GEOLOGIC MAP SERIES, NO.10

Water Resources Agency, University of Delaware

W75° 45′00″ W75 ° 37 ′ 30 ″ REFERENCES This is a map of the crystalline bedrock units in the Piedmont of Delaware and adjacent Alcock, J. E., 1989, Tectonic units in the Pennsylvania-Delaware Piedmont: Evidence Plank, M. O., Srogi, L., Schenck, W. S., and Plank, T. A., in press, Geochemistry of the Pennsylvania. The southern boundary of the mapped area is the updip limit of the from regional metamorphism and structure: Philadelphia, Pennsylvania, mafic rocks, Delaware Piedmont and adjacent Pennsylvania and Maryland: Potomac Formation (Woodruff and Thompson, 1972, 1975). Soil, regolith, and surficial University of Pennsylvania, unpublished Ph.D. dissertation, 251 p. Delaware Geological Survey Report of Investigations No. 60. deposits of Quaternary age are not shown. This map is available in both analog and digital formats from the Delaware Geological Survey (DGS) website; data on individual \_1991, Evolution and assembly of the Pennsylvania Piedmont, West Grove Schenck, W. S., 1997, Stratigraphic classification and nomenclature of the rocks in the rock types can be found in the DGS Data Repository.<sup>1</sup> and Coatesville quadrangles, in Evolution and Assembly of the Pennsylvania-Delaware Piedmont: Newark, Delaware, University of Delaware, Delaware Piedmont Crawford, M. L. and Crawford, W. A. eds.: 8th Annual unpublished M. S. thesis, 106 p. The map incorporates much of the previous work done in the Piedmont (Bascom et Meeting of the Geological Association of New Jersey, p. 5.1-5.19. Schenck, W. S., and Plank, M. O., 1995, Data report on rock cores from Red Mill Road, al., 1909; Bascom and Miller, 1920; Bascom and Stose, 1932; Ward, 1959; Woodruff and Thompson, 1972, 1975; Higgins et al. 1973; Crawford and Crawford 1980; Crawford \_1994, The discordant Doe Run thrust: Implications for stratigraphy and Harmony Road, Prices Corner, and Newport, Delaware: Delaware Geological and Mark, 1982; Wagner and Srogi, 1987; Srogi, 1988; Alcock, 1994; Woodruff and Plank, 1995; and Plank and Schenck, 1997). The map includes the adjacent Pennsylvania structure in the Glenarm Supergroup, southeastern Pennsylvania Piedmont: Geological Society of America Bulletin, v. 106, p. 932-941. Piedmont to show the entire extent of the Mill Creek Nappe and the Arden Pluton. We Smith, R. C., and Barnes, J.H., 1994, Geochemistry and geology of metabasalt in Alcock, J., and Wagner, M. E., 1995, Metamorphic discontinuities in the Pennsylvaniasoutheastern Pennsylvania and adjacent Maryland, in Faill, R. T., and Sevon, W. D. eds., were aided in mapping the geology around the Landenberg and Avondale anticlines by Various aspects of Piedmont geology in Ladncaster and Chester counties, Pennsylvania: Harrisburg, Pennsylvania, Guidebook for the 59th Annual Field Conference of Pennsylvania Geologists, p. 45-72. J. E. Alcock (personal communication, 2000). The amphibolites in Pennsylvania are as Delaware Piedmont; evidence for early Paleozoic assembly: Ottawa, Ontario, mapped in the Pennsylvania Geologic Atlas (Berg and Dodge, 1981). We have attempted National Research Council of Canada, Journal Canadien des Sciences de la to show the larger amphibolite bodies within the Wissahickon Formation in Delaware. Schenck (1997) gives a detailed history of previous geologic work in the Piedmont of Srogi, L., 1988, The petrogenesis of the igneous and metamorphic rocks in the Wilmington Complex, Pennsylvania-Delaware Piedmont: Philadelphia, Berg, T. M. and Dodge, C. M., 1981, Atlas of preliminary geologic quadrangle maps of Pennsylvania: Pennsylvania Geological Survey Map 61, West Grove, Kennett Delaware and adjacent Maryland and Pennsylvania. Pennsylvania, University of Pennsylvania, unpublished Ph. D. dissertation, Our model for the geologic history of the Delaware Piedmont is one of eastward Square, Wilmington North, and