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PRELIMINARY BEDROCK GEOLOGIC MAP OF A PORTION OF THE WILMINGTON 30- BY 60-MINUTE QUADRANGLE, SOUTHEASTERN PENNSYLVANIA

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by Gale C. Blackmer

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Description of Units

Geologic Units of a Portion of the Wilmington 30- by 60-minute Quadrangle, Southeastern Pennsylvania

By Gale C. Blackmer, Pennsylvania Geological Survey

Introduction

The Wilmington 30- x 60-minute quadrangle includes rocks that range in age from Middle Proterozoic to Silurian, and in metamorphic grade from lowest greenschist to granulite facies. Tectonic environments represented in the quadrangle include continental basement rocks, shelf sediments, marine sediments spanning rift to drift, a fragment of a magmatic arc, and deep-seated plutons. By way of introduction, a speculative tectonic history for the area follows. This history is compiled from discussion with all the authors whose work contributed to this map, with additional input from Plank and others (2000) and Srogi (2004).

As the Iapetus Ocean opened during the latest Precambrian to early Cambrian, a rift margin developed on the eastern side (present coordinates) of Laurentia. Sediments that became the Glenarm Group, Glenarm Wissahickon, and Mt. Cuba Wissahickon were deposited in marine rift basins floored by continental crust represented by the Baltimore Gneiss. In these rift basins, the sediments intermingled with continental rift-related basalts that became the White Clay Creek Amphibolite. The Kennett Square Amphibolite with its ocean-floor geochemical signature, now found associated with the Mt. Cuba Wissahickon, represents the transition from rift to drift. The Peters Creek Schist, with its interlayers of oceanic-affinity Bald Friar Metabasalt, may represent the culmination of sedimentation in the rift basins. As true sea-floor spreading progressed during the Cambrian, a passive margin formed inboard of the rift basins. The transgressive shelf sequence of the Chickies Formation, Antietam and Harpers Formations, and Conestoga Formation through Vintage Formation was deposited at this time over Laurentian continental basement gneiss. The clay-rich sediments that became the Octoraro Formation were deposited on the continental slope and rise.

In the early Ordovician, the Wilmington Complex metaigneous rocks were forming as part of a magmatic arc built over an east-dipping subduction zone in the Iapetus Ocean. The boninitic amphibolites in the Rockford Park Gneiss indicate subduction of relatively young and hot lithosphere, possibly even a mid-ocean ridge. Intimate interlayering of Mt. Cuba Wissahickon with Wilmington Complex rocks in Pennsylvania and Delaware suggest that the eastern part of the Mt. Cuba may have been deposited with Wilmington Complex volcanic rocks in a forearc basin, or it may have been tectonically incorporated into the forearc accretionary prism during subduction. The sliver of Mt. Cuba Wissahickon east of the Wilmington Complex exhibits a metamorphic episode contemporaneous with arc magmatism.

Evidence of shelf drowning and deformation in the sedimentary rocks of central and eastern Pennsylvania indicates that the Taconic Orogeny reached this area in the late Ordovician. Finding evidence of the same orogeny in the deep-seated rocks of the Pennsylvania Piedmont is more problematic. As yet, no evidence of metamorphic mineral growth during the late Ordovician has been found. However, growth of metamorphic monazite during the early Silurian is common to the Wilmington Complex, Wissahickon Formation (restricted sense, as defined herein), and Mt. Cuba Wissahickon formation at least as far west as the Delaware state line (the western Mt. Cuba and the Glenarm Wissahickon have not been investigated). A metamorphic event of this magnitude and intensity requires tectonic burial, perhaps as the magmatic arc overrode its forearc accretionary complex. Northeast-trending fabrics and major thrust faults in the area date from this period of subduction and collision.

The position of the Wissahickon Formation (restricted sense; eastern part of the historic Wissahickon Formation) throughout the preceding period is enigmatic. It must be early Silurian or older in age because it is intruded by the Silurian-aged Springfield Granodiorite. Unlike the adjacent Mt. Cuba Wissahickon, it carries no evidence of stratigraphic interrelation to the Wilmington Complex, or of a metamorphic episode that might be related to Wilmington Complex magmatism. The geochemistry of interlayered amphibolites suggest that it may have been deposited in a back-arc basin with continental crustal input, perhaps in some other part of Iapetus.

The Silurian was a period of high heat flow in the Pennsylvania Piedmont, marked by high-temperature metamorphism centered on the Brandywine Blue Gneiss and emplacement of both mafic and felsic plutons. The Arden Plutonic Supersuite, the Springfield Granodiorite, and the Ridley Park Granite were emplaced at this time. Because the trace element geochemistries of Silurian mafic igneous rocks are close to back-arc basin basalts, Plank and others (2001) suggest an extensional environment with high mantle heat flow. Such an environment could have resulted from slab break-off following oblique collision of the Wilmington Complex arc, or from back-arc extension over a newly-established west-dipping subduction zone.

Early Devonian metamorphism recorded by monazite growth in the Wissahickon Formation (restricted sense) marks renewed plate convergence. Late fabrics and motion along high-angle ductile shear zones (Rosemont Fault, Cream Valley Fault, zone marked by Peters Creek tectonite) are probably related to the Alleghanian Orogeny. Minor high-angle brittle faults, some of which exhibit undeformed slickensides, probably date from Mesozoic extension.

Dividing the Wissahickon

A major innovation of this map is its treatment of the Wissahickon Formation. The most recent definition of the extent of the Wissahickon Formation in Pennsylvania (Miles and Whitfield, 2001) includes rocks that vary significantly in their lithology, metamorphic history, and association with other rock units. Lumping all of these rocks together in one formation may be obscuring real tectonic differences. For this reason, the Wissahickon Formation in Pennsylvania is herein tentatively divided into three informal units: Wissahickon Formation (restricted sense), Mt. Cuba Wissahickon formation, and Glenarm Wissahickon formation. Official designation and renaming await the results of ongoing field and laboratory investigations. Each of these units is described individually in the Description of Units section below.

Description of Units

Mafic and felsic gneiss – This amphibolite facies gneiss underlies Mine Ridge, in the northwest corner of the map area. Mine Ridge is at the southwest end of a belt of Grenville gneiss massifs that lies northwest of the Appalachian metamorphic core (Faill, 1997). Hoersch and Crawford (1988) describe the gneiss of Mine Ridge as primarily felsic with subordinate mafic gneiss. The sparse exposures observed in the current map area are mafic, hornblende-bearing gneiss with centimeter-scale, wispy to throughgoing felsic layers. The gneiss is assumed to be of Middle Proterozoic age by correlation with gneiss in the Honey Brook Upland, with which it is contiguous at its eastern end (Crawford and Crawford, 1980).

