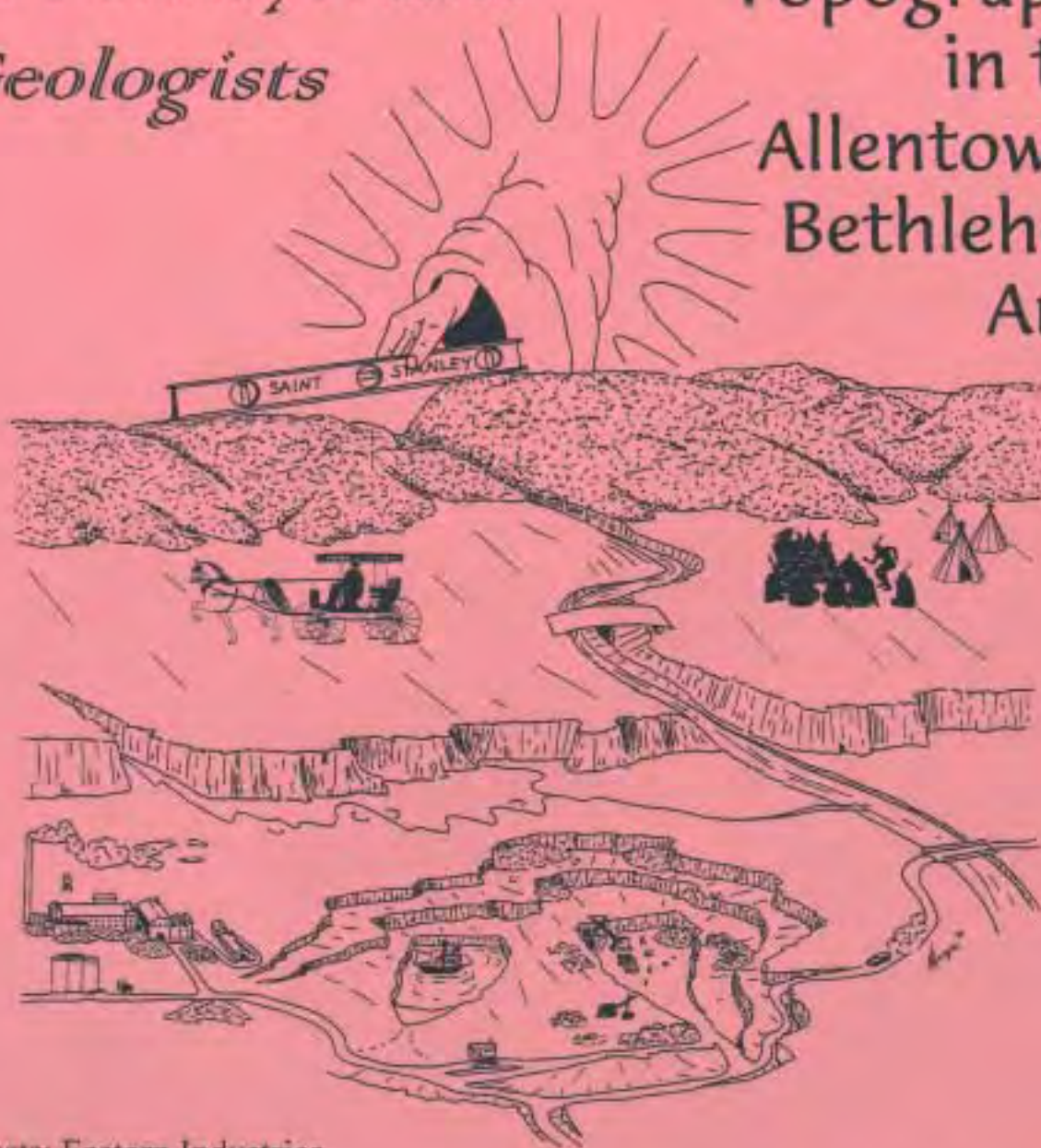


*64th Annual
Field Conference
of Pennsylvania
Geologists*

Economic &
Environmental
Geology and
Topography
in the
Allentown -
Bethlehem
Area



Hosts: Eastern Industries
Lafarge Corporation
Pennsylvania Geological Survey

September 30, October 1 and 2, 1999
Allentown, PA

Guidebook for the

64TH ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

ECONOMIC AND ENVIRONMENTAL GEOLOGY AND TOPOGRAPHY IN THE ALLENTOWN-BETHLEHEM AREA

Samuel W. Berkheiser, Jr. and W. D. Sevon, Field Conference Organizers

W. D. Sevon and Gary M. Fleeger, editors

Contributors and field trip leaders:

Duane D. Braun, Bloomsburg University

David A. Bremer, Lafarge Corporation

Kurt Carr, Pennsylvania Historical and Museum Commission

Gary M. Fleeger, Pennsylvania Geological Survey

James H. Fullton, Jr., Lafarge Corporation

Dru Germanoski, Lafayette College

J. E. Godfrey, PADOH, Environmental Health Assessment

Dagmar Llewellyn, S. S. Papadopoulos and Associates

Edward Pany, Northampton, PA

W. D. Sevon, Pennsylvania Geological Survey

Michael G. Slenker, Eastern Industries, Inc.

September 30 – October 2, 1999

Hosts: Eastern Industries

Lafarge Corporation

Pennsylvania Geological Survey

Headquarters: Days Inn Conference Center, Allentown, PA

Cover: The Great Spirit checks the level of the Schooley peneplain while W. M. Davis directs his survey across the flat upland of the Harrisburg surface and the local natives take a break from mining jasper. Meanwhile, the Somerville surface is being lowered even more.

Art work by: John A. Harper.

Guidebooks distributed by:

Field Conference of Pennsylvania Geologists, Inc.

PO Box 5871

Harrisburg, PA 17110-5871



Group photographs of the 1998 Field Conference of Pennsylvania geologists.

TABLE OF CONTENTS

	Page
Geology in the Allentown-Bethlehem area – W. D. Sevon.....	1
Geological literature.....	1
Topography.....	1
Geology for Day 1.....	2
Stratigraphy.....	2
Structure.....	3
Geology for Day 2.....	6
The Lehigh Valley landform assemblage: relationships between topography and geology, and differential erosion – Dru Germanoski.....	9
Introduction.....	9
Physiography and geology.....	10
Methods.....	11
Results.....	15
Predominant topographic surfaces.....	15
Topography and peneplains.....	20
Topography, geology, and differential erosion.....	21
Discussion.....	25
Conclusions.....	29
Acknowledgements.....	30
Pleistocene geology of the Allentown area – Duane D. Braun.....	31
Introductory overview.....	31
Pseudo-moraine west of Allentown.....	36
Pseudo-moraine depressions partly obscure true sinkholes.....	38
Glacial Lake Packer and the ice marginal kames.....	38
Other glacial margins crossing the carbonate belt.....	39
Use of limestone residuum thickness to estimate the age of glaciations.....	39
Summary.....	40
Heleva landfill superfund site, Coplay, Pennsylvania – Dagmar Llewellyn.....	41
Introduction.....	41
Groundwater remediation system.....	43
Local geology.....	45
Hydraulic head distribution and groundwater flow system.....	47
Transmissivity distribution.....	48
Recharge and discharge conditions.....	48
The 1994 sinkhole at North 7th Street, centre city, Allentown P – Thomas D. Gillespie.....	49
Introduction.....	49
Geology of the regional karst terrain.....	52
Geologic conditions at the 7th Street sinkhole site.....	53
Reconstruction of sinkhole development.....	62
Geologic hazards and land use planning.....	64
Procurement, tool production, and sourcing research at the Vera Cruz jasper quarry in Pennsylvania – James W. Hatch and Patricia E. Miller.....	67
Introduction.....	67

Geology.....	67
Quarry design and operation.....	69
Tool production and use.....	71
Chemical sourcing of jasper.....	76
Summary.....	77
Acknowledgements.....	78
References cited.....	79
Road log – Day 1.....	85
Heleva landfill superfund site driveby.....	85
Stop 1 – Atlas cement museum – Edward Pany.....	85
Stop 2 – Lafarge cement processing plant – James Fullton & David Bremer.....	87
Stop 3 – Lafarge cement limestone quarry – James Fullton & David Bremer.....	88
Stop 4 – Saylor Park: Lunch and Schoefer lime kilns.....	89
Stop 5 – Eastern Industries Whitehall Quarry – Michael Slenker.....	91
Stop 6 – Eastern Industries Ormrod/Lehigh Quarry – Michael Slenker.....	95
Stop 7 – Ranger Lake.....	103
Road log – Day 2.....	104
Stop 8 – Pre-Illinoian pseudo-moraine – Duane Braun.....	104
Stop 9 – High Quality Polishing contamination site – J. E. Godfrey.....	106
Stop 10 – Vera Cruz jasper quarry – Kurt Carr.....	109
Stop 11 – Pre-Illinoian kame – Duane Braun and lunch	109
Stop 12 – Ringing Rocks block field – W. D. Sevon & Gary Fleeger.....	112
Stop 13 – South Mountain topography overview – Dru Germanoski.....	121

LIST OF ILLUSTRATIONS

Figure 1. Geologic map and cross sections, Cementon and Catasqua quadrangles.....	5
Figure 2. Cross sections in the Hellertown and Riegelsville quadrangles.....	7
Figure 3. Location map with physiographic provinces and study area.....	10
Figure 4. Photograph of three principal erosion surfaces.....	15
Figure 5. Topographic profile F-F' – crest of Blue Mountain.....	16
Figure 6. Geologic map of the Tipton quadrangle.....	18
Figure 7. Topographic profile G-G' – across Martinsburg rocks.....	19
Figure 8. Topographic profile H-H' – across carbonate rocks.....	19
Figure 9. Topographic profile I-I' – across Proterozoic basement rocks.....	21
Figure 10. Topographic profile A-A' – normal to regional strike.....	22
Figure 11. Topographic profile B-B' – normal to regional strike.....	24
Figure 12. Topographic profile D-D' – normal to regional strike.....	25
Figure 13. Photograph of Camelhump.....	26
Figure 14. Plot of maximum elevations of Proterozoic and Mesozoic rocks.....	26
Figure 15. Oxygen isotope record of Pleistocene glacial events.....	32
Figure 16. Illinoian and older Pleistocene time divisions.....	33
Figure 17. Map of regional pattern of glacial limits in southeast Pennsylvania.....	34
Figure 18. Map of Leverett's Illinoian moraine.....	35
Figure 19. Cross section of shale valley with till and colluvium.....	36
Figure 20. Cross section of development of pseudo-moraine.....	37
Figure 21. Cross section of surficial materials known from borehole logs.....	38

Figure 22. Location map for Heleva Landfill Superfund site.....	42
Figure 23. Groundwater extraction system for Heleva site.....	43
Figure 24. Geologic map of the Heleva site.....	44
Figure 25. Geologic cross section along axis of Heleva plume.....	47
Figure 26. Aerial view of Corporate Plaza building after sinkhole collapse.....	50
Figure 27. Ground view of Corporate Plaza building after sinkhole collapse.....	50
Figure 28. General plan of the North 7th Street sinkhole.....	51
Figure 29. Aerial view looking into the North 7th Street sinkhole.....	50
Figure 30. Geologic map below North 7th Street and the Corporate Plaza building.....	55
Figure 31a. Location map for soil borings, rock cores, and cross sections.....	56
Figure 31b. Cross sections A-A and B-B.....	57
Figure 31c. Cross section C-C.....	58
Figure 31d. Cross sections D-D and E-E.....	59
Figure 32. View looking west into sinkhole prior to grouting.....	60
Figure 33. View looking west into sinkhole during grouting.....	60
Figure 34. View looking east at northwest corner of building.....	60
Figure 35. Close-up view of base of northwest corner of building.....	60
Figure 36. Schematic subsidence profile of sinkhole.....	61
Figure 37. Soil movement vectors plotted on geologic map.....	65
Reprint Figure 1. Physiographic provinces and jasper-bearing outcrops.....	68
Reprint Figure 2. Selected jasper quarries in the Reading Prong.....	69
Reprint Figure 3. Geologic setting of Vera Cruz quarry.....	69
Reprint Figure 4. Topographic setting of Vera Cruz quarry.....	69
Reprint Figure 5. Topographic map of Vera Cruz quarry.....	70
Reprint Figure 6. Topography of Crater 1.....	71
Reprint Figure 7. Topography of Crater 2.....	71
Reprint Figure 8. Stratigraphic profile of Crater 1.....	72
Reprint Figure 9. Stratigraphic profile of Crater 2.....	72
Figure 38. Flow diagram of cement making process.....	87
Figure 39. Diagram of Coplay Cement Mill B.....	90
Figure 40. Cross section through kiln.....	90
Figure 41. Geologic map for Whitehall and Ormrod/Lehigh quarries.....	93
Figure 42. Cross sections for Whitehall and Ormrod/Lehigh quarries.....	93
Figure 43. Aerial photograph of the Whitehall quarry.....	96
Figure 44. Aerial photograph of the Ormrod/Lehigh quarry.....	100
Figure 45. Surficial geology map of pseudo-moraine area, Stop 8.....	104
Figure 46. Stereographic pair of aerial photographs for area of Stop 8.....	105
Figure 47. Location map for High Quality Polishing site.....	107
Figure 48. Surficial geology map of area of kame, Stop 11.....	110
Figure 49. Ringing Rocks barren boulder field.....	112
Figure 50. Surficial geology map of the Ringing Rocks area.....	113
Figure 51. Relationship between intruded diabase and paleo-Jurassic surface.....	114
Figure 52. Waterfalls at Ringing Rocks.....	115
Figure 53. Trough on streambed above waterfalls.....	116
Figure 54. Block of diabase separated into four pieces.....	117
Figure 55. Diabase block with pitted surface.....	118

Figure 56. Opferkessel-like features on diabase block.....	118
Figure 57. Diabase block with channels of possible fluvial origin.....	118
Figure 58. Diabase boulder with pothole.....	119
Figure 59. Diabase block with v-shaped polygonal furrows.....	119
Figure 60. Polished section of weathered diabase cobble.....	120
Figure 61. Location map with physiographic provinces and study area.....	122
Figure 62. Photograph of the three principal erosion surfaces.....	123
Figure 63. Photograph of Camelhump.....	125
Figure 64. Topographic profile B-B' – normal to regional strike.....	127

LIST OF TABLES

Table 1. Descriptions of lithostratigraphic units in the study area.....	12
Table 2. Topographic maps used to make profiles.....	14
Reprint Table 1. Soil profile descriptions.....	73
Reprint Table 2. Debitage: percent heat treatment by reduction class.....	74
Reprint Table 3. Debitage: percent of total number by reduction class.....	75
Reprint Table 4. Chronology and composition of projectile points.....	75
Reprint Table 5. Elemental composition of jasper samples.....	77
Reprint Table 6. Discriminant analysis on 8 variables.....	77

GEOLOGY IN THE ALLENTOWN-BETHELHEM AREA

by
W. D. Sevon
Pennsylvania Geological Survey
Harrisburg, PA 17105-8453

GEOLOGICAL LITERATURE

The Allentown area is the site of some extremely complex geology, the understanding of which is still in progress. Over the years since the work of Miller and others (1939, 1941) the rocks have not changed or moved. However, new concepts and much more intense collection of data have led to better, albeit not necessarily final, interpretations of not only the structure, but also the stratigraphy.

The works of Miller and others (1939, 1941) can be considered typical examples of county reports from that period of time: heavy emphasis on physiography, climate, history, and mineral industry; an adequate discussion of stratigraphy; and a cursory discussion of the structure. The reader should not consider this a criticism of the work, it is merely a recognition of a different era. These works also indicate that the geology was understood in only the simplest manner as is indicated by the simplicity of the geologic maps and the total lack of faults in the carbonate areas. The later work of Sherwood (1964), still used by many as a basic guide to the Jacksonburg Formation, represents a major step forward in collection and interpretation of structural data. Sherwood introduced the term *nappe*, a sheetlike, allochthonous rock unit that has moved on a predominantly horizontal surface either by thrust faulting, recumbent folding, or both. Sherwood's stereograms indicate that he collected a considerable amount of data. Despite all that, Sherwood's cross sections are only a start towards understanding the full complexity of the geology.

Drake (1969) discussed new interpretations of geology in the Delaware Valley based on his work that was underway at that time. MacLachlan (1967, 1983) divided the carbonate rocks of the Great Valley of Pennsylvania into four stratigraphic sequences (from west to east): Cumberland Valley, Lebanon Valley, Schuylkill, and Lehigh Valley. These sequences result from deposition on different parts of the Laurentian carbonate shelf. Their recognition is important in the proper interpretation of the rocks. Most recently, Drake (1987; 1993; 1996a, b, c; 1999; Drake and others, 1967; Aaron and Drake, 1997) has presented new structural interpretations based on mapping done primarily in the 1960's and 1970's during which time he collected a very large amount and variety of data. The interested geologist should be aware that, at least in the foreseeable future, these open-file reports probably will not be published, but are available. Anyone needing the best available geological information for the Allentown area should obtain these reports.

The following discussion of geology is divided into two parts relating specifically to Day 1 and Day 2 of the trip. Day 1 is discussed in more detail than Day 2.

TOPOGRAPHY

The area visited by the 1999 Field Conference of Pennsylvania Geologists is a good place to easily see the relationship between two different aspects of geology and topography. First, the

topography reflects very well contrasts in lithology, such as between carbonate, shale, and igneous rock. Second, the topography developed on carbonate rock shows no detectable relationship to the underlying extremely complex structure.

Most of the trip is in the Great Valley Section, Ridge and Valley Province, which divides readily into a shale upland region and a carbonate lowland region. The shale uplands can be further subdivided into districts and areas, but the carbonate lowland is remarkably similar from the Susquehanna River on the west to the Delaware River on the east. This lowland is called the Lebanon Lowland Region. Adjacent to the Lebanon Lowland Region on the south are rounded hills that rise several hundred feet above the lowland. These hills are part of the Reading Prong Section of the New England Province. For a detailed discussion of the area's topography see the paper by Germanoski (p. 9 - 30).

GEOLOGY FOR DAY 1

The discussion of geology that follows is directed at only those parts of the Cementon and Catasaqua quadrangles where the Field Conference will spend the entire first day. The information is taken entirely from Drake (1999) and in some places may be an uncited direct quote. For the most part, references given in Drake (1999), of which there are many, are not included.

Stratigraphy

Rocks in the parts of Cementon and Catasaqua quadrangles traversed on the Field Conference (Figure 1) are sedimentary rocks of Cambrian and Ordovician age. The pre-Middle Ordovician rocks were deposited on the east-facing (present direction) shelf on the Laurentian craton after opening of the Iapetus Ocean. At the beginning of the Taconic orogeny, the shelf floundered forming the Martinsburg foreland basin. Flysch and deltaic deposits filled that basin by Middle and lower Upper Ordovician. Carbonate rocks viewed on this Conference are all part of the Lehigh Valley Sequence. The following brief descriptions are in order from oldest to youngest.

Allentown Dolomite (OCa). The Allentown Dolomite is light gray (N7) to dark gray (N3), fine to medium grained, thin to medium bedded, massive to laminated, rhythmically-bedded dolomite that typically weathers to light (N7) and dark (N3) gray. Nodular and bedded chert and orthoquartzite are common. The unit is characterized by oolite, algal stromatolites, intraformational conglomerate, ripple marks, and mud cracks. Shelly fauna occurs locally. The unit is about 1,900 ft thick.

Stonehenge Formation (Beekmantown Group) (Os). The Stonehenge Formation is thin bedded, medium dark gray (N4), very fine grained dolomite, fine to medium grained, silt-ribbed, laminated dolomite and limestone, and solution collapse breccia. The unit grades down into the underlying Allentown Dolomite with the base marked by thin bedded, medium dark (N4) to dark (N3) gray dolomite or limestone that has thin shale partings. The unit is about 700 ft thick.

Rickenbach Dolomite (Beekmantown Group) (Or). The Rickenbach Dolomite is medium (N5) to medium dark (N4) gray and medium to coarse grained. It contains rosettes of light gray (N7) chert as well as medium light (N6) to medium (N5) gray, fine grained, laminated dolomite containing dark gray (N3) chert nodules, lenses, and beds. It grades down into the underlying Stonehenge Formation. The unit is about 600 ft thick.

Epler Formation (Beekmantown Group) (Oe). The Epler Formation is medium (N5) to medium dark (N4) gray, thin to thick bedded, fine grained and much less medium grained silty limestone interbedded with thin to thick bedded, light (N7) to medium (N4) gray, cryptocrystalline to medium grained dolomite. It grades down into the underlying Rickenbach Dolomite. The unit is about 800 ft thick.

Jacksonburg Limestone: Cement Limestone Facies (Ojl). The cement limestone facies of the Jacksonburg Limestone is medium gray (N6), largely well bedded, medium to coarse grained calcarenite and fine to medium crystalline, high calcium limestone. Thickness not certain, but may be as much as 400 ft.

Jacksonburg Limestone: Cement Rock Facies (Ojr). The cement rock facies is dark gray (N3) to grayish black (N2), fine to very fine grained, argillaceous limestone. In most exposures bedding has been totally obliterated by slaty cleavage. Contains a crystalline limestone interval identical to the underlying cement limestone facies (Ojl). Thickness is not certain, but may be as much as 1,000 ft.

Martinsburg Formation: Bushkill Member (Omb). The basal part of the Bushkill Member is black (N1) to dark gray (N3) slate that passes upward into interbedded slate and graywacke siltstone. Beds are mostly less than 0.5 inches thick and few beds exceed 4 inches in thickness. Silt-clay ratios range from about 1:3 to 1:6 and the different rock types form “ribbons” on slaty cleavage surfaces. The member grades down into the underlying Jacksonburg Formation. The unit is about 4,000 ft thick.

Structure

Pre-Silurian rocks in eastern Pennsylvania structurally constitute the Reading Prong nappe megasystem. Five major nappes, from west to east and highest to lowest are: the Lebanon Valley, the Applebutter, the Irish Mountain, the Musconetcong, and the Lyon Station. These have a fault-propagation fold aspect and were defined largely by their cover sequences. They constitute a crystalline duplex that is probably the northeasternmost exposure of a crustal duplex that lies beneath the Newark basin and the Piedmont (Drake, 1991). The depth of autochthonous basement increases west from the Delaware River with concomitant more intense and complex deformation in the cover rocks. The crystalline rocks in the nappe were not folded. Only the cover rocks of the Musconetcong and Lyon Station nappes crop out in the Cementon quadrangle. The rocks are characterized by thin-skinned deformation and constitute the newly defined alenide tectonic facies of Hsu (1995).

The rocks the Field Conference will visit at Stops 3, 5, 6, and 7 are either the Jacksonburg or Epler that are part of the Musconetcong Nappe lying above the Haafsville thrust fault (Figure 1). These rocks are complexly folded and the folds depicted in the cross sections are modeled on natural folds seen in outcrop. A major recumbent fold has been mapped from the Catasauqua quadrangle west to the Ormrod area where its axial surface has been rotated past the horizontal. Two special types of mesoscopic folds are abundant: quasiflexural and cascade. The quasiflexural folds, common to interbedded limestone and dolomite sequences in the Epler formation, constitute dolomite beds that have been deformed by flexural-slip or flexural-flow and limestone beds have accommodated themselves to the form surface by irregular and contorted flow. Cascade folds are common in rocks of the Jacksonburg Limestone and Martinsburg Formation. The axial surfaces of such folds dip northwest down the regional dip and have a northwest-dipping

upright limb and an overturned southeast-dipping limb. These folds did not form by gravity tectonics as modeled by Sherwood (1964).

Five distinguishable fold phases are, from oldest to youngest: Musconetcong, Iron Run, Hokendauqua, Manunka Chunk, and Stone Church. Folds of the first two phases are generally obscure or obliterated by later folding. Folds of the final phase are fairly large to large open structures and were the cause of the arching that allowed the formation of the Whitehall window. Various lines of convergent reasoning lead to the conclusion that the Musconetcong, Iron Run, and Hokendauqua fold phases are Taconic in age and the Manunka Chunk and Stone Church fold phases are Alleghanian in age.

GEOLOGY FOR DAY 2

The discussion of geology for Day 2 of the Field Conference will constitute a dialog about the rocks you do not see along the drive. The Days Inn is built on top of the Epler Formation that is part of the Musconetcong Nappe above the Haafsville thrust fault. After leaving the Days Inn the route enters the Jacksonburg Limestone when it turns onto Crackersport Road (mile 0.9) and crosses the axis of the Iron Run syncline before passing under Interstate 78 at mile 2.7. Stop 8 is on the Epler Formation. Soon after turning left onto Krocks Road in Krocksville (mile 5.5) the route crosses the Black River thrust fault and passes onto the Irish Mountain Nappe and rocks of the Upper Cambrian age **Muhlenberg Member** of the **Allentown Dolomite**. These rocks are medium (N5) to medium light (N6) gray, thick-bedded dolomite and magnesium limestone. The unit contains interbedded calcareous sandstone that serves as host for stratabound limonite deposits that were widely exploited in the past. Limonitic sandstone is characteristic float. The unit is about 850 ft thick. Numerous old limonite pits occur in the area traversed, but few are visible from the roads traveled.

When the route passes the Brookside Country Club (mile 9.9) the underlying rock is Upper Cambrian **Tuckerton Member** of the **Allentown Dolomite**. These rocks are light (N7) to medium dark (N4) gray, medium to thick-bedded dolomite and magnesium limestone. The unit is about 650 ft thick. The route quickly passes across the Emmaus thrust fault and onto rocks of the Middle and Lower Cambrian **Leithsville Formation**. These rocks are thick bedded, medium (N5) to medium dark (N4) gray, finely crystalline dolomite cyclically interbedded with platy and shaly-bedded dolomite. The unit is about 1,000 ft thick and grades down into the **Hardyston Quartzite**. The route traverses the Hardyston for a short distance when it joins PA Route 100 at mile 11.4. The Hardyston is light gray (N7) to moderate reddish brown (10R4/6), thin to medium bedded quartzite, arkosic sandstone, and quartz-pebble conglomerate. The unit contains abundant jasper that will be seen at Stop 10. The Hardyston may be up to 800 ft thick.

The route quickly leaves the Hardyston and travels briefly over a **microperthite alaskite** which is a medium to coarse grained, grayish pink (5R8/2) to light brownish gray (5YR6/1) gneissoid to indistinctly foliated alaskite composed principally of microcline, microperthite, quartz, and oligoclase. This rock is quickly left and by the time PA Route 100 joins PA Route 29 (mile 12.4) the bedrock is **amphibolite**, a medium grained, dusky green (5G3/2) to grayish black (N2) rock composed of hornblende and andesine. Some phases contain biotite, clinopyroxene, orthopyroxene, or magnetite. This presumably is the rock that underlies Stop 9. These crystalline rocks are Middle Proterozoic in age.

After viewing the jasper of the Hardyston Quartzite at Stop 10, the route travels an interval largely covered by drift with no bedrock exposed. Stop 11 is at the base of South Moun-

tain, one of the largest of the Reading Prong hills. Drake (1996a) infers that the Applebutter thrust fault passes under the drift at Stop 11. Rocks on the mountain above Stop 11 are mainly microperthite alaskite with some amphibolite. After the Field Conference leaves Stop 11 and joins Interstate 78 East (mile 22.2) it passes through cuts in South Mountain that do not expose much rock, but what can be seen is amphibolite. The rocks in this part of South Mountain are involved in a series of overturned anticlines and synclines that have curving trends approximately normal to the trend of South Mountain (Drake, 1996a).

After Interstate 78 cuts through South Mountain it parallels the base of the mountain with Saucon Valley to the south. The geology in the valley, the site of the former Friedensville zinc mine, is very complex as indicated by the cross section in Figure 2. Most of the surface along the base of South Mountain is covered with drift. After exiting Interstate 78 at Hellertown, the route travels across hills of crystalline rocks and valleys of carbonate rocks until it encounters rocks of the Mesozoic basin within a half mile after joining PA Route 611 at Durham Furnace (mile 39.8). Again the geology is complex with complexity only partly reflected by topography (Figure 2). Some outcrops of red Triassic-age sediments occur along PA Route 611 and the Coffman Hill diabase and underlying hornfels will be viewed at Stop 12. The route retraces to Hellertown and then up South Mountain to Stop 13.

The rock beneath the surface at Stop 13 is hornblende granite. After leaving Stop 13 there is very little of a geological nature to be seen on the route back to the Days Inn except for those items previously mentioned for Interstate 78.

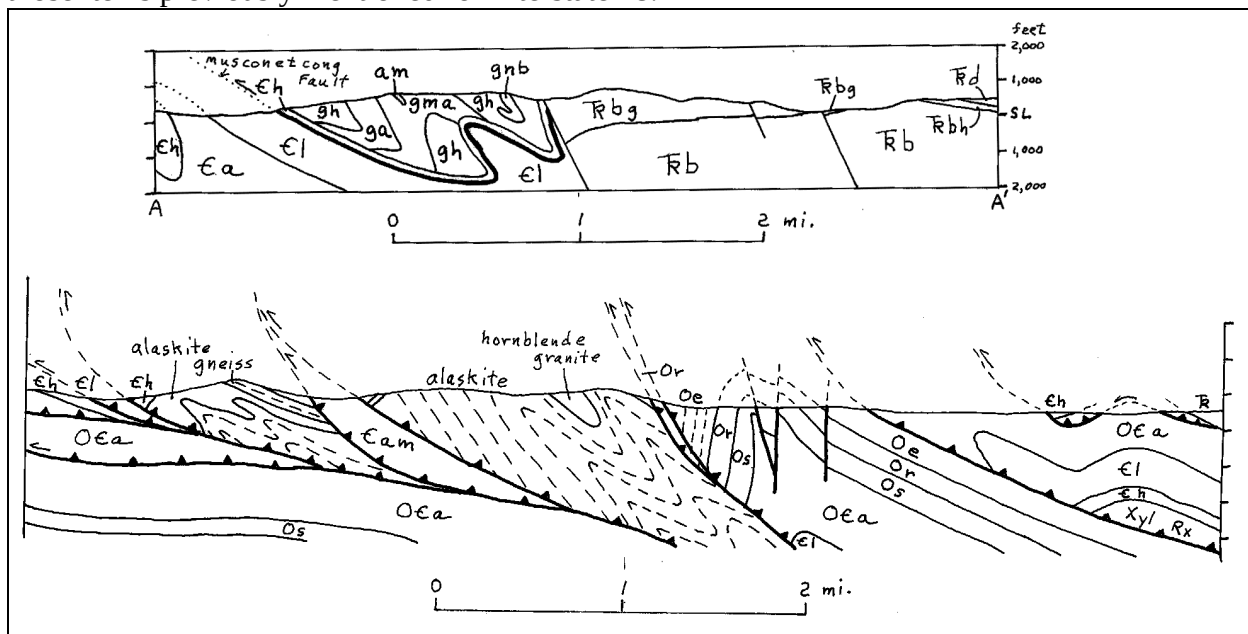


Figure 2. Cross sections in the Hellertown and Reigelsville quadrangles to illustrate complexity of geology in the area. Redrawn from Drake (1996b) and Drake and others (1967). Cl – Leithsville Fm.; Ch – Hardyston Fm.; Cam – Muhlenberg Mbr., allentown Fm.; Oca – Allentown Fm.; Os – Stonehenge Limestone; Or – Rickenbach Dolomite; Oe – Epler Fm.; Trbg – Brunswick Fm., fanglomerate; Trb – Brunswick Fm.; Trd – diabase; Trbh – hornfels; am – amphibolite; ga – microperthite alaskite; gma – microantiperthite alaskite; gn – hornblende granite; gnb – biotite-quartz-palgioclase gneiss;



THE LEHIGH VALLEY LANDFORM ASSEMBLAGE: RELATIONSHIPS BETWEEN TOPOGRAPHY, GEOLOGY, AND DIFFERENTIAL EROSION

by

Dru Germanoski

Department of Geology and Environmental Geosciences

Lafayette College

Easton, PA 18042

germanod@lafayette.edu

INTRODUCTION

The origin and development of the landforms and physiography of the Lehigh Valley area and the central Appalachians has attracted the attention of geologists and physical geographers for over a century (Davis, 1889, 1899; Davis and Wood, 1890; Campbell, 1903, 1933; Bascom, 1921; Knopf, 1924; Ashley, 1930; Ward, 1930). Indeed, William Morris Davis' famous landform evolution model, "The Geographical Cycle" (Davis, 1899), was largely based on observations of landforms in the Lehigh Valley and the surrounding region. The topic of Appalachian landform evolution still attracts a substantial amount of consideration (Hack, 1960, 1975, 1980; Flint, 1963; Wolfe, 1977; Sevon, 1985, 1989; Sevon, Potter, and Crowl, 1983; Costa and Cleaves, 1984; Cleaves, 1989; Marsh and Lewis, 1990). Despite the long history of effort, the question is perhaps best described as "unresolved" in the minds of many geomorphologists, geologists, and geographers familiar with the region.

The most striking characteristics of the Lehigh Valley landscape assemblage are the remarkably even-crested ridge-tops and topographic surfaces that trend approximately northeast-southwest. These relatively even-crested ridges and topographic surfaces led Davis to the conclusion that each surface represented an episode of uplift followed by either nearly complete planation (peneplanation), or planation interrupted by an episode of uplift (partial planation). Davis' ideas were quickly accepted and adopted as an axiom upon which to base future research. In relatively quick succession a series of papers were written that elaborated upon Davis' initial model (Campbell, 1903, 1933; Bascom, 1921; Knopf, 1924; Ashley, 1930; Ward, 1930). Although the planation papers were all based upon a model of erosion that cut across lithotypes and structure, one of the most interesting aspects of these papers is that the authors all noted that the erosion surfaces were more or less coincident with specific lithotypes. The rather clear relationship between lithology and landform served as the basis for Hack's (1960, 1975) ideas on landform development in the Appalachians. For the most part, this paper follows that line of reasoning; in particular my interpretation of the Lehigh Valley landforms can be summarized by Hack's statement that, "...the diversity of form is largely the result of differential erosion of rocks that yield to weathering in different ways" (Hack, 1960). However, my perspective differs from Hack's insofar as I see no need to invoke a dynamic equilibrium wherein the rates of erosion of different lithotypes are equivalent once an equilibrium form is achieved (Hack, 1960).

The focus of this paper is the landform assemblage in the Lehigh Valley area of eastern Pennsylvania and western New Jersey, although the ideas certainly may be transferable throughout the Appalachians and other regions. Nonetheless, a complete evaluation of landform evolution models, peneplains, partial peneplains, etchplanes, dynamic equilibrium, etc. is beyond the

scope of this effort. Rather, this paper represents an evaluation of the Lehigh Valley landforms unencumbered by the preconception of peneplains or partial peneplains.

PHYSIOGRAPHY AND GEOLOGY

The study area encompasses a portion of eastern Pennsylvania and western New Jersey extending from the southern Pocono Plateau south to the Gettysburg-Newark Basin (Figure 3). The area includes portions of the Glaciated Low Plateau and Glaciated Pocono Plateau Sections of the Appalachian Plateaus Province, the Appalachian Mountain and Great Valley Sections of the Ridge and Valley Province, the Reading Prong Section of the New England Province, and the Gettysburg-Newark Lowland Section of the Piedmont Province (Figure 3) (Berg and others,

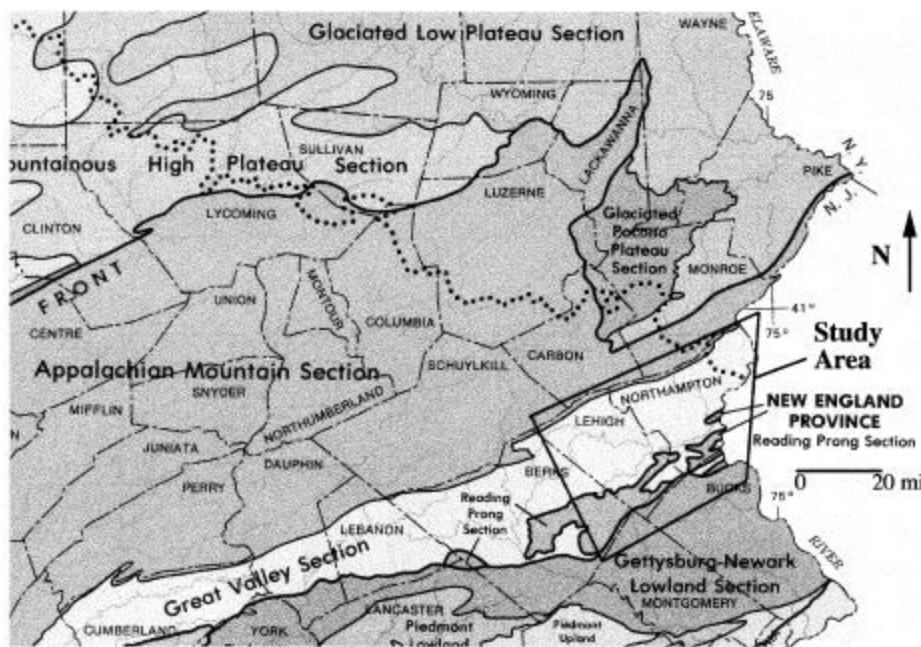


Figure 3. Location map showing the physiographic provinces and sections represented in the study area (from Berg and others, 1989).

1989). The Glaciated Low Plateau consists of a broad, undulatory upland surface, and the Glaciated Pocono Plateau consists of rounded hills and valleys both underlain by nearly horizontal or gently dipping siliclastic rocks of Devonian age. The Appalachian Mountain Section consists of long narrow ridges underlain by siltstone, sandstone, and conglomerate, and broad to

narrow valleys underlain primarily by shale and carbonates of Silurian and Devonian age. The Great Valley Section consists of a very broad valley; the northwestern half is a deeply dissected surface underlain by slate in eastern Pennsylvania and western New Jersey, and the southeastern half is a gently undulating karst surface underlain by carbonates all of Cambro-Ordovician age. All of the rocks of the Ridge and Valley Province are deformed, folded, and thrust faulted. The Reading Prong Section consists of rounded and locally elongate ridge-tops underlain by Precambrian age (Middle Proterozoic) intrusive crystalline rocks, gneiss, and quartzite with intervening valleys underlain by Cambro-Ordovician carbonates. The igneous and metamorphic rocks are typically fault-bounded basement blocks and nappes (Lyttle and Epstein, 1987). The Gettysburg-Newark Lowland Section consists of rolling lowlands underlain by red and gray shale and siltstone and isolated hills and uplands underlain by sandstone, conglomerate, and diabase intrusives of Triassic and Jurassic age. The structure of the Gettysburg-Newark Lowland Section

consists primarily of half-grabens.

The congruity between physiographic sections and geology described above makes it clear that a more detailed knowledge of the geology of the region is fundamental to a discussion of the landscape assemblage. The geology of the region is very diverse in terms of lithotype, age of the units, structure, and geologic history. In general terms, the area is underlain by nearly every lithotype imaginable – intrusive igneous rocks, gneiss, schist, quartzite, marble, slate, siliciclastic rocks, carbonates, and unconsolidated glacial cover. More detailed descriptions of the lithologic units are given in Table 1. Rocks range in age from Middle Proterozoic to Jurassic, and in the northern half of the study area bedrock is mantled with glacial deposits as recent as Late Wisconsinan in age. Virtually all of the major faults and folds throughout the study area strike northeast-southwest. The structural deformation of the Pocono Plateau rocks consists primarily of gentle folds whereas the rocks of the Appalachian Mountain and Great Valley Sections are intensely folded and faulted. These rocks are often steeply dipping and locally folds are overturned (Davis and others, 1967; Drake, 1967; Drake and others, 1967; Drake and others, 1969; Epstein, 1973; Lyttle and Epstein, 1987; Drake, 1993). In the Reading Prong Section, the Middle Proterozoic age basement blocks, primarily intrusive igneous, gneisses, and localized pegmatitic igneous rocks (Table 1), are bounded by low to high angle thrust faults (Lyttle and Epstein, 1987) that separate them from the adjacent Cambro-Ordovician carbonates. Most of the thrusting is believed to have occurred during the Taconic and Alleghenian orogenies (Lyttle and Epstein, 1987). Farther south, the siliciclastic rocks of the Gettysburg-Newark Section are deposited in the extensional fault bounded Triassic and Jurassic Basin. These rocks dip slightly to the north and are cut by Jurassic age diabase dikes and sills (Lyttle and Epstein, 1987). Rocks are often grouped based on similarities in age and lithology following the work of previous workers, in particular, the geologic maps included in Berg and Dodge (1981) (Table 1).

METHODS

Data and observations presented and discussed here are based on field observations made over a twelve-year period, analyses of 7.5-minute topographic maps, and analyses of geologic maps at a variety of scales. Topographic and geologic map sources are listed in Table 2 and References Cited. Regional topographic profiles were measured from 7.5-minute topographic maps using an electronic digitizer and geologic contacts were digitized at a variety of scales (depending on map availability) and overlain on the topographic profiles. Profile data were measured at the contour interval or at the index contour interval depending on the ruggedness and/or consistency of the topography. Four regional-scale topographic profiles were measured perpendicular to strike to best illustrate relationships between topography and geology (Table 2). Two of the strike-perpendicular profiles extended from the Appalachian Mountain Section across the Great Valley and Reading Prong Sections to the Gettysburg-Newark Basin, one extends from the Great Valley Section to the Gettysburg-Newark Basin, and another was very localized. In addition, four regional-scale topographic profiles were measured parallel to strike following nearly homogeneous lithotypes (Table 2).

The strike-parallel profiles include one drawn along Blue/Kittatinny Mountain following the outcrop belt of Silurian age quartzites, one drawn southwest to northeast along the Martinsburg slate/shale/graywacke outcrop belt, another drawn southwest to northeast along the trend of the Great Valley carbonate sequence, and one zigzagged southwest to northeast along the outcrop belt of Middle Proterozoic age Reading Prong basement blocks making up the South

Table 1. Generalized descriptions of major lithostratigraphic units present in the study area listed in outcrop position from north to south. (descriptions from: Davis and others, 1967; Drake, 1967; Drake and others, 1967; Drake and others, 1969; Epstein, 1973; Epstein and others, 1974; Lyttle and Epstein, 1987; Drake, 1993). Descriptions given here are extremely brief, see original sources for more detailed descriptions, especially Lyttle and Epstein (1987).

Lithostratigraphic Unit	Age	Description
Appalachian Mountain Section		
Mahantango Fm.	Middle Devonian	massive, non-bedded, silty shale, with prominent cleavage
Marcellus Fm. Buttermilk, Palmerton, Schoharie, Esopus Fms.	Middle Devonian Lower to Middle Devonian	fissile clay shale, argillaceous limestone, clay shale, siliceous sandstone (Stone, Stony, Undivided Chestnut ridges), well-bedded hard siltstones
Oriskany Group., New Scotland and Coeymans Fms. Undivided	Lower Devonian	white quartz sandstone, chert, sandstone, pebble conglomerate, minor shale and siltstone
Poxono Island, Bossardville, and Decker Fms. Undivided	Upper Silurian	laminated to thinly bedded limestone, dolomite, and shale; sandstone and siltstone near the top
Bloomsburg Fm.	Middle Silurian	laminated to massive red siltstone, shale, and sandstone
Shawangunk Fm.	Lower Silurian	planar-bedded and crossbedded partly conglomeratic quartzite, interbedded sandstone, siltstone and minor shale
Great Valley Section		
Martinsburg Fm.	Middle to Upper Ordovician	thin- to thick-bedded slate, shale, and graywacke
Shochary Fm.	Middle to Upper Ordovician	thin- to thick-bedded calcareous, pyrite-rich graywacke interbedded with slate, calcisiltite, and minor conglomerates
New Tripoli Fm.	Middle to Upper Ordovician	thin, evenly-bedded calcareous, graywacke interbedded with thick slate and calcisiltite beds
Jacksonburg Fm.	Middle Ordovician	upper facies is thin-bedded argillaceous limestone with slaty cleavage; lower facies medium- to thick-bedded high calcium limestone
Beekmantown Group	Lower to Middle Ordovician	thin- to thick-bedded dolomites
Allentown Fm.	Upper Cambrian to Lower Ordovician	rhythmically bedded dolomite

Leithsville Fm.	Lower to Middle Cambrian	interbedded dolomite, calcitic dolomite, phyllite, thin beds and stringers of quartz and dolomite sandstone
Hardyston Fm.	Lower Cambrian	thin-bedded to massive feldspathic quartzite interbedded with arkose, quartz pebble conglomerate or silty shale or phyllite

Reading Prong Section

Byram Intrusive Suite	Middle Proterozoic	Microperthitic and microantiperthitic alaskite. Microperthite, microantiperthite, quartz and oligoclase alaskite. Hornblende granite and associated biotite granite. Gneissoid granite, foliated granite, and sparse granite gneiss
Metasedimentary Layered Sequence	Middle Proterozoic	Marble. Calcite marble and dolomite marble, much of the dolomite marble altered to serpentine, tremolite, and talc. Biotite-quartz-plagioclase gneiss. Well-layered gneiss of variable composition always containing conspicuous biotite potassic feldspar gneiss. Gneiss and minor granofels. Local interlayers of biotite-quartz-plagioclase gneiss and feldspathic quartzite. Pyroxene-gneiss. Well-layered to nearly massive, granoblastic gneiss composed principally of diopsidic pyroxene and plagioclase and lesser quantities of hornblende, quartz, biotite, and magnetite
Losee Metamorphic Suite	Middle Proterozoic	Oligoclase-quartz gneiss. Poorly foliated granoblastic gneiss and minor granofels albite-oligoclase granite. Gneissoid granite, composed principally of albite, oligoclase, quartz, and minor amounts of sodic hornblende, or more rarely augite or magnetite albite pegmatite. Coarse-grained rock composed principally of albite, quartz and lesser amounts of microperthite
Hexenkopf Complex	Middle Proterozoic	Hornblende-augite-quartz-andesine gneiss. Strongly sericitized, chloritized, and silicified gneiss containing hornblende, augite, quartz, andesine, and lesser amounts of epidote, biotite, sphene, garnet, apatite, magnetite, pyrite, chlorite, and zircon epidote-augite-hornblende-plagioclase gneiss. Well foliated gneiss containing sparse amounts of biotite, sphene, and magnetite, and widely varying amounts of quartz. Quartz-garnet-augite granofels. Highly siliceous granofels containing quartz, garnet, augite, and minor saussuritized plagioclase and chlorite.
Rocks of Uncertain Origin and Relative Age	Middle Proterozoic	Amphibolite, fine- to medium grained rock composed principally of hornblende and andesine. Amphibolitic migmatite and related hybrid rocks. Quartz diorite, medium- to coarse-grained rock composed principally of andesine or oligoclase, quartz, and hypersthene.

