CORRELATION OF MAP UNITS

DESCRIPTION OF MAP UNITS

af — **Artificial fill**—Sandy and gravelly materials in areas filled for construction of roads, foundations, bridges, and dams.

CENOZOIC AND UPPER MESOZOIC DEPOSITS

Deposits of Present-day Streams and Valleys

Qmsw — **Marsh and swamp deposits, undivided (Holocene)**—Marsh deposits consist of soft mud and marl; sand, medium-gray to dark-gray; may include grayish-brown peat or peaty sand and mud; thickness generally less than 20 ft (6 m). Deposits of swamp and marsh, mapped in parts of Aquia Creek, may be vegetated by rushes and other grasslike plants. Swamp deposits of the Potomac River include brownish-black mud, muddy sand, and muck containing abundant decaying leaf and stem material and trunks of trees. Unit thickly vegetated by shrubs and trees, occurs as a thin veneer less than 10 ft (3 m) thick directly overlying alluvial fill of stream valleys.

Qal — **Alluvium (Holocene and Pleistocene)**—Fine to coarse gravelly sand and sandy gravel, silt, and clay; unit is light gray to medium gray and yellowish gray; clasts consist mainly of vein quartz, quartzite, and other metamorphic rocks. Deposited mainly in channel, point-bar, and flood plain environments; grades into colluvium along steeper valley walls at margins of unit. Unit is thin along and greatly gullied by streams; including Pleistocene terrace deposits. Thickness along major streams is as much as 50 ft (15 m).

Qds — **Sedgefield Member of Tabb Formation (upper Pleistocene)**—Pebbly to bouldery, fine to coarse, crossbedded sand grading upward to sandy and clayey silt; unit is pale gray to medium gray and yellowish gray. Constitutes surficial deposits of low-level terraces (altitude 25 to 33 ft [8–10 m]) bordering Aquia Creek. Thickness is as much as 40 ft (12 m).

Qsh — **Shirley Formation (middle Pleistocene)**—Fine to coarse sand, in part pebbly and bouldery, light-gray to medium-gray and pale-yellowish-gray; grades upward to silty fine sand and sandy silt, pale-gray to pinkish-gray. Constitutes surficial deposits of terraces (altitude 40 to 50 ft [12–15 m]) along Aquia Creek valley. Thickness is 20 to 60 ft (6–12 m).

Marine, Marginal-marine, and Fluvial-deltaic Deposits

Tpw — **Sand and gravel (Pliocene)**—Interbedded yellowish-orange and reddish-brown gravelly sand, sandy gravel, and fine to coarse sand; very poorly sorted to moderately well sorted, commonly trough crossbedded; includes lesser amounts of clay and silt in thin to medium beds. Unit is as much as 35 ft (11 m) thick. Occurs mainly in southern part of map area as small outliers that cap the relatively undissected upland between Accokeek Creek and Potomac Creek. Unit commonly overlies fine sand of the Calvert Formation where it is absent from the upland across the Potomac and into the Piedmont as high-level terrace deposits that directly overlie crystalline rocks. To the south and east of map area, unit composes extensive sheets of fluvial-deltaic sand and gravel constituting surficial deposits of the Coastal Plain uplands. These strata overlie and interfinger(?) with thin nearshore-shelf deposits of the Pliocene Yorktown Formation outside this quadrangle (Mixon and others, 2000).

Tmrg — **Sand and gravel (Miocene)**—Fine to coarse gravelly sand, sandy gravel, silt, and kaolinite clay; unit is gray to light yellowish-gray, commonly weathers to dark yellowish orange, yellowish and reddish brown, and dark red. Pebbles and cobbles are mainly quartz, quartzite, and crystalline rock and are commonly well rounded and deeply etched; crumbly in part. Unit commonly crossbedded; includes areas west of the Thornburg scarp (Mixon and others, 2000) and constitutes the thin Chantilly Formation capping higher hills in southeastern Fairfax County, where gravels directly overlie crystalline rocks. Locally as much as 50 ft (15 m) thick. Gravel deposits, which are thought to be erosional remnants of the Calvert Formation, are present between the Potomac and Tes and the crystalline rocks. Unit is as much as 35 ft (11 m) thick.

