GUIDEBOOK

47th. Annual Field Conference Of Pennsylvania Geologists

Geology of the Middle Ordovician Martinsburg Formation and related rocks in Pennsylvania

October 1 and 2, 1982
New Cumberland, Pa.

Hosts: George Washington University
National Science Foundation
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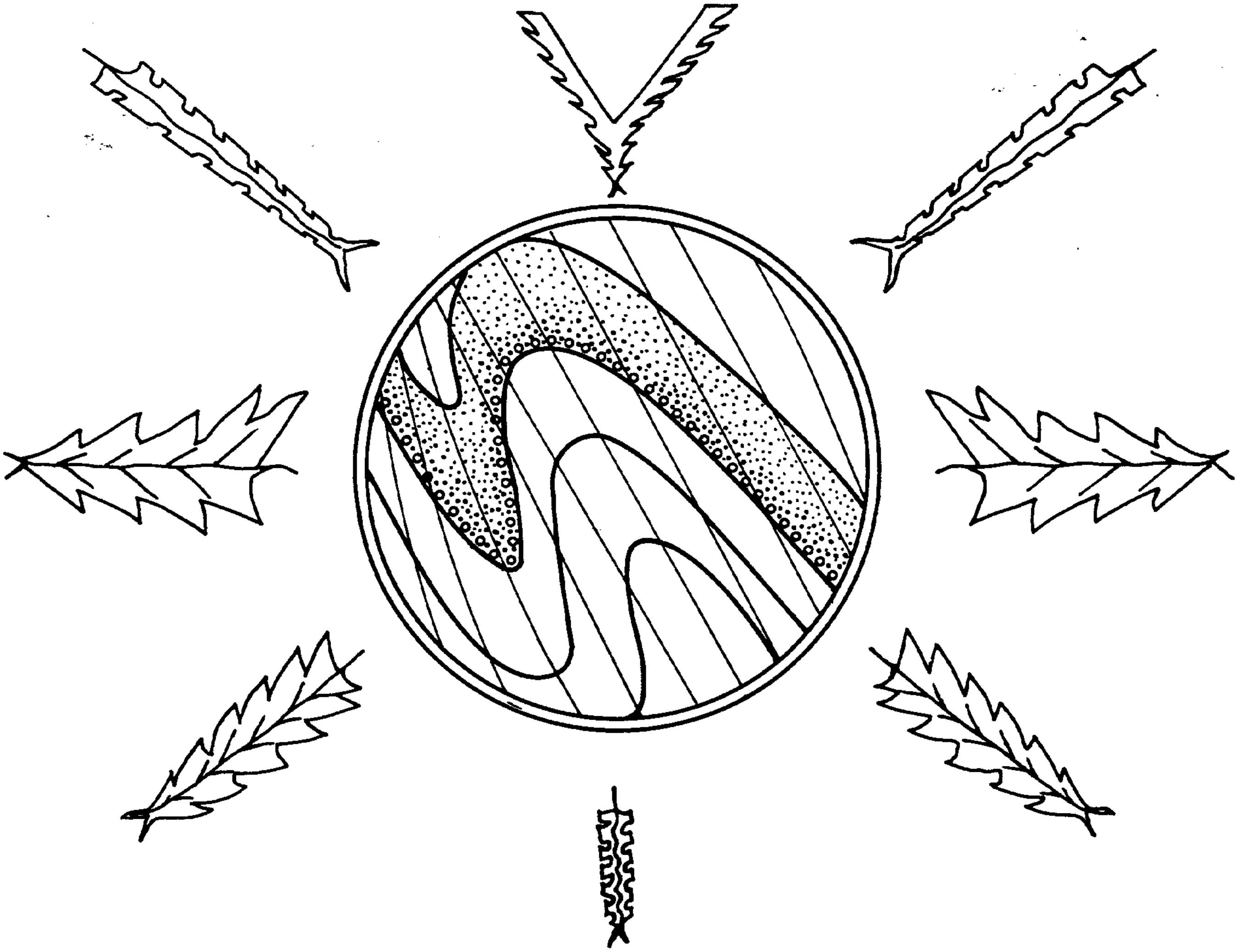

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Guidebook for the

47th ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

GEOLOGY OF THE MIDDLE ORDOVICIAN MARTINSBURG FORMATION AND RELATED ROCKS IN PENNSYLVANIA

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INTRODUCTION

One of the primary goals of geological research is to reconstruct what the earth looked like at specific times in the past and to understand how changes occurred with the passing time. In eastern Pennsylvania, as well as all along the Appalachians, considerable work has been done reconstructing various Paleozoic geographies. The theme of this Pennsylvania Field Conference is the reconstruction of Middle Ordovician tectonic events that changed the great tectonically passive carbonate-rich North American continental margin to an area of basinal sedimentation, which, after later deformations, resulted in the present Martinsburg Formation.

The discussion that follows will examine the Martinsburg Formation, and the areas in Pennsylvania in which it occurs, from several perspectives including structure, stratigraphy, sedimentology and plate tectonics. Each approach provides a facet in the overall purpose of this guidebook and the field trip; that is, to understand as much as possible about eastern Pennsylvania 450 million years ago, and the subsequent geological development of the sediments deposited during this time.

The function of the field trip is, of course, to provide an opportunity for members of the Pennsylvania Field Conference to see the outcrops, lithologies, structures and other features that provide the basic data on which all theories and ideas about the Martinsburg depend. By carefully studying these features, and considering all possible ways of explaining them, we will be able to further our knowledge about the early origins and later histories of these fascinating rocks. Theories, models and ideas are not expected to remain unchanged; they are simply valuable tools to be created, used and discarded along the way and should always be based on observed facts.

The general plan of the field trip is to spend the first day west of Harrisburg where the autochthonous Martinsburg crops out in the Great Valley (Figure 1). Sedimentary features will be examined to provide observational support for the depositional model presented here. Fossils, while not commonly abundant, are present and will provide evidence for the nature of the biostratigraphic control of the Martinsburg Formation. Structural styles will also be examined as they relate to the character of the Taconic and Alleghenian orogenies.

The second day will be spent east of Harrisburg in the allochthonous "Hamburg klippe". This large area, extending from near Carlisle east beyond Hamburg, has affinities to the classic Taconic allochthons of New England, but its origin, internal stratigraphy and emplacement history are controversial and are not well understood. The Field Conference will view all common lithologies of the "Hamburg klippe" and will study the structural and depositional complexities of this terrane that has made interpretation so difficult. Comparisons between these two areas will underscore the fundamental differences between them and will outline the remaining problems and ways to approach their possible solutions.

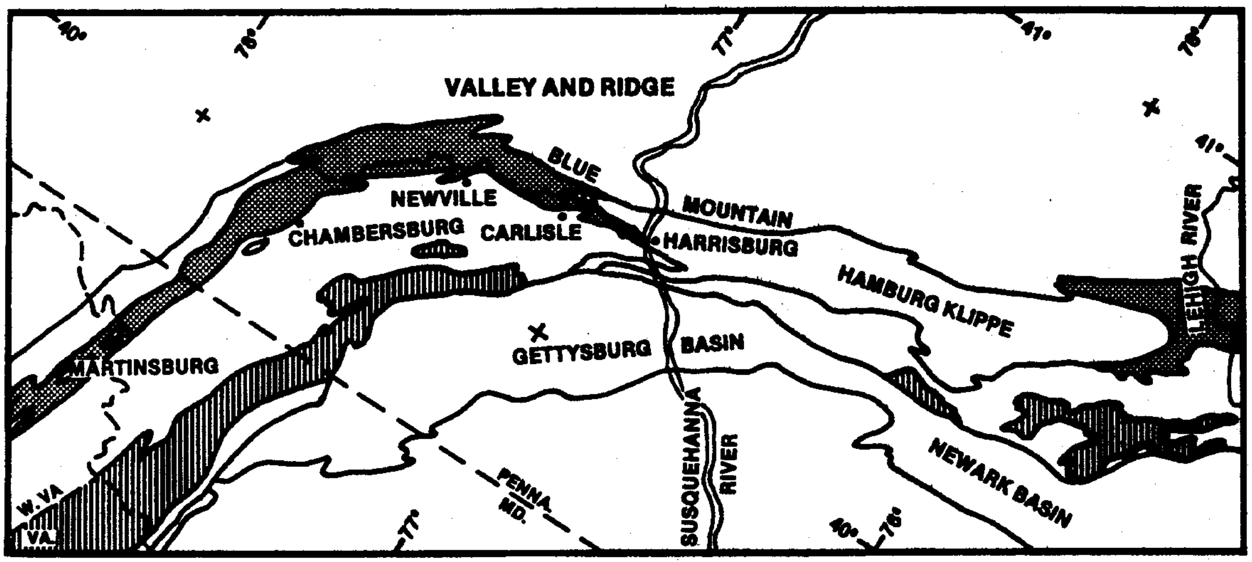

Figure 1. Regional geologic map of southern Pennsylvania. Stippled areas are autochthonous Martinsburg Formation. Vertically ruled areas are Precambrian crystalline rocks of the Blue Ridge and Reading Prong.

INFLUENCE OF GEOLOGY ON EARLY SETTLEMENT

The geology of eastern Pennsylvania has profoundly influenced and controlled the regional development of the area from pre-Colonial times until the present. As land uses and settlement patterns changed, different aspects of the geological framework became important; but always the geology exerted controls, limits, problems, and opportunities for the region.

The first settlers migrated westward from coastal towns and settlements such as Baltimore, Trenton, and Philadelphia located along the Fall Line at the head of navigation for sea-going ships. These early settlers were preoccupied with clearing the land, displacing the indians, and scratching out working farms. They settled in the Great Valley because of the relatively flat topography, abundant trees, readily available water, and the fertile thick soils produced by the carbonate rocks.

This field trip passes through the Great Valley portions of Cumberland, Dauphin, Lebanon and Berks Counties. Trappers are known to have been in the area by 1695 and farmers by 1710. John Harris, Sr., arrived from Yorkshire in 1723 and set up a ferry across the Susquehanna River. This part of the Great Valley was originally included in Lancaster County, set up in 1729, but Cumberland County separated in 1750 and Dauphin County in 1785. John Harris, Jr., was born in the settlement now bearing his name in 1743, and in 1766 built one of the oldest surviving buildings in the area, a limestone mansion now housing the Dauphin County Historical Society. He planned the town in 1785 and later gave to the Commonwealth the land on which the capitol building stands. Twenty-seven years later, Harrisburg became the seat of the government of the Commonwealth in 1812.

Migration, in the early days, was chiefly along the axis of the valley, and as people migrated along the valley they carried their family and place names, as well as their traditions, with them. Established transportation routes also followed the topography and the early migration paths. Even today, a road map shows the topographic control of major highways parallel to the valley axis or parallel to major rivers and streams. During the Revolutionary and Civil Wars, the Great Valley played an important role as supplies, food, and troops were moved along it.

The Valley and Ridge province to the west served to focus settlement in the Great Valley. Transportation over the ridges and into the intermontane valleys and beyond to the Plateau was slow and difficult, even through major water gaps. Thus for the latter part of the 1700's and the early part of the 1800's, settlers were largely confined to the Great Valley and eastward. The area has remained essentially agricultural until recent times.

During the last sixty years, the Great Valley has undergone a slow but steady progressive transition from an agricultural area to a mixed agricultural and urban/industrial area. Many small farms still exist, some in the same families for generation after generation, and are centered around rural agrarian communities. Larger industrial-oriented cities such as Allentown, Bethlehem, Reading, and Harrisburg are constantly growing and changing the land-use patterns of the surrounding areas. Because these towns sprang up chiefly in the most fertile carbonate-rich portions of the valley, they are now expanding over the most suitable farmland, leaving the shaley and sandy Martinsburg Formation for agricultural purposes. In addition, as urban pressures increase in the southeastern portion of the Great Valley, so also do problems of sinkholes, ground subsidence, and water supply, which are directly related to the underlying carbonate rocks.

POPULATION GROWTH AND GEOLOGIC PROBLEMS

Two centuries and more ago the Harrises certainly did not anticipate the modern interaction between population and geological circumstances in the Great Valley. How could they? The area was covered by dense virgin forest except in the few places cleared for farming, and the population density was so low that few such problems arose.

The lower parts of the valley are currently beset with problems having to do with water. Along the river banks the surge of "hundred-year" floods, for example in 1972 and 1975, turned the first floor of the Governor's mansion into a swimming pool and, more importantly for us, destroyed the library and irreplaceable archives of the Pennsylvania Geological Survey.

Away from the rivers, flat ground averaging about 100 m above sea level is underlain by carbonates honeycombed with solution cavities. When such country is farmed, population is thinly dispersed, so the biggest difficulty with the caves is the occasional disappearance of a cow into a sink hole. But, as more people live on such terrain, their water withdrawal and sewage discharge back into the groundwater create a public health danger. Pollution of other types can spread through the interconnected caverns. Some years ago a pipeline leaked gasoline onto the surface of the water table. The evaporated fumes were so hazardous that part of Camp Hill had to be evacuated.

The higher parts of the Great Valley are gently rolling hills underlain by shale and sandstone. A topographic scarp nearly 50 m high marks the change from flat ground with a noticeable lack of surface water courses to the higher ground with abundant little gullies and farm ponds. Here, too, a water problem attends increased population, but different from that on the open carbonates. The shale is impermeable except along fractures, and these are so tight even at shallow depth that some uncased wells produce only a few gallons of water per minute.

Infiltration is extremely small where the ground has been cleared as for new housing. Groundwater flow is so restricted that solid earth tides are recorded by the twice daily rise and fall of water level in wells as the earth's crust flexes, and the joints in the shale open and close (L. D. Carswell, pers. comm.).

In spite of their low yield, wells in the Martinsburg are satisfactory sources for drinking water in rural areas. Septic tanks provide a slow and marginally safe return path through an oxidizing vadose zone. The margin of safety decreases sharply as land use shifts to suburban housing. Two examples illustrate the point. During the drought in 1962, a cooperative water system that fed well water to a group of new houses in the old farming village of Linglestown was shut down by the County health authorities. There was no local sewer system, and the wells became unusable. The next year a man who had sold his farm near Linglestown to a real estate developer complained vociferously at the large assessment for sewer pipe along the newly paved road in front of his ancestral home. His complaint centered on the simple fact that he had never needed a sewer before, failing to address the new fact that by selling his farm for new housing he had hurried the need for a sewer. At least in the vicinity of Harrisburg, the U. S. Geological Survey and the Pennsylvania Geological Survey are to be commended for anticipating the problems of suburban growth and trying to make helpful information available to the public (Carswell and others, 1968; McGlade and Geyer, 1976; Wilshusen, 1979).

GEOMORPHOLOGY

The Great Valley is from 13 to 29 km wide in eastern Pennsylvania (Figure 1). It is composed of several longitudinal sub-provinces; the Cumberland Valley, the Lebanon Valley, and the Lehigh Valley (Figure 2). Rainfall averages 109 cm per year, and results in the familiar humid landforms associated with the central Appalachians. Although the area was originally heavily forested with an unbroken forest canopy, it is now cleared for farming or contains second or third generation forest growth. Because of shifting population patterns, some of the more remote parts of the valley are less densely populated now than fifty years ago.

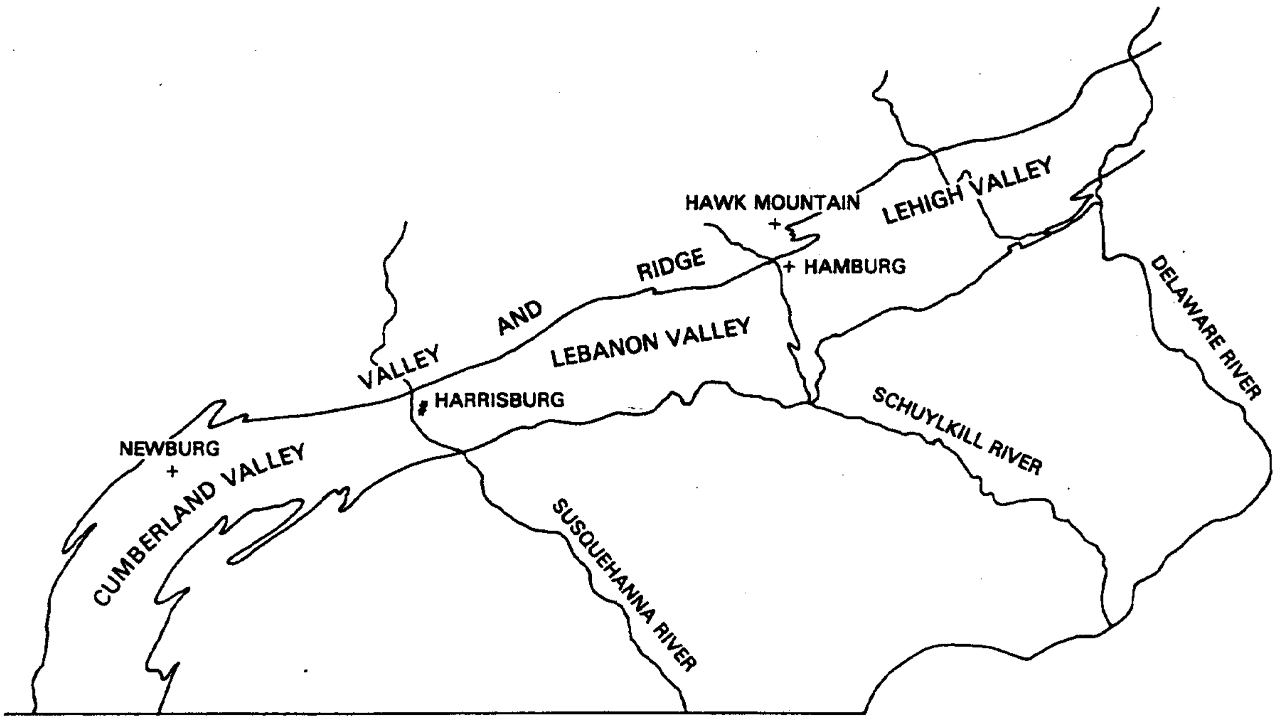

Figure 2. Longitudinal subdivisions of the Great Valley in Pennsylvania.

As we drive across the Great Valley, three topographic levels are discernible and have been considered in the past as residual erosion surfaces of particular ages; in fact the Great Valley of Pennsylvania is the location in which William Morris Davis established many of his views on the process of peneplanation. The highest level at about 350 m is visible to the north at the top of Blue Mountain. It is at the eroding edge of the Tuscarora quartzite in the west and the Shawangunk Conglomerate in the east, and has been called the Schooley peneplain. The lowest landscape we traverse averages 100 m above sea level just south of Harrisburg and 150 m near Lebanon, but has low relief locally of about 30 m. This has been called the Somerville surface and is underlain by Cambrian and Ordovician limestone and dolomite. The northern half or more of the Great Valley is underlain by shale, siltstone, and sandstone on which has been projected the Harrisburg erosion surface. This landscape is much more irregular in altitude. Hills underlain by cherty beds reach 180 m north of Linglestown, and, north of Lebanon, hills of such a height are underlain by diabase. Elsewhere the land surface is typically near 170 m, higher over sandstone and graywacke beds and lower over calcareous shale. Stose (1940) and many others have discussed the possible age(s) of these erosion surfaces, but more recent studies support the views that similar altitudes are related to similar bedrock (Meisler, 1962), that the region has probably been lowered hundreds of meters by erosion during the last hundred million years (Pierce, 1965), and that differences in erosion level on the same rock type, for example at water gaps, are related to local structural details (Epstein, 1966). Davis' ideas have also been refuted by Hack (1960) and others, but the peneplain concept has been supported recently by Sevon (1981), Berry (1982), and others.

Although the portion of the valley that we will visit was not actively glaciated during the Pleistocene glaciations, the Wisconsinan ice front was just to the north of Blue Mountain in Northampton County, and the ice pushed through the Delaware Water Gap and into the valley for a short distance. The Great Valley itself was subject to a periglacial climate during the Wisconsinan maximum and evidences of frozen, frost-shattered bedrock abound (Potter and Moss, 1968).

ECONOMIC GEOLOGY

Economic resources within the Great Valley consist of slate from the Martinsburg Formation, Portland cement rock from the Jacksonburg Formation, building stone from the Cambrian-Ordovician carbonate formations, and sand and gravel from the alluvial stream channels.

Slate was quarried from the Martinsburg in eastern Pennsylvania before 1833 (Rogers, 1858; Behre, 1933), and probably in the previous century (Coons, 1914). In possibly correlative rocks near Peach Bottom, Pennsylvania, commercial quarrying began about 1785. Business flourished after the Civil War, and around the beginning of the twentieth century more than half the slate produced in the United States came from the dozens of quarries and mines in Northampton and Lehigh Counties. For a few years it was even exported to Wales (Coons, 1914). A few quarries reached a depth greater than 200 feet and several operated for more than half a century. Now only two or three quarries are functioning.

The area of this field trip is entirely west of this activity, but a few quarries and prospects were once opened in Dauphin and Lebanon Counties, and Behre (1933) mentioned as of possible economic interest the red slates along Quittapahilla Creek (Stop 8).

Besides slate, several mineral resources have been mined or otherwise removed from the Great Valley, in Pennsylvania or nearby. In West Virginia weathered Martinsburg Shale was used directly to make brick. The Glen-Gery Corporation is now making bricks from weathered shales of the Hamburg klippe near Shoemakersville, near Stop 11. East of the area that we will visit, Pleistocene sand and gravel are important in the local economy. From one end of the Great Valley to the other, the carbonates older than, but in some places thrust upon, the Martinsburg have been used. The charming older buildings in Carlisle and Lebanon and other towns are made of local limestone. The field trip will visit one of the few remaining building stone operations in this area.

The limestones have also been used in chemical processes, including the making of fertilizer, as flux in steel making and in the manufacture of cement. The first Portland cement plant in the United States was built in Coplay, Pennsylvania, in 1871, but natural cement had been produced as early as 1830 (Ames, 1961). The continuation of the Great Valley in New York and Vermont has provided much slate and marble for many decades. Material for road construction is quarried locally from the carbonates and also from the Martinsburg. Although the Cambrian-Ordovician rocks have been prospected by government agencies and private mineral companies (for example, Freedman, 1972), to date no major lead or zinc deposits have been discovered, even though mineral deposits are known from these same rocks in the Saucon Valley south of Bethlehem, Pennsylvania, and from the Bowers-Campbell Mine near Timberville, Virginia in the Shenandoah Valley.

HISTORY OF GEOLOGIC INVESTIGATIONS IN THE GREAT VALLEY

Stratigraphy

The study of geology in eastern Pennsylvania began in the eighteenth century (Fergusson, 1981) and continues with many questions yet unanswered. We pick up the action in the middle of the nineteenth century at the publication of a comprehensive survey of the Commonwealth by H. D. Rogers (1858) describing the stratigraphy and the economic resources and providing an array of cross sections, at various scales, across parts of the region we traverse. What Rogers called the Matinal upper slate was named the Martinsburg Shale by Keith (Geiger and Keith, 1891, Keith, 1894) and described, for the area near Martinsburg, West Virginia, as follows: "It consists of black and gray calcareous and argillaceous shales of fine grain, and shows no variations within this area. It contains 80 percent of argillaceous and siliceous matter, and the remainder is chiefly carbonate of lime." Stose (1906), working in the vicinity of Chambersburg, Pennsylvania, noted that 1000 feet of the shale Keith described was succeeded farther north by soft greenish sandstone about 500 feet thick. He therefore proposed that the Martinsburg become a group, but this has not been followed by later workers.

Stose's work in the Great Valley and adjacent ground continued for decades and led to recognition of the unconformity on top of the Martinsburg in eastern Pennsylvania (Stose, 1930), to the idea that the Reading Prong gneisses were allochthonous (Stose and Jonas, 1935), and to the proposal that a huge mass of shale about 100 miles long was allochthonous in the Great Valley (Stose, 1946). Though his interpretations were controversial at the time, each seems to be supported rather than contradicted by new data, although the relations are more complicated than he inferred. Pavlides and others (1968) reviewed the nature of the post-Martinsburg unconformity and concluded that it reached as far west as Harrisburg but not beyond, following Stose (1909), Willard and Cleaves (1939) and Pierce (1966). The most recent data show this unconformity extending across Cumberland and Franklin Counties at least to the Maryland border (Stephens and Wright, 1981).

Specifics of the Martinsburg stratigraphy and structure in the Great Valley have been more or less continuously in doubt since the formation name was first used (Geiger and Keith, 1891). Those working southwest of the Susquehanna have developed a two-fold subdivision similar to Stose's (1909), but those working east of the Lehigh River have generally followed the view of Behre (1933) that a three-fold subdivision of the unit works best. For example, Drake and Epstein (1967) named three members that they and others have mapped in Northampton and Lehigh Counties. These are the Bushkill Member (lower slate), Ramseyburg Member (middle graywacke) and the Pen Argyl Member (upper slate). However, based on graptolites, Wright, Stephens and Wright (1979) were unable to confirm that the Pen Argyl Member overlies rather than underlies the Ramseyburg Member.

A puzzling aspect of these western and eastern stratigraphic interpretations is the implied difference in thickness of the Martinsburg--1500-2000 feet in Franklin County to as much as 12,000 feet in Northampton County. In reviewing current directions over the entire belt, McBride (1962, p. 43) reported 2250 feet in the southwest and 4000 feet in New Jersey, but 9000 feet in eastern Pennsylvania--even 11,000 feet if Behre's (1933) three-fold subdvision is correct. Drake (1969) suggested 12,000 feet or more. In contrast, Root (1968,

p. 51; 1970, p. 816; 1971, p. 39) declined to give any estimate for Franklin County except that the formation exceeds 1000 feet. The increase of five times in little more than 100 miles suggests two points. One is that further detailed study would be in order for the valley in New Jersey and nearby New York. The other is that, if thickness differences are real, the northern reaches of such a thick marine mud should have had enough organic material to have produced oil and gas that might still be trapped beneath deformed Silurian rocks (Frey, 1973) or in older rocks.

Allochthonous shale within the Martinsburg

In the area between the geographic extremes of the Great Valley in Pennsylvania are some stratigraphic peculiarities already noted by Rogers (1858, p. 240, 250). He recorded not only the presence of red shales in Dauphin and Lebanon Counties, but also that they are not much seen elsewere in the Great Valley and that they "seem to be connected with the calcareous bands, which are more common there than in the district (farther east)". We will see an example of these calcareous bands on Saturday, Stop 11. They were extensively described by Miller (1937) and in recent years have produced Early Ordovician fossils (Carswell and others, 1968; Bergstrom and others, 1972; Bechtel, unpub. ms.). Half a century after Rogers published his observations, Bayley and others (1914) noted that red shales near Jutland, New Jersey, are not only unusual in rock type within the generally gray Martinsburg but also unexpectedly old as far as the graptolites seemed to indicate. They concluded that the red shale and associated rocks were probably allochthonous, following by only a few years similar conclusions for similar rocks in eastern New York (Ruedemann, 1909). New observations on this matter may be found in Perissoratis and others (1979), and Root and MacLachlan (1978).

Kay (1941) re-emphasized the allochthony of shales of the same age as local shallow-water carbonate rocks near Harrisburg, and Stose (1946), as noted above, formalized the concept by naming the Hamburg klippe as a giant thrust sheet resting upon the Martinsburg. He included most of the shale in the Great Valley from Carlisle on the west almost to the Lehigh River on the east in this body of far-travelled rock. While his synthesis did not receive instant applause (Prouty and others, 1955, p. 53-54), and there are still several sticky questions, those rocks in the Great Valley in Lebanon and Dauphin Counties recognized long ago as anomalous by Rogers seem to gain allochthony and believability with the accumulation of data.