Gettysburg-Newark Basin

Diabase	Lower Jurassic	fine- to coarse grained calcic plagioclase and augite rich diabase
Brunswick Gp.	Lower Jurassic and Upper Triassic	thin- to thick-bedded shale, siltstone, sandstone, and red-matrix conglomerate
Quartzite Conglomerate	Upper Triassic	quartz pebble, cobble, and boulder conglomerate in a matrix of siltstone and sandstone

Table 2. 7.5-minute quadrangle maps used to construct topographic profiles.

Profile A-A' Perpendicular to strike (Figure 10)
Kunkletown, PA, 1992 Catasauqua, PA, 1983 Allentown East, PA, 1992 Milford Square, PA, 1992
Profile B-B' Perpendicular to strike (Figure 11)
Wind Gap, PA, 1983 Nazareth, PA, 1992 Hellertown, PA, 1992
Profile D-D' Perpendicular to strike (Figure 12)
Stroudsburg, PA-NJ, 1992 Bangor, PA-NJ, 1994 Easton, PA-NJ, 1994 Riegelsville, PA-NJ, 1978
Profile F-F' Parallel to strike along the crest of Blue Mountain (Figure 5)
New Tripoli, PA, 1994 (75°52'30"W; 40°41'15"N) Slatedale, PA, 1965 Lehigh, PA, 1992
Palmerton, PA, 1984 Kunkletown, PA, 1992 Wind Gap, PA, 1983 Stroudsburg, PA-NJ, 1992
Portland, PA-NJ, 1992 (75°02'45"W; 41°00'N)
Profile G-G' Parallel to strike along the Martinsburg shale/slate (Figure 7)
New Tripoli, PA, 1994 (75°52'30"W; 40°38'15"N) Slatedale, PA, 1965 Cementon, PA, 1964
Catasauqua, PA, 1983 Wind Gap, PA, 1983 Bangor, PA-NJ, 1994
Belvidere, NJ-PA, 1984 (75°2'40"W; 40°52'30"N)
Profile H-H' Parallel to strike along the carbonate belt (Figure 8)
Kutztown, PA, 1994 Topton, PA, 1992 Allentown West, PA, 1992 Allentown East, PA, 1992
Catasauqua, PA, 1983 Nazareth, PA, 1992 Easton, PA, 1994
Profile I-I' Parallel to strike along the South Mountain crest-line (Figure 9)
East Greenville, PA, 1992 Allentown West, PA, 1992 Allentown East, PA, 1992
Hellertown, PA, 1992 Nazareth, PA, 1992 Easton, PA-NJ, 1994 Bloomsbury, NJ, 1970
Profile C-C' Perpendicular to strike (not shown)
Easton, PA-NJ, 1994 Riegelsville, PA-NJ, 1978
Profile E-E' Perpendicular to strike (not shown)
Portland, PA-NJ, 1992

Mountain/Morgan Hill landform assemblage. For practical reasons, elevations and distances on topographic profiles are given in feet and miles, respectively because the USGS topographic map contours are expressed in feet above mean sea level. Although using English units is unconventional in a scientific paper, converting elevations to SI units would make it very cumbersome for the reader to refer to a 7.5-minute quadrangle while reading this paper. In fact, to fully contemplate this topic the reader should consult the appropriate topographic maps. SI equivalent dimensions are given in parentheses throughout the paper.

RESULTS

Predominant Topographic Surfaces

Even the most cursory observation of the topography of the Lehigh Valley region reveals that the landform assemblage is dominated by at least five suites of landforms, each having representative topographic characteristics and elevations above sea level. Sevon (1999) is in the process of creating a composite landform map of Pennsylvania and he recognizes the same land divisions as described here, and in fact, more finely subdivides the landscapes of the Lehigh Valley region.

Terrain 1. The highest topographic feature in the region is the crest-line of Blue/Kittatinny Mountain (The ridge known as Blue Mountain southwest of this area is known as Kittatinny Mountain in the northeastern corner of Northampton County, PA and in New Jersey east of the Big Offset; hereafter in this paper the mountain is simply referred to as Blue Mountain). Blue Mountain forms the skyline to the north-northwest of the Lehigh Valley. The most striking attribute of Blue Mountain is that the ridge is very even-crested when viewed from the distance (Figure 4). Figure 5 shows the topographic profile of the crest of Blue Mountain



Figure 4. Photograph of three of the principal “surfaces” described in the manuscript. Blue Mountain forms the skyline. The label, “Slate Surface” is on the escarpment that separates the higher slate surface from the carbonate surface in the near view. In terms of peneplains described by earlier workers, Blue Mountain is a remnant of the Schooley peneplain, the slate surface is a remnant of the Harrisburg partial peneplain, and the carbonate surface is part of the Somerville partial peneplain. Photo taken from Chestnut Hill in Easton, PA looking north.

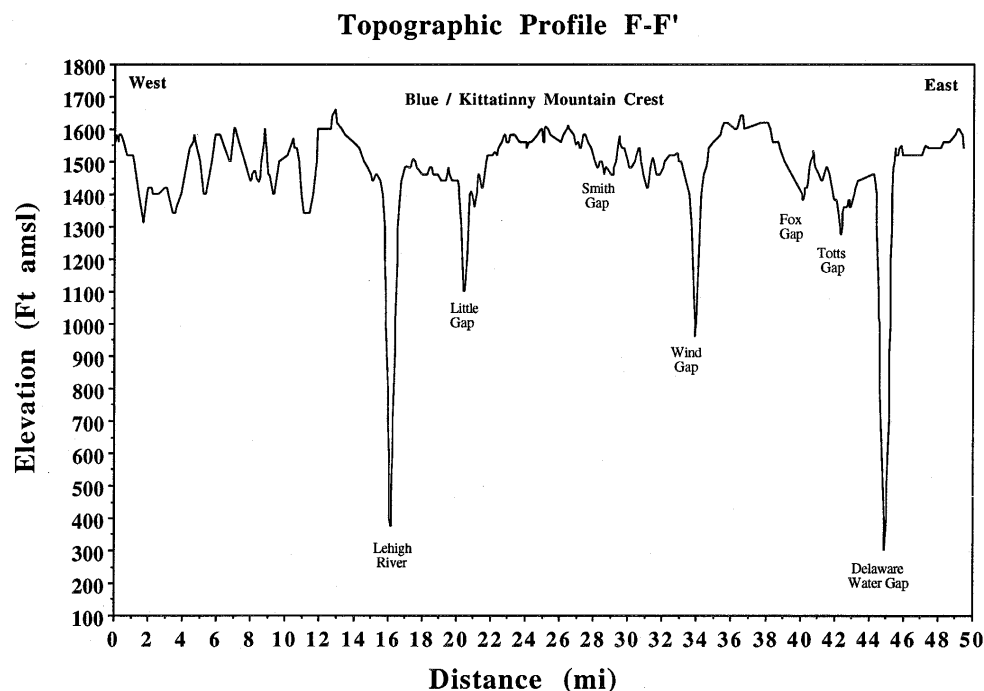


Figure 5. Topographic profile measured southwest to northeast along the crest of Blue Mountain from New Tripoli, PA to the Portland, PA-NJ quadrangles.

wangunk Formation along the entire length of the profile. The average elevation of the summit-line measured along the profile is 1,391 ft (424 m) amsl with a maximum of 1,660 ft (506 m) amsl and a minimum of 300 ft (91 m) amsl at the Delaware Water Gap (Figure 5). Although the summit-line of Blue Mountain is very even along its length, there is as much as 386 ft (118 m) of relief along the mountain crest, excluding the deep gaps formed by the Lehigh and Delaware Rivers and the ancient channels that flowed through Little Gap and the Wind Gap (Figure 5). The average elevation of the crest-line, excluding the segments adjacent to the four major water and wind gaps, is 1,496 ft (455 m) amsl with a standard deviation of only 77 ft (24 m).

Terrain 2. North of Blue Mountain the landscape consists of typical Appalachian Ridge and Valley terrain with long, parallel, narrow-crested ridges alternating with narrow, strike-parallel valleys carved by streams exploiting the outcrop belts and bedding planes of weaker strata. The Appalachian Mountain Section is restricted in width in this area and is bounded on the north by the Glaciated Low Plateau and Glaciated Pocono Plateau Sections of the Appalachian Plateaus Province (Figure 3). The ridges north of Blue Mountain (Godfrey, Chestnut, and Stony Ridges; Indian Hills) are underlain by sandstones that are less resistant to erosion than the Shawangunk quartzite and these ridges vary in elevation from ridge to ridge and along the strike of each individual ridge. Typical elevations range from 700 (213 m) to as much as 1,300 ft (396 m) above mean sea level.

Terrain 3. The topography drops precipitously down the south flank of Blue Mountain to a laterally continuous upland surface underlain by the Ordovician-age Martinsburg shale, slate, and graywacke (Figure 4). This surface is approximately 6-7 miles (10-11 km) wide from northwest to southeast and forms a portion of the Great Valley Section. This surface extends along strike from the Lehigh Valley southeast into Maryland and beyond and northeast into New

from southwest to northeast. The profile begins at the western margin of the New Tripoli quadrangle (75°52'30"W; 40°41'15"N) and follows the crest of Blue Mountain along the county line boundaries to the intersection of the county line and the northern border of the Portland, PA-NJ quadrangle (75°02'45"W; 41°00'N). Blue Mountain is underlain by the Silurian age Sha-

Jersey. The Martinsburg surface, designated as the Slate Hills Region by Sevon (1999), is a broad upland surface heavily dissected by streams and rivers (Figure 6). The relatively high drainage density, rugged topography, and steep-sided valley-side characteristic of this terrain is readily apparent on topographic maps of the area (Figure 6). The topographic profile shown in Figure 7 was drawn southwest to northeast parallel to the outcrop belt of the Martinsburg Formation beginning at the western margin of the New Tripoli quadrangle (75°52'30"W; 40°38'15"N) and extending northeast to just across the Delaware River to the northern margin of the Belvidere NJ-PA quadrangle (75°2'40"W; 40°52'30"N). The topographic profile was drawn along the axis of Shochary Ridge on the New Tripoli and Slatedale quadrangles and, therefore, two topographic surfaces are visible on the profile (Figure 7). Shochary Ridge has an average elevation of 707 ft (216 m) amsl and the rest of the profile east of Shochary Ridge has an average elevation of 559 ft (170 m) amsl with a standard deviation of 121 ft (37 m). The northeast portion of the profile is more representative of the Martinsburg surface as a whole including the terrain adjacent to Shochary Ridge on the north and south.

Terrain 4. The Martinsburg surface is separated topographically from the next surface to the southeast by a prominent escarpment (Figures 4 and 6). The surface has an average elevation of 387 ft (118 m) amsl with a standard deviation of 73 ft (22 m) measured along a strike-parallel topographic profile (Figure 8). This surface is designated as the Lebanon Lowland Region by Sevon (1999) and is underlain by Cambro-Ordovician carbonates (Figure 6; Table 1). The carbonate surface has a much lower drainage density than the Martinsburg surface and consists of a much more subdued karst terrain topography characterized by many closed depressions and sinkholes. The major drainages that cut across this surface originate on the Martinsburg surface or other non-carbonate terrain in the region (Figure 6). The carbonate surface is interrupted by discrete hills underlain by more resistant rocks such as the Martinsburg Formation or Middle Proterozoic crystalline rocks. The significance of these topographic “anomalies” will be discussed in more detail below, however, Cherry and Haas Hills which are shown on the topographic profile of the carbonate terrain (Figure 8) are good examples.

Terrain 5. The Great Valley Section is bounded on the south by the fault-bounded basement blocks of the Reading Prong Section. The Reading Prong terrain consists of round-crested hilltops separated by intervening valleys underlain by Cambro-Ordovician carbonates. Reading Prong hills occur as individual isolated hills when surrounded entirely by carbonates (Camelhump, Saucon Hill, Chestnut Hill; Easton, Hellertown, and Nazareth quadrangles) and in other cases as more continuous rolling uplands when the crystalline basement blocks have larger more contiguous outcrop area (Christines, Gaffney, Hexenkopf Hills; Easton, Hellertown, and Riegelsville quadrangles). Elevations of the Reading Prong terrain are highly variable and range from 1,093 ft (332 m) amsl to 360 ft (110 m) amsl (excluding deep cuts made by Saucon and Lopatcong Creeks and the Lehigh and Delaware Rivers) measured along a topographic profile drawn along the crests of the South Mountain to Morgan Hill ridge-line from the East Greenville to Belvidere, NJ-PA quadrangles (Figure 9). The average elevation of the ridge crest along this profile is 790 ft (241 m) amsl with a standard deviation of 142 ft (43 m). Of the major terrains or surfaces in the Lehigh Valley region, the Reading Prong terrain has the most inconsistent topography. Although the Martinsburg surface (Slate Hills) is deeply incised by a multitude of drainage channels, the elevations of the upland surface (Figure 7) are much more consistent than the upland surface of the Reading Prong ridge-line (Figure 9).

As illustrated on all of the topographic profiles, the region is incised by alluvial valleys cut to elevations as low as 180 ft (55 m) amsl. The Delaware and Lehigh Rivers form the major

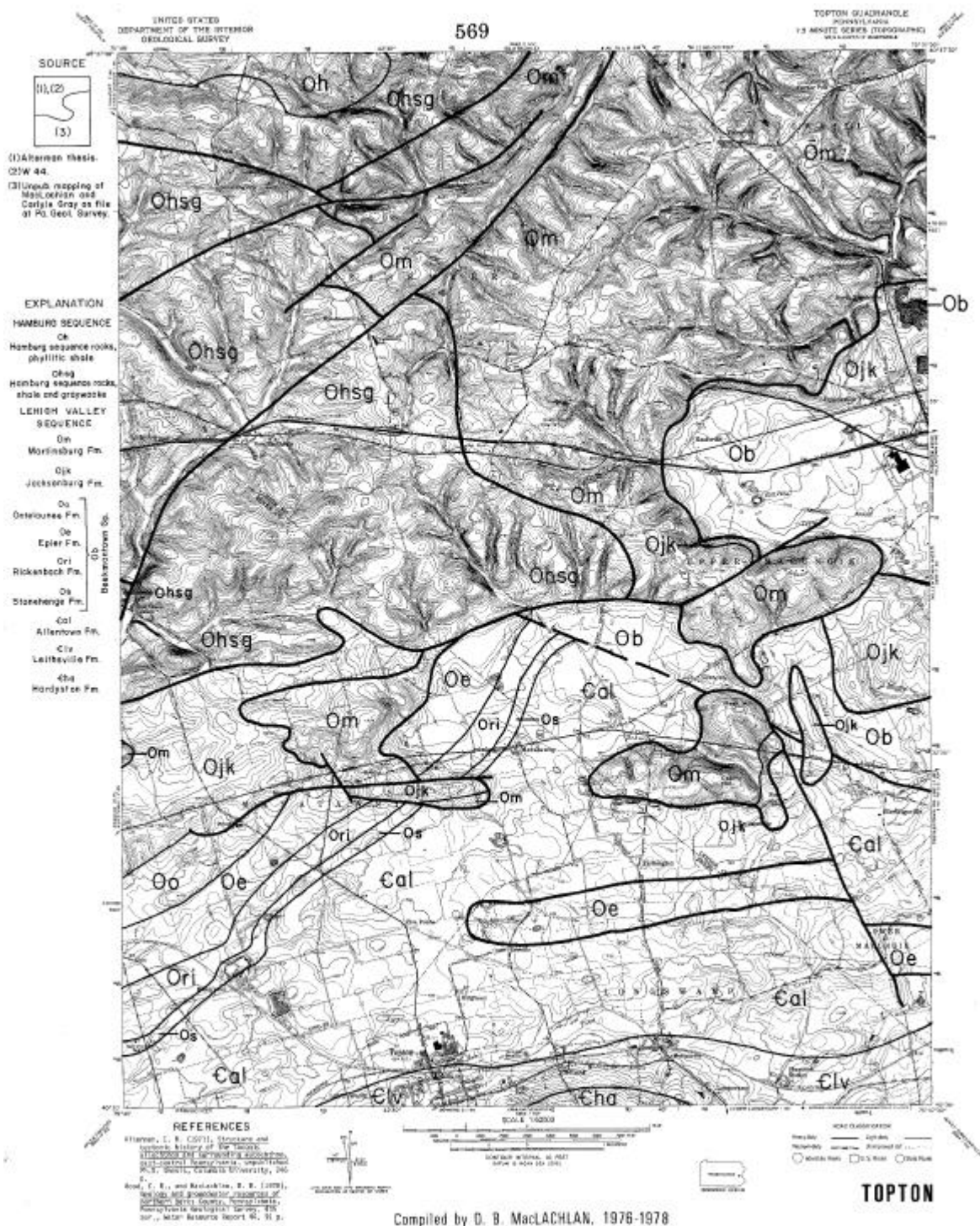


Figure 6. Geologic map of the Tipton, PA quadrangle. The prominent escarpment that trends southwest to northeast separates the Martinsburg slate/shale from the carbonate lowlands to the southeast. Also, note the higher drainage density and more rugged nature of the Martinsburg Formation terrain. Cherry and Haas Hills, the southeasternmost area of Martinsburg, are underlain by relatively resistant slate/shale and project above the carbonate lowlands. From Berg and Dodge (1981).

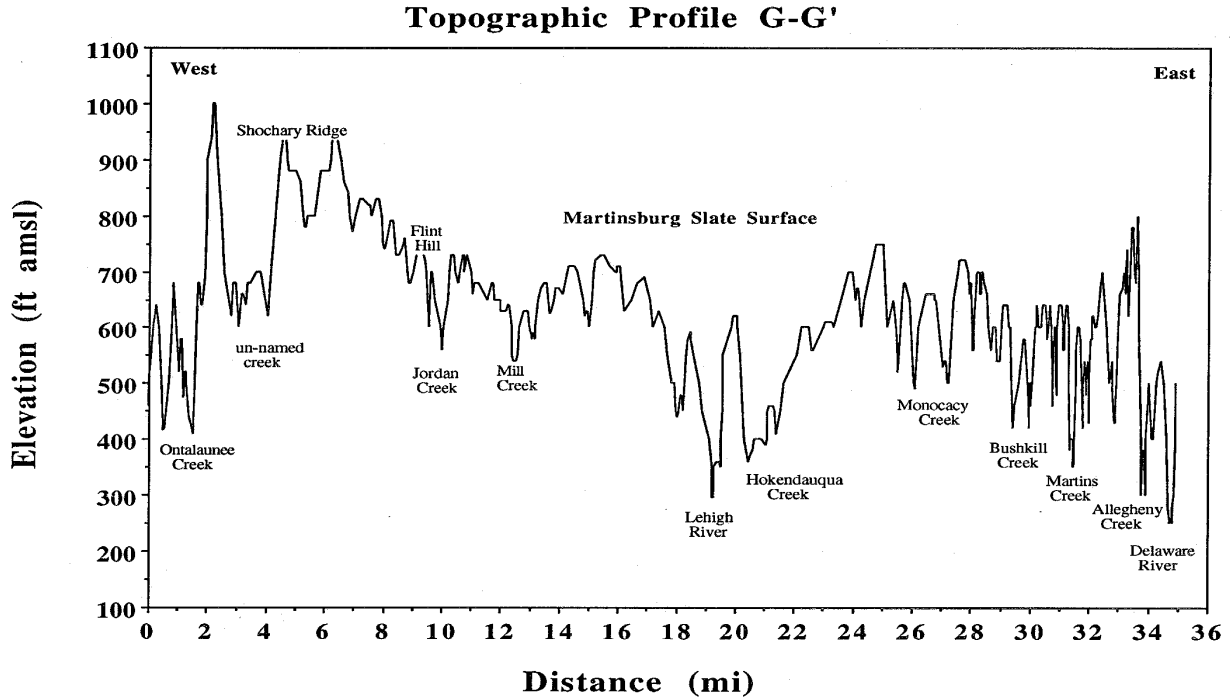


Figure 7. Topographic profile measured southwest to northeast along the outcrop belt of the Martinsburg Formation from the New Tripoli, PA to the Belvedere PA-NJ quadrangles. Note the higher terrain formed by the more resistant sandstone (graywacke) of the Shochary Ridge Formation and the high drainage density of the surface throughout the length of the profile.

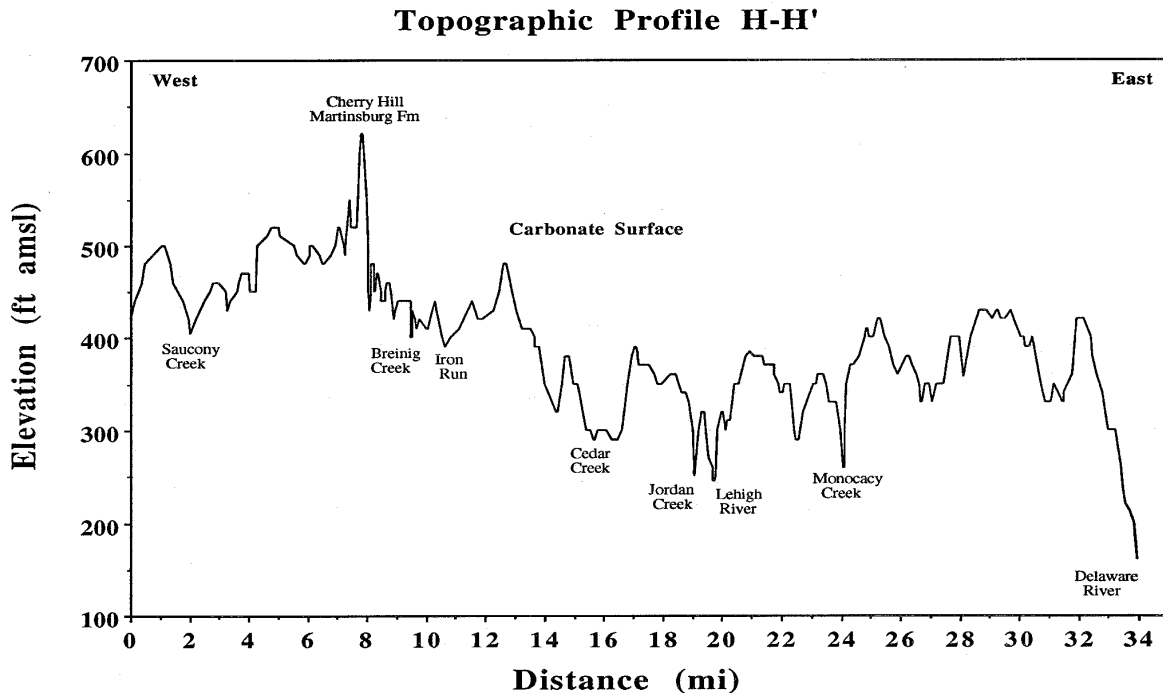


Figure 8. Topographic profile measured southwest to northeast along the outcrop belt of the Cambro-Ordovician carbonates from Kutztown, PA to the Easton, PA quadrangles. Cherry Hill is underlain by more resistant Martinsburg slate/shale and projects above the more soluble carbonates.

base levels in the region. The entire drainage network has cut deeply into the landscape because the two major rivers flow across strike, which most-effectively transfers their base level influence throughout the region.

The topography of the northernmost portion of the Gettysburg-Newark basin is somewhat similar to the Reading Prong terrain insofar as the terrain is typified by distinct, rounded hilltops separated by broad valleys. The distinction between the two physiographic sections is significant when viewed in their entirety. However, with respect to the northernmost portion of the Gettysburg-Newark Basin the distinction between the two is: (1) the relative extent of the hilltops and valleys is inverted, that is, the uplands are predominant in the Reading Prong Section whereas the valleys are predominant in the Gettysburg-Newark Lowland, and (2) the mountains and hills are formed by fault-bounded, crystalline Middle Proterozoic basement blocks in the Reading Prong and by quartzite and quartz-conglomerate alluvial fan deposits and diabase intrusive sheets, both of Mesozoic age, in the Gettysburg-Newark Lowland.

Topography and Peneplains

The well-defined topographic surfaces were interpreted as peneplains by Davis (1889), Davis and Wood (1890), and a number of subsequent workers (Bascom, 1921; Ward, 1930; Knopf, 1924; Ashley, 1930; Campbell, 1933). The peneplains identified in the region are well known and the history of these ideas have been reviewed in detail elsewhere (Sevon and others, 1983), therefore, only brief attention to the peneplain model is given here. The crest-line of Blue Mountain along with the presumably accordant summits of Blue Mountain and the ridges northwest of Blue Mountain were interpreted by Davis (1889; Davis and Wood, 1890) as the remnant of a former peneplain produced by the reduction of the former Appalachian mountain range to near base level. This surface has been referred to as the Schooley Peneplain. The Martinsburg shale/slate surface (Figure 4) has been named the Harrisburg Peneplain (Campbell, 1903) and the carbonate lowlands have been referred to as the Somerville peneplain (Campbell, 1903). The Schooley peneplain was believed to be Cretaceous age and the Harrisburg and Somerville Peneplains were believed to be of middle Tertiary age by early workers (Davis, 1889; Knopf, 1924). Ashley (1930) suggested that the Schooley Peneplain was Miocene age or younger.

Only the Schooley surface would have met the criteria of “peneplain” as defined by Davis as, “a general lowland of denudation, a wide area of faint relief” (Davis 1889), and “as the name for the penultimate form developed in a cycle of erosion” (Davis 1902). The Harrisburg and Somerville surfaces were believed to have formed during cycles of erosion that were interrupted by episodes of uplift and stream rejuvenation before continuous peneplains could be produced. Following Davis’ (Davis, 1889; Davis and Wood, 1890) initial work in the region, subsequent workers identified as many as nine cycles and subcycles of erosion marked by partial erosion surfaces, river terraces, and alluvial gravel deposits (Bascom, 1921; Knopf, 1924). The process or mechanism for peneplanation or “base-leveling” as it was described (Davis, 1889; 1902) was believed to be fluvial erosion resulting from uplift and river planation. Ward (1930) argued that the Somerville surface, confined as it is to the Cambro-Ordovician carbonates, was most likely produced by solution lowering of the limestone subsequent to the development of the Harrisburg peneplain. Thus, Ward (1930) concluded that only two peneplains, the Schooley and the Harrisburg, were produced by uplift and erosion followed by the reduction of the carbonate portion of the Harrisburg peneplain by solution.

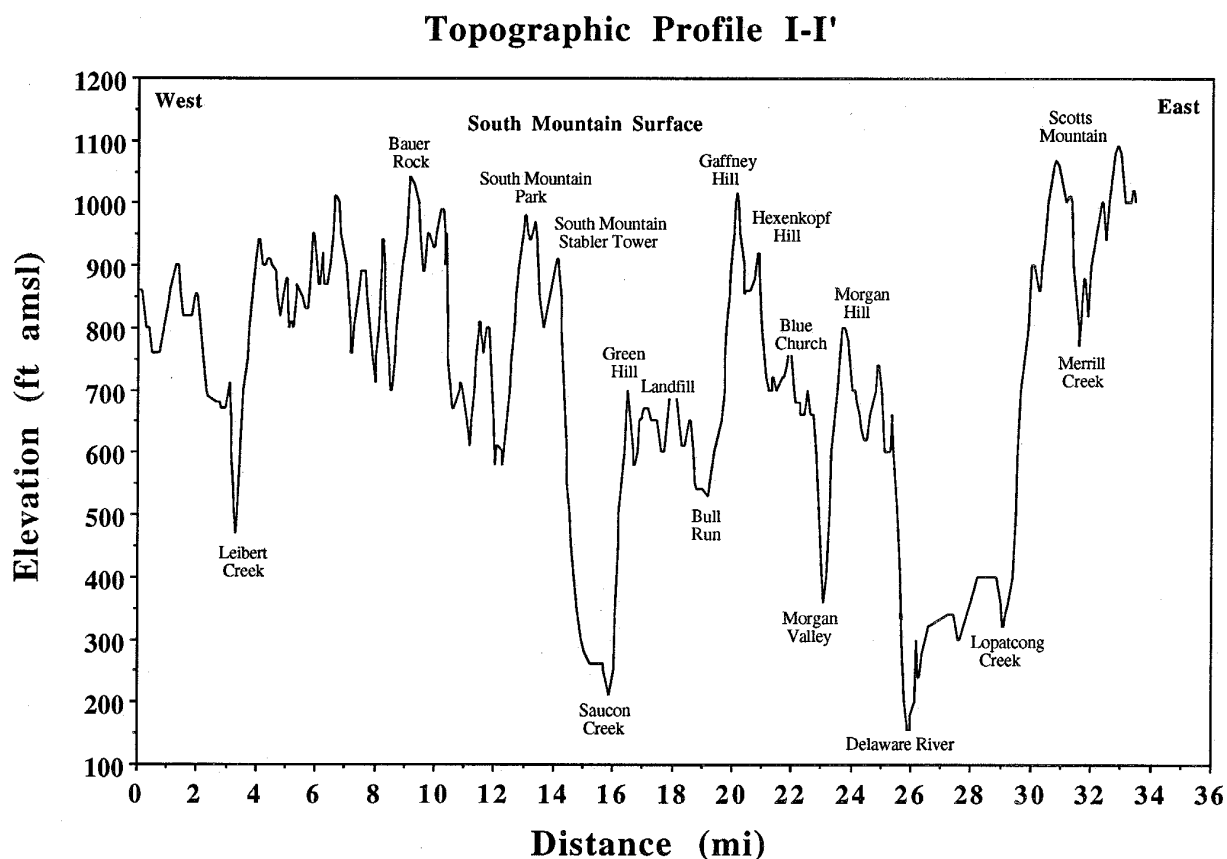


Figure 9. Topographic profile measured southwest to northeast along the crest-line of South Mountain (outcrop belt of the Proterozoic basement blocks) from the East Greenville, PA to the Bloomsbury, NJ quadrangles.

Topography, Geology, and Differential Erosion

The correlation between topography and geology is so strong in this area that crude geologic maps could be constructed purely on the basis of topography. The close relationship between geology and topography is immediately evident when an observer gazes north across the Great Valley to Blue Mountain (Figure 4). Blue Mountain, the highest topographic feature in the region is underlain by the Shawangunk quartzite and conglomerate, the least susceptible to chemical and/or mechanical weathering and erosion. The Martinsburg surface (Slate Hills of Sevon, 1999) somewhat intermediate in resistance to weathering and erosion form the dissected upland surface just south of Blue Mountain and separated from the relatively soluble carbonates by a very prominent escarpment of regional prominence.

The Reading Prong hills south of the Lehigh River are more resistant to erosion than the shale and slate of the Martinsburg Formation and form mountains and hills topographically intermediate in elevation between the Martinsburg surface and Blue Mountain. Topographic profiles drawn perpendicular to strike illustrate the large-scale correspondence between geology and topography and locally show even more subtle relationships between geology and topography. Figure 10 is a topographic profile drawn from the Appalachian Highlands south across the Great Valley, through the Reading Prong Section to the Newark-Gettysburg Section. This profile

Topographic Profile A-A'

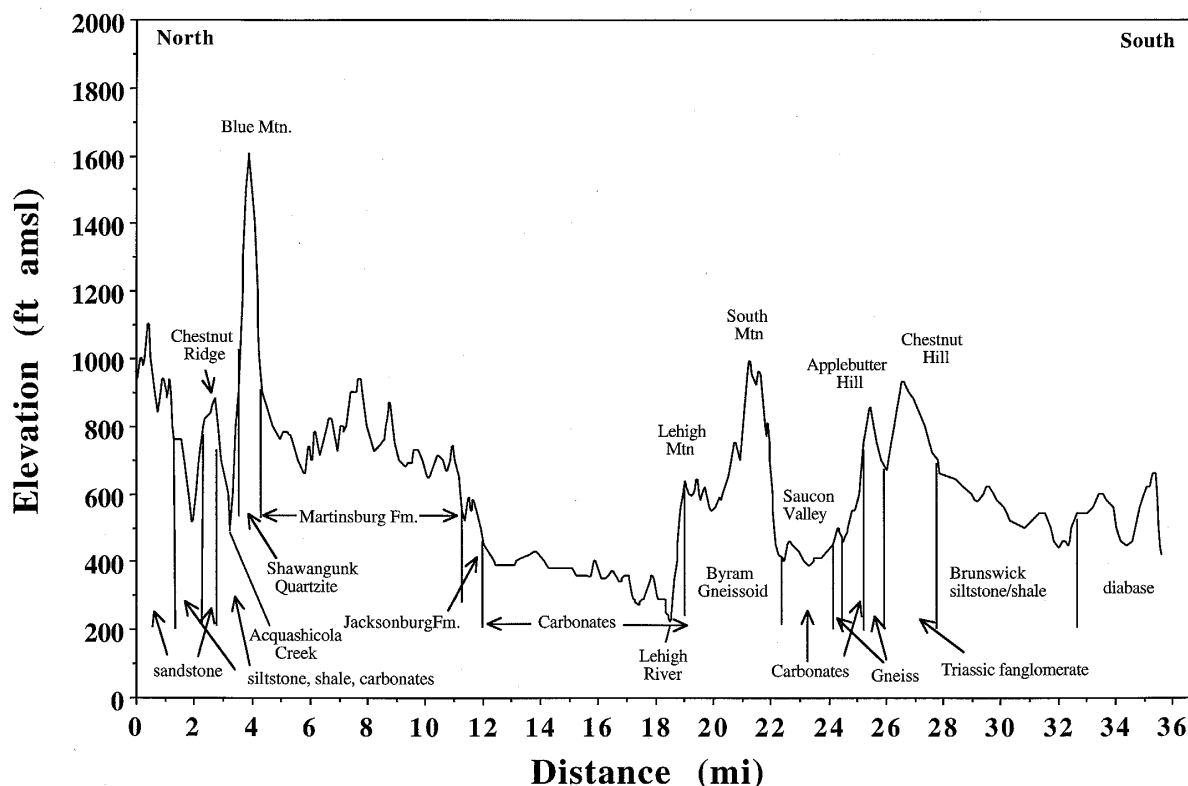


Figure 10. Topographic profile measured north to approximately normal to regional strike from the Kunkletown, PA to Milford Square quadrangles. The profile begins in the Ridge and Valley Province and extends south to the Gettysburg-Newark Lowland. Note the close correspondence between lithology and landforms.

clearly illustrates the correlation between rock resistance to erosion and topography. The valleys in the Ridge and Valley section are strike-parallel stream valleys formed in less resistant shale and siltstone that occur between the more resistant sandstone and quartzite capping the ridge crests. Chestnut Ridge and the unnamed mountains to the north are underlain by sandstone and hold elevations at this point of approximately 900 (274 m) to 1,100 (335 m) ft amsl, whereas Blue Mountain, underlain by more resistant quartzite and quartzite conglomerate, extends to an elevation over 1,600 ft (488 m) amsl (Figure 10). Lehigh and South Mountain and Applebutter and Chestnut Hills, all underlain by Middle Proterozoic crystalline rocks, form ridges and mountains that rise above the intervening carbonate valleys (Figure 10). Similar relationships are evident in topographic profiles drawn successively to the east and also perpendicular to strike (Figures 11 and 12; Table 2). Comparison of the northernmost portions of the profiles shown in Figures 10, 11, and 12 show that the ridge crests of Blue Mountain and Chestnut and Godfrey ridges are not close to accordant and that the elevations of these ridges vary considerably along strike. The relationship between lithotype and topography is further illustrated by the ridge crest of Camelhump (Figures 11 and 13), a small block of crystalline rock that projects approximately 200 ft (61 m) above the surrounding carbonate lowlands. The Reading Prong crystalline rocks all form hills and mountains that rise to elevations varying from 200 (61 m) to 900 (177 m) ft above the surrounding carbonate lowlands (Figures 10, 11, 12, and 13). Flint Hill and The

Lookout are mountains underlain by Jurassic age alluvial-fan quartz conglomerates on the northern margin of the Gettysburg-Newark Basin (Figure 11). Haycock Mountain is similar in elevation to the mountains and hills formed by the Middle Proterozoic crystalline rocks, but it is underlain by Jurassic age diabase, an equally resistant lithotype.

The strike-parallel topographic profiles also show significant relationships between lithology and topography. For example, Schochary Ridge stands as a distinct ridge above the surrounding slate surface because the sandstone (graywacke) that underlies this ridge is more resistant to erosion than the surrounding shale and slate (Figure 7; Table 1). Likewise, Cherry and Haas Hills, outliers of Martinsburg Formation, stand in clear relief above the surrounding carbonate surface because the Martinsburg Formation is more resistant to erosion than the soluble carbonates (Figures 6 and 8). Lithologic variation in the carbonate sequence also shows up in the topography of the region. The Cambro-Ordovician carbonates are fairly similar to one another lithologically with the exception of the Jacksonburg Formation which is notably more argillaceous; so much so in fact that it exhibits slaty cleavage (Table 1). Based on the more siliceous composition of the Jacksonburg one might expect this rock to be more resistant to erosion or solution than the other carbonates. As expected, the Jacksonburg Formation often holds a surface intermediate in elevation between the other carbonates and the Martinsburg surface, a result that did not escape the attention of previous workers (Ward, 1930). The intermediate position of the Jacksonburg Formation is visible on the topographic profile shown in Figure 10.

On the one hand, the relationship between geology and topography is remarkably consistent. However, closer examination of the topographic maps and topographic profiles shows that significant variations in elevation occur within single lithotypes. The variation in elevation of the hills and mountains of the Reading Prong rocks results from variations in lithology (Table 1) which would in turn result in variation in resistance to weathering and erosion, and also to the areal distribution of the outcrop area. The variation in areal distribution of outcrop appears to cause less resistant rocks to stand at higher elevations than they otherwise might and also to allow more resistant rocks to be reduced to lower elevations than they would if they were exposed in larger outcrop area. For example, carbonates exposed in the Jacoby Creek valley near Portland, PA (Portland, PA-NJ quadrangle) hold a surface approximately 200 ft below the surrounding slate upland surface. The carbonates are at an absolute elevation approximately 450 ft above sea level whereas the more areally extensive carbonate surface in the area has an average elevation of approximately 387 ft above sea level. Presumably the carbonates are “protected” from downwasting to some degree by the more resistant surrounding upland. Similar protection is afforded to carbonates exposed between basement blocks of the Middle Proterozoic crystalline rocks south of the Leigh River valley. These carbonate rocks are at higher elevations than carbonates of similar resistance to erosion because they are in “protected isolation.” The valley between Flint Hill and the Lookout (Figure 11) is another example of a weak rock in “protected isolation.” In this case, the Lower Jurassic-Upper Triassic Brunswick Group siltstones and shales hold an elevation of approximately 750-800 ft (229-244 m) amsl when “protected” from erosion by the adjacent Flint Hill quartzite fanglomerate and The Lookout diabase. For comparison, the Brunswick Formation more typically holds elevations on the order of 500 ft (152 m) amsl when “unprotected” by adjacent masses of more resistant rock.

On the other hand, isolated Middle Proterozoic crystalline rocks of limited areal exposure are often eroded to lower elevations than lithologically similar basement blocks that are more massive in outcrop area. Camelhump (Figure 11 and 12), Saucon Hill, Church Hill, Bitts Hill, and other isolated basement blocks provide good examples of hills that do not rise to the same

Topographic Profile B-B'

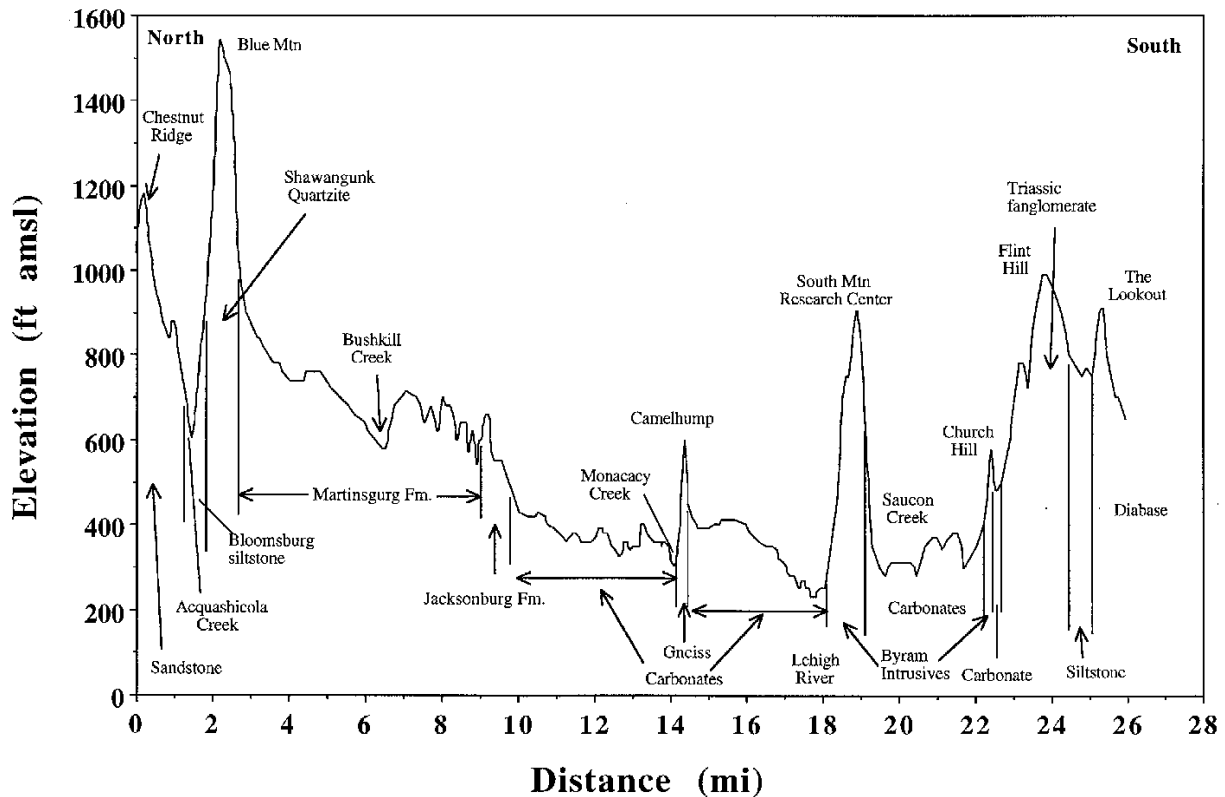


Figure 11. Topographic profile measured north to approximately normal to regional strike from the Wind Gap, PA to Hellertown, PA quadrangles. The profile begins in the Ridge and Valley Province and extends to the Gettysburg-Newark Lowland. Note the close correspondence between lithology and landforms.

elevation as hills and mountains underlain by the same lithotype (Nazareth and Hellertown quadrangles). These rocks can be viewed as being in “exposed isolation” insofar as they are surrounded by markedly less resistant rocks that afford them no protection from erosion. Figure 14 is a plot of outcrop area versus maximum elevation of the hills and mountains underlain by Middle Proterozoic crystalline rocks and Mesozoic diabase, fanquartzites, and fanglomerates. The data show a positive relationship between outcrop area and maximum elevation of the hill or mountain. Although there is a significant amount of scatter in the relationship, the data support the notion that the size of the outcrop area is one of the variables that influences the elevation and degree of weathering and erosion of the basement block. If the basement block is in “exposed isolation,” i.e., surrounded by less resistant rocks, it is more likely to be reduced in elevation by weathering and erosion than if it was adjacent to masses of similarly resistant rocks. The Reading Prong basement blocks of similar lithology form more continuous rolling uplands higher in elevation when the crystalline basement blocks have larger more contiguous outcrop area. For example, Christines Hill, Hexenkopf Hill, and Gaffney Hill are adjacent to one another and reach elevations of 748 ft (228 m), 910 ft (277 m), and 1,016 ft (310 m) amsl respectively (Easton, Hellertown, and Riegelsville quadrangles). Likewise, Granite Hill (800 ft; 243 m amsl), Focht Hill (811 ft; 247 m amsl), and Kirchberg Hill (1,006 ft; 306 m amsl) rise to impressive elevations because they have larger outcrop areas and are adjacent to one another. Undoubtedly,

Topographic Profile D-D'

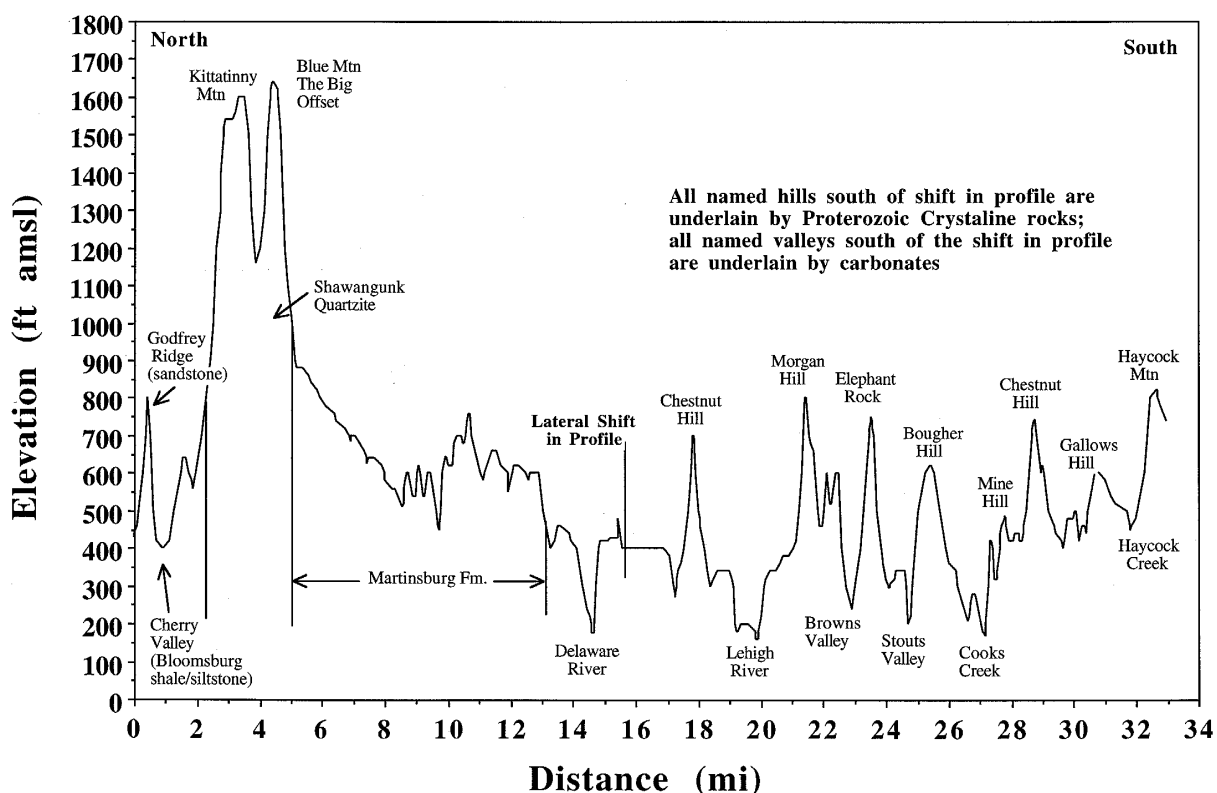


Figure 12. Topographic profile measured north to approximately normal to regional strike from the Stroudsburg, PA-NJ to Riegelsville, PA-NJ quadrangles. The profile begins in the Ridge and Valley Province and extends south to the Gettysburg-Newark Lowland. Note the close correspondence between lithology and landforms.

there is a multivariate control on landform elevation and variations in mineralogy of the basement blocks is one of the variables that likely influence terrain elevations. There is more variation in elevation among the crystalline rocks than within any other lithotype, but there is also more variation in the mineralogy in this terrain than there is within the Shawangunk Formation, the Martinsburg Formation, or among the Cambro-Ordovician carbonates (Table 1). In fact, the abbreviated descriptions of the Middle Proterozoic crystalline rocks provided in Table 1 do not completely reveal the true magnitude of the degree of mineralogic variability present in these rocks [see Lytle and Epstein (1987) for a better sense of the lithologic variability in the Precambrian age basement rocks]. Work on the effects of mineralogic variation is underway, but it is too early to make meaningful conclusions.