Marcus Hook quadrangles. dipping subduction and closure of a forearc basin bringing magmatic arc crust over forearc basin sediments, nearshore deposits, and continental crust during the Taconic Bascom, F., Clark, W. B., Darton, N. H., Kummel, H. B., Salisbury, R. D., Miller, B. L., Wagner, M. E., and Srogi, L., 1987, Early Paleozoic metamorphism at two crustal orogeny. The metaigneous, metavolcanic, and igneous rocks of the Wilmington Complex and Knapp, G. N., 1909, Description of the Philadelphia district-Philadelphia levels and a tectonic model for the Pennsylvania-Delaware Piedmont: represent the magmatic arc, the metasedimentary rocks of the Wissahickon Formation folio: U. S. Geological Survey Geological Atlas of the United States, Folio Geological Society of America Bulletin, v. 99, p. 113-126. represent forearc sediments, and the rocks of the Glenarm Group and Baltimore Gneiss 162, 24 p. with maps, scale 1:62,500. represent Paleozoic nearshore deposits and continental crust of Grenville-age, Ward, R. F., 1959, Petrology and metamorphism of the Wilmington Complex, Delaware, Bascom, F., and Miller, B. L., 1920, Description of the Elkton and Wilmington Pennsylvania, and Maryland: Geological Society of America Bulletin, v. 70, quadrangles, Elkton-Wilmington Folio: U. S. Geological Survey, Geologic Atlas of the United States, Folio 211, 22 p. with maps, scale 1:62,500. Although penetrative deformation and upper amphibolite to granulite facies metamorphism have obscured most igneous fabrics and contact relationships in the Woodruff, K. D., and Plank, M. O., 1995, Geology of the Cockeysville Formation, in Bascom, F., and Stose, G. W., 1932, Description of the Coatesville and West Chester Wilmington Complex, we consider the Brandywine Blue Gneiss, Barley Mill Gneiss, Talley, J. H. ed., Geology and hydrology of the Cockeysville Formation Montchanin Metagabbro, Mill Creek Metagabbro, and Christianstead Gneiss as quadrangles-Coatesville-West Chester folio: U. S. Geological Survey northern New Castle County, Delaware: Delaware Geological Survey, Geological Atlas of the United States, Folio 223, 15 p. with maps, scale metamorphosed plutonic rocks, and the Rockford Park Gneiss, Faulkland Gneiss, and Windy Hills Gneiss as metamorphosed volcanic and volcaniclastic rocks. U-Pb ages of igneous crystallization of zircon for these eight units within the Wilmington Complex Woodruff, K. D., and Thompson, A. M., 1972 (issued 1975), Geology of the Newark area, Delaware: Delaware Geological Survey Geologic Map Series No. 3, Bosbyshell, H., Crawford, M. L., and Srogi, L., 1999, Distribution of overprinting metamorphic mineral assemblages in the Wissahickon group, southeastern range between 488 and 470 Ma. (John N. Aleinikoff, U. S. Geological Survey, personal communication, 2000). Pennsylvania, in Valentino, D. W. and Gates, A. E., eds., The Mid-Atlantic The Arden composite pluton, Bringhurst Gabbro, and Iron Hill Gabbro are probably Piedmont: tectonic missing link of the Appalachians: Boulder, Colorado, \_1975, Geology of the Wilmington area, Delaware: Delaware younger than the other units in the Wilmington Complex because igneous fabrics are Geological Society of America Special Paper 330, 139 p. Geological Survey Geologic Map Series No. 4, scale 1:24,000. preserved, and U-Pb dates on the igneous zircons in the Arden composite pluton are Bosbyshell, H., Sinha, A. K., Crawford, M. L., Fleming, P., Srogi, L., and Lutz, T. M., 1998, Thermal evolution of a convergent orogen; new U-Pb ages of monazite and zircon from the central Appalachian Piedmont [abstract]: Geological Society of reported to be 422+/-6.5 Ma. (Bosbyshell et al., 1998) and 434+/-4 Ma (John N. Wyckoff, D., 1952, Metamorphic facies in the Wissahickon Schist, Aleinikoff, U. S. Geological Survey, personal communication, 2000). Trace elements Philadelphia, Pennsylvania: Geological Society of America in the mafic