RECENT STRATIGRAPHIC STUDY

Once the extent of the Martinsburg Formation became generally known and the Hamburg klippe area defined, the next key step was to unravel the internal stratigraphic and structural relationships between the various lithologic and tectonic units. Basic questions involved: 1) the age and subdivision of that part of the Martinsburg that was clearly gradational with the Jacksonburg Formation in eastern Pennsylvania and with the Chambersburg Formation in the Great Valley south of Carlisle, 2) the structural position and the internal structure and stratigraphy of the Hamburg klippe, 3) the age and structure of small "anomalous" areas including Shochary Ridge, the fossiliferous locality at Swatara Gap, the possible presence of wildflysch near the Hamburg klippe boundary, and Spitzenberg Hill in eastern Pennsylvania, and 4) relationships between these various units.

Different workers still have quite different models and views on nearly all of these problems. In the discussion that follows, these differences will be pointed out not only for the purpose of indicating the nature of the differences, but also to help focus the field trip discussion on problems that remain.

The discovery of fossils, in particular graptolites, at many new localities is proving to be instrumental in making progress towards solving these problems. These fossils have now been used to define biostratigraphic correlations between all of the different parts of the Martinsburg and the Hamburg klippe primarily by using Riva's (1969) graptolite zonation.

The decision to use Riva's zonation scheme (Table 1) rather than Berry's (1960, 1970) stems from the fact that Riva's zonation was developed in the northern Appalachians while Berry's was primarily developed in Texas. The interval from Riva's Nemagraptus gracilis to Climacograptus pygmaeus Zones or from Berry's Zone 12 to Zone 14, the interval spanned by the Martinsburg and some of the Hamburg klippe rocks, is clouded by a continuing disagreement about the correlations from the Texas-based to the Appalachian-based zonation schemes. Basically, the species that define Zone 13 in Texas do not include those found in Zone 13 U in the Appalachians, and therefore a possible unconformity representing all or parts of the Zone 13 U (or Riva's Diplograptus multidens and Corynoides americanus Zones) exists in the Texas sequence. Resolution of the situation rests on determining the extent of the Texas unconformity between Zones 13 and 14, and on a better knowledge of the species present and their ranges in each area. Recent work by Cisne (pers. comm.) has added more complexity to the biostratigraphic picture by his discovery in New York, that some species in this interval appear to be facies controlled, thus raising the possibility that both correlation schemes could, in fact, have time-transgressive components. Fortunately, for the purposes here, these problems do not significantly affect conclusions about the Martinsburg and Hamburg klippe stratigraphy in the Great Valley. It is clear from the sedimentology that Martinsburg rocks containing Diplograptus multidens through Climacograptus spiniferus Zones, contain no detectable internal unconformities, and the present outcrop is parallel to the Ordovician paleoshoreline. As the fossils from the Martinsburg are readily assigned to Riva's zonation scheme, correspond precisely to the order predicted from facing criteria and structure, and do not involve lateral facies changes, there is no ambiguity in applying

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                                     Nemagraptus   Diplograptus  Corynoides    Orthograptus  Climacograptus Climacograptus
                                     gracilis      multidens     americanus    ruedemanni    spiniferus     pygmaeus
                                     Zone          Zone          Zone          Zone          Zone           Zone

Didymograptus sagitticaulis          xxxxxxxxxxxxxx
D. serratulus                        xxxxxxxxxxxxxx
D. subtenuis                         xxxxxxxxxxxxxx
Dicellograptus divaricatus           xxxxxxxxxxxxxxxxxxxxxxxxxxxx
D. sextans                           xxxxxxxxxxxxxx
D. varieties                         xxxxxxxxxxxxxx
Nemagraptus gracilis                 xxxxxxxxxxxxxx
N. exilis                            xxxxxxxxxxxxxx
N. varietias                         xxxxxxxxxxxxxx
Dicranograptus ramosus               xxxxxxxxxxxxxx- - - ? -
D. spinifer                          xxxxxxxxxxxxxx- - - ? -
D. rectus                            xxxxxxxxxxxxxxxxxxxxxxxxxxxx
D. contortus                         xxxxxxxxxxxxxxxxxxxxxxxxxxxx
D. diapason                          xxxxxxxxxxxxxx- - - ? -
D. furcatus                          xxxxxxxxxxxxxx- - - ? -
Orthograptus calcaratus              xxxxxxxxxxxxxx-------- - ? - - - - - ? - -
O. varieties                         xxxxxxxxxxxxxxxxxxxx- ? -
Pseudoclimacograptus scharenbergi    xxxxxxxxxxxxxxxxxxxxxxxxxxxx
P. s. stenostoma                     xxxxxxxxxxxxxx- - - -? -
P. angulatus                         xxxxxxxxxxxxxx- - - -? -
P. modestus                          xxxxxxxxxxxxxxxxxxxxxxxxxxxx
Climacograptus bicornis              xxxxxxxxxxxxxxxxxxxxxxxxxxxx
C. bicornis tridentatus              xxxxxxxxxxxxxxxxxxxxxxxxxxxx
C. brevis strictus                   xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Reteograptus geinitzianus            xxxxxxxxxxxxxxxxxxxxxxxxxxxx
Cryptograptus tricornis              xxxxxxxxxxxxxx- - - ? -
Gloesograptus ciliatus               xxxxxxxxxxxxxx- - - ? -
Lasiograptus pusillus                xxxxxxxxxxxxxx- - - ? -
Leptograptus flaccidus trentonensis  xxxxxxxxxxxxxx- - - ? -
Glyptograptus teretiusculus          xxxxxxxxxxxxxxxxxxxxxxxxxxxx
G. euglyphus                         xxxxxxxxxxxxxxxxxxxxxxxxx----------
Amplexograptus sp.                   xxxxxxxxxxxxxx- - - ? -
Corynoides pristinus                 xxxxxxxxxxxxxx- - - ? -
C. calicularis                       xxxxxxxxxxxxxxxxxCCCCCCCCCCCCCCCCCCCCCCCCC
Dictyonema                           xxxxxxxxxxxxxx- - ? -
Hallograptus mucronatus                          - -xxxxxxxxxxxxxx
Dicranograptus nicholsoni                          xxxxxxxxxxxxxx
Diplograptus multidens                             xxxxxxxxxxxxxx
D. compactus                                       xxxxxxxxxxxxxx
Cryptograptus insectiformis                        xxxxxxxxxxxxxx- - ? - -xxxxxxxxxxxxxxxxxx
Orthograptus amplexicaulis                                  - ? - xxxxxxx--------xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxCCCCCCC
O. calcaratus basilicus                                     - ? ---xxxxxxxxxxxxx
Climacograptus brevis-mohawkensis                           - ? - -
Corynoides americanus                                            CCCCCCCxxxxxx--
Lasiograptus harknessi                                      - ? - -xxxxxxxxxxxx
Climacograptus brevis                                      - ? ------ - - - - ? -
Orthograptus quadrimucronatus                                    - - ? - xxxxxxxxxxxxxxxxxxxxxCCCCCCCCCCCxxxxxxxxxCCCCCCC
Climacograptus caudatus                                          - - ? - xxxxxxx
Neurograptus cf. margaritatus                                -   - - ? - xxxxxxx--------------
Climacograptus mohawkensis                                       --------CCCCCC- ?
Orthograptus ruedemanni                                          --------CCCCCC- ?
Cryptograptus caudatus                                                         - - xxxxxxxxxxxxxxxxxxxxxxxxx
Dicranograptus ramosus                                                         - - xxxxxxxxxxxxxxxxxxxxxxxxx
Climacograptus spiniferus                                                            xxxxxxxxxxxxxx
C. typicalis                                                                         xxxxxxxxxxxxxx
Orthoretiolites, sp.                                                                 xxxxxxxxxxxxxx
Glyptograptus, sp.                                                                   xxxxxxxxxxxxxx
Diplograptus, sp.                                                                    xxxxxxx - - - -
Dicranograptus cf. D. nicholsoni minor                                               xxxxxxxxxxxxxx
Diplograptus ingens                                                                  xxxxxxx
Climacograptus pygmaeus                                                                             CCCCCCCCCCCCC
Leptograptus flaccidus                                                                              xxxxxx-------
Glyptograptus variety                                                                               xxxxxx-------
Orthoretiolite variety                                                                              xxxxxx-------
Corynoides sp.                                                                                      - ? - - - ? -
Orthograptus eucharis                                                                               xxxxxxCCCCCCC
Climacograptus typicalis magnificus                                                                 - - - xxxxxxx
C. t. posterus                                                                                      - - - xxxxxxx
Glyptograptus lorrainensis                                                                                xxxxxxx
Pleurograptus linearis                                                                                        - -

                                        LEGEND
                                   - - - - -    rare
                                   ---------  sparse
                                   xxxxxxxx  present
                                   CCCCCCCC   common
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Table 1. Middle Ordovician graptolite species and zonation. Compiled from Riva (1969, 1974) by K.S. Stamm, George Washington University.

this system to the biostratigraphy of the Great Valley. Difficulties may be encountered where the biostratigraphic correlations are extended across strike (across time transgressive facies) to the Valley and Ridge or to much broader correlations (i.e. to the mid-continent or further). Then, the possibility of facies control and possible long-range miscorrelation problems will enter the story.

Martinsburg internal stratigraphy

As originally defined, the Martinsburg Shale was just that, a fine-grained, slightly calcareous shale found near Martinsburg, West Virginia. Later mapping of the Martinsburg included other rock types such as graywacke and, eventually, all Hamburg klippe rock types including shale, graywacke, limestone and volcanics. Just how these other rock types fitted into the Martinsburg stratigraphy was not clear, and several conflicting models of the internal lithostratigraphy emerged. Thus the two vs three-membered Martinsburg and the allochthonous/autochthonous Hamburg klippe controversies were born.

Due to the presence of abundant minor folds and the lack of large continuous outcrops, it is difficult to establish unambiguous stratigraphic order based on lithology and sedimentary facing criteria alone. This is particularly true in shale-turbidite terranes where lithologies can easily be regarded as monotonous! Fossils have helped resolve many of the correlation problems in the Martinsburg, and we now consider that the autochthonous rocks of the field trip area (the Martinsburg Formation proper) contain a lower shale, a middle turbidite, an upper silty shale and an upper sandstone. West of Harrisburg, this sequence is approximately 2000 m thick. The Hamburg klippe contains a variety of rocks all of which pre-date the Martinsburg Formation. Because the fossils have been so important in refining stratigraphic relationships, the new biostratigraphic information will be discussed before further consideration of the Martinsburg lithostratigraphy.

The large number of new fossilferous outcrops and the good distribution of graptolites, both geographically and stratigraphically, has been most useful in unraveling the internal stratigraphies of the Martinsburg and the Hamburg klippe. It should be stressed that only a few of these outcrops contain so many fossils that a casual search would be productive. It was not at all unusual to search, on hands and knees, for 15-20 minutes before finding any graptolites. The best prospects are those localities that have abundant loose shale chips and are in the full sun. Those in shade commonly weather so that the graptolite material is quickly lost. Fresh outcrops are more likely to break along cleavage than those outcrops where weathering has progressed to the point where breaking along bedding occurs.

Although it is true that graptolites are more easily found where bedding and cleavage are at low angles, fossils can be found even on fold axes where bedding and cleavage are at high angles. Two things are involved: 1) graptolites are more deformed making them more difficult to recognize, and 2) the bedding planes are exposed only on the thin edges of the shale chips, not on the broader cleavage surfaces. Fortunately, with a bit of practice, bedding surfaces can be distinguished from cleavage surfaces, and the presence of graptolites commonly improves the local bedding fissility. Therefore, while a bit more difficult, a search for graptolites in outcrops with bedding and cleavage at high angles can be fruitful.

The Martinsburg Formation east of the Hamburg klippe contains fossils of Diplograptus multidens Zone to Climacograptus spiniferus Zone as do the rocks west of the Hamburg klippe. Figure 3 shows the fossil localities east of the klippe and Figure 4 those west. Fossils associated with each zone are listed in Table 1. Figures 5 and 6 show corresponding lithostratigraphy east and west of the klippe. Figure 7 shows how these graptolite zones correlate to the lithostratigraphy. Thus the lower shale contains Diplograptus multidens Zone forms both in eastern Pennsylvania and west of Harrisburg. The turbidite unit is of Corynoides americanus and Orthograptus ruedemanii Zone ages. The upper shale west of Harrisburg, and possibly the Pen Argyl Member are of Climacograptus spiniferus Zone age.

The contributions of the gratolite zonation to the Martinsburg stratigraphy actually are two-fold. First, the graptolites provide excellent age control for those outcrops where sufficient material was collected. The graptolites, because they span considerable time, act as integrators where enough data exists so that the confusing effect of the many minor folds is effectively filtered out and the larger structures can be seen. This can best be seen near Carlisle, where many small folds are present in a large area of shale, encompassing only one graptolite Zone. A second interesting outcome is that the type area near Martinsburg, West Virginia contains only the lower part of the formation based on fossil data, despite the presence of many minor folds and significant outcrop width. This helps to explain the difficulty early workers had when they tried to correlate other parts of the formation to the "type section"!

Hamburg klippe internal stratigraphy

The presence of the Hamburg klippe has been recognized since Stose defined it in 1946. However, its structural position relative to the Martinsburg Formation and the internal structural and stratigraphic relationships within the klippe are all poorly known and are consequently controversial.

The Hamburg klippe area (Figure 1) contains a diverse array of rock types with olive shale predominating but with graywacke, tan and red slate, thin limestone, chert, sandstone, dolomite, basalt and dolerite also present. Work by Carswell and others (1968), Myers (pers. comm.), and Dyson (1967) among others shows that no simple internal structure can be demonstrated based on map patterns. This apparent lack of internal consistency in structure may be in part due to poor exposure, but may be due to more fundamental reasons.

Published maps on the internal stratigraphy of the klippe (for example, Wood and MacLachlan, 1978; Carswell and others, 1968; and Dyson, 1967) show that lithologic units can typically be followed along strike for a few hundred feet in many cases and for miles in exceptional circumstances. The mappable rock units typically terminate abruptly. There are crude associations of graywacke with olive shale, and red and tan slate with thin bedded limestone that suggest the internal stratigraphy is not totally chaotic. However, it is rare to find more than one or two units that follow each other around a fold nose, or are offset by faults. In some cases "faults" have been drawn where there are two definable units on one side that "match" three units on the other, and "folds" where a single red bed hooks around a nose and ends while nearby units continue along strike! Authors of some maps have proposed a complex sequence of stacked thrust slices (Root and MacLachlan, 1978; Wood and MacLachlan, 1978), but field evidence is such that other possibilities remain.

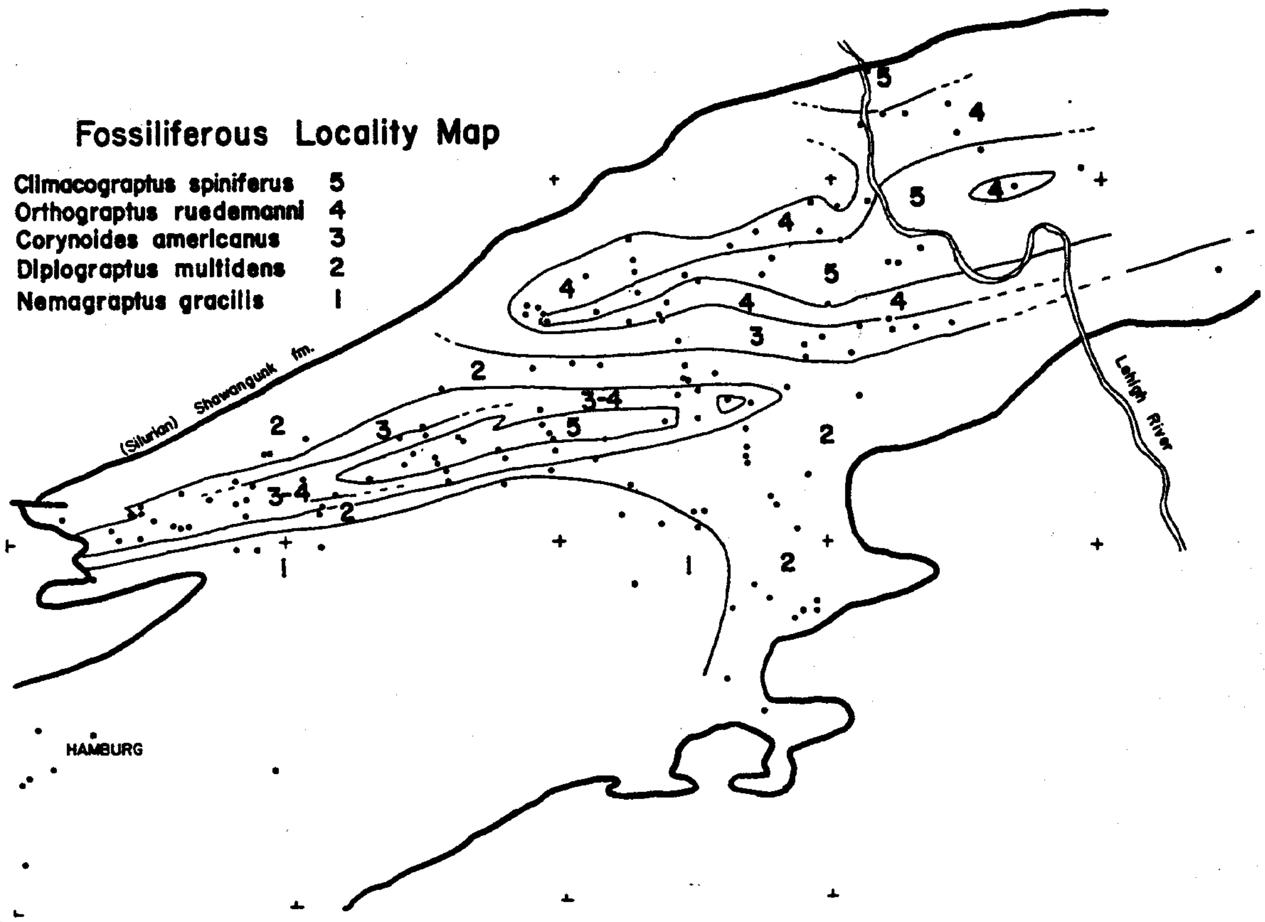


Figure 3. Fossiliferous locality map, east of the Hamburg klippe. Crosses are 7 1/2 minute quadrangle corners.

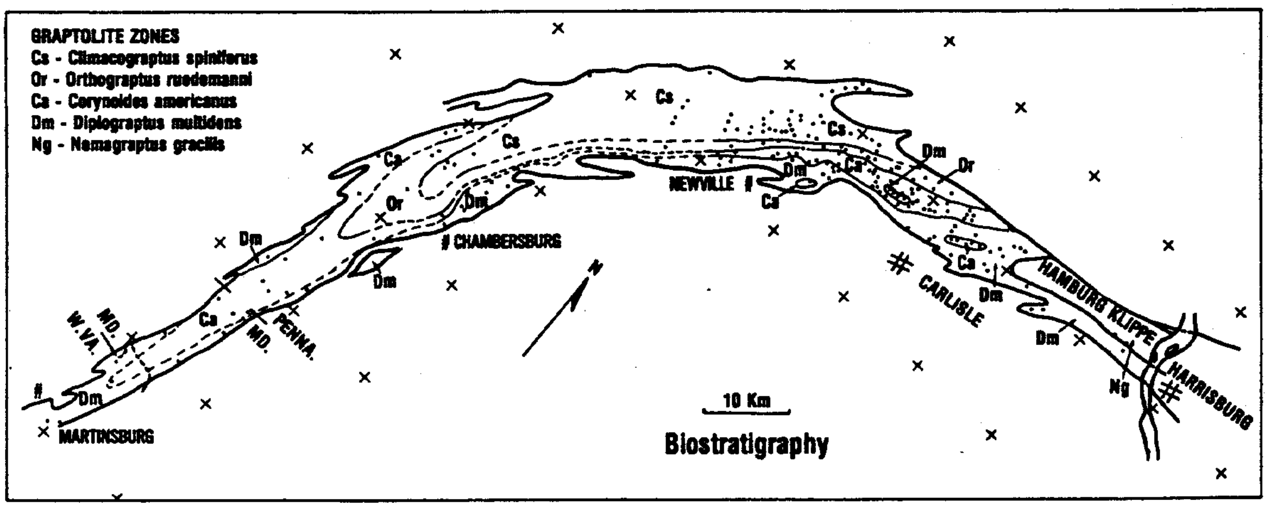


Figure 4. Fossiliferous locality map, west of the Hamburg klippe. Crosses are 7 1/2 minute quadrangle corners.

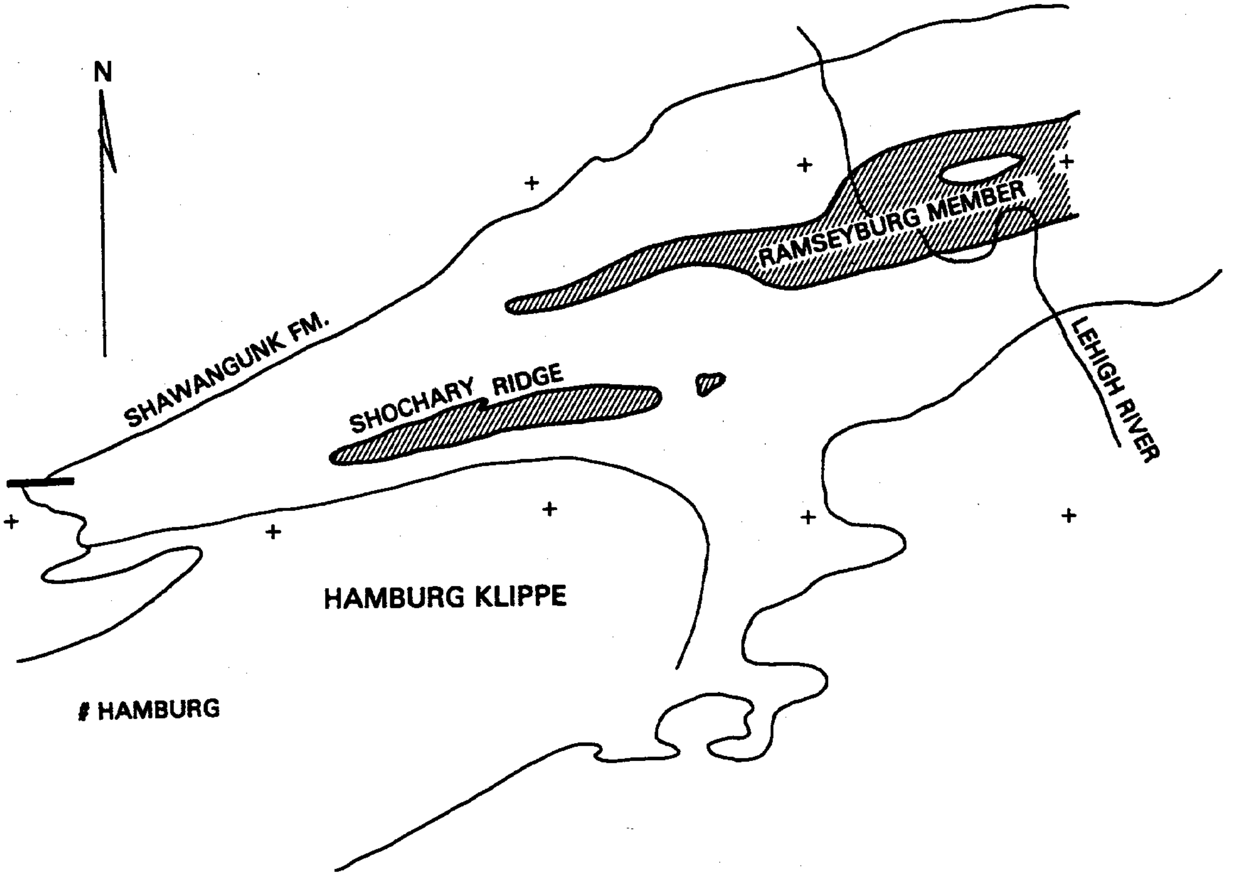


Figure 5. Lithologic map, east of the Hamburg klippe, shale is unpatterned and sandstone is diagonally ruled.

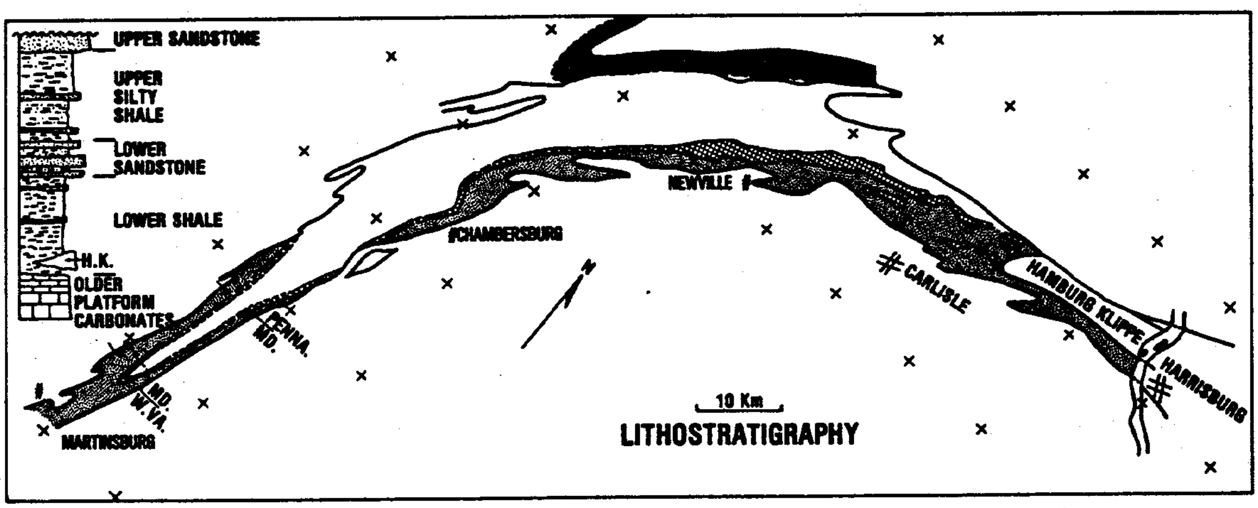


Figure 6. Lithologic map, west of the Hamburg klippe. Stipple = lower shale, cross-hatch = lower graywacke, unpatterned area = upper silty shale, vertically-ruled area = upper sandstone.

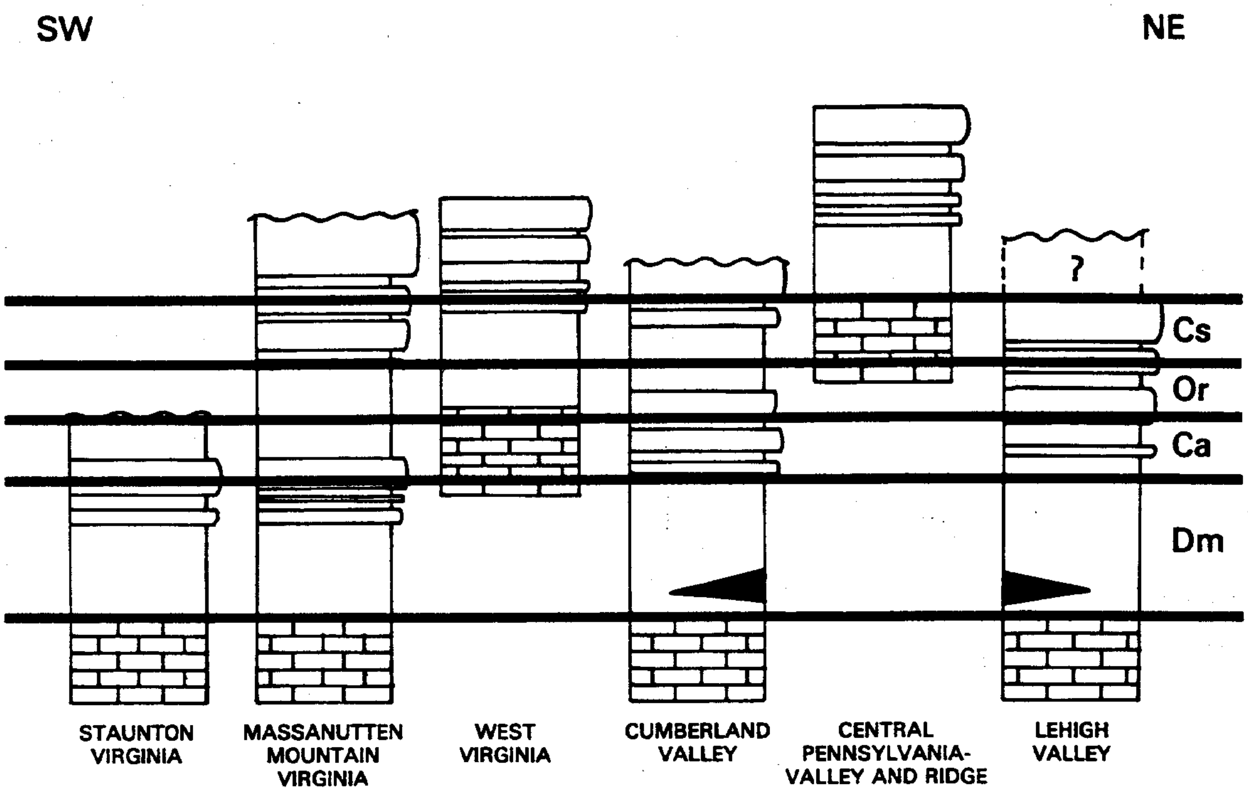


Figure 7. Lithostratigraphic columns and graptolite-based ages in the central Appalachians.