Tc — **Calvert Formation (middle and lower Miocene)**—Clayey fine to very fine quartzose sand, variably silty and clayey; interbedded with diatomaceous silty clay and clayey silt; thick-bedded to very thick bedded or massive. In updip areas, basal 4 to 5 ft (1–2 m) of unit is very poorly sorted; very fine to coarse clayey sand containing abundant granules and fine pebbles of quartz and phosphatic; discontinuous, horizontally bedded clay laminae give distinctive, streaked appearance to sandy outcrops. Unsaturated Calvert is medium olive gray to dark olive gray, grayish olive, and dark greenish gray; lower clayey part of unit weathers to a red-mottled light gray; upper sandy part weathers to a pale yellow, pale yellowish orange, or white. In the map area, the Calvert successively overlies, from southeast to northwest, the Nanjemoy, Aquia, and Potomac Formations; thus, the unconformity at the base of the Calvert is a major erosional unconformity. Near Shelross Shop and Mountain View, the Calvert beds lap across the Potomac Formation onto crystalline rocks of the outer Piedmont including the Garrisonville Mafic Complex (Ogrg) and the Richland Run (Qsg) and Potomac Creek (Ppr) plutons. Thickness ranges from 50 ft (15 m) or more in the eastern part of the map area to a feather edge at the Piedmont overlap. Age of unit based on studies of planktonic foraminifera and diatom and mollusca assemblages (Martin, 1972; Andrews, 1988).

Tn — **Purnsley Group (Nanjemoy Formation, Marlboro Clay, and Aquia Formation)**

Over much of the Coastal Plain part of the map area, a thin to thick blanket of glauconite sand and silt of marine origin unconformably overlies the eroded, irregular surface of the Lower Cretaceous Potomac Formation. These glauconitic strata were named the Purnsley Formation by N.H. Darton (1891) for the extensive exposures along the Purnsley River in the vicinity of Purnsley, Virginia, and Nanjemoy Creek in Charles County, Maryland. These stratigraphic units are thought to be the Potomac River, Clark and Martin (1901, p. 60) also recognized a thin but laterally very extensive pink to red clay, referred to informally as the Marlboro Clay, which separates the Aquia and Nanjemoy glauconitic greensand sequences.

Tnj — **Nanjemoy Formation (lower Eocene)**—Glauconitic quartz sand, very fine to fine, very clayey and silty, micaceous, contains fairly abundant small concretions of iron sulfide; unit is commonly intensely bioturbated, shelly in part; includes a few thin, discontinuous beds of limestone. Fresh exposures are dark olive gray, greenish gray, and olive black; weathers yellowish brown. Only the lower member (Potapaco) of the Nanjemoy (Ward, 1985; Mixon and others, 2000) is present in the southeastern corner of the map area where poorly exposed outcrops are mapped as the Nanjemoy Formation. Thickness of the Nanjemoy unconformably overlies the Marlboro Clay and, locally, where the Marlboro has been removed by erosion, the Aquia Formation. Maximum Formation thickness in the map area is only about 30 ft (9 m). The updip limit of the Nanjemoy Formation is the southeastmost strand of the Brooke fault zone.