rocks of the Arden composite pluton indicate the mafic rocks are similar to enriched mid-ocean ridge basalts (E-MORBS) or back arc basin basalts (Plank et al., Bulletin, v. 63, p. 25-58. America abstracts with program, v. 30, no. 7, p. 125. in press), thus they probably intruded during a late-stage rifting event within the arc. Crawford, M. L., and Crawford, W. A., 1980, Metamorphic and tectonic history of the The metasedimentary rocks and amphibolites of the Wissahickon Formation were Pennsylvania Piedmont: Journal of the Geological Society of London, v. 37, deposited in a forearc basin. Geochemistry of the amphibolites indicates they were derived from a variety of magma sources (R. C. Smith and J. H. Barnes, 1994; Crawford, M. L., and Mark, L. E., 1982, Evidence from metamorphic rocks for Pennsylvania Geological Survey, unpublished reports). One type of amphibolite is overthrusting, Pennsylvania Piedmont, U.S.A.: Canadian Mineralogist, v. 20, enriched in Fe and Ti and has trace element compositions similar to intraplate basalts suggesting the magma formed seamounts within the forearc basin. Another type of amphibolite has trace element compositions similar to mid-ocean ridge basalts Higgins, M. W., Fisher, G. W., and Zietz, I., 1973, Aeromagnetic discovery of a Baltimore Gneiss dome in the Piedmont of northwestern Delaware and (MORBs) and E-MORBs. This magma either erupted during rifting within the forearc basin or was preserved in the basin as a remnant of oceanic crust. southeastern Pennsylvania: Geology, v. 1, n. 1, p. 41-43. Metamorphism in the Delaware and adjacent southeastern Pennsylvania Piedmont varies from amphibolite to granulite grade. The highest grade of metamorphism is recorded in the Brandywine Blue Gneiss and the Rockford Park Gneiss in Delaware with Grauert, B., and Wagner, M. E., 1975, Age of the granulite facies metamorphism of the Wilmington Complex, Delaware-Pennsylvania Piedmont: American Journal of the intensity of metamorphism decreasing from there in all directions (Wycoff, 1952; Science, v. 275, p. 683-691. Crawford and Mark, 1982; Wagner and Srogi, 1987; Alcock, 1989; Plank, 1989; Schenck and Plank, 1995; Alcock and Wagner, 1995; Bosbyshell et al., 1999). The decrease Plank, M. O., 1989, Metamorphism in the Wissahickon Formation of Delaware and adjacent areas of Maryland and Pennsylvania: Newark, Delaware, University has also been noted within the Brandywine Blue Gneiss and the Rockford Park Gneiss where granulite gneiss in the City of Wilmington and east of Concord Pike changes of Delaware, unpublished Masters thesis, 111 p. to amphibolite grade gneiss to the north in Pennsylvania (Ward, 1959). Plank, M. O., and Schenck, W. S., 1997, The Setters Formation in the Pleasant Hill The interfingering of possible Wissahickon metasediments (€owf? in the Faulkland valley, Delaware: metamorphism and structure: Delaware Geological Survey Gneiss) with Wilmington Complex volcanic and volcaniclastic rocks plus the identification Report of Investigations No. 56, 15 p. of a small dike of Rockford Park Gneiss that intrudes the Wissahickon Formation in Glenn Mills, Pennsylvania (Bosbyshell et al., 1999), suggests that the Wissahickon Formation and Wilmington Complex came into contact early in history of the arc. Isotopic evidence based on metamorphic zircons in the Brandywine Blue Gneiss constrains the high grade metamorphism to 441 Ma. (Grauert and Wagner, 1975; Wagner and Srogi, 1987) and 432+/-6 Ma (John N. Aleinikoff, U. S. Geological Survey, personal communication, 2000). The metamorphic ages are similar to the igneous ages of the younger plutons that intruded during the rifting event at about 422 Ma and 432 Ma and indicate that the granulite metamorphism was associated with high heat flow developed during arc rifting. Previous studies have modeled the thrust emplacement of the Wissahickon Formation and the folding and thrusting of the