CHAPTER 4 EOCAMBRIAN, CAMBRIAN, AND TRANSITION TO ORDOVICIAN

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INTRODUCTION

During latest Precambrian and Early Cambrian time, a great thickness of clastic sediments was deposited on an older Precambrian complex of igneous and metamorphic rocks. Later, from the Middle Cambrian into the Early Ordovician, a carbonate bank extended along the shelf edge in Pennsylvania, and deeper water sediments accumulated to the east and southeast. Stratigraphic and petrologic summaries of sections across Pennsylvania indicate the varied sedimentologic and tectonic settings and some of the problems that will require future research.

TECTONIC SETTING

North America was unusually stable during the latest Precambrian to earliest Paleozoic, and marine waters slowly transgressed across the continent during this time. In Pennsylvania, this transgression resulted in the deposition of a wedge of terrigenous sediments (Chilhowee Group) along the continental margin during much of the latest Precambrian and nearly continuously into Early Cambrian time (Figure 4–1). These rest unconformably on older sediments and volcanics, and their deposition was followed by that of several thousand feet of shelf carbonates (Figure 4–2). Part of the region from eastern Pennsylvania to western Massachusetts was positive during most of the Early Cambrian and was not covered by the sea until Middle Cambrian time.

Several nearly contemporaneous lithofacies developed in depositional belts that paralleled the margin of the Cambrian craton (Palmer, 1962, 1971). Nearest the craton was an inner detrital belt consisting of coarse clastics eroded from the cratonic mainland to the west and northwest (Goodwin and Anderson, 1974). Beyond this was a carbonate belt consisting principally of clean carbonate sediments

with oolites and algal stromatolites, suggesting clear shallow water on shelf-edge banks. Seaward of these banks was an outer detrital belt consisting of two lithofacies. Deposition immediately adjacent to the carbonate bank resulted in the formation of black shales and thin argillaceous limestones. Sporadic lenses of angular carbonate blocks occur in this lithofacies and appear to be chaotic slumps fallen from the shelf edge (Rodgers, 1968). Farther offshore, graywackes, shales, and interbedded volcanic rocks formed (Figure 4–3). Many of these rocks are intensely folded and metamorphosed, and they are generally less understood than those of the other belts. Northwestward thrusting of these rocks has superimposed them on the nearer shore facies (see Chapter 18).

ENVIRONMENTS OF DEPOSITION

Interpretation of the environments of deposition for the Eocambrian to Early Ordovician units in Pennsylvania varies in difficulty, depending upon the degree of metamorphism, amount of exposure, and detail to which each unit has been studied.

Fossils are rare to absent in most of the Chilhowee Group, except for burrows of *Skolithos* and *Monocraterion*. Because this group lies unconformably on top of basement rocks, and because it grades conformably upward into units containing a typical Early Cambrian fauna, it commonly is considered to be late Precambrian or Eocambrian in age. This group typically has a basal conglomeratic member, the Hellam Member, which is locally absent. The Hellam is overlain by a vitreous, white, quartz-rich sandstone member (Chickies Formation) containing *Skolithos* tubes. This sandstone member is represented in other areas by the Weverton Formation, the Hardyston Formation, and the Montalto Member of the Harpers Formation (Figure 4–4). Slaty beds are common in parts of the Chickies Formation, especially in York County. Goodwin and Anderson (1974) considered the Chickies Formation to be a tidal-zone accumulation.

The Early Cambrian seas transgressed in a generally northwesterly direction. The sandy coastal deposits are represented by the Eocambrian Chickies Formation in southeastern Pennsylvania, the Eocambrian Weverton Formation and Montalto Member of the Harpers Formation in south-central Pennsylvania, and the late Middle Cambrian Potsdam Sandstone in western Pennsylvania.

Other clastic units within the Chilhowee do not lend themselves as easily to environmental interpretation. The Harpers Formation commonly consists of phyllite and has few, if any, sedimentary structures. The phyllite may represent a lagoonal deposit associated with the tidal-zone deposits of the Chickies and related formations.

The Antietam Formation has an irregular outcrop pattern throughout southeastern Pennsylvania. This outcrop pattern commonly has been interpreted as fault controlled (Bascom and Stose, 1938, and others). Kauffman and Frey (1979) suggested that it could partly reflect the original depositional pattern. They postulated that the Antietam was a barrier island because of its discontinuous and lenticular outcrop pattern in some areas, its low-angle cross-lamination, its pattern of grain-size distribution, and the presence of storm deposits, and because it interfingers with lagoonal sediments of the Harpers Formation.

Carbonate shelf deposits, which lay to the east of the inner detrital belt, onlapped the craton toward the northwest in a manner similar to the transgression of beach sands in the Chilhowee Group as the continental margin subsided. A deeper, partially euxinic basin to the southeast may have been bordered on its southeast during parts of its existence by a landmass (Africa?) or a volcanic island complex that shed clastics and volcanic-rich sediments in a westerly direction into the basin.

The Conestoga Formation in the Lancaster County region may be a deeper water facies, east of and correlative with part of the carbonate bank formations (Figure 4–3). In addition, the Conestoga may be correlated with part of the Glenarm Supergroup, including the Cockeysville Marble, in part, and a portion of the Wissahickon Formation (Figure 4–4).

The Kinzers Formation has yielded a rich assemblage of Early Cambrian fauna, including various species of brachiopods, molluscs, echinoderms, and especially trilobites, such as *Olenellus*, *Paedeumias*, and *Wanneria*. Fossils of Middle Cambrian age, especially *Ogygopsis klotzi*, have been reported from black shales that were thought to be in the upper part of the Kinzers (Campbell, 1971) but that have more recently been interpreted as the Long's Park Tongue of the deeper water Conestoga.

The Cambrian carbonate sequence, with its cyclic pattern of deposition, mud cracks, dolomites, and algal-laminated bedding, probably represents a shallow-water carbonate bank or shelf that was subjected to periodic episodes of near-drying conditions.