Fossil evidence, summarized by Platt and others (1972), indicates that two ages are present - Nemagraptus gracilis Zone based on locally abundant and diverse graptolite faunas, and lowest Ordovician based on one species of graptolite, Dictyonema flabelliforme. Other data collected since Platt's summary reinforce these ages. Myers (pers. comm.) found N. gracilis graptolites in the Bernville area within olive shales, and Repetsky (pers. comm.) has extracted conodonts of the same age from N. gracilis bearing shales. Epstein and others (1972), Repetsky (pers. comm.) and Wright (unpublished) have all found lowest Ordovicican conodonts of Balto-Scandic affinity in the ribbon limestone similar to that from which Platt reported the Dictyonema flabelliforme graptolites. Wright and Stephens (1978) reported the presence of a Pseudoclimacograptus species in a graywacke unit that may indicate the presence of the Glyptograptus teretiusculus Zone. We have subsequently found N. gracilis in other Hamburg klippe lithologies except the limestone, clean sandstone and igneous units. The complete absence of any shelly fossils either macroscopic or as identifiable fragments in thin sections is in striking contrast to most of the Martinsburg where shelly fossils are commonly present.

Based on these confusing and frustrating relationships, several different interpretations have been made. These vary widely in terms of both internal stratigraphy and of the timing and style of emplacement. The resolution of this problem is one of the most interesting and apparently the most intractable left in the "Martinsburg" in Pennsylvania. The major ideas are summarized in the next paragraphs.

Platt and others (1972) first proposed that the obviously exotic lithologies of the Hamburg klippe could be thought of as large blocks or olistoliths within "normal" Martinsburg shale. In this scheme, the olive shale and graywacke within the klippe represent Martinsburg "matrix" in which the red slates, ribbon limestones, volcanics and other exotic lithologies are found. This "matrix" would be the same age as the Martinsburg outside the klippe area. The present faunal data have cast serious doubt on this model, because old (Nemagraptus gracilis Zone or older) fossils have been found in the olive shales and graywackes, but no fossils of "normal" Martinsburg age have been found as yet anywhere in the klippe area.

Wright and Stephens (1978), and Wright, Stephens and Wright (1979) postulated that the entire "klippe" is a coherent block, older than the enclosing Martinsburg Formation, and was emplaced by gravity sliding or possibly by thrusting into the Martinsburg basin during Diplograptus multidens Zone time. This was based on the observations that the Hamburg klippe is everywhere in physical contact with the lower, Diplograptus multidens Zone shale (except where the Silurian unconformably overlies it) and, that in one place the Martinsburg shale unambiguously overlies the Hamburg klippe. At Hawk Mountain (Figure 2) the Martinsburg is in depositional contact upon the Hamburg klippe. The north facing klippe/Martinsburg contact is overlain by the Tuscarora Formation in a pronounced angular unconformity near Hamburg. The absence of Hamburg klippe derived detritus near the front edge of the allochthon (olistoliths of recognizable exotic lithologies) is a problem; it would seem reasonable to expect such blocks to spall off the advancing thrust; however, the absence of wildflysch does not negate this model.

In contrast, Lyttle and Drake (1979) feel that the Hamburg klippe is separated from Shochary Ridge and from the Martinsburg by a thrust fault. They argue that the juxtaposition occurred during the Alleghanian orogeny, based on the geomorphic expression of the Hamburg klippe/Martinsburg contact and on local well-drilling descriptions.

Thus, despite accumulated faunal, structural and sedimentologic data from rocks within the Hamburg klippe area, fundamentally different interpretations on the evolution of these rocks are presently held. The problems, as we see them, can best be attacked by careful re-mapping along the klippe/Martinsburg boundaries and by better detailed mapping and fossil collecting within the klippe boundary.

Shochary Ridge

Shochary Ridge, immediately north of the eastern end of the Hamburg klippe is a syncline cored by sandstone containing brachiopods and other shelly faunas. The sandstone is underlain by shale that crops out on both sides of the sandstone. However, the relationship of the Shochary Ridge sequence to the autochthonous Martinsburg and to the Hamburg klippe has been interpreted in several ways. A good part of the problem has been the poor age control on this sequence and on the adjacent rocks. Willard (1943) and Stose (1930) assigned an Eden/Maysville Late Ordovician age to the Shochary Sandstone; later Platt and others (1972) suggested a late Middle Ordovician age. The Berks County geologic map (Wood and MacLachlan, 1978) shows the Shochary sandstone and the underlying shale of unknown age separated from both the Hamburg klippe and the Martinsburg by faults, following Epstein and others (1972).

The fossils collected from the shale below the Shochary Ridge sandstone and from the adjacent Bushkill Member of the Martinsburg are identical, as are the lithologies. These facts, plus lack of direct evidence of a fault separating the two shales, led Wright, Stephens and Wright (1979) to correlate these two and to correlate the Shochary sandstone with the Ramseyburg Member of the Martinsburg. Lyttle and Drake (1979), and Wright and Stephens (1979) in a discussion and reply discuss the continuing difference in interpretation.

Swatara Gap

The Martinsburg exposure near the gap where Swatara Creek passes through Blue Mountain in Lebanon County is well known for its diverse shelly fauna. Stose (1946) noted the similarity between the Swatara Gap lithology and the Martinsburg west of the Susquehana River, and concluded that these were correlative, although Hamburg klippe lithologies were found only 2-3 kilometers to the south. In contrast, Epstein and others (1972) assigned this outcrop to the Hamburg klippe and argued that its age was early Barneveld (Middle Ordovician). Collections of graptolites and the trilobite Cryptolithus, reported by Wright and others (1977) were used to confirm Stose's original assignment. The graptolites, while not abundant, clearly establish a Climacograptus spiniferus Zone age, consistent with the idea that this outcrop correlates with the upper part of the authochthonous Martinsburg.

Wildflysch terranes

Root and MacLachlan (1978) brought attention to small areas of "anomalous" rocks including graywacke near Carlisle northwest of the Hamburg klippe (Figure 6). They interpreted these patches of graywacke as blocks in a wildflysch terrane adjacent to the klippe. In the absence of fossils this interpretation was reasonable because similar rocks do occur within the klippe and would be expected to spall off or be slivered off the advancing allochthon. However, graptolites found in these "anomalous" graywackes are all Diplograptus multidens or Corynoides americanus Zone forms, not Nemagraptus gracilis or older as would be required if they are allochthonous blocks (Stephens and Wright, 1981). Structural information also indicates that these "blocks" are actually small doubly plunging synclinal keels that preserved the small areas of graywacke. Hence no wildflysch is present along the Martinsburg - Hamburg klippe contact here.

Another such area of possible wildflysch in the Martinsburg in front of the klippe was reported by Alterman (1969). The outcrop in question, near Kempton, Pennsylvania yielded Nemagraptus gracilis Zone fossils from shale overlying the chert cobble layer. This places the deposition of the "wildflysch" too old to be a Martinsburg event; the origin of the cobbles is now a Hamburg klippe problem. Undoubtedly, the Hamburg klippe does contain large blocks of obviously exotic origin, for example the basaltic blocks south of Jonestown (Berg and others, 1980). Some of these are surrounded by olive shale. Yet at the present time no fossils younger than Nemagraptus Gracilis Zone have been collected from matrix shales surrounding the exotic blocks. Thus the presence of wildflysch with autochthonous Martinsburg matrix has yet to be demonstrated.

Spitzenberg Hill and other Upper Ordovician Clastic Localities

Although it will not be visited on this field conference, Spitzenberg Hill, located in Berks County (Figure 8), is a classic locality in eastern Pennsylvania. Spitzenberg Hill, a prominent conical hill 3.5 km northeast of Lenhartsville, is composed of 35 m of poorly sorted coarse-grained red and gray sandstone and conglomerate. The sandstone is extensively cross-bedded and channeled. The conglomeratic layers chiefly contain limestone pebbles, but clasts of sandstone, shale and chert are also present. The average range in pebble size is 3-8 cm, but limestone pebbles as large as 20-27 cm are also common. Table 2 is a measured stratigraphic column of Spitzenberg Hill. Current directions from cross-beds, (Figure 9) indicate a southeastern source for the sediments.

Spitzenberg Hill was first discussed by Behre (1933) who proposed a Triassic age on the basis of lithologic similarity to the Triassic border conglomerates, but suggested the alternative view that Spitzenberg Hill might instead be equivalent to the uppermost Martinsburg Formation. Whitcomb and Engel (1934) and Whitcomb (1942) reviewed these possibilities and decided in favor of a Triassic age.

Mapping in the area by Stephens (1969) and Loring (1969) identified a 100 m thick sequence of similar red and gray sandstones unconformably beneath a large erosional outlier of Tuscarora Quartzite on Sharps Mountain, directly west of Spitzenberg Hill. Although the contact between the Martinsburg Formation and the rocks of Spitzenberg Hill is covered by float from above, structural relations in the vicinity suggest that this contact is also an angular unconformity.

The rocks of Spitzenberg Hill and adjacent Sharps Mountain are correlative to all or part of the Upper Ordovician Bald Eagle-Juniata Formations exposed in water gaps farther west (Stephens, and Wright, 1976). These exposures thus mark the easternmost extent of these Upper Ordovician clastics. We think, that at these localities, the Upper Ordovician rocks are bounded both above and below by angular unconformities. Farther west (e.g. Waggoners Gap) the upper unconformity has disappeared, and the Taconic orogeny is evidenced by the unconformity at the Martinsburg-Bald Eagle/Juniata contact. In Virginia this angular unconformity has largely disappeared: a slight disconformity and a change from marine Martinsburg to fluvial Juniata are all that mark the Taconic orogeny (Schoellkopf, 1982, Diecchio, 1982).

Reconnaissance study indicates that other Upper Ordovician clastic rocks (Bald Eagle equivalent) underlie Little Mountain, a small prominent ridge located just south of Blue Mountain and east of Swatara Gap (Figure 8), and are present as float on Reservoir Hill in the city of Harrisburg.

TABLE 2

Spitzenberg Hill Section

TOP OF SECTION

THICKNESS	CUMULATIVE THICKNESS	
40'	40'	Mostly covered with greenish-gray sandstone float, occasional small outcrop of greenish-gray, medium to coarse grained, well sorted sandstone, no pebbles.
6'	46'	Medium to coarse grained, moderately well-sorted greenish-gray sandstone, no pebbles.
10'	56'	COVER.
4'	60'	Medium to coarse grained, very poorly-sorted red sandstone. Contains limestone pebbles 1/2" to 3" in diameter.
1'	61'	COVER.
2'	63'	Slightly conglomeratic, medium to coarse grained red sandstone.
8.5'	71.5'	COVER.
15'	86.5'	Very coarse limestone conglomerate, some red sandstone and shale pebbles, average pebble diameter is 2-3', maximum pebble size is 7 1/2" to 9".
3.5'	90.0'	Coarse grained red sandstone, fairly massive, extensively cross-bedded, contains a few limestone pebbles (maximum diameter is 1" to 2").
1.5'	91.5'	Coarse grained arkosic limestone conglomerate, contains sparse red shale and black chert pebbles.
9'	100.5'	Well sorted, medium to coarse grained greenish-gray sandstone, extensively cross-bedded, contains very thin lenses of flat limestone pebbles, average pebble diameter is 1" to 3".
4.5'	105'	Medium to coarse grained quartz-rich sandstone, extensively cross-bedded, very little hematite, much green chert.
6.5'	111.5'	Poorly sorted, coarse, greenish-gray sandstone,

		slightly conglomeratic, pebble size is 1/2" to 1-1/2".
1.5'	113'	Poorly sorted, medium to coarse grained, greenish-gray sandstone, many green chert fragments, extensively cross-bedded.
0.5'	113.5'	Poorly sorted, coarse grained greenish-gray sandstone, with 1" to 1 1/2" limestone pebbles.
1.5	115'	Poorly sorted, medium to coarse grained, greenish-gray sandstone, many green chert fragments, extensively cross-bedded.

BASE OF SECTION

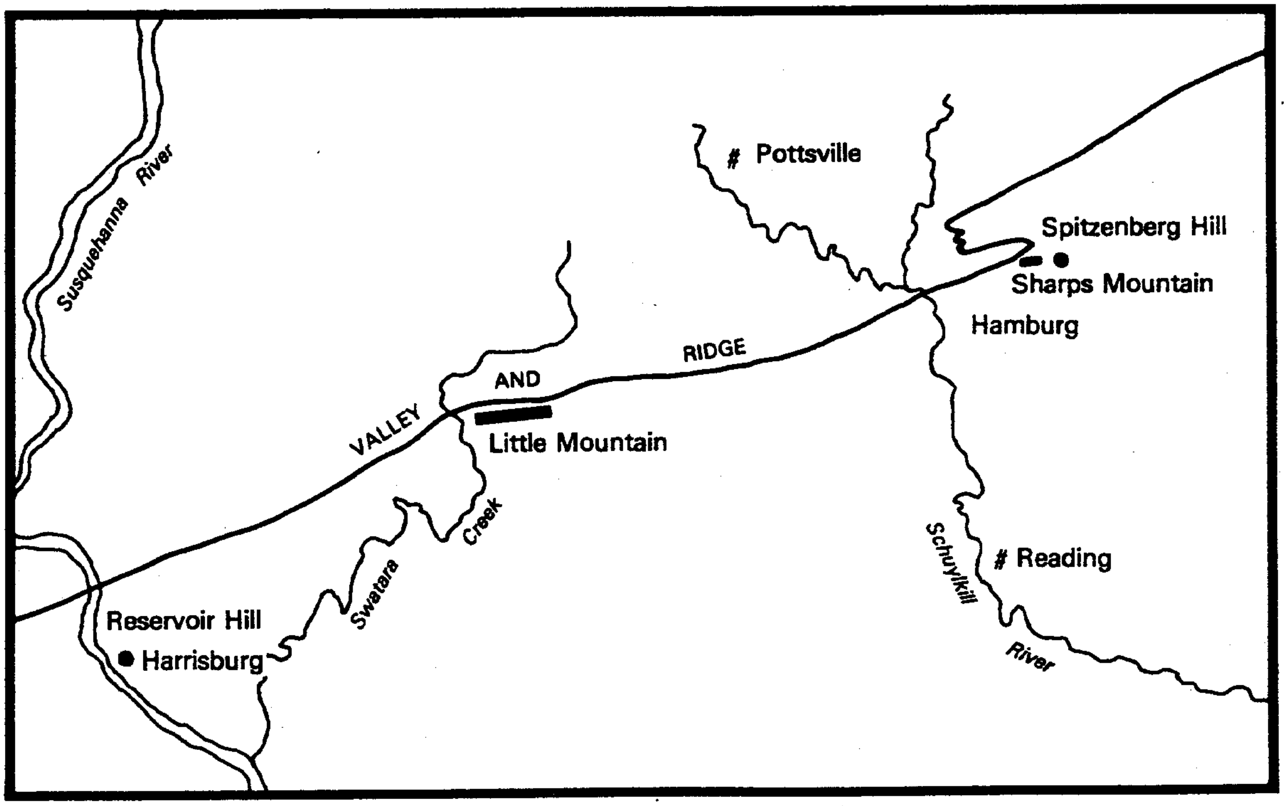


Figure 8. Upper Ordovician clastic rock localities within the Great Valley.

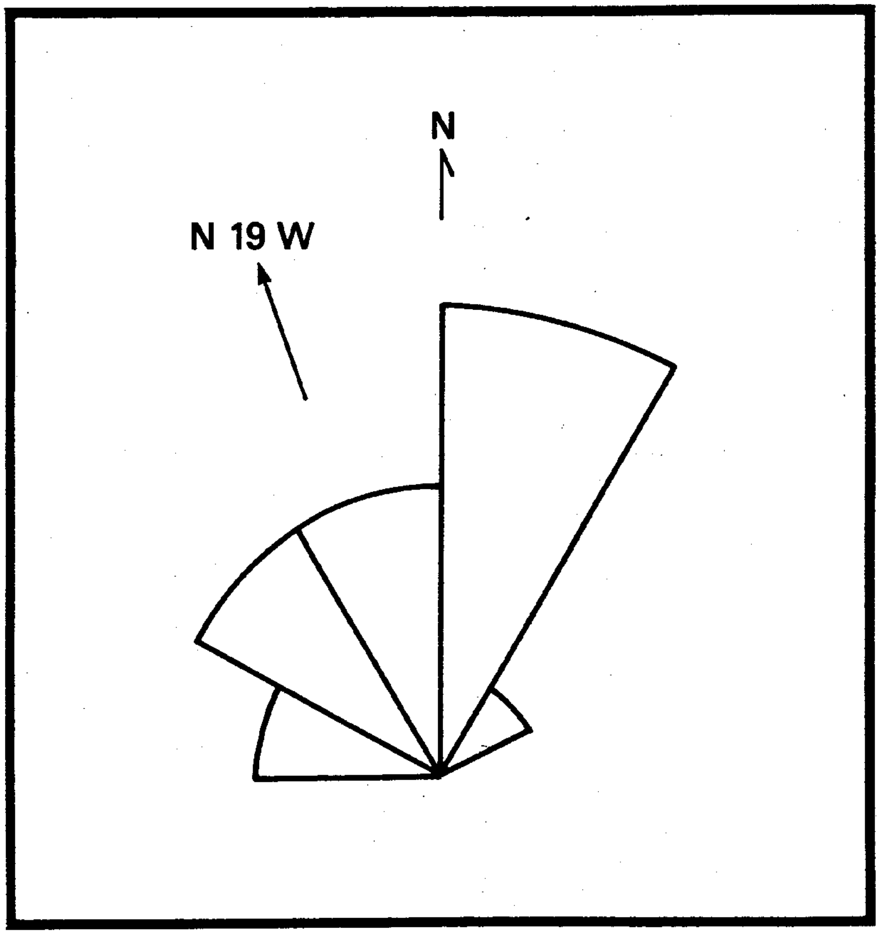


Figure 9. Rose diagram showing paleocurrent distribution at Spitzenberg Hill.

LITHOSTRATIGRAPHY AND SEDIMENTOLOGY OF THE MARTINSBURG AND HAMBURG KLIPPE

The Martinsburg Formation displays a surprising wealth of primary sedimentary features despite relatively poor exposures, pervasive weathering and considerable structural deformation. These sedimentary features, combined with litho- and biostratigraphic control, are adequate to allow development of a detailed facies analysis of most units. Thin-section study reveals that while grain shapes have been considerably altered by pressure solution, primary clast composition has not been rendered unrecognizable. Thus, considerable sedimentologic information can be extracted from the rocks.

The lowest unit of the Martinsburg is a dark, fine-grained limey shale that is in gradational contact with underlying limestones (with the Jacksonburg Formation east of the klippe, and with the Chambersburg Formation west of the klippe). In places there are thin (1-10 cm) limestone layers within the lower part of this shale. These are interpreted as limestone turbidity deposits that were derived from the carbonate platform after initial subsidence. This derivation is difficult to prove sedimentologically, because no cross-beds or flute casts have been observed. However, the layers are weakly graded and contain fine-grained lime mud and quartz-silt planar laminations that are not disturbed by burrowing. This material could not have originated to the east where large volumes of mud were being produced. Transported sparse fossil debris (bryozoans, clams, snails and trilobites) are present. The field trip (Stop 1) will visit this unit where the limestone beds are well developed. In other places, the distinct limestone layers are not present, and the transition is characterized by an upward decrease in $CaCO_3$ content and an increase in thin silty layers in the dark fine-grained shale.

The lower shale unit above this transition zone is composed of dark gray to olive non-calcareous shale with sparse thin silty beds ranging in thickness from a few to a few tens of centimeters. Laminations within the thin siltstone turbidites are mostly horizontal, grading is indistinct and bottom marks rare; this makes it difficult to determine stratigraphic tops, especially in small isolated exposures. (The stop we have chosen to use for this unit (Stop 3) is slightly anomalous in that it contains somewhat thicker silty units and tops can be easily recognized.) These turbidites can be classified as Mutti, Ricchi-Lucchi (1978) type E turbidites (silty, thin, horizontal laminations only). This unit is approximately 800 m thick (maximum) and is gradational with the overlying sandstone unit.

The sandstone unit is recognized both in eastern Pennsylvania, Ramseyburg Member and Shochary Ridge sandstone, and west of Harrisburg. Its estimated thickness west of Harrisburg is 300-500 m. It is made of well developed "C" type turbidites, with Ta-e sequences from 10-45 cm thick, and interbedded hemipelagic shale. These beds typically are individually laterally persistent and possess uniform sedimentary characteristics such as average and maximum grain size, thickness, and sedimentary features. Convolute laminations indicating very high current velocity are present in some beds. Flute casts and other evidence of minor scour and erosion are also found. However, extensive amalgamation of beds is absent, indicating that these were deposited in an environment where deposition far outweighed erosion on average.

West of Harrisburg this sandstone unit changes upward into a uniform siltstone unit that has few if any detectable primary sedimentary features, except for "micro-flaggy" or platey fissility. The siltstone unit, 800 m thick as estimated from map patterns, has fewer but generally sandier turbidites. The unit contains graptolites, but trilobites and other shelly fauna also have been found, especially in the upper part. The upper part of this unit will also be seen on the field trip (Stop 7).

Finally, the upper sandstone that caps the sequence (Stop 7) contains 10-30 cm thick sandy layers that are not graded and do not contain clear turbidite features. Both the sandstone and the very silty interbeds contain shelly faunas and are extensively burrowed. This unit is up to 50 m thick and is unconformably overlain by the Juniata and Silurian sandstones in the field trip area.

Above the Martinsburg is a distinct erosion surface of Taconic age that cuts through every autochthonous unit as well as the Hamburg klippe. The Juniata and Tuscarora Formations (Stop 4) contain unmistakable terrestrial and beach deposits (Cotter, 1982), marking the return of the sea over this unconformity. This unconformity indicates uplift and erosion between late Middle Ordovician and Silurian time in Pennsylvania from the Maryland state line to the Delaware Water Gap.

Current indicators such as flute casts, cross-bed and groove orientations were measured and corrected for bedding-tilt. Plunge corrections were not done, due to lack of local plunge information and the lack of plunges of over 15-20° regionally. Results are shown in Figure 10. The measurements generally come from the turbidite-rich lower sandstone, but the other units also contribute some data. The directions are fairly homogeneous within the autochthonous units, and clearly show a southeastern source.

Clast petrography of the coarser parts of the Martinsburg, primarily the lower sandstone unit (Table 3), reveals that the source area was rich in quartz and metamorphic rocks. The Martinsburg sands are dominated by "metamorphic quartz" with some single crystal quartz, much undulose-extinction quartz and very little volcanic-type quartz. Other components are plagioclase (Ab_{64-75}), metamorphic rock fragments (phyllite, schist) and a suite of heavy minerals that includes rounded zircons, sphene, tourmaline and garnet.

These sedimentologic data have been used to develop a model for deposition of the Martinsburg Formation. The essential features of this model are the formation of a tectonically rapidly depressed basin floored by the carbonate bank, and the appearance of land on the southeast capable of providing quartzose but immature sediment fill. During the Middle Ordovician (specifically in the *Nemagraptus gracilis* - *Diplograptus multidens* Zone interval), the site of the present Martinsburg abruptly subsided. Some lime turbidites were deposited from the northwest, but were soon overwhelmed by mud and silt derived from the southeastern clastic source. Water depths are difficult to estimate, but considering the lack of burrowing, the distal nature of the turbidites, the thickness of units, and the lateral width of the entire clastic wedge system, "ball park" depths in excess of 500 m seem reasonable. Each of these points have alternate explanations, but in aggregate it is reasonable to assume that this basin was on the order of 300-400 km wide and 500 m deep at the time of maximum development. As filling progressed, successively shallower facies migrated northwest across the site of the present outcrop. In a sense the lower shales could be thought of as "rise" deposits, the lower sandstone as the

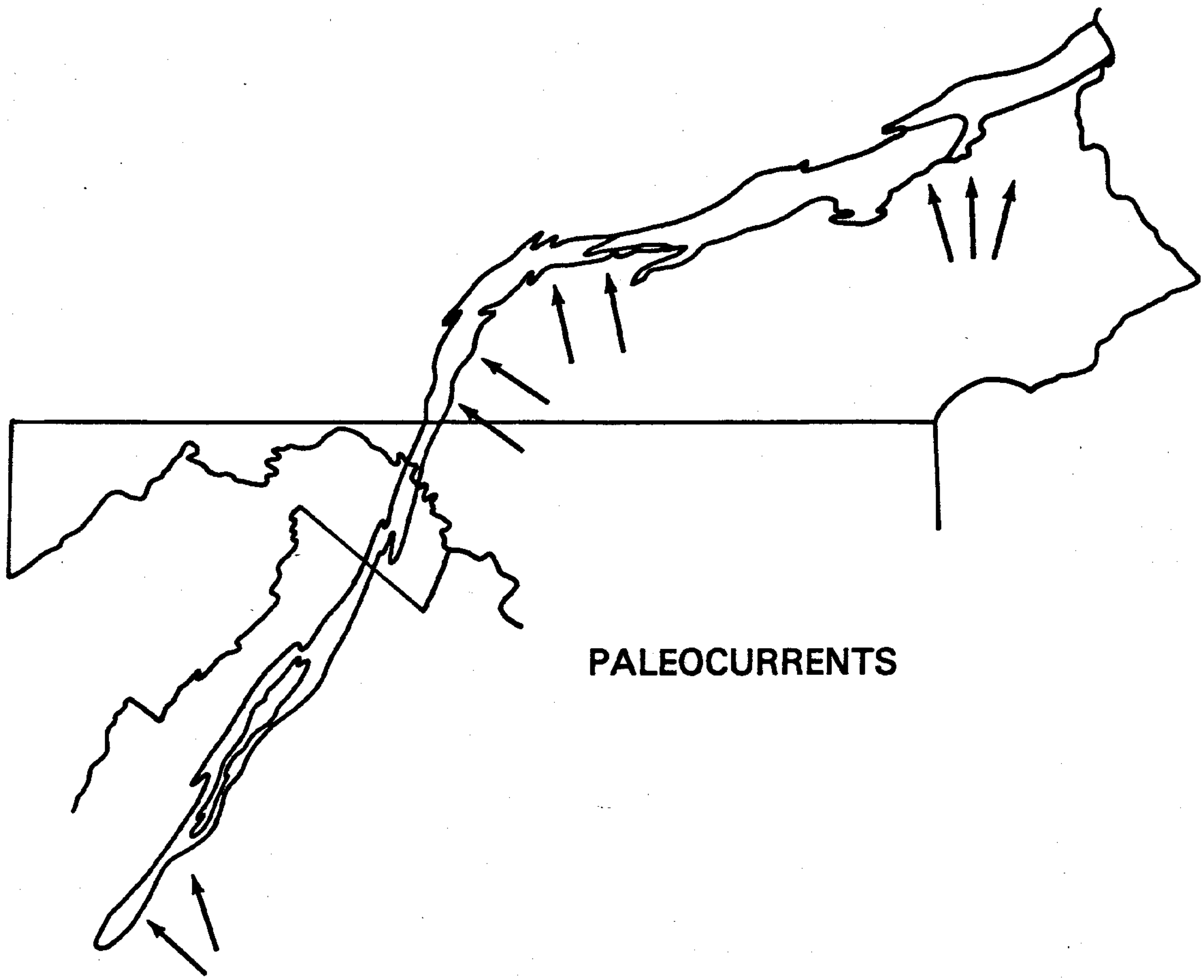


Figure 10. Paleocurrent directions in the Martinsburg Formation, central Appalachians.

