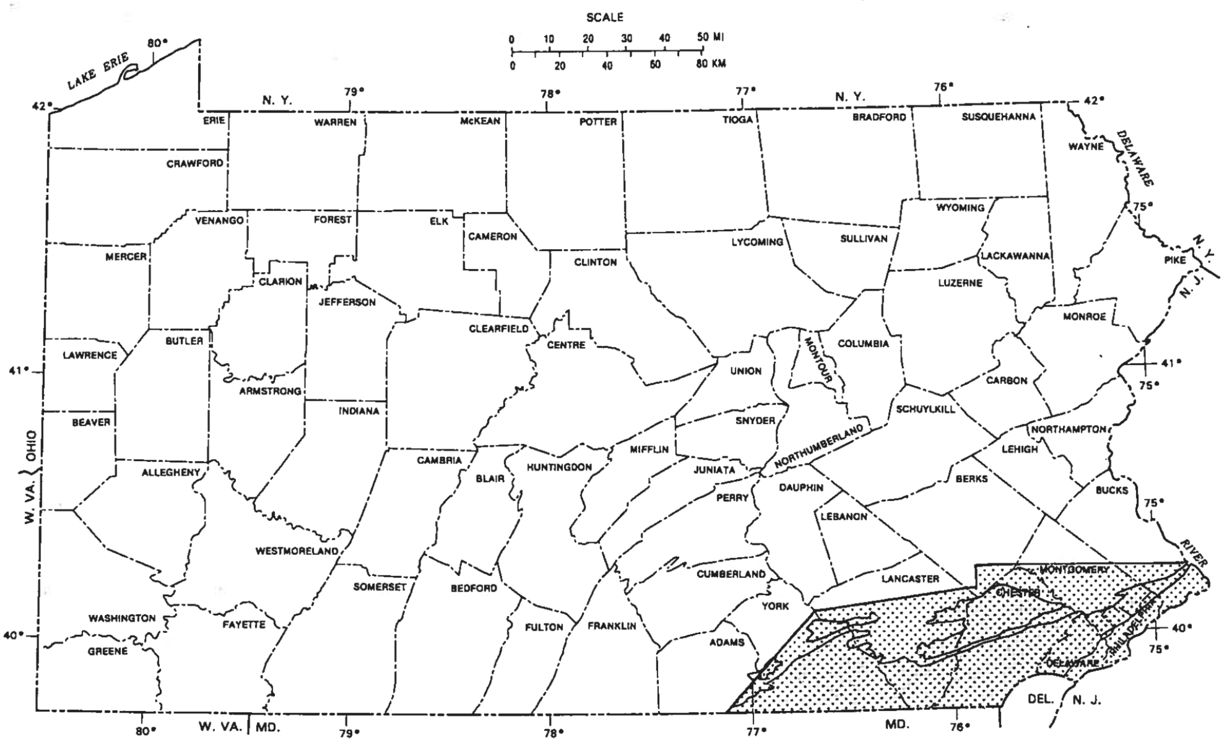

Figure 16–1. Location of the Piedmont Upland section (color) and the area shown in Figure 16–2 (stippled).

CHAPTER 16 PIEDMONT UPLAND

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INTRODUCTION

The Piedmont Upland section of the Piedmont physiographic province (Figure 16–1) is underlain by a group of metamorphosed and complexly deformed sedimentary, volcanic, and plutonic rocks and associated unmetamorphosed intrusive igneous bodies. As described in Chapter 3A, the metamorphosed units range in age from late Precambrian through early Paleozoic. The youngest intrusive rocks are Jurassic. For easy reference, the Piedmont Upland is subdivided into the Northern and Southern Uplands, which are separated by the Piedmont Lowland. Figures 16–2 and 16–3 show that the western part of the Piedmont Upland is overlain by Cambrian and Ordovician metacarbonate rocks, the eastern part is overlapped by Mesozoic clastic sedimentary strata on the north, and the southeastern part is overlapped by Cretaceous, Tertiary, and Quaternary sands and gravels of the Coastal Plain.