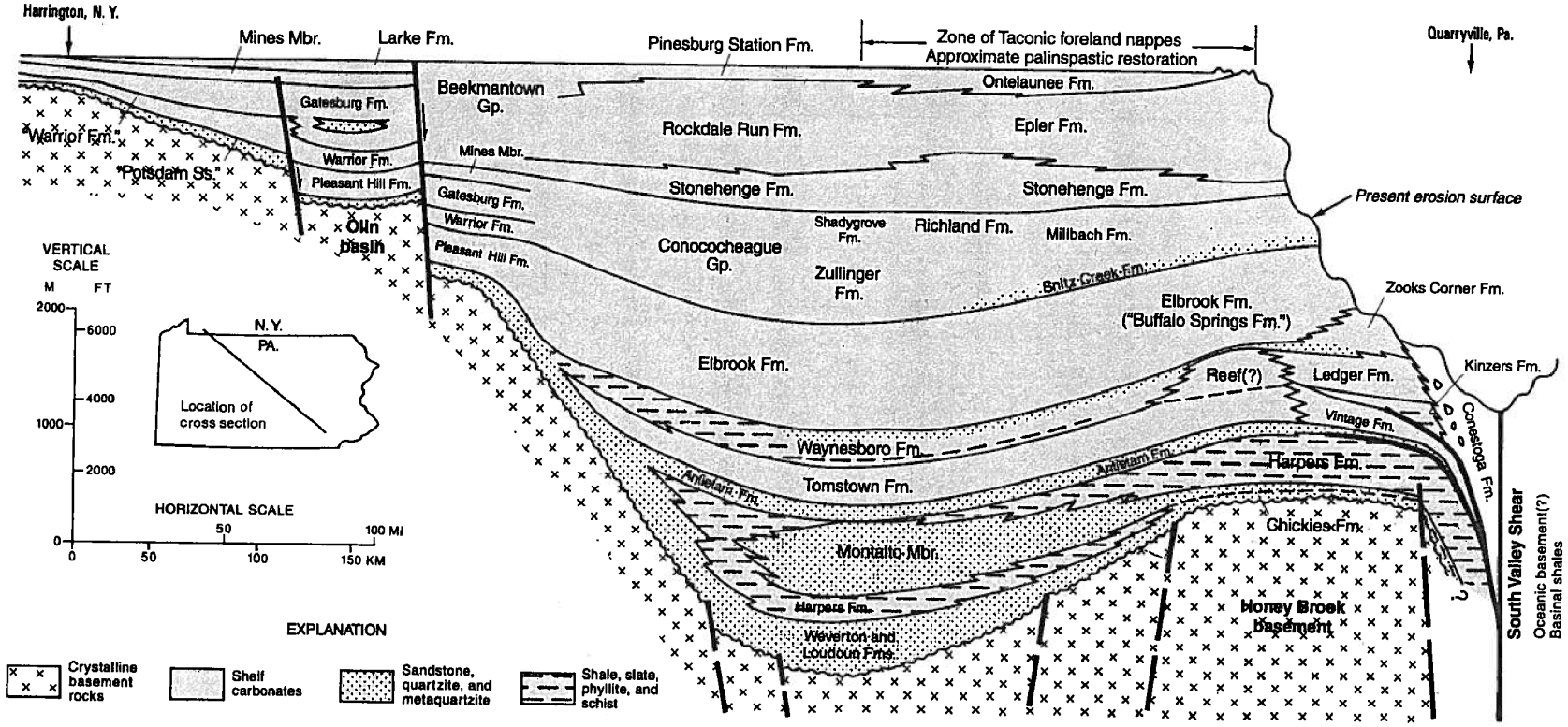


Figure 4–3. Generalized reconstruction of Eocambrian to Lower Ordovician formations. Cross section is not palinspastically restored for Alleghanian shortening east of the Allegheny Front and displacement along Alleghanian décollements in the area of the Taconic nappe zone. Eastern half is modified from MacLachlan (1994, Figure 1, p. 9). Western half is modified from Rankin, D. W., and others (1989), *Pre-orogenic terranes,* in Hatcher, R. D., Jr., and others, eds., *The Appalachian-Ouachita orogen in the United States,* The Geology of North America, v. F–2, Figure 12, p. 51. Western half is modified with permission of the publisher, the Geological Society of America, Boulder, Colorado USA. Copyright ©1989 Geological Society of America.

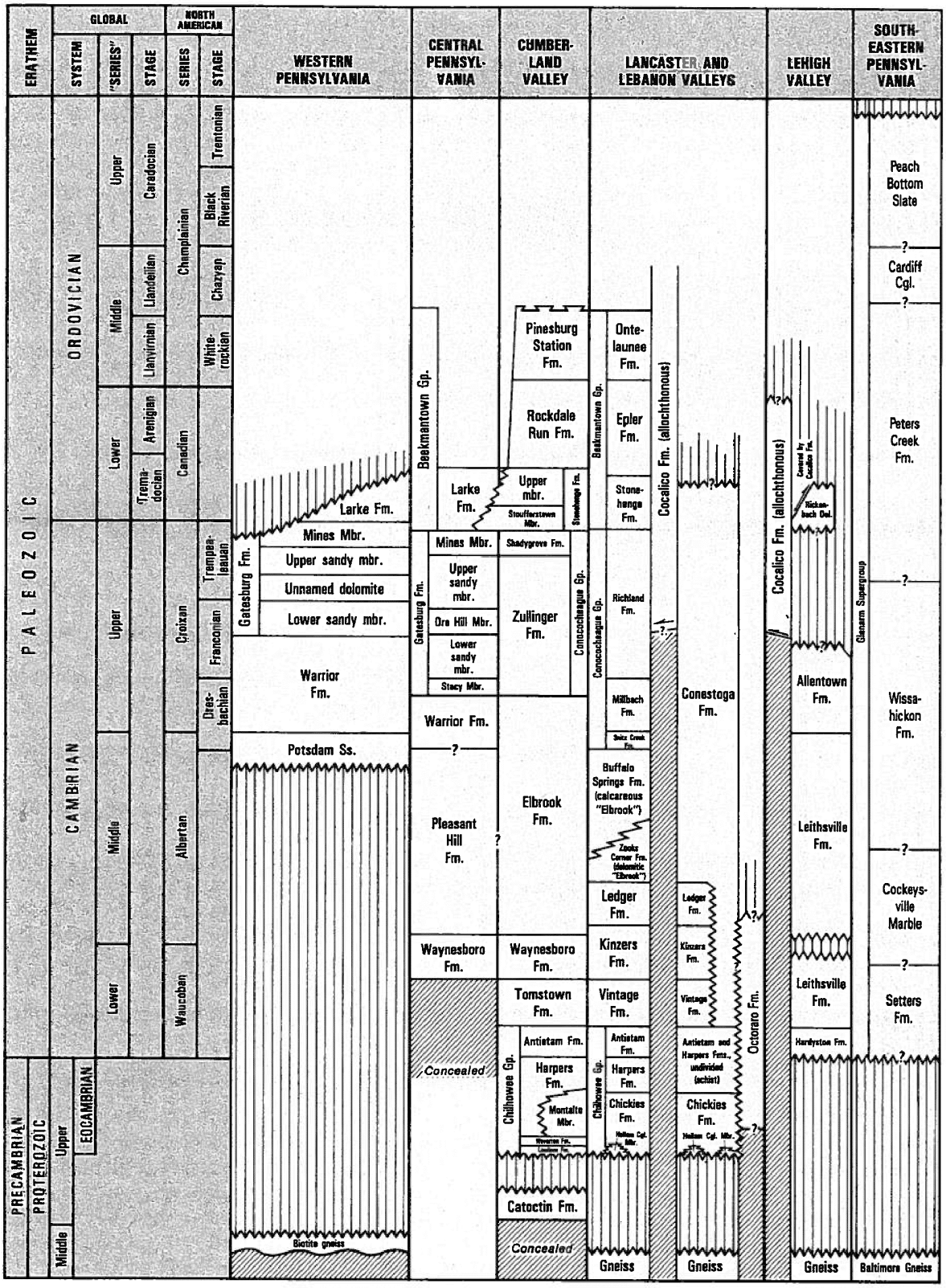


Figure 4-4. Correlation of Eocambrian to Lower Ordovician formations (modified from Berg, McInerney, and others, 1986).