Baltimore Gneiss – Basement rocks called Baltimore Gneiss (as defined by Crowley, 1976) are exposed in the Woodville Nappe, Mill Creek Anticline, Avondale Anticline, West Chester Massif, and Poorhouse Prong. They include a variety of compositions at amphibolite and granulite metamorphic grade.

Undifferentiated felsic, intermediate, and mafic amphibolite facies gneiss dominates the Avondale Anticline, Mill Creek Anticline, and Poorhouse Prong. Intermediate plagioclase-hornblende-quartz-biotite gneiss with local orthopyroxene, clinopyroxene, potassium feldspar, and garnet is predominant. Swirling migmatite leucosome and biotite-rich restite layers are common. Felsic gneiss consists of quartz, plagioclase, microcline, and biotite with local muscovite and garnet. Felsic gneiss dominates the Woodville Nappe. Mafic gneiss is hornblende-plagioclase-quartz amphibolite with garnet and subordinate biotite. Mafic gneiss generally occurs in bodies too small to appear on the map. A small body of impure white, coarsely crystalline marble, historically called Franklin Marble (Bascom and Stose, 1932), lies within the amphibolite facies gneiss in the central part of the Avondale Anticline.

Amphibolite facies pelitic gneiss informally called the Sycamore Mills gneiss is found in the eastern end of the Avondale Anticline. It consists of garnet, biotite, sillimanite, quartz, plagioclase, and orthoclase, with local kyanite and muscovite.

Granulite facies gneiss is found in the eastern part of the Avondale Anticline and comprises most of the West Chester Massif. Most of the granulite gneiss is heterogeneous felsic, intermediate, and mafic compositions. Felsic to intermediate gneiss composed of plagioclase, quartz, orthopyroxene, clinopyroxene, garnet, hornblende, and biotite predominates. Metagabbro has subophitic texture and consists of olivine, orthopyroxene, clinopyroxene, and plagioclase. All compositions have coronas of garnet, amphibole, or clinopyroxene between plagioclase and orthopyroxene grains. Several mappable bodies of quartzofeldspathic granulite gneiss consisting of quartz, plagioclase, potassium feldspar, orthopyroxene, clinopyroxene, garnet and biotite, and intermediate and mafic granulite gneiss composed of orthopyroxene, clinopyroxene, plagioclase, and garnet are found in the West Chester Massif.

Glenarm Group

Setters Formation – The Setters Formation consists of metaclastic rocks overlying the Baltimore Gneiss in presumed unconformity. Three lithologies are present in the map area: microcline gneiss, quartzite, and pelitic schist. Microcline gneiss contains 50% or more microcline, with quartz, biotite, and muscovite. Locally the rock is schistose due to a large amount of post-kinematic muscovite. The unusually high potassium content of this rock suggests that it may have originated as volcaniclastic material (Blackmer and Srogi, 2004). Quartzite consists of 80-90% quartz with microcline, muscovite, and biotite, and local interlayers of microcline gneiss. Where microcline gneiss and quartzite cannot be separated at map scale due to interlayering or lack of outcrop, they are mapped as undifferentiated Setters Formation. Biotite-muscovite-quartz pelitic schist with abundant pegmatite pods and large crystals of tourmaline and garnet, herein informally named Avondale schist, is found as a lens near the southwest end of the Avondale Anticline. The Green Lawn marble is a small lens of white, coarse-grained impure calcite marble with minor quartz and phlogopite, which is completely surrounded by Setters Formation metaclastic rocks.

The microcline gneiss, quartzite, and pelitic schist of the Setters in Pennsylvania are similar but not identical to the gneiss member, quartzite member, and garnet schist member, respectively, described by Crowley (1976) for the Setters Formation in Maryland. Unlike in Maryland, microcline gneiss is interlayered with quartzite, and pelitic schist occurs as a single lens within microcline gneiss.

Cockeysville Marble– The Cockeysville Marble either overlies the Setters Formation or lies with presumed unconformity above the Baltimore Gneiss, the same stratigraphic position occupied by the Cockeysville Marble in Maryland. In Pennsylvania, it consists of layered calcite and dolomite marble with minor phlogopite, quartz, microcline, and diopside. Six-inch to six-foot thick layers of sulfidic quartzose schist consisting of quartz, plagioclase, microcline, muscovite, and biotite, with local sillimanite and garnet, are a common feature of the Cockeysville Marble in Pennsylvania.

Mappable metaclastic layers within the marble, herein informally called Baker gneiss, consist primarily of microcline-muscovite-quartz-biotite gneiss similar to Setters microcline gneiss. South of Landenberg, the gneiss is interlayered with muscovite-microcline-quartz-biotite-sillimanite-sericite-garnet schist. A similar package of metaclastic rocks and marble has been observed in Maryland near top of the Cockeysville Marble. Choquette (1960) and Crowley (1976) place these rocks in the overlying Wissahickon Formation or Wissahickon-equivalent Loch Raven Schist. Hopson (1964) places them in the Cockeysville. Because in Pennsylvania the metaclastic rocks are clearly layers or lenses within marble, these rocks are retained in the Cockeysville.

Glenarm Wissahickon formation – The name “Glenarm Wissahickon” formation was first applied to all of the Wissahickon west of the Wilmington Complex (Faill, 1997). It is used here in a more restricted sense to refer to the Wissahickon north of the Avondale Anticline. The Glenarm Wissahickon formation is divided into three members. The Doe Run schist is a garnet-staurolite-kyanite pelitic schist with abundant biotite and muscovite. Sparse sillimanite is also present in the south and east of the outcrop extent. Amphibolite interlayers are rare. The two amphibolite occurrences that have been analyzed have the continental initial rift composition of White Clay Creek Amphibolite (Smith and Barnes, 2004). The Laurels schist is a quartz-plagioclase-muscovite-chlorite-garnet schist with minor biotite. It can be distinguished from the Doe Run schist by its well-defined compositional layering. It is interpreted as highly strained and retrograded pelitic schist within the Embreeville thrust zone. The third member, the Greystone schist, is a quartz-plagioclase-muscovite-chlorite metasandstone to psammitic schist, locally having biotite and garnet. It is distinctly finer-grained and richer in quartz and feldspar than the Doe Run schist. The Doe Run and Greystone schists are found along strike from each other. Their contact is interpreted as a tear fault in the Embreeville thrust sheet (Wiswall, 2004, written communication). The Glenarm Wissahickon is in depositional contact with the Glenarm Group and Baltimore Gneiss (Blackmer, 2004).