In the Piedmont Upland, the dominant structural grain trends northeast to east-northeast. The region consists of a series of thrust-bounded nappes and slabs that juxtapose rocks of various ages and degrees of metamorphism. These are described in more detail below. Superimposed on these thrust slabs, broad arches generate linear outcrop belts of Precambrian gneisses (metamorphosed during the Grenville orogeny, about 1,000 Ma) in the Honey Brook-Mine Ridge anticlinorium in the Northern Upland and the Buck Ridge-West Chester-Avondale anticlinorium in the Southern Upland (Figures 16–2 and 16–3). Between these structures lies a synclinorium consisting of the Whitemarsh syncline and, along strike to the southwest, the Peach Bottom synform. The Chester Valley, south of the Honey Brook Upland, is underlain by the northern limb of this fold. Major subvertical northeast-striking faults, including the Brandywine Manor fault, the Cream Valley fault, the Huntington Valley fault, and the Rosemont fault (Figure 16–2), cut through the blocks containing Grenville-age gneisses and juxtaposed them against younger rocks. Smaller scale structures, including minor folds, foliations, and lineations in the metamorphic rocks, generally parallel the regional structural trend.

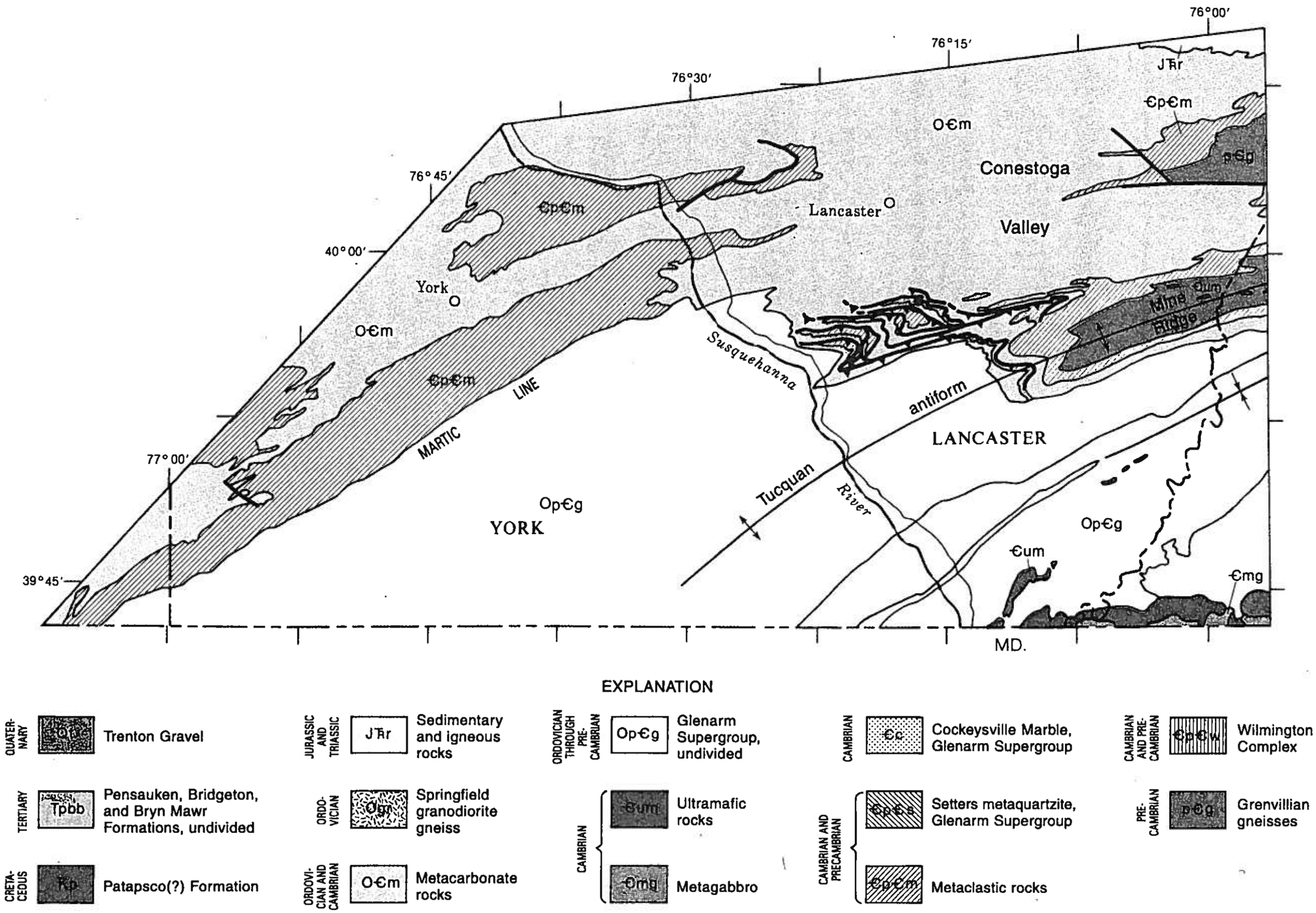

Figure 16–2. Geological features of the Piedmont Upland. Contacts and faults are modified from Berg and others (1980). Features identified by number are (1) Honey Brook anorthosite and (2) Arden pluton. Cross sections are shown in Figure 16–3.