DISCUSSION

Previous workers have often cited the “remarkable” consistency of elevation along Blue Mountain and among the linear ridges of the Ridge and Valley as evidence of a former peneplain surface. Conversely, I view the “remarkable” correspondence between lithotype and topography as strong evidence that the landscape of the Lehigh Valley region was produced by differential erosion of dissimilar rocks. In many respects this interpretation is similar to Hack’s (1960; 1975)

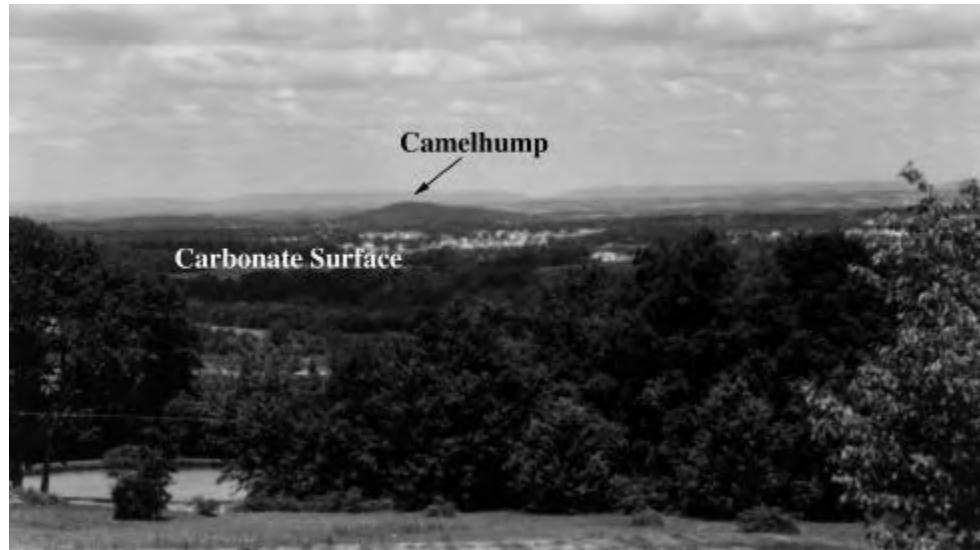


Figure 13. Photograph of the Camelhump, a fault-bounded basement block composed of Middle Proterozoic potassic feldspar gneiss and a lesser amount of Hardyston Quartzite (Lyttle and Epstein, 1987). Camelhump is surrounded by less resistant carbonates. Blue Mountain is visible forming the skyline in the far distance. Photo taken from the northwest flank of Gaffney Hill east of Hellertown, PA looking north.

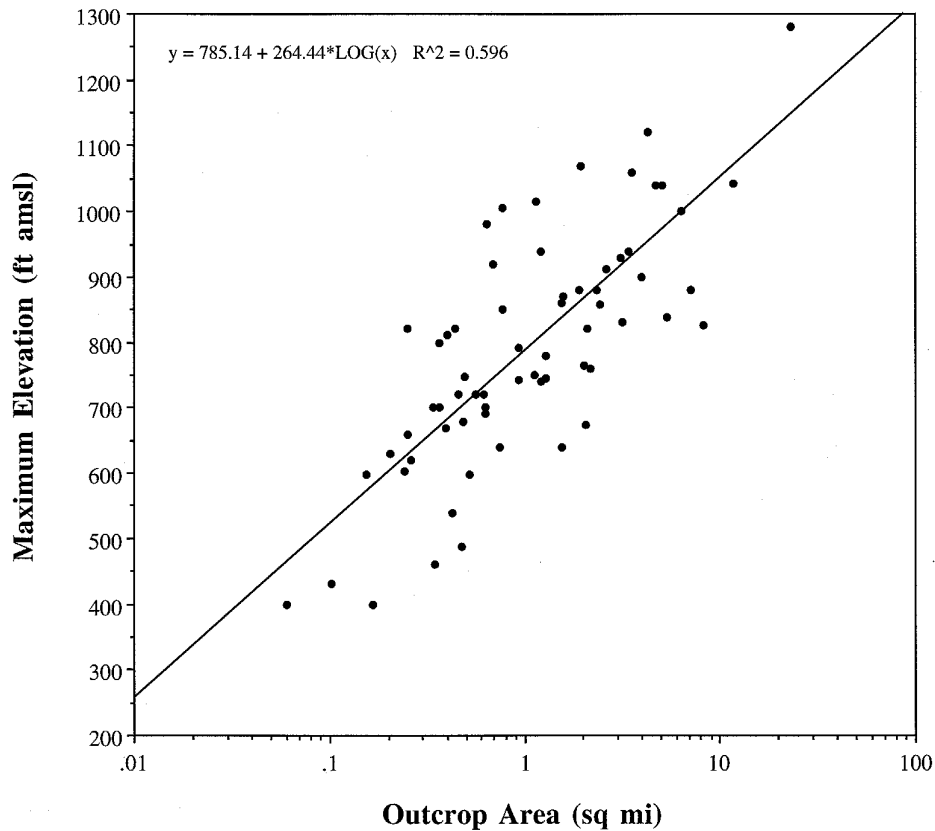


Figure 14. Plot of maximum elevation of Proterozoic igneous and metamorphic rocks and Mesozoic diabase and quartzite conglomerates as a function of outcrop area. A log scale is used because of the range of areas in the data set. Elevation also probably varies due to variations in lithology and associated variations in resistance to erosion among these rocks.

viewpoint with the exception that I see no reason to believe that the landscape developed its configuration rapidly through differential erosion followed by an ongoing episode where all landforms are being lowered at a constant rate.

The correlation between lithotype and topography suggests that the topography was produced by differential erosion of rocks of variable resistance to erosion. The actual processes of denudation are some combination of chemical and mechanical weathering and removal of weathered debris by creep, mass movement, stream and runoff erosion, and at times, glaciation. The relative significance of these processes will vary from rock to rock and from time to time as climate changes (Sevon, 1985) and uplift occurs (Hack, 1980; Poag and Sevon, 1989).

The Shawangunk quartzite and conglomerate would be expected to be very resistant to chemical weathering and data collected by Sevon (1984) supports this assumption. Sevon (1984) calculated a chemical weathering rate of 0.26 m/my for quartz sandstone in Pennsylvania. This rock and the surface it forms apparently is lowered primarily by mechanical weathering and colluviation. The boulder fields and thick colluvial wedge that has accumulated on the flanks of Blue Mountain provide further evidence of the importance of mechanical weathering and mass movement as the primary mechanism of erosion of this Mountain. The intermediate elevation of the Middle Proterozoic crystalline rocks require that they be eroded at rates that exceeded the rates of erosion of Blue Mountain, yet not as rapid as the rates of erosion that denuded the landscape of the Martinsburg shale slate region. Sevon (1985) cites work by Upton (1982) that yields a weathering rate of 0.42 m/my for a granite in Maine. Furthermore, Sevon (1981; 1985) provides data that suggests that the Martinsburg Formation is being denuded at a rate of 23-38m/my in the Opossum Creek Watershed, and, based on work by Jennings (1983) and White (1984), Sevon (1985) suggests the carbonates in the Cumberland Valley are being lowered at a rate ranging from 25m/my (White 1984) to 40 m/my (Jennings, 1983). Regardless of whether these rates are absolutely accurate or not, the relative trends are consistent with theoretical expectations. The crystalline rocks likely are lowered by a combination of chemical weathering and soil erosion and mechanical weathering and colluviation. The sandy saprolite deposits common to the crests of South Mountain and other crystalline basement hills and ridges attest to the significance of chemical weathering of these rocks (Miller and others, 1939), while the thick accumulation of boulder colluvium on the flanks of these mountains attests to the significance of mechanical weathering and mass movements as agents of denudation. The Martinsburg Formation is denuded by weathering, colluviation, and stream and soil erosion as evidenced by the well-defined drainage networks and high drainage density and the high suspended sediment loads of streams draining this lithology (Sevon, 1985; Reed, 1980). The relative solubility of the carbonates is evident by the work of Jennings (1982) and White (1984) and the high density of sinkholes and closed depressions mapped in the area (Meyers and Perlow, 1984; Kochanov, 1988). Ward recognized the importance of chemical dissolution of the carbonates as a denudation mechanism in 1930. Of course the carbonates are also eroded by runoff removal of the soil and the weathering mantle.

Sevon (1985) made a compelling argument that the relative rate of weathering and erosion has changed with climate throughout the Cretaceous, Tertiary, and Quaternary, but nonetheless, the relative-rate differential of weathering and denudation of different lithotypes could easily have produced the landscape we see today, despite climate change influences. If denudation rates are variable for different lithotypes as the result of fundamental differences in resistance to erosion, then there is no need to suggest that the landscape evolved rapidly to a state of dynamic equilibrium where erosion rates remain constant for disparate lithologies through time

as suggested by Hack (1960). Moreover, to argue on the one hand that variation in weathering and erosion potential are responsible for producing lithology-mediated topography in the manner suggested here mitigates the suggestion that landscape denudation occurs at constant rates independent of lithology once dynamic equilibrium has been achieved.

The peneplain explanation for the Lehigh Valley landforms is problematical on a variety of levels. The only evidence of a peneplain was Davis' observation of apparently accordant summits of the ridges in the Ridge and Valley. Many of the ridges do appear visually to be in topographic accordance. However, the elevations of these ridges vary by hundreds of feet. Furthermore, the only ridges that are in near accordance are those underlain by similar rock type, specifically, silica-cemented quartz sandstone or conglomerate. As illustrated in Figures 10, 11, and 12, ridge-top elevation can decrease significantly among adjacent ridges if the lithology differs significantly. There is also a significant rise in elevations from the ridge tops of the Ridge and Valley to the Appalachian Plateau. For example, the highest points along Blue Mountain reach elevations of just over 1,600 ft (488 m) amsl, whereas sandstone ridge-tops on the Pocono Plateau, a mere 20 miles (32 km) away reach elevations of 2,165 ft (660 m) amsl. To explain such disparities, early works suggested that the elevation changes reflected surfaces that sloped towards the ocean or were deformed by crustal upwarping subsequent to planation (Bascom, 1921; Knopf, 1924). Significant differences in elevation between the Appalachian Plateau and adjacent ridge crests are more easily explained in terms of differences in erosion related to rock structure, lithology, and continuity of outcrop. The Appalachian Plateau is capped by much more laterally extensive resistant sandstones than the relatively narrow-crested outcrop widths of sandstone capped ridges of the Ridge and Valley. In addition, most of the Plateau is drained to the west by streams that must travel much greater distances to reach the same base level [much of the reversal of drainage from the Ohio River system to the eastward flowing Potomac and Susquehanna Rivers has occurred in the relatively recent geologic past (Morisawa, 1989)].

As researchers working in Davis' wake continued to identify erosion surfaces, the models of erosion and uplift became more complicated. Multiple erosion cycles required multiple cycles of uplift and the mechanism driving multiple episodes of uplift was lacking. Rebound associated with erosional removal of mass is unlikely to serve as a mechanism for discrete cycles of uplift because, as demonstrated by Gilchrist and Summerfield (1991), uplift driven by denudation is continuous rather than episodic. Pavich's (1985) assertion that, "isostatic compensation for mass lost by weathering and erosion has been a major component of continued uplift of the Piedmont throughout the Cenozoic" are consistent with Gilchrist and Summerfield's conclusion. Sedimentation data suggest that there were indeed several episodes of high sedimentation rates centered around the Middle Jurassic (sedimentation that predates any conceivable timing of the Schooley surface), Late Cretaceous, Middle Miocene, and the currently high sedimentation rates associated with the Quaternary; however, correlation with peneplains remains problematical.

Braun (1989) used Poag and Sevon's (1989) sedimentation data to determine rates of erosion in the Central Appalachians and his analyses show that as much as an average of 1.1 kilometers of material has been removed from the Central Appalachians inboard of the Coastal Plain since the middle Miocene. In fact, Poag and Sevon's (1989) data show that the Appalachian landscape has been reduced 120 to 150 m during the Quaternary (Braun, 1989). Thus, Braun (1989) argues that too much material has been eroded from the landscape in the recent geologic past to preserve peneplain surfaces. Furthermore, without reliable age dating of erosion surfaces, any correlation between any particular surface and any particular depositional pulse must remain suppositional. Braun's (1989) analyses suggest that it is unlikely that any reliable surface date is

forthcoming. Moreover, the relationship between tectonic or isostatic uplift and pulses of sedimentation does not provide any evidence of peneplanation; the only conclusion that can reliably be drawn from the correlation of uplift and depositional events is that uplift causes erosion. Erosion does not have to produce a peneplain. It is equally likely, if not more likely, that episodes of tectonic and/or isostatic uplift produced episodes of landscape denudation characterized by differential erosion of rocks of varying resistance. The argument for differential erosion is based on fairly well accepted physical and chemical principles – some minerals, and consequently, rocks composed of those minerals, are more susceptible to chemical and/or physical weathering and erosion. These relationships should remain somewhat constant providing climate doesn't change so dramatically as to reverse the relationships (Sevon, 1985). Indeed, Poag and Sevon (1989) suggest that the sedimentation rates in the Baltimore Canyon Trough correlate rather poorly with paleoclimatic reconstructions.

With the exception of Ward, early workers scarcely considered processes of erosion in detail. The implicit assumption seemed to be that all denudation occurred by lateral planation of streams. Recent work demonstrates the importance of weathering (Cleaves and others, 1970; Costa and Cleaves, 1984; Pavich, 1985, 1989) in landscape reduction. My belief is that differential erosion of the Lehigh Valley area has occurred through the interaction of weathering and erosion processes described above. If peneplanation or "baselevelling" as it was called occurred as the result purely, or even primarily through river planation, it seems to me that partial peneplains should be perpendicular to strike and parallel to the transverse drainage of the major rivers that cross the Ridge and Valley. Instead, we see partial peneplains bounded by escarpments that parallel strike (Figure 4). Some workers have reached the conclusion that the carbonate Somerville peneplain was never a peneplain (or partial peneplain) produced by a cycle or subcycle of uplift and erosion, but rather was once part of the Harrisburg peneplain that was subsequently lowered by solution weathering of the carbonate portion of the Harrisburg surface (Ward, 1930; Miller and others, 1939). This assertion would at least explain the strike-parallel escarpment that separates the Harrisburg from the Somerville peneplains. However, in view of Poag and Sevon's (1989) data that show that the major rivers that drain this portion of the Appalachians (Susquehanna, Schuylkill, and Delaware) have been in place since the Late Jurassic, one should expect wide water gaps produced by lateral planation, or at least well defined strath terraces where the rivers cut gaps across structure. Yet each of these rivers flow through very narrow water gaps.

It seems at least as likely that "accordant" elevation summits and smooth-crested ridges are the expected result of weathering and erosion of similar lithologies as high mountains (Slingerland and Furlong, 1989; Roden and Miller, 1980) are progressively reduced by denudation processes as are the preservation of peneplains and peneplain remnants during millions of years of erosion. If we accept the notion that the major surfaces and ridge-lines in the area are remnants of peneplains it suggests that the landscapes that we see are relict landscapes produced only by peneplanation followed by rapid incision and near stasis.

CONCLUSIONS

Clearly, the long-standing controversy that has surrounded the question of the evolution of the Appalachian landscape has resulted primarily from the lack of unequivocal evidence recording such change. The reliance on peneplanation models by early workers reflect the paradigm of their time. Hopefully, the assertion that the Lehigh Valley landform assemblage results from differential erosion of dissimilar rocks is closer to the truth rather than simply the alle-

giance to the geomorphic paradigms of the late 20th century. Regardless of one's academic predisposition to invoke one paradigm or another, the relationship between topography and geology is straightforward if not unequivocal. Whereas peneplanation and cycles of uplift require close representation in the depositional record and a mechanism for episodes of uplift followed by tectonic quiescence, the differential erosion model has no such requirement. Differential erosion is simply a result of variation in rock resistance to erosion and its influence on topography is unconstrained by rates of uplift or tectonism. The existence of strike-parallel erosion surfaces that nicely mirror lithologic variations, along with the absence of master drainage-parallel partial peneplains makes it very difficult for me envision the Harrisburg or Somerville surfaces as being produced, all or in part, from river planation. The conclusion that the Lehigh Valley landforms represent the results of differential erosion of rocks of varying resistance to erosion is advanced on the basis of the strong association between geology and topography, rather than a matter of convenience or simplicity. This conclusion is also similar to the conclusions of other workers studying Appalachian landforms in the recent past (Hack, 1960, 1975, 1980; Flint, 1963; Braun, 1989).

ACKNOWLEDGMENTS

I would like to thank William Sevon of the Pennsylvania Geological survey for reviewing and editing this manuscript, for asking me to participate in the field conference in the first place, and for sharing unpublished landform maps and landform descriptions. I would also like to acknowledge the help of Carrie Ryder, Lafayette College, and my wife Leann for helping me transfer digitized data into spreadsheets.

PLEISTOCENE GEOLOGY OF THE ALLENTOWN AREA

by

Duane D. Braun

Department of Geography & Geosciences,
Bloomsburg University, Bloomsburg, PA 17815
570-389-4139; dbraun@planetx.bloomu.edu

INTRODUCTORY OVERVIEW

During the last two decades the full multiplicity of cold-warm alternations and associated glacial advances has been recognized from marine oxygen isotope records (Figure 15) and radiometric dating of terrestrial deposits of interbedded volcanic and glacial material (Figure 16). The oxygen isotope record has been used as a time-space diagram of glaciation (Figure 15) (Shackleton, 1987; Braun, 1989). About ten isotope maxima have approached or exceeded the amplitude of the late Wisconsinan event and would have been expected to have ice extent similar to or greater than the late Wisconsinan limit (LW line on Figure 15). Four early to middle Pleistocene isotope maxima, stages 6, 12, 16, and 22 (>W line on Figure 15) exceeded the late Wisconsinan maximum. The terrestrial record suggests that there may be as many as five or six middle and early Pleistocene ice advances more extensive than the late Wisconsinan advance of the North American Laurentide ice sheet (Bowen and others, 1986) (Figure 16). Nearly all Pleistocene isotope maxima approached the amplitude of the early Wisconsinan isotope maxima (Figure 16). That degree of coldness would have brought ice into New York State and periglacial conditions into Pennsylvania.

Thus, in the Allentown region of eastern Pennsylvania as many as ten glaciations may have approached the late Wisconsinan terminus and four probably reached beyond that limit (Figure 17). The late Wisconsinan advance destroyed nearly all traces of previous advances right up to the late Wisconsinan terminal margin (Figure 17). The more extensive early to middle Pleistocene advances left a fragmentary record as much as 45 miles (70 km) to the southwest of the late Wisconsinan margin (Figure 17). The only area of older glacial deposits that has a significant thickness and retains limited relict constructional topography is in a belt 3 to 7 miles (5-10 km) wide in front of and sub-parallel to late Wisconsinan boundary. This margin is currently interpreted as the late Illinoian limit, the most recent glacial advance to extend beyond the late Wisconsinan limit (Figure 17) though the degree of weathering of the material suggests an even older age. Farther to the southwest and sub-parallel to the Illinoian limit is a 10 to 30 mile (15 to 48 km) wide belt of thin, very discontinuous to almost nonexistent glacial drift materials of pre-Illinoian age (Figure 17). These materials are most likely of pre-Illinoian B, D, and/or G age (Figure 16), the most extreme isotope stages 12, 16, and 22 (Figure 15).

Recent paleomagnetic information (Gardner and others, 1994; Sasowsky, 1994) indicates that the maximal pre-Illinoian limit, just west of Allentown, is early Pleistocene in age. Samples of pre-Illinoian-aged varves from several sites in the West Branch Susquehanna valley and clay drapes from the Eastern Middle Anthracite field at Jeansville have a strong reversed polarity magnetism. The reversed polarity indicates an older than 788 Ka age (Figure 16) for the maximal advance of the Laurentide glacier (Figure 17). The pre-Illinoian-G event at about 850 Ka (Figure 15) is the only early Pleistocene-late Pliocene cold event to exceed the late Wisconsinan amplitude (Braun, 1989) so it is the most reasonable choice for the age of the glacial limit.

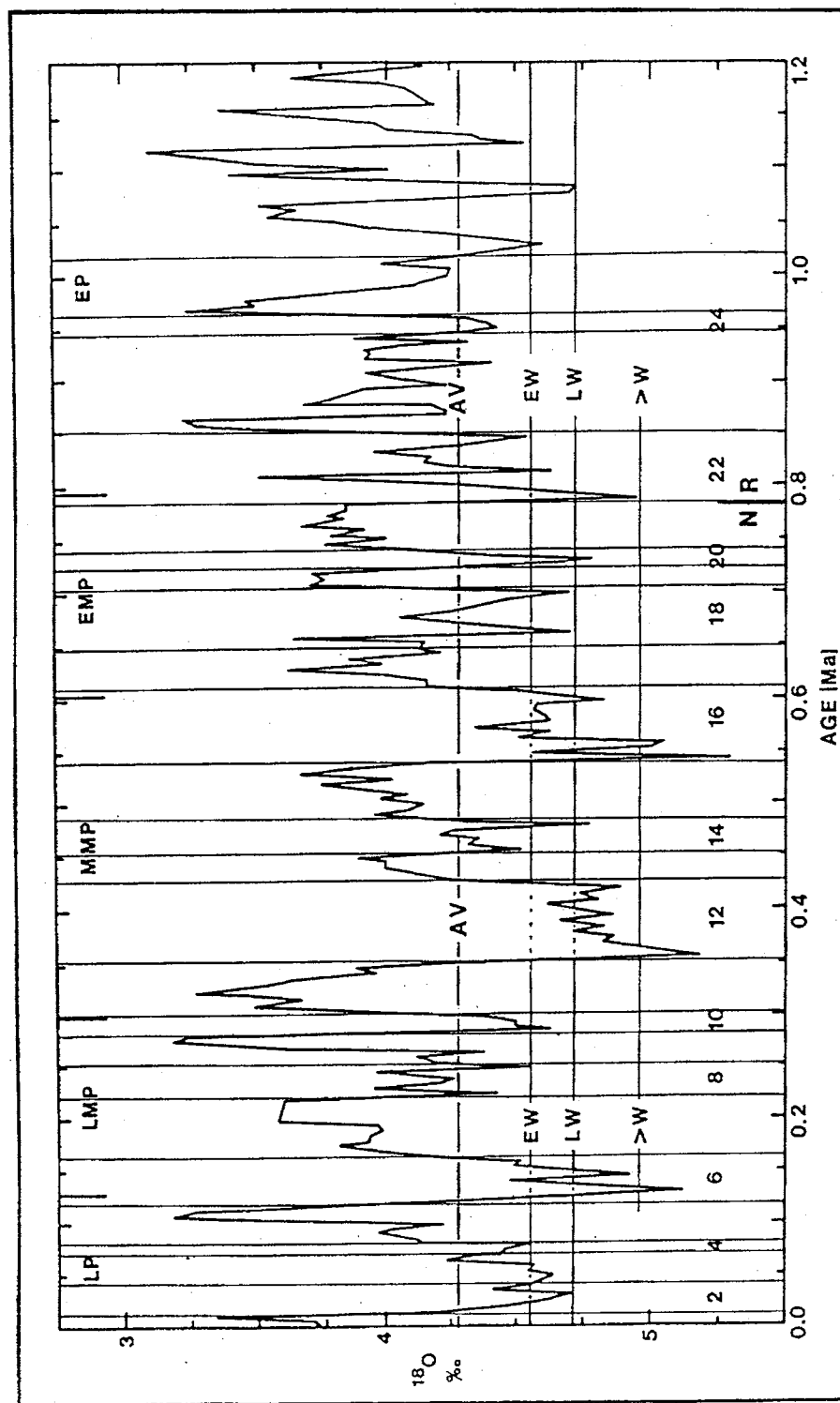
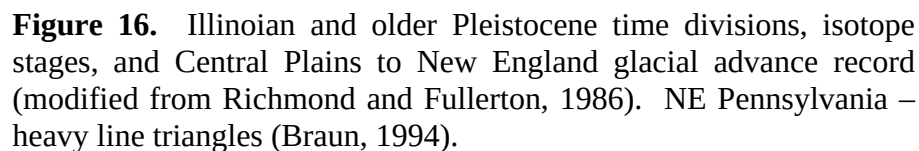


Figure 15. Oxygen isotope record showing the number and amplitude of glacial events during the Pleistocene (Braun, 1989, Figure 2A). Ten or more events have an amplitude similar to that of the late Wisconsinan (LW) and should have brought ice near or into eastern Pennsylvania. Four events have a markedly greater amplitude (>W), sufficient that ice should have advanced beyond the late Wisconsinan limit. Periglacial conditions should have reached eastern Pennsylvania under early Wisconsinan (EW) or even average conditions (AV) (Porter, 1989). LP – late Pleistocene; LMP – late middle Pleistocene; MMP – middle middle Pleistocene; EMP – early middle Pleistocene; EP – Normal-Reversed magnetic polarity boundary.



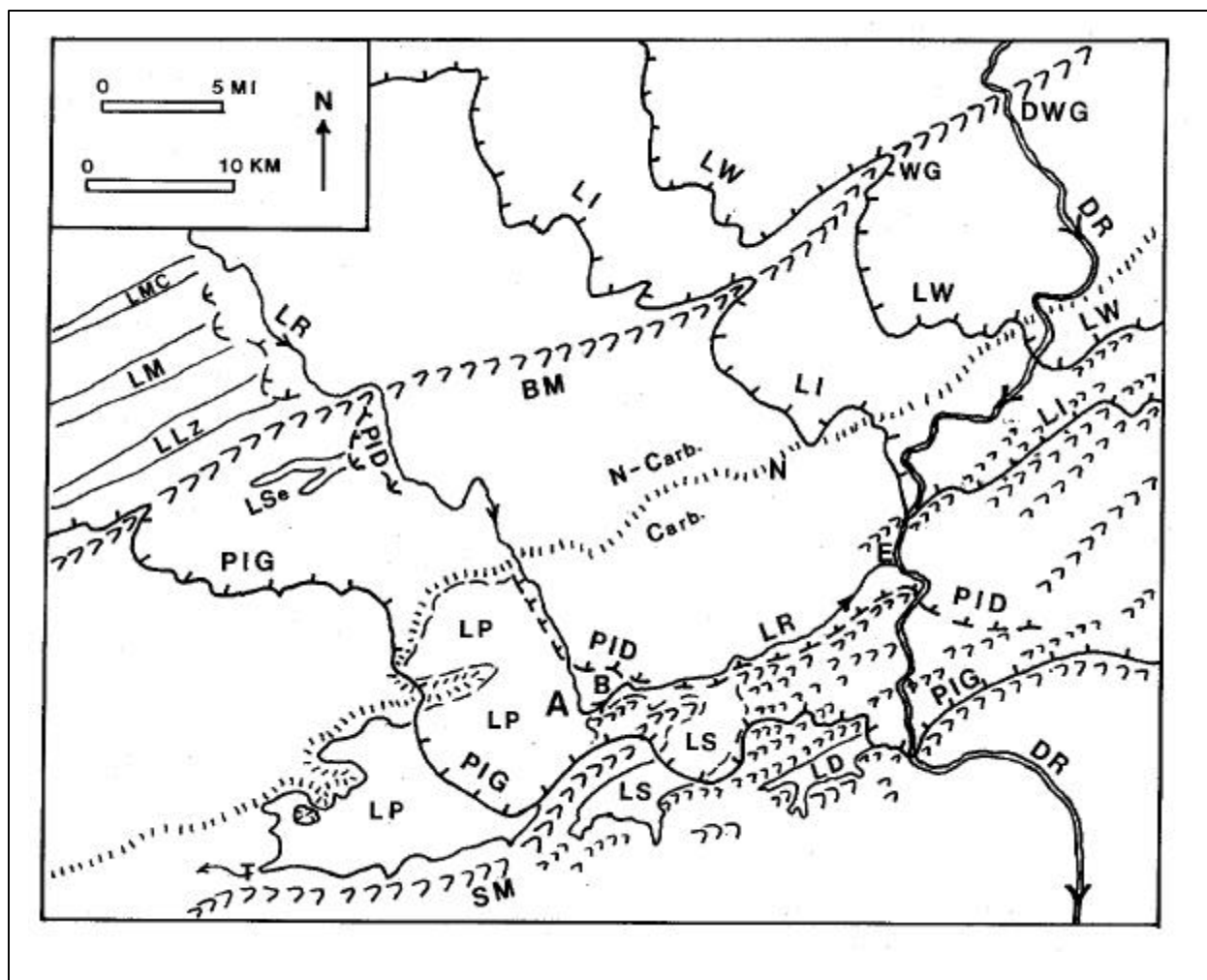


Figure 17. Map showing the regional pattern of glacial limits in the glaciated area of south-eastern Pennsylvania.

- | | |
|--|---------------------------------|
| LW -- Late Wisconsinan Limit | LD -- Glacial Lake Durham |
| LI -- Late Illinoian or Pre-Illinoian-B Limit | LLz -- Glacial Lake Lizard |
| PID -- Pre-Illinoian-D Limit or
Pre-Illinoian-G Recessional | LM -- Glacial Lake Mahoning |
| PIG -- Pre-Illinoian-G Limit | LMC -- Glacial Lake Mauch Chunk |
| Lse -- Glacial Lake Slatedale | LP -- Glacial Lake Packer |
| DR -- Delaware River | LS -- Glacial Lake Saucon |
| A -- Allentown | N -- Nazareth |
| B -- Bethlehem | LR -- Lehigh River |
| T -- Tipton | WG -- Wind Gap |
| E -- Easton | |

Material with a strong normal polarity magnetism is located 1.5 miles (2.5 km) east of a reversed polarity site in the Eastern Middle Anthracite field near Beaver Meadows. The Beaver Meadows site records an advance younger than 788 Ka, probably either a pre-Illinoian B or D advance (Figure 16).

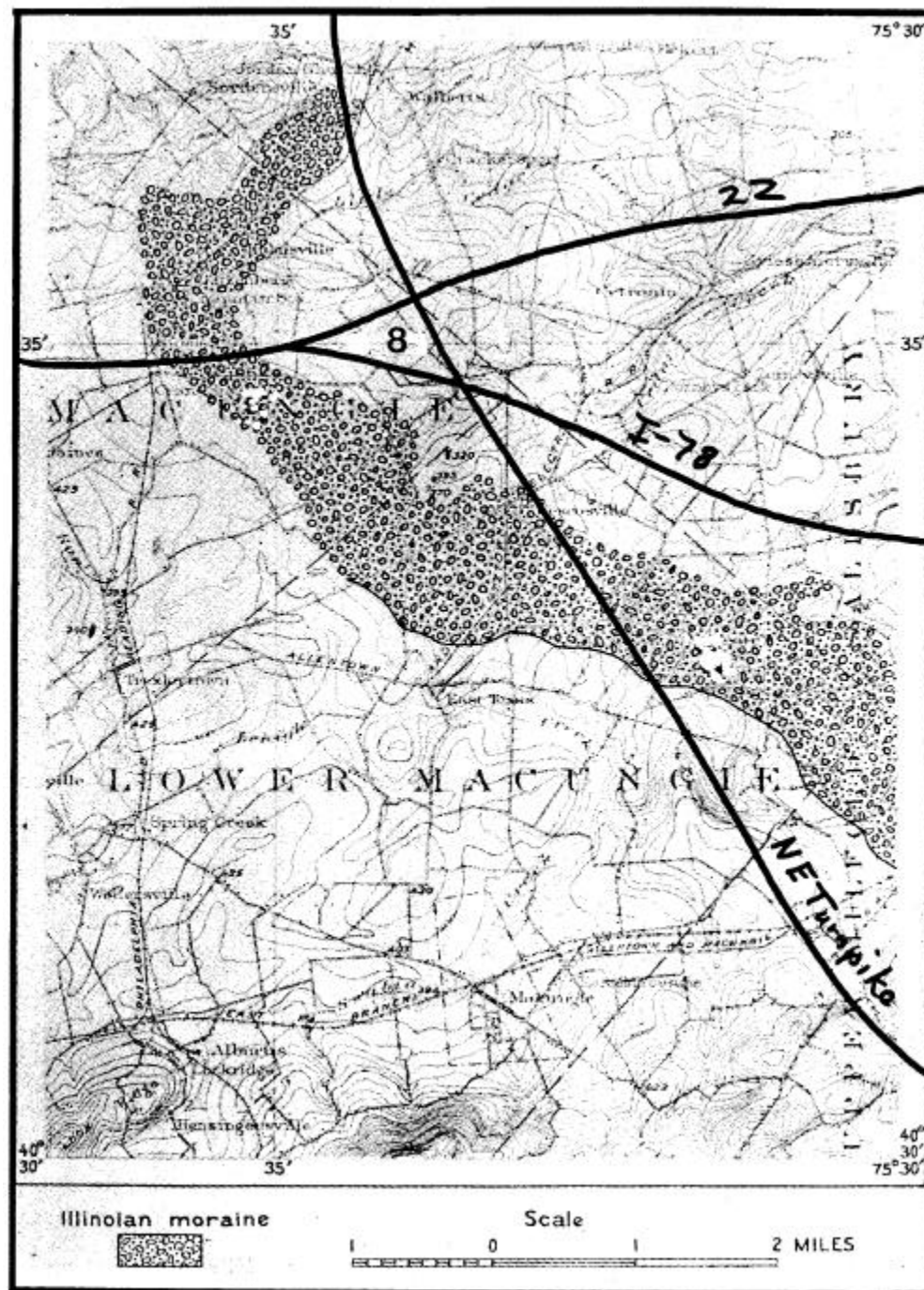


Figure 18. Leverett's (1934, Figure 31) Illinoian moraine across the Great Valley in the Allentown West 7.5-minute quadrangle. Major highways and field trip stop number added.

PSEUDO-MORaine WEST OF ALLENTOWN

More than sixty years ago Frank Leverett (1934) mapped a moraine trending northwest across the Great Valley carbonate belt just west of Allentown, PA (Figure 18). The moraine was about one mile wide, showed subdued swell and sag (knob and kettle) topography (to be viewed at STOP 8), and was thought to date from the Illinoian glacial stage. Since that time it has been generally assumed that the sags were genuine glacial kettles.

Recently completed mapping of the surficial geology of the Allentown area (Braun, 1996a), done in the context of overall Pleistocene history discussed above, indicates that the "moraine" (pseudo-moraine) has a polygenetic origin initially related to glaciation (Braun, 1996b). The pseudo-moraine does mark the southernmost glacial limit in eastern Pennsylvania and there are subtle differences in the landscape to either side of that limit.

The glacial deposits under the pseudo-moraine have been undergoing weathering and erosion for at least 850,000 years (pre-Illinoian-G age). The degree of erosion of the deposits is most clearly seen in the slate and shale belt north of Allentown where only the broadest hilltops retain any glacial materials. On a few hilltops where glacial till (diamict) thicker than 6 ft (2 m) remains, numerous depressions form a "patterned" ground effect that suggests a periglacial origin for the depressions (Braun, 1994, 1996b). Where only a few feet (<1 m) of glacial deposits remain overlying the slate or shale bedrock, weathering has penetrated and rubefied (reddened from oxidation of iron) the bedrock several feet (1-2 m) below the glacial material (Braun, 1996b). In most of the slate and shale belt the glacial materials have been eroded completely from the hills and redeposited as colluvium in the valleys (Figure 19). Any original constructional knob and kettle topography has long since been removed from the landscape.

In the carbonate belt around Allentown glacial diamict remnants are more extensive, having been "trapped" by 800,000 years of solutional lowering of the landscape (Figure 20).

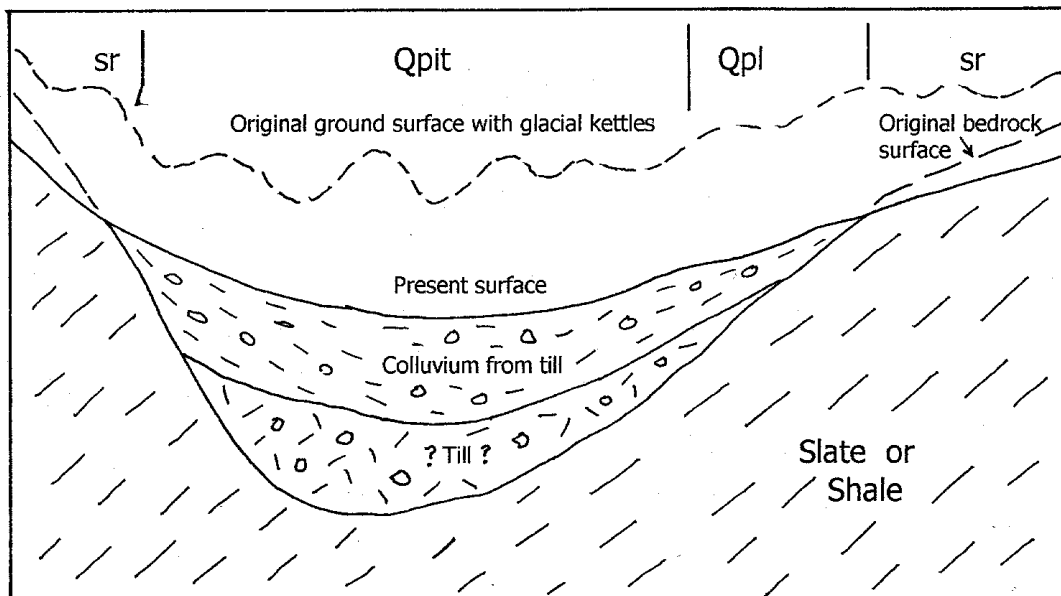


Figure 19. Schematic cross-section across a typical slate or shale valley showing the probable position of the original ground surface and the surficial geology map units. Qpit = > 2m of "till"; Qpl = < 2m of "till", often just sandstone erratics in shaly colluvium; sr = shaly residuum and colluvium

Reviews of studies of carbonate denudation rates in Pennsylvania indicate that deposits this old should have been lowered on the order of 100 ft (30 m) or more (Sevon, 1989; Ciolkosz & others, 1995). There should be at least 3 to 10 ft (a meter to several meters) of residuum from the dissolution of the carbonates under the "let down" old glacial material (Sevon, 1989; Ciolkosz & others, 1995) and this is what is observed under the pseudo-moraine (Braun, 1996b). Also there is a subtle but distinct pattern of thinner diamict remnants on the hilltops and thicker remnants in the valleys and especially in solutional depressions (seen in both outcrop and borehole observations) indicating erosional redistribution of the original glacial deposits (Figure 21). The pseudo-moraine does have a relatively thicker and more continuous glacial mantle than elsewhere and probably once had a genuine morainic topography about 100 ft above the present landscape (Figure 20). Now though the deeply eroded and "let down" colluvium (collapse-uvium??) derived from glacial material is draped over underlying bedrock features (Figure 21). In places on the present hilltops, colluvium derived from carbonate residuum overlies the colluvium derived from the glacial diamict (Braun, 1996b). This suggests repeated episodes of topographic reversal as the lowering of the landscape has proceeded.

The present swell and sag topography is composed of smaller scale periglacial depressions that developed in the reworked glacial material and that are superimposed on larger scale bedrock solution features (STOP 8). For more discussion of periglacial activity in this region see several review papers in Braun, 1994 and the entire guidebook of Marsh, 1999. The numerous smaller scale depressions commonly contain wetlands and perennial ponds (STOP 8) that make the pseudo-moraine landscape distinctly different from the surrounding more "karstic" landscape. Thick sand and gravel deposits in ice marginal kame deposits at the base of South Mountain that are partly buried by extensive periglacially derived boulder colluvium (STOP 11), further attest to the reshaping of the landscape by periglacial activity.

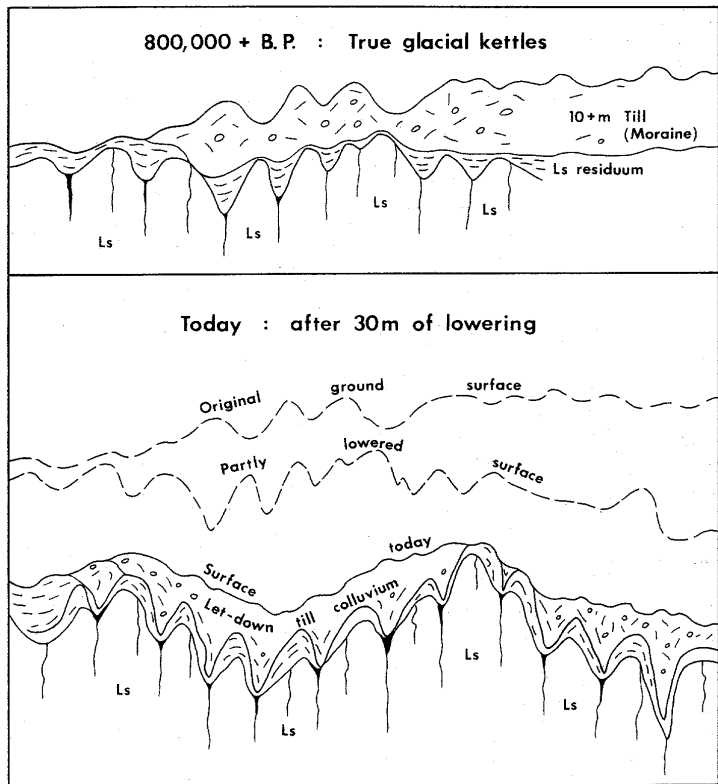


Figure 20. Schematic cross-sections showing the development of the "pseudo-moraine." The upper cross-section shows the 850,000-year-old moraine with genuine glacial kettles. The limestone pinnacles were in direct contact with the till while limestone residuum remained in the weathered fractures. The lower cross-section shows the original ground surface as dashed lines, the present "pseudo-moraine" surface, the layers of remnant let-down till, a continuous layer of residuum under the "till," and the fractured limestone.