Table 3. Clast petrography of Hamburg klippe and Martinsburg graywacke.

Area	unstrained quartz, %	strained quartz, %	feldspar %	rock fragments, %	opaques %	matrix %
1	49	17	2	7	1	25
2	48	21	1	6	2	23
3	43	26	3	10	7	11
4	55	23	1	5	4	11
5	50	20	7	12	7	5

Area 1 - Shochary Ridge, Berks County; Area 2 - Ramseyburg Member, Lehigh County; Area 3 - Lower sandstone, west of Harrisburg; Area 4 - Upper sandstone, west of Harrisburg; Area 5 - Hamburg klippe graywacke, west of Hamburg.

"slope" and the upper shale and sandstone as "shelf" deposits of this basin, keeping in mind that this was a cratonic basin, not a continental margin.

The sedimentary rocks of the Hamburg klippe are more difficult to assign to sedimentary facies; however, some new information is available. Beginning with the oldest rocks so far identified, the lowest Ordovician banded limestones, a deep-water origin seems likely. These thin fine-grained limestone beds contain undisturbed laminations of fine quartz silt in the micrite. The interbedded shale is very fine and dark; burrowing is not observed and shelly debris is lacking. This deposit presumably pre-dates the onset of tectonism, and the sediment type is compatible with a distal passive margin environment (shelf-derived lime mud and quartz, fine hemipelagic shale, all deposited outboard of the continental slope).

The red slate unit contains sparse graptolites that probably belong to the Nemagraptus gracilis Zone. The red shale is fine-grained in most places, but does contain thin layers of coarser material. This red-colored debris is interbedded with thin transported (cross-bedded) dolomite beds and beds of light green shale. The dolomite beds have yielded graptolites in three localities, the best of which we will visit (Stop 12). Rare layers of excellently rounded, coarse single-crystal quartz grains have been found in the red slate.

These features can be explained, perhaps not uniquely, by the following model. The exposure of the carbonate bank that produced the Middle Ordovician unconformity resulted in the development of a terra rosa or red soil that eroded rapidly. At the same time, the exceptionally well rounded quartz was being exposed and re-worked. The red mud was transported to the sea, bypassing the remaining marine shelf, and was deposited on the continental rise. The deposition rate was such that it exceeded the ability of marine life to supply enough organic carbon to reduce the iron; thus, these sediments retained their red color, despite deposition in a marine environment. The similarity, except for Fe^{+2}/Fe^{+3} ratios, between the red and associated green shales supports this interpretation (Wright and Feeley, 1979). The dolomite and the rounded quartz also bypassed the carbonate banks in small quantities and were deposited oceanward of the continental margin.

In the Glyptograptus teretiusculus-Nemagraptus gracilis Zones interval, the detritus shows a striking change from mature to quite immature sources which we think marks the change from passive margin to active tectonics. The first indication of immature sediment in the Hamburg klippe is the arrival of a graywacke containing possible Glyptograptus teretiusculus Zone forms. Riva (pers. comm.) was not entirely positive of this age assignment; however this graywacke also appears to stratigraphically underlie the Nemagraptus gracilis age red slate in the Hamburg area. If correct, interbedding of mature sediment from the shelf with coarse, immature detritus from the east would be indicated, beginning in Glyptograptus teretiusculus Zone time.

The Hamburg klippe graywackes were derived from the same general source as the sandstones of the Martinsburg, based on clast compositions and ratios between clast types (Wright and Kreps, 1979). Thus, these graywackes, and associated olive shales and metabentonites are judged to be the first major products derived from the new tectonic land to the east. The depth of water is difficult to determine, but the faunas and sedimentary features of the turbidites can be used to support a deep-water environment.

STRUCTURAL FEATURES OF THE GREAT VALLEY

The regional structure of the autochthonous Martinsburg Formation (first day of trip) is remarkably simple and is dominated by the northern extension of the Massanutten synclinorium. To the south, in Virginia, where the synclinorium is best known, the structure is cored by Silurian and Devonian quartzite and shale at Massanutten Mountain. The Martinsburg Formation is present beneath these younger rocks and is underlain on both limbs of the synclinorium by older Cambrian-Ordovician carbonate rocks.

The large synclinal structure can be traced through the type section of the Martinsburg at Martinsburg, West Virginia, through Maryland, and into the field trip region in southern Pennsylvania (Figure 11). An almost complete stratigraphic section of the Martinsburg is present beneath the Upper Ordovician/Silurian rocks at Massanutten Mountain, but to the north and south, the uppermost stratigraphic units are removed by erosion (Schoellkopf, 1982).

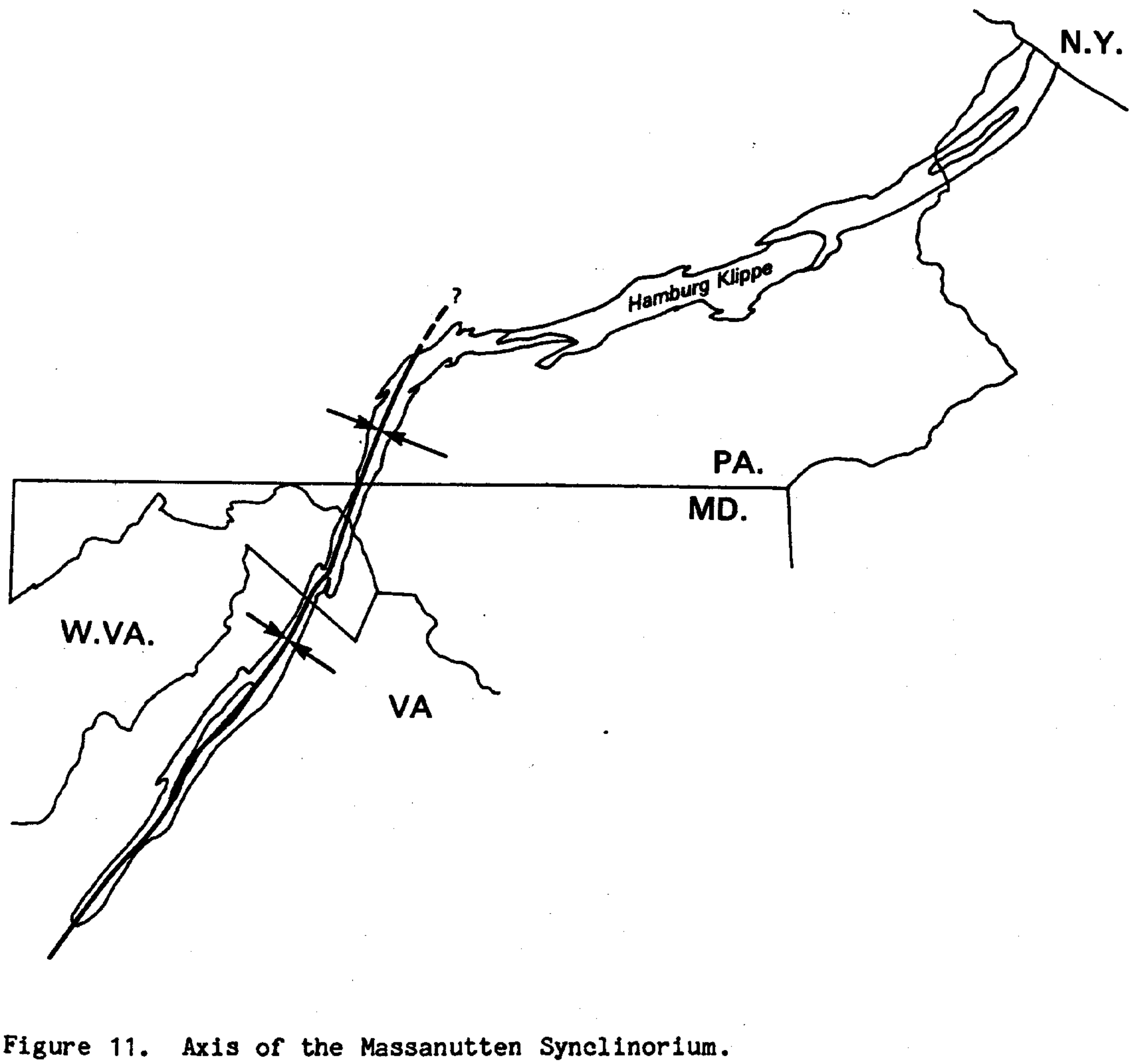


Figure 11. Axis of the Massanutten Synclinorium.

At a point northwest of Chambersburg, Pennsylvania, the older carbonates of the western limb of the synclinorium disappear beneath the Silurian Ridge of Blue Mountain. From at least this point, to the north and east, the angular unconformity of the Taconic orogeny is present beneath the Upper Ordovician Juniata Formation. The basic synclinal nature of the Martinsburg outcrop belt is still reflected in the map pattern and in the facing directions of the prominent lower graywacke member of the Martinsburg.

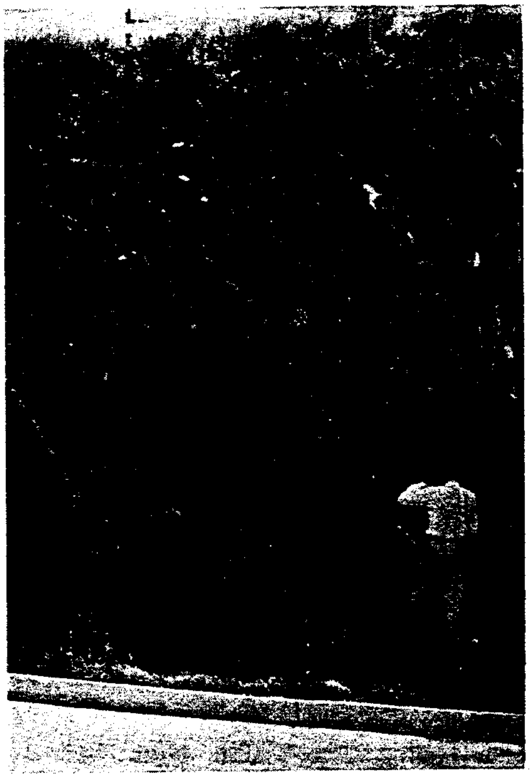
The axis of the Massanutten synclinorium rises and plunges along its strike resulting in a series of culminations and depressions along the synclinal structure. At the southern end of the outcrop belt, near Staunton, Virginia, the axis plunges northeast beneath the younger Upper Ordovician/Silurian rocks of Massanutten Mountain. It rises northward from beneath these younger rocks and crosses a culmination near Martinsburg, West Virginia and then gently plunges northward in Maryland and Pennnsylvania.

Traverses across the synclinorium in Virginia, West Virginia, and Maryland reveal that it is an asymmetric structure with a vertical to overturned eastern limb and a western limb which dips moderately to the southeast. The cleavage in this area is axial planar to the synclinorium, as well as to minor folds, and thus dips 60-70° to the southeast.

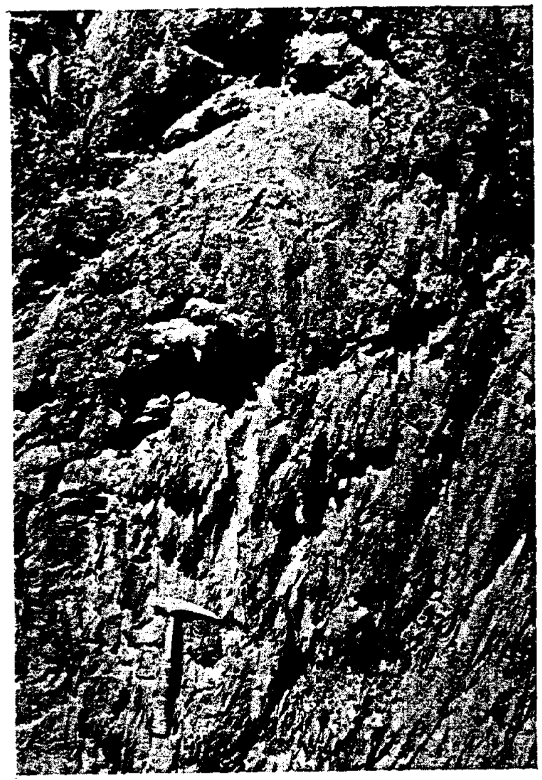
Minor folds are abundant within the Martinsburg. Although they have variable styles, which range from open and upright concentric folds to overturned and asymmetric similar folds (Plate 1), most mimic the style of the major synclinorium. Because of the abundance of these minor structures, with attendant dip and younging direction reversals, and the sparse distribution of outcrops, detailed structural mapping within the area is impossible, except at selected localities.

Structures within the Hamburg klippe are more complex than within the autochthonous sequence. In addition to the upright to slightly northwestward verging folds of the Alleghanian orogeny, earlier deformations are clearly imprinted on most of the rocks of the Hamburg klippe. These early structures are characterized by soft-sediment(?) isoclinal recumbent folds (similar to those seen at Stops 11 and 12), and an early cleavage that is nearly parallel to bedding. This cleavage, if axial planar to associated folds, implies a pre-Alleghanian isoclinal folding event. This cleavage is folded by the Alleghanian deformation.

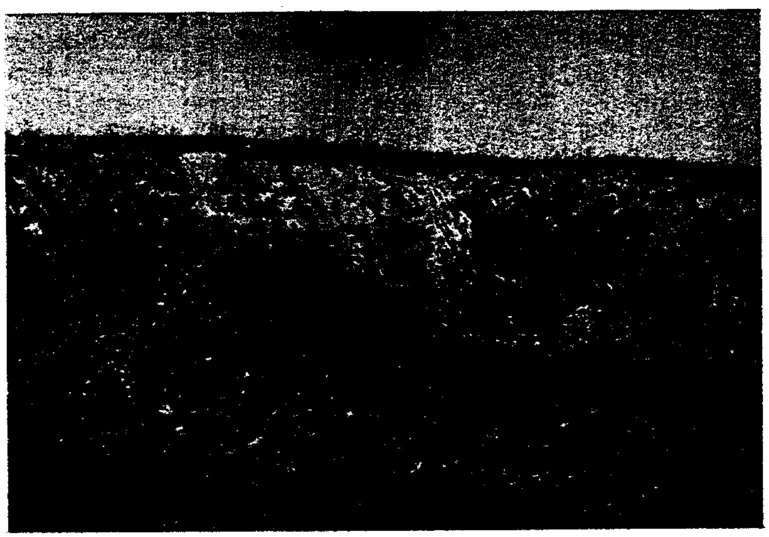
The most pervasive structure within the Martinsburg is a well-developed penetrative axial plane cleavage. This striking feature has been studied by many geologists from before the time when slate was an important resource. We return once again to the perspicacious H. D. Rogers, who wrote (1858, p. 237) "In nearly every part of the district the strata display an excessive amount of <u>cleavage</u>, the divisional planes or joints dipping almost invariably towards the <u>S.S.E.</u>, or parallel with the planes which bisect the anticlinal and synclinal flexures." Later works have shown that his study says a lot, but it doesn't say it all. For example, Rogers did not indicate when the cleavage formed or how, though he did indicate he was not much taken with the notion of compressive forces being important.



a. Isoclinal folds in basal limey unit (Stop 1).



b. Asymmetric similar fold in lower shale.



c. Open upright concentric fold in middle graywacke.

Plate 1. Fold styles in the Martinsburg Formation.

It is not our intention here to review the study of cleavage since Rogers commented upon it. This has been done (Siddans, 1972; Wood, 1974). However, it is a fact that there has been much attention given to cleavage in the clastic rocks of the Great Valley, and it is also true that slate has been economically important near the area of our trip. Thus it seems appropriate to summarize some of the ideas generated by examining these slaty rocks and to consider the observations that bear on those ideas.

The thorough study by Behre (1927) led him to the conclusion that the economically important material he was interested in, namely slate, had formed as a result of folding during the Ordovician Period. Three lines of evidence led him to this. The Martinsburg slate and the older carbonate rocks along the south side of the Great Valley have small recumbent folds whereas the folds in the Valley and Ridge province are nearly upright and have much greater wave lengths. Also an angular unconformity was recognized above the Martinsburg in eastern Pennsylvania. Finally, pieces of slate were reported to be in the basal Silurian conglomerate. This looked like a convincing array of data.

Deformation of the slaty cleavage was recognized later by Broughton (1946) in New Jersey, just east of the Delaware River. The slaty cleavage was thought to form by flattening whereas fracture cleavage presumably formed from some sort of shear. Following the terminology of Leith (1905), slaty cleavage was considered a metamorphic process with the growth of new micas in addition to the rotation of platy minerals into parallelism.

Reappraisal of the observations, inferences and assumptions that had led Leith to his genetic scheme, and new observations of cleavage in the Martinsburg along the Delaware River, brought Maxwell (1962) to the startling proposal that the slaty cleavage he examined was not dependent on metamorphism - on the growth of new minerals at high temperature - but, instead, that it formed by compression of wet mud during syndepositional Taconic folding. This paper had a profound and lasting effect on the topic. With hindsight, it may be safe to say that Leith's review and summary deadened research by presenting the situation as known; Maxwell excited new thinking by presenting a radically new and different viewpoint. In the ensuing twenty years every facet of his suggestion and evidence has been examined and re-examined, some people finding in favor (Carson, 1968; Alterman, 1973), others finding against (Geiser, 1975; Groshong, 1976; Beutner and others, 1977), but all finding new ways of looking thanks to Maxwell's proposal.

Cleavage in the Martinsburg and other rocks in Pennsylvania is by no means exhausted as a research topic. J. B. Epstein (1974; Epstein and Epstein, 1969) indicated that the most prominent cleavage near the contact with the overlying Shawangunk conglomerate is axial planar to folds affecting the conglomerate, and is thus synchronous with Valley and Ridge folding. He also noted new mineral growth and suggested 200°C as a likely temperature for the rocks at the time. Finally, he noted that pressure dissolution was an important mechanism. Holeywell and Tullis (1975) developed evidence for new mineral growth and against simple mechanical reorientation of pre-existing grains. Beutner's evidence against rotation of platy minerals and for dissolution has been confirmed by Woodland (1982).

Pressure dissolution as a mechanism in deformation, particularly to produce cleavage in clay-rich rocks like the Martinsburg, has repeatedly proved to be important in recent years. A recent article implies that half the original shale has dissolved away so that we see in slate mostly the insoluble residuum of the original material (Wright and Platt, 1982).

Much work remains to be done on the mechanisms and kinetics of cleavage formation by pressure dissolution. The fine structure of cleavage is now being investigated by a variety of methods including the scanning electron microscope (for example, Borradaile and others, 1982). The chemistry of both the dissolved and residual minerals is being studied by electron microprobe and energy dispersive systems. Results of these experimental and theoretical studies are needed before cleavage in low-grade rocks like the Martinsburg can be completely understood.

REGIONAL GEOLOGIC RELATIONSHIPS

The previous sections have described the internal stratigraphy and structural relationships of the Martinsburg and Hamburg klippe in the Great Valley. Although the field trip will not visit areas outside the Great Valley, certain other rocks in Pennsylvania and in the adjacent mid-Atlantic states should be discussed before attempting to develop an overall geologic history and plate tectonic model for this region.

The Reedsville Formation in the Valley and Ridge of Pennsylvania, Maryland, and West Virginia is essentially the lateral (cross-strike) equivalent of the Martinsburg in a gross sense as it is a shale and graywacke sequence that overlies Ordovician carbonates and underlies the Upper Ordovician-Silurian sandstones. However, correlations of age, thickness, sedimentary facies and lithology between the two have not been well developed. Postulated long distance translation along the Blue Mountain decollement (Drake, 1969) and between the Reedsville and lower rocks (Pierce, 1966) brought up the possible physical juxtaposition of packages of rocks that are not closely related. The demonstration of major thrusts in the southern Appalachians (Cook and others, 1979; Harris, 1979) strengthens this possibility by analogy. Graptolite collections from the Reedsville have shed some light on these problems and the results are summarized below.

Graptolites were collected at several localities (Figure 12) from near the Great Valley to near the Allegheny Plateau. The most striking thing shown by these collections is the transgressive nature of the Coburn Limestone-basal Reedsville (Antes) contact. It youngs from the *Corynoides americanus* Zone near Chambersburg to the *Climacograptus spiniferus* Zone at State College. This explains some of the difficulties in correlating the Reedsville and Martinsburg Formations, because previously the Reedsville (Swartz, 1948) was thought to be entirely younger than the Martinsburg. The westward younging also is quite compatible with the westward sediment transport directions determined for both formations. No tectonic transposition between the Reedsville and Martinsburg can be detected by biostratigraphy or facies analysis. This, due to the rapid time-transgressive nature of the Reedsville, probably limits any translation to a few tens of kilometers at most, and therefore strengthens the interpretation that the Reedsville is a direct, lateral extension of the same depositional system as the Martinsburg.

To the southeast, possible correlations of the Martinsburg with units in the Piedmont face more formidable problems. Here, metamorphism and physical separation by Triassic rifting have more thoroughly obscured relations. Historically, two fundamentally different ideas have been postulated: first, that the Glenarm series is entirely older than the rocks to the west, and is offset by the Martic thrust; second, that the Glenarm series is correlative with rocks to the west. There is no adequate fossil evidence available to choose between these possibilities at present. Yet there is considerable support for the idea that the Glenarm sequence (Setters, Cockeysville, and Wissahickon Formations) is correlative to the Cambro-Ordovician passive margin and the Martinsburg (Fisher and others, 1979). Age constraints and sedimentary facies of the Wissahickon metamorphosed flysch sediments make correlation with the Martinsburg attractive. The Wissahickon contains clasts that are larger to the east in agreement with the sediment transport direction of the Reedsville/Martinsburg system. In addition, clast compositions are compatible with the sandstones of the Martinsburg.

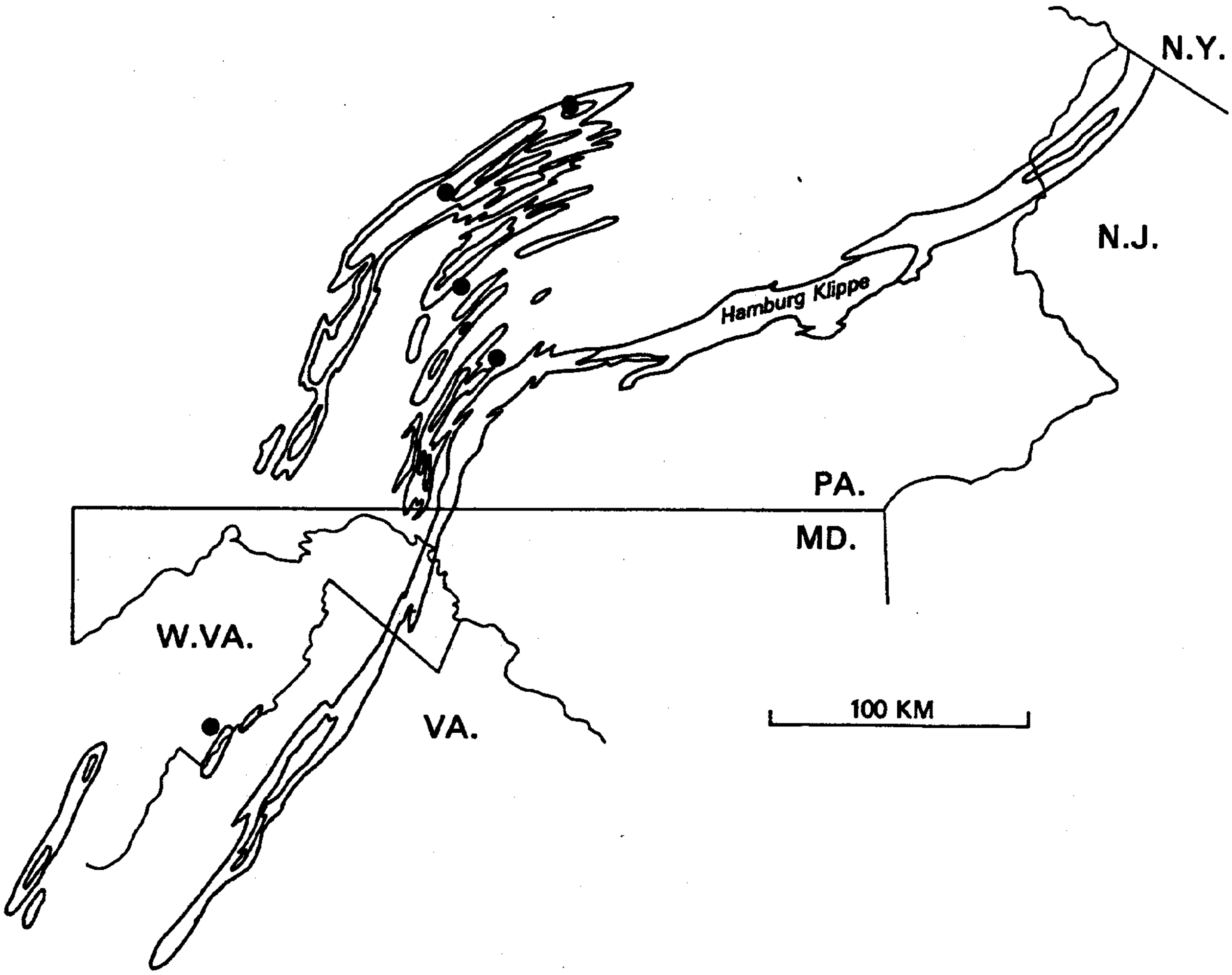


Figure 12. Localities of Middle Ordovician clastic rocks (Martinsburg and Reedsville Formations). Dots indicate collected graptolite localities in the Reedsville.

GEOLOGIC HISTORY

In constructing this history, we have made the following assumptions, all of which are controversial to some degree as discussed on previous pages.

1. That the Glenarm sequence is correlative to the Great Valley carbonate - Martinsburg sequence, following Fisher and others (1979).

2. That the Hamburg klippe is a single coherent block that originated east of the shelf edge.

3. Thac the Hamburg klippe was thrust and/or slid into the Martinsburg basin during the Middle Ordovician before much easterly-derived mud was present, and has not moved differentially with respect to the overlying Martinsburg.

4. The Reedsville and Martinsburg are not significantly transposed by major thrusting and can be considered as being in correct relative positions for reconstruction of the Middle Ordovician paleogeography.

5. That Shochary Ridge is a part of the autochthonous Martinsburg Formation.

With these assumptions, the overall history we envision for the Martinsburg can be summarized in six phases. Each of these involves a distinct change in the development of the present area of eastern Pennsylvania and was deduced from the accumulated evidence and interpretations presented earlier.