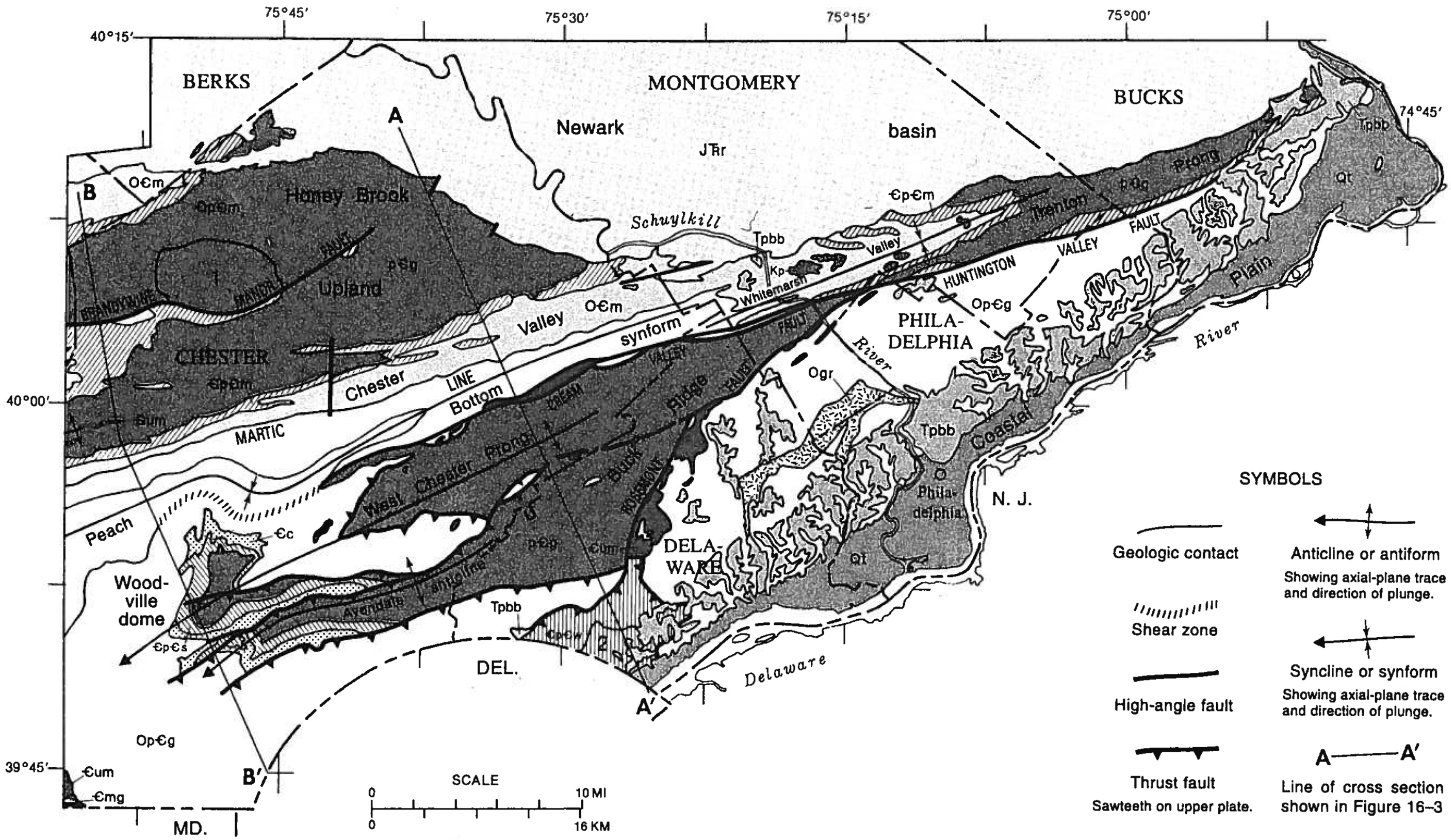

Figure 16–2. ***(Continued).***

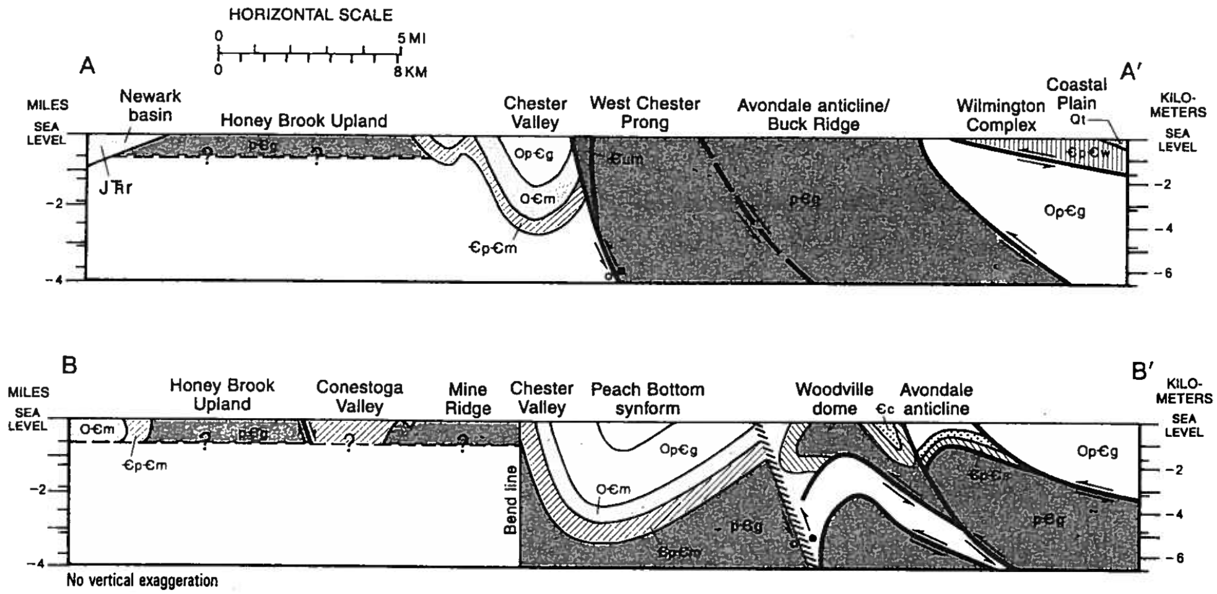

Figure 16–3. Generalized geologic cross sections through the Piedmont Upland. The lines of section are marked and patterns for lithologic units are explained on Figure 16–2. Thrust motion is indicated by arrows. Transcurrent motion is indicated by dots and circles: dot, motion toward viewer; circle, motion away from viewer. Units shown on Figure 16–2 that are of very limited extent or thickness are not shown in the cross sections.