PSEUDO-MORAINE DEPRESSIONS PARTLY OBSCURE TRUE SINKHOLES

From an environmental or applied geology perspective, the discussion above clearly indicates that the pseudo-moraine is a karst landscape with a let-down “frosting” of material that started out as glacial till on a land surface significantly above that of the present (Figure 20). Detailed borehole records (Figure 21) show true sinkholes are often 100’s of feet across and are often completely filled by clayey colluvium derived from the blanket of “colluviated till”. The smaller scale periglacial depressions, typically tens of feet across their shorter dimension, are draped over and partly to completely obscure the larger infilled sinkhole features. These depressions then are neither moraine kettles or sinkholes. Areas of pseudo-moraine should be tested in more detail by borehole and shallow geophysics to identify sinkhole hazards than in adjacent areas without such camouflage.

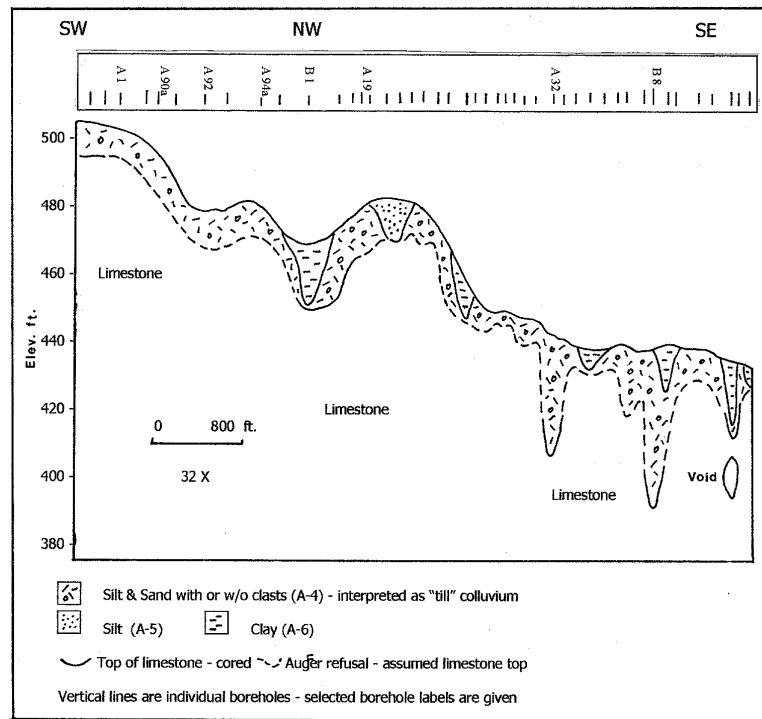


Figure 21. Cross section of unconsolidated materials and the bedrock surface constructed from borehole logs for Interstate 78 where it diverges from US Route 22 (section line shown on Figure 8). This is within an area of abundant shallow depressions of the "pseudo-moraine". Note how the overall ground surface follows the bedrock surface except in genuine sinkholes. The more prominent sinkholes are several hundred feet across, much larger than the depressions at the surface (from Senior Research Project by Aaron Wright).

GLACIAL LAKE PACKER AND THE ICE MARGINAL KAMES

In the Great Valley carbonate lowland to the west of Allentown, the drainage is to the east, towards the former glacier. A proglacial lake should have been impounded there. In that area Williams (1893,1917) described outcrops of clay-rich material (Packer Clay) that he thought represented the deposits of a lake he named Glacial Lake Packer. Similar deposits were observed during the recently completed mapping (Braun, 1996a). Large kame deltas would be expected to form at the edge of the glacier. Remnants of such sand and gravel deposits are present on both the north and south edges of the pseudo-moraine belt across the Great Valley (Braun, 1996b). On the north side, intensely weathered gravels cap the shale hills where Jordan Creek (also impounded by ice blockage) enters the Great Valley. On the south side of the Great Valley, a deeply weathered mass of sand and gravel extends from the base of South Mountain (STOP 11) to the north side of the town of Emmaus. The presence of the kames indicates considerable

meltwater discharge issuing from the ice, certainly sufficient to maintain a shallow (100 ft or so) lake that discharged westward to the Schuylkill River. This same glacial limit is marked by a pseudo-moraine in the Saucon Valley and probably also impounded proglacial lakes in the Saucon and Durham valleys (Figure 17).

OTHER GLACIAL MARGINS CROSSING THE CARBONATE BELT

As discussed above, the pseudo-moraine west of Allentown marks the oldest and farthest southeast advance of Laurentide ice sheets. The pseudo-moraine marks a continuous belt of thicker glacial drift that was originally deposited during a significant still stand or equilibrium of the edge of the continental ice sheet. To the east of the pseudo-moraine, the colluvium derived from glacial deposits is considerably thinner and less continuous in its areal extent. This thinner, discontinuous pattern of remnants indicates where the edge of the glacier was retreating rather than standing still. So, very simply, other ice margin positions representing a significant still stand of ice in the Great Valley should also be marked by a relatively thick and continuous belt of reworked glacially derived materials.

Two such belts of thicker glacial “drift” have been observed crossing the Great Valley carbonate lowland. The easternmost belt crosses the Great Valley just north of Easton and west of the Delaware River (Figure 17). This ice margin position lines up with the late-Illinoian or Pre-Illinoian-B glacial limit that has been traced across eastern Pennsylvania (Braun, 1985, 1988; 1994). The other belt of “drift” crosses the Great Valley starting in a southerly direction just west of the Lehigh River, turns in a southeasterly direction under the city of Bethlehem, and then turns easterly to follow the base of South Mountain and the other ridges of the Reading Prong (Figure 17). For much of its length this belt coincides with the course of the Lehigh River and a considerable amount of material has been removed by the Lehigh River in post glacial times.

Borehole and excavation exposures (Williams, 1893) indicate that 100 ft or more of sand and gravel with some till underlies Bethlehem. Isolated outcrops of similar thickness of material were observed at several sites both northwest and east of Bethlehem during the recently completed surficial deposit mapping (Braun, 1996a). This ice position is probably the northeasternmost one that could have held in a glacial Lake Packer. Any ice margin farther to the northeast would have permitted meltwater to freely escape down the Lehigh Valley to the Delaware Valley. A reasonable age for the Bethlehem ice margin is the extreme cold oxygen-isotope stage 16 event (Figure 15) (Pre-Illinoian-D) at about 650 Ka (Figure 16). However, without any way to date the materials, the deposits could represent a pre-Illinoian-G recessional position or yet another of the Pre-Illinoian E to A glaciations (Figure 16).

USE OF LIMESTONE RESIDUUM THICKNESS TO ESTIMATE THE AGE OF GLACIATIONS

The Great Valley limestone lowland may be the one place in Pennsylvania that the number and approximate age of pre-Wisconsinan glaciations can be determined. The key is the thickness of residuum under the “colluviated till”. There should be an increasing thickness of the residuum under the glacial material of successively older glaciations. Since the glaciations are discrete events separated by 100 Ka or more, one may be able to find distinctly different thicknesses under the different-aged glacial materials. This would require a lot of detailed work at a number of sites on limestones of equal insoluble residue. This also assumes that production of

residuum has been about the same during the climate oscillations of the last million years. Still, the limestone residuum thickness is the best potential relative age or even quasi-absolute dating technique that could work for the entire Pleistocene epoch in eastern Pennsylvania.

SUMMARY

About 10 glacial-interglacial alternations have affected eastern Pennsylvania over the last one million years. All 10 cold events should have caused periglacial activity to Pennsylvania. Three to six of the coldest glacial events brought glaciers near to and even over the Allentown area. The ice advance that covered Allentown is very old, probably the pre-Illinoian-G event at 850 Ka. In the carbonate lowland around Allentown such a length of time of dissolution should result in 100 ft of land surface lowering. This means that the sag and swell topography west of Allentown is a pseudo-moraine formed by repeated land surface collapse and periglacial activity. The pseudo-moraine actually makes it more difficult to identify sinkholes than in adjacent areas. Thick kame deposits along the north and south margins of the main carbonate lowland support the concept that proglacial lakes were impounded in the main carbonate lowland and smaller carbonate lowlands within the Reading Prong. At least three ice margins of different ages are present in the carbonate lowland between Allentown and Easton. Detailed work mapping out differences in limestone residuum thickness under the glacially derived materials may permit a reasonable age designation for those three and possibly other ice margins on the carbonate belt.

HELEVA LANDFILL SUPERFUND SITE, COPLAY, PA

by
Dagmar Llewellyn, Senior Project Scientist
S. S. Papadopoulos & Associates
7944 Wisconsin Avenue
Bethesda, MD 20814-3620

INTRODUCTION

The Heleva Landfill Superfund Site is located between the villages of Ormrod and Iron-ton in Lehigh County, Pennsylvania (Figure 22). Allentown is about 5 miles south of the site, and somewhat lower in elevation.

The Heleva Landfill began operations as a sanitary landfill in 1967. Waste was disposed in unlined pits that remained after iron ore (limonite) was mined from iron-rich overburden deposits in the 1800's and early 1900's. The sanitary landfill accepted between 250 and 350 tons per day of general refuse, paper, wood and orchard wastes from the Allentown area. In addition, liquid industrial wastes, including trichloroethene (TCE) and acetone, were reportedly released into shallow trenches or basins adjacent to the landfill pit between 1967 and 1970. The landfill was closed by the Pennsylvania Department of Environmental Resources in May, 1981 because of operating deficiencies. Subsequent evaluations of soil and groundwater data from the site indicated the likely presence of dense, non-aqueous-phase liquids (DNAPLs) in soils and groundwater underlying portions of the Landfill and adjacent areas.

The potential presence of TCE in groundwater at the Ormrod community well was first reported to the Pennsylvania Department of Health in 1970. A series of investigations to characterize the nature and distribution of contaminants emanating from the Heleva Landfill were conducted in the ensuing years. The plume, during the 1970s, extended from the landfill southward to a limestone quarry that was then being operated by the LaFarge Corporation. Dewatering at that quarry induced flow of groundwater from the landfill toward the quarry. In 1982, quarrying operations at the LaFarge quarry intercepted a karst feature, which led to flooding and closure of the quarry. Since that time, the groundwater contamination associated with the landfill has migrated toward the southeast to local discharge areas, including Coplay Creek and Ranger Lake.

Today, the Heleva Landfill Project Area, extending from the Heleva Landfill to down-gradient surface-water bodies, contains a long, relatively narrow plume of groundwater (Figure 23) in bedrock impacted by volatile organic compounds, including TCE and its degradation products dichloroethene (DCE) and vinyl chloride (VC), as well as acetone. The TCE plume originates in an area on the southeast edge of the Landfill and extends to downgradient surface-water bodies; the acetone plume is restricted to the immediate vicinity of the Landfill due to biodegradation. The plume is oriented in a northwest-southeast direction, aligned with the direction of groundwater flow and also with observed zones of high transmissivity, which extend down to a depth of approximately 250 feet. Contaminant concentrations down gradient of the landfill are significantly lower, in some places by orders of magnitude, than they were in the 1970's when contamination was first detected.

Impacted groundwater discharges to abandoned, water-filled quarries, including Ranger Lake, the former Lafarge quarry, another former quarry, and also possibly to Coplay Creek.

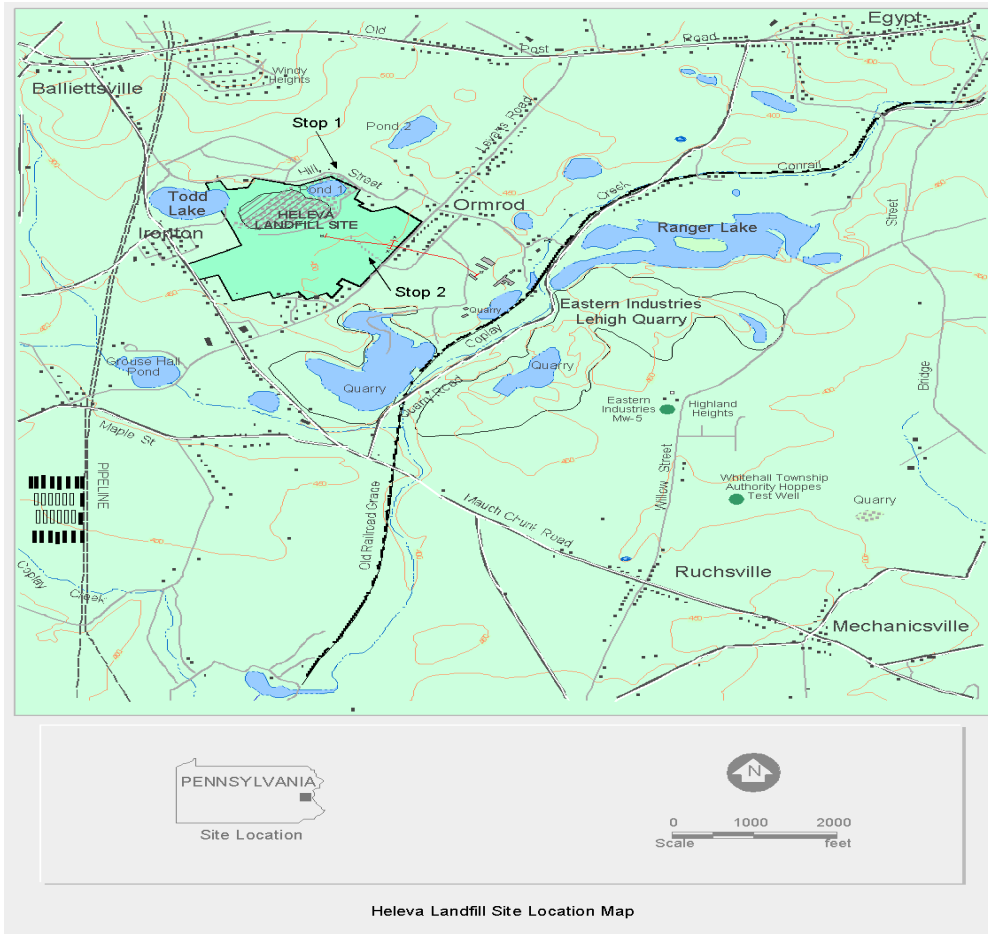


Figure 22. Location map for the Heleva Landfill Superfund Site. Note the position of Ranger Lake and Eastern Industries Lehigh quarry. The red line corresponds to the approximate center of the contaminant plume.

VOC concentrations are significantly decreased upon reaching the discharge areas as a result of dilution and volatilization. VOC concentrations have been detected in some surface-water monitoring events, but generally are below maximum contaminant levels (MCL's) established for drinking water and discharge levels established for Coplay Creek.

Although the main axis of the plume does not flow in the direction of the Eastern Industries Lehigh Quarry, the U.S. Environmental Protection Agency installed well pairs, including shallow and deep well pairs, on the northwest and southeast sides of the deepest part of this quarry. Chemical analyses performed on water samples from these wells demonstrated that contamination is not flowing beneath this quarry to affect domestic wells in the nearby village of Ruchsville.

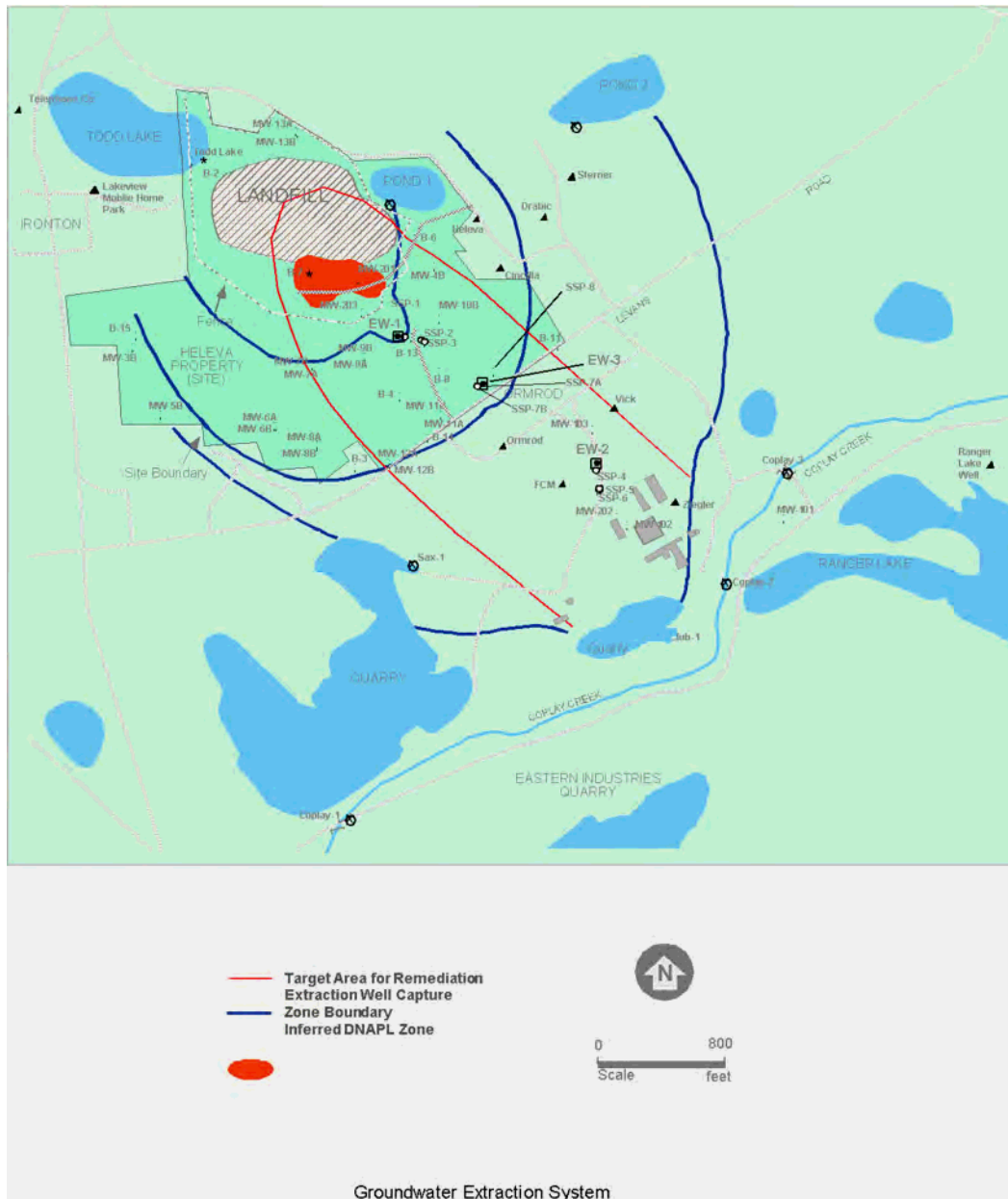


Figure 23. Groundwater extraction system for the Heleva Landfill Superfund Site.

GROUNDWATER REMEDIATION SYSTEM

A pump-and-treat groundwater remediation system began operating at this site this year. A treatment plant has been constructed to remove volatile organic compounds from 450 to 650 gallons per minute of groundwater pumped from extraction wells located along the contaminant plume emanating from the Heleva Landfill. The treatment system will also remove from the water the high iron concentrations that result from the high iron content of the overburden materials. This volume of water is being pumped from only three extraction wells, due to the high production capacity of the karst carbonates underlying this site. Water from the treatment plant is discharged to Coplay Creek.

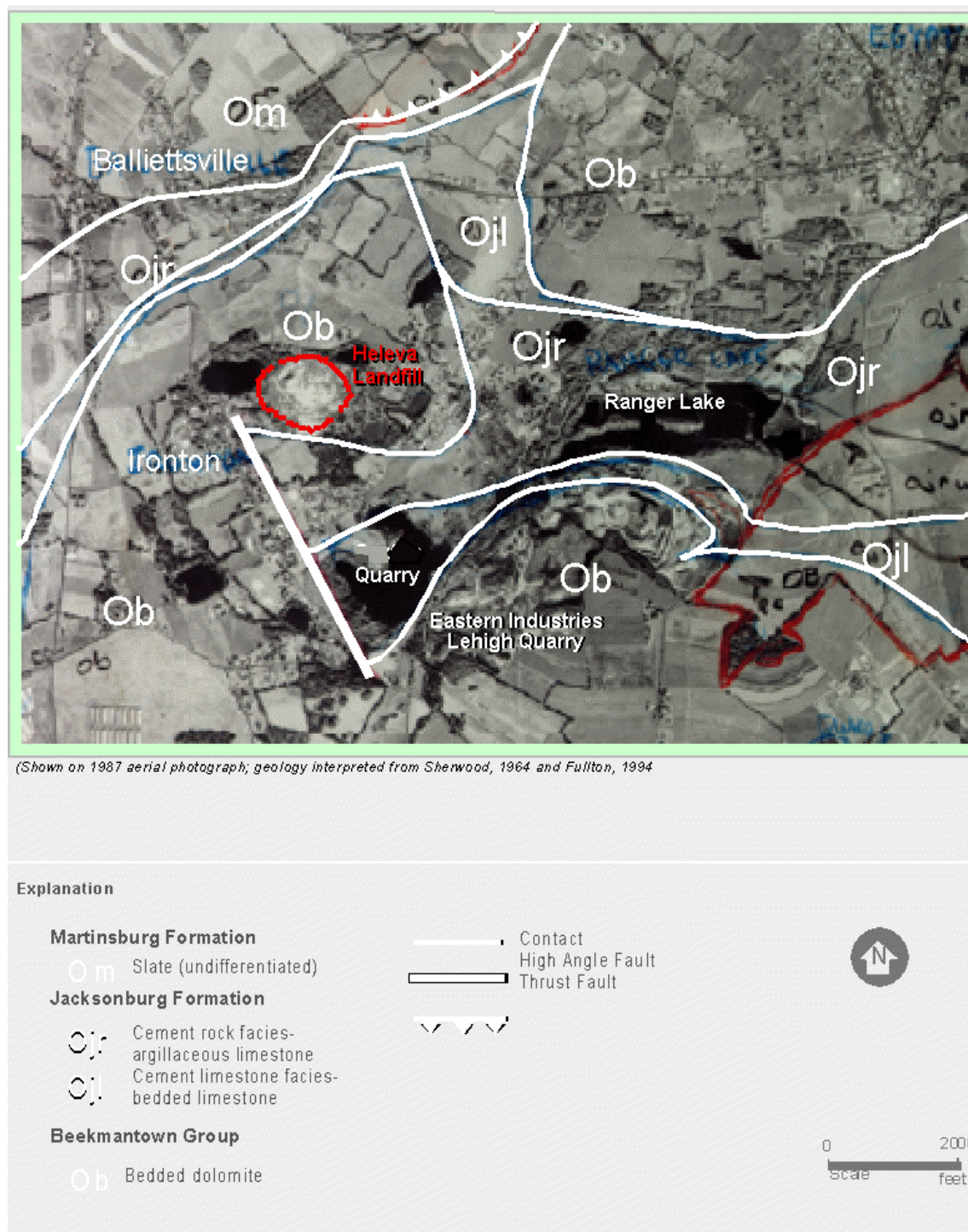


Figure 24. Geologic map of the Heleva Landfill Superfund Site area.

The groundwater extraction system includes three extraction wells oriented in a line along the axis of the zone of impacted groundwater. The well furthest upgradient (closest to the source area), EW-1, is being pumped to contain the dissolved plume associated with DNAPLs in the source area. Analysis has shown that pumping of this well at an average flow rate of 150

gallons per minute (gpm) is sufficient to capture groundwater from the entire area believed to be affected by DNAPL, without remobilizing the DNAPL source. EW-1 is ideally situated in an area of very high transmissivity, which extends to and includes much of the inferred DNAPL zone. The zone of high transmissivity acts as a drain and conduit for the aquifer system, collecting water from throughout the upgradient area. Two additional wells located further downgradient in the Non-DNAPL Area, EW-2 and EW-3, are being pumped at average flow rates of 200 and 100 gpm, respectively, to contain and restore the impacted groundwater between the DNAPL area and local discharge areas.

LOCAL GEOLOGY

The area to the north and northwest of the Landfill is underlain by the Ordovician Martinsburg Formation, which consists mainly of slate with some sandstone and siltstone (Figure 24). The remainder of the regional area is underlain by carbonate rocks (limestones and dolomites) of the Ordovician Jacksonburg Formation, the Ordovician Beekmantown Group, and the Cambrian Allentown Formation. The bedrock aquifer in the Project Area consists primarily of carbonate rocks of the Beekmantown Group and Jacksonburg Formation, and contains abundant secondary permeability features, including fractures and solution cavities. The presence of secondary permeability features is the dominant factor determining the aquifer transmissivity and contaminant migration pathways. Highly altered zones are characterized by transmissivities which may be as high as 50,000 ft²/day, while nearby, more-competent rock of the same formation can have a transmissivity 100 times lower.

The groundwater contamination plume that extends southeast from the landfill has been found to generally follow a northwest-southeast trending zone of high transmissivity characterized by karst features. These karst features have been interpreted to be aligned along the contact between the Beekmantown and Jacksonburg Formations, and extend to a depth of about 250 ft. Contamination by volatile organic compounds has only been confirmed within the permeable materials 250 ft deep or shallower. Beneath about 250 ft deep, the rock has been found to be quite tight, with minimal secondary permeability features.

There are two models for the geologic structure beneath and in the immediate vicinity of the Heleva Landfill that have been presented in the literature. Both models explain the presence of rocks of the older Beekmantown Group overlying rocks of the younger Jacksonburg Formation at this location. In the first of these, the nappe model, a faulted, overturned fold (a nappe) places the Jacksonburg Formation at a depth of 150 to 200 ft below the land surface, and maintains the contact relations between the two geologic units. In the second model, the thrusting model, the Jacksonburg is at greater depth, and there is a thrust-fault contact between the geologic units.

During drilling of extraction well EW-1 and the associated observation wells in the DNAPL Containment Area, a significant number of voids within the limestone were encountered, mainly at depths ranging from 165 to 260 ft. These voids resulted in borehole instability as well as excessive water production. Ejection of water and cuttings from boreholes adjacent to and in some cases significantly shallower than the hole being drilled indicates a lateral interconnection between these voids, as well as significant vertical hydraulic connection. Also, vibration and compressed air injection during drilling of EW-1 resulted in settling of unstable overburden materials into the vertical fractures within the bedrock. From there it is believed that the overburden materials moved along the vertical fractures into voids, and through the voids into the

borehole, from which they were pumped out along with cuttings. This occurrence also indicates a high level of vertical interconnection of fairly large fractures in this area, extending from the top of bedrock to the void zone. Drilling at SSP-8, an observation well associated with test extraction well EW-3 and located some 700 ft from EW-1, revealed a similar concentration of voids at depths from about 140 to 170 ft below ground surface. Problems of ground instability were not encountered at this site, and the main concentration of voids, between 138 and 146 ft deep, is probably clay filled.

The data obtained during the drilling of EW-1 and the observation wells in its vicinity indicate a dolomitic rock underlain by limestone. Voids appear to be most abundant in the region at and just below this contact, which has been interpreted to represent the contact between the Beekmantown rocks above and the Jacksonburg rocks below. This contact may be either a fault contact, or the natural, unconformable contact encountered in the cement quarries. The depths at which it was encountered suggest that it is likely to be the unconformable contact.

Geologic samples collected from borings drilled for EW-2 and its associated observation wells matched the descriptions of the Cement-Rock Facies of the upper Jacksonburg Formation - argillaceous limestone containing graphite. Large voids were not encountered during the drilling of these wells, but the rocks were fractured and highly unstable. In contrast, the boring log for a monitoring well located approximately 200 ft north of EW-2, indicates that the well was drilled through chert breccia. This suggests that the well was drilled on the other side of the contact, since the Beekmantown Group is known to contain chert layers, and that there may be a fault contact between these units at this location. The boring logs for monitoring wells south of EW-2 indicate that they were drilled in the Cement-Rock Facies of the upper Jacksonburg Formation, as were EW-2 and its associated observation wells.

Information obtained during drilling of EW-3 and its associated observation wells was generally consistent with that from the other sites. The competent, argillaceous, Cement Rock Facies of the Jacksonburg Formation is overlain by a heavily fractured sequence of Beekmantown Group mixed carbonates. Extensive voids identified during drilling of a monitoring well at this location appear to correlate strongly with voids identified at EW-1, consistently occurring within the Beekmantown Group close to the Jacksonburg Formation contact. The depth at which the contact between the Beekmantown Group and Jacksonburg Formation was encountered, averaging 150 to 190 ft, supports the nappe model hypothesis for describing the occurrence and distribution of the geologic units in the local area. However, the absence of any positively identified Cement Limestone Facies of the Jacksonburg Formation from the sequence implies a locally faulted relationship. The presence of faulting may also be supported by the concentration of voids and fractures at or near the base of the Beekmantown Group. A geologic cross section oriented along the axis of the contaminated plume shows how thinning of the Beekmantown Group from northwest to southeast, proposed by both Sherwood (1964) and Fullton (1994), is supported by the findings of this drilling program.

As indicated in Figure 25, unstable overburden materials at EW-1 subsided during drilling, causing a sinkhole to form around the well. The subsidence is attributed to the unstable overburden because the 18-inch-diameter well casing, extending from the land surface to the bedrock, was not affected by the subsidence, and because such a large volume of brown clay (matching overburden materials) washed out from the borehole during drilling of the bedrock at depths below 170 ft. Drilling at EW-3 and nearby monitoring wells supports this interpretation of overburden instability. At these locations, significant voids were found within the overburden. It is probable that a significant proportion of the overburden materials within the Project

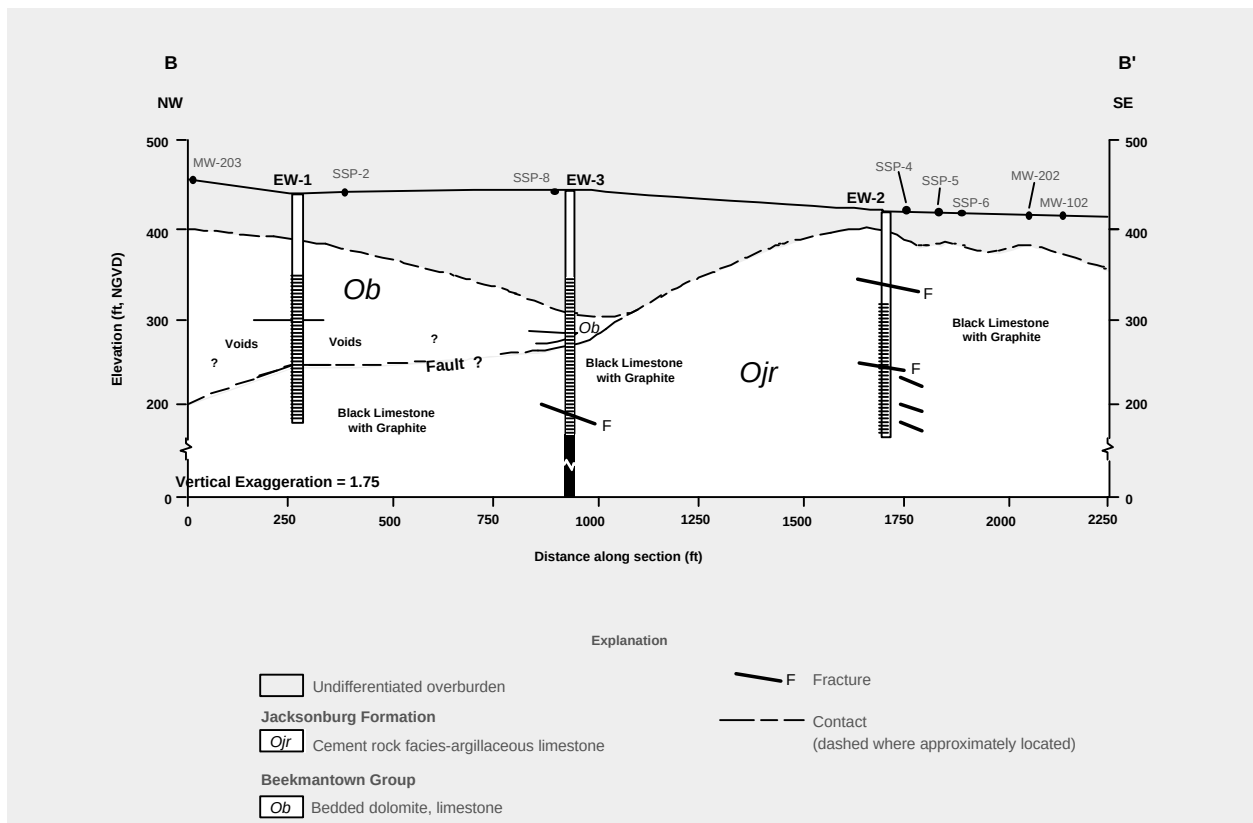


Figure 25. Geologic cross section along the axis of the plume originating at the Heleva Land-fill Superfund Site.

Area consists of mine spoils from previous limonite mining or uncompacted fill, rather than native soils, explaining the unstable conditions encountered. In the vicinity of EW-3, sandy/gravelly deposits, possibly of alluvial origin, exist beneath these unstable, clay-rich overburden materials.

HYDRAULIC HEAD DISTRIBUTION AND GROUNDWATER FLOW PATTERNS

Groundwater levels in the Project Area are impacted by both regional and local control features. On a regional scale in this area, groundwater gradients are generally oriented from the northwest toward the southeast. Groundwater flows along these gradients, and discharges to Jordan Creek and the Lehigh River, with localized discharge to quarries, lakes, ponds and creeks occurring throughout the region. In some areas, gradients may be oriented towards local discharge features such as ponds and quarries. The areas characterized by flatter gradients coincide with bedrock zones containing solution cavities and fractures of high transmissivity. Steeper hydraulic gradients indicate zones of lower transmissivity.

Well pairs consisting of an upper well completed in overburden and a lower well completed in bedrock generally exhibit downward vertical gradients, indicating that recharge occurs through the overburden to the bedrock across much of the site.

TRANSMISSIVITY DISTRIBUTION

In the region surrounding the Heleva Site, the Martinsburg Formation is characterized by low transmissivity, while the Jacksonburg Formation and the Beekmantown Group have higher transmissivities. The low-transmissivity Martinsburg Formation extends to the northwest from Todd Lake. The Project Area overlies carbonate formations of the Beekmantown Group and Jacksonburg Formation.

The distribution of transmissivity within carbonate formations in the vicinity of the Landfill has been identified from analysis of the hydraulic head distribution and aquifer tests. The distribution is characterized by relatively small, highly transmissive zones separated by zones of lower transmissivity. The distribution reflects the presence of solution cavities, fractures, and possibly faulting in the area downgradient from the landfill.

RECHARGE AND DISCHARGE CONDITIONS

In the immediate vicinity of the Heleva Landfill, a low-permeability clay material exists near the land surface, and perched water has been observed within that material. These conditions indicate that the rate of recharge occurring through soil infiltration is limited. The presence of numerous surface-water bodies indicates that significant recharge directly from these points likely occurs, as they are in contact with deeper and transmissive aquifer formations.

Local surface-water bodies that provide groundwater recharge include ponds, abandoned quarries or streams that have higher water levels than the surrounding groundwater level. In the local area, discharge occurs to streams, ponds, and quarries in which water levels are lower than the surrounding groundwater level. These local surface-water features can exhibit significant control on local groundwater levels. In the vicinity of the Heleva Landfill, Eastern Industries Lehigh Quarry, Ranger Lake, the former LaFarge quarry, another former quarry, and possibly some reaches of Coplay Creek, receive groundwater discharge. Four of these five surface-water features have outlets to the regional surface-water system: Coplay Creek, which is a tributary to the Lehigh River; the Eastern Industries Lehigh Quarry, from which water is pumped to Coplay Creek; and Ranger Lake and the former LaFarge Quarry, which have man-made outlets to Coplay Creek. The Eastern Industries Lehigh Quarry is being actively dewatered at this time, resulting in a significant lowering of groundwater levels near this quarry. This feature creates a strong local drain or intercept for groundwater. The other former quarry does not have a surface-water outlet, but does interact with the local groundwater system. Groundwater flows into it on its upgradient sides, and out of it on its downgradient side. Water is exchanged between the surface-water bodies and the groundwater system as water is added to the surface-water bodies by surface runoff and lost from them through evaporation.

Discharge areas in the vicinity of the Heleva Landfill have changed over the years, as quarries have been dewatered during operation and have filled with water after they were abandoned. Locally, groundwater flow directions may have varied over time, depending on the quarries in operation and the amount of dewatering.

THE 1994 SINKHOLE AT NORTH 7TH STREET, CENTRE CITY, ALLENTOWN, PENNSYLVANIA

Sinkhole Hazards in the Lehigh Valley and the Implications for Land Use and Development Decisions

by
Thomas D. Gillespie, P.G.
Environmental Liability Management
Doylestown, PA 18901

INTRODUCTION

At 12:25 a.m. on February 23, 1994, the Water Authority of the City of Allentown detected a significant leak in its underground water distribution pipe network. Over the course of the ensuing several hours, approximately 11,400,000 litres (38 m³ [38,000 l] per minute) of water was lost from the supply system. The location of the leak was not determined until approximately 3:30 a.m. when the entire paved surface of North 7th Street near Hamilton Circle sagged (Figure 26). The water authority had diverted water from the area and ended the water release by 4:00 a.m., but by 4:30 a.m. both the paved street surface and portions of the newest office building in Centre City Allentown (The Corporate Plaza Building, Figure 27) had collapsed into a large sinkhole that measured approximately 30 by 15 m, and was up to 6 m deep (Figure 28, Figure 29).

Although the 7th Street sinkhole was an exceptionally dramatic example of the phenomenon, sinkholes are common throughout Pennsylvania's Great Valley Section that includes the Lehigh Valley. Although the opening of a sinkhole, including the 1994 collapse at 7th Street, is often attributed to losses of water from municipal supply and drainage structures, in reality sinkholes are the product of underlying geology. In other words, it is not always a case of water leaks causing sinkholes, but of sinkholes causing the high frequency of water leaks, which then exacerbate the magnitude of sinkholes. Data from the 7th Street sinkhole indicate that the principal cause of the 1994 sinkhole was a natural soil sink. The loss of water from the municipal supply system only increased the size of the sinkhole.

The frequent occurrence of sinkholes in areas with carbonate bedrock is a natural consequence of the interaction of water and water-soluble rock and thus are an inherent property or condition of the terrain. Because of the annual loss of property and money resulting from sinkholes and because of the potential hazard to the safety and welfare of citizens of the Commonwealth, land use planning in sinkhole-prone areas such as the Lehigh Valley should involve more than simply the planning and use of *available* space. Land use decisions in such areas should be based on a thorough understanding of geologic/hydrogeologic conditions. Such understanding of the natural geologic conditions can be integrated into evaluations of potential risks and can be used to develop engineering options to mitigate against such risks and losses. Decisions about sinkhole mitigation based on such knowledge and evaluations could have prevented the loss of the Corporate Plaza building during the 1994 sinkhole on North 7th Street, even though the sinkhole would likely have developed regardless of the presence or absence of the office building.



Figure 26. Aerial views of the Corporate Plaza building (arrow) after sinkhole collapse. Hamilton Circle is at the lower right of the photograph.



Figure 27. View of Corporate Plaza building looking south on 7th Street toward Hamilton Circle. Note missing brick support column and sagging facade of building. Also, in upper right, note that the northwest corner of the building has subsided.



Figure 29. Aerial view looking into the 7th Street sinkhole during grouting. The sinkhole extends beyond the NW corner of the building at the far right, and below grade to the left under the two medium-height buildings.

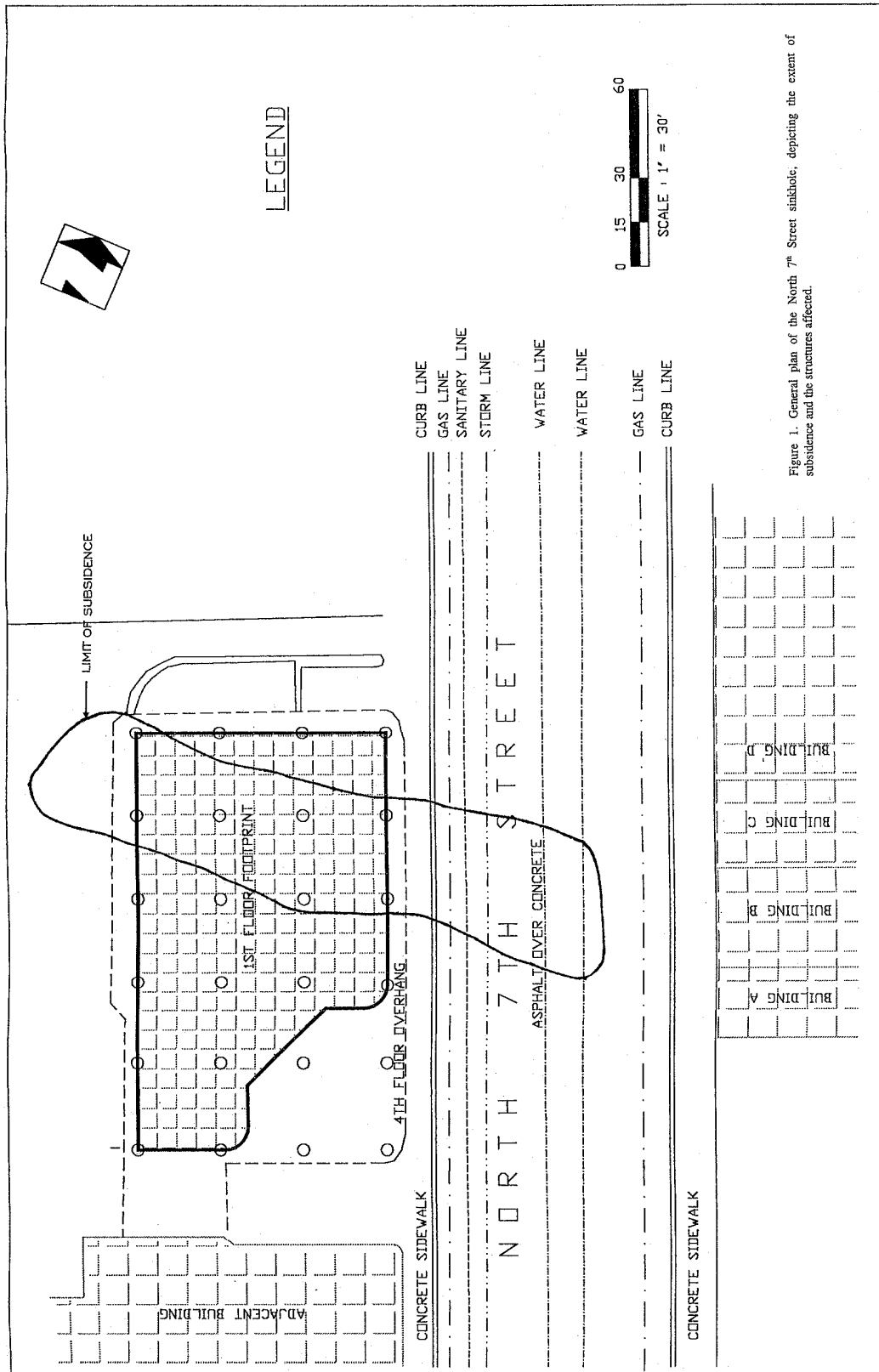


Figure 1. General plan of the North 7th Street sinkhole, depicting the extent of subsidence and the structures affected.

Figure 28- General plan of the North 7th Street sinkhole, depicting the extent of subsidence and the structures affected.

GEOLOGY OF THE REGIONAL KARST TERRAIN

Allentown is in the Great Valley Section of the Ridge and Valley physiographic province, that extends southwest from Easton to Chambersburg in Pennsylvania (Berg and others, 1989) and beyond the state borders into both New Jersey and Maryland. The City of Allentown is underlain predominantly by the Allentown Formation, a Cambrian dolomitic limestone that has been described thoroughly by the Pennsylvania Geologic Survey and others. Rather than discuss the properties of the Allentown Formation, a general discussion of the particular geologic causes of sinkhole development and of the types of sinkholes that generally form in the Lehigh Valley is provided.

Sinkholes are one manifestation of the natural development of karst terrains, that occur in areas where the underlying bedrock (e.g., limestone and dolomite) is composed of minerals that are soluble in mildly acidic vadose and/or groundwater. Sinkholes are a surface phenomena that result from the removal by solution of the carbonate portions of the bedrock. This dissolution is followed by downward movement of unconsolidated soil into the solution openings in the rock. Thus, the cause of sinkholes is related to the movement and action of water in the subsurface, with the highest frequency of sinkhole openings generally occurring in the wettest seasons of the year (Dougherty, 1994). According to the Pennsylvania Geologic Survey, the Allentown Formation is one of the most sinkhole-prone geologic formations in the state (Kochanov, 1994).

The Cambrian Allentown Formation was subject to all Paleozoic phases of Appalachian tectonism and deformation. As a result, the formation has been extensively folded and contains several joint sets and numerous systems of faults. Depending on the particular facies within the formation (i.e., the massive, grey, dolomitic facies, or a grey to brown, thinly bedded limestone facies) the frequency and orientation of bedding planes, joints, and faults varies significantly.