Phase I Passive margin development

Following rifting during the late Precambrian or early Cambrian, a passive margin developed with extensive shallow-water carbonate sedimentation. The youngest of these passive-margin deposits in the Great Valley are the Jacksonburg Formation, the Chambersburg Formation, and their equivalents of Middle Ordovician age. The Hamburg klippe contains two units that were deposited during this phase, the lowest Ordovician ribbon limestone and black shale unit and the red slate unit, containing graptolites of the *Nemagraptus gracilis* Zone. Both are interpreted as deep-water deposits of material washed over the shelf edge from the northwest. These thin units are of the same age as some of the shallow-water units on the craton, but are of a very different facies.

Phase 2 Onset of tectonism

The arrival of coarse immature sandstone, mud, and volcanic ash beds, of *Nemagraptus gracilis* and possibly *Glyptograptus teretiusculus* Zone age, marks the first tectonic disturbance of the passive margin that can be detected in the Hamburg klippe, the oldest deep water sediments examined in this study. The graptolites precisely date the active/passive margin transition between the Glyptograptus teretiusculus and the Nemagraptus gracilis Zone. This tectonic disturbance clearly must involve volcanism and uplift of an eastern source; however, the plate tectonic environment has not been resolved completely. Fisher and others (1979) postulate development of an island arc to the east of the craton and plate convergence via a west-dipping subduction zone. The Wissahickon is interpreted as flysch derived from rocks similar to the Baltimore Complex which was thrust from the east. Age constraints on the Wissahickon are poor due to the lack of fossils, but the age must be in the range of 550 MY (age of the James Run volcanics, boulders of which are included in the Wissahickon) to the Middle Ordovician age of the overlying Arvonia Slate. However, the graywackes in the Hamburg klippe and in the Martinsburg which would be derived from this terrane do not contain identifiable volcanic debris. This is difficult to reconcile with the idea that the eastern source was a simple island arc. Other possibilities are that a microcontinent is involved in obduction and/or that only metamophosed portions of the arc complex provided sediment. Whatever the precise configuration, the fossils in the Hamburg klippe may well be the best control on the onset of tectonism along the central Appalachians.

Phase 3 Basin formation

The next event in the story is the formation of the Martinsburg basin which will later receive clastic sediment. The abrupt, but transitional, depositional contact between carbonate and shale east and west of the Hamburg klippe, as well as the faunal control, indicate that the basin formed rapidly between the Nemagraptus gracilis and the Diplograptus multidens Zones. This event appears to involve a down-warp of the entire eastern edge of the old carbonate platform. The deepest facies of the Wissahickon-Martinsburg-Reedsville system are clearly on the eastern edge, with a progressive shallowing to the west. This flexural bending of the craton margin was probably caused by loading of the eastern margin by an obducted slab of rock, either a microcontinent or the roots of the island arc.

Phase 4 Basin filling

Immediately after obduction and basin formation, some carbonate sediment was transported eastward from the remaining carbonate bank; however, by far the most important source of sediment was the uplifted slab to the southeast. The immature clastic debris soon diluted and overwhelmed the relatively small amounts of carbonate detritus. The Hamburg klippe, originally deposited off the bank to the southeast of the continental platform, was also obducted to the point where it could slide, or be thrust, into the new basin. Following this, a sequence of southeasterly-derived sediments filled the basin. The stratigraphic progression from shale to turbidite to silty shale ending in shallow-water sandstone, and the primary sedimentary features these units contain are entirely compatible with basin filling from the southeast. Across strike (and across the paleo-shoreline) the dramatic time-transgressive nature of the Reedsville is also in accord with the model, which predicts a northwestward prograding set of facies.

Phase 5 Taconic unconfomity phase

In the Valley and Ridge province the marine Reedsville is conformably overlain by beach and/or delta facies sandstones (Bald Eagle Conglomerate) and fluvial sandstone and shale (Juniata Formation). Equivalents of these nearshore and terrestrial sediments are also present in the Great Valley at Massanutten Mountain disconformable above the Martinsburg, (Schoellkopf and others, 1981) indicating that deposition continued even after the sedimentary fill reached sea level. The Martinsburg Formation north and east of Chambersburg as far as Harrisburg is overlain unconformably by the nearshore and fluvial sandstone sequences of the Bald Eagle and Juniata Formations. The shallow marine and terrestrial deposits now missing were probably deposited, but were removed by Upper Ordovician erosion. In places in eastern Pennsylvania, this erosional event removed all of the autochthonous Martinsburg and even part of the Hamburg klippe. Thus differential uplift on the order of 1500 m between Virginia and eastern Pennsylvania is implied. To the north, this unconformity increases into New Jersey where the Silurian was deposited on carbonate and, in a few places, even on the Precambrian. This was possibly caused by continuing compression, which uplifted the recently deposited Middle Ordovician sediments, and removed them by erosion. That Taconic deformation did occur is also supported by the observed cleavage in Martinsburg blocks caught up in the Late Ordovician syenite intrusion near Beemerville New Jersey (Ratcliffe, 1981).

Phase 6 Burial and late deformation

As tectonic activity waned, the epeiric sea migrated back to the east, depositing clean sand over the older rocks that had been emergent. The Tuscarora Quartzite and the Shawangunk Conglomerate represent this event, and form a cap to the unconformity.

The next detectable deformational episode involves late Paleozoic compression caused by a continent-continent collision between the North American and African cratons. In

> eastern Pennsylvania, major folds and axial plane cleavage were formed, probably at considerable depths. These folds and associated cleavage are most likely related to deeper detachment faulting or thrusting.

This study of the Martinsburg Formation in the Great Valley of Pennsylvania contributes to understanding Middle Ordovician tectonism, related subsidence, uplifts and sedimentation, Taconic deformation and later tectonic episodes. The biostratigraphic, lithologic and structural data presented here provide the basis for regional models. Parts of the story are incomplete, as clearly attested by the many differences in interpretation discussed. Many aspects of the synthesis presented here strongly depend on our assumptions, and those assumptions are all dubious to some degree. Thus, we are all in the position of being the reader of an exciting novel that is missing its last chapter - it is at the same time frustrating and tantalyzing trying to find or reconstruct the end of the story.

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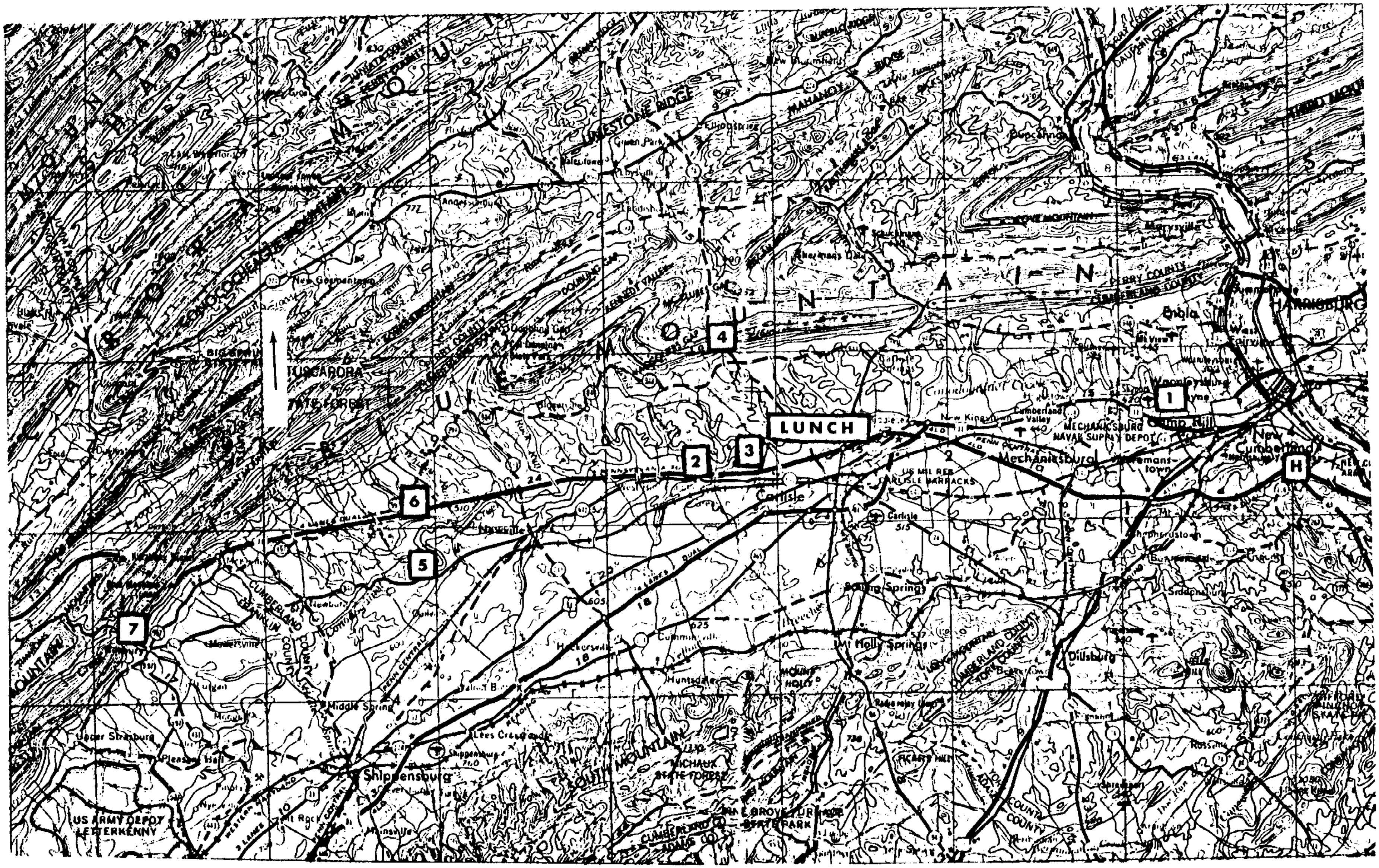
Figure 13. Field trip localities - Day 1 (Harrisburg 1:250,000 sheet) H = Headquarters Hotel.



ROAD LOG AND STOP DESCRIPTIONS

DAY 1

Cum. Miles	Inc. Miles	Description
0.0	0.0	BOARD buses in parking lot of Villa Leo Inn at Exit 18-A on I-83. TURN RIGHT from parking lot onto entrance ramp for I-83 (North).
0.1	0.1	ENTER I-83.
0.3	0.2	Cumberland County line.
1.8	1.5	TAKE Exit 20 on LEFT for Routes 11-15 (Camp Hill).
2.1	0.3	ENTER Harrisburg Expressway.
2.6	0.5	Lower Allen Township.
4.1	1.5	FOLLOW SIGNS for 11-15 North to Camp Hill.
4.3	0.2	JOIN Routes 11-15.
4.8	0.5	At THIRD TRAFFIC LIGHT, TURN LEFT on Carlisle Pike.
6.8	2.0	At FOURTH TRAFFIC LIGHT, TURN RIGHT on Sporting Hill Road.
7.1	0.3	CROSS bridge over Conodoguinet Creek.
7.2	0.1	TURN LEFT into large parking lot immediately past Conodoguinet Creek.
		STOP 1

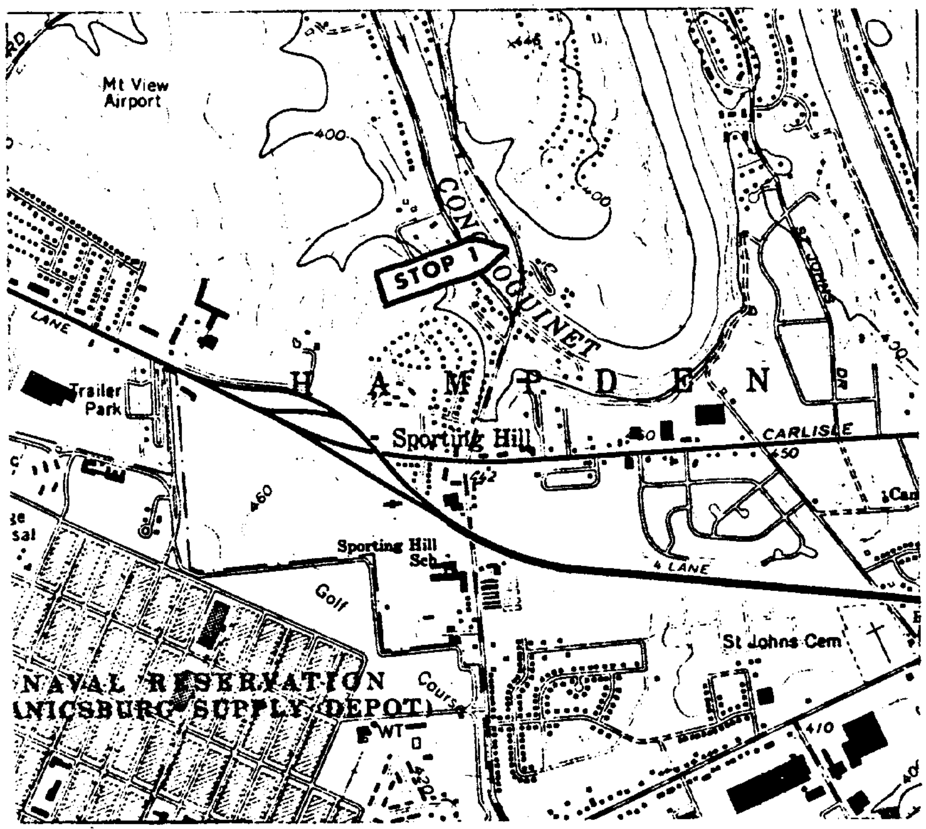


Figure 14. Stop 1 - Day 1. Road cut on Sporting Hill Road, located in the NW 1/4 of the Lemoyne 7 1/2' Quadrangle.

This outcrop serves two purposes; first, to illustrate the lowest part of the autochthonous Martinsburg, and second, to show several structural features. The outcrop has been studied in detail by Greta Gill (Gill, 1980). The contact with the underlying carbonates is just on the other side of the bridge, across Conodoguinet Creek, and the contact with the Hamburg klippe is about one km to the north.

The lowest part of the Martinsburg is commonly limey shale, but here well developed thin limestone layers are interbedded with the dark shale. These beds are interpreted as lime turbidites that originated to the west just after the basin was formed. Elsewhere, the turbidites are not as well developed and the carbonate is more thoroughly mixed with the phyllosilicates. Despite considerable looking, this outcrop has not yet yielded fossils.

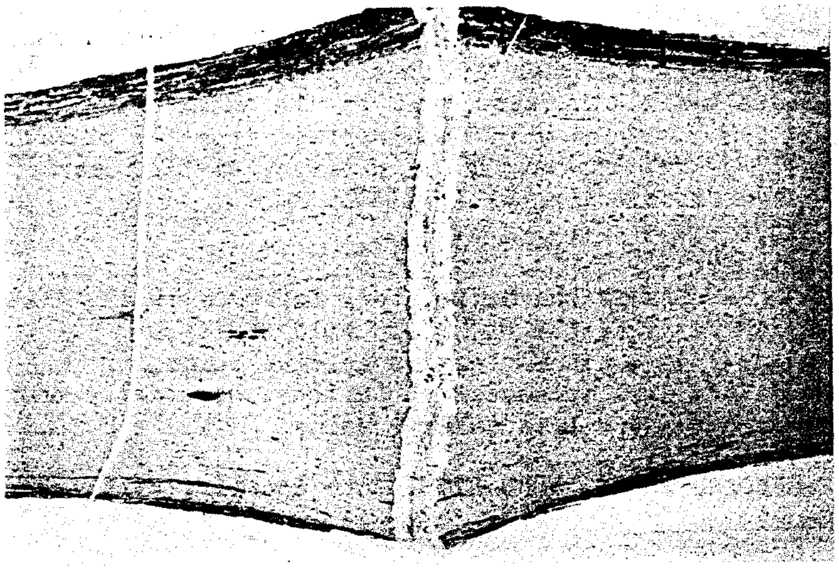
The spectacular isoclinal folds seen from across the road have tight hinges and straight limbs and verge to the northwest. On closer inspection, a diversity of minor folds with widely varying plunges can be seen.

Cleavage is axial planar to the folds, but is not uniformly developed due to the presence of pre-cleavage calcite veins and of the limestone beds. Of particular interest is the way calcite veins normal to bedding prevent cleavage shortening. Plate 2 shows examples of these veins cutting a limestone bed. Note that the limestone bed is thickest next to the veins and thinnest between veins. This feature and a folded vein (now removed from the outcrop) have been used to document a 40% shortening normal to cleavage that is caused by removal of material by pressure dissolution (Gill, 1980).

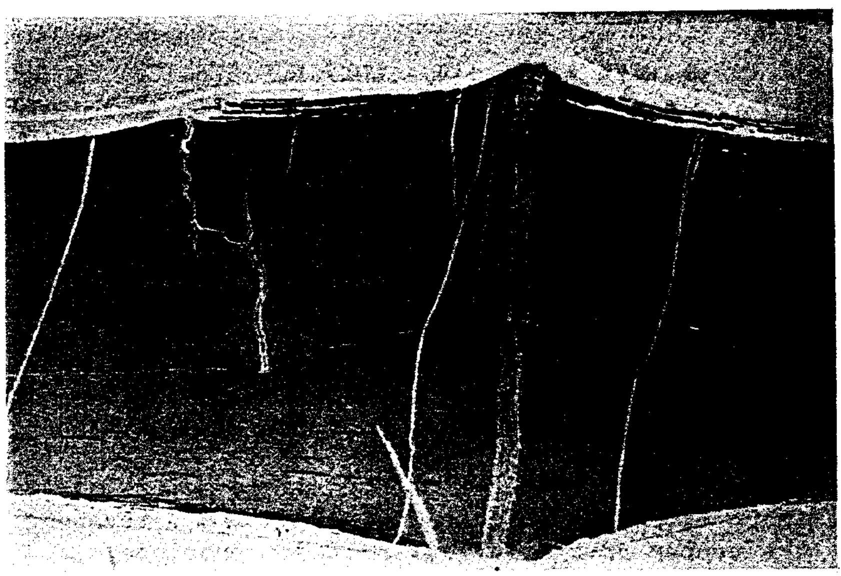
Things to see include:

1. the sedimentary features in the limestone beds,
2. the folds and fold styles,
3. pre-cleavage calcite veins,
4. cleavage variations, especially near veins,
5. late calcite veins.

7.2	0.0	REBOARD BUSES, TURN RIGHT onto Sporting Hill Road.
7.3	0.1	RE-CROSS Conodoguinet Creek.
7.7	0.4	At TRAFFIC LIGHT, TURN RIGHT on Carlisle Pike.
8.2	0.5	MERGE with Route 11 South. Blue Mountain ahead and to the right.
10.8	2.6	Junction with Route 114. CONTINUE STRAIGHT on Route 11.
11.6	0.8	Gently rolling topography, typical of carbonate terrains in fields on right.
12.5	0.9	View of South Mountain to left.
12.7	0.2	Cumberland Valley High School on right.
13.5	0.8	Low escarpment on right is a tongue of Martinsburg shale.
14.7	1.2	Major powerline crossing, Blue Mountain on right.
15.6	0.9	Cross Stoney Ridge. Stoney Ridge is a Triassic diabase dike which extends discontinuously from the Gettysburg Basin to the center of the Valley and Ridge province.
16.2	0.6	Intersection with I-81, CONTINUE on Route 11.
16.9	0.7	Village of Middlesex.
17.3	0.4	Pennsylvania Turnpike entrance on right, STAY IN LEFT LANE for Route 11.
17.4	0.1	PASS BENEATH Pennsylvania Turnpike.



a. Pre-cleavage vein showing deflection of cleavage bands around vein. Vein is 2.5 cm long.



b. Broken pre-cleavage vein showing concentration of insolubles due to solution loss at vein ends. Vein is 2.5 cm long.

Plate 2. Photomicrographs of pre-cleavage calcite veins found at Stop 1.

19.3	1.9	Enter Borough of Carlisle, founded in 1751. The first white man settled in the Cumberland Valley sometime before 1720. He was James LeTort, an Indian trader. By 1750 there were 3000 settlers in the new county of "Cumberland". The county seat was located where the Great Road from the Susquehanna River to the Potomac River was crossed by Indian trails leading to gaps in the North and South Mountains. This new town was named for Carlisle, the county seat of Cumberland County, England. (Abstracted from notes in the files of the Cumberland County Historical Society.)
19.6	0.3	Cross railroad tracks.
20.1	0.5	TRAFFIC LIGHT, CROSS North Street.
20.2	0.1	TRAFFIC LIGHT, CROSS E. Louther Street.
20.3	0.1	TRAFFIC LIGHT, TURN RIGHT to follow Route 11 in center of town. Directly ahead on the right-hand corner of the intersection is the old County Courthouse, built in 1846. It is of Georgian style and was designed to be fireproof. A front pillar bears the scars of the Civil War. It was hit by a cannon ball when the Confederates, under General Fitzhugh Lee, shelled Carlisle on July 1, 1863.
20.5	0.2	J. Herman Bosler Free Library Building on left.
20.6	0.1	Dickinson College on right and left. Older college buildings, as well as the wall surrounding the campus, are of local limestone (Stone, 1932).
21.3	0.7	TURN RIGHT on Route 641, PASS BENEATH railroad tracks and immediately TURN LEFT to follow Route 641.
23.2	1.9	Junction with Route 465 on left, CONTINUE STRAIGHT on Route 641.
23.5	0.3	West Pennsboro Township line.
23.7	0.2	Notice changing land use patterns with new houses scattered on what were, until recently, farm fields.
25.4	1.7	Town of Plainfield.
26.0	0.6	TURN RIGHT on Bears Road, just before small rise on Route 641.
26.1	0.1	PASS BENEATH Pennsylvania Turnpike.
26.2	0.1	Small sinkhole on left in field.
26.8	0.6	Entrance to the quarry is on the left around the bend in the road.

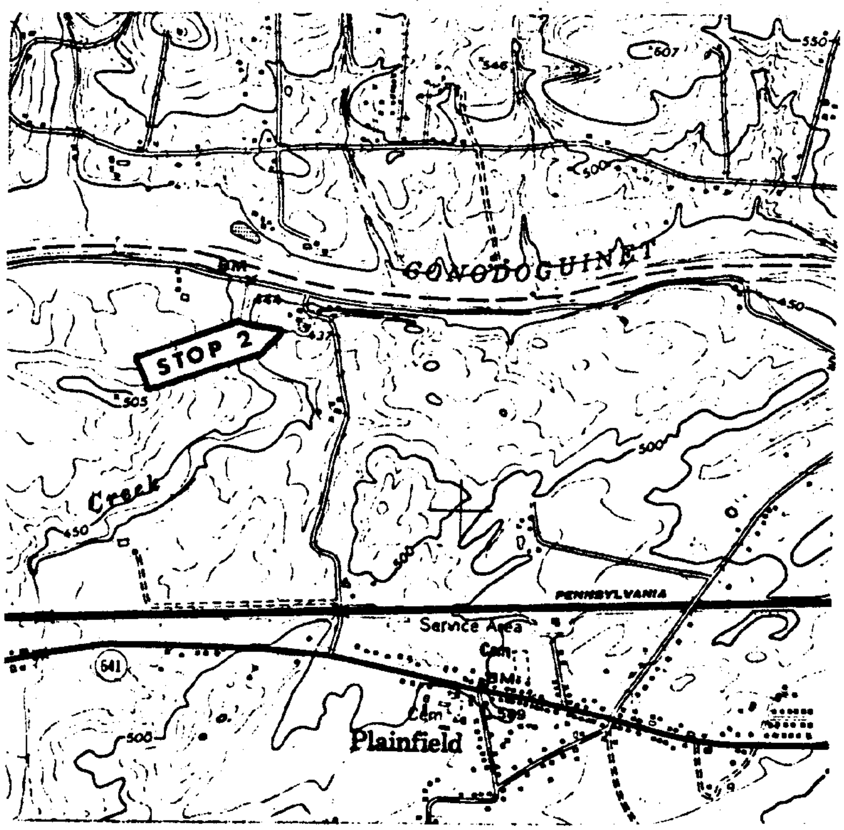


Figure 15. Stop 2 - Day 1. Paul W. Morrison Building Stone Quarry, located in the NE 1/4 of the Plainfield 7 1/2' Quadrangle.

Paul W. Morrison Building Stone Quarry. Stop 2.

We thank Noel Potter of Dickinson College for bringing it to our attention and suggesting its inclusion in this guidebook. The quarry is in the Ordovician St. Pauls Group, part of the Cumberland Valley sequence (Berg and others, 1980). The rock is a dark gray thick-bedded, finely crystalline limestone. Small amounts of rock are quarried here for building stone. Similar small quarries within the region provided stone for many of the substantial houses, churches, and other buildings of the last century. The Morrison Quarry provides small quantities of shaped building stone for use at the service areas along the Pennsylvania Turnpike.

The limestone here occurs in 4-6 inch thick beds separated by thin shaley partings. It is quarried by blasting and trimmed to shape by means of the small "guillotine" rock splitter within the pit.

This exposure in the St. Pauls Group is of interest because these rocks are typical of the Cambro-Ordovician platform carbonates which underlie the clastic rocks of the authochthonous Martinsburg Formation. Thus this exposure is representative of the earliest part of our geologic story. These rocks record a passive continental margin in the Lower to Middle Ordovician on the western edge of the proto-Atlantic.

In this quarry, notice the thick-bedded limestones, containing brachiopods, snails, and bryozoans. The beds here trend N12E and dip 25° to the southeast. A series of calcite-filled en-echelon extension gashes trend N30W on the back wall of the quarry. At the time of preparation of this discussion, a series of calcite-filled veins were exposed on the eastern wall of the quarry, trending N30W 65SW.

26.8	0.0	REBOARD BUSES, TURN LEFT on Bears Road.
26.9	0.1	TURN RIGHT at "T" intersection. Conodoguinet Creek on left.
27.7	0.8	Mayfield Farm, a handsome limestone farm house and barn on right.
28.0	0.3	Inactive building stone quarry on right.
28.3	0.3	TURN LEFT onto unnumbered hard-surfaced road (at "Charles Cornman" mailbox).
28.6	0.3	TURN RIGHT at "T" intersection onto Bears School Lane.
29.0	0.4	TURN LEFT at "T" intersection onto unnumbered hard-surfaced road.
29.5	0.5	Scattered carbonate outcrops in field on left.
29.9	0.4	TURN LEFT at "T" intersection and CROSS BRIDGE.
30.0	0.1	TURN LEFT at "T" intersection onto Route 486 (Conodoguinet Ave.), 100 yards past bridge.
30.1	0.1	Lower Frankford Township line.
30.4	0.3	Cross contact (not exposed) of Ordovician Martinsburg Formation and underlying Ordovician carbonates.
30.5	0.1	DEPART BUSES at pull-in on right side of road, (first wide pull-in after small shale outcrops).