NORTHERN UPLAND

In Mine Ridge and in the part of the Honey Brook Upland north of the Brandywine Manor fault, little is known of the structure because of very limited exposures. The region of the Honey Brook Upland south of the Brandywine Manor fault has more exposure, but detailed structural information is lacking. The principal structural elements of the crystalline rocks are a pervasive foliation (Figure 16–4) and compositional banding (Figure 16–5), which strike N75°E and dip steeply to the south. In some outcrops, the banding is isoclinally folded (Figure 16–6). The same trend characterizes the axial-plane orientation of isoclinal folds in the overlying late Precambrian through lower Paleozoic metasediments (Figure 16–2), and hence these folds developed during the Taconic orogeny in the Late Ordovician, or later. Aeromagnetic data (Crawford and Hoersch, 1984) suggest that the anorthosite massif in the northern part of the Honey Brook Upland (Figure 16–2) has steep contacts with the country rocks and that, from its eastern contact, the anorthosite extends a couple of miles under a thin cover of charnockite.

The following information suggests that the Honey Brook Upland and Mine Ridge are not rooted and are, perhaps, less than 1 km (0.6 mi) thick (Figure 16–3): (1) Only shallow rock units (less than 600 m [2,000 ft] deep) of appropriate susceptibility contrast were needed for computer modeling of aeromagnetic data for the anorthosite massif in the northern part of the Honey Brook Upland (Crawford and Hoersch, 1984); (2) the general pattern of magnetic anomalies in the Honey Brook Upland is similar to that of Mine Ridge and quite distinct from those of the Chester Valley and the Southern Upland, except possibly in the area of the West Chester Prong and the Avondale anticline (see Chapter 3A and Figure 16–2) (U.S. Geological Survey, 1978; Hoersch and Crawford, 1988); (3) a preliminary gravity profile across the Honey Brook Up-

Figure 16–4. Foliated gneiss characteristic of Mine Ridge, along U.S. Route 30E bypass, west of Coatesville, Chester County.

land (Hoersch and Crawford, 1988) shows only the prevailing regional trend; and (4) a preliminary Bouguer anomaly map of Mine Ridge has no anomaly patterns that can be associated with the surficial geology and also shows only the prevailing regional trend (Hoersch and Crawford, 1988).

SOUTHERN UPLAND

The Grenville-age (1,000 Ma) gneisses south of the Chester and Whitemarsh Valleys occur in the Buck Ridge-West Chester-Avondale anticlinorium and reappear to the southwest in Maryland in the Baltimore-Washington anticlinorium. The gneisses of the Avondale anticline, the Woodville dome, and the Wilmington Complex, the rocks of the State Line ultramafic complex, and the metasedimentary rocks that surround them were tectonically emplaced as a series of ductile nappes and thrust slabs transported toward the North American continent before or during the Late Ordovician Taconic orogeny (about 440 Ma) (Wagner and Srogi, 1987; Figure 16-3). The stacked pile of thrust slabs and nappes was subsequently deformed by the uplift of the underlying basement, now exposed in the uparched and upfaulted blocks of the West Chester Prong and the eastern end of Buck Ridge. The age of this uplift is not known but is younger than the thrusting.