Mt. Cuba Wissahickon formation – The Mt. Cuba Wissahickon formation lies between the Wilmington Complex and Avondale Anticline, and includes a sliver east of the Wilmington

Complex. It is named for outcrops near Mt. Cuba, Delaware. The Mt. Cuba Wissahickon includes pelitic gneiss and pelitic schist with subordinate amphibolite and pegmatite. The predominant lithology is quartz-plagioclase-biotite-muscovite gneiss, with or without minor sillimanite and small garnets. Mica content in the gneiss varies, but the sum of quartz and feldspar is always greater than mica. Pegmatite bodies of various sizes and relative ages are ubiquitous. Some appear to be the products of in-situ partial melting. Patches of pelitic schist within the gneiss with abundant biotite, sillimanite, and large garnets may represent restite. Near the contact with the Cockeysville Marble around the west end of the Avondale Anticline, the schist also has staurolite. Distribution of the schist cannot be accurately mapped due to lack of outcrop. However, occurrences tend to be located near pegmatite outcrops and marble. Layers of amphibolite are common in the Mt. Cuba Wissahickon. Geochemical analyses of some of these amphibolites show that two geochemical populations are present (Smith, 2004; Smith and Barnes, 2004). Kennett Square Amphibolite with ocean floor basalt geochemistry is found primarily in a belt near the Avondale Anticline. White Clay Creek Amphibolite with continental initial rift geochemistry is found in smaller bodies in the southern and eastern portion of the outcrop extent. Several small bodies of marble exposed within the outcrop extent of the Mt. Cuba Wissahickon are assumed to be antiformal uplifts of Cockeysville Marble. They might also be tectonic inliers of Cockeysville or marble interlayers of depositional origin. An area of microcline gneiss east of Kennett Square is likewise assumed to belong to the Setters Formation, but may have a different origin.

The Mt. Cuba Wissahickon is in presumed depositional contact with the Glenarm Group. Middle Proterozoic ages of detrital zircons from the Mt. Cuba Wissahickon at Yorklyn, Delaware suggest that these sediments were derived from the Laurentian margin (Aleinikoff and others, in press). At its eastern boundary in Delaware, the Mt. Cuba Wissahickon is intimately interlayered with Wilmington Complex volcanic rocks (Plank and others, 2000).

Electron microprobe chemical ages of monazite show that the Silurian metamorphism ubiquitous across the area is the only metamorphic episode recorded in monazite from the Mt. Cuba Wissahickon at Yorklyn, Delaware (approximately 6 miles northeast of Landenberg, Pennsylvania). The sliver of Mt. Cuba east of the Wilmington Complex exhibits an additional Early Ordovician metamorphism at 484-472 Ma, coeval with magmatism in the Wilmington Complex (Bosbyshell, 2001).

Wissahickon Formation – The name Wissahickon Formation is retained in a restricted sense for the easternmost extent of the Wissahickon rocks, including the type locality in Fairmount Park in Philadelphia, Pennsylvania, which lies east of the map boundary. These rocks consist of pelitic schist and gneiss interlayered at centimeter scale with psammitic granofels and quartzite. This well-defined layering is characteristic only of this part of the Wissahickon and does not appear in the Mt. Cuba Wissahickon or Glenarm Wissahickon. Appearance and mineralogy vary considerably with metamorphic grade, which increases southward from lower to upper amphibolite facies. Interlayers of amphibolite with geochemical affinity to back-arc basin and within-plate basalts are common. The Wissahickon Formation (restricted sense) is associated with neither the Glenarm Group nor Wilmington Complex.

Electron microprobe chemical ages of monazite from the Wissahickon Formation (restricted sense) show no metamorphism older than a Silurian event that is ubiquitous across this unit and the Mt. Cuba Wissahickon. However, there is a younger metamorphic event during the Devonian, at 377 ±

3.3 Ma (Bosbyshell, 2001).

Amphibolite – Hornblende-plagioclase-quartz amphibolite occurs as layers within the Glenarm Wissahickon formation, Mt. Cuba Wissahickon formation, and in one location in the Setters Formation. In the Glenarm Wissahickon, amphibolite is fine-grained, black rock with visible white flecks. It is found as meter- to outcrop-scale layers with contacts parallel to the regional dominant foliation. In the Mt. Cuba Wissahickon and Setters, amphibolite is coarse-grained, more uniformly black, and may include clinopyroxene, diopside, and quartz-epidote symplectite. It is found both as relatively thin (outcrop-scale) layers within the host rock and as relatively large bodies elongate parallel to strike of the dominant foliation.

Analyses of major, minor, and trace elements for a number of amphibolite samples from Pennsylvania and Delaware fall into two groups (Smith and Barnes, 2004; Smith, 2004). White Clay Creek Amphibolite has a range of alkalic compositions typical of continental initial rift basalt. This unit has thus far been found in the Glenarm Wissahickon and Mt. Cuba Wissahickon. Kennett Square Amphibolite has compositions typical of ocean-floor basalt, and has been found in the Mt. Cuba Wissahickon.

Pegmatite – Granitic pegmatite bodies of various sizes and ages are present in most units in the map area. Primary constituents are quartz and potassium feldspar, with lesser muscovite, biotite and, locally, garnet and tourmaline. Size ranges from layers several centimeters thick to mappable lenses. Especially in the Mt. Cuba Wissahickon, earlier pegmatite layers are deformed with the early foliation, whereas later pegmatite lenses cut across foliation.

Peters Creek Schist – The Peters Creek Schist is a pinstriped quartz-plagioclase-muscovite-biotite-chlorite-epidote ± garnet schist having abundant magnetite and discontinuous quartz veins and pods. Quartz-feldspar layers alternating with submillimeter- to millimeter-scale mica layers give the rock its distinctive striped appearance. Centimeter- to outcrop-scale layers of gray or tan metasandstone are common. Rare discontinuous layers of greenstone identified by Smith and Barnes (1994) as Bald Friar Metabasalt are found in the Peters Creek Schist within the map area. These greenstones have the geochemical signature of ocean-floor basalts (Smith and Barnes, 1994; Smith, 2004).

The schist grades over a distance of a few meters into a unit exhibiting markedly more strain, informally called Peters Creek Schist – variably tectonized. Although much of this unit is still recognizable as Peters Creek, all of the rocks exhibit mylonitic or phyllonitic characteristics. Centimeter- to meter-scale phyllonite interlayers are common. Meter-scale metasandstones are more abundant than in the “normal” schist. The variably tectonized unit grades into a branching true tectonite, informally called the Peters Creek tectonite. The southern branch of the tectonite is dark-greenish-gray quartzose phyllonite. The northern branch is black to silvery-black phyllonite containing little matrix quartz although quartz veins are common. These two bands merge off the map to the northeast to form a single band of black or dark greenish-gray phyllonite composed primarily of muscovite and chlorite and having abundant quartz veins. The tectonite marks the trace of a shear zone that roughly corresponds to part of the Pleasant Grove-Huntingdon Valley shear zone of Valentino and others (1994).