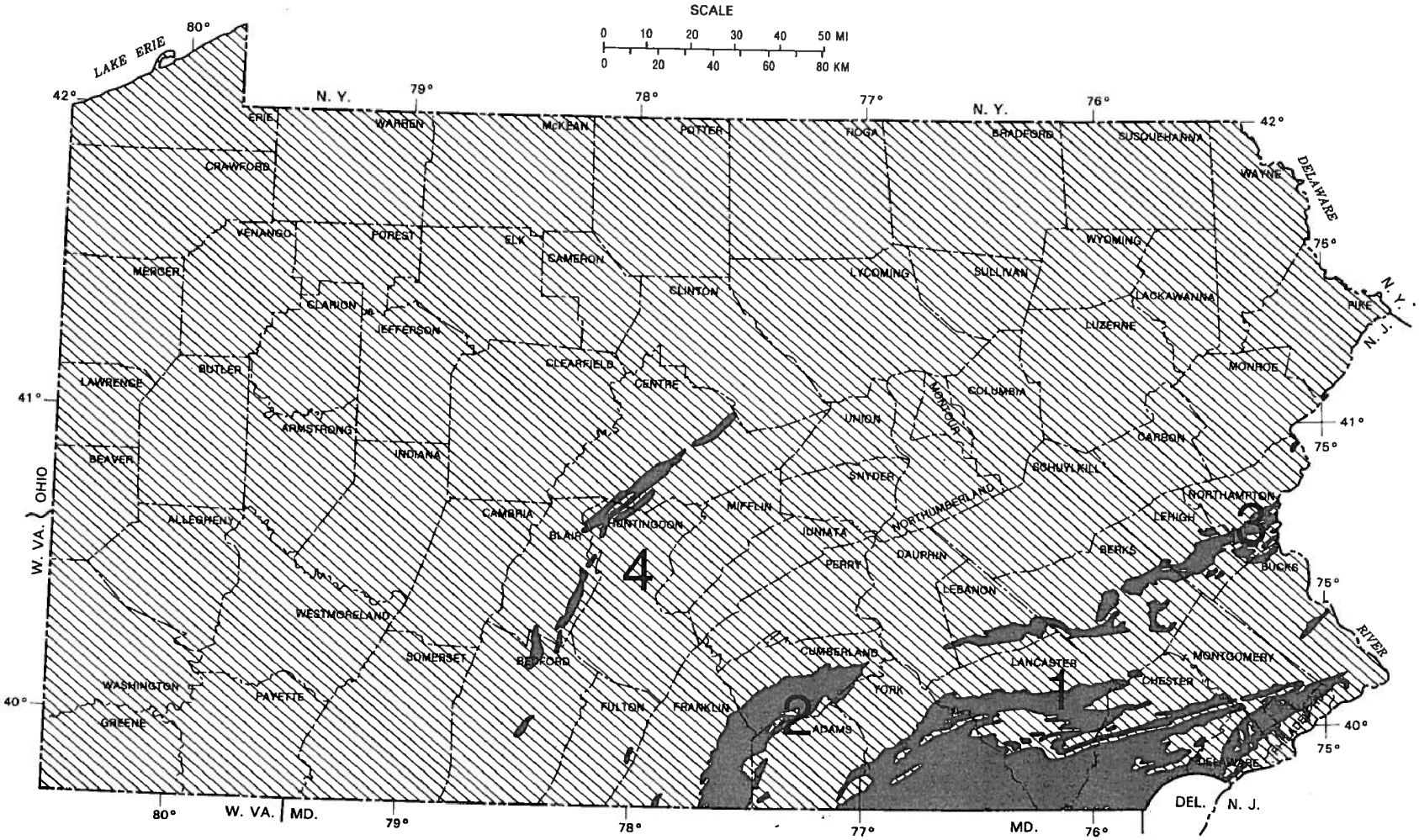


Figure 4–5. Map of areas containing Eocambrian to Lower Ordovician formations in Pennsylvania. Areas of outcrop are indicated by the solid color (from Pennsylvania Geological Survey, 1990). The diagonal line pattern denotes areas containing the same units in the subsurface. The locations of units discussed in the text are as follows: (1) Lancaster-Lebanon Valley and Piedmont; (2) Cumberland Valley and South Mountain; (3) Lehigh Valley; and (4) central and western Pennsylvania.

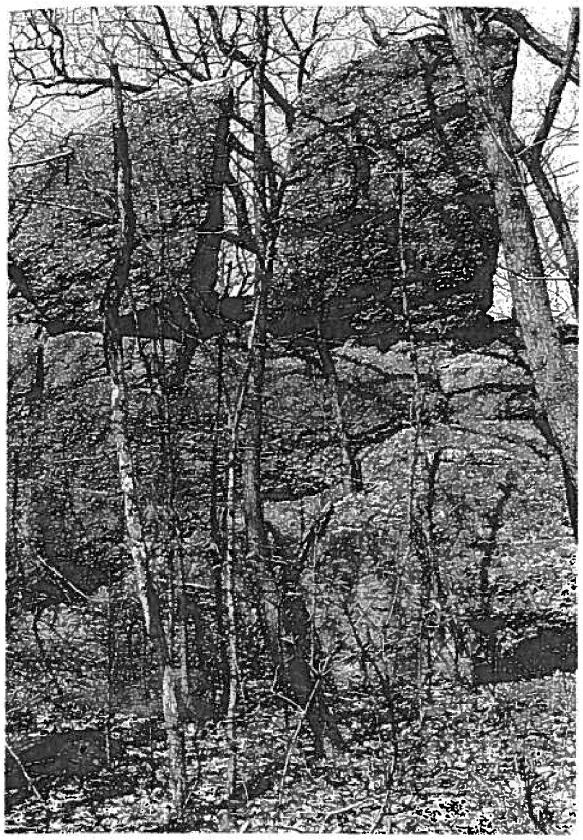


Figure 4–6. Quartz-pebble conglomerate beds of the Hellam Conglomerate Member of the Chickies Formation, Chimney Rock, York County. Photograph by A. R. Geyer.

in the region. Thus, the sedimentary units conformable below the Antietam are commonly called Eocambrian to distinguish them from the true Cambrian. The upper part of the Antietam is characterized by well-laminated, calcareous metaquartzite with rust-colored iron oxide pockets and molds of fossils. The formation varies in thickness from 0 feet to as much as 300 feet. It commonly forms elongate, discontinuous topographic highs along its strike. These ridges are, in places, terminated and offset by faults. In other places, the discontinuous nature may be caused by variations in its original depositional thickness.

The beginning of a tremendous thickness of carbonate rocks is marked by the Vintage Formation, a thick-bedded to massive, finely crystalline, gray dolomite. It commonly contains fine, wavy, siliceous or argillaceous laminae. Some beds appear knotty or mottled (Figure 4–9), having lighter and darker siliceous and calcareous masses in a finely crystalline dolomite matrix. These beds commonly weather to pinnacle surfaces. The crystal faces cause "sparkling" reflections on some surfaces. Locally, other lithologies are interbedded with the typical dolomites, including white, pinkish-gray, and medium-gray limestones and some finely crystalline marbles.