The uppermost thrust slab crops out in the southeasternmost exposed portion of the Piedmont. It contains the Wilmington Complex, which overlies the Wissahickon Formation (part of the Glenarm Supergroup) and has a nearly planar subhorizontal contact (Srogi, 1982). Crawford and Mark (1982) and Wagner and Srogi (1987) suggested that this contact is a major thrust fault (cross section A–A′ in Figure 16–3). North and west of the Wilmington Complex, the gneisses of the Woodville dome and the western end of the Avondale anticline, which are mantled by the Glenarm Supergroup, are in the cores of northwestward-directed recumbent nappes with sheared-off lower limbs (Mackin, 1962; cross section B–B′ in Figure 16–3). The Wissahickon schists that lie between the Wilmington Complex and the Woodville dome and Avondale anticline appear to lie in a separate thrust sheet (Alcock, 1994). The State Line ultramafic complex that lies along the Pennsylvania-Maryland border east of the Susquehanna River (Figure 16–2) is the northern edge of a similar group of thrust sheets and nappes mapped in the Maryland Piedmont (Fisher and others, 1979). The timing of the thrusting is not clear. The Wilmington Complex appears to have been emplaced no later than the Late Ordovician Taconic metamorphism (Crawford and Mark, 1982; Wagner and Srogi, 1987). As noted in the previous section, the emplacement of the Mine Ridge-Honey Brook Upland slab may have occurred during the same time interval.

Figure 16–5. Banded and foliated amphibolite-facies gneiss of the Honey Brook Upland, Little Conestoga Road, west of Marsh Creek Lake, Chester County.

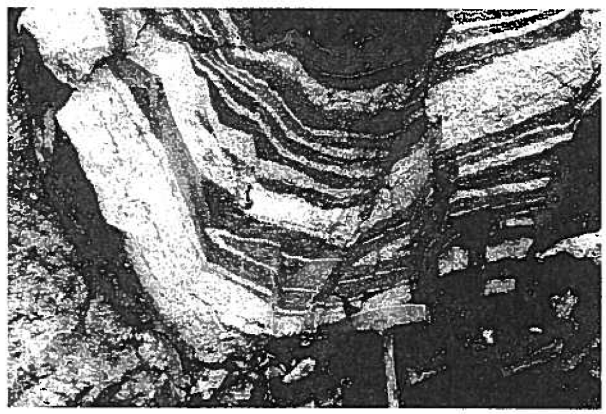

Figure 16–6. Isoclinal folds in gneiss in the Honey Brook Upland, at the spillway on Marsh Creek Lake, Chester County.

The rocks of Grenville age (1,000 Ma) in the core of the Buck Ridge-West Chester-Avondale anticlinorium are bounded by three steeply dipping faults: Cream Valley, Huntington Valley, and Rosemont (Figure 16–2). These three faults are interpreted to be related to vertical uplift of blocks of basement gneiss subsequent to nappe emplacement. The West Chester Prong is an upright anticline having a steeply overturned northern limb cut by the Cream Valley fault (see cross section A–A′ in Figure 16–3). The fault separates Grenville-age granulite- and amphibolite-facies rocks on the south from greenschist-facies rocks of the Glenarm Supergroup on the north. Slivers of amphibolite-facies Wissahickon Formation schists are caught up in the fault zone. Wagner and Srogi (1987) suggested that the West Chester Prong is autochthonous or parautochthonous; Elliott and others (1982) and Fisher (personal communication, 1982) suggested that this block forms a hanging-wall anticline. The West Chester Prong anticline also folds the overlying Woodville and Avondale nappes of Grenville-age basement and metasediments of the Glenarm Supergroup as shown by the hook pattern of the Woodville dome (Figure 16–2; cross section B–B′ in Figure 16–3). The Huntington Valley fault appears to be the eastward continuation of the Cream Valley fault (Bascom and others, 1909; Armstrong, 1941). It separates Baltimore Gneiss overlain by the Chickies and Ledger Formations on the north from Wissahickon Formation schist on the south. The Buck Ridge block is bounded on the southeast by the steeply dipping to vertical Rosemont fault. Textures in the metamorphic rocks along the faults suggest that faulting occurred after the peak of metamorphic activity and, therefore, was post-Ordovician.