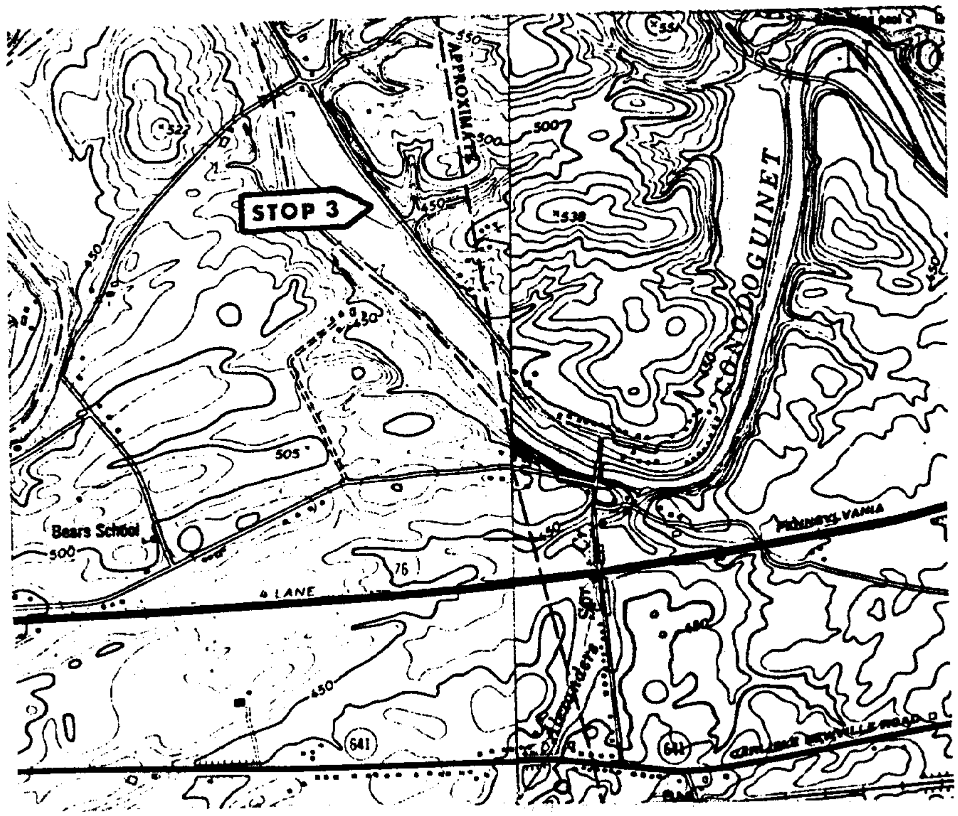


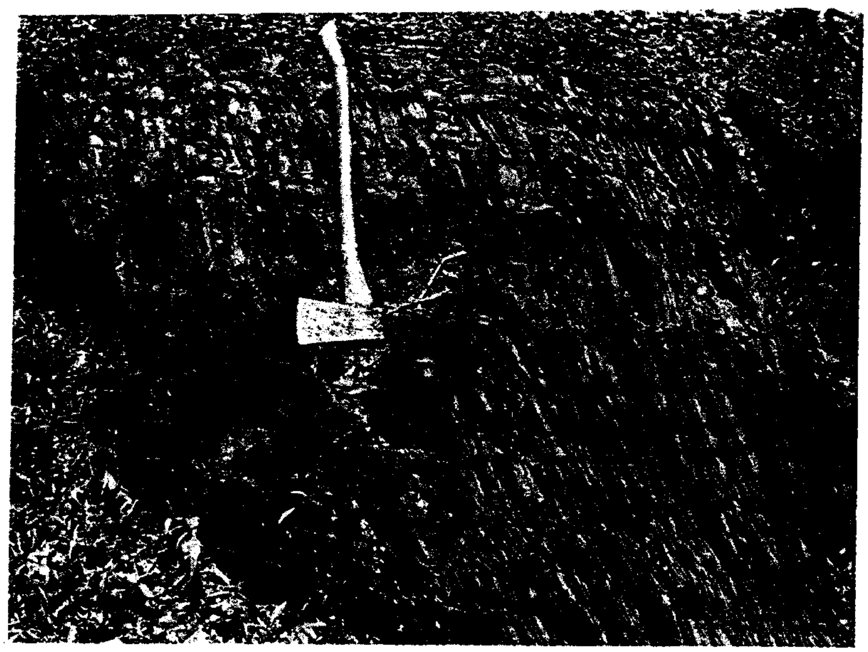
Figure 16. Stop 3 - Day 1. Roadcut located in the NE 1/4 of the Plainfield 7 1/2' Quadrangle and the NW 1/4 of the Carlisle 7 1/2' Quadrangle.

STOP 3

The purposes of this long stop are to see an example of the lower shale member of the Martinsburg, to note a style of folding different from that of Stop 1, and to observe sedimentary features typical of this member.

The contact with the underlying carbonate is approximately 1/2 km to the south, so this is stratigraphically just above the level seen at Stop 1. This outcrop has yielded graptolites of the Diplograptus multidens Zone, but the fossils are discouragingly sparse. One of the features to see at this stop is the many folds along the road. The shale and thin siltstones are folded in northwest verging open folds with strongly developed axial planar cleavage (Plate 3). These folds plunge unusually steeply to the northeast. Note the relationship between cleavage and the folds and also the variation in thickness of beds relative to position on the fold. Even though we will walk a considerable distance across strike, we will not go through very much stratigraphic section, but will see the same rocks repeated over and over. In microcosm, this is the style of folding in this region that is responsible for the widely varying map outcrop widths seen on Figure 6. The units are strongly folded but the amplitudes are such that many folds can be crossed before significant stratigraphic section is cut. It also points out the dangers inherent in estimating thickness from map patterns in structurally complex and poorly exposed areas. Thus, thicknesses reported for the Martinsburg, including our estimates, are likely to be in error on the high side.

a. Northwest verging anticline with steep southeast-verging axial plane cleavage.



b. Bedding cleavage relations. Cleavage dips steeply to the southeast.

Plate 3. Photograph of folds, Stop 3.

Other features to note are the undisturbed, fine laminations and cross-beds in the silty layers. These layers are interpreted as the distal turbidites that first reached this part of the Martinsburg basin. Presumably, thicker and coarser turbidites, which would be the more proximal continuation of these beds, were being deposited to the east. Note the lack of shelly fossils and the lack of burrowing in the shale or siltstone.

Features to see:

1. distal turbidites and sedimentary features,
2. folds and cleavage,
3. variation of fold style across strike (along road).

30.9	0.4	REBOARD BUSES at intersection of 486 and 427. TURN RIGHT onto Route 427, TAKE RIGHT-HAND FORK (Willow Grove Road).
31.0	0.1	Outcrop of Martinsburg shale on left.
31.5	0.5	TURN RIGHT onto McClures Gap Road.
31.8	0.3	TURN LEFT onto Union Hall Road.
32.1	0.3	Hard right bend in road. FOLLOW paved road.
32.3	0.2	Hard left bend in road. FOLLOW paved road. Notice the low hills and rolling topography characteristic of the Martinsburg Formation.
32.9	0.6	View of Blue Mountain on left.
33.2	0.3	TURN LEFT at STOP SIGN onto Waggoners Gap Road (Route 74).
33.4	0.2	TURN RIGHT into North Middleton Township Park. The Park is located largely on the flood plain of Conodoguinet Creek.

LUNCH STOP

33.4	0.0	REBOARD BUSES, TURN RIGHT onto Route 74 North (Waggoners Gap Road) from Park.
36.7	3.3	Junction with Route 944, CONTINUE STRAIGHT on Route 74.
36.8	0.1	Silurian Tuscarora stone farmhouse on right.
37.0	0.2	Loose Blocks of Tuscarora in colluvium shed from Blue Mountain.
37.2	0.2	Lower Frankford Township line.
37.4	0.2	North Middletown Township line.
38.2	0.8	Ordovician Juniata Formation crops out on right.

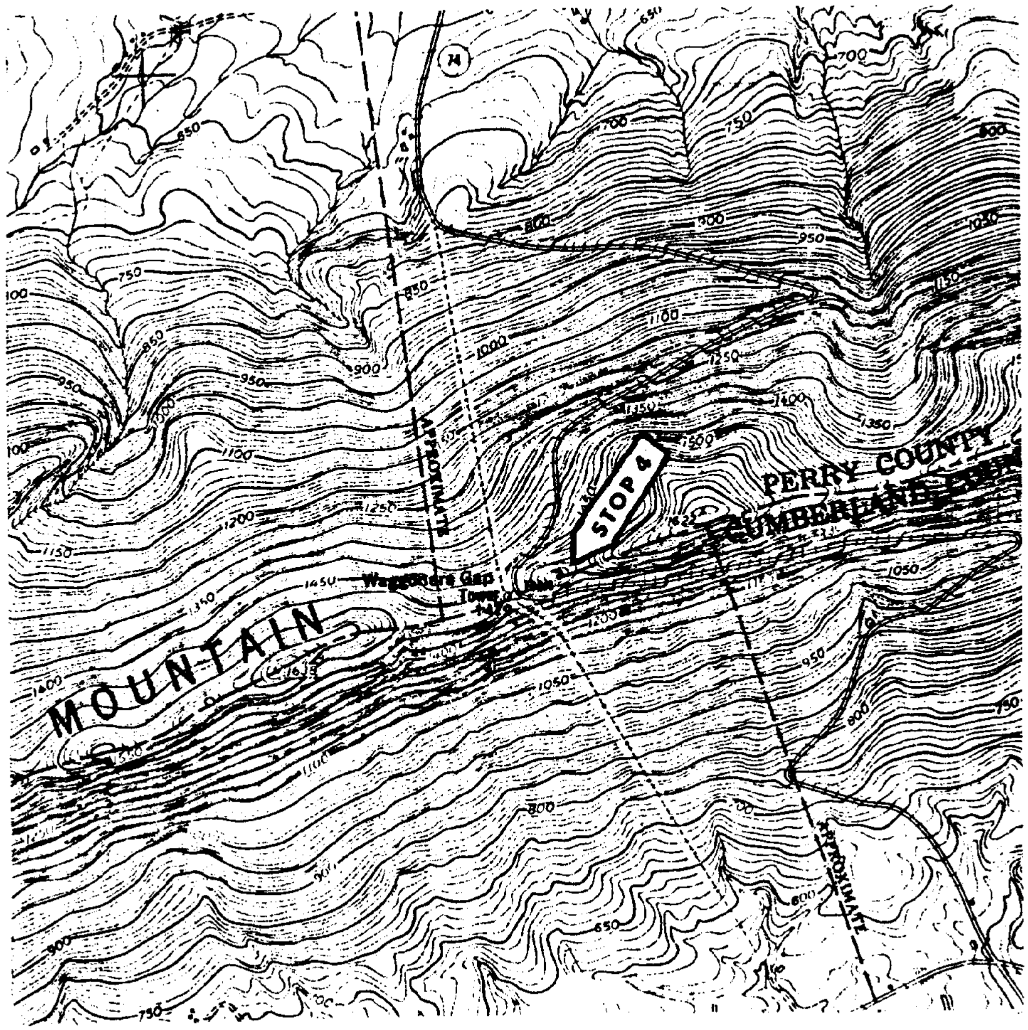


Figure 17. Stop 4 - Day 1. Waggoners Gap on Route 74 at the crest of Blue Mountain, located in the SE 1/4 of the Landisburg 7 1/2' Quadrangle.

38.7	0.5	STOP 4 - EXIT BUSES, proceed uphill.
38.9	0.2	Waggoners Gap microwave relay tower. BUSES TURN AROUND here for REBOARDING.

The purpose of this stop is two-fold: one, to gain an overview, weather permitting, of the Great Valley and its geomorphic expression, and two, to examine the Upper Ordovician Juniata and Lower Silurian Tuscarora Formations, which stratigraphically overlie the Martinsburg west of Harrisburg in Pennsylvania, Maryland, and Virginia. Waggoner's Gap is located in the southeastern quarter of the Landisburg 7-1/2 minute quadrangle. The crest of the ridge at this point has an elevation of 1479 feet; thus, it is lower by 100 to 120 feet than the ridge crest on either side. Blue Mountain is the southeasternmost ridge in the Valley and Ridge province. The ridge is comprised of Tuscarora quartzite and coarse red Juniata sandstone. The Cumberland Valley portion of the Great Valley, immediately to the southeast, is underlain by Middle Ordovician Martinsburg shales and graywackes. Southeast of the

Martinsburg, the Great Valley is floored by Cambro-Ordovician stable platform carbonate rocks. In the distance, we can see South Mountain, the northeastern end of the Blue Ridge province.

Here, as everywhere else along the front of Blue Mountain, thick colluvium covers the hillside and spills into the valley bottom. The poorly-sorted colluvium is derived chiefly from the Tuscarora Formation and covers not only the underlying Juniata Formation, but also the upper portion of the Martinsburg sequence. For this reason, even where present, the uppermost member of the Martinsburg (Stop 7) is rarely seen, being exposed primarily in cuts on roads that cross the ridge.

We are indebted to Ed Cotter, of Bucknell University, for the following discussion on the lithofacies of the Juniata and Tuscarora Formations. The 1983 Field Conference of Pennsylvania Geologists will be hosted by Bucknell and will more fully develop the ideas presented here.

> "In contrast to the view that the entire exposed Tuscarora Formation (Lower Silurian) in Pennsylvania is of braided fluvial origin, I have determined that the Tuscarora of central Pennsylvania accumulated in a variety of coastal and shelf, as well as fluvial, environments. The migration of these environments in response to eustatic and continent-wide sea level fluctuations produced the generalized proximal-distal lithofacies profile seen in Figure 18. At the beginning of Early Silurian time, a glacioeustatic sea level rise caused the transgressive onlap of a high-energy, wave-dominated beach system southeastward across central Pennsylvania. At about the same time, a tectonic adjustment of the Taconic Highlands source terrain resulted in the influx of coarser sediment into fluvial systems flowing northwestward toward the Appalachian Basin. Recorded in the stratigraphic succession at this locality is the interaction between these two events: the basal transgression of a high-energy beach system, and the rejuvenated basinward thrust of the braided fluvial system. More complete documentation of the evidence and reasoning underlying the interpretations advanced here can be found in Cotter (1982).
>
> This succession can be considered in terms of three units: (1) the uppermost Juniata Formation, conformably overlain by (2) about 30 meters of horizontally laminated white quartz arenite at the base of the Tuscarora Formation, and (3) cross-laminated, sublitharenitic Tuscarora above the covered interval. In terms of depositional origins, the three units represent the interposition of a high-energy beach lithofacies between two lithofacies of braided fluvial origin. The unequivocal demonstration of beach depositional features at such a proximal locality reinforces the interpretation that a significant transgressive event occurred as Tuscarora history began.

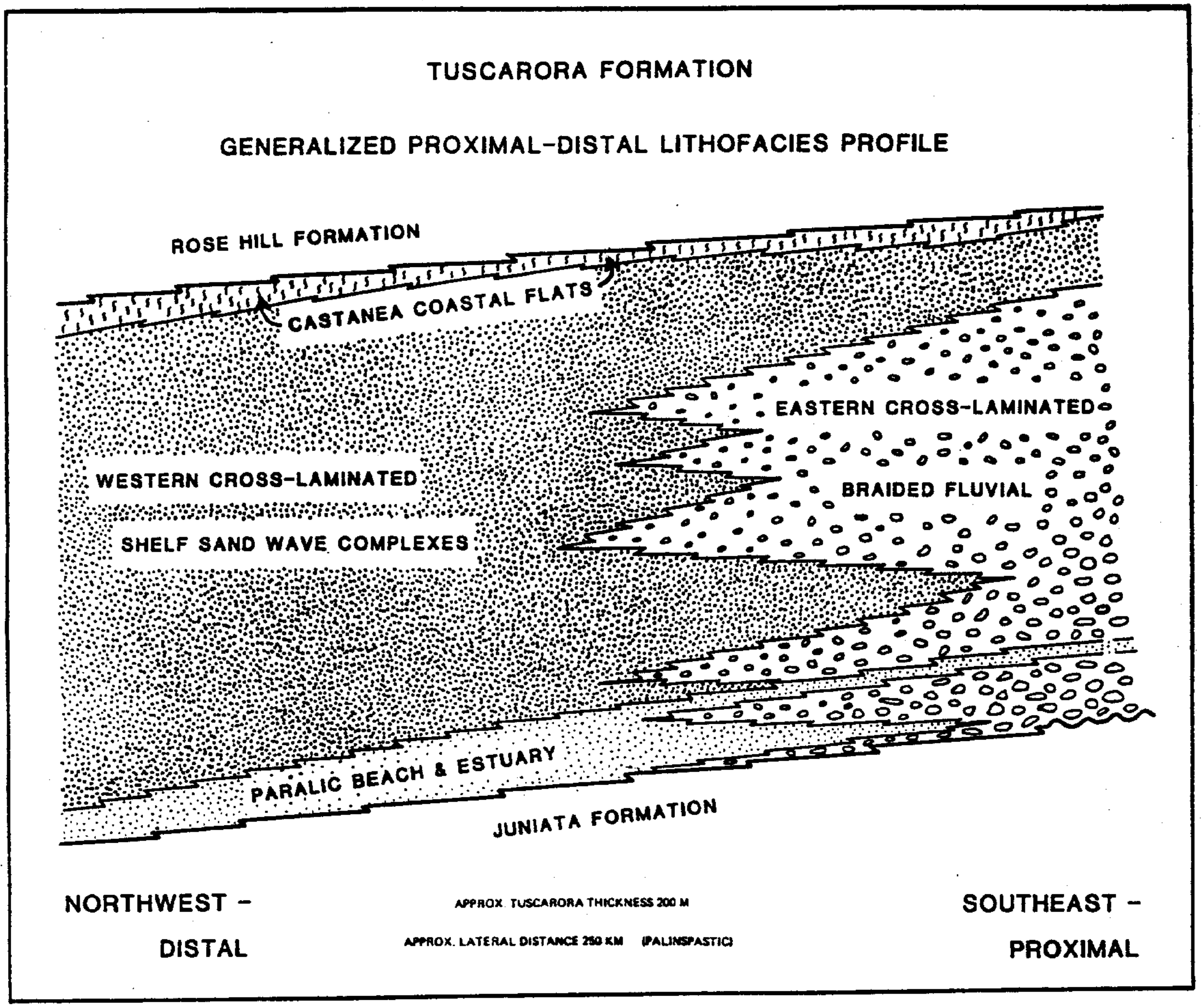


Figure 18. Generalized proximal - distal lithofacies profile of the Tuscarora Formation (from Cotter, 1982).

Uppermost Juniata and Cross-Laminated Tuscarora Lithofacies. The many similarities, other than color, between the uppermost part of the Juniata Formation and that part of the Tuscarora above the covered interval make it possible to consider them together. These units consist of interbedded sandstone and subordinate thin shales. The sandstone is medium- to coarse-grained litharenite and sublitharenite with poor sorting and subangularity. Gravel sizes occur at the bases of some beds, and there are common shale intraclasts of the same characteristics as the thin interbedded shales. Most of the sandstone is cross-stratified, with troughs more abundant than planar types. There is a suggestion of cyclicity of fining- and thinning-upward sequences. The bases of a number of sandstone beds in both units show the biogenic structures of deposit-feeding animals. The composite features of the uppermost Juniata and the cross-laminated Tuscarora indicate that deposition took place in braided fluvial systems. Rivers that deposited the uppermost Juniata continued into Tuscarora time with approximately the same magnitude and fluvial style. The only significant change was in the color of the deposits. Sedimentation in this northwestward-flowing river system was interrupted by retrogradation of the coast and transgressive onlap of the beach lithofacies.

Basal Horizontally Laminated Lithofacies. - The basal 30 meters of the Tuscarora Formation is all sandstone; there is no shale, either interbedded or as intraclasts. All the sandstone above the lowest 2 meters is pure quartz arenite that is fine- to medium-grained, well-sorted, and with rounded grains. The most common sedimentary structure is horizontal (even parallel) lamination, consisting of alternating laminae of slightly coarser and slightly finer grains. Also present are symmetrical ripples and the antidune lamination characteristic of beach foreshores. Cross-laminated beds are uncommon, and those that do occur show sediment transport to the east or southeast. The biogenic structures of deposit-feeders such as Arthrophycus, are missing. This assemblage of features clearly shows that this unit originated in a high-energy, wave-dominated beach system.

Compositional Contrast. - The compositional contrast between the basal horizontally laminated lithofacies and the cross-laminated units above and below it illustrate the role of depositional processes in determining sandstone composition. The pure quartz arenite of the beach unit is distinctly more mature, both texturally and compositionally, than the sublitharenite and litharenite of the bounding units. If the mature quartz arenite of the basal Tuscarora were due to influx of sediment of different composition, one would not find a return to sublitharenite above the covered interval where the characteristics return to those of braided fluvial deposits. The pattern here is similar to that at numerous localities in central Pennsylvania. Fluvial sandstones (whether Juniata or Tuscarora) are sublitharenitic to litharenitic, and the beach sandstone, derived from the sediment of those rivers, is quartz arenite. Less durable grains, such as rock fragments, chert and polycrystalline quartz were gradually removed from the sand by the high-energy wave processes."

On the basis of the foregoing, we can conclude that a profound change in environment occurred across the Martinsburg-Juniata boundary. The Martinsburg Formation represents deep to intermediate marine sedimentation, whereas the Juniata is indicative of a near-sea level braided fluvial system. The basal Tuscarora, with its change to a marine beach facies grading upward to the braided fluvial sequence again, represents a shoreline of transgression and regression.

PROCEED SOUTH on Route 74 (Waggoners Gap Road).

39.4	0.5	North Middleton Township line.
39.9	0.5	Switchback.
40.7	0.8	North Middleton Township line.
44.4	3.7	PASS North Middleton Township park on left, PROCEED south on Route 74.
44.8	0.4	Cross Conodoguinet Creek.
45.8	1.0	PASS BENEATH Pennsylvania Turnpike.
45.9	0.1	Borough of Carlisle.
46.3	0.4	Large carbonate outcrops in yard on right.
46.4	0.1	YELLOW BLINKING LIGHT, CONTINUE STRAIGHT.
46.6	0.2	TURN RIGHT at STOP SIGN onto N. College Street (to follow Route 74).
46.9	0.3	CROSS railroad tracks at TRAFFIC LIGHT.
47.0	0.1	Dickinson College Geology Building on left.
47.1	0.1	TURN RIGHT at TRAFFIC LIGHT onto Route 11.
47.8	0.7	TURN RIGHT on Route 641, PASS BENEATH BRIDGE and MAKE IMMEDIATE LEFT TURN to follow Route 641 (West).
49.7	1.9	Junction with Route 465, CONTINUE STRAIGHT on Route 641.
51.8	2.1	Town of Plainfield.
52.5	0.7	Small carbonate outcrop in yard on left.
52.7	0.2	Pennsylvania Turnpike on right.
53.9	1.2	Sparse carbonate outcrops in field on right.

54.4	0.5	Old limestone farmhouse on right.
55.7	1.3	Re-entrant in Blue Mountain caused by folding, on right.
58.1	2.4	Enter Borough of Newville.
58.2	0.1	Laughlin Mill on left. Grist Mill built in 1763 by William Laughlin, the oldest such structure in the region.
58.5	0.3	TRAFFIC LIGHT, junction with Route 233, CONTINUE WEST on Route 641. Notice the slate roofs on some of the older buildings.
60.6	2.1	Carbonate farmhouse on right.
61.4	0.8	Cross Green Spring Creek.
62.3	0.9	Village of Green Spring. Route 641 West curves to the right.
64.4	2.1	MAKE HARD RIGHT onto paved road at "State Game Lands" sign.
64.6	0.2	TURN LEFT across one lane stone bridge over Conodoguinet Creek.
65.5	0.9	CROSS unnamed creek.
65.6	0.1	Junction with Gameland Road - CONTINUE STRAIGHT.
65.9	0.3	TURN RIGHT on Parkhill Road (unpaved).
66.8	0.9	TURN RIGHT on Bridgewater Road.
67.7	0.9	TURN LEFT at "T" intersection onto Gameland Road 375.
67.8	0.1	BEAR RIGHT at "Y" junction to stay on Bridgewater Road.
67.9	0.1	Pavement ends, dirt begins.
68.0	0.1	8-ton bridge on right - BEAR LEFT to follow main road.
68.7	0.7	STOP 5

Buses will TURN AROUND. Approximately 6,000 feet ahead is one of the few remaining wooden covered bridges in this region. It is closed to vehicular traffic.

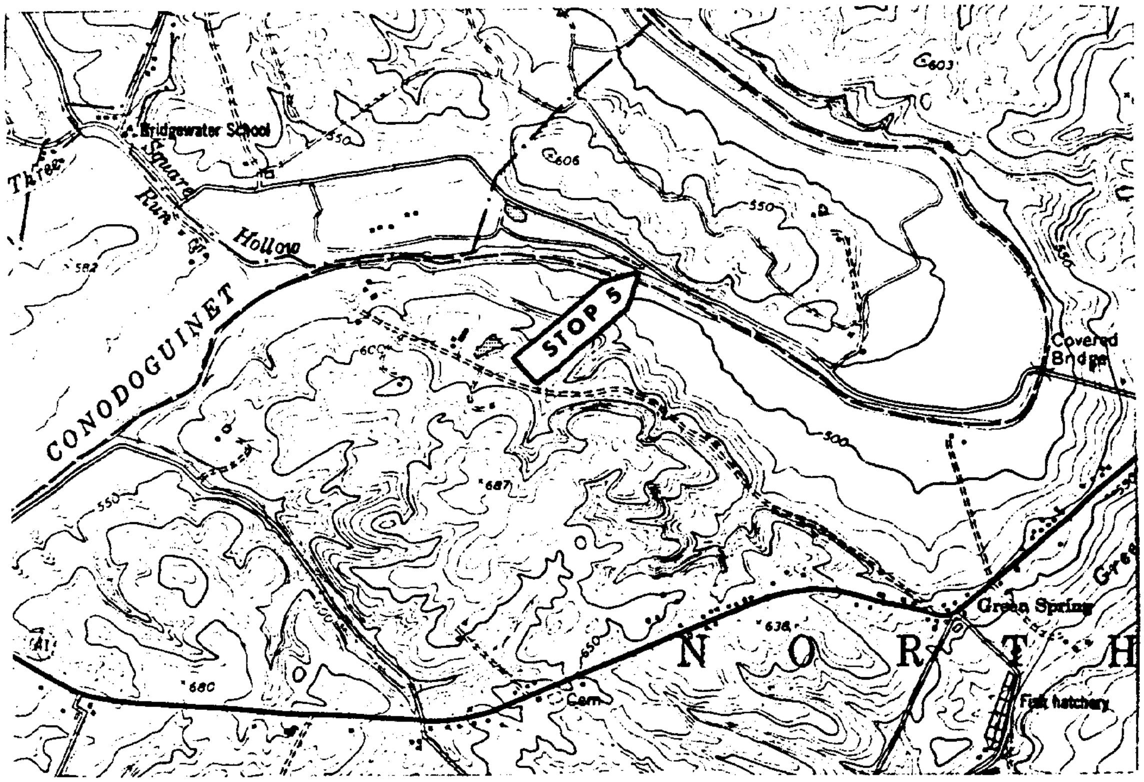


Figure 19. Stop 5 - Day 1. Road cut located in the SW 1/4 of the Newville 7 1/2' Quadrangle.

This outcrop continues our stratigraphic progression up through the authochthonous Martinsburg units. This exposure of the middle graywacke unit does not have examples of the thickest turbidite beds found elsewhere in this unit, but does have a wide selection of sedimentary and structural features.

The obvious sandstone beds are nearly vertical, and sedimentary features that define depositional tops are easily seen. The suite of sedimentary features, including graded beds, sole marks and internal features, have been interpreted as products of turbidity current deposition. Fossils are again sparse at this outcrop, but a very good suite of graptolites that indicate the Corynoides americanus Zone has been collected.

Structural features of note here include cleavage and several sets of later slickensides. Faulting of the sandstone beds, producing bedding wedges, is present. Several beds have distinct grooves on their surfaces, and these should be examined to determine if they are of sedimentary origin or are due to later deformation.

68.7	0.0	REBOARD buses.
69.4	0.7	Begin pavement - end dirt.
69.5	0.1	TURN LEFT at 3-way intersection, TURN RIGHT 200 feet <u>before</u> 10 Ton Bridge onto dirt road (onto Bridgewater Road).
70.4	0.9	STOP 6 (At intersection of Parkhill Road and Bridgewater Road.)