Tm — **Marlboro Clay (upper Paleocene)**—Kaolinitic silty clay and clayey silt, light-gray to dark-gray, lightbrown, and pale-red to reddish-brown. Appears massively bedded, but cores and weathered outcrops show laminated to thin-bedded character of unit. Clay is commonly interbedded with lesser amounts of laminated and ripple-cross-laminated fine silt; small scour channels filled with sandy silt occur locally in updip areas. Rare molds of small mollusks, agglutinated foraminifers, a few diversity, discoid assemblage, and the freshwater alga Pseudoschizaea indicate a brackish-water depositional environment. Gradational contact with underlying Aquia Formation is commonly marked by interbedding, over a 2- to 3-ft (0.5- to 1.0-m)-thick interval, of thin beds of kaolinitic Marlboro Clay and fine sand of the Aquia Formation. Unconformable relation with overlying Nanjemoy Formation indicated by abrupt, chevron contact and by large, sand-filled burrows extending from base of Nanjemoy downward for 2 to 8 ft (0.6–2.4 m) or more into the Marlboro Clay. Spectromorph data (Frederiksen, 1979) from lower part of Marlboro indicate a late Paleocene age. The Marlboro Clay is present only in extreme southeastern corner of map area where it is preserved on downthrown side of Brooke fault zone. Thickness ranges from less than 1 ft (0.3 m) to about 20 ft (6 m). Unit is shown by symbol Tm at top of underlying Aquia Formation

Ta — **Aquia Formation (upper Paleocene)**—Glauconitic quartz sand, fine to medium, variably clayey and silty, thick- to very thick bedded or massive, sparsely to abundantly, finely, Fresh exposures are light olive gray to dark olive gray, olive black, and greenish black; weathers to yellowish gray, grayish yellow, grayish orange, and reddish brown. In the southeastern, downdip part of the map area, the Aquia sand is commonly interbedded with a few thick beds of sandy and shelly limestone; locally, in shelly beds of updip areas, silica replaces calcium carbonate as the cementing material; unit is locally hard, flinty rock. Unconformable contact relations between Aquia Formation and underlying Potomac Formation is commonly marked by fine to coarse pebbles in basal Aquia. Formation thickness ranges from a few feet in the northwestern corner of the map area to 70 ft (21 m) or 18 ft (5.5 m) on the downthrown, eastern side of the Brooke fault zone.

Kp — **Potomac Formation (Lower Cretaceous)**—Includes three main sediment types. Type 1 consists of fine to coarse kaolinitic quartz sand and sandstone, thick- to very thick-bedded, trough crossbedded, poorly sorted; clay-silt matrix constitutes as much as 40 percent of sediment. Fresh exposures are light olive gray to olive gray; weathers to various shades of other metamorphic rocks. Outcrops are very light gray to medium gray or pinkish gray; fresh core material may be greenish gray or bluish gray. Locally, white to light gray, well-cemented sandstone forms discontinuous low cliffs or rocky outcroppings. Intraformational conglomerates containing pebble-size clasts of clay and silt are common; locally, clay-silt boulders up to 3 ft (1 m) in diameter suggest undercutting and caving of channel banks. Type 1 sediments are interpreted as channel-lag and channel-bar or point-bar deposits. Type II sediments consist of clay and silty clay, clayey silt, and clayey fine sand; unit is greenish gray, commonly mottled red or reddish brown; clay minerals are mainly illite and smectite. Commonly forms clay-silt plugs, 3 to 20 ft (1–6 m) thick and 7 to 65 ft (2–20 m) wide, within a dominantly medium to coarse sand sequence; clay plugs are believed to have formed by filling of abandoned stream channels (cutoffs) by fine sediments during flood stages. Cuffed stems of a plant, Frenelopsis (Ward, 1985), are common in Type II sediments. Type III, siliceous clay, occurs in lenses and lenticular beds of dark-gray/olive black to olive-gray, lignitic sandy silt, clay, and silty fine sand and sandstone. Buggy in part. Occurrence as thin to thick beds associated with type I sediments suggests deposition in swales of point bars and in swampy areas of flood plains. Types I and III sediments may contain well-preserved leaf and stem impressions of ferns, cycadophytes, conifers, and the angiosperm Frenelopsis (table 1). Thickness of Potomac Formation ranges from a feather edge at western limit of outcrop belt to about 600 ft (182 m) in the subsurface at the eastern part of the map area. Analysis of pollen (Frederiksen, 1979) and leaves from the Potomac beds in and near the map area indicate an Early Cretaceous (Barremian?), Aptian, and Albian age for outcrop and subsurface strata (Doyle and Hickey, 1976; Doyle and Bierman, 1975)