Most of the chemical erosion within a rock mass occurs along and immediately adjacent to the planar discontinuities (e.g., joints and faults) through which most water flows. The brittle deformational structures within a rock mass provide an important control on the frequency, orientation, and regional trends of karst features. In general, **solution channels** form along individual joint and fault planes. Larger **solution cavities** (caverns of varying size) form where conjugate joint sets and/or fault zones provide for large-scale dissolution in three dimensions. **Solution openings** develop *within* the mass of a rock formation. The presence of pervasive planar discontinuities in the rock also causes preferential erosion of the bedrock surface, typically along the traces of the planes, resulting in an irregular bedrock surface. As a result, karst features in the Allentown Formation can occur along regular trends. For example, solution channels that form along major, pervasive joint sets will tend to be sub-parallel to each other, and the resulting bedrock surface will likely consist of:

- A sub-parallel series of troughs in the bedrock surface that occur where the solution along large or open joints has removed significant volumes of the rock.
- A series of ridges that separate the troughs. These ridges consist of relatively erosion-resistant unjointed blocks of rock.
- A number of isolated non-connected pinnacles. This will occur where there is a strong conjugate joint set and troughs develop along both joint trends.

Both types of karst forms occur in the Allentown Formation. At the site of the 7th Street sink-hole, the bedrock surface consists of a series of ridges and troughs.

Typically the bedrock karst features in the Lehigh Valley are covered with a mantle of unconsolidated soil, composed mostly of silty sand and pebbles of glacial origin and residual clay-rich soil that forms as a regolith. The soil is thickest where it forms an infilling in bedrock

troughs and thinnest where it forms a veneer over the ridges. The resulting karst topography consists of a series of rolling hills and valleys (in the case of ridge and trough sequences), or an apparently less regular landscape composed of isolated hills and closed depressions (in the case of pinnaciling).

The most common type of sinkhole in the Allentown Formation occurs when the soil in a bedrock trough moves downward into the solution channel or solution cavity, a process known as **raveling**. When soil raveling into the underlying bedrock, it moves along a preferential path called a **soil pipe**, and enters the underlying rock through a solution opening known as a **throat**. Most raveling occurs during seasons when percolating vadose water is abundant and/or when the groundwater elevation rises into the soil. The loss of soil creates a void space at the base of the soil, i.e., at the soil/bedrock interface. Subsequently, overlying soil moves downward into the void space in the underlying soil. Over time, the void space slowly migrates upward through the soil column to the ground surface as overlying soil continues to move downward into the rising void. When the soil void intersects the ground surface, a sinkhole develops. Depending on the depth of the groundwater below the rock surface and the degree of solution channel connection in the rock, the raveled soil may be transported within the rock, leaving space in the bedrock solution openings for continued raveling of the overlying soil and the continued development of sinkholes. This appears to have been the case at 7th Street. After the Corporate Plaza Building was demolished, there was evidence of previous filling of a sinkhole at almost the same location.

GEOLOGIC CONDITIONS AT THE 7th STREET SINKHOLE SITE

The bedrock surface at the site of the 1994 sinkhole is highly irregular and consists of a series of east-west trending ridges (approximately 1-3 m below grade) separated by deep, soil-filled troughs (6-15 m below grade) (Figure 30). The soil infilling is typically brown, silty sand with some clay that contains occasional angular, gravel or cobble-sized, carbonate clasts.

The Corporate Plaza building was constructed over two ridge and trough sequences. The February 23 sinkhole formed in the southernmost trough. A third, smaller bedrock ridge was present in the center of the trough in which the sinkhole formed (Figure 30). The presence of that smaller ridge, which terminated in the center of 7th Street and did not extend below the Corporate Plaza building, played a critical role in the development and final size of the sinkhole. The east façade of the building was above the deepest part of the trough, which is more than 12 m below grade.

Based on soil and rock boring logs drilled as part of the geotechnical evaluation for construction of the building (F & M Associates, Inc., 1977; 1984), soil raveling was likely occurring prior to the construction of the building (Figure 31). Such loss of soil into underlying solution channels and/or cavities was evident by the decrease in the driller's blow counts in standard soil penetration tests, and as recorded losses of drilling fluid into the soil at discrete depths in the troughs. According to this evidence, soil pipes and/or soil voids had formed or were forming at least 10 years prior to the 1994 event.

In addition, void spaces in the bedrock (solution cavities/channels), that were either open or that contained a clay infilling, were discovered during the pre-construction drilling and coring. These solution openings were noted by either a rapid drop in the drill stem, or by a loss of drilling fluid. Because the rock was cored, it was possible to determine which of the voids contained a soil fill. Although solution openings were discovered in the bedrock, the rock coring strategy focussed on determining the quality of the rock (using standard measurements of core recovery

and Rock Quality Designation) in the bedrock ridges rather than in the adjacent troughs. Typically during the investigations, coring into the bedrock in a ridge extended 3-5 m (10-15 ft) into the rock. In the troughs, however, where there was the greatest potential for sinkhole development, coring only extended 1 m (3 ft) into rock. In other words, the focus of the rock competency evaluation was in the rock that was the most competent rather than in the rock with the greatest probability for karst-related activity and potential problems. Of perhaps greater significance to the fate of the building is the fact that, at the deepest parts of the troughs, where the most erosion has occurred and the potential for loss of soil was the greatest, the depth to bedrock was not even determined.

The 7th Street sinkhole was an elongate depression that formed within the northern of the two troughs below the Corporate Plaza building (Figure 30). The depth of the sinkhole varied along its length, with the maximum subsidence of approximately 5 m below the west sidewalk of 7th Street and immediately below one of the support columns of the former building (Figures 31, 32, and 33). To the west the amount of sinkhole depression decreased steadily until the only evidence was a fresh crack in the concrete floor pavement of the adjoining parking garage. An exception to the low amount of subsidence to the west was at the support column for the north-west corner of the Corporate Plaza building, which subsided 1.7 m (Figures 34 and 35).

To the east, the sinkhole terminated abruptly in a vertical face approximately 3 m from the eastern sidewalk (Figures 28 and 30). Another sinkhole developed to the east within the same soil-filled bedrock trough below two attached buildings on the east side of 7th Street (Figure 36). This second sinkhole, although associated with the main sink, was separated from it by approximately 10-12 m of relatively undisturbed soil. This secondary sinkhole is not considered in the remainder of this discussion.

In the main sinkhole below 7th Street, all loss of soil was downward into bedrock, through a single soil pipe and sinkhole throat, located below the western sidewalk and one of the support columns of the building's eastern façade (Figure 32). There was no eruption of soil or water onto the surface of the ground. The total volume of soil and other material that moved downward into bedrock via the sink was approximately 700-800 m³.

Apart from the soil that was washed into the underlying bedrock, approximately 25 m³ of masonry from the building was lost completely into the sinkhole, including a concrete column footing that measured approximately 10 m³ (3x3x1.5 m) and approximately 10-15 m³ of brick and concrete block. In addition, approximately 25-50 m³ of sidewalk and the stones and brick from several former building foundations that were present below the 7th Street sidewalk, also were lost completely into the sinkhole. None of this material was visible in the bottom of the sinkhole, which was approximately 5 m below grade. Based on the size of the concrete footing which was lost completely into the soil pipe, the diameter of that soil pipe was at least 4.5 m.

Apart from the volume of material lost, approximately 11,400,000 l (3,000,000 gal) of water flowed into the underlying bedrock at a rate of 38,000 l/min (633 l/sec). This is equivalent to 166 gal (22 ft³)/sec. For perspective, the typical summer flow for the Delaware River is approximately 3,000 ft³/sec.

Based on the observations and evidence, the extraordinary magnitude of the 7th Street sinkhole resulted from scouring by high-pressure water from the ruptured water supply pipe. The initial cause of the rupture of the water supply pipe, however, was the development of a natural soil pipe centered at the point where greatest subsidence occurred in the sinkhole.

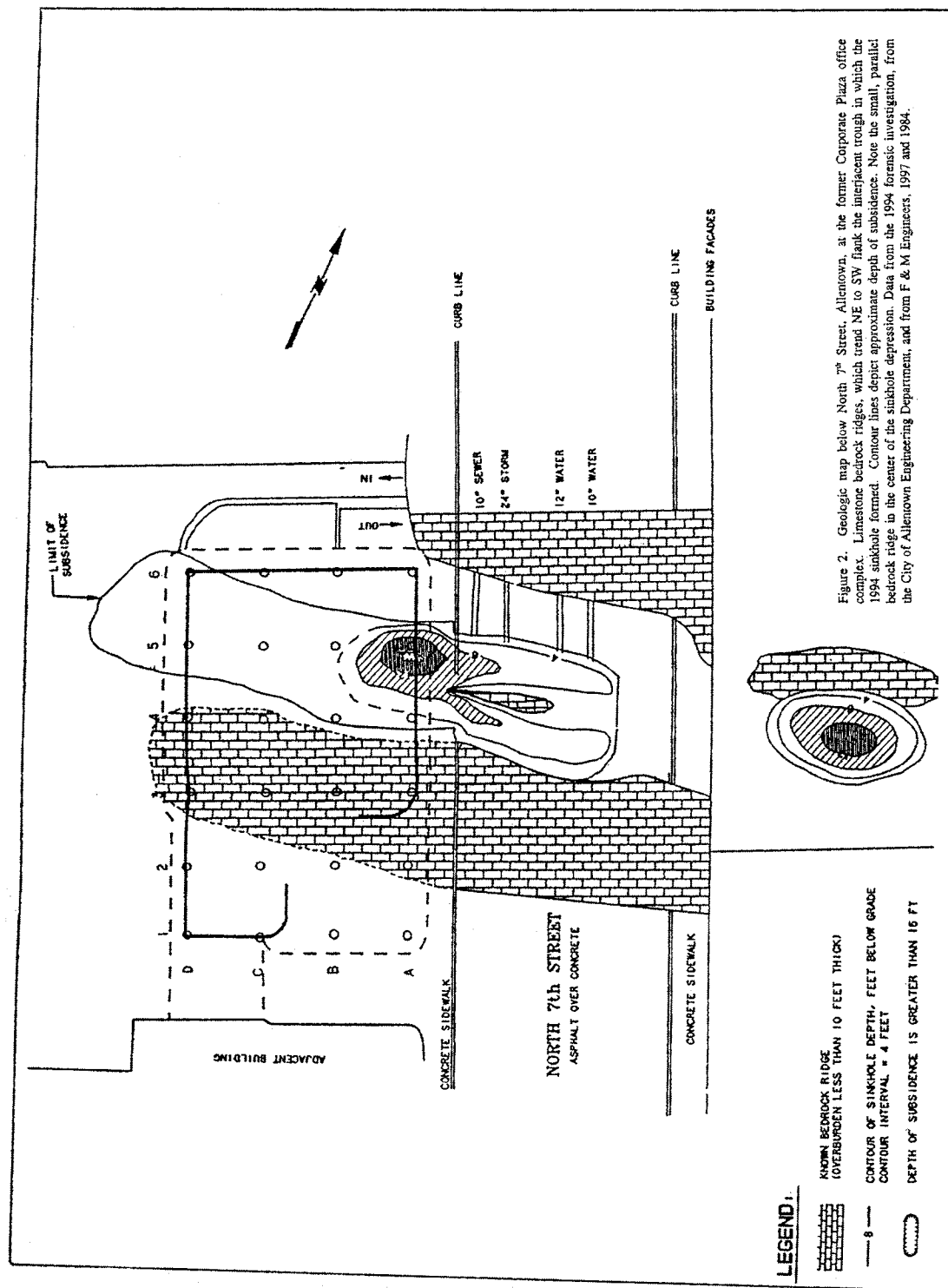


Figure 2. Geologic map below North 7th Street, Allentown, at the former Corporate Plaza office complex. Limestone bedrock ridges, which trend NE to SW flank the interjacent trough in which the 1994 sinkhole formed. Contour lines depict approximate depth of subsidence. Note the small, parallel bedrock ridge in the center of the sinkhole depression. Data from the 1994 forensic investigation, from the City of Allentown Engineering Department, and from F & M Engineers, 1997 and 1984.

Figure 30- Geologic map below north 7th Street, Allentown, at the former Corporate Plaza office complex. Limestone bedrock ridges, which trend NE to SW flank the interjacent trough in which the 1994 sinkhole formed. Contour lines depict approximate depth of subsidence. Note the small, parallel bedrock ridge in the center of the sinkhole depression. Data from the 1994 forensic investigation, from the City of Allentown Engineering Department, and from F & M Engineers, 1997 and 1984.

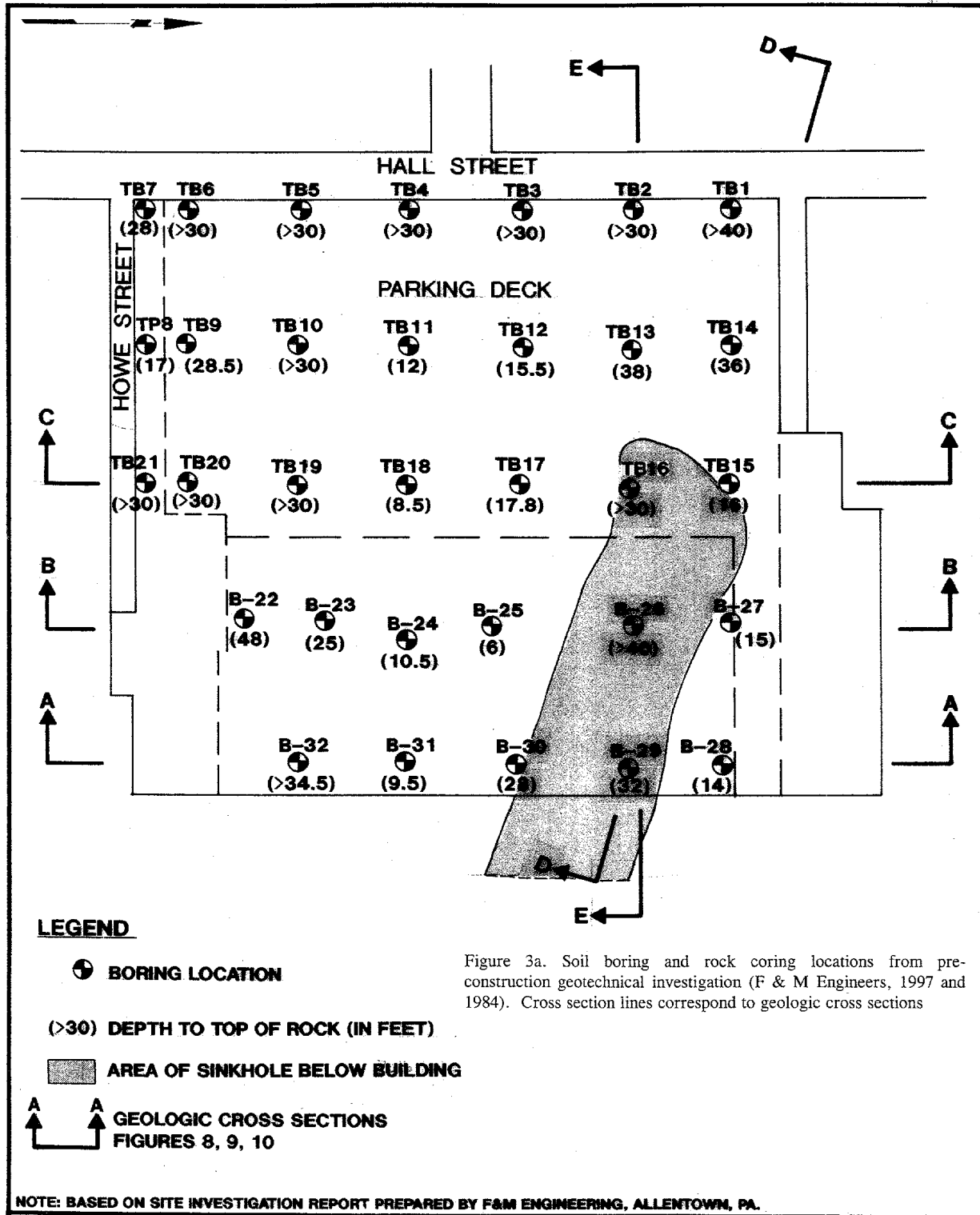


Figure 31a. Soil boring and rock coring locations from pre-construction geotechnical investigations (F & M Engineers, 1997 and 1984). Cross section lines correspond to geologic cross sections shown in Figures 31b, c, and d.

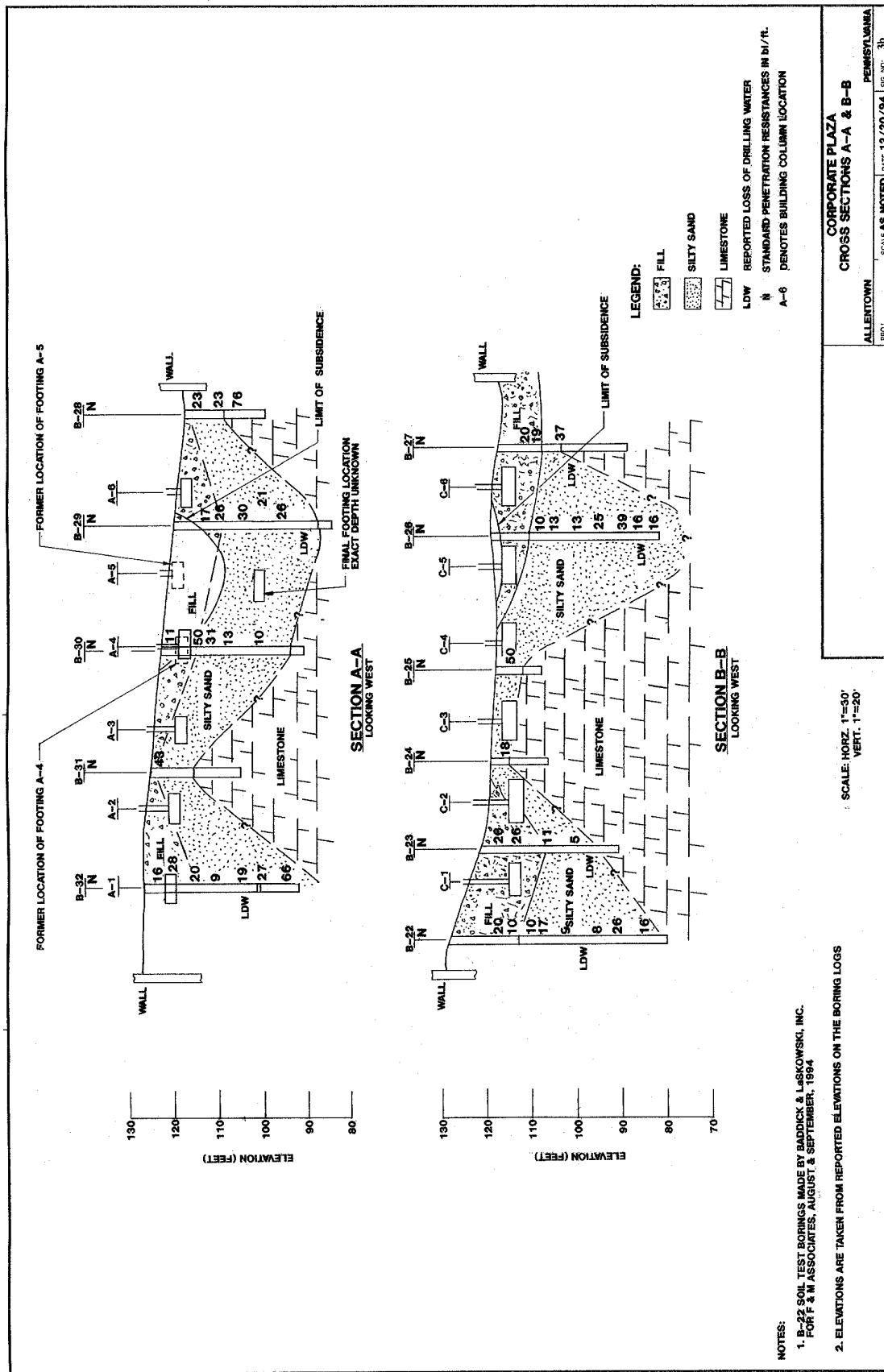


Figure 31b. Cross sections A-A and B-B.

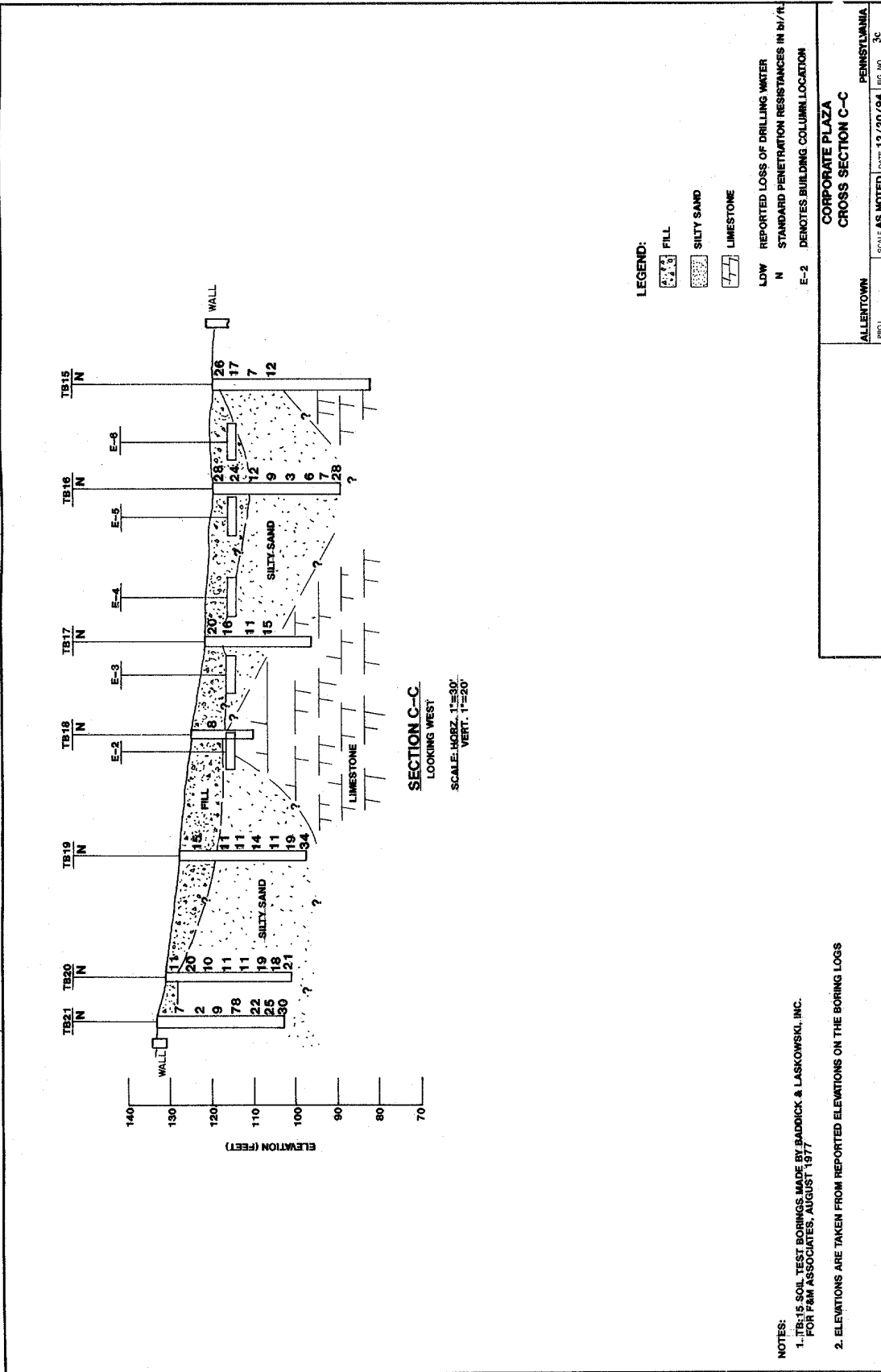


Figure 31c. Cross section C-C.

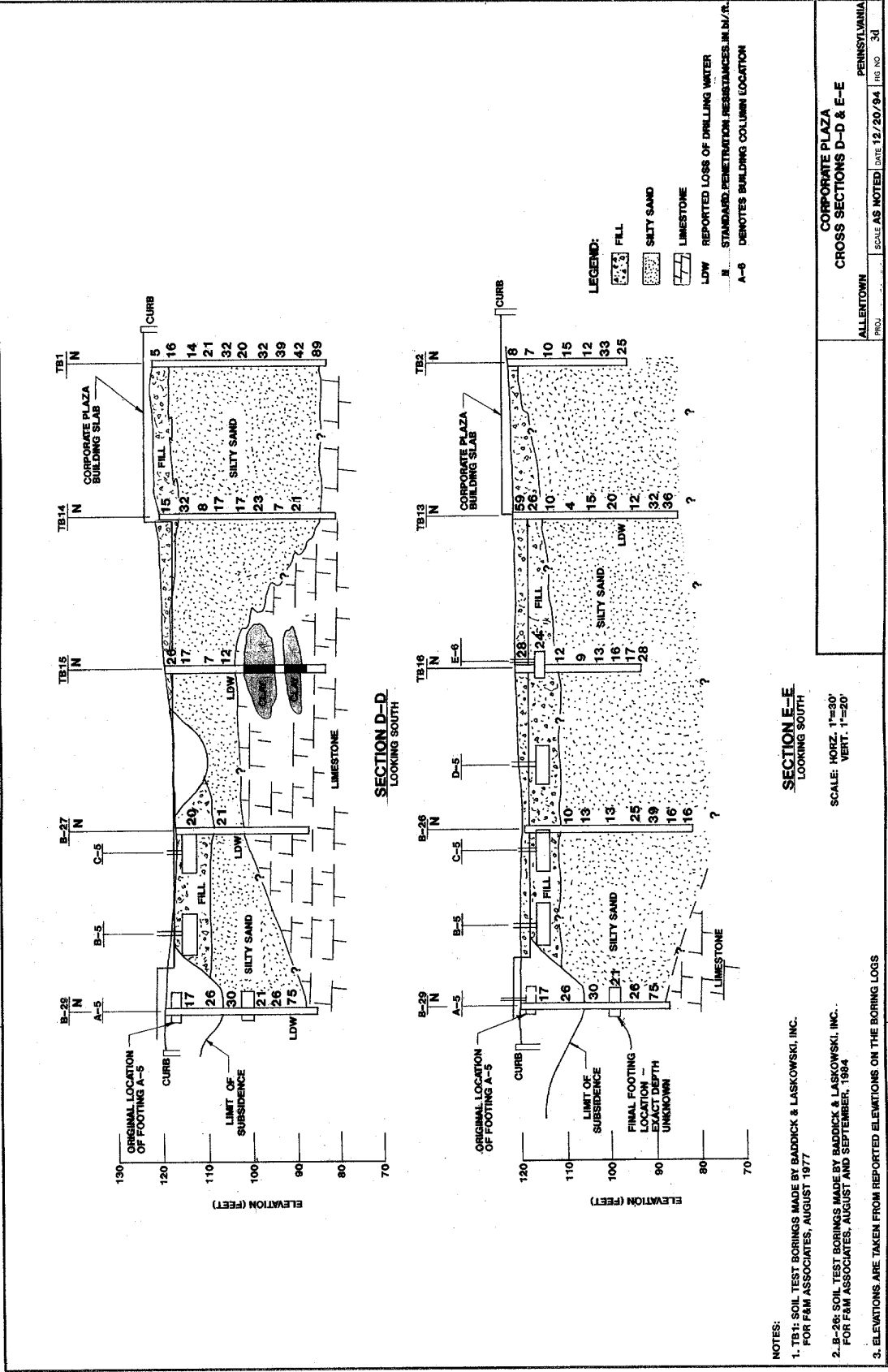


Figure 31d. Cross sections D-D and E-E.



Figure 32. View looking west into sinkhole prior to grouting. Note building support columns suspended in mid-air. The volume of material associated with the column which was lost into the sinkhole can be estimated by comparing with the adjacent column. The slabs below the building are the basement floor. Note the small central bed-rock ridge in the lower left of the photograph.



Figure 33. View looking west into the sinkhole at the time of grouting. View shows vertical northern sidewall and underground utilities severed during the collapse.

Figure 34. View looking east at the northwest corner of building where support column subsided 1.7 m. Photograph was taken after demolition of the adjacent parking garage.



Figure 35. Close-up view of the base of the northwest corner of the building, looking southeast.



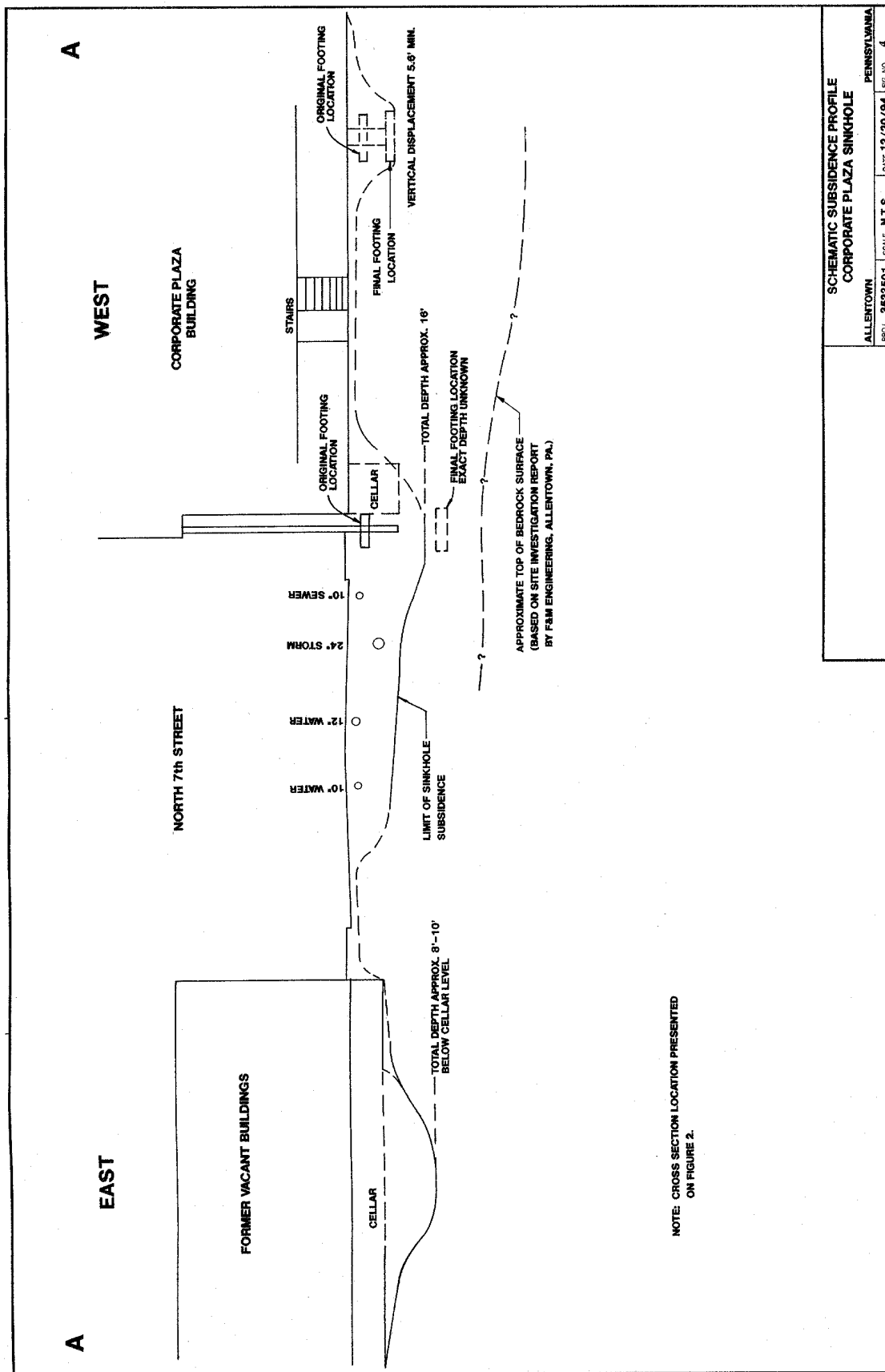


Figure 36. Schematic subsidence profile of Corporate Plaza sinkhole.

RECONSTRUCTION OF SINKHOLE DEVELOPMENT

The 7th Street sinkhole did not develop suddenly or without warning. Although it was not recognized as precursory settling, evidence of subsidence was noticed by tenants in the Corporate Plaza building during several days prior to the development and final collapse of the sinkhole. Such evidence included:

- Office doors no longer closed properly. They were offset in the door jambs.
- Tenants heard rumbling/creaking noises in the restrooms and stairwells.
- Concrete chips and dust that spalled from the roof of the parking garage, were present on the garage floor and on tenants' automobiles.
- Hanging pictures were crooked on some office walls.
- One hanging picture near the entrance to the building was found on the floor on the morning before the collapse (February 22, 1994). The fallen picture was discovered on Monday morning by the same office manager who had been the last person to leave the building on the previous Friday when the picture was still hanging.

Based on the observations and information gathered in the forensic investigation conducted immediately after the sinkhole formation, the following sequence of events occurred prior to the collapse.

Soil raveling over an unknown period of time resulted in the formation of a soil void above a bedrock solution channel/cavity at the base of the northern soil-filled bedrock trough (Figures 30 and 31). As raveling removed additional soil, a natural soil pipe developed in the bottom of the bedrock trough below the western 7th Street sidewalk. Over time, the soil void expanded and moved upward in the soil column in the center of the soil-filled bedrock trough. The presence of the foundations of former buildings below the western sidewalk and the foundation of the Corporate Plaza building itself (both above the ultimate sinkhole throat) caused the upward migration of the soil void to be deflected to the east (below 7th Street). There it followed the small central rock ridge (Figure 30) that sloped upward toward the east from the throat of the sink at the bedrock surface to a point beneath the water-supply pipes below the street.

Once there was a void space below the water pipes, a small, undetectable crack could have developed, that would have resulted in a low-volume, low rate loss of water¹. Such a loss, although undetectable by the City Water Authority, could have accelerated further loss of soil into the soil pipe. This would have caused an increase in the void size and, consequently, the extent of water pipe undermining. As the void space increased in size, the unsupported length of undermined pipe increased to a critical point at which the pipe was not strong enough to support its own weight plus the weight of the overlying street pavement and vehicles. At that critical point, the water supply pipe ruptured.

Once the water supply pipe ruptured (12:25 a.m. on February 23rd) the pressurized water flowed at a high rate (38 m³/min) into the void, causing further erosion and increasing the size of the void space. Of greatest importance to the interpretation presented herein, the water flowed directly down the existing soil pipe and into bedrock via the existing sinkhole throat, carrying the additional scoured soil with it. As the size of the scoured void and the soil pipe increased with the increasing volume of water, further loss of soil was accelerated. The scouring and enlarging

¹ This point is speculation, as the development of the sinkhole based on the conditions already outlined does not require the presence of leaking water from a pipe.

processes continued until, after approximately three hours, the street began to sag. After the supply pipe rupture was found and the water authority terminated flow to that section of the supply pipe, the remaining water in the now substantial void drained into the underlying bedrock. After the pressure of the water that was contained below the street pavement and building was removed (by shutting off the supply, thus providing for complete drainage of the soil void), several of the footing supports along the east façade of the Corporate Plaza building sank. This was followed by collapse of the adjacent sidewalk and the unsupported street surface pavement. The collapse began at the point of maximum subsidence at the throat of the sinkhole (below the western sidewalk) and spread outward toward the east across the street (C. Hunselberger, 1994). Following the initial collapse, soil continued to ravel into the sinkhole throat for several hours at a decreased rate, and at approximately 12:20 p.m., the northwest column support of the Corporate Plaza building sank by approximately 1.7 m (Figure 34, 35, and 36). Slower subsidence continued through the remainder of the day.

Based on an interpretation of the observations during the geotechnical evaluation of the site (F & M Associates, 1977 and 1984), there was, at that time, a potential soil sink in the base of the bedrock trough in which the sinkhole ultimately formed. This potential soil sink was evidenced by the loss of drilling fluid at or near the bedrock surface at a location that was approximately 10 m below grade at the position of the ultimate throat of the sinkhole. The development of a soil pipe at this location and the subsequent formation of an upward-migrating soil void was evidenced by the pre-collapse settling that was occurring in the Corporate Plaza building and adjoining parking garage several days prior to February 23rd.

The existence of a soil void and soil pipe *prior to* the water supply pipe rupture is evidenced by the nature of the rupture of the pipe and the subsequent loss of water. The rate of the loss of water, beginning *immediately* upon the pipe rupture, was approximately 38 m³ (38,000 l)/min. A leak of that volume and flow rate can only occur through the full (or nearly full) aperture of a water pipe; i.e., it could not have been accommodated by a crack or break in the pipe. Therefore, the rupture had to have severed the supply pipe completely and the two ends of the pipe must have been offset by a distance at least equal to the pipe diameter (approximately 30 cm). It is not likely that the pipe ruptured in more than one location. Inspection of the pipe ends and sections of the pipe in the sinkhole support a conclusion that it broke in the north end of the sinkhole and was pulled apart at couplings in the southern end of the depression at the time of the street collapse. Such movement of one or both of the broken ends of the water pipe could not have occurred within the compacted soil of the supply pipe trench as long as the underlying native soil remained in its state of natural compaction. That is, a contiguous mass of compacted soil extending from the bottom of the supply pipe trench down to the bedrock surface would not have provided sufficient room or mobility for such an offset to occur.

The loss of 38 m³/min that occurred completely below grade could not have been accommodated in a natural soil. Natural soil would have had a water seepage velocity far less than the rate and volume that was actually transmitted. Therefore, because the water was lost completely into the subsurface at a flow rate significantly greater than could be accommodated by the native soil in its undisturbed state, open conduits, or soil pipes, must have been present *prior to* the supply pipe rupture. Such conduits provided the hydraulic connection from the water pipe at the point of rupture into the underlying bedrock.

Soil pipes/conduits could not have been formed as a result of (after) the release of the pressurized water because there was no eruption of water onto the ground surface and no flow of water or scoured sediment into underground utility lines or municipal water drainage structures.

Such surface eruption and the flow of water and sediment via underground routes into subsurface utility trenches and access-ways are typical in non-carbonate terrains where natural soil sinks and soil pipes do not occur.

The movement of *soil* within the developing sinkhole was determined by plotting soil movement vectors, using approximate topographic elevation contours for the interior of the sinkhole (Figure 37). Vectors that depict the direction of soil movement within the sinkhole are drawn normal to the contours, in a manner similar to any flow direction vectors (e.g., ground-water flow). Based on the vectors in the sinkhole all soil moved down a single soil pipe and into a single throat downward into the underlying bedrock.

The throat of the sinkhole was approximately 15-20 m from the water supply lines (Figure 36). A soil pipe must have been present prior to the water-pipe rupture and subsequent water loss because there is no mechanism by which soil could be scoured *first* at the point of rupture and then moved *through* intervening, intact soil directly into the sinkhole throat and into the underlying bedrock. Because all soil flowed downward into bedrock through a single sinkhole throat via a soil pipe, the *first* soil that was lost into the underlying bedrock was the soil at the soil/bedrock interface below the eastern façade of the former office building. Such soil loss had to have occurred prior to the February 23rd collapse.

Because there were no subsurface drainage structures that had obviously leaked over time prior to the 1994 sinkhole collapse and because of the data from the geotechnical investigations conducted prior to building construction, it seems clear that the development of the original soil pipe was the result of natural processes.

GEOLOGIC HAZARDS AND LAND USE PLANNING

Because different land areas are composed of different geologic materials and have different geologic conditions and differing sets of inherent natural hazards, land use planning should consist of more than just *space use* planning. Land use planning in areas where natural geologic hazards exist should ensure that risks are minimized or, preferably, eliminated. In karst terrains such as are present in the Lehigh Valley, sinkhole investigations should be conducted routinely for commercial and industrial buildings, as well as for planned residential developments where significant storm water management is necessary.

Sinkhole mitigation measures are routinely included in commercial and industrial development in many municipalities in the karst areas of Pennsylvania, although many municipalities still do not require such sinkhole investigations or mitigations. Alternatively, foundation designs have, in many circumstances, been adapted to specific types of sinkhole hazards.

The 7th Street sinkhole would likely have occurred in much the same manner as it did whether the Corporate Plaza building was present or not. The initial cause of the sinkhole was raveling of soil into a natural soil pipe and thence into a conduit into the underlying cavernous carbonate bedrock. The sinkhole occurred in February, which is one of the principal sinkhole months, and, typical of most natural geologic processes, had likely been developing over the course of many years.

The scale of the sinkhole was magnified by the loss of pressurized water from a pipe of the city supply system that ruptured as a result of the loss of supporting soil into the underlying carbonate bedrock. The 7th Street sinkhole was, as a result, more spectacular than sinkholes that develop in agricultural or undeveloped areas. Although the magnitude of the sinkhole was great in comparison with most other sinkholes in the Allentown Formation, it is entirely possible that

the former Corporate Plaza building could have withstood the loss of the underlying soil and might remain standing today if a different foundation system had been used. For the Corporate Plaza building, the available geotechnical data could have been interpreted to support a decision to utilize a different foundation system than the spread footing foundation that was constructed.²

The cost to conduct a sinkhole investigation is minimal compared with the overall site investigation and preparation processes. Pre-construction sinkhole mitigation and/or enhanced foundation design and construction can be costly. Such “up front” costs are typically minimal, however, compared to the costs and danger associated with either the damage to, or the complete loss of property caused by events such as the 7th Street sinkhole.

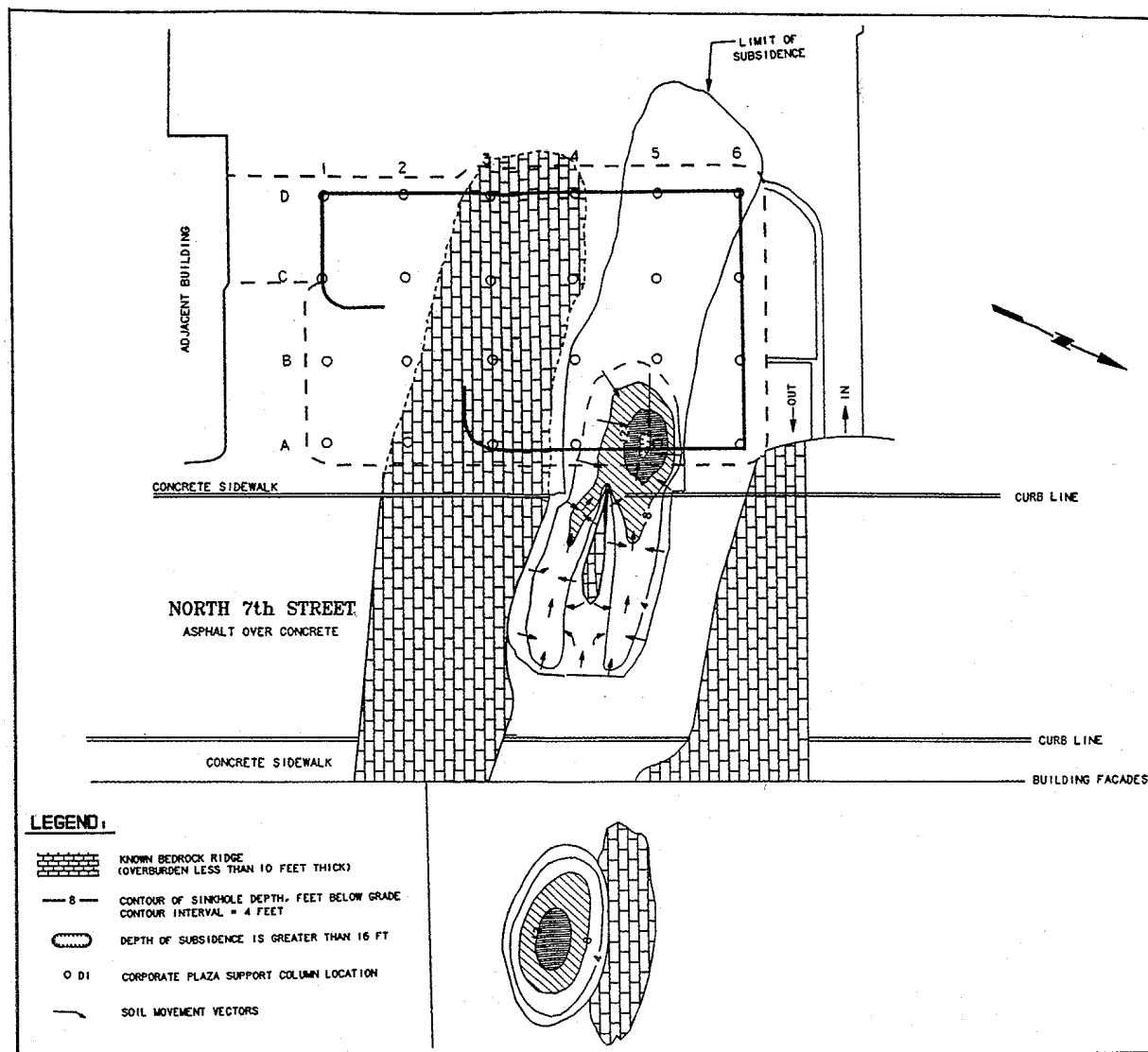


Figure 37- Soil movement vectors plotted on the geologic map. The vectors show that all soil flowed ultimately into the deepest part of the sinkhole depression, and that there was one locus of soil loss into underlying bedrock.

² Many of the larger buildings in Centre City Allentown have foundations designed to withstand the loss of soil below the building.

