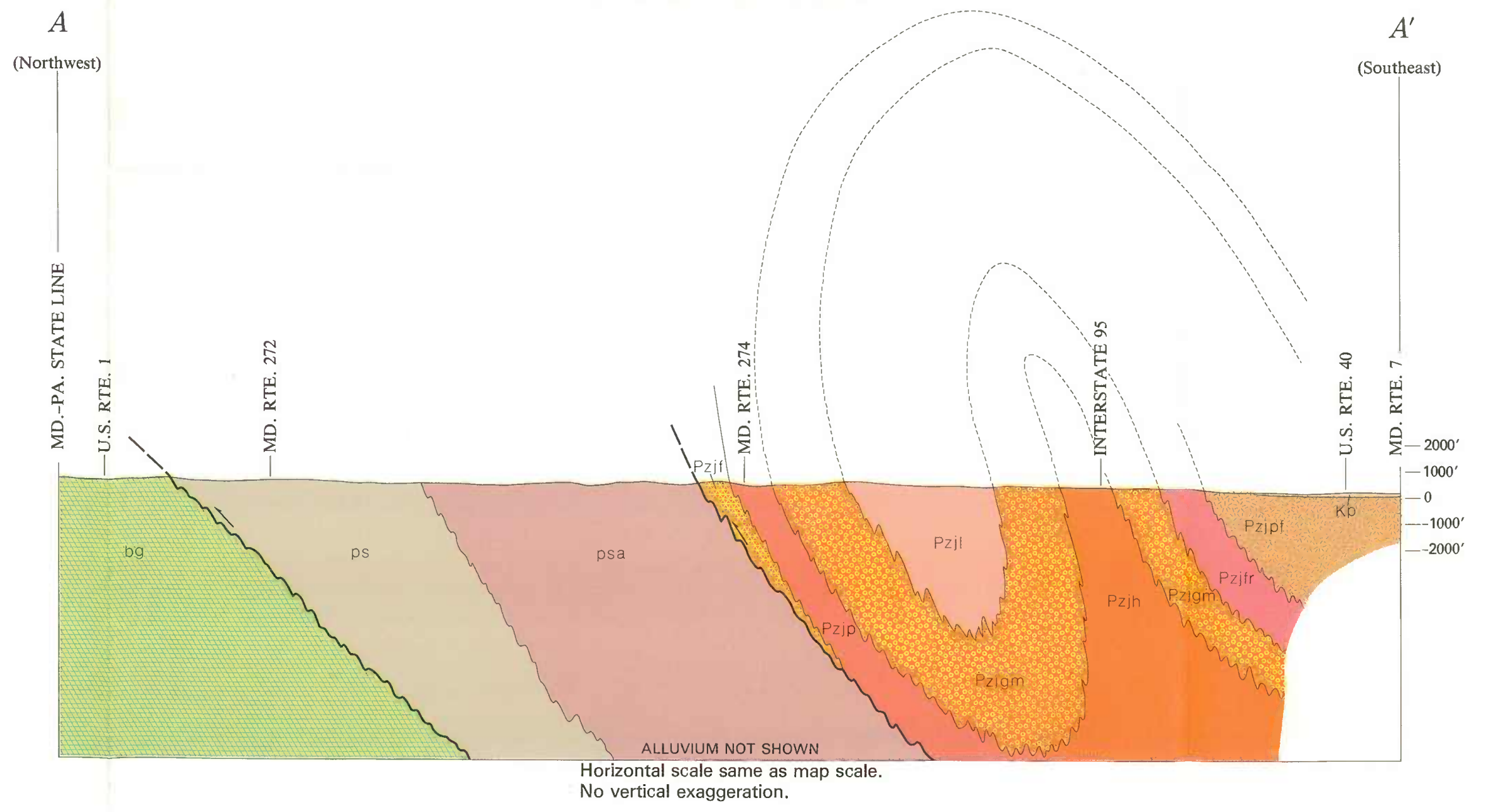


Base map: Maryland Geological Survey
Topographic Map of Cecil County, 1977

Crystalline rocks mapped by Michael W. Higgins, 1968-1972.
Sedimentary rocks mapped by Louis C. Conant, 1966-1972.
Coastal Plain — Piedmont contact mapped jointly by both authors.

Publication authorized by the Director, U.S. Geological Survey
Edited by Jonathan Edwards, Jr., Maryland Geological Survey
Drafted and scribed by Margaret P. Ketcham McCabe, Maryland Geological Survey

GEOLOGIC CROSS SECTION



Horizontal scale same as map scale.
No vertical exaggeration.