PALEOZOIC AND PROTEROZOIC ROCKS OF THE PIEDMONT

Metasedimentary and Metavolcanic Rocks

Ol — **Lunga Reservoir Formation (Ordovician)**—Metadiamictite (metamorphosed sedimentary mélange) consisting of nonstratified pebbly, micaceous, quartzofeldspathic metagraywacke with granule- to boulder-size clasts of metasedimentary and metaigneous rock are supported. Characterized by abundant polycrystalline, granoblastic quartz lenses that are commonly flattened as clasts, also contains chips and pebbles of gneiss and schist, some of which have internal foliation affwart that of surrounding matrix. Some metaconglomerate exposures contain clasts of metamafic rock, including greenstone, thought to be derived from the Catoctin Formation. Age is Ordovician (Pavlides, 1989, 1995, 2000). Unit interpreted by Pavlides (1989, 2000) as part of a back-arc basin.

Ogrg — **Quartz mylonite and ultramylonite (Ordovician)**—Light-gray to medium-gray, very fine grained, thin-bedded, metamorphic alteration is less intense, and metamorphosed ernstatite-bearing pyroxenite, websterite, and norite are locally present (Pavlides, 1995, 2000). Interpreted as part of a volcanic arc (Pavlides, 1981, 2000) or a remnant of oceanic crust (Pavlides, 1989, p. 180).

Ogn — **Gneiss of the Potomac Creek pluton (lower Paleozoic or Neoproterozoic?)**—Gray, fine-grained to medium-grained, foliated and lineated, biotite-quartz-plagioclase gneiss of tonalitic, dioritic, or granodioritic composition. Includes accessory epidote, sphene, garnet, and minor muscovite. Contains thin (<1 cm) granitoid layers concordant with gneissic foliation (Pavlides, 1980, fig. 4), concordant granitoid and pegmatite layers up to 25 ft (8 m) thick, and irregular granitoid masses (Pavlides, 2000, p. 5). Petrographic, geochemistry, and geochronology have not been studied; contact relations undetermined due to poor exposure. Previously mapped and described as tonalite gneiss (Pavlides, 1980, pl. 1), granodioritic gneiss (Pavlides, 1995; Pavlides, 2000, p. 5), or diorite gneiss (Pavlides, 1990; Mixon and others, 2000), and inferred to intrude either Ta River Metamorphic Suite (Pavlides, 1980, pl. 1) or Po River Metamorphic Suite of Mathews (Pavlides, 2000, p. 5). Exposed in southwestern corner of quadrangle

EXPLANATION OF MAP SYMBOLS

Contact—Dotted where concealed

Structure contour—Drawn at the base of the Aquia Formation. Contour interval 10 ft

FAULTS

Fault—Sense of displacement not known

High-angle fault—Dashed where inferred; dotted where concealed; U, upthrown side; D, downthrown side. Arrows show relative strike-slip movement

Thrust fault—Sawteeth on upper plate; dashed where inferred; dotted where concealed

FOLDS

Foliation folds—Showing axial trace, direction of dip of limbs and plunge direction, where known or inferred. Foliation may be parallel to bedding and (or) compositional layering

Anticline

Syncline

Minor folds

Anticline

Syncline

Dorsal or Z-fold

PLANAR FEATURES

(May be combined with linear features; some symbols show positions of outcrops measured before flooding by artificial lakes)

Strike and dip of bedding

Inclined

Vertical

Overturned

Strike and dip of compositional layering

Inclined

Vertical

Strike and dip of cleavage

Inclined

Vertical

Strike and dip of joints—Two or more sets shown at point of intersection

Inclined

Vertical

Strike and dip of phyllitic foliation—Includes semi-schistosity and transposition foliation