Neither the upper or lower contact of the Peters Creek Schist is exposed in the map area. They are interpreted as a thrust fault and a shear zone, respectively, based on structural patterns and strain gradients.

Octoraro Formation – The Octoraro Formation in the map area is quartz-muscovite-chlorite-plagioclase schist with thin interlayers of black phyllonite. Chloritoid and pyrite, or pseudomorphs of limonite after pyrite, are locally abundant. Millimeter-scale plagioclase porphyroclasts are characteristic of the unit. Well-developed schistosity lends a moderate fissility to the rocks. Non-penetrative, late foliation surfaces and folds are common. Although the Octoraro Formation is distinct from the adjacent Peters Creek tectonite, the common occurence of quartzo-feldspathic material as discontinuous lenses bounded by foliation surfaces and the phyllonite interlayers indicate that the Octoraro is also highly tectonized.

Neither the upper or lower contact of the Octoraro Formation is exposed in the map area. They are interpreted as a shear zone and a thrust fault, respectively, based on structural patterns, strain gradients, and metamorphic grade differences.

Ultramafic rocks – Variously sized bodies of ultramafic rocks are found within the Baltimore Gneiss, all parts of the Wissahickon Formation, and the Peters Creek Schist and variably tectonized schist. They are primarily serpentinite, ranging in color from dark green to yellow-green. Steatite, chlorite-talc schist, anthophyllite schist, pyroxenite, and norite are also present. The relationships between the ultramafic and surrounding rocks, and between the ultramafic bodies themselves, are unclear. The age of these rocks is also uncertain. The largest bodies lie along and near the Rosemont Fault. Other concentrations of ultramafic rocks are close to the boundary between the Avondale Anticline and West Chester Massif, and to the Cream Valley Fault. The remaining small bodies are scattered through the surrounding rocks with no apparent pattern.

Chickies Formation – The Chickies Formation is light-gray to white, massive or thin-bedded, vitreous quartzite, commonly having spaced mica partings. Thin quartzose schists are locally interlayered with the quartzite. Tourmaline is a locally common accessory mineral. The Chickies lies with presumed unconformity above the mafic and felsic gneiss of Mine Ridge.

Antietam and Harpers Formations, undivided – The Antietam and Harpers Formations, undivided, are thinly layered quartzose schists consisting of alternating laminae of quartz-feldspar and mica. Randomly oriented tourmaline is found on micaceous foliation planes. Thin layers of granitic pegmatite are common. The Antietam and Harpers Formations lie conformably above the Chickies Formation.

Conestoga Formation through Vintage Formation, undivided – The Conestoga Formation through Vintage Formation, undivided, includes carbonate rocks of various composition. From youngest to oldest, the formations include the Conestoga, Elbrook, Ledger, Kinzers, and Vintage. Most of these units were not observed in the map area, although the topographic expression of the Chester Valley, previous mapping (Bascom and Stose, 1932), and a number of boulders of gray-and-white banded crystalline limestone blasted from foundation holes in a new housing development indicates their presence. Several outcrops of Conestoga Formation close to the Octoraro contact show it to be a massive to thinly layered, blue-gray crystalline limestone having schistose partings, abundant calcite veins, and small calcite pods. The Conestoga Formation is locally unconformable above the entire Vintage to Elbrook sequence.

Chester Park gneiss - The Chester Park gneiss is a medium to coarse grained plagioclase-quartz-biotite gneiss and schist. Local aluminous domains contain muscovite, garnet, kyanite, sillimanite, or cordierite. Irregularly shaped, elongate biotite-rich enclaves range in size from a few centimeters to several meters long. The unit is generally massive, but layering, defined mainly by biotite abundance, is present locally. The origin of this unit is uncertain. The aluminous character of some of the rock is consistent with a sedimentary or possibly volcanic rock. On the other hand, poor compositional layering and the presence of enclaves suggests an intrusive igneous origin.

Lima Granite – The Lima granite is variably foliated plagioclase-microcline-quartz-hornblende-biotite gneiss and granofels. A sample of Lima granite from a quarry in Lima that is now the site of the Granite Run Mall (sample currently in the Bryn Mawr College collections) contains xenoliths of ultramafic rock, demonstrating that the granite is intrusive into and therefore younger than the ultramafic rock.

Wilmington Complex

The Wilmington Complex is a complex of metamorphosed igneous rocks consisting of metavolcanic units, metaplutonic units, and undeformed plutons. It is a fragment of an Ordovician-Silurian magmatic arc with later Silurian intrusions (Plank and others, 2000). The majority of the complex lies in New Castle County, Delaware. Three units extend into Pennsylvania and are described below: Rockford Park Gneiss, Brandywine Blue Gneiss, and Arden Plutonic Supersuite.

Rockford Park Gneiss – The Rockford Park Gneiss occurs as discrete bodies of interlayered mafic and felsic gneiss, completely enclosed in the Brandywine Blue Gneiss (Plank and others, 2000). The nature of the contacts is obscured by deformation and metamorphism. Only one of the Rockford Park bodies crosses the state line from Delaware into Pennsylvania.

Within the Rockford Park Gneiss, boundaries between mafic and felsic layers are sharp. The felsic layers consist of quartz and plagioclase, minor orthopyroxene and, locally, clinopyroxene. Mafic layers are fine-grained, and consist of plagioclase, orthopyroxene, clinopyroxene, and hornblende with minor quartz and biotite. Trace element signatures of the mafic rocks are similar to modern boninites.

Igneous zircons from a felsic layer from the type section in Rockford Park in Wilmington, Delaware give a SHRIMP U-Pb age of 476±4 Ma. Metamorphic zircons from the same sample give an age of 432±6 Ma (Plank and others, 2000).

Brandywine Blue Gneiss – In Delaware, the Brandywine Blue Gneiss is granulite facies felsic gneiss with thin, discontinuous mafic layers and pods. The felsic gneiss consists of greater than 60% quartz and plagioclase, with or without orthopyroxene, clinopyroxene, and hornblende. Mafic layers contain plagioclase, hornblende, clinopyroxene and/or orthopyroxene. The rock is strongly lineated, giving weathered surfaces a pinstriped or banded appearance. Igneous zircons from the felsic gneiss give a SHRIMP U-Pb age of 476±6 Ma (Plank and others, 2000).