Overlying the Vintage Formation is a unit containing shale, limestone, and dolomite called the Kinzers Formation. The lower part is dominantly medium- to dark-gray shale (Figure 4–10) with rusty partings. The upper part is dominantly limestone.

Overlying the Kinzers Formation are light-gray dolomite beds of the Ledger Formation. The Ledger is

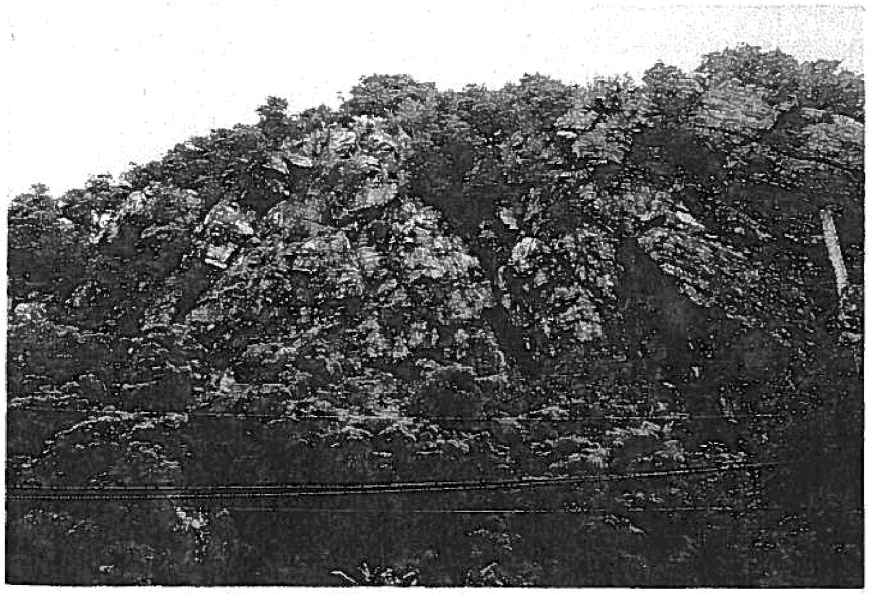


Figure 4–7. Chickies Rock, an anticline of massive-bedded metaquartzite layers, 3 miles north of Columbia, Lancaster County, along the east bank of the Susquehanna River.

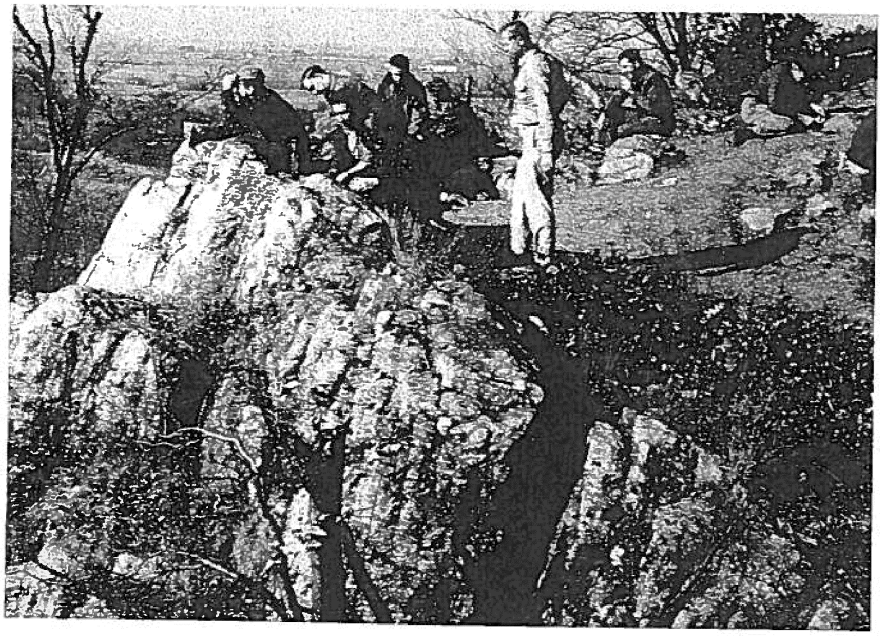


Figure 4–8. Chickies Formation at the top of Chickies Rock, the type locality (same location as Figure 4–7). Bedding dips gently to the right; fracture cleavage dips steeply to the left. Identifiable figures include R. M. Foose, standing in the center foreground, and A. R. Geyer, head bent over, second from the left. Photograph from the archives of the Department of Geology, Franklin and Marshall College, Lancaster, Lancaster County.

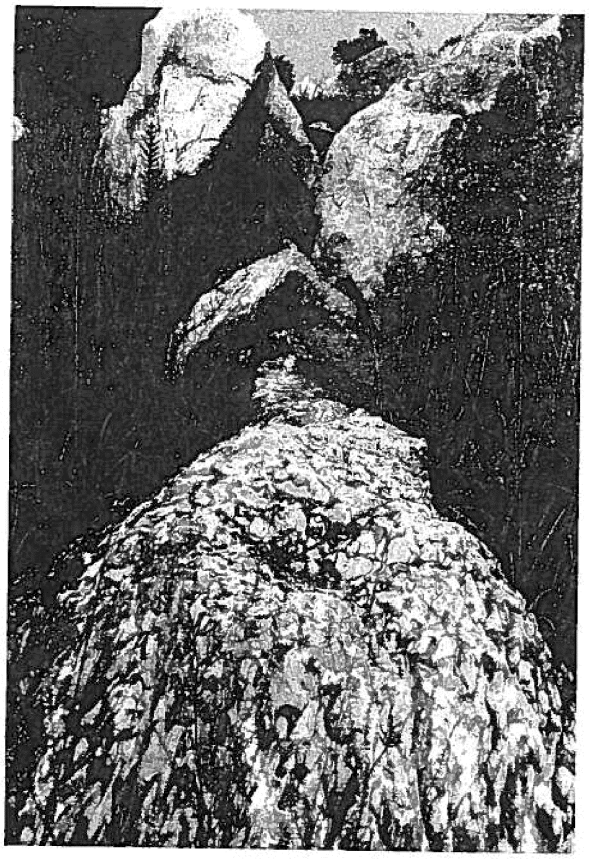


Figure 4–9. Mottled beds of the Vintage Formation, weathering to a pinnacle surface, in a borrow pit along Pa. Routes 272 and 283, 2 miles northwest of Lancaster, Lancaster County.

dominated by massive-bedded, medium- to coarsely crystalline, sparkling dolomite (Figure 4–11). In fresh exposures, the rock commonly exhibits dark mottling. Near the middle of the formation, oolitic (Figure 4–12), siliceous, or cherty beds occur. This formation weathers to a dark, deep-red, granular clay soil, commonly containing residual, fine quartz grains and fine crystals of dolomite.