This paper is reproduced from the Journal of Field Archaeology, v. 12, p. 219-230, 1985 by permission of Al B. Wesolowsky, Managing Editor, JFA, Boston Univ., 675 Commonwealth Ave., Boston, MA

Procurement, Tool Production, and Sourcing Research at the Vera Cruz Jasper Quarry in Pennsylvania

James W. Hatch
Patricia E. Miller

The Pennsylvania State University
University Park, Pennsylvania

Prehistoric jasper quarrying and tool production at the Vera Cruz site, located near Allentown, Pennsylvania, are investigated through studies of quarry design, lithic heat treatment, intrasite spacing of tool production, and through functional and temporal analyses of artifacts. A methodology combining neutron-activation analysis and discriminant analysis is outlined, and the chemical profiles of seven regional jasper quarries are offered as a first step toward resolving speculation concerning the long-distance trade of this material.

Introduction

Nearly a century ago, Henry C. Mercer published his classic report of survey and test excavations at the jasper quarries in the Reading Prong district of eastern Pennsylvania. Appearing in 1894, this article described the distinctive yellow and red color of the area's jasper, the expansive prehistoric quarrying operations carried out to recover it, and the manufacturing sequence followed by local toolmakers.¹ Artifacts suspected of being made of "Pennsylvania Jasper" have since been reported at sites from Massachusetts to Virginia, suggesting a regionally important role for these quarries in trade and other cultural developments.²

In the summer of 1981, the Pennsylvania State University conducted test excavations at the Vera Cruz site (36Lh12), one of the few jasper quarries in the area to survive the residential construction and farming activities of the last century. Our purpose was to consider three issues left unresolved by Mercer and all subsequent investigators:

1. *What was the engineering design and mode of operation of the quarries?* Were these simple open-pit quarries or more sophisticated shaft-and-gallery designs?

2. *What was the nature of tool production and tool use at the site?* Where and how were jasper tools made? What role, if any, did heat treatment play in tool production? How long was the quarry in use, and what types of tools were produced?
3. *Is it possible to distinguish chemically between jasper quarried inside and outside of the Reading Prong?* The advantages of chemical sourcing are archaeologically well established and, if successful, this technique could substantiate the many claims of long-distance trade of this material.

This report presents our conclusions to all three research problems.

Geology

Jasper is an iron-rich, siliceous, crypto-crystalline lithic material that was frequently used in the manufacture of prehistoric tools. In the eastern United States, jasper occurs in several physiographic areas, including the Ridge and Valley, Blue Ridge, and Reading Prong provinces. Figure 1 shows the location of selected outcrops within each province known to have been quarried in prehistoric times. These deposits are found within pre-Cambrian metamorphics, within Cambrian sandstone, upper Cambrian and Ordovician limestones, and at contacts between limestone, sandstone, or metamorphics. Jasper is also found in secondary matrices, such as Pleistocene terrace gravels, resulting from glacial or fluvial redepositions.

The jaspers of eastern Pennsylvania are located within

1. H. C. Mercer, "Indian Jasper Mines in the Lehigh Hills," *AmAnth* 7 (1894) 80-92.

2. H. M. Wormington, *Ancient Man in North America*, 4th edn. *Denver Museum of Natural History Popular Series* No. 4 (Denver 1957) 71; Wm. A. Ritchie, *The Archaeology of New York State*, rev. edn. (Harbor Hill Books: Harrison, New York 1980) 8-9.

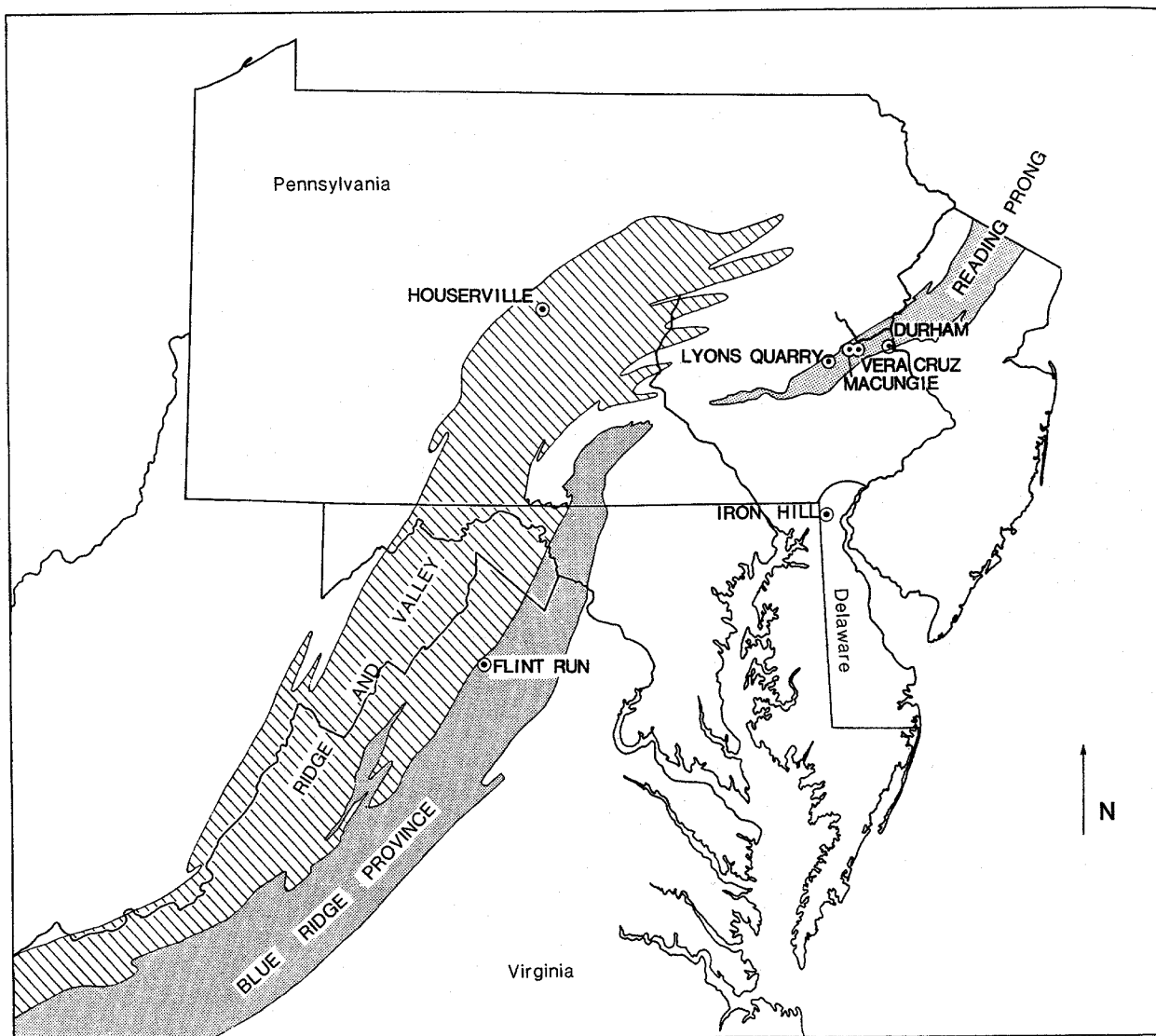


Figure 1. Selected physiographic provinces and jasper-bearing outcrops in the Mid-Atlantic region.

the Reading Prong. Although their specific geologic context has been a subject of debate, the weight of evidence supports their association with the Hardyston formation, a sandstone and quartzite stratum of Cambrian age.³

3. George W. Stose and Anna I. Jonas, "Highlands Near Reading, Pennsylvania: An Erosion Remnant of a Great Overthrust Sheet," *GSA* 48 (1934) 757-779; Donald M. Fraser, "Replacement of Hardyston Quartzite by Jasper," *Proceedings of the Pennsylvania Academy of Science* 11 (1937) 57-61; Lucianne Lavin and Donald R. Prothero, "Microscopic Analysis of Cherts within and Adjacent to the Delaware River Watershed," *Man in the Northeast* 21 (1981) 3-16; Benjamin L. Miller, Donald M. Fraser, and Ralph Leroy Miller, *Northampton County, Pennsylvania. Pennsylvania Geological Survey, 4th Series, County Report C-48* (1939).

Jasper deposits within this context tend to be localized. The nine quarries shown in Figure 2 were examined by us in 1981, although Richard Jordan and associates of Bryn Mawr College have since located additional outcrops and quarries in the area.

The Vera Cruz quarry clearly shows a relationship with the Hardyston formation (FIG. 3). The quarry occupies an area of 130 m × 400 m on the crest of a locally distinct ridge. In 1955 when the site was bisected for the construction of the Pennsylvania Turnpike, John Witthoft of the University of Pennsylvania observed a concentrated and nearly vertical deposit of jasper nodules in the profile of the roadcut. The deposit intersected the

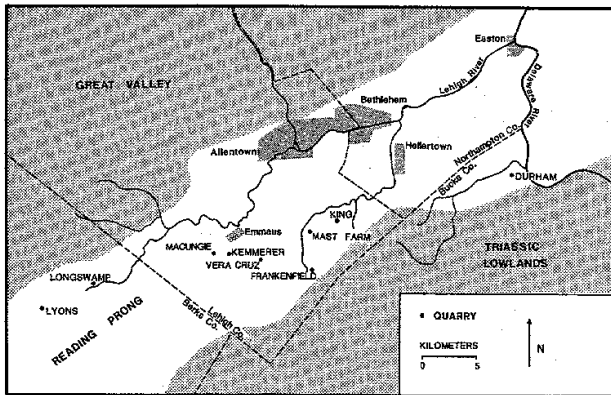


Figure 2. Selected jasper quarries in the Reading Prong district of eastern Pennsylvania.

surface near the ridge crest, suggesting that erosion through the millennia had resulted in the concentration of jasper nodules at or near the surface and within a few dozen meters on either side of the exposed deposit. Although jasper debitage indicative of tool manufacture is currently found over an area of 0.67 sq km on the crest and flanks of the ridge (FIG. 4), quarrying activity was confined to the zone of concentrated nodules. Figure 5 shows the location and size of the 67 extant quarry craters. Despite centuries of erosion since these craters were excavated and their jasper removed, the surface of the craters and contiguous backdirt piles still undulates dramatically and is a reminder of the intensive labor invested in lithic procurement.

Quarry Design and Operation

The design characteristics of prehistoric mining op-

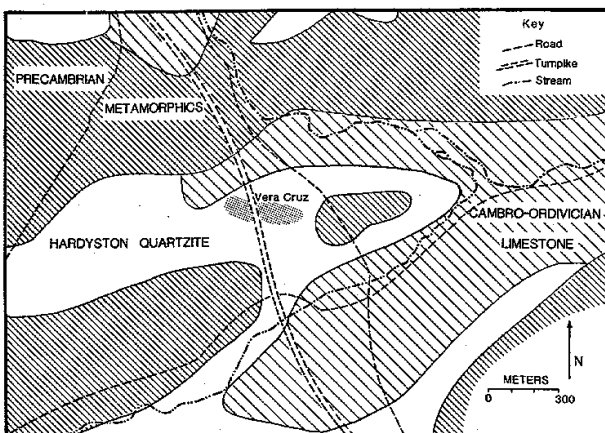


Figure 3. Geologic setting of the Vera Cruz quarry (geological information courtesy of Pennsylvania Geological Survey).

erations around the world vary considerably.⁴ The geological context of the resource is the major factor constraining the choice of quarry design. Simple open-pit excavations provide access to a lithic resource that is eroding from surface bedrock. Where the desired resource is buried under intact bedrock, however, shaft and gallery techniques may be necessary.

Because of Witthoft's observation that jasper cobbles were present in the soil matrix at Vera Cruz, open-pit quarrying was believed to be the primary technique used. To confirm that shafts and galleries were not present and to investigate the pit quarrying activity, excavations were undertaken using a cross-sectioning approach. The profiles of these sections served to distinguish internal stratigraphy as well as the profiles of the quarry edges adjacent to the unexcavated ridge matrix. Two craters, one of intermediate size (Crater 1) and one of relatively small size (Crater 2), were chosen. Figures 6 and 7 show the dimensions of each crater and the arrangement of excavation units, while Figures 8 and 9 show the succession of strata revealed through excavation.⁵

These excavations clarify two aspects of prehistoric quarry design. First, the quarrying procedure apparently

4. See, e.g., W. H. Holmes, *Handbook of Aboriginal American Antiquities, Part I: The Lithic Industries*. Bureau of American Ethnology Bulletin 60 (1919) 155-273; Peter W. Bosch, "A Neolithic Flint Mint," *SAm* 240 (June 1979) 126-132.

5. Stone debris has been tossed into several of the Vera Cruz craters, resulting in deep piles of rock along the slopes and in the centers of the pits. The distribution of this debris in Craters 1 and 2 is indicated in figs. 6 and 7 by patterned rock design. Because of the depth of this deposit in Crater 1 (ca. 0.6 m) and because the piles are found in craters in the center of the site, they may have resulted from prehistoric quarry activity rather than from the clearing of historical agricultural fields.

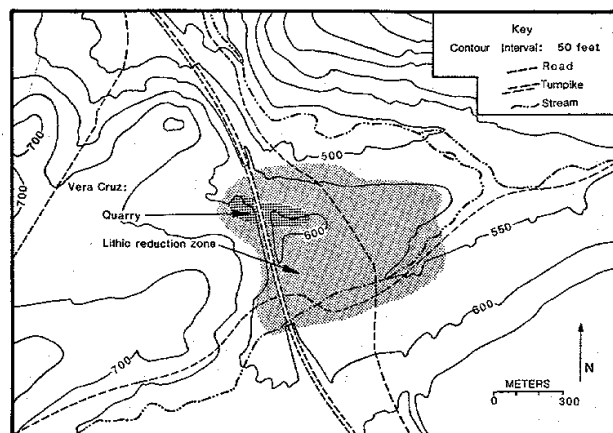


Figure 4. Topographic setting of the Vera Cruz quarry and lithic reduction zone.

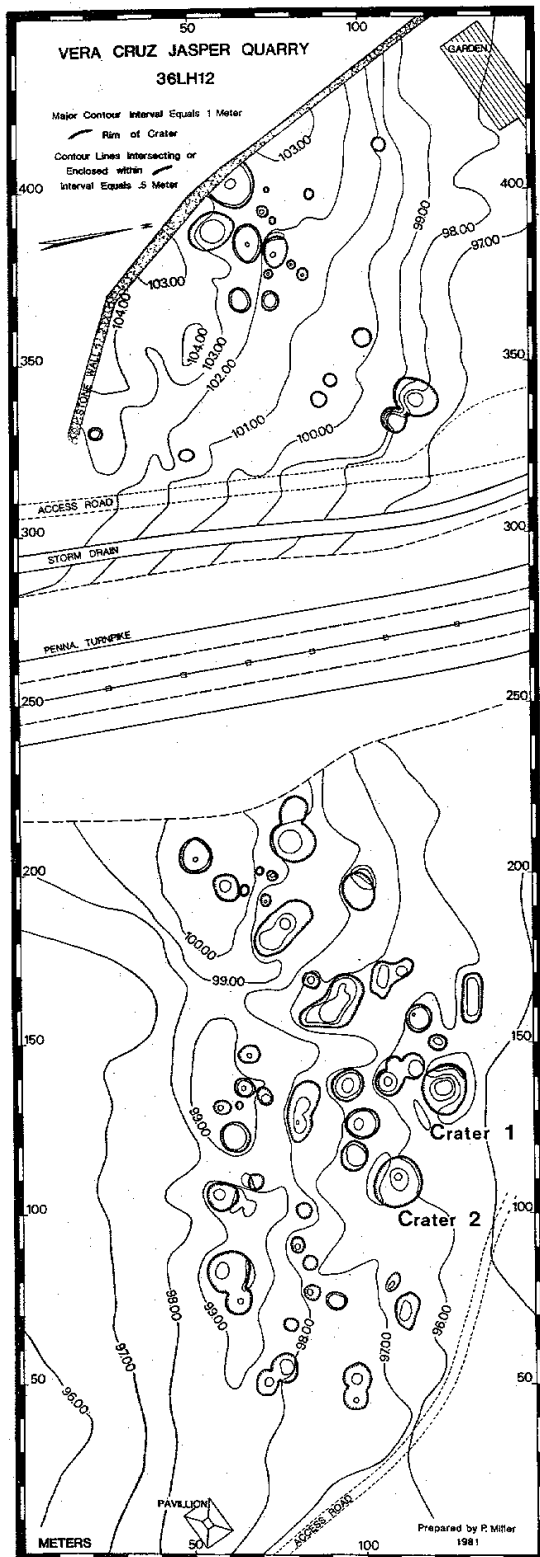


Figure 5. Topographic map of the Vera Cruz quarry. Contour intervals are 1.0 m outside the craters and 0.5 m within them. Elevations on Figures 5-9 are based on an arbitrary datum of 100.00 m.

involved the removal of soil from a roughly circular area, leaving a basin-shaped depression and a donut-shaped ring of backdirt along the basin's edge. The ultimate depth of the excavation was no doubt conditioned by the frequency of nodules as the quarrying proceeded, while the size of the crater was affected by the number of miners available and the length of time each spot was worked. Once the usable jasper had been removed and the crater abandoned, soil and discarded nodular debris began to fill the depression. Much of the fill must have washed in as the ring of backdirt surrounding the crater was flattened and compressed through erosion. It is likely, however, that a percentage of the fill of some craters came from soil thrown in by miners as they opened new craters adjacent to old, abandoned ones.

The second and more surprising aspect of the activity at Vera Cruz concerns the extent of prehistoric quarrying that took place. Rather than finding undisturbed stratigraphy adjacent to the outer edges of Craters 1 and 2, we discovered disturbed soil horizons littered with chipping debris. Only the lower portions of Craters 1 and 2 had extended below this disturbed zone and encountered a previously undisturbed zone of soil and jasper nodules (FIGS. 8, 9 and TABLE 1). This clearly indicates that Craters 1 and 2 had been dug into a previously quarried section of the site. Even the stratigraphy in the NE extension of Trench 1, located 10.5 m beyond the current edge of Crater 1, revealed prehistoric disturbance extending 1.8 m below the current ground level (FIG. 8 and TABLE 1). We conclude from these profiles that the entire ridgetop, an area of 130 m $\times$ 400 m, was probably quarried in prehistoric times, not just those places with currently visible craters.

This conclusion is supported by two independent observations. While examining the Vera Cruz ridge profile exposed during Turnpike construction, Witthoft saw a continuous scatter of jasper debitage just below the ridge surface. What is more, at the nearby Macungie jasper quarry all nine of the test pits that H. C. Mercer dug outside of craters encountered a disturbed soil matrix and debitage. It appears that at both Macungie and Vera Cruz the initial quarrying activity consisted of removing surface nodules and excavating broad, shallow basins for buried nodular material. Once the entire surface of these sites had been cleared of near-surface material, craters were excavated for more deeply buried nodules. The labor expended on securing jasper from these later quarrying activities must have been significant, not only because the nodules themselves were deeper, but because the upper portions of these craters would frequently have to be excavated through redeposited fill from earlier quarrying operations.

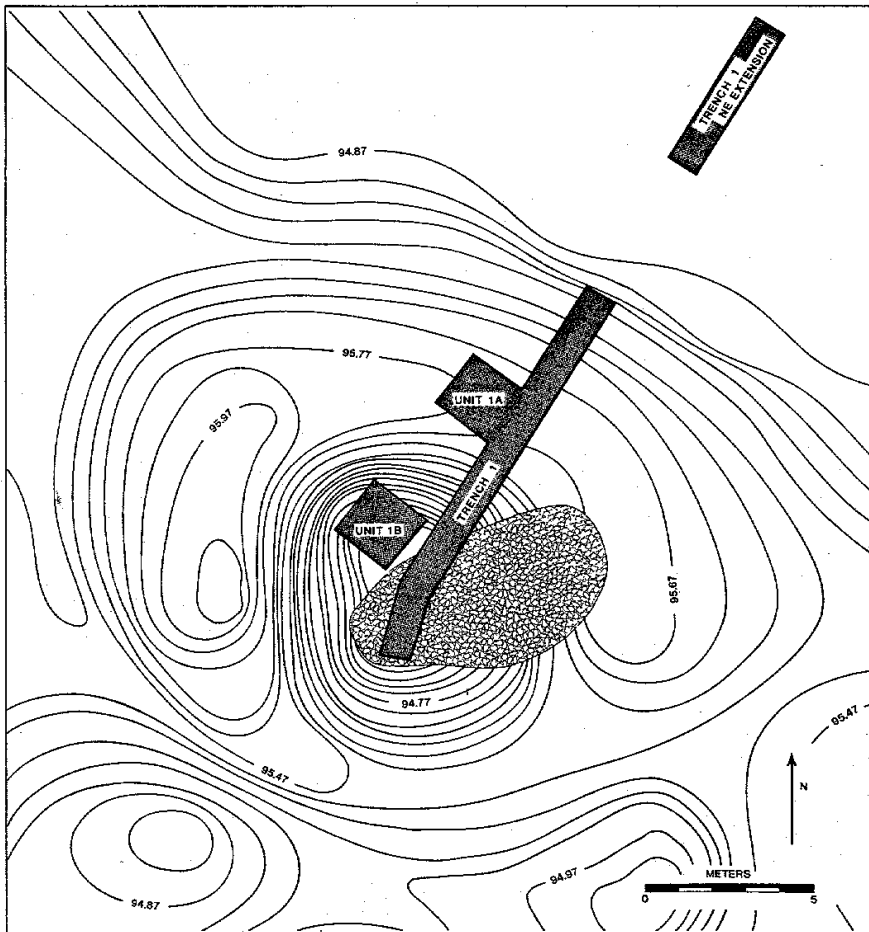


Figure 6. Crater 1: topography and excavation units.

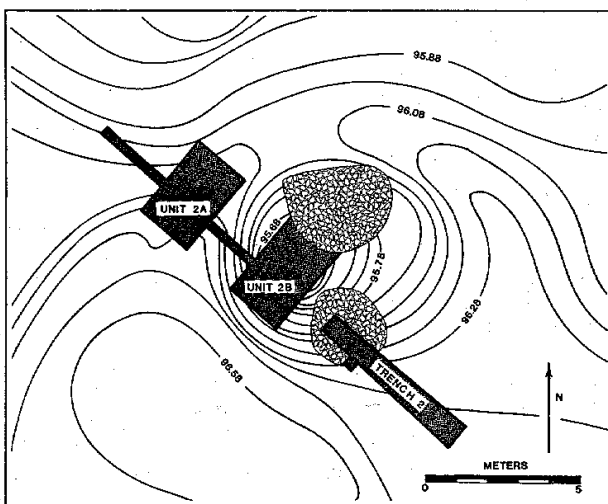


Figure 7. Crater 2: topography and excavation units.

Tool Production and Use

In addition to the cross-sectioning trenches discussed above, fieldwork at Vera Cruz included the excavation of four 2 m × 2 m test pits in the quarry and the collection of two separate surface samples from limited areas in the tool manufacturing zone surrounding the quarry. The test pits were excavated at Craters 1 and 2, one at the lowest point of each crater and one on top of each ring of backdirt (FIGS. 7, 8). Excavations were conducted by the natural levels visible in profile on the contiguous cross-sectioning trenches. Our field research focused on variation within each crater (depression versus adjoining ring of backdirt), between Craters 1 and 2, and between the quarry and the manufacturing zone outside the quarry. These results can be used to address two issues regarding tool production: 1) was heat applied to the Vera Cruz jasper and, if so, at what stages of tool manufacture, and 2) were different stages of the core reduction sequence at Vera Cruz conducted in distinct zones within the site?

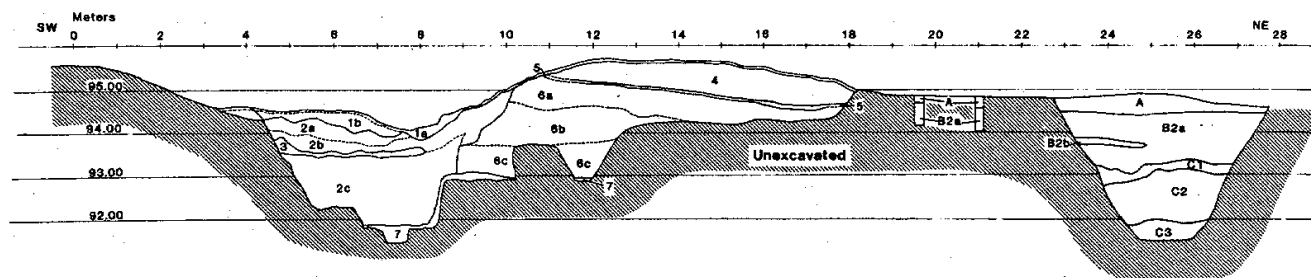


Figure 8. Crater 1: stratigraphic profile of the NW walls of Trench 1 and the Northeast Extension. The key to this figure is in Table 1.

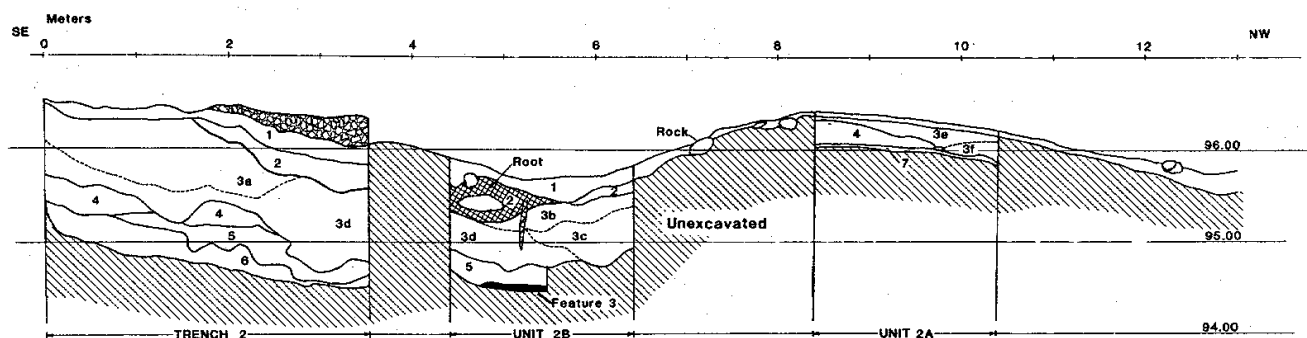


Figure 9. Crater 2: stratigraphic profile of the SW walls of Trench 2 and Units 2A and 2B. The key to this figure is in Table 1.

Heat Treatment in Tool Production

The Houserville jasper quarry and workshop of central Pennsylvania, excavated by Hatch in 1978, provides us with a detailed example of the use and effects of heat treatment of jasper.⁶ As at Vera Cruz, the vast majority of unworked jasper nodules at Houserville are of a yellow to golden brown color, whereas a large percentage of the thinning flakes exhibit complete or partial reddening. Schindler et al. demonstrate that the transition from yellow to red in the Houserville jasper is accomplished by exposure to heat (200°–300°C) and that this color transition is caused by the recrystallization of the material's geothite component (yellow) to hematite (red). These chemical and visual changes occur synchronously with the formation of microcracks, the loss of mechanically bound water, and a 50% reduction in fracture

toughness in the Houserville jasper. These changes facilitated the removal of flakes with less pressure and with more control. The Houserville assemblage clearly indicated that greater control was desirable in the later stages of tool production, because the greatest percentage of reddened flakes occurred in the final or "intermediate thinning flake" category. Although we have not replicated the heat-treatment experiments of Schindler et al. for Vera Cruz jasper, we believe that both their analytic results concerning the chemical changes induced by heat treatment as well as the core reduction sequence they propose are useful for our purposes.

To evaluate the use of heat treatment at Vera Cruz, the debitage recovered from the four crater test units was sorted according to its stage in the lithic reduction sequence and according to whether or not the piece showed evidence of heat treatment. Aside from a small number of prismatic blade fragments, indicative of Paleo-Indian toolmaking, all subsequent manufacture appears to center on the making of fine preforms and finished tools through the removal of percussion-struck biface thinning

6. Debra L. Schindler, James W. Hatch, Conran A. Hay, and Richard C. Bradt, "Aboriginal Thermal Alteration of a Central Pennsylvania Jasper: Analytical and Behavioral Implications," *AmAnt* 47 (1982) 526–544.

	Crater 1	Crater 2
<i>Disturbed Fill from Original Quarrying</i>		
Buried humus layer	Level 5	
Orange-brown to brown sandy silt, mottled at base	Level 6	
Humus layer	Level A	
Reddish-brown sandy silt	Level B2	
Reddish-brown clay loam		Level 4
Yellow-orange clay loam		Level 5
Brown sandy loam		Level 7
<i>Disturbed Fill from Later Quarrying</i>		
Humus layer	Level 1	Level 1
Heavily mottled reddish-orange and brown sandy silt	Level 2	
Reddish-gray silty clay	Level 3	
Reddish-orange sandy silt and occasional mottles	Level 4	
Brownish-tan loam		Level 2
Yellow-tan and orange clay		Level 3
<i>Undisturbed Sterile Soil</i>		
White-gray compact silt and orange mottling	Level 7	
Undisturbed silt and banded hues reflecting decomposed bedrock	Levels C1-C3	
White-gray compact silt and orange mottling		Level 6

Table 1. Soil profile descriptions:
Craters 1 and 2.

flakes. Debitage categories were defined according to the model developed by Schindler et al. for the same tool-making methods at Houserville.⁷ Jasper debitage showing no evidence of a platform or a bulb of percussion was classified as *shatter*. Shatter may be produced at any stage of the reduction sequence. *Primary trimming flakes* were removed during the initial stages of manufacture as shown by the presence of cortex and the absence of flake removals on the outer surface. *Crude bifacial thinning flakes* are large and thick with small angles between the platform surface and flake axes. The outer surface of crude flakes clearly shows that cortex had been removed. *Intermediate* and *fine bifacial thinning flakes* represent progressively smaller and thinner flakes with larger angles between the platform surface and the flake axes. Outer surfaces show repeated flake removals from earlier stages in the reduction sequence. Heat treatment was considered to be present if any portion of the pieces showed evidence of reddening. In addition to the crater samples, two samples were collected from fields adjacent to the quarry and were sorted in the same way.

Approximately 22,000 pieces of debitage were recovered.

7. Ibid. 538.

ered during the Vera Cruz excavations, deriving from four subsurface and two surface units. Debitage recovered from a single collection unit represents a cluster sample containing individual jasper pieces that are not spatially independent of each other in their characteristics. Consequently, the sampling unit for statistical treatment is the collection unit. Although the statistical treatment of these data was hampered by small sample size, some patterning in the distribution of heat treatment was apparent.

A statistical model was developed to test the following hypotheses:

1. The frequency of heat treatment was higher in later stages of the lithic reduction sequence.
2. Heat treatment took place more frequently in the workshops than in the quarry.
3. Within the quarry, heat treatment took place more frequently in the center of the craters than on the rims.

The SAS General Linear Models, a regression procedure, was used to test for significant differences in heat treatment.⁸ Comparisons were made among classes

8. Jane Helwig and Kathryn A. Council, eds., *SAS User's Guide* (SAS Institute, Inc.: Cary, North Carolina 1979).

Table 2. Debitage: percentage heat treatment by reduction class.

	Primary Trim	Crude Flakes	Intermediate Flakes	Fine Flakes	Shatter
Crater 1 Unit A	0.4	0	3.6	5.5	3.1
Crater 1 Unit B	6.9	6.9	13.4	18.3	10.5
Crater 2 Unit A	19.2	24.2	19.7	24.7	29.9
Crater 2 Unit B	17.1	16.6	27.3	40.4	34.2
Surface Sample 1	0	11.9	27.8	47.8	33.3
Surface Sample 2	25.0	19.2	62.5	81.1	45.2

of the reduction sequence, between samples from the adjacent workshops and the craters, between samples from the rim and center of craters, and, additionally, between samples from the two excavated craters.

That the model as a whole was significant ($p < .0001$) indicates that the comparisons listed above collectively explain the variability in the treated material. The importance, however, of the individual comparisons as sources of this variability differed. Although there was no significant difference between the use of heat treatment in the adjacent fields and its use within the quarry, there was a significant difference in heat treatment among reduction classes ($p < .03$). An examination of the data (TABLE 2) indicates that heat treatment is generally greatest in the fine thinning flakes and shatter categories and lowest in the crude thinning flakes and primary trim. As at Houserville, heat treatment at Vera Cruz took place to a greater degree in the late stages of the reduction process.

Although an examination of Table 2 indicates that heat treatment occurs at an overall higher frequency in the centers of the craters than at their rims, the statistical test for significance failed to confirm this difference. This failure is probably a result of the small sample size ($n=2$ craters). The statistical model did indicate a difference between the two craters; i.e., a greater amount of heat treatment took place in Crater 2 than in Crater 1 ($p < .0001$). This fact supports our field impression that Feature 3 of Crater 2 was a hearth for the heating of jasper preforms and that the rim of Crater 2 was a location for the thinning of preforms.

Spatial Patterning in Tool Production

A second issue that was addressed in the debitage analysis was whether or not different stages in the core reduction sequence had taken place in distinct areas within the site. The distribution of debitage, preforms, and finished tools at a number of reported quarry sites indicates a spatial segregation in the stages of the tool-making process and the occurrence of specialized workshops.⁹

9. Schindler et al., op. cit. (in note 5); C. M. Smith, *A Descriptive*

The small number of samples from Vera Cruz precludes a statistical consideration of whether or not different stages of the reduction sequence were variously represented in the adjacent workshops as opposed to the craters. In examining Table 3, however, it seems clear that fine flakes are more heavily represented in the workshops of the surrounding fields in terms of their percentage of non-shatter debitage ($\bar{X}$ workshops = 59.9%, $\bar{X}$ quarry = 32.5%). In contrast, primary trim seems much more heavily represented in the quarry ($\bar{X}$ workshops = 3.8%, $\bar{X}$ quarry = 24.1%). This result supports a reconstruction of the tool-manufacturing process in which blocks of raw material were reduced in a preliminary fashion within the quarry area, and the production of most of the fine preforms and finished tools took place in workshops adjacent to the quarry.

Tool Use within the Quarry

To determine if activities besides those of quarrying and biface manufacture had taken place at the site, debitage recovered from test excavations and surface collections was examined for use. After a careful visual inspection of the ca. 22,000 pieces, only 42 utilized flakes were discovered. All of the utilized flakes came from the intermediate bifacial thinning flake category. The 42 flakes exhibited a total of 49 utilized edges, each of which was examined under a binocular microscope at 20 $\times$ magnification in order to observe wear characteristics that would indicate the nature of its use at the site. The analysis was guided by experiments reported in Tringham et al. in which the distribution, size, and type of microscars detached from working edges during use were related to the mode of action and type of worked material involved in the activity.¹⁰

Sketch of Flint Ridge, Licking Co., Ohio. Smithsonian Institute Annual Report (Washington, D.C. 1884) 851–873; Barbara A. Purdy, *Florida's Prehistoric Stone Technology* (University of Florida Press 1981).

10. Ruth Tringham, Glenn Cooper, George Odell, Barbara Voyteck, and Anne Whitman, "Experimentation in the Formation of Edge Damage: A New Approach to Lithic Analysis," *JFA* 1 (1974) 171–196.

Table 3. Debitage: percentage of total number by reduction class.

	Primary Trim	Crude Flakes	Intermediate Flakes	Fine Flakes
Crater 1 Unit A	27.6	12.2	27.0	33.2
Crater 1 Unit B	28.6	13.0	25.8	32.7
Crater 2 Unit A	24.9	17.4	27.1	30.7
Crater 2 Unit B	15.2	17.4	34.2	33.2
Surface Unit 1	0.8	17.8	22.9	58.5
Surface Unit 2	6.7	14.4	17.7	61.3

According to Tringham et al., the mode of action (longitudinal versus transverse) is indicated by the distribution of scars along the working edge. Transverse action (scraping, shaving, planing) results in the detachment of microflakes or scars from one surface of the edge. Longitudinal action (cutting, sawing) detaches microscars from both surfaces of the edge. Of the 49 edges examined, 15 showed evidence of longitudinal action. The remaining 34 edges were used in transverse action. A subset of the transverse edges includes five semicircular edges that could only have been used to scrape or shave cylindrical objects such as branches, bone, or antler.

The nature of the worked material is indicated by the size, depth, and shape of the microscars.¹¹ All edges examined had microscars of the same scale as those shown to have resulted from use on materials of medium hardness such as wood. Only 10 of the 49 edges showed any evidence of stepped scars, which are characteristic of use on hard materials such as bone or antler.

Although the flakes examined do not represent a contemporaneous assemblage, the predominant activity suggested by the wear characteristics is woodworking: sawing, scraping bark, and shaping into a final form. Because of the toolmaking activities in evidence at the

quarry, it is likely that this woodworking involved the manufacture of hafting elements. Activities involving soft material cannot be ruled out, because the microscars resulting from such activities tend to be very small and may have been missed in the initial inspection of the debitage.

Of the 49 utilized edges examined for wear characteristics, only five showed any evidence of heat treatment. This percentage (10.2%) is considerably lower than the percentage of heat treatment among all intermediate flakes (25.7%). We believe that yellow intermediate thinning flakes were preferred for woodworking activities because they had not suffered reduced fracture toughness from heat treatment and were, as a result, less prone to breakage.

Chronology and Intensity of Quarry Use

A collection of 90 points and point fragments found in the tool manufacturing zone surrounding the Vera Cruz quarry provides a basis for statements regarding chronology, phase-specific intensity of use, and raw material exploitation in the region.

Table 4 indicates that all major episodes of human occupation in the eastern United States are represented at Vera Cruz and suggests the continuous usage of the quarry over a 10,000-year period. If, however, we divide the admittedly small number of points by the duration of each phase, then the Late Archaic, Middle Woodland, and Late Woodland periods appear to have been the most active toolmaking episodes in the site's history. Table 4 also shows a steady increase in the jasper component of the point assemblage from Paleo-Indian through Early Woodland times. Eastern U.S. hunting and gathering groups are believed to have experienced a gradual constriction of their territorial base and a rise in regional population density during this time. Such reductions in territorial size would have resulted in less lithic variety within each territory, a trend that may account for the

11. Ibid. 189-191.

Table 4. Chronology and composition of projectile points from the Vera Cruz lithic reduction zone.

Period	Approximate Duration	Total Points	Points/ 1000 Years	Points of Jasper	% Jasper of Total	Points of Other	% Other of Total
Paleo-Indian	? -8000 B.C.	1	?	0	0	1	100.0
Early Archaic	8000-5000 B.C.	14	4.7	5	35.7	9	64.3
Middle Archaic	5000-2000 B.C.	18	6.0	9	50.0	9	50.0
Late Archaic (and Transitional)	2000-1000 B.C.	30	30.0	20	66.7	10	33.3
Early Woodland	1000 B.C.-500 A.C.	1	0.7	1	100.0	0	0
Middle Woodland	500-1000 A.C.	10	20.0	0	0	10	100.0
Late Woodland	1000-1550 A.C.	16	35.2	2	12.5	14	87.5

proportional increase of jasper up to the Middle Woodland.

From the Middle Woodland period on, agriculturally based tribal societies are found in the area. This shift in lifestyle is believed to have resulted in the redefinition of territories and new social contexts for the exchange of material items, including lithics. Table 4 indicates that most of the projectile points found at Vera Cruz during the Middle and Late Woodland periods are made of other materials (notably chert and flint). A similar pattern is seen in many areas of Pennsylvania, including the region surrounding the Houserville jasper quarry. There, chert and flint were preferred to jasper for the manufacture of small dart and arrow tips, presumably because of the superiority of their knapping characteristics; the rest of the lithic assemblage, however, was fashioned from a wider variety of materials, including jasper.¹² Although Table 4 clearly indicates that the Vera Cruz quarry was intensively utilized during Middle and Late Woodland times, we will not know what specific role jasper played in the local tool industry until we have better control over the lithic assemblages of the area's habitation sites and until experiments are conducted on the relative advantages to the knapper of flint, chert, and jasper.

Chemical Sourcing of Jasper

Although "Pennsylvania Jasper" is well known and is the reputed raw material of artifacts found on many sites in the NE United States, little work has been done to provide a firm basis of identification for this material. The only published trace element analysis is by M. James Blackman who analyzed materials from the Newark gabbro of Delaware and from several quarries of "Pennsylvania Jasper" using atomic absorption and flame emission spectroscopy.¹³ Because Blackman's sample sizes were too small for the determination of statistical significance (from one to five samples per quarry), however, his results must be treated with some reservations.

In conjunction with the excavations at Vera Cruz, jasper samples were collected and trace-element analyses conducted to provide chemical composition data for use in source identification. An attempt was made to include at least one set of samples from each geologic province in this region. In the Hardyston formation, of the several

major quarry sites that are known, four were included in the analysis: Vera Cruz and Macungie (Lehigh County), Lyons (Berks County), and Durham (Northampton County). Additional analyzed material included jaspers of the Newark gabbro formation at Iron Hill, Delaware, the Nittany dolomite formation at Houserville, Pennsylvania, and the Flint Run complex in the Shenandoah Valley, Virginia (FIG. 1).

Neutron-activation analysis was selected as the analytic technique because of its sensitivity and because several elements could be analyzed simultaneously. Fifteen to 20 samples (ca. 500 mg per sample) from each of the sites were irradiated for one hour in the central thimble of the TRIGA reactor, a part of the Breazeale Nuclear Reactor Facility at The Pennsylvania State University. The samples were analyzed in either of two Ortec gamma ray (coaxial lithium-drifted germanium) detectors. Pulse heights produced by either detector were converted to peak energies, and the peak areas determined using a Nuclear Data ND680 Pulse Height Analyzer/Computer System. Data from standard samples of known chemical composition, irradiated with each set of jasper samples, were used to convert the peak areas to composition in parts per million. The results for the eight elements quantified in the analysis are presented in Table 5.

The jasper samples analyzed in this study represent calibration data for the future source identification of jasper artifacts through the use of the multivariate statistical technique known as discriminant analysis. This procedure is designed to identify unknowns through the use of mathematical functions developed from such calibration data. One means of evaluating the potential success of discrimination is to treat the calibration samples as a series of unknowns and classify each sample into a source on the basis of the functions developed from the calibration data. The degree to which this classification conforms to the actual group identity of the samples is a measure of the success of the discrimination.

Table 6 presents the results of the SAS discriminant procedure and indicates that for jasper sources outside eastern Pennsylvania the discriminant analysis is 100% successful. In other words, the elements copper, arsenic, manganese, potassium, samarium, lanthanum, scandium, and iron were sufficiently consistent within quarries and variable between quarries to identify all of these samples according to their source location. Attempts to decrease the number of variables needed for discrimination by eliminating the least important elements (manganese and lanthanum) had important negative effects on the success of identification.

Within quarries of the Hardyston formation, the accuracy of the classification varies between 58% and

12. Conran A. Hay, "An Analysis of the Chipped Stone Assemblages from the National Register Survey—1978," in James W. Hatch, ed., *The Fisher Farm Site: A Late Woodland Hamlet in Context*. Department of Anthropology, The Pennsylvania State University, Occasional Papers 12 (University Park 1978) 65–82.

13. M. James Blackman, "The Geochemical Analysis of Jasper Artifacts and Source Material from Delaware and Pennsylvania," *Transaction of the Delaware Academy of Science* (1974) 37–48.

Table 5. Elemental composition of jasper samples: mean and (standard deviation) in parts per million.

Source (No. Samples)	Cu	As	Mn	K	Sm	La	Sc	Fe
Macungie (19)	14.2 (19.0)	3.30 (3.26)	308.7 (372.0)	1404.7 (1077.)	1.15 (1.09)	4.04 (4.85)	0.423 (0.214)	13451.0 (7043.0)
Vera Cruz (20)	6.83 (3.68)	8.07 (7.19)	448.0 (603.0)	608.0 (315.0)	1.34 (2.91)	3.90 (9.91)	0.380 (0.284)	13780.0 (14527.0)
Durham (20)	8.79 (4.05)	3.17 (4.07)	195.0 (139.0)	1881.0 (2707.0)	0.682 (0.577)	3.55 (4.38)	0.610 (0.792)	11020.0 (6299.0)
Lyons' Quarry (19)	2.78 (2.66)	1.66 (2.51)	283.4 (381.0)	1051.0 (1002.0)	1.15 (0.860)	3.67 (5.10)	0.453 (0.501)	14584.0 (22207.0)
Iron Hill (20)	7.15 (11.10)	0.660 (0.284)	173.0 (99.3)	179.0 (58.2)	0.407 (0.184)	0.793 (0.391)	4.27 (1.43)	69265.0 (29475.0)
Flint Run (16)	1.01 (1.25)	1.59 (3.6)	247.0 (609.0)	157.0 (79.4)	0.133 (0.162)	0.649 (0.749)	0.327 (0.609)	18738.0 (30713.0)
Houserville (18)	1.89 (1.12)	29.7 (12.8)	92.9 (82.3)	96.6 (35.8)	1.82 (0.580)	4.59 (1.61)	3.32 (1.94)	120771.0 (62925.0)

Table 6. Discriminant analysis on eight variables: classification summary.