The rocks in Pennsylvania herein called Brandywine Blue Gneiss were called Confluence gneiss by Bosbyshell (2001). These are intermediate to felsic gneiss and interlayered intermediate, felsic, and mafic gneiss. Mineral assemblages indicate amphibolite facies metamorphism, although the local presence of orthopyroxene indicates that some areas reached granulite facies. Although these rocks are contiguous with the Brandywine Blue Gneiss in Delaware, the interlayered nature of the gneiss and the boninitic character of some of the mafic rocks is similar to the Rockford Park Gneiss.

Arden Plutonic Supersuite – As described in Plank and others (2000), the Arden Plutonic Supersuite includes a variety of mafic, intermediate, and felsic rocks that intrude the Brandywine Blue Gneiss. Current mapping shows it also intruding the Chester Park gneiss. The Ardentown Granitic Suite, Perkins Run Gabbronorite Suite, and biotite tonalite comprise the Supersuite.

The Ardentown Granitic Suite is a collection of silicic rocks that probably crystallized from a granitic magma (Srogi and Lutz, 1997). Specifically, it includes quartz norite, quartz monzonorite, opdalite, and charnockite. The mineralogy, common to all rock types, is plagioclase, orthopyroxene, clinopyroxene, potassium feldspar, quartz, and biotite. An interesting characteristic of these rocks is the presence of phenocrysts of potassium feldspar and plagioclase up to two inches long (Plank and others, 2000). The best estimate of the age of the Ardentown is a SHRIMP U-Pb age of 434±4 Ma on igneous zircons (Plank and others, 2000).

The Perkins Run Gabbronorite Suite is collection of mafic and minor intermediate rocks that crystallized from mantle-derived basaltic magma. Typical compositions are 50-60% labradorite, subequal amounts of orthopyroxene and clinopyroxene, hornblende, and lesser olivine and biotite. Field evidence shows commingling of the silicic Ardentown and gabbroic Perkins Run magmas (Plank and others, 2000).

Biotite tonalite is found as rounded boulders in three locations. It differs from the Ardentown Granitic Suite in its significantly lower K_2O content and rarity of potassium feldspar (Plank and others, 2000).

Springfield Granodiorite – The Springfield Granodiorite is a body of medium to coarse grained, moderately to strongly foliated granodioritic gneiss composed of plagioclase, quartz, microcline, biotite, epidote, and minor hornblende. Accessory minerals include sphene, magnetite, apatite, and zircon. Portions of the Springfield exhibit porphyritic

texture characterized by 2-4 cm plagioclase and microcline crystals. Xenoliths of Wissahickon Formation are present along the irregular southern contact. The Springfield has a mylonitic texture, and its northern contact is highly tectonized. Igneous zircons give a SHRIMP U-Pb age of 427±3 Ma (Bosbyshell and others, 2005).

Mafic gneiss – Fine to coarse grained, foliated to massive amphibolite and metagabbro, composed of hornblende, plagioclase, biotite, quartz and pyroxene, with accessory epidote, apatite, and titanite. Pyroxene occurs as small cores of relict grains now almost entirely replaced by hornblende.

Ridley Park Granite – Medium to coarse grained, moderately to strongly foliated granitic gneiss composed of microcline, quartz, plagioclase, biotite, and muscovite. Accessory minerals include garnet, apatite, titanite, and zircon. The Ridley Park Granite occurs as sills and larger bodies within the Wissahickon Formation. Postel (1940) reports that it intrudes the Springfield Granodiorite in several localities.

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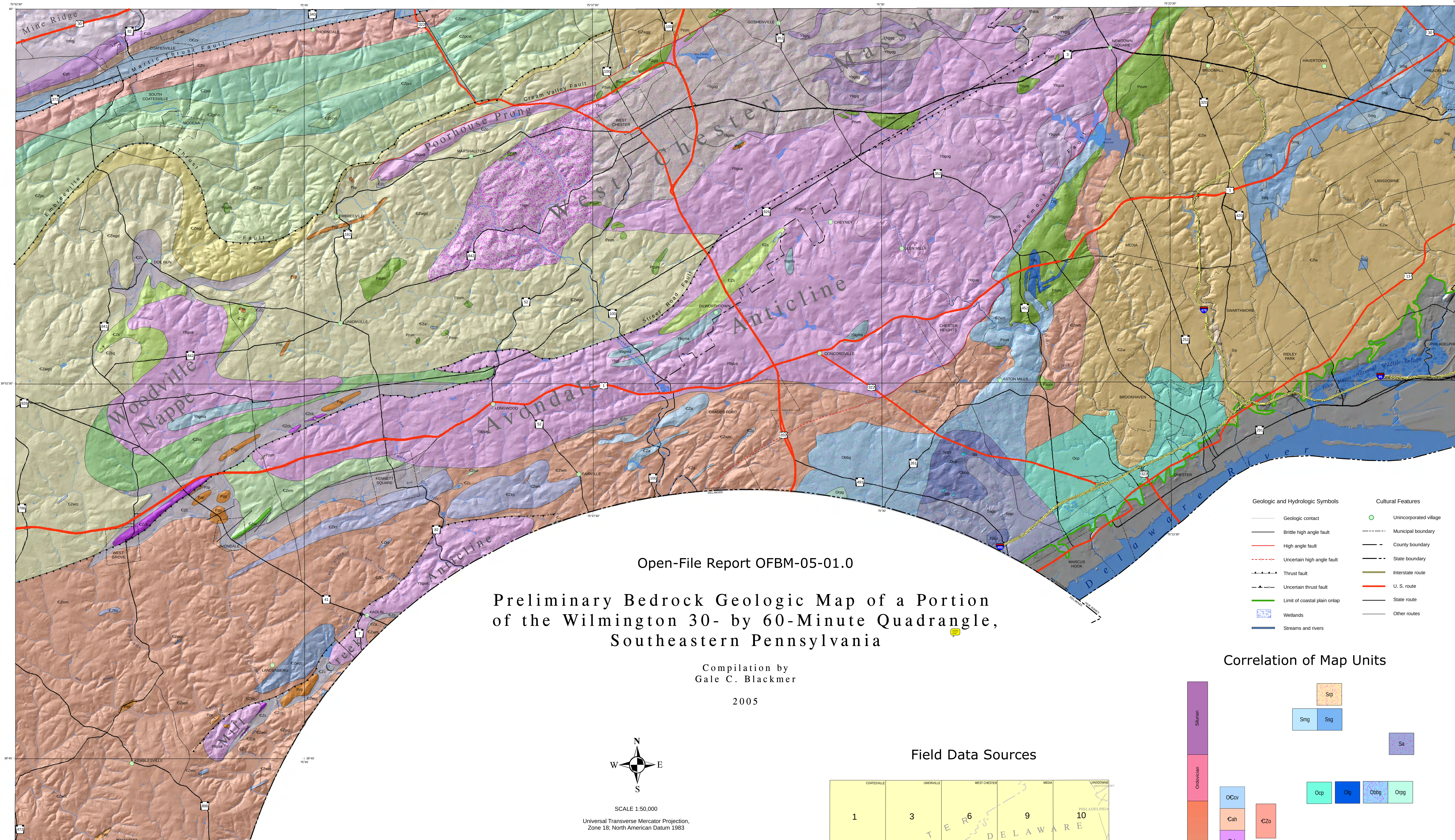