Mill Creek Nappe as events that occurred during northwest directed Taconic compression. These events probably represent a continuum beginning with the deformation of the Baltimore Gneiss, the Glenarm units, and the n Formation. As subduction closed the forearc basin between the mag arc and ancient continent, Wissahickon sediments were thrust over developing nappes in the Baltimore Gneiss and its Glenarm cover. Folding continued, and this initial thrust contact was also folded. In a final compressional event, a thrust developed that cut the first thrust and brought the Baltimore Gneiss and Glenarm Group ove Wissahickon to the northwest (Alcock, 1989, 1991, and 1994; Woodruff and Plank, 1995; Correlation of Map Units <sup>1</sup> This map accompanies Delaware Geological Survey (DGS) Report of Investigation No. 59, "Bedrock Geology of the Piedmont of Delaware and Adjacent Pennsylvania." Paper copies of this map as DGS Geologic Map Series No. 10 are available as print on demand from the DGS, or as downloadable digital files from the DGS web site at http://www.udel.edu/dgs. A digital image of the map in Adobe Portable Document File format (PDF) can be found under the "Publications" button. Digital transportation, hydrology, boundary, hypsography, and geology layers in ARCInfo, and ARCView formats can be found under the Technology Transfer button. An Excel file containing the outcrop location, lithology, and strike and dip information is also available through the DGS Data Repository located at the same URL as above under "Publications." N39° 45′00″ Lithologic Descriptions of Map Units Wilmington Complex Sing Iron Hill Gabbro Massive coarse- to very coarse-grained, unmetamorphosed and undeformed, gabbroic dike. Large Black to very dark green, coarse- to very coarse-grained, uralitized olivine-hypersthene gabbronorite and pyroxenite with subophitic textures. Primary minerals are calcic plagioclase, orthopyroxene, dark feldspar grains have pronounced schiller. Intrusive into the Wissahickon Formation; clinopyroxene, and olivine. Amphibole is secondary, a pale blue-green actinolite. Olivine, when however, contact with Wissahickon gneisses is not exposed. present, is surrounded by coronas similar to those in the Bringhurst Gabbro. The gabbronorite is deeply weathered leaving a layer of iron oxides, limonite, goethite, and hematite, mixed with Coarse- to very coarse-grained granitic pegmatite with tourmaline crystals locally. Where outcrop ferruginous jasper. The jasper contains thin seams lined with drusy quartz. Contacts with the Christianstead Gneiss are covered with sediments of the Coastal Plain. Diagonal line pattern on map indicates area covered by Coastal Plain sediments. is present, pegmatite is tabular and concordant with the regional trend of the underlying Wissahickon Formation. Lenticular xenoliths of Wissahickon gneisses occur locally in the pegmatite. Bringhurst Gabbro Interlayered psammitic and pelitic gneiss with amphibolite. Psammitic gneiss is a medium-to fine-grained biotite-plagioclase-quartz gneiss with or without small garnets. Contacts with pelitic gneiss are gradational. Pelitic gneiss is medium- to coarse-grained garnet-sillimanite-limitic gneiss are gradational. Coarse- to very coarse-grained gabbronoite with subophitic textures. Primary minerals are plagioclase, olivine, clinopyroxene and orthopyroxene. Olivine, where present, is surrounded by an inner corona of orthopyroxene and an outer corona of pargasitic hornblende, both with spinel symplectites. The gabbronorites locally contain abundant xenoliths of mafic Brandywine Blue Gneiss. biotite-plagioclase-quartz gneiss. Unit has a streaked or flasered appearance owing to the segregation of garnet-sillimanite-biotite stringers that surround lenses of quartz and feldspar. Arden Plutonic Supersuite Throughout, layers of fine to medium-grained amphibolite composed of plagioclase and