Inclined

Vertical

Strike and dip of early schistosity

Inclined

Vertical

Strike and dip of magmatic flow foliation

Inclined

Vertical

LINEAR FEATURES

(May be combined with planar features)

Bearing and plunge of inclined late mineral lineation

Bearing and plunge of horizontal late mineral lineation

OTHER SYMBOLS

(Provide control for cross section)

U.S. Geological Survey corehole—TD=Total depth, in feet

U.S. Geological Survey auger hole

Water well—G, geophysical log; L, lithic log; TD=Total depth, in feet

U.S. Geological Survey trench and borehole that exposed Dumfries fault zone near Stafford. Va. Detail in figure 2

Potomac Electric Power Company trench that exposed upper part of Dumfries fault zone

Roadcut exposure that showed vertical Cretaceous strata on downthrown side of Dumfries fault zone, Va. Route 630

Outcrops in high-voltage electric line, Dumfries fault zone

Paleocene fossiliferous limestone locality

Cretaceous palynomorph locality

Cretaceous megafossil plant locality (table 1)

Radiometric age determination (uranium-lead zircon) for Chopawamsic Formation (Horton and others, 1998)

Active quarry (Vulcan Materials Company Stafford quarry)

DISCUSSION

INTRODUCTION

The Stafford 7.5-min quadrangle, comprising approximately 55 square miles (142.5 square kilometers), is located in northeastern Virginia, in about 40 miles (64 km) south of Washington, D.C. The region's main north-south transportation corridor, which connects Washington, D.C., and Richmond, Virginia, crosses the quadrangle. U.S. Highway 1, and the heavily used CSX and Amtrak railroads. Although the northern and eastern parts of the Stafford quadrangle have undergone extensive suburban development, the remainder of the area is still dominantly rural in character. The town of Stafford is the county seat.

The Stafford 7.5-min quadrangle is located in the Fredericksburg 30×60' quadrangle, where information on the regional stratigraphy and structure is available from Mixon and others' (2000) geologic map and multisheet explanatory text. In addition to straddling the "Fall Zone" boundary between the Appalachian Piedmont and the Atlantic Coastal Plain provinces, this quadrangle contains the best preserved and best exposed segment of the Stafford fault system, an important example of late Cenozoic faulting in eastern North America (Mixon and Newell, 1977). This 1:24,000-scale geologic map provides a detailed framework for interpreting and integrating topical studies of that fault system.

Our geologic map differs from two decades of intermittent geologic mapping and related investigations by the authors in this part of the Virginia Coastal Plain. Earlier mapped in the Piedmont by Pavlides (1990) has been revised by additional detailed mapping in selected areas, particularly near Abel Lake and Smith Lake, and by field evaluation of selected contact relations.

GEOMORPHIC SETTING

The Stafford quadrangle encompasses parts of two very different geologic provinces—the Appalachian Piedmont to the west and northwest and the Atlantic Coastal Plain to the east and south. The Piedmont province consists of steeply dipping, metamorphosed sedimentary, volcanic, and intrusive rocks having a pronounced northeast-trending structural grain. Fresh, unweathered rock, exposed in the deeper stream valleys and in the deeper quarry pits, is commonly hard and resistant to erosion. The gentler slopes and ridge tops are covered by a mantle of soft decomposed rock (saprolite), as much as 40 ft (12 meters [m]) thick, derived by weathering of the underlying crystalline rock. The surface of the crystalline rock is irregular but dips eastward at low angles (generally less than 10 inch [inch]). Saprolite is commonly thicker and more complete stratigraphic units, their paleontology and age, environments of deposition, and geologic history, have been described in reports by Mixon and others (1992, 1998b, 1999, 2000); Reinhardt and others (1980a,b); Ward (1985); and Weems and others (1986).