Open-File Report OFBM-05-01.0

Preliminary Bedrock Geologic Map of a Portion of the Wilmington 30- by 60-Minute Quadrangle, Southeastern Pennsylvania

Compilation by
Gale C. Blackmer

2005

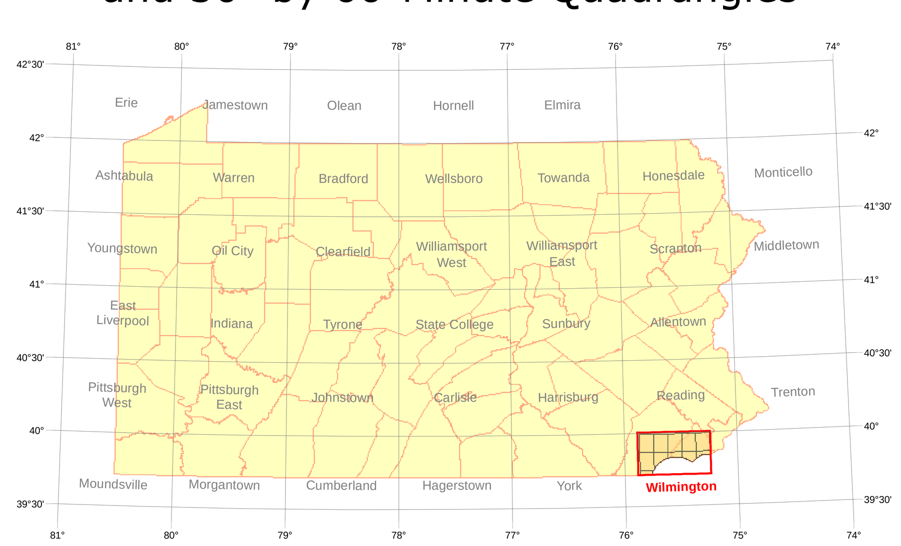
SCALE 1:50,000

Universal Transverse Mercator Projection, Zone 18; North American Datum 1983

1 0.5 0 1 2 3 4 KILOMETERS

1 0.5 0 1 2 3 4 MILES

Location of Map Area and 30- by 60-Minute Quadrangles



Map Credits

Geology

Locations of faults and geologic contacts of bedrock units are based on field mapping by persons listed under Field Data Sources.

Base Map

Municipal, county, and state boundary lines are clipped and modified from Pennsylvania Department of Transportation layers, http://www.pasda.psu.edu/access/padot.shtml, 2004, 1:24,000-scale accuracy.

Pennsylvania 7.5-minute quadrangle boundaries are from the U. S. Geological Survey, Quadrangle boundaries in Pennsylvania, http://gis2.pasda.psu.edu/Pasda/UCI_Metadata/pasdaquads24k.htm#3, 2002, 1:24,000 scale accuracy.

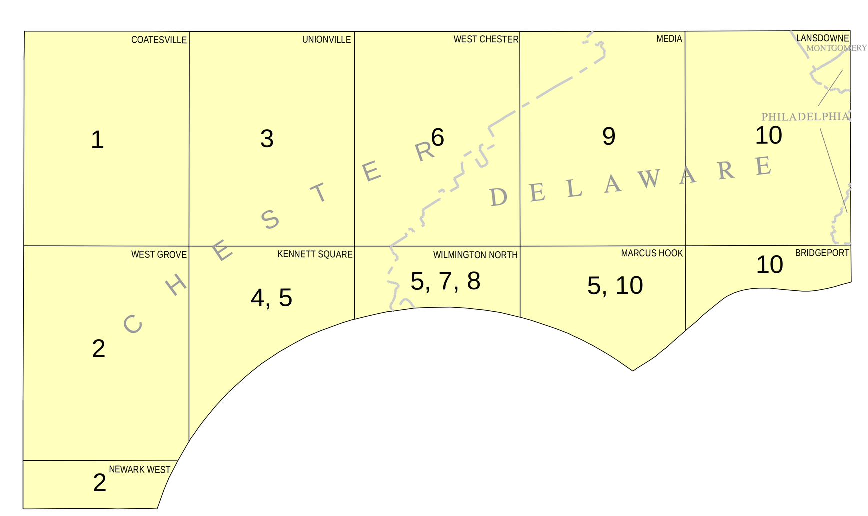
Water bodies are from the U. S. Geological Survey, National Hydrography Dataset (NHD), http://nhd.usgs.gov/, 1:24,000 scale accuracy.

Shaded relief layer is from the seamless raster format of the USGS National Elevation Dataset (NED) 1/3 arc second (10m) data, http://ned.usgs.gov/.

Other

Map layout and design by Gale C. Blackmer and Stuart O. Reese, Pennsylvania Geological Survey, 2005. Cartography by Stuart O. Reese, 2005.

Field Data Sources



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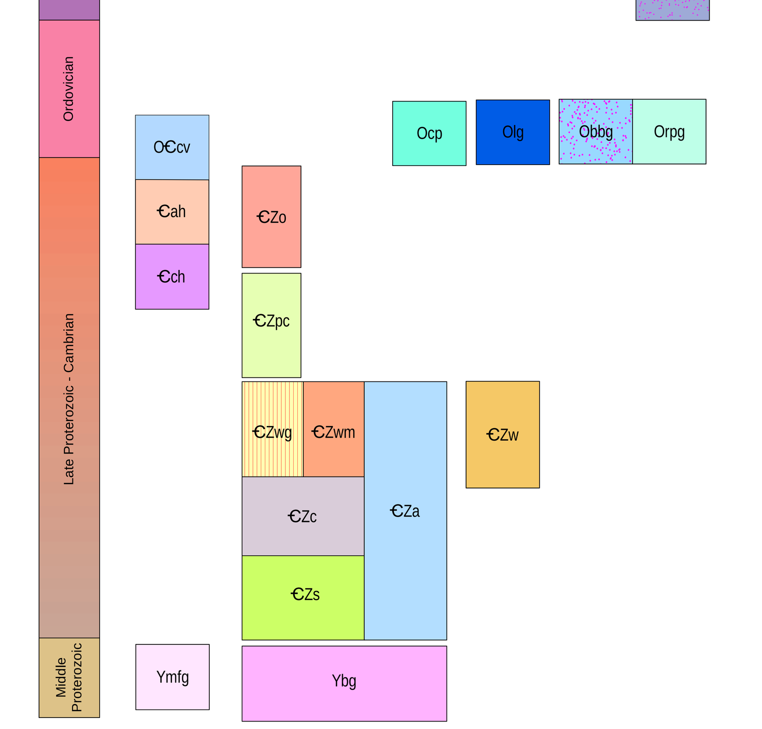
Geologic and Hydrologic Symbols