Conformably overlying and interbedded with the Ledger Formation is the Zooks Corner Formation. The dominant lithology is thin- to thick-bedded, medium-gray, very finely crystalline dolomite. The dolomite may be locally white to dark gray and silty or sandy. There are sporadic occurrences of dolomitic sandstones. Some siliceous and argillaceous laminae occur throughout the formation. Primary sedimentary structures include small-scale cross-lamination, ripple marks, graded bedding, mud cracks, and some rip-up clasts. Within the formation are some limestones, commonly with thin dolomite laminae. Near the base are white, light-gray, and pink to rust-colored dolomites. The Zooks Corner Formation is approximately 1,600 feet thick at its type locality in Lancaster County.

The interbedded limestone and dolomite sequence that is gradational with the underlying Zooks Corner Formation has been designated the Buffalo Springs Formation. The usage followed here coincides with that of Geyer and others (1963) and Berg, McInerney, and others (1986), who considered the formation to be Middle Cambrian. It is composed of white to very light pinkish gray to dark-gray limestones, which

Figure 4–10. Outcrop of shale of the lower Kinzers Formation, 2 miles northwest of Lancaster, Lancaster County, in the northeast quadrant of the interchange of Pa. Routes 72 and 283. The 10-foot-high outcrop shows steeply dipping bedding at depth and downhill creep toward the right, in the upper part of the exposure. Photograph by W. H. Bolles.

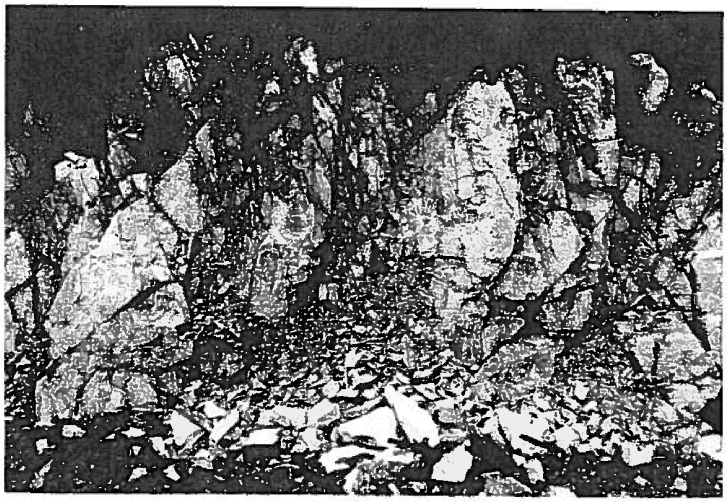


Figure 4–11. Outcrop of the Ledger Formation, 6 feet high (note the hammer in the right center of the photograph), composed of well-jointed, massive dolomite, from a railroad cut near Longs Park, on the northwest edge of Lancaster, Lancaster County. Bedding is obscure but is nearly horizontal.

weather light gray, interbedded with light-pinkish-gray to yellowish-gray and dark-gray dolomites, which weather to a yellowish-gray or buff color (Figure 4–13). The limestones contain local oolite lenses and some dolomite laminae. The dolomites contain argillaceous, silty, or sandy beds, algal mats, mud cracks, ripple marks (Figure 4–14), cross-laminations, and local rip-up clast conglomerates. Stromatolites occur in both the limestone and dolomite beds (Figure 4–15) (Meisler and Becher, 1968). The formation varies in thickness from about 1,500 feet up to 3,800 feet.

The Conococheague Group contains a variety of carbonate lithologies and can be variously subdivided into different formations in different parts of the region. Three formations, the Snitz Creek, Millbach, and Richland, persist over a wide area and are useful for mapping. The Snitz Creek is a sandy dolomite that commonly is light to dark gray and finely crystalline. It may be argillaceous, silty, or sandy. Some sporadic layers of dolomitic quartz sandstone occur within this formation. These beds are more resistant and commonly form a significant topographic rise above the surrounding carbonates. They weather to a very sandy soil. The Snitz Creek Formation grades upward into the Millbach Formation, which is dominated by limestones containing some chert beds, lenses, and stringers. Interbedded limestones and dolomites overlying the Millbach constitute the Richland Formation. The proportion of limestone to dolomite varies considerably in the Richland Formation. It is estimated to be 70 percent limestone and 30 percent dolomite in the Conestoga Valley section, whereas dolomite apparently dominates in the Lebanon area.

The Conestoga Formation occurs in contact with rocks as old as the Antietam Formation and as young as the Beekmantown Group. Rodgers (1968) considered it to be the deeper water equivalent of these shelf units. It includes gray, finely to coarsely crystalline limestone, argillaceous limestone, some graphitic to micaceous laminae, and some angular carbonate clasts in a calcareous matrix (Figure 4–16). The clasts range in size from pebbles to boulders up to 5 feet across. Jonas and Stose (1930) considered the clasts to be part of a basal conglomerate, but they have been found in a number of positions within the formation and have been interpreted as lenses or tongues of a shelf-edge breccia by Rodgers (1968). Some coarsely crystalline, silty, and sandy

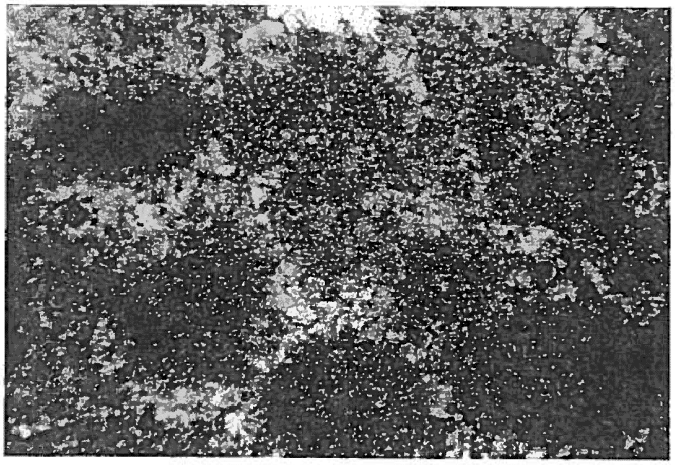


Figure 4–12. Photomicrograph showing relict ooids in recrystallized dolomite from the Ledger Formation along the railroad tracks 0.5 mile west of the Armstrong plant in the northern part of Lancaster, Lancaster County. Individual ooids are approximately 0.7 mm in diameter; the entire view is 2.5 mm wide. Cross-polarized light.

Figure 4–13. Tight isoclinal folds in the Buffalo Springs Formation along the Cornwall-area railroad tracks north of Rexmont, Lebanon County. Fold axes are nearly horizontal. Competent dolomite beds (white) show brittle-type fracture. Incompetent limestone beds (light gray) show flowage. Note the field notebook for scale. Photograph by A. R. Geyer.

limestones occur within the Conestoga, as do some beds of dark-gray dolomite. Because of intensive folding (Figure 4–17) and the absence of clear stratigraphic units within the Conestoga, its true thickness is in doubt. It must be at least 1,000 feet thick and could be considerably thicker.