	From Group	Number of Observations and Percents of Total Classified Into Group							Total
		1	2	3	4	5	6	7	
Macungie	1	11 57.89	1 5.26	0 0	0 0	2 10.53	5 26.32	0 0	19 100.00
Vera Cruz	2	1 5.26	13 68.42	0 0	0 0	0 0	5 26.32	0 0	19 100.00
Flint Run	3	0 0	0 0	14 100.00	0 0	0 0	0 0	0 0	14 100.00
Iron Hill	4	0 0	0 0	0 0	20 100.00	0 0	0 0	0 0	20 100.00
Lyons	5	1 5.88	0 0	1 5.88	0 0	15 88.24	0 0	0 0	17 100.00
Durham	6	3 15.00	1 5.00	1 5.00	0 0	0 0	15 75.00	0 0	20 100.00
Houserville	7	0 0	0 0	0 0	0 0	0 0	0 0	18 100.00	18 100.00

88%. Twenty-one errors occurred in a total of 75 classifications. All but one of these misclassifications involve other quarries in the Hardyston formation. The lower accuracy of classification results both from the variability in chemical composition within a single jasper deposit and from the relative similarity of jasper within a single geological context such as the Hardyston formation. This is demonstrated by the chemical composition data for the four Hardyston quarries (TABLE 5: Macungie, Vera Cruz, Durham, and Lyons' Quarry), which show that the means of all eight elements are similar and that the standard deviations are very large. That discrimination among these quarries can be made to the degree stated (58%–88%) is because of the ability of the discriminant analysis to consider all of the eight elements simultaneously and thus to partition the compositional data discretely according to quarry source. The quantification of

additional chemical elements, using longer or shorter irradiation times, should improve the accuracy of classification within the Hardyston formation by increasing the number of discriminating variables.

The results of the statistical procedure suggest that jasper of the eastern United States can be discriminated on the basis of trace-element composition with a measurable margin of error. Rather than identifying the geological source of jasper artifacts on the basis of sometimes misleading macroscopic characteristics, future identification can be made through a reliable and replicable methodology.

Summary

Research at the Vera Cruz site has demonstrated that for approximately 10,000 years open-pit quarrying was

conducted to secure nodular jasper for the production of stone tools. Topographic mapping of the site demonstrates an undulating landscape of quarry pits with surrounding rings of backdirt. Cross-section test trenches reveal that the entire ridge was disturbed by prehistoric quarrying, with the existing pitted landscape representing only the latest episode of activity.

Research at Vera Cruz concerned not only the design and operation of the quarry, but also the nature of jasper tool production and use. Analysis of debitage recovered from test excavations indicates that the initial trimming of nodules occurred in the quarry area, whereas further bifacial thinning was more commonly performed in the surrounding workshops. Heat, applied to the jasper to reduce fracture toughness, was primarily used in the later stages of tool production. An analysis of the microscar characteristics of utilized flakes suggests that the working of wood for hafting elements also occurred on-site.

A third focus of research was the feasibility of the chemical analysis of jasper as a means of identifying raw material sources. In total, 132 jasper samples from seven sources in the eastern United States were analyzed using neutron-activation analysis. The application of discriminant analyses to these data resulted in successful classification among sources outside eastern Pennsylvania on the basis of the eight elements. For jasper sources within the Hardyston formation of eastern Pennsylvania, the success of the discrimination is somewhat less but can likely be increased through the quantification of additional chemical elements.

Acknowledgments

The authors would like to acknowledge the help of several individuals in the conduct of this research. Richard Geidel assisted in the supervision of the Penn State field school's excavations at Vera Cruz. He and the students worked in a very conscientious manner. Dorothy Humpf assisted in the classification of the debitage. Mr. Thomas Unser and his associates on the Upper Milford Township Board of Supervisors generously provided their assistance before and during the excavations. Dr. Richard Jordan and Mr. Glenn Sheehan of Bryn Mawr College shared with us their special insights into the region as well as unpublished data. Technical facilities and training for the neutron-activation analysis were provided by the faculty and staff of the Breazeale Nuclear Reactor Facility of The Pennsylvania State University. Jasper samples from quarries outside Pennsylvania were provided by Dr. William Gardner of the Catholic University of America and Dr. Daniel Griffith of the Delaware Archaeological Society. The Pennsylvania Geological Survey provided recent geological data

that aided us both in locating quarries and understanding the distribution of jasper as a resource. Finally, special thanks go to Mr. Charles Treichler and Mr. Earl Feather, residents of Vera Cruz, for introducing us to the distinctive Pennsylvania German hospitality of the region.

James W. Hatch is an Associate Professor in the Department of Anthropology at The Pennsylvania State University. His current interests in archaeological chemistry involve research in the heat treatment of lithics and nutritional trace elements in human bone. His ongoing research includes bioarchaeological studies of Mississippian and Mayan societies.

Patricia E. Miller is a graduate student at The Pennsylvania State University where she received her Master's degree in May 1982. Her interests include Eastern U.S. archaeology, cultural ecology, and optimal foraging research.

REFERENCES CITED

- Aaron, J. M., and Drake, A. A., Jr., 1997, Geologic map of the Nazareth quadrangle, Northampton County, Pennsylvania: U. S. Geological Survey, Open File Report 96-33.
- Ashley, G.H., 1930, Age of the Appalachian peneplains: Geological Society of America Bulletin, v. 41, p. 695-700.
- Bascom, F., 1921, Cycles of erosion in the Piedmont province of Pennsylvania: Journal of Geology, v. 29, p. 540-559.
- Berg, T. M., Dodge, C. M., and others, 1981, Atlas of preliminary geologic quadrangle maps of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 61, 636 p.
- Berg, T. M., and others, 1989, Physiographic Provinces of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 13.
- Bowen, D.Q., Richmond, G. M., Fullerton, D. S., Sibrava, V., Fulton, R. J., and Velichko A. A., 1986, Correlation of Quaternary glaciation in the Northern Hemisphere, *in*, Sibrava, V., Bowen, D. Q., and Richmond, G. M., eds., Quaternary glaciations in the Northern Hemisphere: Quaternary Science Review, v. 5, p. 509-511.
- Bradley, J., 1965, Intrusion of major dolerite sills: Royal Society of New Zealand Transactions (Geology), v. 3, p. 17-55.
- Braun, D. D., 1989, Glacial and periglacial erosion of the Appalachians, *in*, Gardner, T. W. and Sevon, W. D., eds., Appalachian geomorphology: Geomorphology, v. 2, no. 1-3, p. 233-258.
- Braun, D. D., 1994, Late Wisconsinan to pre-Illinoian (G?) glacial events in eastern Pennsylvania, *in*: Braun, D. D., ed., Late Wisconsinan to pre-Illinoian (G?) glacial and periglacial events in eastern Pennsylvania: 57th Friends of the Pleistocene Field Trip, Hazleton, PA, Guidebook, p. 1-21. (U.S. Geologic Survey Open File Report. 94-434) (available from PA Geological Survey, \$5.30, contact Jon Inners).
- Braun, D. D., 1996a, Surficial geology of the Allentown 30x60 minute quadrangle: Pennsylvania Geological Survey, 4th ser., 1 map, scale 1:100,000; text, 17 p.
- Braun, D. D., 1996b, Pseudo-morainic topography of the Allentown area of eastern Pennsylvania: 15th Annual Field Trip of the Harrisburg Area Geological Society, Guidebook, 28 p. (available from: Harrisburg Area Geological Society, c/o PA Geological Survey, P.O. Box 8453, Harrisburg, PA 17105-8453).
- Braun, D. D., 1996c, Surficial geology of the Pennsylvania part of the Riegelsville 7.5-minute quadrangle: Pennsylvania Geological Survey, 4th ser., Open File Report 96-45.
- Campbell, M. R., 1903, Geographic development of northern Pennsylvania and Southern New York: Geological Society of America Bulletin, v. 14, p. 277-296.
- Campbell, M. R., 1933, Chambersburg (Harrisburg) peneplain in the piedmont of Maryland and Pennsylvania: Geological Society of America Bulletin, v. 14, p. 553-573.
- Carey, J. B., and Yaworski, M., 1963, Soil survey of Lehigh County, Pennsylvania: Soil Conservation Service, U. S. Department of Agriculture, 114 p.
- Ciolkosz, E. J., Cronce, R. C., Sevon, W. D., and Waltman, W. J., 1995, Genesis of Pennsylvania's limestone soils: University Park, Pennsylvania State University Agronomy Series no. 135, 28p.
- Cleaves, E. T., Godfrey, A. E., and Bricker, O. P., 1974, Chemical weathering of serpentinite in the eastern Piedmont of Maryland: Geological Society of America Bulletin, v. 85, p. 437-444.

- Cleaves, E. T., 1989, Appalachian Piedmont landscapes from the Permian to the Holocene, *in*, Gardner, T. W and Sevon, W. D., eds., *Appalachian geomorphology: Geomorphology*, v. 2, p. 159-179.
- Cleaves, E. T., Godfrey, A. E., and Bricker, O. P., 1970, Geochemical balance of a small watershed and its geomorphic implications: *Geological Society America Bulletin*, v. 81, p. 3015-3032.
- Costa J.E., and Cleaves, E.T., 1984, The piedmont landscape of Maryland: A new look at an old problem: *Earth Surface Processes and Landforms*, v.9, p. 59-74.
- Davis, R. E., Drake, Jr., A. A., and Epstein, J. B., 1967, *Geologic Map of the Bangor Quadrangle Pennsylvania-New Jersey*: U. S. Geological Survey, Geological Quadrangle Series, Map GQ-665.
- Davis, W. M., 1889, The rivers and valleys of Pennsylvania: *The National Geographic Magazine*, v. 1, no. 3, p. 183-253.
- Davis, W. M., 1899, The geographic cycle: *Geographical Journal*, v. 14, p. 481-504.
- Davis, W. M., 1902, Base level, grade, and peneplain: *Journal of Geology*, v. 10, p. 77-111.
- Davis, W. M., and Wood, J. W., 1890, The geographic development of northern New Jersey: *Boston Society of Natural History Proceedings*, v. 24, p. 365-423.
- Drake, A. A. Jr., 1967, *Geologic Map of the Easton Quadrangle New Jersey-Pennsylvania*: U.S. Geologic Survey, Geological Quadrangle Series, Map GQ-594.
- Drake, A. A., Jr., 1969, Precambrian and lower Paleozoic geology of the Delaware Valley, New Jersey-Pennsylvania, *in*, Subitsky, S., ed., *Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions*: New Brunswick, NJ, Rutgers University Press, p. 51-131.
- Drake, A. A., Jr., 1987, *Geologic map of the Tipton quadrangle, Lehigh and Berks Counties, Pennsylvania*: U. S. Geological Survey, Geological Quadrangle Series, Map GQ-1609.
- Drake, A. A., Jr., 1991, Basement-cover relations in the Durham and Reading Hills – a reappraisal: *Geological Society of America Abstracts with Programs*, v. 23, no. 1, p. 23-24.
- Drake, A. A., Jr., 1993, *Bedrock geologic map of the Allentown West quadrangle, Lehigh and Berks Counties, Pennsylvania*: U. S. Geological Survey, Geological Quadrangle Series, Map GQ-1727.
- Drake, A. A., Jr., 1996a, *Geologic map of the Allentown East quadrangle, Lehigh, Northampton, and Bucks Counties, Pennsylvania*: U. S. Geological Survey, Open File Report 96-22 (currently in press as Geological Quadrangle Series, Map GQ-1804).
- Drake, A. A., Jr., 1996b, *Geologic map of the Hellertown quadrangle, Northampton, Bucks, and Lehigh counties, Pennsylvania*: U. S. Geological Survey, Open File Report 96-547.
- Drake, A. A., Jr., 1996c, *Geologic map of the Catasauqua quadrangle, Northampton and Lehigh Counties, Pennsylvania*: U. S. Geological Survey, Open File Report 96-700.
- Drake, A. A., Jr., 1999, *Geologic map of the Cementon quadrangle, Lehigh and Northampton Counties, Pennsylvania*: U. S. Geological Survey, unpublished manuscript.
- Drake, A. A., Jr., McLaughlin, D. B., and Davis, R. E., 1967, *Geologic map of the Riegelsville quadrangle, Pennsylvania – New Jersey*: U. S. Geological Survey, Geological Quadrangle Series, Map GQ-593.
- Drake, A. A., Jr., Epstein, J. B., and Aaron, J. M., 1969, *Geologic map and sections of parts of the Portland and Belvidere quadrangles, New Jersey-Pennsylvania*: U. S. Geological Survey, Geological Quadrangle Series, Map I-552.
- Epstein, J. B., 1973, *Geologic map of the Stroudsburg quadrangle, Pennsylvania-New Jersey*:

- U.S. Geological Survey, Geological Quadrangle Series, Map GQ-1047.
- Epstein, J. B., Sevon, W. D., Glaeser, J. D., 1974, Geology and mineral resources of the Lehigh and Palmerton quadrangles, Carbon and Northampton Counties, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Atlas 195cd, 460 p.
- Epstein, J. B., 1990, Geologic map of the Wind Gap quadrangle, Northampton and Monroe Counties, Pennsylvania: U.S. Geological Survey, Geological Quadrangle Series, Map GQ-1645.
- Faas, R. W., and Flocks, J. M., 1966, Some acoustic properties of the Ring Rocks diabase, Kintnersville, Pennsylvania (abs.): Pennsylvania Academy of Science Proceedings, v. 40, no. 1, p. 12.
- Flint, R. F., 1963, Altitude, lithology and the Fall Zone Peneplain in Connecticut: *Journal of Geology*, v. 71, p. 683-697.
- Fritz, J., and Meierding, T., 1989, Paleoclimatic implications of Appalachian blocksheets: *Pennsylvania Geographer*, v. 27, no. 3 & 4, p. 1-12.
- Fullton, James, H., Jr., LaFarge Corporation, Whitehall, PA, personal communication, 1994.
- Gardner, T. W., Sasowsky, I. D., and Schmidt, V. A., 1994, Reversed polarity glacial sediments, West Branch Susquehanna River Valley, Central Pennsylvania: *Quaternary Research*, v. 42, p. 131-135.
- Gibbons, J., and Schlossman, S., 1970, Rock music: *Natural History*, v. 79, no. 10, p. 36-41.
- Gilchrist, A. R., and Summerfield, M. A., 1991, Denudation, isostasy and landscape evolution: *Earth Surface Process and Landforms*, v. 16, p. 555-562.
- Hack, J. T., 1960, Interpretation of erosional topography in humid temperate regions: *American Journal of Science*, v. 258-A, p. 80-97.
- Hack, J. T., 1975, Dynamic equilibrium and landscape evolution, *in*, Melhorn, W. N., and Flemal, R. C., eds., *Theories of landform development*: Binghamton, N.Y., State University of New York, Publications in Geomorphology, p. 87-102.
- Hack, J. T., 1980, Rock control and tectonism - their importance in shaping the Appalachian Highlands: U. S. Geological Survey Professional Paper 1126-B, p. B1-B17.
- Halliburton NUS/Gannet Fleming, 1995, Draft expanded site investigation for the High Quality Polishing and Plating site, Old Zionsville, Lehigh County, Pennsylvania.
- Herman, G. C., and Montverde, D. H., 1989, Tectonic framework of Paleozoic rocks of northwestern New Jersey; Bedrock structure and balanced cross sections of the Valley and Ridge province and southwest Highlands area, *in*, Grossman, I.G., ed., *Paleozoic Geology of the Kittatinny Valley and southwest Highlands Area*, New Jersey: Sixth Annual Meeting of the Geological Association of New Jersey, Field Guide and Proceedings.
- Hsu, K. J., 1995, *The geology of Switzerland, and introduction to tectonic facies*: Princeton, NJ, Princeton University Press, 250 p.
- Jennings, J. N., 1983, Karst landforms: *American Scientist*, v. 71, p. 578-586.
- Knopf, E. B., 1924, Correlation of residual erosion surfaces in the eastern Appalachian highlands: *Geological Society of America Bulletin*, v. 35, p. 633-668.
- Kochanov, W. E., 1987, Aerial photographs prove sinkhole origin: *Pennsylvania Geology*, v. 18, no. 2, p. 11-13.
- Kochanov, W. E., 1988, Sinkholes and karst-related features of Northampton County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Open File Report 87-02.
- Leverett, F., 1934, Glacial deposits outside the Wisconsin terminal moraine in Pennsylvania: Pennsylvania Geological Survey, 4th ser., General Geology Report G7, 123 p.

- Lyttle, P. T., and Epstein, J. B., 1987, Geologic map of the Newark 1°x2° quadrangle, New Jersey, Pennsylvania, and New York: U. S. Geological Survey, Geological Quadrangle Series, Map I-1715.
- Marsh, B., 1999, Paleoperiglacial landscapes of central Pennsylvania: 62nd Northeast Friends of the Pleistocene Field Trip, Lewisburg, PA, Guidebook, 69 p.
- Marsh, B., and Lewis, P., 1990, Landforms and human habitat, *in*, Miller, E. W., ed. The geography of Pennsylvania: University Park, PA, The Pennsylvania State University Press,
- Meyboom, A. F., and Wallace, R. C., 1978, Occurrence and origin of ring-shaped dolerite outcrops in the eastern Cape Province and western Transkei: Geological Society of South Africa Transactions, v. 81, p. 95-99.
- Miller, B. L., Fraser, D. M., and Miller, R. L., 1939, Northampton County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., County Report C 48, 496 p.
- Miller, B. L., Fraser, D. M., Miller, R. L., Willard, B., and Wherry, E. T., 1941, Lehigh County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., County Report C 39, 492 p.
- Montgomery, A., 1956, Thermal metamorphism of redbeds by diabase at Ringing Rocks, near Kintnersville, PA: Pennsylvania Academy of Science Proceedings, v. 30, p. 176-181.
- Morisawa, M., 1989, Rivers and valleys of Pennsylvania, revisited, *in*, Gardner, T. W., and Sevon, W. D., eds., Appalachian geomorphology: Geomorphology, v. 2, p. 1-22.
- Myers, P. B., and Perlow, M., Jr., 1984, Development, occurrence, and triggering mechanisms of sinkholes in the carbonate rocks of the Lehigh Valley, eastern Pennsylvania: Orlando, FL, First Multidisciplinary Conference on Sinkholes, Proceedings.
- Papadopoulos, S. S., & Associates, and McLaren/Hart, 1996, Final design report for the groundwater extraction system, Heleva Landfill Superfund Site, North Whitehall Township, Pennsylvania.
- Pavich, M. J., 1985, Appalachian piedmont morphogenesis: weathering, erosion, and Cenozoic uplift, *in*, Morisawa, M., and Hack, J. T., eds., Tectonic geomorphology: Binghamton, NY, 15th Annual Geomorphology Symposium, State University of New York, Boston, MA, Allen and Unwin, p. 229-319.
- Pavich, M. J., 1989, Regolith residence time and the concept of surface age of the Piedmont "Peneplain", *in*, Gardner, T. W., and Sevon, W. D., eds., Appalachian geomorphology: Geomorphology, v. 2, p. 181-196.
- Peltier, L. C., 1959, Late Pleistocene deposits, *in* Willard, B., and others, Geology and mineral resources of Bucks County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Bulletin C 9, p. 181-183.
- Pennsylvania Department of Health and the Agency for Toxic Substances and Disease Registry, 1997, Health consultation, High Quality Polishing and Plating Site, Lehigh County, Pennsylvania.
- Poag, C. W., and Sevon, W. D., 1989, A record of Appalachian denudation in post-rift Mesozoic and Cenozoic sedimentary deposits of the U.S. middle Atlantic continental margin, *in*, Gardner, T. W., and Sevon, W. D., eds., Appalachian geomorphology: Geomorphology, v. 2, p. 119-157.
- Porter, S. C., 1989, Some geological implications of average Quaternary glacial conditions: Quaternary Research, v. 32, p. 245-261.
- Psilovikos, A., and Van Houten, F. B., 1982, Ringing rocks barren block field, east-central Pennsylvania: Sedimentary Geology, v. 32, p. 233-243.
- Reed, L. A., 1980, Suspended-sediment discharge, in five streams near Harrisburg, Pennsylv-

- nia, before, during, and after highway construction: U.S. Geological Survey Water-Supply Paper 2072, 37 p.
- Richmond, G. M., and Fullerton, D. S., 1986, Summation of Quaternary glaciations in the United States of America, *in*, Sibrava, V., Bowen, D. Q., and Richmond, G. M., eds., Quaternary glaciations in the Northern Hemisphere: Quaternary Science Review, v. 5, p. 183-196.
- Roden, M. K., and Miller, D. S., 1989, Apatite fission-track thermochronology of the Pennsylvania Appalachian Basin, *in* Gardner, T. W., and Sevon, W. D., eds., Appalachian geomorphology: Geomorphology, v. 2, p. 39-51.
- Sasowsky, I. D., 1994, Paleomagnetism of glacial sediments from three locations in eastern Pennsylvania; *in*, Braun, D. D., ed., Late Wisconsinan to pre-Illinoian (G?) glacial and periglacial events in eastern Pennsylvania: 57th Northeast Friends of the Pleistocene Field Trip, Hazleton, PA, Guidebook, p. 21-24. (U. S. Geologic Survey Open File Report 94-434).
- Sevon, W. D., 1979, Devonian sediment-dispersal systems in Pennsylvnaia (abs.): Geological Society of America Abstracts with Programs, v. 11, no. 1, p. 53.
- Sevon, W. D., 1981, Evidence for the reality and age of the Chambersburg peneplane in southeastern Pennsylvania (abs.): Geological Society of America Abstracts with Programs, v. 13, no. 3, p. 176.
- Sevon, W. D., 1984, A sandstone weathering rate from northeastern Pennsylvania (abs): Geological Society of America Abstracts with Programs, v. 16, no.1, p. 63.
- Sevon, W. D., 1985., Pennsylvania's polygenetic landscape: Harrisburg Area Geological Society, 4th Annual Field Trip, Guidebook, 55p.
- Sevon, W. D., 1989, Erosion in the Juniata River drainage basin, Pennsylvania, *in* Gardner, T. W., and Sevon, W. D., eds., Appalachian Geomorphology: Geomorphology, v.2, p. 303-318.
- Sevon, W. D., 1999, Landform map of Pennsylvania: Pennsylvania Geological Survey, 4th ser., mapping in progress.
- Sevon, W. D., Potter, N. Jr., and Crowl, G. H., 1983, Appalachian peneplains: an historical review: Earth Sciences History, v. 2, p. 156-164.
- Shackleton, N. J., 1987, Oxygen isotopes, ice volume, and sea level: Quaternary Science Review, v. 5, p. 183-190.
- Sherwood, W. C., 1964, Structure of the Jacksonburg Formation in Northampton and Lehigh Counties, Pennsylvania: Pennsylvania Geological Survey, 4th ser., General Geology Report 45, 64 p.
- Slingerland, R., and Furlong, K. P., 1989, Geodynamic and geomorphic evolution of the Permian-Triassic Appalachian Mountains, *in*, Gardner, T. W., and Sevon, W. D., eds., Appalachian geomorphology: Geomorphology, v. 2, p. 23-37.
- Upton, R. L., 1982, Two weathering surfaces on glacially polished granite (abs): Geological Society of America Abstracts with Programs, v. 14, nos. 1 & 2, p. 92.
- Ward, F., 1930, The role of solution in peneplanation: Journal of Geology, v. 38, p. 262-270.
- White, W. B., 1984, Rate processes: chemical kinetics and karst landform development, *in*, LaFleur, R.G., ed., Groundwater as a geomorphic agent: Boston, Allen and Unwin, p. 227-248.
- Willard, B., Freedman, J., McLaughlin, D. B., and others, 1959, Geology and mineral resources of Bucks County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Bulletin C 9, 243 p.

- Williams, E. H., Jr., 1893, Extramorainic drift between the Delaware and the Schuylkill: Geological Society of America Bulletin, v. 5, p. 281-296.
- Williams, E. H., Jr., 1917, Pennsylvania glaciation first phase: privately published, Woodstock, Vermont, 101 p.
- Wolfe, P. E., 1977, The geology and landscapes of New Jersey: Crane Russak , NY, 351 p.

ROAD LOG – DAY 1

Mileage		Description
Inc.	Total	
0	0	Leave parking lot of Days Inn Conference Center. Follow Bulldog Road north paralleling PA Route 309.
0.4	0.4	Stop Sign. TURN LEFT onto Ridgeview Dr.
0.1	0.5	Stop Light. TURN RIGHT onto PA Route 309.
0.3	0.8	Stop Light. Proceed straight ahead.
0.2	1.0	Stop Light. Proceed straight ahead.
0.7	1.7	Stop Light. Proceed straight ahead.
0.7	2.4	Stop Light. Proceed straight ahead. Lime Kiln Road to right.
0.4	2.8	Stop Light. Proceed straight ahead. Orefield Road to right.
2.6	5.4	Stop Light. TURN RIGHT onto Sand Spring Road. Currently crossing shales of the upland region of the Great Valley Section.
1.4	6.8	The route is about to go down slope on the southern margin of the Martinsburg shales and then onto the carbonate rocks of the Jacksonburg Formation and then the Epler Formation as we approach Ironton. From here on the route is south of the border between the carbonates (right) and shales (left).
0.9	7.7	Stop Sign. TURN LEFT onto Mauch Chunk Road in Ironton.
0.1	7.8	View on right of water-filled quarry in foreground. In background is field with many vent pipes. This is the Heleva Superfund Site. As we proceed ahead there will be several other views of the site. We will not be stopping here and we are not able to visit the processing facility, but there will be discussion of this site later in the day.
0.1	7.9	TURN RIGHT onto Hill Street.
0.05	7.95	Stop Sign. TURN RIGHT following Hill Street.
0.75	8.7	Stop Sign. TURN LEFT onto Levans Road.
0.6	9.3	Stop Sign. TURN RIGHT onto PA Route 329.
1.0	10.3	Passing through the town of Egypt.
0.2	10.5	Stop Sign. BEAR RIGHT following PA Route 329.
0.4	10.9	Stop Light. Proceed straight ahead across PA Route 145.
0.3	11.2	Borough limits of Cementon.
0.5	11.7	Stop Light. Proceed straight ahead.
0.2	11.9	Passing over the Lehigh River. Enter Northampton County.
0.3	12.2	Stop Light. Proceed straight ahead. Carini's on right is a good restaurant.
0.2	12.4	Stop Light. TURN RIGHT onto Laubach Avenue.
0.7	13.1	TURN LEFT into south entrance of Northampton Municipal Offices parking lot.
STOP 1.		ATLAS CEMENT MUSEUM
		Leader: Edward Pany

This stop consists of introductory comments by Edward Pany followed by a tour of the Atlas Cement Museum. Because of the small size of this very fine museum, please follow Mr. Pany's instructions with regard to moving and viewing within the museum.

HERITAGE OF THE CEMENT INDUSTRY IN THE LEHIGH VALLEY

The history of cement in the Lehigh Valley started in 1826 with the digging of the Lehigh Coal and Navigation Company canal. Rock suitable for a natural cement was found at Siegfrieds Bridge. Four kilns 15 ft long produced the amazing total of 10 barrels of cement each day to use in the canal construction.

The Portland Cement so common today was first produced in Coplay by David O. Saylor. After much experimentation, some on his kitchen stove, he perfected Portland Cement and received a patent in 1871. Today he is called 'The father of Portland Cement industry in America'.

Over 30 companies constructed 61 plants in the Lehigh Valley since Saylor's monumental efforts. Jose Navarra, a native of Spain, founded the Atlas Portland Cement Company in Coplay in 1889. He then constructed the world's largest Portland Cement plant in Northampton in 1895.

At its peak the plant boasted 5000 employees, 200 horses, 8 farms, a power plant, and two railroads. Cement for the Panama Canal and many other grand structures was produced there. The first white cement was produced there in 1910.

In 1931 the United States Steel Corporation purchased the Atlas Portland Cement Company. They continued to operate the plant and constructed a new wet process plant on the site in 1943. The plant sadly ceased operations on August 24, 1982.

The cement industry has been a cornerstone of many of our local communities. Thousands of men and women were employed by the cement companies. A great influx of immigrants from central Europe provided a steady and stable labor supply. The communities of Northampton, Cementon, Egypt, Coplay, Bath, Nazareth, Stockertown, Fogelsville, and Martins Creek all have deep cement roots.

As time passed, the industry, which was very labor intensive, was transformed by technology. Slowly, companies closed and passed into history. The Nazareth, Alpha, Lawrence, Penn Dixie, Penn Allen, Bath Portland, Giant, Lone Star, and many others became memories.

Today the industry continues in the Lehigh Valley with modern and efficient plants. Proudly continuing the cement tradition in Lehigh County is the LaFarge Corporation of Whitehall. Keystone Cement, Essroc, and Hercules operate efficient plants in Northampton County. Allentown Cement carries the cement banner in Berks County.

When the Atlas closed in Northampton, Edward Pany, a Northampton High School United States history teacher led a drive to preserve the history of the plant and its contributions to the Lehigh Valley and the world. For 25 years he researched the plant's history and collected numerous artifacts. He was thankful that the company employed his father and many local residents. Mr. Pany worked with his father during his college years and he never forgets those days and the friends he made at the plant.

When the U. S. Generating Company planned to construct a coal-burning power plant on the Atlas site, the company sought Mr. Pany's advice. They promised to fund a structure to preserve the history of the famed plant for future generations. The result is the beautiful building located adjacent to the Borough of Northampton Administration Center on Laubach Avenue.

The display is a breath-taking trip back in time. Over 1,000 photographs, artifacts, videos, wall of honor, and the Atlas Spirit mural grace the museum. The museum has been visited and enjoyed by many students, citizens, and civic groups. Mr. Rodger Firest, a high school art and graphic arts instructor has donated countless hours in helping the museum become a reality.

The local cement industry and a number of industries have made contributions to support the museum's educational mission. The museum is staffed by non-paid volunteers. No tax revenue has been used to fund the operation. Mr. Pany serves as the volunteer curator.

To keep the cement tradition alive, the museum honors a cement worker each month. The employees name and photograph appear along with a story in the local press. The employees name is also placed on a wall of honor that remembers the efforts of these workers. The museum has preserved a page of local history for everyone to enjoy.

Leave Stop 1. TURN LEFT onto Smith Lane. **Stop Sign. TURN RIGHT** onto Laubach Avenue.

- | | | |
|-----|------|--|
| 0.1 | 13.2 | Wilson Block House on the right. |
| 0.5 | 13.7 | Stop Light. TURN LEFT onto PA Route 329 (E. 21 st Street). |
| 0.3 | 14.0 | Stop Light. Proceed straight ahead. |
| 0.2 | 14.2 | Pass over Lehigh River. Enter Lehigh County. |
| 0.2 | 14.4 | TURN LEFT into parking lot of Whitehall Plant of Lafarge Corp. |
- STOP 2. TOUR OF WHITEHALL PLANT OF LAFARGE CORP.**
 Leaders: James Fullton and David Bremer

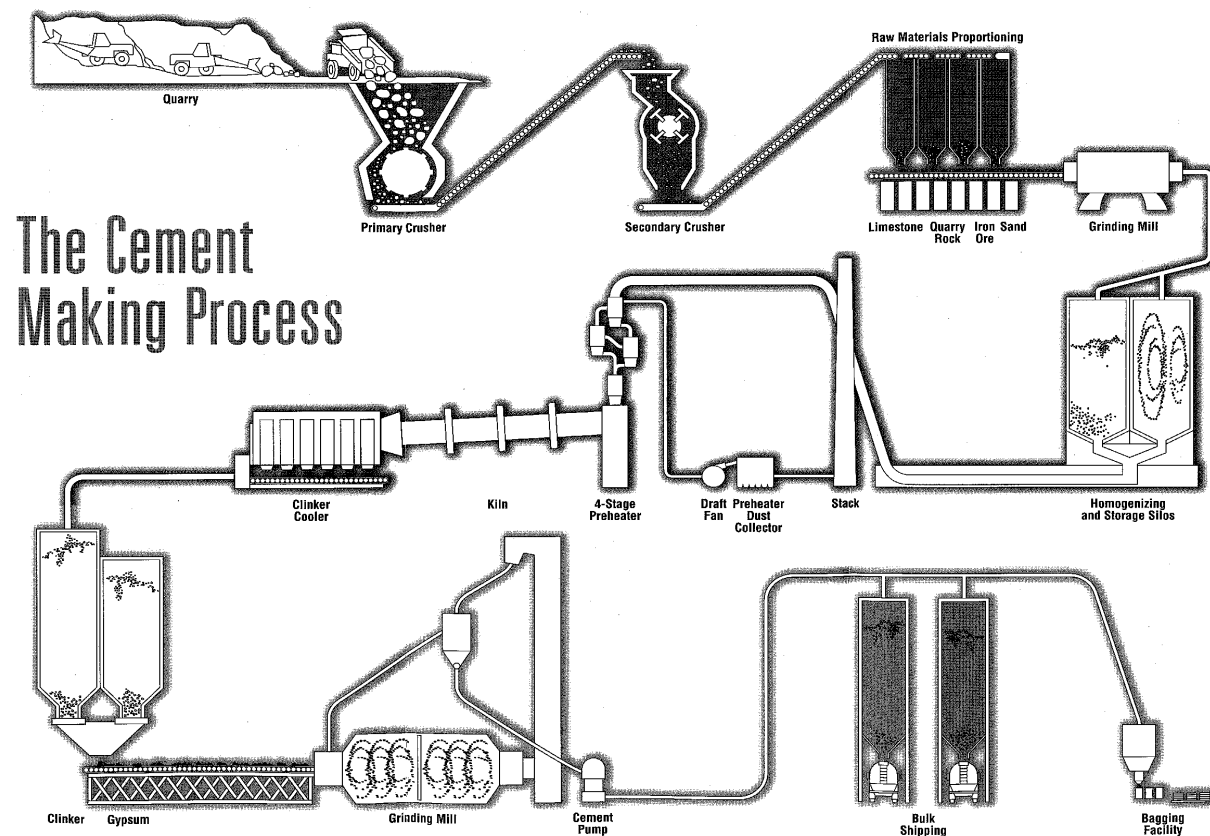


Figure 38. Flow diagram of the cement making process.

Leave Stop 2. TURN RIGHT onto PA Route 329.

- | | | |
|-----|------|--|
| 0.4 | 14.8 | Stop Light. Proceed straight ahead. |
| 0.3 | 15.1 | Stop Light. Proceed straight ahead. |

0.2 15.3 Cross Hokendaugua Creek and immediately **TURN LEFT** onto quarry access road. Proceed to **STOP 3**.

STOP 3. LAFARGE CORPORATION NORTHAMPTON AND EGYPT QUARRIES TOUR

Leaders: James Fullton and David Bremer.

The Whitehall cement plant began operation in 1899 with 20 kilns and 8 finish mills. At that time, the plant consumed only cement rock (limestone) as its primary kiln feed. The cement rock was mined from the Cementon quarry located on the original plant property. As the mine reserves played out, the Whitehall purchased property on the other side of the Lehigh River in Northampton and began mining in the 1950's. The Northampton quarry has been the primary supplier of kiln feed (cement rock) from the 50's until today. As the reserves began to fade at Northampton in the early 90's, Lafarge began the search for a new source of cement rock for the Whitehall plant. This search ended in Egypt, not across the ocean, but just across PA Route 145. As Northampton quarry dies out in the next few years, the Egypt quarry will be brought on line as the primary supplier of cement rock for the plant. This stop on the Field Conference will include analysis of the geologic structure of the Northampton quarry and follow the cement rock into the plant to see how it is processed.

NORTHAMPTON QUARRY

The Northampton quarry is located in the Ordovician age Jacksonburg Formation that resides in the Great Valley Section of the Valley and Ridge Province in eastern Pennsylvania. The Jacksonburg lies below the Martinsburg slate and above the dolomitic Beekmantown Formation.

Historically, the Jacksonburg Formation has been divided into two main units, by increasing age, the cement rock facies and the cement limestone facies (Miller, 1941). The cement rock facies has been further subdivided into an argillaceous limestone that is interbedded with upper crystalline limestone, in the middle of the argillaceous unit, and the lower crystalline limestone at the bottom of the unit (Sherwood, 1964). The fine-grained, argillaceous limestone unit is easily recognized by its dark gray color and its distinct flow cleavage. The upper and lower crystalline limestones can be recognized by their coarse crystalline grain size and massive structure. The lower crystalline tends to be more massive in structure than the upper, and can also be recognized by a distinctive bentonite layer in some locations. The Northampton quarry is located in the cement rock facies.

Structurally, two distinct folding events shaped the Jacksonburg Formation. The first event deformed the formation into large recumbent isoclinal folds. The quarry is located on one of these folds, which is called the Northampton nappe. This fold overturned the Jacksonburg Formation leaving the cement limestone facies above the cement rock facies. However, inspection of the Northampton quarry does not show this overturned sequence. The argillaceous limestone is located at the top of the quarry and the two crystalline units are at the bottom. This evidence shows that the quarry is actually located where the Northampton nappe is being overturned (right side up).

The second folding event is characterized by small crinkle folds and larger open folds superimposed on the initial folding event that deformed the bedding and flow cleavage of the original rock units (Sherwood, 1964). Graphitic slickensides show evidence of this secondary

folding event in the quarry. The folding was so disruptive to the original structure that it is very difficult to see any distinct contacts.

EGYPT QUARRY

The Egypt quarry is also located in the Northampton nappe of the Jacksonburg Formation. Unlike the Northampton quarry, the sequence of rocks in Egypt is more characteristic of the Northampton nappe: they are overturned with the oldest units on top.

Beyond the geology of the quarry, this was a green field project for the Whitehall plant. Because of the opportunities presented with a new quarry, it is our objective to try new innovative ideas and correct mining mistakes of the past. Some of the new ideas that are being tested and implemented are:

Farmable berms. Instead of unsightly stripping piles, all stripping is being hauled to berms designed with slopes that can be farmed.

Mechanical mining. Tests were conducted to evaluate the feasibility of mechanical mining at the quarry. Results show that mechanically, this mining method is very impressive. It eliminates drilling, blasting, mucking, and primary crushing.

Implementing non-traditional de-watering methods. The objective is to eliminate large sumps, standing water on benches, headaches of standard piping, and other historical problems associated with water control.

Leave Stop 3. TURN RIGHT onto PA Route 329.

0.2 15.5 **Stop Light. TURN LEFT** onto Laubach Avenue.

0.8 16.3 **Stop Sign.** Proceed straight ahead.

0.1 16.4 **Stop Light. TURN LEFT** and cross Hokendaugua Creek. Now on Main Street.

0.1 16.5 **Stop Light.** Proceed straight ahead.

0.1 16.6 **Stop Light. TURN RIGHT** onto 9th Street and pass over Lehigh River.

0.3 16.9 **Stop Light. TURN RIGHT** onto North 2nd Street.

0.1 17.0 **Stop Sign.** Proceed straight ahead.

0.1 17.1 **TURN RIGHT** into parking lot of Saylor Park.

STOP 4. LUNCH AND SCHOEFER KILNS.

Lunch will be catered at the pavilion. There is a tour guide present at the kilns to provide information and direction to the museum that is operated by the Lehigh County Historical Society. Please avail yourself of the opportunity either before or after you have eaten lunch.

SAYLOR CEMENT MUSEUM

Portland cement is made from rocks containing lime, silica, and alumina; Lehigh County cement rock contains all three ingredients. The rocks must be burned and cooled to form clinker, a marble-sized cement product. The first kiln used here at the Coplay Cement Company was a dome kiln. Laborers shaped the raw materials into bricks then loaded them into the kiln to be burned between layers of coal. Dome kilns were inefficient. The materials burned unevenly, and the kilns had to shut down often so workers could remove clinker.

In 1893 Coplay Cement built Mill B (Figure 38), containing the Schoefer kilns (Figure 39) that are still standing today. These kilns worked the same way as a dome kiln, except that

they could run continuously. Originally enclosed in a large building, the kilns were just part of the factory complex (Figure 39) necessary for cement production:

1. Store house. Raw materials arrived here by railroad, many directly from the company's nearby cement rock quarry.
2. Raw materials mill. Here the rocks were ground into a fine powder.
3. Brick factory. Laborers shaped the ground raw materials into bricks.
4. Brick dryer. Bricks were dried.
5. Elevator. Bricks and coal were raised.
6. Loading. Coal was loaded into the kilns through the top door. The bricks went in at the next level and the clinker was unloaded at the bottom.
7. Cement mill. Clinker traveled by inclined plane to the cement mill where the marble sized pieces were ground into cement powder.
8. Stock house and cooper shop. The finished cement moved by conveyor bridge to the stock house, where it was placed into barrels made in the cooper shop. The cement was shipped by railroad.

Unfortunately, Coplay Cement made a bad business decision when they built the Schoefer kilns. Across the Lehigh River in Northampton, the Atlas Cement Company built America's first rotary kiln and discovered a way to make it operate with cheap fuel. The rotary kilns not only ran continuously, they also eliminated the need to shape raw materials into bricks. Coplay's Schoefer kilns were soon outdated and they were shut down in 1904, replaced by rotary kilns.

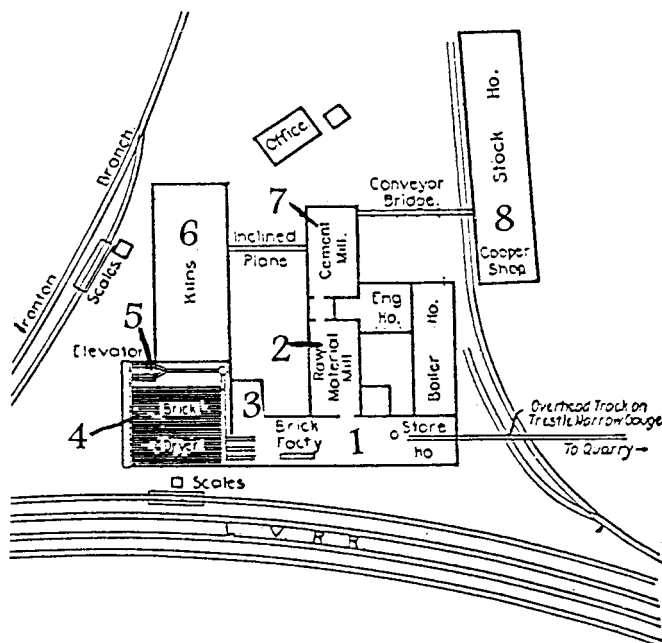


Figure 39. Diagram of Coplay Cement Mill B

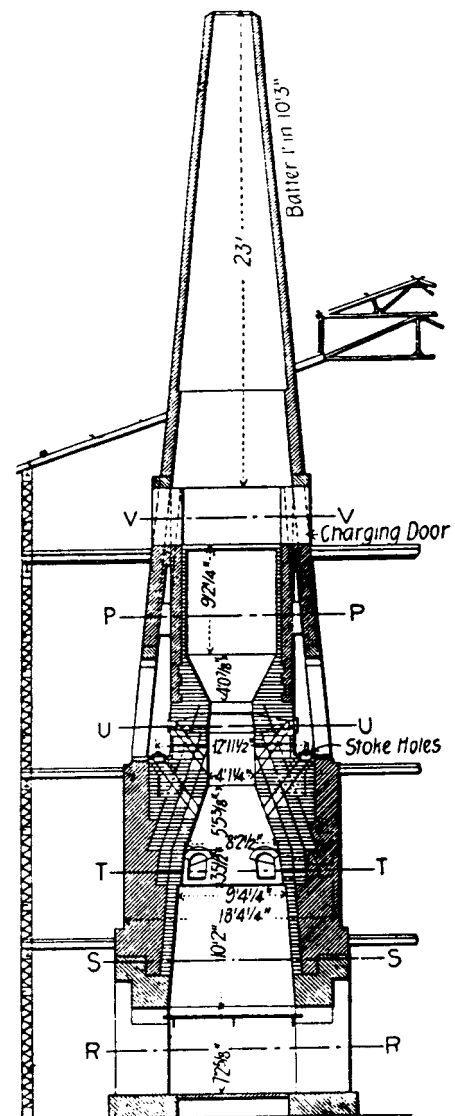


Figure 40. Cross section through kiln.

- Leave Stop 4. TURN LEFT** onto North 2nd Street.
- 0.1 17.2 **Stop Sign. TURN RIGHT** onto Keefer Street.
- 0.1 17.3 **Stop Sign. TURN LEFT.**
- 0.1 17.4 **Stop Light. TURN RIGHT** onto Chestnut Street.
- 0.6 18.0 **Stop Sign.** Proceed straight ahead.
- 0.3 18.3 **Stop Sign. TURN LEFT** onto 6th Avenue.
- 0.3 18.6 **Stop Sign. TURN RIGHT** onto South Church Street.
- 0.1 18.7 **Stop Light.** Proceed straight ahead across PA Route 145.
- 0.5 19.2 **TURN LEFT** into Whitehall Quarry access road.
- STOP 5. EASTERN INDUSTRIES, INC. WHITEHALL QUARRY**
Leader: Michael Slenker

HISTORY

The currently active quarry is an expansion of the abandoned Lehigh Portland Cement Co. quarry. Eastern Industries purchased the property in 1960. Initially only 2A subbase material was produced. The adjacent property to the southwest was purchased in 1975 and it was discovered that dolomite and limestone of the Epler Formation occurred at a depth of 70 ft. In 1985, after a test-drilling program, it was determined that relatively higher calcium carbonate limestone occurred in two areas of the quarry. Sales of this "high calcium limestone" to local cement plants soon began. It is well known that the reason the Portland cement industry centered in this eastern Pennsylvania region is because the argillaceous limestone had the exact impurities needed for cement manufacture. Additions of clay, iron, and sand are rarely needed and the availability of the nearby Annville and other high calcium limestones make the location ideal. Kiln temperatures can be lower if the correct mix is already in the limestone.