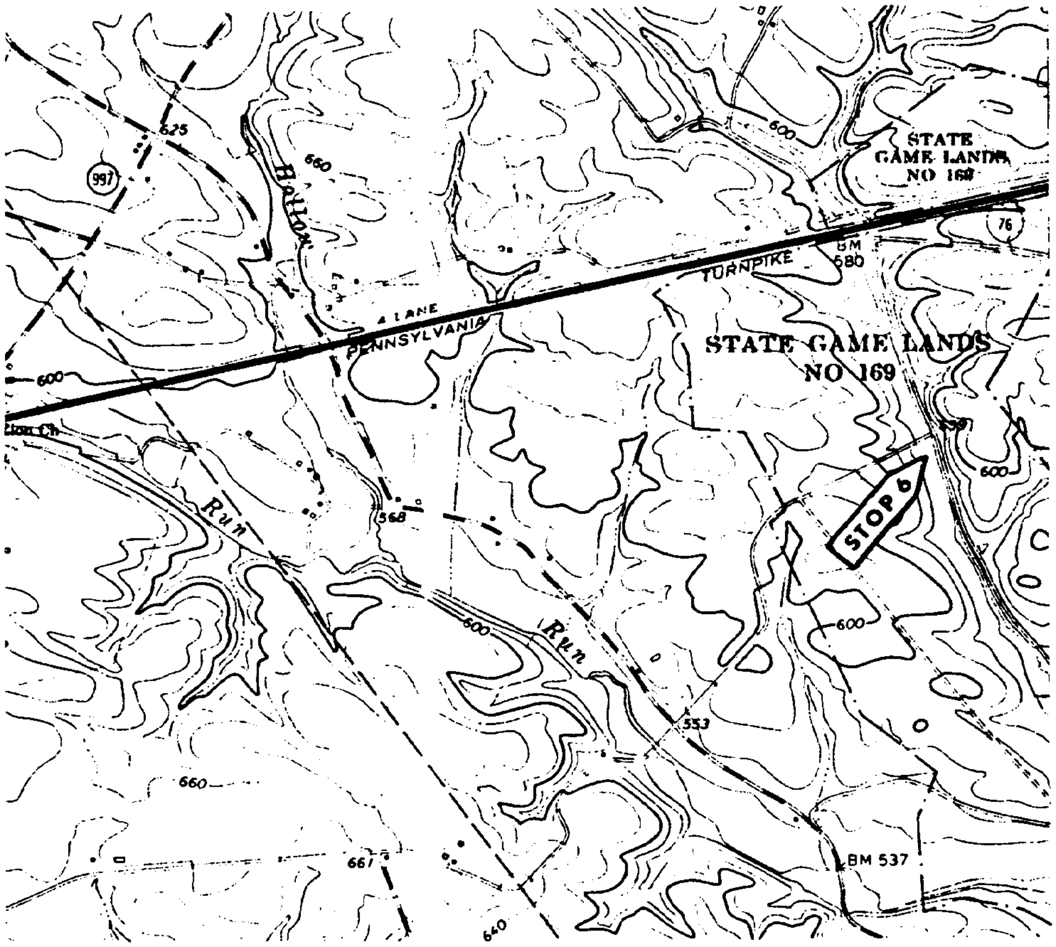


Figure 20. Stop 6 - Day 1. Road cut located in the SE 1/4 of the Newburg 7 1/2' Quadrangle.

This outcrop, several kilometers north of Stop 5, serves to show features characteristic of the upper shale unit. Probably the least "interesting" in terms of sedimentary features, it does point up the difficulty of distinguishing the upper shale from the lower one on the basis of lithology. A good suite of graptolites has been collected from this outcrop and they are commmon enough that, with some searching, several should be found.

Several small folds are also present in this outcrop, and should be compared to those seen elsewhere.

		REBOARD buses and CONTINUE in same direction.
70.8	0.4	STOP SIGN, CONTINUE STRAIGHT.
70.9	0.1	PASS BENEATH Pennsylvania Turnpike and TURN LEFT at next intersection on Heberling Road (#365).
71.0	0.1	TURN RIGHT onto paved road (Bridgewater Road).
71.2	0.2	STAY on paved road, STRAIGHT ahead.
71.4	0.2	Blue Mountain ahead.
71.9	0.5	TURN LEFT onto Route 997 at "T" junction.
72.2	0.3	BEAR LEFT at "Y" junction.
73.5	1.3	PASS BENEATH Turnpike, CONTINUE south on Route 997.
76.1	2.6	STOP SIGN at junction with Route 696. TURN RIGHT at STOP SIGN to CONTINUE SOUTH on Route 997.
77.6	1.5	Franklin County line.
77.7	0.1	Entrance to Pennsylvania Turnpike on right.
80.6	2.9	Blue Mountain on right, South Mountain on left.
81.7	1.1	TURN RIGHT onto Route 641.
82.6	0.9	STOP 7
		PULL OFF in Highway Dept. Maintenance area on right side of road. Buses will CONTINUE ahead to TURN AROUND.

This outcrop completes our stratigraphic traverse of the autochthonous Martinsburg and shows the upper part of the upper shale unit and the upper sandstone unit. The highway is a busy one, so please be mindful of approaching traffic. In the lower outcrop look for evidence of bioturbation and shallow-water faunas. Note the lithologic change between this outcrop and the one to the west. The abundant shelly debris, evidence of bioturbation and lack of the typical turbidite features clearly distinguish this sandstone from the one seen at Stop 5. Graptolites have been found in this unit, but unfortunately not at this particular place.

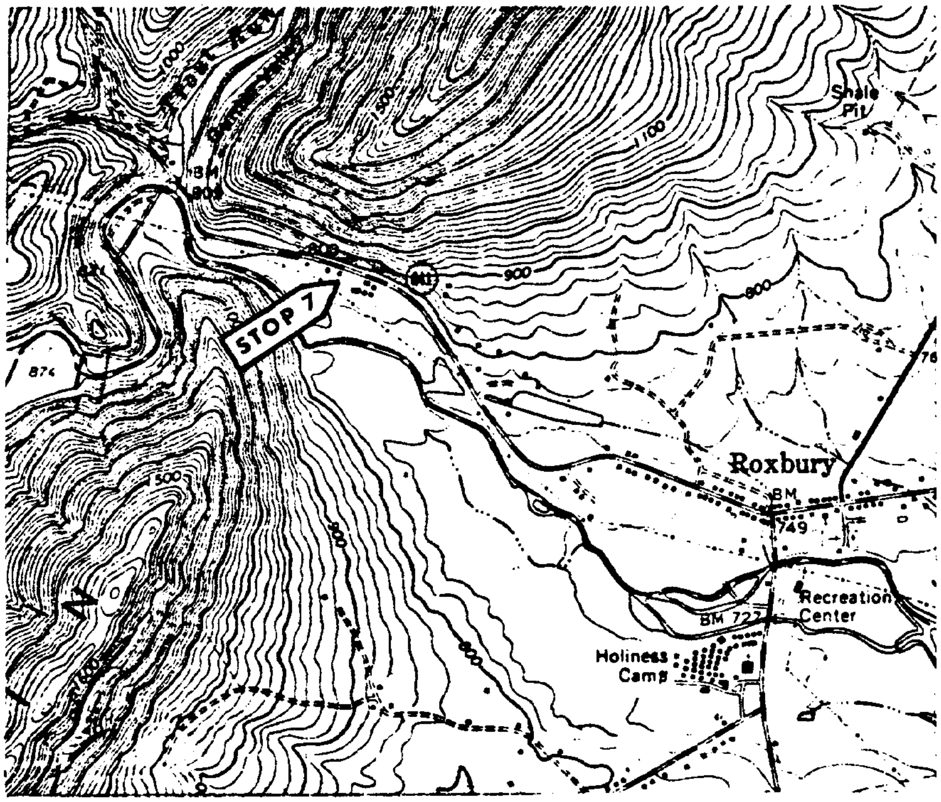


Figure 21. Stop 7 - Day 1. Road cut located along Route 641 SE of Blue Mountain in the NE 1/4 of the Roxbury 7 1/2' Quadrangle.

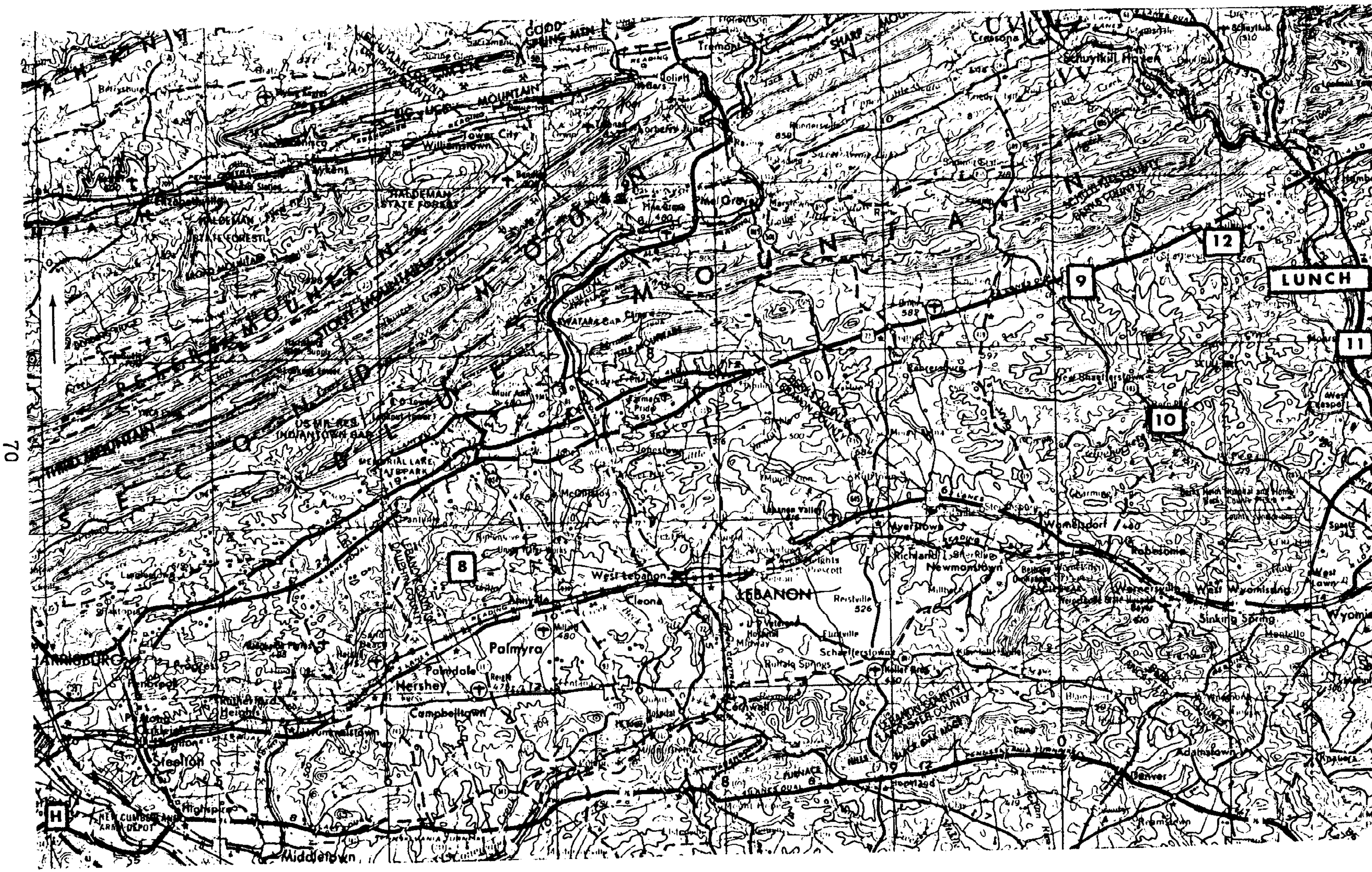
On the first part of the drive back to the Motel, we will see good exposures of all the units of the authochthonous Martinsburg, which will serve as a review. The middle graywacke unit is particularly well exposed.

		REBOARD BUSES. Proceed SOUTH on Route 641.
83.5	0.9	TURN LEFT onto Route 997.
84.6	1.1	Blue Mountain on left, South Mountain on right.
87.5	2.9	TURN LEFT at entrance to Pennsylvania Turnpike Interchange #15.
87.8	0.3	TURN RIGHT for Route 76 East (Harrisburg).
88.1	0.3	Cumberland County line.
88.8	0.7	Colluvium in road cuts.
89.9	1.1	Colluvium in road cuts.

92.5	2.6	Old brick barn in distance on right.
93.5	1.0	Road cuts in upper shale (Omb).
98.3 98.5	4.8- 5.0	Excellent exposures of lower graywacke (Omb).
100.0	1.5	Excellent exposures of lower graywacke (Omb).
100.8	0.8	Newville Maintenance Building on left.
101.1	0.3	Exposures of lower shale (Omb).
101.7	0.6	Cross Conodoguinet Creek and contact of Martinsburg Formation with underlying platform carbonates.
101.9	0.2	Outcrops of Ordovician Carbonates.
102.5	0.6	Outcrops of Cambro-Ordovician Carbonates.
105.5	3.0	Plainfield service area.
112.6	7.1	Interchange #16 - Carlisle.
122.3	9.7	Interchange #17 - Gettysburg Pike (Route 15).
125.9	3.6	York County line.
128.2	2.3	TAKE Exit #18 on right - Harrisburg West.
128.5	0.3	TURN RIGHT on Route 83 to Harrisburg.
128.7	0.2	TURN RIGHT on Exit 18A for Limekiln Road.
128.8	0.1	TURN LEFT at STOP SIGN onto Limekiln Road. PROCEED 100 feet and TURN LEFT into Villa Leo parking lot.

END DAY 1

Figure 22. Field trip localities - Day 2 (Harrisburg and Newark 1:250,000 sheets) H = Headquarters Hotel.



ROAD LOG AND STOP DESCRIPTIONS
DAY 2

Cum. Miles	Inc. Miles	Description
0.0	0.0	BOARD BUSES in Villa Leo parking lot, TURN RIGHT from parking lot onto entrance ramp for I-83 (North).
0.1	0.1	ENTER I-83.
0.3	0.2	Cumberland County line.
1.9	1.6	TURN RIGHT to follow I-83 (North).
2.8	0.9	Dauphin County line - Cross Susquehanna River.
4.6	1.8	Swatara Township line.
6.3	1.7	Sign for Route 322-Hershey.
6.7	0.4	STAY RIGHT for EXIT 28 for Route 322 to Hershey.
13.5	6.8	Junction of Routes 422 and 322. FOLLOW MAIN ROAD for Route 422 East.
14.4	0.9	Hershey Lodge and Convention Center on right.
15.4	1.0	Town of Hershey - Note unique street lights. Route 422 becomes "Chocolate Avenue".
16.1	0.7	Junction of Route 743 with Route 422. CONTINUE STRAIGHT on 422 East.
16.2	0.1	Hershey Foods Headquarters on left. Intersection of E. Chocolate Ave. with Cocoa Ave.
16.6	0.4	Cross Spring Creek.
18.5	1.9	Enter Palmyra.
19.4	0.9	TRAFFIC LIGHT, TURN LEFT onto N. Railroad St.
19.7	0.3	Cross railroad track.
20.4	0.7	TURN RIGHT onto W. Ridge Road.

20.8	0.4	Old limestone barn on right.
21.0	0.2	STOP SIGN, CONTINUE STRAIGHT.
21.1	0.1	Old limestone barn on right.
21.6	0.5	Millard Quarry (Bethlehem Steel Corp.) in Annville Limestone just out of sight beyond hill on right. Lime, metallurgical limestone and commercial stone are produced from the Middle Ordovician Annville Formation at these quarries (Sims, 1968).
22.2	0.6	TURN LEFT onto Naftzinger Road before Millard Quarry entrance.
22.5	0.3	STOP SIGN, TURN RIGHT at intersection.
23.7	1.2	Cross Quittapahilla Creek and TURN RIGHT onto Syner Road. PARK in pull-out, 200 feet from intersection on right.

STOP 8

Figure 23. Stop 8 - Day 2. Road cuts located in the NE 1/4 of the Palmyra 7 1/2' Quadrangle. Millard Quarries in the Annville Limestone are located just north of the Reading Railroad tracks.

This stop is located in the north-central part of the Palmyra 7-1/2 minute quadrangle. Road cuts on the north bank of Quittapahilla Creek and along a new stretch of the road north over the hill make up the outcrops to be examined.

We stop here to examine several rock types that contrast with the gray shale, interbedded black siltstone and light-weathering limestone, and quartz arenite and calcarenite found elsewhere in the Hamburg klippe. No fossils have been recovered locally, so we are limited in the specifics of our interpretation.

Published mapping at this location (Geyer, 1970) is interpreted from the work of John R. Moseley in the Fifties. The map pattern (Figure 24) of shaly units distinguished in the field is difficult to interpret in any simple and coherent way, a problem elsewhere in the Great Valley (Root and MacLachlan, 1978). Even though most now agree on the allochthony of the red shale units and the ribbon limestone exposures within Stose's (1946) Hamburg klippe, whether the klippe is a single mass, or several large masses, or a melange of slide blocks embedded in normal Martinsburg is a topic still actively studied.

Several kinds of evidence support one or another of these hypotheses. In keeping with the single klippe is the general lack of graptolites younger than *Nemagraptus gracilis* within its outline; were the area of the alleged klippe really all melange, that is, blocks of far-travelled shale in the Martinsburg *senso stricto*, one would expect young fossils suitable for the authochthonous Martinsburg, but none have been found (Platt and others, 1972). Suggestive of large separate sheets are long bands of the klippe rocks without a clear sequence repeated in anticlines and synclines. Granting poor outcrop, one wishes some orderly pattern had emerged in at least one of the quadrangles published in the decades since allochthony was first proposed (Stose, 1930; Kay, 1941). The new geologic map of Pennsylvania (Berg and others, 1980) summarizes admirably the data available; for lack of direct evidence of its presence, normal Martinsburg is not shown interleaved among the bands of allochthonous rock.

Blocks and sheets of "Taconic-looking" shaly rocks that slid into the Martinsburg mud during its deposition would rationalize the disjointed pattern recorded by Moseley at this locality, but inconvenient in such a scenario are the exposures of Epler and Allentown limestones inferred within windows by Geyer (1970) as shown in Figure 24. Other isolated exposures of shallow-water carbonates appear elsewhere in the Great Valley shales. E. B. Knopf (1962) showed them as tectonic fish at Stissing Mountain, N. Y. In Pennsylvania, but east of the klippe, Aldrich (1967) described blocks of Cambrian Allentown Dolomite embedded in, or at least, surrounded by authochthonous Martinsburg. The new Pennsylvania state geologic map (Berg and others, 1980) hints at other hypotheses by showing the two pods near this stop faulted against Hamburg klippe shales. One implication might be that the pods are windows, but through klippe shales, the southern boundary of which would be hidden a bit farther south.

We offer these structural possibilities for discussion.

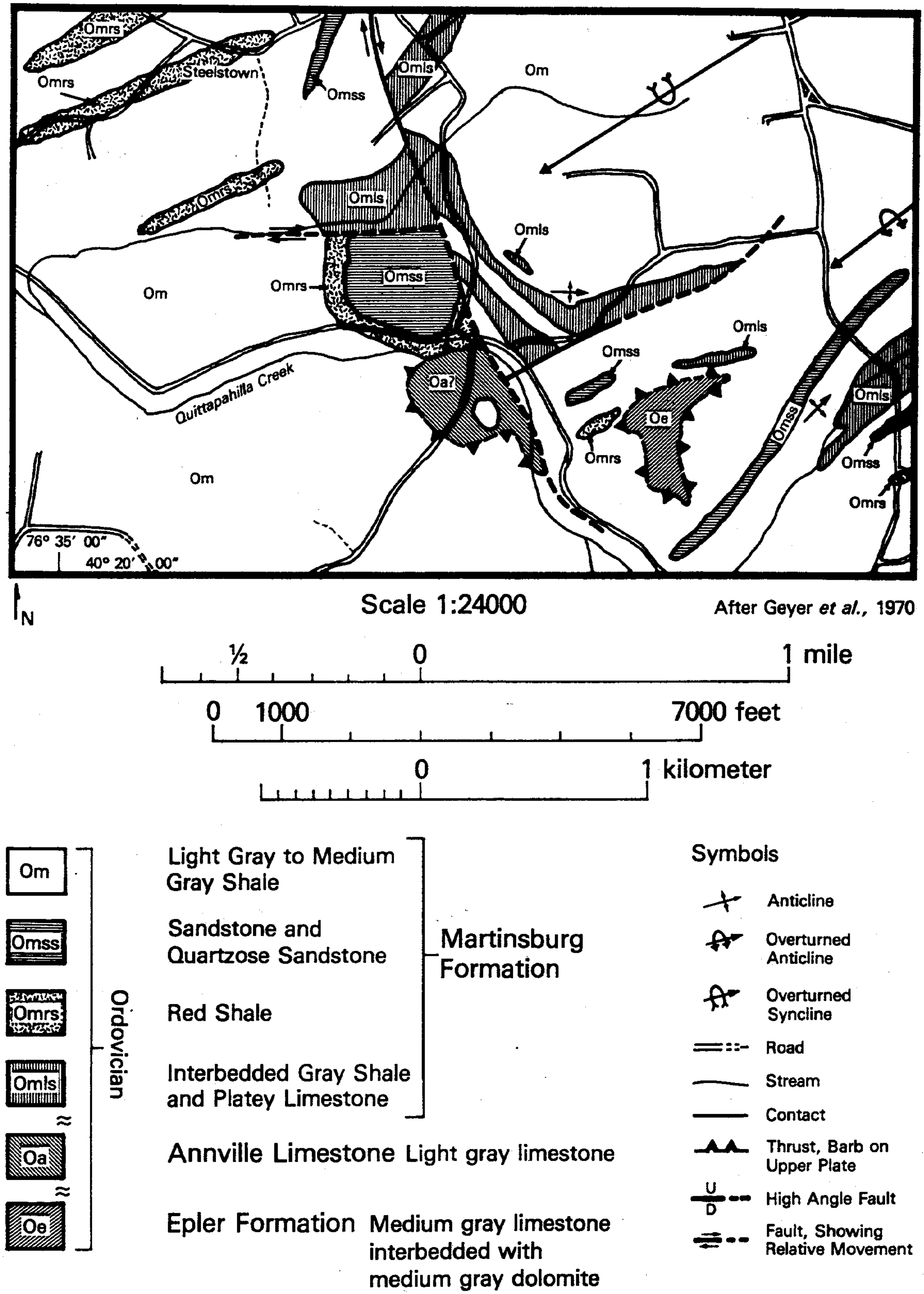


Figure 24. Geologic map of Stop 8, after Geyer and others (1970).

		REBOARD BUSES, CONTINUE EAST along creek.
23.8	0.1	TURN LEFT onto School Creek Lane.
24.7	0.9	STOP SIGN, TURN LEFT onto Clear Spring Road.
25.1	0.4	STOP SIGN, MAKE HARD RIGHT TURN onto Bellegrove Road.
26.1	1.0	Intersection with Kaufman Road, MAKE IMMEDIATE LEFT (50 feet) onto Ono Road.
27.6	1.5	Cross Swatara Creek.
29.2	1.6	Intersection with McGillstown Road. CONTINUE NORTH on Ono Road.
29.9	0.7	BEAR LEFT at "Y" junction to follow Ono Road.
30.6	0.7	TURN LEFT at "T" intersection onto concrete road.
30.7	0.1	Town of Ono.
30.9	0.2	TURN RIGHT on Lincoln School Road.
31.1	0.2	STOP SIGN, TURN RIGHT at Ono Diner onto Route 22 East.
33.3	2.2	PASS BENEATH Route 72.
36.3	3.0	Northern Lebanon High School on left.
37.2	0.9	Junction with Route 343. Continue east on Route 22.
38.1	0.9	Continue east on Route 22 (to I-78).
39.5	1.4	Lebanon County line.
39.7	0.2	STAY LEFT, FOLLOW I-78 and Route 22 East.
40.2	0.5	Berks County line.
40.6	0.4	Little Mountain to the left is an outlier of Silurian Tuscarora Sandstone and older coarse clastics south of the main Silurian ridge.
42.3	1.7	PASS BENEATH Route 645.
44.0	1.7	Flat-topped Tuscarora ridge to the left. Notice the fold re-entrant in the ridge.
44.8	0.8	PASS BENEATH Route 501.
49.1	4.3	PASS BENEATH Route 419.

50.6	1.5	TURN RIGHT at Exit 7 for Pennsylvania Route 183 (Strausstown).
50.7	0.1	STOP SIGN, TURN RIGHT onto Route 183 South.
51.0	0.3	TURN LEFT at yellow blinking light onto "OLDE 22".
51.2	0.2	Handsome stone church on left.
51.5	0.3	At the bottom of the hill, just across the small creek, TURN LEFT into dirt drive. STOP at red brick house for permission to visit quarry. CONTINUE STRAIGHT AHEAD to right of the white barn into large quarry on hill behind barn.

STOP 9

Buses will proceed back to intersection of driveway and "OLDE 22".

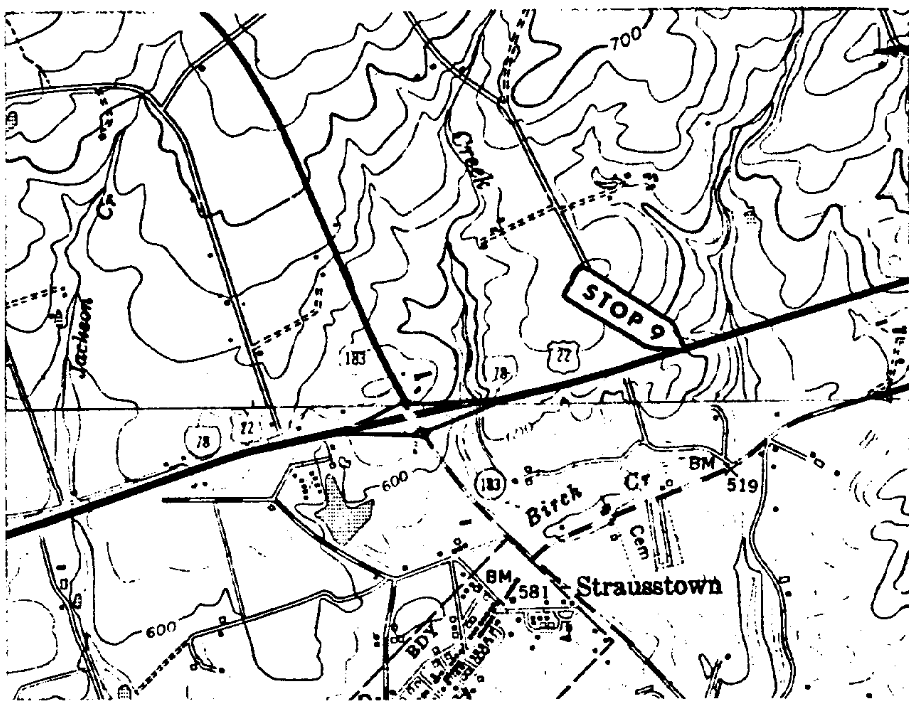


Figure 25. Stop 9 - Day 2. Graptolite quarry located in the NE 1/4 of the Friedensburg 7 1/2' Quadrangle and the SE 1/4 of the Strausstown 7 1/2' Quadrangle.

This stop is in a small road-fill quarry adjacent to Interstate 81. Here the Hamburg klippe shale is olive-gray when fresh, but deep weathering has altered most material to a light tan color. The bedding is near vertical, as is the cleavage. This stop is representative of the sedimentary rocks derived from the onset of tectonism (that is, this represents the southeasterly derived clastics deposited along with the red slates and ribbon limestones derived from the continental margin). These rocks are mapped by Wood and MacLachlan (1978, plate 1) as part of their lithotectonic unit 1.

This locality is chiefly a fossil stop. Graptolites are relatively abundant in the quarry and can be found on loose shale chips and, in places, on the outcrop itself. There are several different species of graptolites here, all of the <u>Nemagraptus gracilis</u> Zone. Note that bedding and cleavage are nearly parallel and that the graptolites are well preserved. Many are high-lighted by rusty, iron oxide coatings. Similar graptolite-rich shale occurs on the stripped hill slopes on the southwestern edge of the small cemetery on the south side of "Olde 22" between here and Route 183.