CUMBERLAND VALLEY AND SOUTH MOUNTAIN SEQUENCE

The oldest exposed rocks in the Cumberland Valley are those of the Late Proterozoic Catoctin Formation, altered rhyolitic flows that are finely laminated in red to purple colors and altered basalt composed of chlorite and epidote (MacLachlan and Root, 1966). Overlying the Catoctin is the Loudoun Formation, consisting of sericitic slate and purple-gray, poorly consolidated and poorly sorted, arkosic sandstone and conglomerate. It, in turn, is overlain by the Weverton Formation, which contains more than 1,000 feet of coarse, gray feldspathic sandstone and white quartzose sandstone. The Weverton has a quartz-pebble conglomerate at its base.

Dark-greenish-gray phyllite and schist make up the Harpers Formation in this area. The Montalto Member is a prominent, massive, hard, white to gray metaquartzite that occurs near the middle of the Harpers in the southern part of South Mountain and in contact with the Weverton in the northern half of South Mountain. This member contains *Skolithos* tubes and megaripples, and averages several hundred feet in thickness, except in the Shippensburg area, where it is 1,000 feet or greater. The total thickness for the Harpers Formation in this region ranges up to 2,750 feet.

Conformably overlying the Harpers Formation is the Antietam Formation, a metaquartzite, the color of which ranges from gray through blue gray to white. Some beds are very pure quartzose sandstones with many *Skolithos* tubes. The Antietam commonly weathers to brownish tan. It varies from 500 to 800 feet in thickness.

Undifferentiated massive dolomitic limestone marks the lower part of the Tomstown Formation. A mottled silty dolomite in the middle part of the formation is overlain by dolomitic limestone and limestone in the upper part. Thin shaly interbeds occur throughout the formation, which is estimated at 1,000 to 2,000 feet in total thickness.

The Waynesboro Formation consists of 1,000 feet or more of interbedded red to purple shale and sandstone in the lower and upper parts, and some beds of dolomite and blue, impure limestone in the

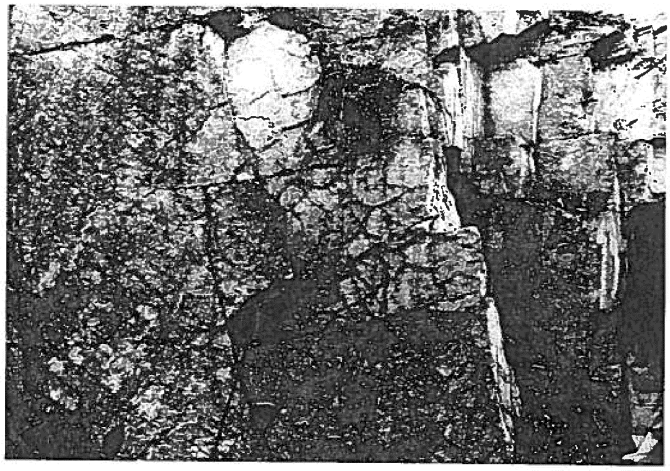


Figure 4–14. Ripple-marked (left side of photograph) and mud-cracked (center) silty limestones and dolomites in the Buffalo Springs Formation, 1 mile east of Morgantown, Berks County. The outcrop is 6 feet high (see person to right). The view is perpendicular to bedding.

middle part. The Waynesboro Formation is considered to be an upper Lower Cambrian to lower Middle Cambrian unit.

The Middle to Upper Cambrian Elbrook Formation is estimated to be greater than 3,000 feet in thickness. It consists of pure, dark limestone at the base, ridge-forming, medium-gray limestone and dolomite in the middle, and light-colored calcareous shale and argillaceous to silty limestone at the top.

The Conococheague Group consists of the Zullinger and Shadygrove Formations, and is considered to be primarily an Upper Cambrian unit. The Zullinger contains interbanded and interlaminated limestone and dolomite, thin- to thick-bedded stromatolitic limestone, and several thin, local quartz-sandstone beds. It is over 2,500 feet thick. The Shadygrove Formation contains pure, light-colored limestone that includes some stromatolites, and abundant pinkish limestones and cream-colored cherts. It averages 650 feet in thickness.

The Ordovician Beekmantown Group conformably overlies the Shadygrove Formation. The basal formation is the Stonehenge, which includes in its lower part the Stoufferstown Member, a coarse, conglomeratic limestone containing dark-gray, siliceous laminae. This member forms prominent ridges. The upper member of the Stonehenge Formation is an unnamed stromatolitic, fine-grained limestone. Together, these members total about 1,000 feet in thickness.

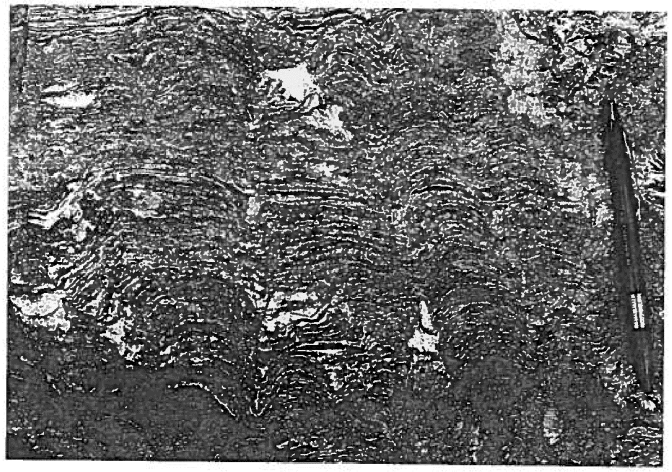


Figure 4–15. Stromatolites in the Buffalo Springs Formation (same location as Figure 4–14).

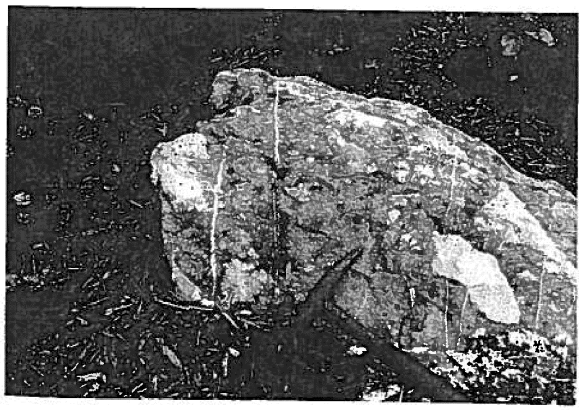


Figure 4–16. Angular limestone clasts in a granular, crystalline, carbonate matrix within the Conestoga Formation, 3 miles west of Lancaster, Lancaster County.

The Rockdale Run Formation is the middle formation of the Beekmantown Group. Over 2,500 feet thick, it is mostly limestone with some dolomite interbeds. Nearly 500 feet of pinkish, marbly limestone and chert occurs near the base of the Rockdale Run. Some stromatolites and chert occur in the middle of the formation.