By far the greater volume of sediment in the dominantly crossbedded, lithofacies sands and sandstones assignable to the Potomac Formation (Kp). Coarse channel-lag and channel-bar deposits and clay plugs indicate deposition in coalescing streams. Well-preserved leaves and stems of ferns and cycads, and silicified trunks of large conifers indicate abundant vegetation. About 20 to 30 mi (35–50 km) east of the Stafford quadrangle, where the Lower Cretaceous sedimentary basin is much deeper, Bauld-Keller (personal commun., 1998) interpreted the Potomac Formation of the Chesapeake Bay as a coastal plain, at least in part, as the mouth of a drowned river. The continental deposits of the Potomac Formation are overlain with great erosional unconformity by sediments of the Pamunkey Group, which consist mainly of thick-bedded or massive glauconitic quartz sand of marine origin. In the eastern part of the quadrangle, mollusks are concentrated in thick to very thick beds suggesting shoal-shelf depositional environments. In western updip areas, however, black heavy mineral laminations, burrows of the Ophiomorpha nodosa type, and small bars composed of clean, well-sorted sand become more common upward in the section—indicating shoaling-upward marine waters.

The Calvert Formation (Tc) includes three to very fine quartzose sand, variably silty and clayey, interbedded with thick- to very thick bedded, diatomaceous silty clay and clayey silt. Unit is dark olive gray and greenish gray and commonly contains fish teeth and scales, bones of marine vertebrates including whales, poorly to well-preserved diatom floras, and foraminifera. Diatomaceous deposits commonly reflect a shallow-shelf, nearshore environment with a fair amount of nutrients available.

STRUCTURES OF THE COASTAL PLAIN

The Stafford quadrangle is the type area of the Stafford fault system, a series of en echelon, northeast-trending, high-angle reverse faults that extend for approximately from northern Spotsylvania County, Virginia, northeastward along the inner edge of the Coastal Plain for 42 mi (68 km) to Newington in southern Fairfax County, Virginia (see Mixon and others, 2000; Davis and others, 2002). The dominantly compressional faulting includes both the ancient crystalline rocks of the northeastern Piedmont and the overlying, much younger sedimentary formations of the Virginia Coastal Plain (Mixon and Newell, 1977, 1982; Sanders and Mixon, 1981). The few outcrops of the faults commonly show steeply northwest-dipping to vertical fault planes along which the Piedmont metamorphic rocks are upthrown at high angles over unconsolidated Lower Cretaceous sands of the Potomac Formation (Kp). Although vertical displacement of strata by individual faults is moderate (20–200 ft [6–61 m]), the Stafford faults appreciably affect the present distribution and thickness of Coastal Plain formations. For example, between Aquia Creek and Potomac Creek, the southeasternmost fault of the Brooke fault zone has caused the Paleocene and Eocene strata to be much thicker in the downthrown block than in the upthrown block. This abrupt change in thickness of Paleocene and Eocene strata is shown by the Marlboro Clay (Tm) and the Nanjemoy Formation (Tn) (fig. 1). On the southeastern, downthrown side of the fault, the lower and middle Miocene Calvert Formation (Tc) overlies the Lower Eocene Nanjemoy Formation. On the northwestern, upthrown side of the fault, the Miocene beds directly overlie the upper Paleocene Aquia Formation. Thus, the Marlboro and the Nanjemoy beds were eroded from the upthrown side of the fault during middle Eocene to early Miocene time. These relations indicate a middle Tertiary episode of deformation in this region.

ECONOMIC GEOLOGY

The Stafford map area is important economically because of its abundant water resources including two freshwater reservoirs (Smith Lake and Abel Lake) that supply much of the drinking water for Stafford County. The subsurface water supply depends mainly on water-sands drilled into the Potomac aquifer which is recharged, in part, through the extensive, sandy outcrop belt of the Potomac Formation (see Mixon and others, 2000).