52.0	0.5	TURN RIGHT on "OLDE 22".
52.5	0.5	Intersection of "OLDE 22" and Route 283, TURN LEFT on Route 183 (South).
56.2	3.7	STOP SIGN at "T" intersection, TURN LEFT to follow Route 183 South.
57.8	1.6	Cross Creek.
58.1	0.3	Bernville on left.
58.7	0.6	Penn Township line.
58.8	0.1	PARK BUSES on wide shoulder on right, before intersection with road to Robesonia.

STOP 10

Buses will turn around for REBOARDING on other side of road.

This long road cut exposes medium gray shales interbedded with medium gray, brown weathering, thin, wispy-laminated, cross-bedded, siltstones at the south end of the outcrop. The dominant cleavage strikes northeast and dips toward the southeast. Notice that the cleavage orientation is somewhat variable from one end of the outcrop to the other, and there is the suggestion of another, more subtle, cleavage and a mica fabric parallel to bedding. The fold style in the southern half of the outcrop is one of gentle open folds, the axial planes of which are defined by the dominant, southeast dipping cleavage. Near the large gully that separates the northern and southern portions of the outcrop, beds of coarse silt and fine-grained graywacke from 2.5 to 30 cm thick are present. This southern part of the outcrop was mapped by P. B. Myers (compiled in Wood and MacLachlan, 1978, Plate 1) as lithotectonic unit 2 of the allochthonous Hamburg sequence.

The covered interval marked by a large gully on the east side of the road most likely conceals a tectonic contact with the rocks to the north. Note the distinct lithologic and tectonic contrast between the units north and south of the gully. The rocks north of the gully are mapped as lithotectonic unit 3

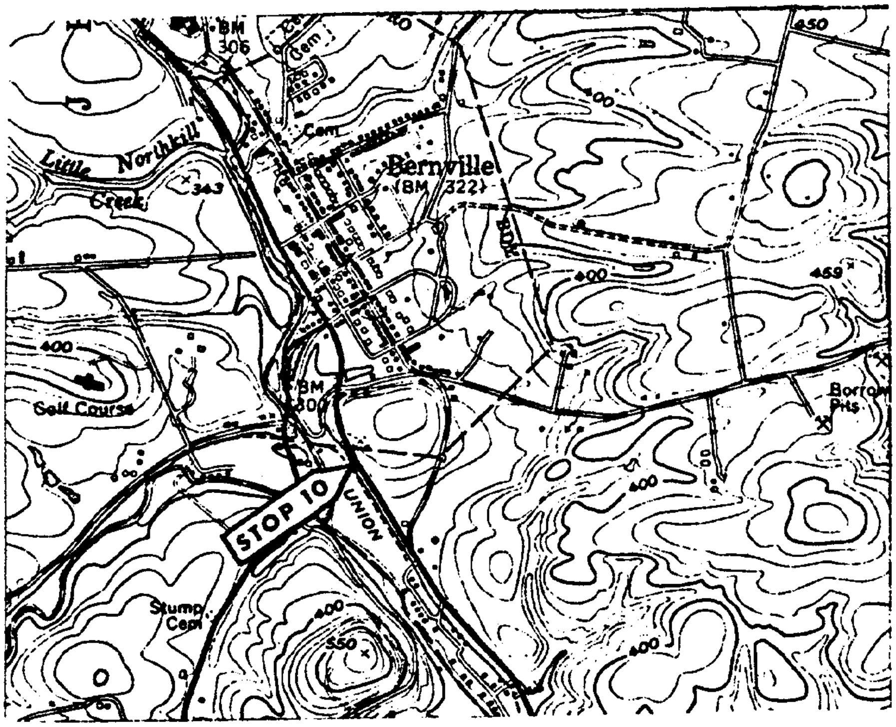


Figure 26. Stop 10 - Day 2. Road cut on Route 183 south of Bernville, located in the SW 1/4 of the Bernville 7 1/2' Quadrangle.

(Wood and Maclachlan, 1978, Plate 1) and are separated, on their map, by a thrust fault which carries the rocks of lithotectonic unit 3 over the rocks of unit 2. The rocks north of the gully consist of a strongly tectonized tan micaceous shale. Notice the outcrop of red slate across the river to the northwest. This part of the section is characterized by a pervasive cleavage with a steep but variable dip to the southeast, and development of a strong pencil cleavage. Numerous slickensides, with variable orientation, especially at the northeastern end of the outcrop, suggest major shearing. Blocks of limestone, graywacke, and chert, up to one meter in diameter, are present in the sheared and tectonized shale matrix, suggesting that this is a melange or olistostrome-bearing unit.

Remnants of the course of the old Union Canal can be seen adjacent to the eastern edge of Northkill Creek. The Canal extended from Reading northwest to this point, and then paralleled Tulpehocken Creek to the southeast to a point near Myerstown, just west of the Berks County-Lebanon County Line. One of the original canal stones from Lock 36 can be seen in Ubenhauer Park (established in 1851) in Bernville.

End of Stop 10 - REBOARD buses.

Proceed on Route 183 North.

59.0	0.2	Yellow blinking light, PROCEED THROUGH on 183 North.
59.6	0.6	TURN RIGHT, IN 100 FEET BEAR HALF-LEFT onto Shartlesville Road.
59.8	0.2	Bernville Grange Hall on right.
60.5	0.7	TURN RIGHT onto Irish Creek Road.
60.9	0.4	Right angle "dog-leg" in road.
61.3	0.4	Northkill Rod and Gun Club on left.
61.4	0.1	Right angle "dog-leg" in road.
62.0	0.6	BEAR LEFT on Irish Creek Road (at intersection with Molasses Hill Road).
63.6	1.6	Dirt road on right to microwave tower atop Scull Hill, CONTINUE on Irish Creek Road.
64.2	0.6	Junction of Irish Creek Road with Tilden Road on left, CONTINUE on Irish Creek Road.
65.4	1.2	TURN LEFT at "T" intersection with Bellmans Church Road to follow Irish Creek road.
67.1	1.7	Borough of Centerport.
67.2	0.1	TURN RIGHT at "T" intersection onto Main Street for 100 feet, BEAR LEFT on main road at "Y" junction.
67.5	0.3	Center Township line.
67.8	0.3	TURN LEFT onto Shoey Road (to Shoemakersville) from Main Street.
68.8 69.2	1.0- 1.4	View to right-front of Spitzenberg Hill in distance.
69.5	0.3	Cross railroad tracks.
69.7	0.2	Cross Schuylkill River, enter Borough of Shoemakersville.
69.8	0.1	TURN LEFT at STOP SIGN onto Main Street.
69.9	0.1	Cross railroad tracks, proceed on Main Street.
70.3	0.4	TURN RIGHT onto Ninth Street, CONTINUE to parking area (on right) for Shoemakersville City Park.

LUNCH

		After lunch, PROCEED SOUTH along access road at west edge of Park.
70.6	0.3	TURN LEFT on Eighth Street.
70.7	0.1	STOP SIGN, TURN RIGHT onto Reber Street. CONTINUE on Reber Street to SECOND STOP SIGN (Noble Ave.).
70.9	0.2	TURN LEFT onto Noble Ave.
71.1	0.2	TRAFFIC LIGHT, TURN RIGHT onto Route 61 (South).
72.0	0.9	Glen-Gery Plant on left. Quarries on hill behind plant provide shale for the manufacture of bricks.
72.8	0.8	Graywacke in road cuts, both sides of highway.
73.1	0.3	At crest of hill, BEAR RIGHT on unmarked gravel drive into small quarry.

STOP 11

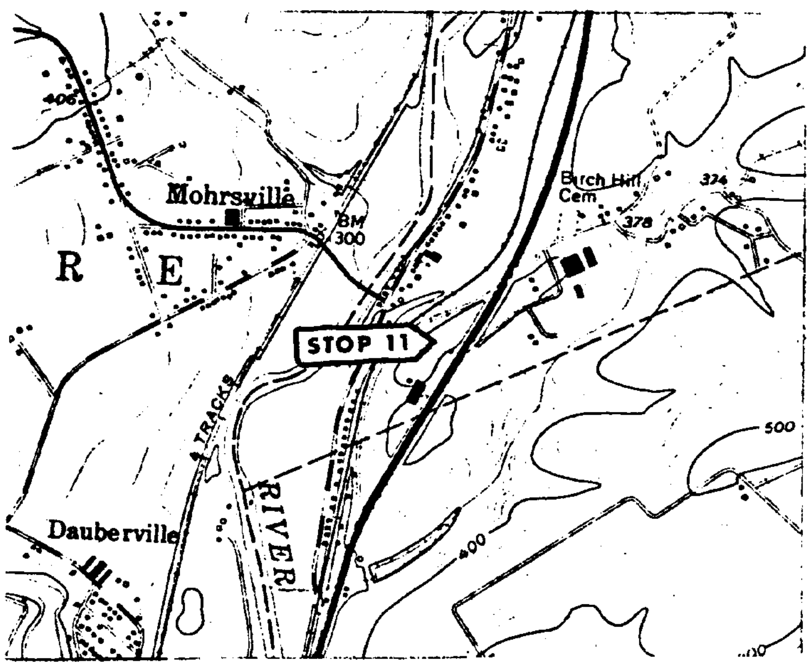


Figure 27. Stop 11 - Day 2. Small stripped anticline located on Route 61 in the NW 1/4 of the Temple 7 1/2' Quadrangle.

This stop is a study in structural details. It was the subject of a senior thesis by Tim Bechtel at Bryn Mawr College in the spring of 1982, and we are indebted to him for allowing us to discuss some of his findings.

In brief, the purpose of this stop is to examine small features suggesting how the rock accommodated compressive stress to produce the little anticline. Stylolites in the light limestone layers and cleavage and crenulations in the dark shaley layers attest to removal of calcite by pressure dissolution. Calcite fibers in pressure shadows next to pyrite and calcite veins approximately perpendicular to cleavage imply local redeposition of some part of the dissolved material. Disrupted bedding that does not continue in adjacent beds is inferred to have formed when the sediment was still soft in the Early Ordovician, but penetrative small folds and a fault indicate vergence to the northwest, in keeping with the slight asymmetry of the fold as a whole.

The anticline is in the Temple quadrangle, about a third of a mile southeast of Mohrsville, between Pennsylvania Route 61 and the Schuylkill River. About 7 m of rock is exposed at the time of writing, but the material is being removed, hence the fresh rock. The anticline plunges about 8° toward N60°E. The surrounding gently rolling hills have been interpreted by MacLachlan (1979) as underlain by extraordinarily complicated folds and faults. Stose (1976) drew the south edge of his Hamburg klippe just south of here to separate Lower Paleozoic shallow-water carbonates around the Reading Prong from the correlative shales to the north.

Discontinuous layers of aphanitic black limestone 2-5 cm thick alternate with beds of black silty shale. The outcrop has a striped appearance because the limestone layers weather light gray. In many places the limestone layers pinch and swell irregularly. The resulting extreme distortions of bedding apparently formed while the sediments were still soft, for the adjacent beds show little or no involvement in the contortions. The limestone layers contain a little silt-sized quartz and pyrite crystals as large as 1 cm. White mica and chlorite and dark opaque material are also present. The calcareous shale layers are mostly calcite, but also contain quartz, mica, chlorite, pyrite, and opaque clay or carbonaceous material. How much mica is detrital and how much diagenetic is unclear.

A few conodonts were dissolved out of the limestone and indicate an Early Ordovician age, but the faunule is meager. A richer fauna has been extracted from somewhat similar rocks near Lenhartsville (Epstein and others, 1972; Bergstrom and others, 1972) Platt collected probable Early Ordovician graptolites from this rock type near Harrisburg (Carswell and others, 1968).

Interesting details at this outcrop include the soft-sediment slumps mentioned above and a variety of later structures. An early cleavage, parallel to bedding, is seen in Plates 4 and 5. This early cleavage remains bed-parallel and is folded by the anticlinal arch. A later fold-related axial plane cleavage is superposed on this early structure. Silty layers have tiny crinkles that separate into axial plane cleavage in the shale (Plate 4), but these are not visible in the limestone beds. Instead, stylolites have formed at intervals of 5 to 20 cm in the carbonate layers, with spacing roughly proportional to bed thickness. Calculations by Bechtel suggest that 30% of the volume of the rock

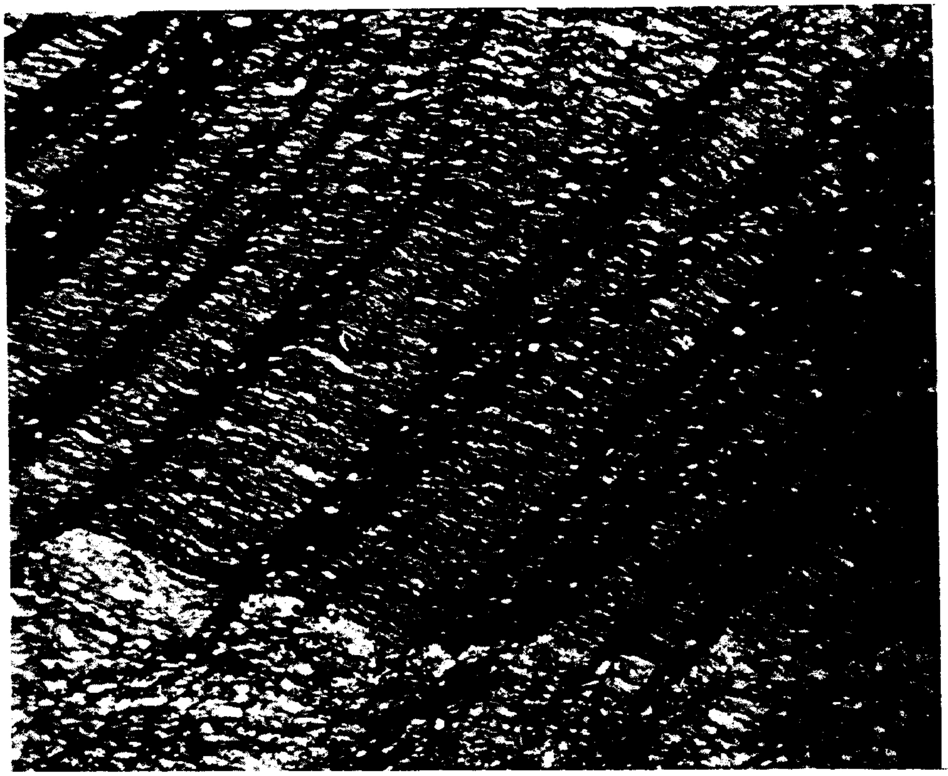


Plate 4. Photomicrograph showing pressure solution bands, Stop 11. Scale X-30.

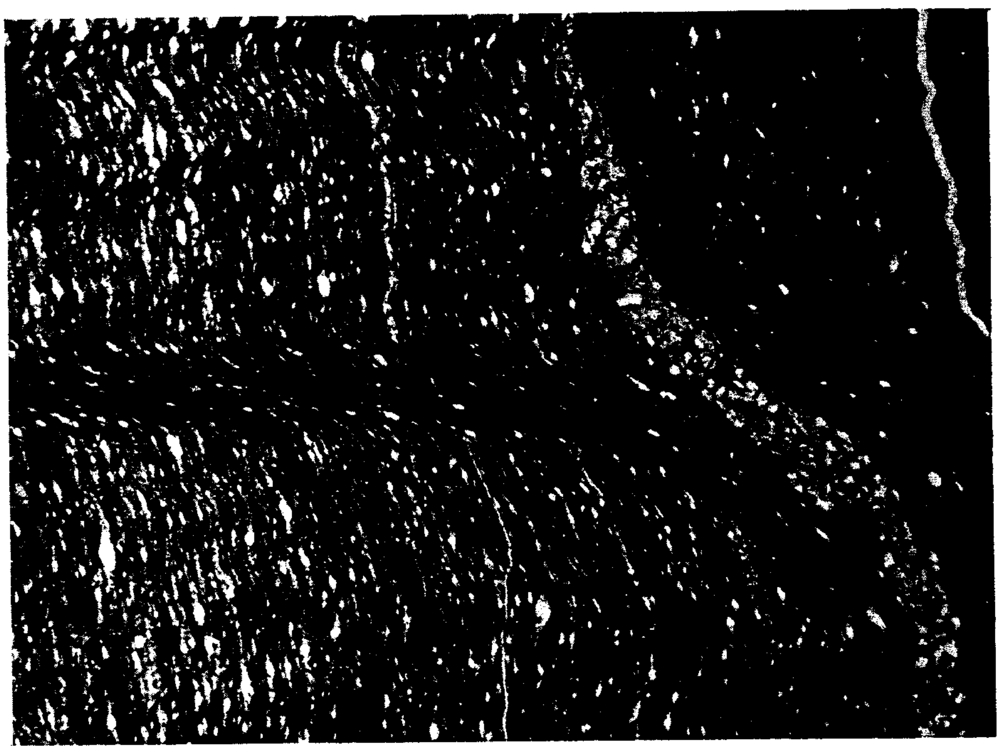


Plate 5. Photomicrograph showing depletion of calcite and rotation of micas along crenulation zones. Stop 11. Scale X-30.

was removed by dissolution of calcite. Within the cleavage bands, calcite amounts to about 25% of its abundance in the relatively unstrained rock between cleavage. Under the microscope, crenulations show depletion of calcite along with rotation of mica flakes into crenulation zones (Plate 5).

Abundant fibers in pressure shadows are found in both limestone and shale around pyrite crystals and clusters. Bechtel showed that these have rotational symmetry rather than mirror symmetry across the cleavage, and therefore inferred that the fibers grew during rotation of the stress field with respect to the pyrite buttress and hence presumably during folding and formation of cleavage.

Among the variety of veins and joints, one set is exclusively in the limestone beds. Members of this set terminate against shale, and in common cases are offset or cut off by stylolites.

A minor fold on the east limb of the anticline shows northwestward vergence. An east-dipping fault near the core of the anticline is inferred to have thrust displacement from the rock types on opposite sides and from the vein swarm at 45° to the fault surface (Figure 28).

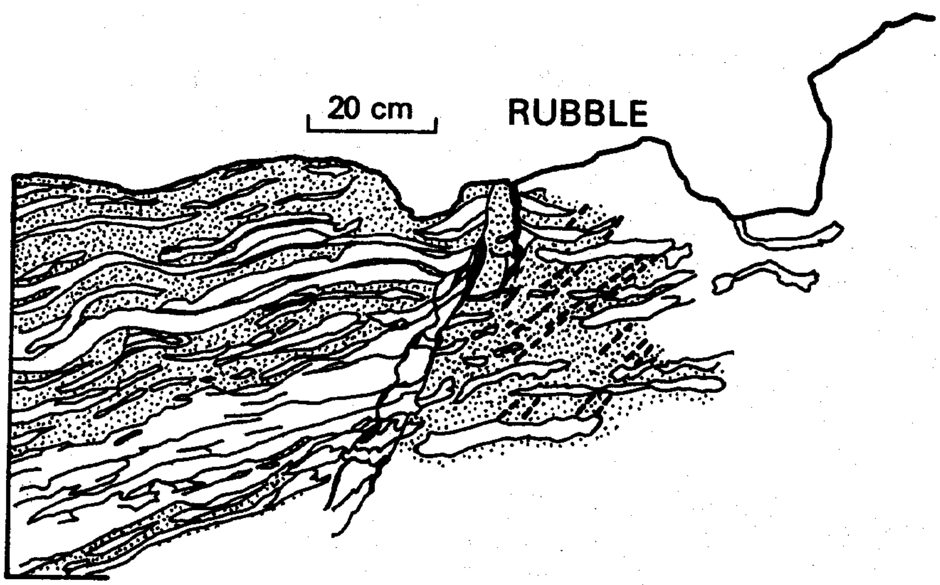


Figure 28. East dipping fault and vein swarm - Stop 11.

In summary, this stop shows a small anticline of limestone and shale. Interbeds of different rock types have deformation features of several types pointing mostly toward dissolution of calcite as the dominant deformation mechanism. The rock type is a deeper-water facies than rocks of the same age in the vicinity, so it is inferred to be allochthonous.

73.2	0.1	REBOARD BUSES, and TURN RIGHT onto Route 61-South (to turn buses around).
74.3	1.1	TURN LEFT onto Bellmans Church Road and TURN LEFT IMMEDIATELY onto Indian Manor Road.
74.5	0.2	STOP SIGN at intersection with Route 61-North. Proceed on Route 61-North.
75.3	0.8	Perry Township line.
77.4	2.1	Borough of Shoemakersville.
77.6	0.2	Noble Ave. on left, CONTINUE ahead on Route 61-North.
79.6 79.7	2.0- 2.1	Graywacke in road cuts, both sides of highway.
80.4	0.7	Hamburg exit. BEAR RIGHT to exit here, CONTINUE on S. Fourth St.
81.2	0.8	Hamburg Plow Works (established 1882) on right.
81.4	0.2	AT SECOND TRAFFIC LIGHT, TURN LEFT onto State Street.
81.8	0.4	Cross Schuylkill River on State Street.
82.1	0.3	PASS BENEATH Route 61 overpass.
82.3	0.2	Junction with road on right to Routes 61 and 22 - CONTINUE STRAIGHT on State Street (which becomes Hex Highway).
83.7	1.4	Tilden Township building on right.
84.9	1.2	TURN HALF-LEFT onto St. Michael's Road.
85.3	0.4	TURN RIGHT onto Creamery Road.
85.9	0.6	MAKE HARD LEFT onto Mill Road.
86.0	0.1	MAKE HARD RIGHT onto dirt drive for red slate quarry.
86.1	0.1	STOP 12. This stop is private property. Permission to enter MUST be obtained from George E. Wagner Farm.

This quarry contains a wealth of minor structural features. Compare the structural history detailed here with that developed at Stop 11. The rocks of the Hamburg klippe sequence exposed here are red and green slates with interbedded gray dolomite. The dolomite interbeds weather to dark chocolate brown. A few layers contain well rounded quartz grains floating in the shale matrix. The rocks are mapped by Wood and MacLachlan (1978, plate 1) as part of their lithotectonic unit 1.

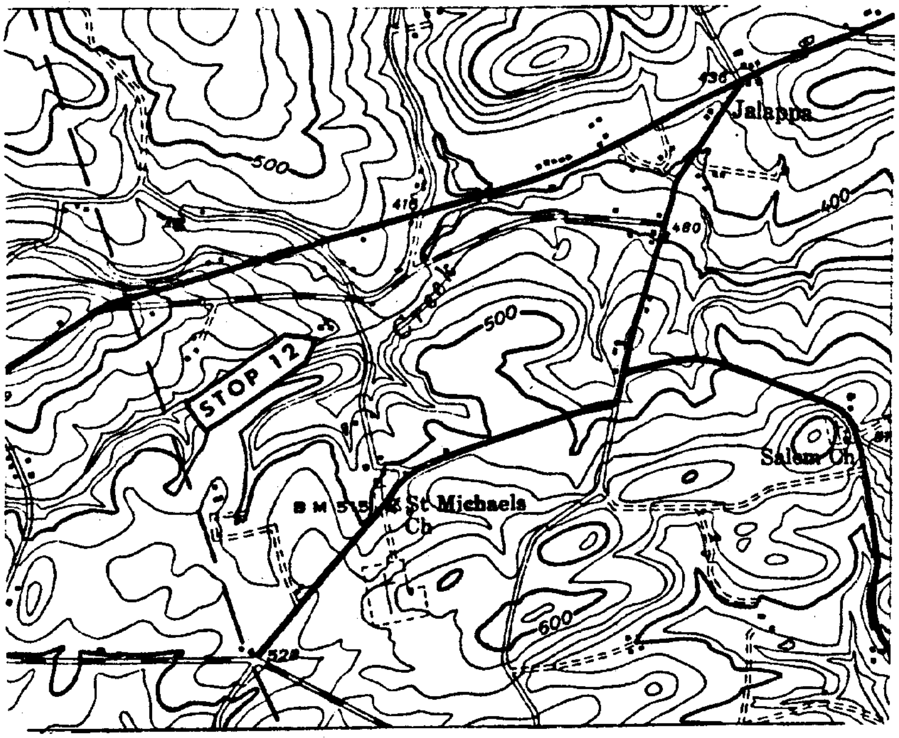


Figure 29. Stop 12 - Day 2. Small quarry in red slate located in the SE 1/4 of the Auburn 7 1/2' Quadrangle.

These rocks represent a deep-water facies deposited off the edge of the passive continental margin at the onset of Taconic tectonism. Graptolites collected from this quarry, and similar localities, are from the Nemagraptus gracilis Zone.

The dominant structural feature in the quarry is a series of isoclinal folds of differing scales overturned toward the northwest. The cleavage associated with these folds is sub-parallel to the bedding and trends approximately N80E and dips 65 degrees to the southeast. We believe this cleavage is due to pressure dissolution. Evidence of this is found in the dolomite beds, some of which contain truncated calcite veins normal to bedding, which have buttressed the dolomite beds and protected them from dissolution as outlined at Stop 1. In addition, thin wispy black seams of insoluble residue can be seen parallel to this cleavage. Minor calcite-filled veinlets, chiefly in the dolomite, are perpendicular to the cleavage and most likely are the result of minor extension parallel to the cleavage.

Numerous green reduction spots are found in the quarry and are associated with the dominant cleavage. The long axis of the reduction spots is parallel to the dip of the cleavage, and the short axis is perpendicular to the cleavage plane. It is unclear whether these spots are deformed pre-tectonic features or syn-tectonic in nature. In any case the ratio of the three axial lengths of the ellipsoid represented by these spots is : 0.3-1.0-1.7. If these spots are pre-tectonic, their shape implies considerable flattening in the plane of the cleavage with significant extension in the dip direction. The reduction spots can also be explained as syn-tectonic features whose dimensions are controlled not by deformation of an originally spherical object, but rather whose elliptical shape is controlled by solution migration and variable rates of chemical transport parallel and perpendicular to the cleavage.

A later, more subtle, cleavage is also present throughout the quarry. This second cleavage strikes approximately N50E and dips 10 to 30 degrees to the northwest. This later cleavage is a true crenulation cleavage and deforms both the original bedding and the earlier dissolution cleavage. Close examination of the earlier formed reduction spots shows that they are kinked by this later cleavage. In addition, the earlier more steeply dipping cleavage is gently warped, as can be seen in several locations within the quarry.

Once again, as in most localities within the Hamburg klippe, we find evidence of two deformations, an early period of isoclinal folding with development of a dissolution cleavage sub-parallel to bedding, and a later deformation. The age of these events, and their relation to the structural history of the region is unclear and remains a major topic for research.

86.2	0.1	TURN LEFT from Quarry Drive onto hard paved road (Mill Road).
86.3	0.1	TURN LEFT onto Creamery Road.
86.6	0.3	STOP SIGN, TURN LEFT onto Hex Highway (Old 22).
88.5	1.9	Village of Shartlesville.
89.5	1.0	TURN RIGHT to I-78 just past Shartlesville Hotel on left. Pass above I-78.
89.6	0.1	TURN LEFT onto entrance ramp I-78 West.
89.9	0.3	Join I-78 West.
111.8	21.9	Junction I-78 West with I-81 South. KEEP LEFT for I-81 South to Harrisburg.
115.5	3.7	Junction Route 934. Indiantown Gap in Blue Mountain visible on right, CONTINUE on I-81.
122.0	6.5	Manada Gap to right.
129.4	7.4	MOVE LEFT for Route I-83 South, to York.
130.6	1.2	TAKE EXIT on LEFT for Route I-83 South.
134.7	4.1	KEEP RIGHT at "Y" junction of I-83 and I-283-76. Remain on I-83 South.
137.4	2.7	City of Harrisburg.

138.7	1.3	Cross Susquehanna River.
139.8	1.1	BEAR RIGHT at "Y" junction of Routes I-83 and 11-15. Stay on I-83 South.
141.6	1.8	TURN RIGHT at Exit 18-A for Limekiln Road.
141.8	0.2	STOP SIGN, TURN LEFT on Limekiln Road. Pass under I-83.
142.0	0.2	TURN LEFT into Villa Leo parking lot.

END OF TRIP