The Pinesburg Station Formation marks the top of the Beekmantown Group and is probably Middle Ordovician. It contains about 450 feet of light-colored,

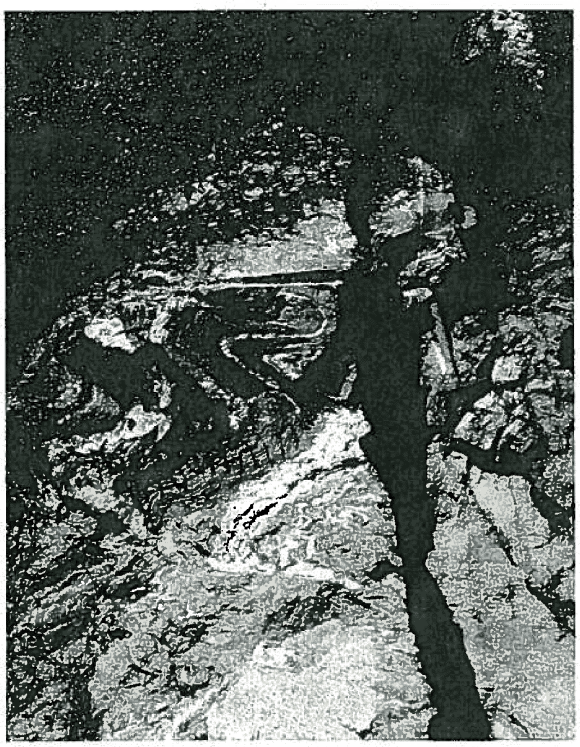


Figure 4–17. Tightly folded Conestoga Formation along the east side of Pa. Route 272, 5 miles south of Lancaster, Lancaster County. Note the hammer for scale. Photograph by W. H. Bolles.

thick-bedded, finely laminated dolomite, and some limestone.

LEHIGH VALLEY SEQUENCE

Unconformably overlying basement rocks in the Lehigh Valley region of eastern Pennsylvania is the Hardyston Formation. The thickness of this resistant unit is variable, reaching a maximum of nearly 800 feet. The formation consists of a variety of lithic types: conglomerate and arkose (especially abundant near the lower contact), feldspathic sandstone, siliceous sandstone, silty shale, and some local jasper pebbles. The Hardyston has discontinuous lenticular beds of iron-stained quartz-pebble conglomerate, coarse, poorly sorted arkose, and some well-developed *Skolithos* tubes (Figure 4–18).

Conformably overlying the Hardyston Formation is a thick, poorly exposed carbonate sequence called the Leithsville Formation. It is composed of interbedded gray, fine- to coarse-grained dolomite and calcitic dolomite, light-gray to tan phyllite, calcareous phyllite, and thin stringers of quartz and sand-sized dolomite. Some thick beds of quartz sandstone are present. The formation ranges up to 1,000 feet in thickness. Cyclic bedding occurs within the Leithsville, which has repetitions of beds of thin quartz-bearing or sand-sized dolomite, some phyllite, local dark-gray chert, large oolites, rip-up clasts, ripple marks, and some graded bedding.

Conformably overlying the Leithsville Formation is the Allentown Formation. It is a gray, fine- to medium-grained, highly recrystallized dolomite that weathers to alternating light and dark beds. Bedding varies from finely laminated to thick bedded. Sedimentary features are common, including local disconformities, ripple marks, mud cracks, cross-laminations, graded beds, and load casts. Oolites are very abundant, forming well-sorted beds and lenses up to 2 feet thick. Several types of stromatolites also occur throughout the Allentown Formation. In most places, these are followed by supratidal dolomites with desiccation cracks. Cyclic units range from 5 feet to about 30 feet in thickness. The lower member of the cycle commonly has an irregular bottom contact and contains flat-pebble conglomerate beds and some oolites. This grades upward into thinly interbedded limestone and dolomite, which is followed by stromatolitic dolomite and mud-cracked dolomite. The entire formation is nearly 1,700 feet thick. Its upper contact with the Ordovician Rickenbach Dolomite is commonly picked at the top of the last shallow-water dolomite and the start of rocks having a higher calcite content (Drake, 1969, p. 84).

STRATIGRAPHY OF CENTRAL AND WESTERN PENNSYLVANIA

The subsurface stratigraphy of Cambrian units in western Pennsylvania is similar to that in the central part of the state (Wilson, 1952; Wagner, 1966b; Colton, 1970). Lying on the Precambrian basement complex in western and northwestern Pennsylvania (but cropping out only in New York) is the Potsdam Sandstone, a basal sandstone, varying from a feather edge to as much as 100 feet in thickness. It is a pink to red arkosic sandstone containing granules and pebbles of quartz and, rarely, gneiss and other lithic fragments.

The general thinning of the Cambrian section toward the continental interior is interrupted locally by a pronounced thickening into the Rome Trough in southwestern Pennsylvania (see Chapter 20).

The oldest formation exposed in central Pennsylvania is the Waynesboro Formation, which is of

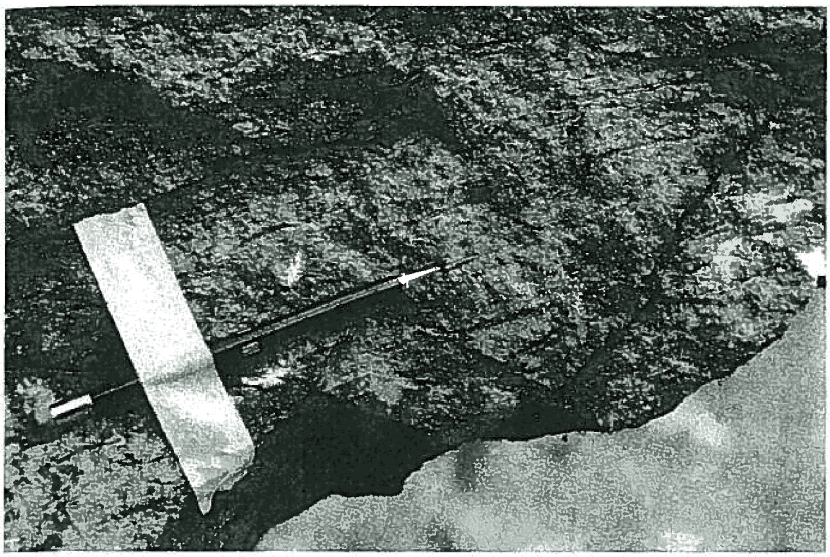


Figure 4–18. *Skolithos* tubes in siliceous sandstone of the Hardyston Formation in the Lehigh Valley. The pencil points to a well-developed tube emerging from the plane of the outcrop. Bedding is obscure and is oriented nearly vertical in the photograph. Photograph by J. M. Aaron.

Early to Middle Cambrian age. This unit is characterized by coarse- to medium-grained brown sandstone interbedded with red and green shales. In the south-central part of the state, the Waynesboro is underlain by clastics of the Chilhowee Group.

Overlying the Waynesboro is the Pleasant Hill Formation. The lower part of the Pleasant Hill is characterized by thinly layered, argillaceous, sandy, and micaceous limestone and some calcareous shale. The upper part is thick-bedded, fine-grained, dark-gray limestone (Butts, 1945). Some sandy, silty, and shaly limestone layers persist into the upper part locally. Middle Cambrian fossils have been collected from the upper part of this formation. Wilson (1952) considered the Pleasant Hill Formation to be of early Middle Cambrian age.