The Wissahickon Formation has been complexly deformed. Along Wissahickon Creek, east of the Schuylkill River in northwestern Philadelphia, Amenta (1974) recognized three major episodes of deformation that coincided with the metamorphism of the schist. Weiss (1949), Amenta (1974), and Tearpock and Bischke (1980) noted that the structures dip to the northwest throughout much of the eastern part of the Wissahickon Formation schist belt (southeast of Buck Ridge and east of the Wilmington Complex) and steepen to vertical adjacent to the Rosemont and Huntington Valley faults. Foliations in the schists adjacent to and west of the Wilmington Complex also dip to the northwest, but near the Avondale anticline to the north, they dip southeast.

The greenschist-facies phyllite of the Octoraro Formation that lies between the Buck Ridge-West Chester-Avondale anticlinorium and the Chester and Whitemarsh Valleys is interpreted as representing a low-grade metamorphic equivalent of the Wissahickon Formation. The late Precambrian through Ordovician metaclastic and metacarbonate rocks of the Chester and Whitemarsh Valleys and the Octoraro phyllite lie in a syncline bounded by the Precambrian blocks of the Honey Brook Upland and Mine Ridge on the north, the West Chester Prong on the south, and the Trenton Prong to the east (Figures 16–2 and 16–3). The south limb of the syncline is cut off by the Cream Valley fault west of the Schuylkill River.

The nature of the contact between the Octoraro phyllite and the Cambrian and Ordovician metacarbonate rocks of the Chester and Whitemarsh Valleys has been the subject of considerable debate and controversy. This contact is part of the Martic Line (Figure 16–2) and was interpreted as an overthrust by Knopf and Jonas (1929). The controversy arises in part because the age of the Glenarm Supergroup is unknown for certain and in part because the contact is poorly exposed. Detailed mapping by Cloos and Hietanen (1941) in the area between the end of Mine Ridge and the Susquehanna River, where Knopf and Jonas (1929) defined the Martic thrust, led them to conclude that the Martic Line is not a thrust fault but is simply the contact between the lower Paleozoic carbonate formations and the overlying phyllite. There is no evidence of any major stratigraphic offset at this contact either in the footwall or in the hanging wall. Cloos and Hietanen (1941) did, however, identify a series of north or northeasterly directed thrusts west of the end of Mine Ridge and south of Lancaster (Figure 16–2) that repeat the lower Paleozoic section north of the Martic Line. On the other hand, recent work (Lyttle, 1982; Duffy and Myer, 1984) supports the hypothesis advanced by Knopf (1931) that the phyllites, at least in part, have been tectonically deformed and recrystallized. Along the Susquehanna River, Freedman and others (1964) presented evidence that the phyllite-carbonate contact, whatever its nature, predates the deformation that has affected all units. Hill (1989) agreed with this interpretation and suggested that the deformation and low-grade metamorphism in a zone 1 to 3 km (0.5 to 2 mi) wide in the vicinity of the Martic Line is a feature associated with dextral-transcurrent movement along a ductile shear zone (cross section B–B′ in Figure 16–3). Because the deformation and metamorphism occurred later than the metamorphic and structural features associated with the Taconic orogeny, this shearing is post-Taconic in age.

Freedman and others (1964) pointed out that, in the Northern Upland, the uplift of Mine Ridge arched upward the formerly south-dipping foliations of the overlying late Precambrian through Ordovician clastic and carbonate metasediments (Tucquan antiform; see Figure 16–2). Therefore, in this area also, uplift of the basement-cored blocks is a relatively late event.