hornblende, Ardentown Granitic Suite Explanation of Symbols several inches to <30 feet thick or as large massive bodies are in sharp contact with the psammitic Medium- to coarse-grained granitic rocks containing primary orthopyroxene and clinopyroxene; includes quartz norites, quartz monzonorites, opdalites, and charnockites (nomenclature following Streckeisen, 1976). Feldspar phenocrysts and pelitic gneisses. An attempt has been made to show some of the amphibolites mappable at the scale of the map. Granitic pegmatite is ubiquitous and occurs at all scales. Pyroxene bearing quartzite with garnet occurs locally near the contact with the Wilmington Complex. An ultramafic lens composed of cumulus layers of serpentinized peridotite, metapyroxenite, and metagabbro occurs near Hoopes Reservoir. The ultramafic lens may be correlative with the Baltimore Mafic Complex. common. Mafic enclaves locally abundant in proximity to gabbronorites. Dashed where inferred or concealed Perkins Run Gabbronorite Suite Fine- to coarse-grained gabbronorite and minor diorite with subophitic to ophitic textures, variably foliated or lineated. Plagioclase, orthopyroxene, clinopyroxene, Strike and dip of major foliation or layering, Fine to medium grained amphibolite composed of plagioclase and hornblende in sharp contact with the psammitic and pelitic gneisses. and hornblende are major minerals; biotite and olivine locally present. Olivine dip degrees indicated by number. "ST" indicates typically surrounded by corona structures as described for the Bringhurst Gabbro. dips between 85° and 90°. Metapyroxenite and metagabbro (undifferentiated) ontemporaneous with the Ardentown Granitic Suite. Coarse-grained rocks composed of interlocking grains of light colored, fibrous amphiboles, most likely magnesium-rich cummingtonite and/or anthophyllite with possible clinochlor. These rocks become finer grained and darker as hornblende Strike and vertical dip of major foliation or layering Fine- to medium-grained, equigranular biotite tonalite usually occurring as rounded boulders. Tonalites are leucocratic (15-25 modal percent matic minerals), ligh replaces some of the Mg-rich amphiboles. Associated with the metapyroxenites a gray to buff on fresh surfaces, and locally contain mafic enclaves with reddish rims, coarse-grained metamorphosed gabbros composed of hornblende and plagioclase. The Fault, dashed where inferred.
"D" on down thrown side "I the result of iron hydroxide staining. Possibly intrusive into the Perkins Run metapyroxenites and metagabbros are probably "D" on down thrown side "U" on up thrown side Gabbronorite Suite. **Brandywine Blue Gneiss A** Line of cross section Massive fine-grained dark to light yellow-green serpentinite. Contacts with the Obby Medium- coarse-grained granulites and gneisses composed of plagioclase, quartz, orthopyroxene clinopyroxene, brown-green hornblende, magnetite, and ilmenite. Mafic minerals vary from < 5-30 Wissahickon Formation are not exposed. modal percent. A lineation due to a preferred orientation of quartz and mafic minerals is obvious Thrust fault, dashed where inferred Glenarm Group on weathered surfaces. Unit contains thin, discontinuous fine-grained mafic layers. Cockeysville Marble **Rockford Park Gneiss** In Delaware, predominately a pure, coarsely crystalline, blue-white dolomite marble Fold axis, plunge in direction of arrow Orpg Fine-grained mafic and fine- to medium-grained felsic gneisses interlayered on the decimeter scale. interlayered with calc-schist. Major minerals in the marble include calcite and Layers are laterally continuous, but mafic layers commonly show boudinage. Felsic layers are dolomite with phlogopite, diopside, olivine, and graphite. Major minerals in the composed of quartz and plagic clase with < 10 modal percent pyroxene. Mafic layers contain subequal calc-schist are calcite with phlogopite, microcline, diopside, tremolite, quartz, ₩ U-Pb Age sample locations amounts of plagioclase, pyroxene, and hornblende. Penetrative deformation and granulite facies plagioclase, scapolite, and clinozoisite. Pegmatites and pure kaolin deposits and metamorphism have obscured igneous fabrics and contact relationships. Mill Creek Metagabbro Setters Formation Coarse-grained gabbroic and metagabbroic rocks, variably metamorphosed and deformed. Primary sq In Delaware, predominately an impure quartzite and garnet-sillimanite-biotite-**Location of Study Area** minerals are hornblende and plagioclase. microcline schist. Major minerals include microcline, quartz, and biotite with minor plagioclase, and garnet. Muscovite and sillimanite vary with metamorphic grade. Accessory minerals are iron-titanium oxides, zircon, sphene, and apatite. Coarse-grained gabbroic and metagabbroic rocks, variably metamorphosed and deformed. Primary Microcline is an essential constituent of the quartzites and schists and serves to igneous minerals include olivine, clinopyroxene, orthopyroxene, and plagioclase. distinguish the Setters rocks from the plagioclase-rich schists and gneisses of the Coarse-grained, foliated tonalite gneiss. Major minerals are biotite, hornblende, plagioclase, and quartz. Includes mafic enclaves or layers composed of subequal amounts of hornblende and granitic gneiss with swirling leucosomes and irregular biotite-rich restite layers is the dominant plagioclase. Also includes a coarse-grained granitic lithology composed of biotite, microcline, lithology and constitutes approximately 75 to 80 percent of the exposed rocks. The remaining 20 plagioclase, and quartz. to 25 percent comprises hornblende-biotite gneiss, amphibolite with or without pyroxene, and pegmatite. Granitic gneiss is composed of quartz, plagioclase, biotite, and microcline. Minor and Christianstead Gneiss accessory minerals are garnet, muscovite, magnetite, ilmenite, sphene, apatite, and zircon. The Coarse-grained, foliated granodioritic gneiss. Major minerals are biotite, microcline, plagioclase, and quartz. Includes thin layers of fine-grained foliated amphibolite plus hornblende gneiss contains plagioclase, quartz, hornblende, and biotite with/without orthopyroxene. Accessory minerals are garnet, muscovite, clinozoisite, perthitic orthoclase, iron-titanium oxides, sphene, and apatite. Amphibolites are composed of subequal amounts of hornblende and plagioclase with minor quartz, biotite, clinopyroxene, and orthopyroxene. Ofg Predominantly fine- to coarse-grained amphibolites and quartz amphibolites with minor felsic rocks, probably metavolcanic. Major minerals are amphibole and plagioclase with/without pyroxene and/or quartz. Amphibole may be hornblende, cummingtonite, gedrite, and/or anthophyllite. Halos of plagioclase and quartz around porphyroblasts of magnetite, orthopyroxene, and garnet are common Thinly interlayered, fine- to medium-grained hornblende-plagioclase amphibolite, biotite gneiss, and felsic gneiss, possibly metavolcanic. Felsic gneisses contain quartz and plagioclase +/microcline with minor pyroxene and/or hornblende and/or biotite. Metamorphic grade in this unit decreases from granulite facies in the northeast to amphibolite facies toward the southwest. Correlated with the Big Elk Member of the James Run Formation in Cecil County, Maryland. **Schematic Cross Section** Base maps - Delaware Department of Transportation centerline file 1997) created from Digital Orthophoto Quarter Quads (1997). Pennsylvania Department of Transportation, Streams and Roads (1991). Hypsography - USGS 7.5 - Minute Series Topographic Maps. Created in cooperative agreement between the State of Delaware and the USGS (1991-1993). Coastal Plain Sediments Hydrology - USGS 7.5 - Minute Series Topographic Maps. Created in cooperative agreement between the State of Delaware and the USGS (1991-1993). Map composed by Nicole M. Minni