- Geologic contact
- Brittle high angle fault
- High angle fault
- Uncertain high angle fault
- Thrust fault
- Uncertain thrust fault
- Limit of coastal plain onlap
- Wetlands
- Streams and rivers

Cultural Features

- Unincorporated village
- Municipal boundary
- County boundary
- State boundary
- Interstate route
- U. S. route
- State route
- Other routes

Correlation of Map Units



Combined Units in Correlation Chart

- ЄZwg — Glenarm Wissahickon formation
- Ybg — Baltimore Gneiss
- Sa — Arden Plutonic Supersuite

BEDROCK UNITS

Pzum — Ultramafic rock
Primarily serpentinite, ranging in color from dark green to yellow-green. Steatite, chlorite-talc schist, anthophyllite schist, pyroxenite, and norite are also present. Relationships between the ultramafic and surrounding rocks, and between the ultramafic bodies themselves, are unclear. Age is also uncertain.

Pzp — Pegmatite
Granitic pegmatite bodies of various sizes and ages. Primary constituents are quartz and potassium feldspar, with lesser muscovite, biotite and, locally, garnet and tourmaline.

Srp — Ridley Park Granite
Medium to coarse grained, moderately to strongly foliated granitic gneiss composed of microcline, quartz, plagioclase, biotite, and muscovite. Accessory minerals include garnet, apatite, titanite, and zircon.

Smg — Mafic gneiss
Fine to coarse grained, foliated to massive amphibolite and metagabbro, composed of hornblende, plagioclase, biotite, quartz and pyroxene, with accessory epidote, apatite, and titanite. Pyroxene occurs as small cores of relict grains now almost entirely replaced by hornblende.

Ssg — Springfield Granodiorite
Medium to coarse grained, moderately to strongly foliated plagioclase-quartz-microcline-biotite-epidote gneiss having minor hornblende. Portions exhibit porphyritic texture characterized by 2-4 cm plagioclase and microcline crystals.

Wilmington Complex

Arden Plutonic Supersuite

Sags — Ardentown Granitic Suite
Silicic rocks containing plagioclase, orthopyroxene, clinopyroxene, potassium feldspar, quartz, and biotite. Includes quartz norite, quartz monzonorite, opdalite, and charnockite. Phenocrysts of potassium feldspar and plagioclase are common.

Spgs — Perkins Run Gabbronorite Suite
Mafic and minor intermediate rocks, typically having 50-60% labradorite, subequal amounts of orthopyroxene and clinopyroxene, hornblende, and lesser olivine and biotite. Contemporaneous with the Ardentown Granitic Suite.

Sbt — Biotite tonalite
Equigranular biotite tonalite is found as rounded boulders.

Orpg — Rockford Park Gneiss
Interlayered mafic and felsic gneiss. Felsic layers consist of quartz and plagioclase, minor orthopyroxene and, locally, clinopyroxene. Mafic layers are fine grained, consisting of plagioclase, orthopyroxene, clinopyroxene, hornblende, and minor quartz and biotite. The nature of the contacts with the Brandywine Blue Gneiss is obscured by deformation and metamorphism.

Obbg — Brandywine Blue Gneiss
In Pennsylvania, intermediate to felsic gneiss and interlayered intermediate, felsic, and mafic gneiss. Mineral assemblages indicate amphibolite facies metamorphism, although the local presence of orthopyroxene indicates that some areas reached granulite facies.

Olg — Lima Granite
Variably foliated plagioclase-microcline-quartz-hornblende-biotite gneiss and granofels. Intrusive into the surrounding ultramafic rock.

Ocp — Chester Park gneiss
Medium to coarse grained plagioclase-quartz-biotite gneiss and schist. Local aluminous domains contain muscovite, garnet, kyanite, sillimanite, or cordierite. Irregularly shaped, elongate biotite-rich enclaves range in size from a few centimeters to several meters long. Generally massive, but layering, defined mainly by biotite abundance, is present locally.

OЄcv — Conestoga Formation through Vintage Formation, undivided
Carbonate rocks of various composition. Elbrook, Ledger, Kinzers, and Vintage Formations not exposed in map area. Conestoga Formation is massive to thinly layered, blue-gray crystalline limestone having schistose partings, abundant calcite veins, and small calcite pods.

Єah — Antietam and Harpers Formations, undivided
Thinly layered quartzose schists consisting of alternating laminae of quartz-feldspar and mica. Randomly oriented tourmaline on micaceous foliation planes. Thin layers of granitic pegmatite are common.

Єch — Chickies Formation
Light-gray to white, massive or thin-bedded, vitreous quartzite, commonly having spaced mica partings. Thin quartzose schists are locally interlayered with the quartzite. Tourmaline is a locally common accessory mineral.

ЄZo — Octoraro Formation
In the map area, quartz-muscovite-chlorite-plagioclase schist with thin interlayers of black phyllonite. Chloritoid and pyrite, or pseudomorphs of limonite after pyrite, are locally abundant. Millimeter-scale plagioclase porphyroclasts are common. Well-developed schistosity lends a moderate fissility to the rocks.

ЄZpc — Peters Creek Schist
Pinstriped quartz-plagioclase-muscovite-biotite-chlorite-epidote ± garnet schist having abundant magnetite and discontinuous quartz veins and pods. Quartz-feldspar layers alternating with submillimeter- to millimeter-scale mica layers give the rock its distinctive striped appearance. Centimeter- to outcrop-scale layers of gray or tan metasandstone are common.

ЄZpcvt — Peters Creek Schist – variably tectonized
Facies of Peters Creek Schist exhibiting mylonitic or phyllonitic characteristics but still recognizable as Peters Creek Schist. Centimeter- to meter-scale phyllonite interlayers are common. Meter-scale metasandstones are abundant. Grades into Peters Creek tectonite.

ЄZpct — Peters Creek tectonite
Southern branch is dark-greenish-gray quartzose phyllonite. Northern branch is black to silvery black phyllonite containing little quartz, although quartz veins are common. The bands merge off the map to the northeast.