The Peach Bottom fold, cored by the Peters Creek Formation, the Cardiff Conglomerate, and the Peach Bottom Slate (all of the Glenarm Supergroup), is another controversial feature. Poor exposure has frustrated regional mapping in the southwestern Piedmont on either side of the Susquehanna River. Some workers (Knopf and Jonas, 1929; Agron, 1950; Southwick, 1969) classified the fold as a syncline based on their interpretation of stratigraphic relations. Higgins (1972), however, argued that sedimentary structures demonstrate that the fold is anticlinal. An analysis of the aeromagnetic map of the area (Fisher and others,

1979) suggests that units of the Wissahickon Formation in this region can be distinguished based on their magnetic signatures. Using this as a guide, Fisher and others (1979) concurred with the analyses of Freedman and others (1964) and Wise (1970), which suggest that much of the Piedmont south and west of the end of Mine Ridge is characterized by refolded folds; the Peach Bottom fold is one of these (see cross section B–B′ in Figure 16-3). Fisher and others (1979) included the Peters Creek Formation with the youngest subdivision of the Wissahickon and hence retained the interpretation that the Peach Bottom fold is synclinal. According to their interpretation, the metavolcanic units (part of the Wissahickon Formation) that crop out in the western Piedmont, in York County, also lie in the core of a synclinal structure.

TECTONIC INTERPRETATIONS

From the structural data, the authors interpret the tectonic evolution of the Piedmont Upland to reflect sedimentation along a late Precambrian-early Paleozoic stable continental margin, followed by tectonic transport of the offshore and continental-margin sedimentary units and of the crystalline rocks of the continental-margin basement toward the continent in thrust slabs and nappes. This tectonic telescoping was initiated by the emplacement of the Wilmington Complex, the base of a hot slab of metamorphic and igneous rocks, possibly the root of a volcanic arc. The Wilmington Complex thrust slab is analogous to the thrust slice containing the James Run volcanic rocks in the Maryland Piedmont, which were emplaced in a similar stratigraphic position (Crowley, 1976). The formation of large-scale recumbent nappes and thrust slices affected the entire lower Paleozoic section as far north as the northern boundary of the Great Valley (Chapters 4 and 18). The time of emplacement of the Avondale and Woodville nappes and of the Mine Ridge-Honey Brook Upland slab has not been established but must be 440 Ma (Taconic orogeny) or older. Metamorphism accompanied and outlasted the thickening of the crust by thrusting and nappe emplacement. Subsequently, the Piedmont units were uparched and upfaulted to produce the major upright anticlinoria and synclinoria. The timing of this is uncertain, but it was a postmetamorphic process. Potassium-argon dates (Lapham and Root, 1971) demonstrate that the metamorphic rocks had cooled significantly by Mississippian time. These data and the large volume of clastic material in the Silurian through Pennsylvanian units in the Appalachian Mountain section of the Ridge and Valley province suggest that uplift of the Piedmont occurred throughout the middle Paleozoic.

PROBLEMS AND FUTURE RESEARCH

A thorough study of structures in the Northern Upland and structures in the Southern Upland of Bucks, Lancaster, and York Counties is long overdue. Past and present work focuses primarily on the central part of the region.

As indicated in Chapter 3A, more detailed studies of the metamorphic histories of the rocks in the Piedmont Upland will help to decipher the history of burial and subsequent uplift during the Grenville and Taconic orogenies. The ages of deformational events are virtually unknown. A careful geochronological study is needed to determine the timing of faulting and other deformation. The age of the Glenarm Supergroup in Pennsylvania also remains unknown. This problem must be solved before the controversy concerning the nature of the contact between the Octoraro phyllite and the Cambrian and Ordovician metasediments that lie north of that phyllite (the Martic Line) can be resolved.

A series of ground magnetometer traverses across the ultramafic bodies should provide information concerning their shape and orientation in three dimensions. In Mine Ridge, as well as in the Southern Upland, this, in turn, might allow one to deduce the relationship between these bodies and shallow thrust faults.

RECOMMENDED FOR FURTHER READING

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