In western Pennsylvania, the Potsdam is overlain by the Warrior Formation. In central Pennsylvania, several units have been differentiated between the basal Cambrian section and the Warrior Formation. The Warrior Formation has a variety of rock types. The most common is a dark, argillaceous or platy, fine-grained limestone, which is characterized by oolites, stromatolites, and a variety of fossils. Interbedded with this limestone is dark, finely crystalline, silty dolomite. The proportion of limestone to dolomite varies from place to place. There appears to be a cyclic character to much of this formation. The upper and lower contacts of the Warrior appear to be conformable. The formation varies from about 400 feet in northwestern Pennsylvania to as much as 1,340 feet in north-central Pennsylvania.

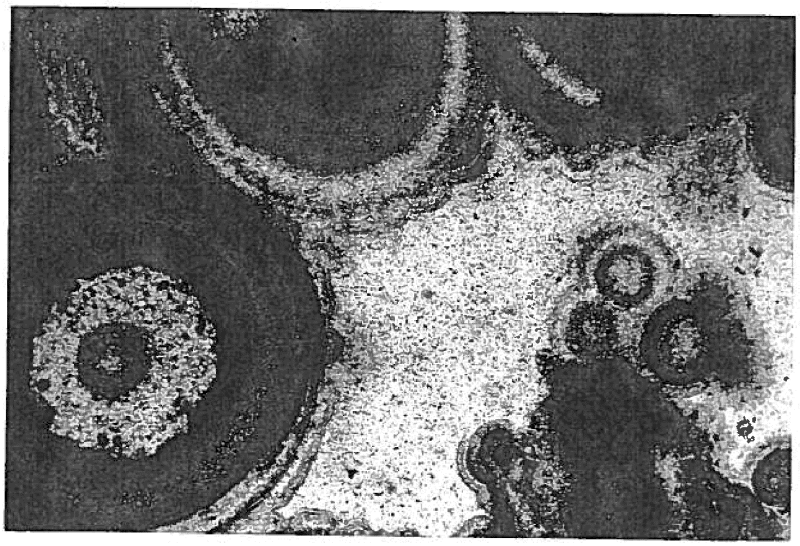
The Gatesburg Formation consists of five mappable members, two thick interbedded sandstone and dolomite units and three thinner dolomites with little or no sandstone (Figure 4–4). These members include the Stacey Member, a dark, crystalline, massive dolomite; the Lower sandy member, a sandy dolomite and quartzose sandstone; the Ore Hill Member, a nonsandy carbonate sequence; the Upper sandy member, consisting of some limestone beds in central Pennsylvania and dolomite and sandstone in western parts of the state; and the Mines Member, a unit of dolomite having local chert, some siliceous oolite (Figure 4–19), and little or no sandstone.

The Cambrian-Ordovician contact is commonly placed at the upper boundary of the Gatesburg Formation (Mines Member). This appears to be a conformable contact with the overlying Larke Formation and its lateral equivalent, the Stonehenge Formation of the Beekmantown Group. Some workers place the Cambrian-Ordovician boundary within the Larke and Stonehenge Formations, making the lowest parts of each of these formations latest Cambrian in age (Figure 4–4).

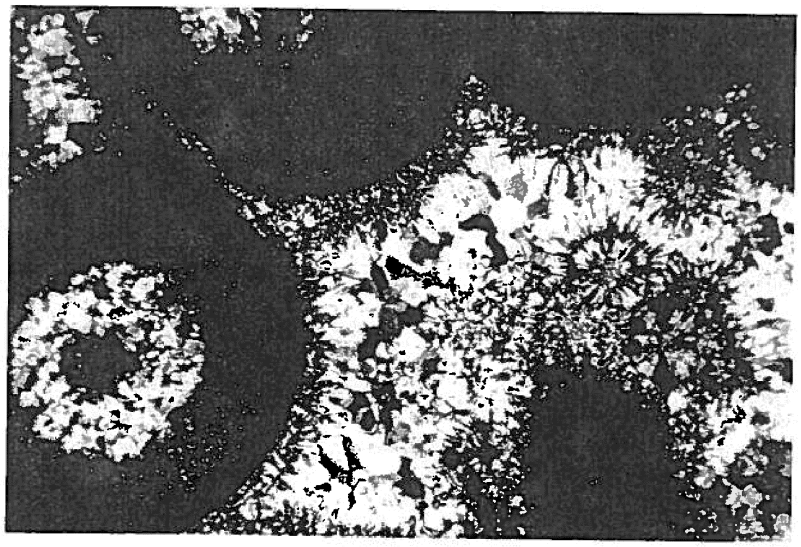
PROBLEMS AND FUTURE RESEARCH

The nature of the Precambrian-Cambrian boundary continues to be an unresolved problem. Detailed mapping of the units near the boundary must be integrated with a regional analysis of past and current work.

The age, environment of deposition, and sedimentary tectonic history of units within the Glenarm Supergroup have not yet been resolved. Support can



A



B

Figure 4–19. Photomicrographs of the oolitic Mines Dolomite Member of the Gatesburg Formation from near State College, Centre County. The width of view is 2.5 mm. A, plane-polarized light; B, cross-polarized light. Original carbonate ooids are completely replaced by very fine grained chert and overgrown by chalcedonic quartz (fibrous). The void space between ooids, perhaps originally occupied by calcite cement, is now occupied by coarse chert.

be found for both a Precambrian age and an early Paleozoic age. Continuation of mapping projects may produce paleontological, sedimentologic, and lithologic information to help solve these problems.

The nature of the outcrop pattern of the Antietam Formation has not been fully resolved. Whether the elongate topographic ridges are the result of primary deposition as shoestring sands or are tectonically controlled can only be resolved by further detailed mapping in critical areas.

The stratigraphic relationship of the Kinzers Formation to adjacent units has been a subject of much discussion. It has been determined that the shale member does not occur toward the north and/or northwest. Whether this is the result of stratigraphic pinchout, tectonic control, or lateral facies changes can only be determined by additional mapping.

The age of the Kinzers Formation has long been considered to be Early Cambrian because of the excellent *Olenellus* fauna found in Lancaster County (Jonas and Stose, 1930; Stose and Stose, 1944). More recently, Campbell (1971) reported the occurrence of a Middle Cambrian fauna, characterized by *Ogygopsis klotzi*, in black shales in the upper part of the Kinzers Formation. It has been suggested that the upper shale is another part of the Conestoga-like lithology

intertonguing into the carbonate-shelf bank (Long's Park Tongue) (Kauffman and Campbell, 1969). The Kinzers Formation probably should be restricted to the Early Cambrian rather than extended up into the Middle Cambrian (Figure 4–4). The details of the black shale tongues can only be determined by further mapping and petrologic study of the shales.

Much has been written about the Conestoga Formation and its relationship to other Cambrian-Ordovician rocks in southeastern Pennsylvania. Jonas and Stose (1930) considered the Conestoga to be unconformable on at least the Ledger, Kinzers, and Vintage Formations. Others mapping in this region have described it as being in contact, perhaps, with rocks as old as the Antietam and as young as the Elbrook and even the Conococheague (Wise, 1970). Whether this contact is unconformable or intertonguing can only be determined by further detailed mapping and petrologic studies of the Conestoga and the units immediately adjacent to it.

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