Fine-grained to coarse-grained intrusive rock of the Garrisonville Mafic Complex (Ogrg), quarried about 2 mi (3 km) west of the town of Garrisonville, is an abundant source of crushed stone used for road metal and other construction purposes. Rocks of the Chopawamsic Formation contain gold and base-metal massive sulfide deposits of submarine volcanic exhalative origin (Pavlides and others, 1982), but no such deposits have been mined in this quadrangle.

In the early 19th century, building stone from sandstone of the Lower Cretaceous Potomac Formation was obtained from small quarries on Government Island at the head of tidewater on Aquia Creek. The stone was used originally in construction of part of the U.S. Capitol Building and part of Aquia Church, which is about 2 mi (3 km) north of Stafford along U.S. Highway 1. Rapid weathering and structural failure of stone used in the Capitol building have led to the removal of the stone.

Table 1.—Floral list compiled for Potomac Formation from shallow excavation about 2 mi (3 km) south-southwest of Stafford County Courthouse, in the southwest quadrant at the intersection of Interstate I-95 and Va. Route 628. The location of these floras is indicated by the 8th symbol on the map.

[Plant fossil identifications by L.J. Hickey, written commun., 2003]

Ferns:
Anaspiroptiridium oustum Fontaine
Onychiopsis goeppertii (Schenk) Berry

Cycadeoids:
Dioonites buchianus (Ettingshausen) Bornemann
Nageiopsis zamioides Fontaine
Nilssonia densinervse (Fontaine) Berry
Scleropteris elliptica Fontaine

Conifers:
Araucarites sp.
Sphenolepidium sp.

Angiosperm:
Frenelopsis crassinervse Fontaine

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Rocks of igneous intrusive origin in the Stafford quadrangle are variably metamorphosed. They include tonalitic to dioritic and granodioritic gneiss of the Potomac Creek pluton (Pzlgn), amphibolite and hornblendite of the Garrisonville Mafic Complex (O2gsv), quartz mylonite (Ogrg), and metamorphosed equigranular metatonalite of the Richland Run pluton (Qsg), and muscovite-biotite granite (S2ogr). The muscovite-biotite granite (S2ogr) is interpreted to crosscut rocks of the Garrisonville Mafic Complex and Richland Run pluton on the basis of map relations.

The metamorphic rocks in the quadrangle have not been mapped in detail. In general, pelitic mineral assemblages in the Quantico Formation, and mafic mineral assemblages in the Chopawamsic Formation, Garrisonville Mafic Complex, and amphibole metagabbro show an increase in metamorphic grade from the northeast to the southwest (Pavlides, 2000). Schist of the Quantico Formation contains minor garnet in the northern part of the quadrangle and staurolite + garnet in the southern part, where kyanite + quartz veins also are locally present (Pavlides, 1995). $^{40}Ar/^{39}Ar$ dating of hornblendes along the same metamorphic gradient near Fredericksburg, Va., indicates that this metamorphism was a late Paleozoic (Alleghanian) event (Sutter and others, 1985).

STRUCTURES OF THE PIEDMONT

Foliation and Minor Structures

An overview of the structural geology, including foliations, lineations, and small folds, as well as regional folds and faults, is provided by Pavlides (1995, 2000). The northeast-trending Quantico synclinorium is cored by the Quantico Formation and is well defined across most of the Fredericksburg 30×60' quadrangle (Mixon and others, 2000). In the Stafford 7.5-min quadrangle, however, the outcrop of the Quantico Formation is relatively narrow and contains a series of alternating synforms and antiforms rather than a single synformal axis. The other folds shown on this map do not appear to be major regional structures.

Piedmont Faults

Chopawamsic thrust fault.—The Chopawamsic fault is interpreted to be an early Paleozoic thrust fault that emplaced the Chopawamsic volcanic-arc terrane onto the rifted margin terrane of the Mine Run Complex (Pavlides, 1989