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

GEOLOGIC MAP OF CECIL COUNTY

by

Michael W. Higgins and Louis C. Conant, U.S. Geological Survey

1986

Prepared in cooperation with
United States Department of the Interior
Geological Survey

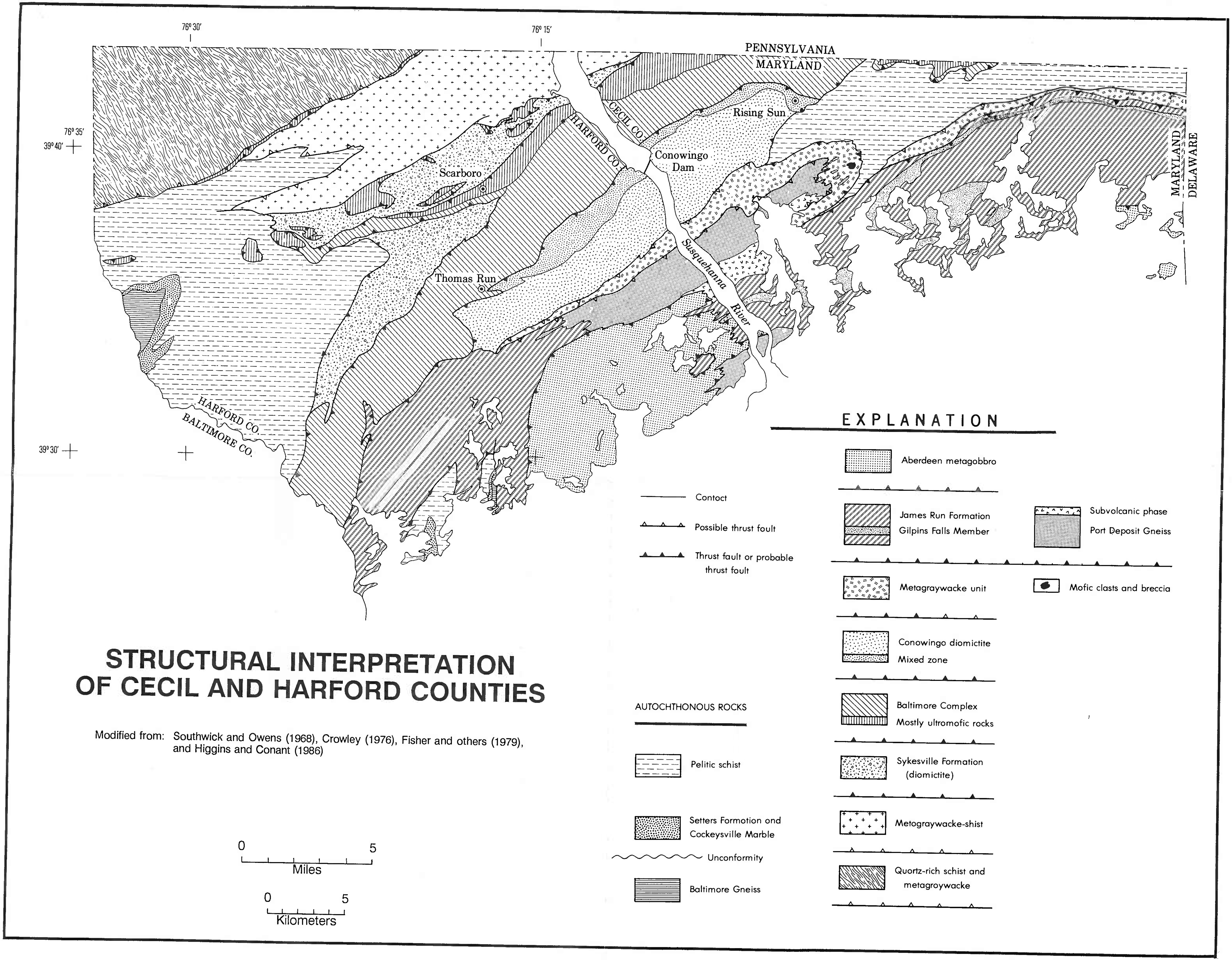
Scale 1:62500

1 1/2 0 1 2 3 4 Miles

1 1/2 0 1 2 3 4 5 Kilometers

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

Plate 2: Structural interpretation of Cecil and Harford Counties



STRUCTURAL INTERPRETATION OF CECIL AND HARFORD COUNTIES

Modified from: Southwick and Owens (1968), Crowley (1976), Fisher and others (1979), and Higgins and Conant (1986)