ЄZa — Amphibolite
Hornblende-plagioclase-quartz amphibolite, with or without clinopyroxene. Occurs as layers or pods within the Mt. Cuba Wissahickon formation, Glenarm Wissahickon formation, and Setters Formation. Where contacts are exposed, amphibolite is concordant with layering and foliation in the surrounding rocks. Those occurrences that have been analyzed fall into two groups based on geochemistry.

ЄZks — Kennett Square Amphibolite
Geochemically similar to ocean-floor basalt. Diopside, epidote and quartz-epidote symplectite are common.

ЄZwcc — White Clay Creek Amphibolite
Geochemically similar to continental initial rift basalt.

ЄZw — Wissahickon Formation
Pelitic schist and gneiss interlayered at centimeter scale with psammitic granofels and quartzite. Appearance and mineralogy vary considerably with metamorphic grade, which increases southward from lower to upper amphibolite facies. Interlayers of boninitic amphibolite are common.

ЄZwm — Mt. Cuba Wissahickon formation
Pelitic gneiss and pelitic schist with subordinate amphibolite and pegmatite. Predominant lithology is quartz-plagioclase-biotite-muscovite gneiss, with or without minor sillimanite and small garnets. Mica content in the gneiss varies, but the sum of quartz and feldspar is always greater than mica. Pegmatite bodies of various sizes and relative ages are ubiquitous. Some appear to be the products of in-situ partial melting. Patches of pelitic schist within the gneiss with abundant biotite, sillimanite, and large garnets may represent restite. Staurolite is present in the schist near the contact with the Cockeysville Marble around the west end of the Avondale Anticline.

Glenarm Wissahickon formation

ЄZwgd — Doe Run schist
Garnet-staurolite-kyanite pelitic schist with abundant biotite and muscovite. Sparse sillimanite also present in the south and east. Amphibolite interlayers are rare.

ЄZwgl — Laurels schist
Quartz-plagioclase-muscovite-chlorite-garnet schist with minor biotite. Characterized by well-defined compositional layering. Interpreted as highly strained and retrograded pelitic schist within the Embreeville thrust zone.

ЄZwgg — Greystone schist
Quartz-plagioclase-muscovite-chlorite metasandstone to psammitic schist, locally having biotite and garnet. Distinctly finer-grained and richer in quartz and feldspar than the Doe Run schist.

Glenarm Group

ЄZc — Cockeysville Marble
In Pennsylvania, layered calcite and dolomite marble with minor phlogopite, quartz, microcline, and diopside. Six-inch to six-foot thick layers of sulfidic quartzose schist consisting of quartz, plagioclase, microcline, muscovite, and biotite, with local sillimanite and garnet, are common.

ЄZcb — Baker gneiss
Microcline-muscovite-quartz-biotite gneiss similar to Setters microcline gneiss, interlayered with muscovite-microcline-quartz-biotite-sillimanite-sericite-garnet schist.

ЄZs — Setters Formation
Undifferentiated microcline gneiss and quartzite.

ЄZsm — Setters microcline gneiss
Gneiss containing 50% or more microcline, with quartz, biotite, and muscovite. Locally schistose due to abundant post-kinematic muscovite.

ЄZsq — Setters quartzite
80-90% quartz with microcline, muscovite, and biotite, and rare local interlayers of microcline gneiss.

ЄZsa — Avondale schist
Biotite-muscovite-quartz pelitic schist with abundant pegmatite pods and large crystals of tourmaline and garnet.

ЄZsg — Green Lawn marble
White, coarse-grained impure calcite marble with minor quartz and phlogopite.

Baltimore Gneiss

Ybgu — Undifferentiated Baltimore Gneiss
Heterogeneous amphibolite and granulite facies, medium- to coarse-grained, mafic to felsic gneiss. Granulite facies gneiss contains pyroxene; amphibolite facies gneiss contains hornblende.

Ybgua — Undifferentiated amphibolite facies gneiss
Heterogeneous felsic, intermediate, and mafic amphibolite facies gneiss. Predominant lithology is intermediate plagioclase-hornblende-quartz-biotite gneiss with local orthopyroxene, clinopyroxene, potassium feldspar, and garnet. Swirling migmatite leucosome and biotite-rich restite layers are common. Felsic gneiss consists of quartz, plagioclase, microcline, and biotite with local muscovite and garnet. Mafic gneiss is hornblende-plagioclase-quartz amphibolite with garnet and subordinate biotite.

Ybgma — Mafic amphibolite facies gneiss
Hornblende-plagioclase-quartz amphibolite with garnet and subordinate biotite.

Ybgf — Franklin Marble
White, coarsely crystalline, impure marble with abundant quartz and phlogopite.

Ybgsm — Sycamore Mills gneiss
Amphibolite facies pelitic gneiss consisting of garnet, biotite, sillimanite, quartz, plagioclase, and orthoclase, with local kyanite and muscovite.

Ybgug — Undifferentiated granulite facies gneiss
Heterogeneous felsic, intermediate, and mafic granulite facies gneiss. Predominant lithology is felsic to intermediate plagioclase-quartz-orthopyroxene-clinopyroxene-garnet-hornblende-biotite gneiss. Mafic gneiss has subophitic texture and consists of olivine, orthopyroxene, clinopyroxene, and plagioclase. All compositions have coronas of garnet, amphibole, or clinopyroxene between plagioclase and orthopyroxene grains.

Ybgqg — Quartzofeldspathic granulite facies gneiss
Quartz-plagioclase-potassium feldspar-orthopyroxene-clinopyroxene-garnet-biotite gneiss.

Ybgig — Intermediate and mafic granulite facies gneiss
Orthopyroxene-clinopyroxene-plagioclase-garnet gneiss, locally having hornblende and biotite.

Ymfg — Mafic and felsic gneiss
Mafic, hornblende-bearing gneiss with centimeter-scale, wispy to throughgoing felsic layers. Exposures are sparse in the map area.

PRINTING INSTRUCTIONS

All pages of the document except the geologic plate are 8.5 x 11 inches. The geologic plate is 57 inches wide and 34 inches high. To print the entire document on letter paper, simply execute the print command in Adobe Acrobat Reader or Adobe Acrobat. The geologic plate should automatically be reduced to fit on the letter-sized paper.

If you wish to plot the map at its published size of 57 x 34 inches, open the Acrobat file and display the map. Next, execute the File/Print command. When the print dialog opens click the radio button for “Current Page.” Next, make sure the plotting device is selected as the current printer and open the properties for that device. Navigate to the page setup and select a paper size that is at least 57 x 34 inches. Your plotting device may include the ability to specify the exact dimensions of the paper. If you select paper that is smaller than 57 x 34 inches, the Acrobat Print dialog provides a “fit to page” option that will automatically resize the map to fit on the paper selected. Just keep in mind that the verbal scale will only be correct when the map is printed at its published size of 57 x 34 inches.