ECONOMICS

Seventy five percent of the sales at Whitehall are of 2A and 3A subbase aggregate. Fifteen percent of sales are of #1 "white" screenings used primarily for cement block production. The remaining 10 percent of sales are of high calcium limestone sold to local cement plants to "sweeten" their raw mix. The high calcium limestone is sold as shot rock and does not need to be processed through the crushing and screening plant. It is loaded directly from the muck pile onto steel-bodied trucks. It is necessary to selectively mine the high calcium limestone. This requires a chemical laboratory to be located on the property to analyze for calcium carbonate. Drill cuttings are collected and labeled in paper bags every 5 ft when drilling in a possible high calcium area. The samples are then selected, dried, pulverized, and analyzed with an EGTA titration test method that is accurate to 0.5% CaCO₃. The minimum guarantee is 80% CaCO₃. An occasional 5 ft sample will reach 92% CaCO₃, but an average of 84% CaCO₃ is generally maintained. When in doubt, a "ring or crinkle" sound will help determine the calcium carbonate content. However, some of the pure dolomite will also "ring" and a dilute (8% HCL) acid test is needed.

The magnesium content is also very important along with iron, aluminum and silica. One of the two high calcium areas of the quarry was abandoned for high calcium sales because, even though it contained the required calcium, it was too high in magnesium. The lab at Whitehall

tests only for calcium carbonate. It is assumed that the limestone that is high in calcium carbonate will meet the cement company's chemical range for the other minerals. The shipments are checked at the larger and better-equipped cement company chemical labs.

Some shots end up as a mix of high and low calcium limestone. With quarry planning, there is an attempt to isolate the high calcium limestone. However, the dip of the beds and natural lateral variations of the calcium content of the limestone sometimes require the blasters to try to "throw" the top, bottom, left or right parts of a shot in opposite directions in an effort to isolate the high calcium from the lower calcium limestone. Even with all this effort, it is sometimes necessary to use a bulldozer to further separate a shot. All the limestone not shipped to the cement plants is used for 2A-subbase aggregate production.

The Jacksonburg limestone from the more crystalline beds does produce a type "A" aggregate that will pass Penn-Dot (Pennsylvania Department of Transportation) specifications. The Jacksonburg limestone tends to break into elongated pieces. This elongation causes problems with the strength and finishing qualities of ready-mix cement and asphalt. However, certain crushers can help alleviate the elongated-shape problem. The argillaceous limestone from the cement rock facies usually fails the PennDot sodium sulfate test which simulates freezing and thawing. For these reasons Eastern Industries produces only type "A"-2A subbase and #1 screenings from the Jacksonburg limestone. The "road aggregate" will continue to be produced from the Epler Formation dolomite and limestone at the Ormrod/Lehigh Quarry which is the next stop on the tour (Stop 6).

GEOLOGY

The quarry occurs predominately in the Jacksonburg Formation of Ordovician age (Figure 41). The controlling structure in the quarry is an overturned syncline with an axis bearing N63°W (Figure 42). Two smaller, overturned anticlines with their associated overturned syncline were discovered in the Epler Formation, also of Ordovician age, as they were exposed by mining. They have the same general axis bearing. First-generation folds are recumbent and isoclinal, probably associated with the "Northampton nappe" that extends from Weaversville, PA to nearby Ironton (a distance of approximately 3 miles) and caused abundant axial plane flow cleavage. Second-generation folding deformed preexisting beds and was responsible for associated slip cleavage. The two visible folds evident in the Epler are probably second-generation folds that are smaller and superimposed homoaxially on the first generation folds. The appearance of the Epler in this position of the quarry was a surprise and is contrary to what we would expect with the large overturned syncline as seen on cross-section D-D'. Possibly, a previously unseen anticline of smaller magnitude than the overturned syncline is responsible. There are no exposed traces of a fault that would cause the Epler to appear here.

Jacksonburg Limestone Formation

The Jacksonburg Formation has been generally divided into two units: the upper Cement Rock Facies rests comfortably on the lower Cement Limestone Facies. The maximum thickness of the Jacksonburg in eastern Pennsylvania is generally around 1,150 ft. The Cement Rock Facies can be divided into three sub-units. On top is the "argillaceous limestone" (dirty limestone). Bedding is usually totally obliterated by the flow cleavage in the "argillaceous limestone". This youngest member also comprises the bulk of the formation. This is a dark gray to almost black,

fine grained, argillaceous limestone with evident flow cleavage. Some carbonaceous content occasionally produces shiny graphite surfaces occurring along shear planes or slickensides. Interbedded in the "argillaceous limestone" near the middle is the "upper crystalline limestone",

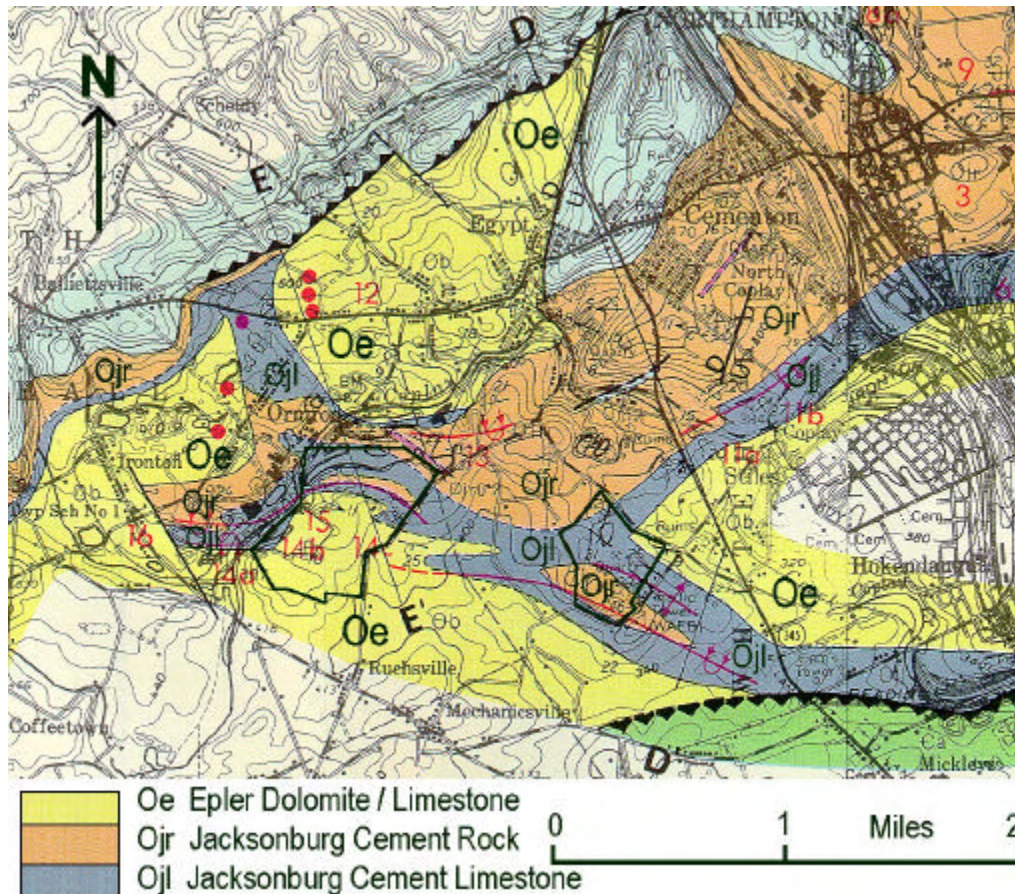


Figure 41. Geologic map of Jacksonburg and Epler Formations at the Whitehall (right outlined quarry) and Ormrod/Lehigh (left outlined quarry) quarries. From Sherwood, 1964.

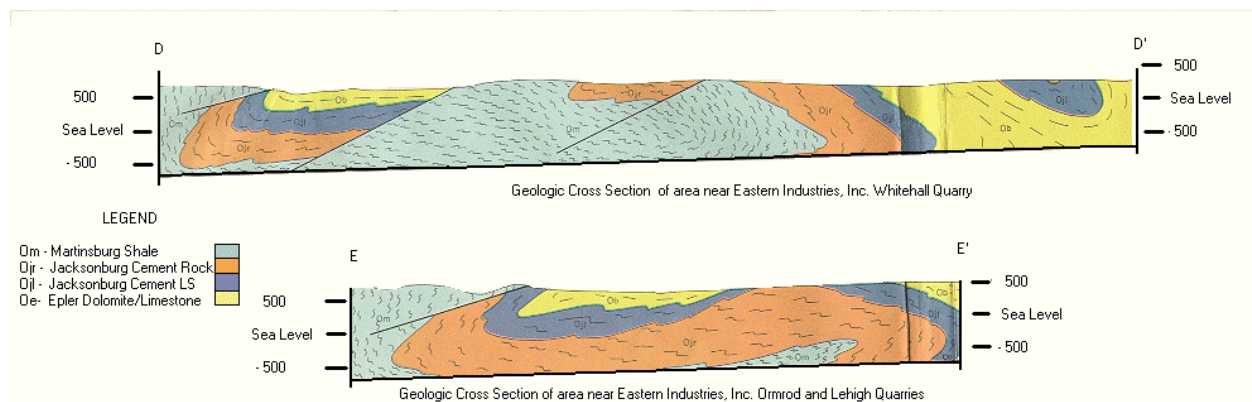


Figure 42. Cross sections D-D' for the Whitehall Quarry and E-E' for the Ormrod/Lehigh Quarry. See Figure 41 for locations of cross sections. From Sherwood, 1964.

which is a layer of less argillaceous limestone. Another layer near the bottom of the "argillaceous limestone" is the "lower crystalline limestone". These two crystalline limestones are medium gray and coarsely crystalline. The lower sub-unit is the slightly coarser of the two. The crystalline limestones thin to the west and finally disappear around Fogelsville. Not present in most descriptions of the Jacksonburg Formation is the presence of a 15 to 20 ft thick dolomitic bed which at Whitehall separates the "upper crystalline limestone" from the "lower crystalline limestone". It is possible that this dolomitic bed occurs within one of these crystalline limestone beds (probably the upper crystalline limestone) and does not actually separate the two sub-units.

The units mined at Whitehall are: (1) It is believed that the "argillaceous limestone" of the Cement Rock Facies is used for the bulk of the aggregate production. It is possible that some of the beds that are described and mapped as the argillaceous limestone of the Cement Rock Facies at this quarry are actually less carbonaceous beds of the Cement Limestone Facies. It is known that the calcium carbonate content of these beds drops off significantly and for quality control purposes they were all classified as Cement Rock. The exact contact of the Cement Limestone and the Cement Rock Facies has not been established at Whitehall yet. (2) It is believed that the "lower crystalline limestone" and the "upper crystalline limestone" are used for the high calcium sales. (3) Finally, the Epler Formation is used for the "white" dolomite screening production. It is believed that the lowest beds of the cement limestone facies are the high calcium limestone beds that were rejected by the cement companies due to a higher magnesium carbonate content (7% MgCo₃). This rejected area occurs in the beds at the southwest end of the quarry, next to the disconformable contact of the Epler Formation and the Jacksonburg cement limestone facies.

In general, the Jacksonburg can be considered to have a gradational change from the older carbonates of the Beekmantown Group, through the cement limestone facies, then into the argillaceous limestones and on up to the younger Martinsburg shales above. Thus, the stratigraphic sequence generally picks up more detrital sediment and becomes less carbonaceous (except for the two crystalline limestone layers located within the cement rock facies) as the sediments get younger.

Epler Formation of the Beekmantown Group

The Epler limestone/dolomite is a light gray, thickly bedded, finely crystalline dolomite interbedded with medium gray, finely crystalline limestone. This interbedding becomes evident in faces of the quarry that have been exposed to weathering for several years. The dolomite weathers to a tan color while the limestone remains a medium gray. Approximately 30 percent of the exposed beds seem to be limestone. The axes of the exposed overturned anticlinal folds trend northwest toward the Ormrod/Lehigh Quarry, which is the next stop on the tour (Stop 6).

Bentonites

Beds of bentonite are found in all the cement companies quarries mining the Jacksonburg. Five beds are readily evident at Whitehall. They range in thickness from 3 to 36 inches. Pyrite cubes are evident in two of the beds. Early X-ray diffraction studies identified strong montmorillonite and quartz peaks. Presently, it has not been determined if these bentonite beds are related to the bentonite beds located in central Pennsylvania.

WALKING TOUR – WHITEHALL QUARRY

Geology and sites of stops for the walking tour are shown on Figure 43.

- Stop 1. High calcium crystalline limestone beds.
15-ft thick dolomitic bed separating the crystalline members.
Clay seam - sinkhole. No fault displacement noted.
"Marker beds" 1 to 24 inches thick, with secondary mineralization and drag-like folding are sometimes used to separate various chemical beds.
- Stop 2. 3-ft thick bentonite bed. On top is crystalline limestone and below argillaceous limestone.
- Stop 3. Syncline (?); strike of axis - N60°W; Plunge unknown.***
Bentonite bed with pyrite cubes to right.
To left small fault; strike N30°W, dip 20°NE.
*** anticline syncline determination based on the relationship to the Epler Formation located to the southwest in this part of the quarry.
- Stop 4. Anticline; axis strike E-W; axis plunge unknown.
Syncline; axis strike E-W; axis plunge unknown.
Possible fault; strike N30°W; dip 40°SW.
On bench above: Anticline; axis strike E-W; axis plunge unknown. Normal fault; strike N40°W; dip 80°SW.
- Stop 5. Anticline-syncline-anticline sequence.*
Top anticline; axis strike N80°W; axis plunge unknown.
Mid syncline; axis strike N75°W; axis plunge unknown.
Bottom anticline; axis strike N85°W; axis plunge horizontal.
*Recumbent fold
- Stop 6. Anticline; axis strike N60°W; axis plunge 7°NE.
Possible controlling fault with horizontal slickensides. Strike N50°E; dip 23°SE; NW fault block moved SW. Also in the bench above, 40 ft to the NW, possibly an associated fault with approximately the same strike and dip.
- Stop 7. Two bentonite beds.
Beds dip to the east at top of ramp.

Leave Stop 5. TURN RIGHT onto South Church Street.

- 0.1 19.3 **TURN RIGHT** onto Columbia Street.
- 1.1 20.4 **Stop Sign. BEAR RIGHT** onto Peach Tree Road.
- 0.7 21.1 **Stop Sign. TURN RIGHT** onto Mauch Chunk Road in Mechanicsville.
- 0.4 21.5 **Stop Light.** Proceed straight ahead through Ruchsville.
- 0.8 22.3 **TURN RIGHT** onto Quarry Street.
- 0.6 22.9 **TURN RIGHT** into quarry entrance, Baseline Contracting Inc.
- STOP 6. EASTERN INDUSTRIES, INC. ORMROD/LEHIGH QUARRY.**
Leader: Michael Slenker

Figure 43. Aerial photograph of the Whitehall quarry and local environs. The numbers 1-7 are the sites of stops along the walking tour of the quarry. The other half of the aerial photograph is on the opposite page.





HISTORY

The active quarry is now actually a single quarry that is the result of one quarry "day-lighting" into another. The original Eastern Industries quarry, called the Ormrod Quarry, began operation in 1972. It began in an existing, very small cut in the hillside at the north end of the property and proceeded in a southerly direction through a farmfield and at a higher topographic level. The high topographic level had very little clay overburden. As the mining proceeded to the southern end of the property, the clay overburden increased in thickness as the topography lowered. The combination of the lower starting elevation, the increased clay overburden, and the presence of sinkholes in the low areas made the mining of clean aggregate stone a costly endeavor at Ormrod.

The property located directly west of the Ormrod Quarry, called the Lehigh Stone Quarry, had a smaller aggregate plant and quarry that previously was in operation since about 1900 or earlier. It is an extension of the Lobach Quarry which was worked for high-calcium limestone for some of the cement plants. At one time Giant Portland Cement Co. mined high-calcium limestone here. Some was sold to Lehigh Portland Cement Co. Eastern Industries recently filled in the high-calcium quarry with overburden. This old water filled quarry was located directly south of Quarry Street which runs by the entrance to the quarries. Since the early sale of high-calcium stone, the quarry has produced only aggregate stone. When the Lehigh Stone property became available in 1988, it was purchased by Eastern Industries, Inc. for its aggregate reserve. If high-calcium limestone is encountered at depth in the Jacksonburg along the contact with the Epler, it will be considered for sale to cement companies. To date, the test holes in the property have found that any high calcium limestone encountered is not of a large enough intercept to be considered for selective mining.

ECONOMICS

Presently 100 percent of the sales at Ormrod/Lehigh are for aggregate. Around 1987 a small amount of high-calcium limestone was sold to cement companies from the Ormrod Quarry. This high-calcium limestone came from the east side of the quarry where the Epler Formation limestone/dolomite is in contact with the Jacksonburg Formation. Mining was stopped in this eastward direction because the PennDot type "A" Epler Formation dolomite/limestone was exhausted. Several shots of the cement limestone facies of the Jacksonburg Formation were sold to a cement company. Then, mining was stopped in this direction to eliminate the possibility of the adjacent abandoned Giant Portland Cement Co. water filled quarry (now owned by the Ranger Lake Rod and Gun Club) from flowing into the Ormrod Quarry. This property, directly west of Ranger Lake, is also owned by Eastern and future reserves of Jacksonburg limestone, similar to the Whitehall Quarry, eventually will be mined. The dolomites and limestones of the Epler Formation make an excellent aggregate that produce very good Penn-Dot results for the LA-abrasion and sodium sulfate tests. The particle shape of the dolomite is usually cubical while the limestone is somewhat more elongated. Limestone and dolomite, are excellent sources for aggregate, because they are not abrasive enough to wear down the iron and steel of the crushing and screening plant, but they are still very sound physically. Sandstones and most igneous rocks also make excellent aggregate, but production costs are much higher because of their abrasive nature. In roadway surface applications where skid resistance is important and for railroad ballast where durability is important, aggregate other than dolomite or limestone is needed. Future

production in the Jacksonburg Formation from the Ormrod Quarry towards Ranger Lake will be exclusively 2A subbase and #1 screenings similar to what is now being produced at the Whitehall Quarry.

HYDROLOGY

The floor of the Ormrod Quarry is 120 ft below the water level of Ranger Lake and only 500 ft to the west at one location (Figure 44). Every time Eastern Industries needed to proceed 40 ft deeper in the Ormrod Quarry, it was necessary to sit before the North Whitehall Township Board of Supervisors with proof that the preceding mining had not affected the water of Ranger Lake. At the time of the first appearance before the Board, the late Dr. Carl Warmkessel testified that the Jacksonburg Limestone is a "tight" limestone, not prone to sinkholes or solution channeling and has relatively low permeability compared to other limestones and dolomites due to its argillaceous nature. Dr. Warmkessel was the geologist for the Giant Portland Cement Company that operated the quarry that is now Ranger Lake. To date, he was correct in predicting that the Jacksonburg barrier would prevent or slow down any water flow from Ranger Lake west to the Ormrod Quarry. Presently, there is no water being pumped from the Ormrod Quarry to the nearby Coplay Creek. Any water that collects at the bottom of the quarry is only used for make-up water for the recirculated aggregate washing plant.

After 1988, when the Lehigh Stone Company was purchased, nearly all the production came from the Lehigh Quarry. As mining progressed for two added 40-ft deep levels, it became apparent that water was entering the quarry from the west-northwest end of the quarry. The groundwater flow in this area is generally to the southeast. The position of Coplay Creek and an abandoned water filled quarry (previously operated by the Whitehall Cement Co. now Lafarge) located to the north-northwest dictated that mining proceed to the southeast. For this reason, the north and northwest faces of the quarry will remain until full depth (80 ft deeper) and the full lateral expansion to the southeast is attained for the remainder of the quarry. At a later time, as sort of a last mining effort, the north and northwest faces will be completed. In this manner, if the water from the Coplay Creek or the abandoned quarry were to break through, less reserves would be lost if the quarry had to be abandoned. Presently, from the Lehigh Quarry, only a small volume of mine de-watering water is pumped through a settlement basin to the Coplay Creek. The two quarries were joined in 1997 when the top level of the common wall joining them was mined. Eventually, the Ormrod Quarry, the Lehigh Quarry, and the future Jacksonburg mining between the Ormrod Quarry and Ranger Lake will all be one large water reservoir. A section of the western highwall of Ranger Lake will be mined out joining this reservoir to Ranger Lake and creating a 185-acre lake following reclamation.

GEOLOGY

The two quarries occur predominately in the Epler Formation of Ordovician age. The controlling structure in the area is an overturned syncline with a curved "S"-shaped axis generally bearing east-west. Most of the folding seems to take place near the contact with the Epler and the Jacksonburg along the northern side of the quarry. The smaller folds here are probably second-generation folds which have similar bearing axis's to the general east-west overturned syncline which is first generation.



Figure 44. Aerial photograph showing Ormrod/Lehigh quarries and the geology of the area. The numbers 1 - 8 are the sites of stops along the walking tour of the quarry. The other half of the photograph is on opposite page.

The summaries of the Jacksonburg and the Epler Formations are contained in the descriptions for Stop 5 (p. 92) and are not repeated here. Several differences are noted however. The Epler Formation at Ormrod/Lehigh Quarry, especially near the contact with the Jacksonburg, seems to have a higher proportion of limestone to dolomite than at the Whitehall Quarry. In some shots of the top level of the Lehigh Quarry, towards the south face, the intensely folded beds create a problem with the physical characteristics of the aggregate. Some of the limestone has become brittle and much of it becomes soft and powdery. Some of the shots actually had to be wasted to the overburden pile because of this problem. If this stone were to be produced for aggregate, it could break down in its asphalt or concrete final uses. Also, at Ormrod/Lehigh, there are numerous sinkholes while at Whitehall just one is evident. There is considerably more stripping at the Ormrod/Lehigh Quarry than at the Whitehall Quarry. However, sale of the clay helps reduce the stripping costs.

ENVIRONMENTAL

Located one mile north of the Ormrod/Lehigh Quarry is the Heleva Landfill, which was identified as a CERCLA Federally Funded Superfund Site. The main pollutant is TCE, but other VOC pollutants are also involved. Eastern Industries is working with the US-EPA with regard to the Heleva site. Four monitor wells are located on the Lehigh property and water samples from these wells along with quarry water is tested semi-annually. To date, no pollutants have been found in the water, but some traces have occurred in several deep private wells in the area. The TCE is heavier than water and any plume will tend to flow deep. As mentioned earlier, the groundwater flow is generally to the southeast, however, the local shallow surface flow is probably north toward the Coplay Creek. The landfill is capped with clay and attempts to aerate have been tried and others are planned. Heleva is of great concern because of its potential impact on the planned 185-acre lake.

WALKING TOUR - ORMROD / LEHIGH QUARRY

Geology of the quarry and sites on the walking tour are shown in Figure 44.

- Stop 1. Concurrent reclamation has begun to the southwest. Bus stop -- Note karst surface with pinnacles to the south.
Water pumped from west-end of quarry. Note water entering quarry from west-ern faces.
- Stop 2. Epler dolomite on top of this block that slipped down.
- Stop 3. ??? Seems to be Jacksonburg on top here. It makes more sense that the limestone on top is just limestone interbedded within the Epler.
- Stop 4. Syncline? - axis strike N15°E; axis plunge 15°W.***
Note exfoliation along shale interbeds.
* * * anticline - syncline determination based on relationship to the underlying Jacksonburg limestone which is overturned at Ormrod/Lehigh.
- Stop 5. Syncline - axis strike N15°E; axis plunge 17°W. Also associated anticline to the east.
- Stop 6. Sinkhole - possible fault ?
Anticline syncline pair on each side of sinkhole.
- Stop 7. Anticline - syncline - anticline.
West anticline - axis strike N45°E; axis plunge 5°W.

East anticline - axis strike N40°E; axis plunge 7°W.
 Note striped, altered appearing limestone occurring to the west of the east syncline.
 Stop 8. North wall anticline - axis strike N60°E; plunge 12°W
 East wall series of anticlines and synclines. Starting from north: Syncline axis strike. N70°E; axis plunge approximately horizontal (note soft, altered-appearing limestone at apex of fold). Strike of beds between folds - strike N80°E; dip 40°S. Anticline - axis strike E-W; axis plunge 10°E. Syncline - axis strike E-W; axis plunge 10°E.
 On north face of bench below - anticline; axis strike N20°E; axis plunge 27°W.

Leave Stop 6. TURN RIGHT onto Quarry Street.
 0.6 23.5 **TURN RIGHT** onto lane leading to Fisher's Paradise, Ranger Lake.
STOP 7. RANGER LAKE.

Ranger Lake is only a drive-by, we will not be exiting the buses at this stop. The purpose is to allow you to view up close the current use of an abandoned water-filled quarry. Fishing is the primary interest here although we will be turning the buses at the site of a well-used shooting range. Note the quarry wall on the far side of the lake. This is the rock wall that will be quarried away in the final stages at the Lehigh Quarry to allow the two lakes to connect. As you might guess, successful containment of the contaminant plume from the Heleva Superfund site is important to Ranger Lake and its future enlargement.

Leave Stop 7. TURN LEFT onto Quarry Street.
 1.1 24.6 **TURN LEFT** onto Mauch Chunk Road.
 0.3 24.9 **TURN RIGHT** onto Cedar Crest Blvd.
 0.8 25.7 **Stop Light. TURN RIGHT** onto Orefield Road.
 1.1 26.8 **Stop Sign. BEAR RIGHT** following Orefield Road.
 1.1 27.9 **Stop Light. TURN LEFT** onto PA Route 309.
 0.5 28.4 **Stop Light.** Proceed straight ahead.
 0.7 29.1 **Stop Light.** Proceed straight ahead.
 0.7 29.8 **Stop Light.** Proceed straight ahead.
 0.2 30.0 **Stop Light.** Proceed straight ahead.
 0.3 30.3 **Stop Light. TURN LEFT** onto Ridgeview Drive. Immediately **TURN RIGHT** onto Bulldog Drive.
 0.5 30.8 Arrive at parking lot of Days Inn Conference Center. **End of Day 1.**
Remember: Social hour at 6:30 pm and Annual Banquet at 7:30 pm.

ROAD LOG – DAY 2

Mileage Inc.	Total	Description
0	0	Leave parking lot of Days Inn Conference Center. Follow Bulldog Road north paralleling PA Route 309.
0.4	0.4	Stop Sign. TURN LEFT onto Ridgeview Drive.
0.1	0.5	Stop Light. Proceed straight ahead across PA Route 309.
0.1	0.6	TURN LEFT onto Hausman Road.
0.3	0.9	Stop Sign. TURN RIGHT onto Crickersport Road.
1.6	2.5	Stop Sign. TURN LEFT onto Blue Barn Road. Stop Light. Proceed straight ahead.
0.2	2.7	Pass under Interstate 78.
0.1	2.8	TURN LEFT onto Oak View Drive.
0.8	3.6	BEAR RIGHT onto Oak Lane.
0.2	3.8	Stop Sign. TURN RIGHT onto Werley Drive.
0.2	4.0	Pull off onto right side of road. STOP 8.
STOP 8.		PSEUDO-MORAINIC TOPOGRAPHY
		Leader: Duane Braun

This stop is one of the few remaining places that the pocket wetlands (vernal ponds) in the depressions on the pseudo-moraine can be readily seen. In coming years this last bit of farmland will become developed for housing or commercial uses like the surrounding area already has been developed. You may have noticed that development is already starting on the east side of the road across from the farmhouse behind us. This property is farmed by a tenant; the owner lives in California. Fragments of the pseudo-moraine will only be preserved at wooded sites in a few local parks unless somebody finds some endangered species in the

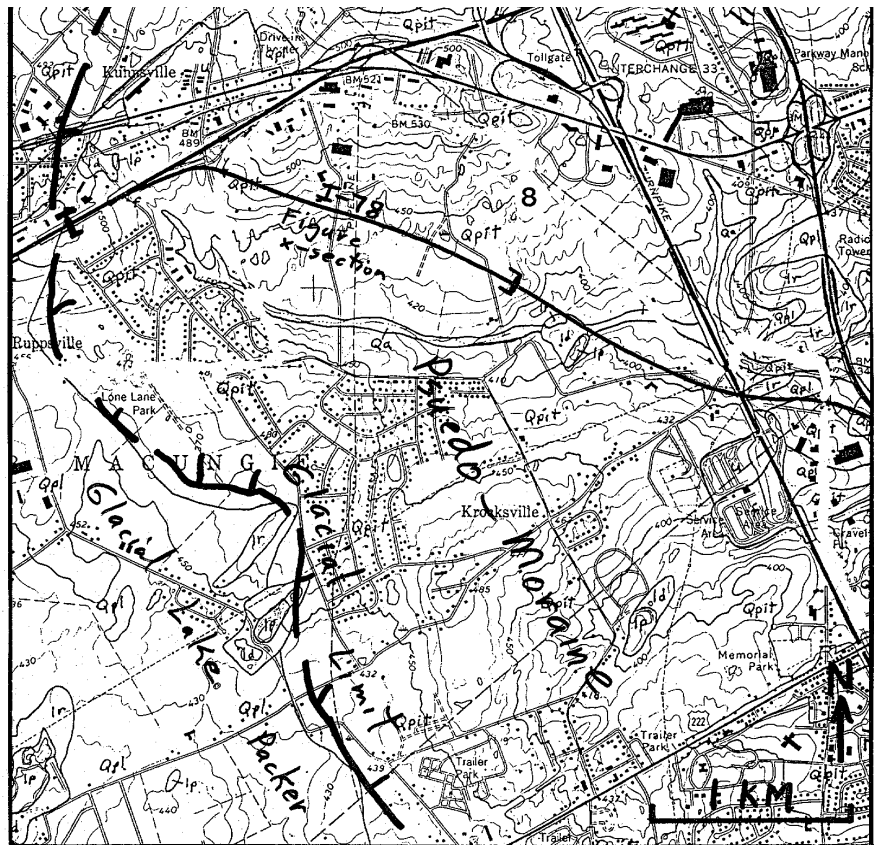


Figure 45. Surficial geology map of part of the Allentown West 7.5-minute quadrangle. Number 8 is site of Field Conference Stop. Map units identified in Figure 48, p.110.

wetlands at this site to preserve the current land use.

On the topographic map (Figure 45) the pseudo-moraine is shown as a series of small ponds and depression ovals. An aerial photograph of the site (Figure 46) shows many more, such features. As discussed earlier (p. 36), this morainic-looking landscape is not a moraine because the entire landscape has been lowered about 100 ft since this area was glaciated about 850,000 years ago (Figure 20, p. 37). There once was a moraine here, but as this carbonate landscape was lowered by repeated sinkhole collapse, the original moraine landform was totally destroyed. While this collapse process was taking place, there were repeated cold climate episodes (about 9 of them) that brought periglacial conditions to this area. These periglacial episodes caused the development of in-ground ice masses and the melting of these ice masses in turn caused the depressions that we see here today as a pseudo-moraine.



Figure 46. Stereographic pair of aerial photographs showing the area of Stop 8.

		Leave Stop 8. Proceed straight ahead.
0.8	4.8	T-Intersection. TURN LEFT. Immediately, Stop Sign. TURN RIGHT onto Cetronia Road.
0.7	5.5	Stop Sign. TURN LEFT onto Krocks Road in Krocksville.
1.0	6.5	Stop Light. Proceed straight ahead across US Route 222.
0.4	6.9	Stop Sign. Proceed straight ahead.
0.6	7.5	Stop Light. TURN LEFT onto Lower Macungie Road.
0.5	8.0	Stop Light. Proceed straight ahead.
0.3	8.3	Stop Light. TURN RIGHT onto Brookside Road.
1.6	9.9	Bottom of hill, Brookside Country Club golf course on right.

- 0.8 10.7 **Stop Light.** Proceed straight ahead across Buckeye Road. To the right (west) is the borough of Macungie. On June 23, 1986 a large sinkhole opened suddenly in a street separating an apartment and a townhouse complex in the southwest part of Macungie. The sinkhole measured approximately 75 ft in diameter and 35 ft in depth. Damage to the street and buried utility lines was extensive. The collapse occurred in colluvial and recent fill materials overlying the Middle Cambrian Leithsville Formation. Aerial photographs on file at the Pennsylvania Geological Survey in Harrisburg showed an interesting history for the sinkhole. In 1947 the sinkhole was a roughly circular water-filled pond roughly 200 ft in diameter. In 1958 there was a deep hole with no water and 1-3 probable openings that drained the pond. In 1964 and 1971 the hole was filled and cultivated. Repair of the sinkhole occurred over a period of more than 3 months and cost the borough more than \$400,000. We lack information on liability claims. (from Kochanov, 1987)
- 0.7 11.4 **Stop Sign. TURN LEFT** onto PA Route 100, Kings Highway North.
- 1.0 12.4 **Stop Sign. BEAR RIGHT** following PA Routes 100 and 29.
- 0.2 12.6 **Stop Light.** Proceed straight ahead.
- 1.3 13.9 **TURN RIGHT** into parking lot of Nancy's Garden which is owned by Nancy's Nursery southwest across the road. Park at the south end of Nancy's Garden parking lot near the chain link fence. This parking lot is private property and permission to park here while visiting the site should be obtained. Note that although the site being visited is not marked for No Trespassing, it is private property. Current ownership of the property is unclear so liability is also unclear. Be careful! The Field Conference expresses special thanks to the owners and operators of Nancy's Nursery for allowing us access to Nursery grounds and providing parking space for buses.

STOP 9. HIGH QUALITY POLISHING

Leader: J. E. Godfrey

The High Quality Polishing Site is a former electroplating facility on a 2-acre property, approximately 50 ft off PA Route 100 and $\frac{3}{4}$ mile southwest of Old Zionsville in Lehigh County, Pennsylvania (Figure 47). The site consists of a large process building and two unlined, 'dry' lagoons. The facility operated for approximately 23 years from 1959 or 1960 to 1983 when it became inactive and abandoned. Before its closure in 1983, metal products were cleaned, reshaped, repaired, and electroplated with various finishes. The company used a variety of materials including acids, cyanides, caustic cleaners, metal alloys, and paint (Halliburton NUS/Gannet Fleming, 1995). At the time of abandonment, the site contained approximately 100 55-gallon drums and more than 13,000 gallons of various liquids and sludges. Most of the tanks and vats were extensively corroded. The drums contained both raw materials and waste products from tank-cleaning operations.

On-site groundwater is contaminated with trichloroethene (TCE) and other chemicals as a result of past electroplating activities. Well-water sampling results indicate that TCE has migrated off site to two commercial (irrigation) wells at Nancy's Nursery in the property adjacent to the site. Nancy's Nursery wells are slightly up gradient of the former disposal lagoons (Figure 41) and about 100 ft apart. Wells #1 and #2 are each drilled to a depth of 200 ft and have surface casing lengths of 52 ft and 32 ft, respectively. The combined yield of the wells (90 gal/min) has been sufficient to hydraulically capture contaminated groundwater from the site. TCE at con-

centrations up to 1,800 g/L (ppb) has been reported in Nancy's Nursery well #2. Preliminary sampling results indicate that well #2 (farthest from lagoons) has the higher TCE concentration. This is probably because it has the higher yield (55 gal/min) and may be better connected through fractures to residual zones of TCE in the subsurface. Sampling results from all nearby private wells show that only on-site monitoring wells and Nancy's Nursery wells are contaminated by the site at this time.

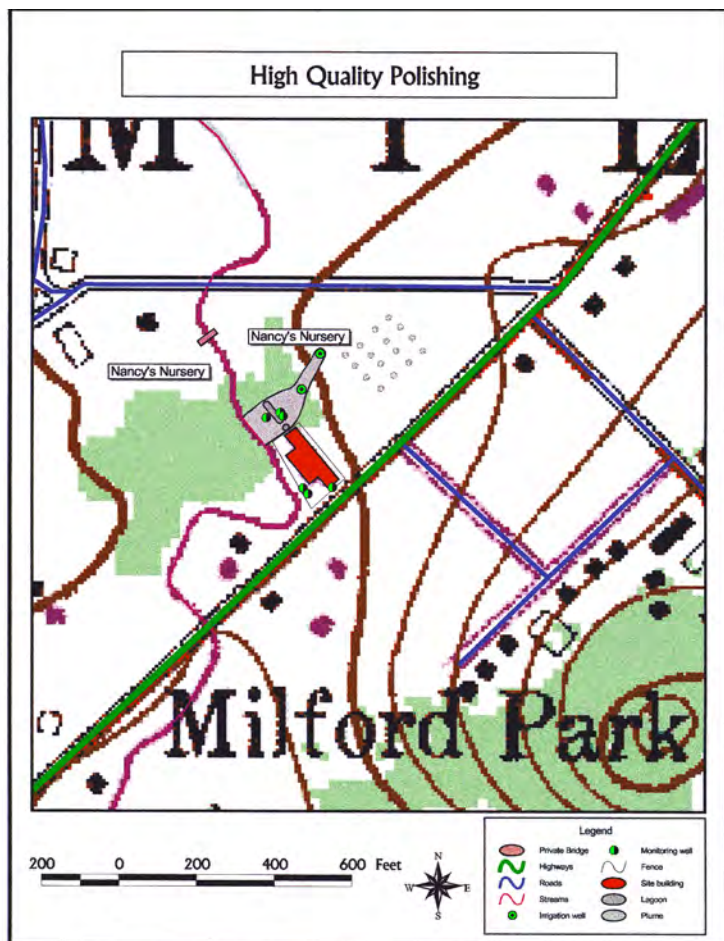


Figure 47. Location map for High Quality Polishing environmental site. Road immediately southeast of site is PA Route 100. Contour immediately east of site is 700 feet. Contour interval = 20 feet. Elevation rises to east.

Pennsylvania Department of Environmental Protection requested that Pennsylvania Department of Health review analytical data and determine if use of contaminated groundwater at Nancy's Nursery presents a public health threat to workers and customers. The TCE concentration of 1,800 ppb is near the odor threshold for sensitive individuals. Workers who might shower in the water or workers and customers in a poorly ventilated greenhouse would be subject to inhalation of TCE in vapors and aerosols. Inhalation of high concentrations of TCE may affect the kidneys, liver, central nervous system, and respiratory system and may cause cancer (PA-DOH and the Agency for Toxic Substances and Disease Registry, 1997). Acute exposure may have many effects including nausea, dizziness, fatigue, and irritation of the eyes, nose, and throat. However, current data show TCE in Nancy's Nursery wells at levels that should not cause adverse health effects under existing **outside** exposure scenarios (no greenhouses). It does not present a public health hazard to workers or

customers who may inhale TCE as it volatilizes out of contaminated nursery irrigation water into ambient air. The small amount of volatile TCE would be rapidly diluted by air and potential exposure doses would be very low. However, it is prudent to avoid prolonged exposure to the contaminated irrigation water in enclosed areas such as greenhouses or shower stalls that may be constructed in the future. The two commercial wells at Nancy's Nursery are believed to be used only for irrigation purposes and, therefore, potential health effects from ingestion of contaminated drinking water have not been evaluated.

By far, the most serious public health threat posed by the site are the numerous physical hazards that are particularly dangerous to children. As you will see when visiting the site, there are several large open water-filled vats (drowning hazard), collapsing structures, and even an abandoned refrigerator with door still attached. The fence has been breached allowing ready access to the site. Please use caution as you walk about and examine what is left of the facility.

Significance of Site

On the surface this may seem to be a relatively insignificant site, hardly worth a stop on the Field Conference. However, there is more here than is apparent at first glance. First consider the site. It is somewhat obscure because of the fencing, vegetation, and inactivity. People in vehicles speeding by on PA Route 100 probably rarely notice the site. The site is not posted with No Trespassing signs. The fence is breached. The site is now adjacent to a large parking lot where children may be left unattended in vehicles while parents visit Nancy's Garden. Temptation to explore is always present. There is definitely a hazard here. Consider how many similar inconspicuous sites are present in Pennsylvania and elsewhere.

What can be said about cleanup of the site? First of all, ownership of the site is obscure. Secondly, because at present the site does not pose any perceived environmental threat there is no pressure for cleanup. Nancy's Nursery might be interested in the property, but not interested in any liability related to the contaminants. Who is responsible for cleanup?

Finally, what is the underlying geology and its relationship to contaminant movement? The site occurs adjacent to Indian Creek on what could be termed an intermediate upland that exists between the higher Furnace Hill to the north and a lower, steeper gradient part of the creek in Powder Valley to the south. The upland has quite low gradient slopes and no defined floodplain boundary exists for Indian Creek in the site area. No outcrops exist within at least ½ mile of the site so that bedrock mapping is not simple. The geologic map for the area (East Greenville quadrangle, Berg and others, 1981, p.183) shows the site to be underlain by hornblende gneiss. Furnace Hill immediately north of the site is mapped as granite gneiss and a narrow band of Hardyston Formation is mapped between the site and the base of Furnace Hill. Rocks in Indian Creek are gneiss and sandstone, presumably Hardyston. The surface material in the area around the site could be alluvium, colluvium, or weathered residuum. The soils report for Lehigh County (Carey and Yaworski, 1963) shows the site to be on Atkins silt loam, a dark, deep, poorly drained, floodplain soil. Soils to the east on Nancy's Garden property are Montalto silt loams with 3-8 percent slopes. The Montalto is deep, fine textured, reddish soil developed from igneous or metamorphic rocks. Locally mapped to the west of the site is Glenville silt loam with 3-8 percent slopes. The Glenville is a deep, moderately well drained soil with dark surface layer and strong brown to yellowish brown subsoil with brownish gray mottling between 26 and 34 inches below the surface. Depth to bedrock beneath the Atkins, Montalto, and Glenville soils is 3-35 ft, 3-20 ft, and 2.5-10 ft respectively. The depths to bedrock may be too shallow for this area considering that the contaminated wells on Nancy's Nursery property are cased to depths of 32 and 52 ft. These soils and their mapped distribution contribute little to geologic interpretation.

Considering the almost complete lack of real geological information relating to this site it is difficult to evaluate what is going on. Indian Creek is not known to be contaminated now or in the past. The on-site wells and two wells on Nancy's Garden property are contaminated. No other wells in the area are contaminated. The simple solution is that the contaminants have

moved downward and outward from the lagoons, probably at a slow rate because of the nature and thickness of the soil. Some of the contaminant has encountered a fracture or fractures in the gneiss and has migrated to the Nancy's Nursery wells, possibly with movement enhanced by water withdrawal for irrigation purposes. Sounds simple doesn't it? How do you prove it?

- Leave Stop 9. TURN LEFT** onto PA Route 100.
- 1.4 15.3 **Stop Light. TURN RIGHT** onto Shimerville Road.
- 0.3 15.6 **BEAR RIGHT** onto Main Road West at road fork.
- 0.3 15.9 Pass under Pennsylvania Turnpike Northeast Extension.
- 0.3 16.2 **Stop Sign. TURN LEFT** in center of Vera Cruz.
- 0.2 16.4 **TURN LEFT** into Jasper Park entrance (Upper Milford Twp.).
- STOP 10. VERA CRUZ JASPER QUARRY**
- Leader: Kurt Carr

This small public park provides access to a site of considerable archaeological importance. The widespread distribution of product from this and similar nearby quarries is still under investigation. The paper by Hatch and Miller (p. 67-78) provides existing knowledge about this site. Please remember that collecting is not permitted.

- Leave Stop 10. TURN LEFT** onto main road.
- 1.1 17.5 **BEAR RIGHT** onto Pennsylvania Avenue.
- 0.4 17.9 **Stop Sign.** Proceed straight ahead. Now in Emmaus.
- 0.5 18.4 **Stop Sign.** Proceed straight ahead. Corner of 6th and Broad Streets.
- 0.2 18.6 **Stop Sign. TURN LEFT** onto South 4th Street. Traffic from left does not stop.
- 0.1 18.7 **TURN RIGHT** through parking area, cutoff triangle before traffic light.
- 0.1 18.8 **Stop Light.** Proceed straight ahead onto Main Street.
- 0.0 18.8 **Stop Light.** Proceed straight ahead.
- 0.1 18.9 **Stop Light.** Proceed straight ahead.
- 0.5 19.4 **Stop Light. TURN RIGHT** onto East Main Street.
- 0.3 19.7 **TURN RIGHT** following East Main Street.
- 0.1 19.8 **Stop Sign. TURN RIGHT** onto Alpine Street.
- 0.1 19.9 **TURN LEFT** into parking lot. **STOP 11 and LUNCH.**
- STOP 11. A DEEPLY WEATHERED AND ERODED KAME**
- Leader: Duane Braun

This stop will consist of a 15-minute walk along the base of South Mountain to an abandoned gravel pit (Figure 48). Along the way we will cross boulder colluvium from the mountain and abandoned iron ore pits that indicate the area is underlain by limestone. Beware, this area is tick heaven.

The ice lobe that occupied the Great Valley lowland blocked the east-draining Little Lehigh Creek and impounded a shallow proglacial lake named Glacial Lake Packer by Williams (1893) (Figure 17, p. 34). The lowest available outlet col westward to the Schuylkill River system is at an elevation of about 500 ft (152 m) at Topton, Pennsylvania. The large mass of outwash deposited between the ice lobe and South Mountain at Emmaus Junction has a top elevation of 500 ft (149-152 m). This suggests that the outwash deposit represents a large kame delta built into Glacial Lake Packer and graded to the outlet at Topton. (These elevations relate to the

present elevation of an area underlain by carbonate rock. Such elevations were probably 30 m or more higher at the time of glaciation. See p. 37.)

The upper 2 m of the material exposed in the pit are a roundstone diamict with a bright reddish yellow clayey matrix. Below that there are 2 to 4 m of gravel with some fine matrix material. Below a covered interval and exposed elsewhere in the floor of the pit is yellow brown sand. The entire thickness of the exposure shows evidence of weathering, as would be expected in >788,000 year old material. The degree of weathering of the deposit has limited the use of the material even before the area became developed. The amount of fine matrix and the scarcity of sound or fresh clasts made the material difficult to wash and resulted in little useable product. The material has been used for compactable fill due to its poorly sorted (well-graded) texture.

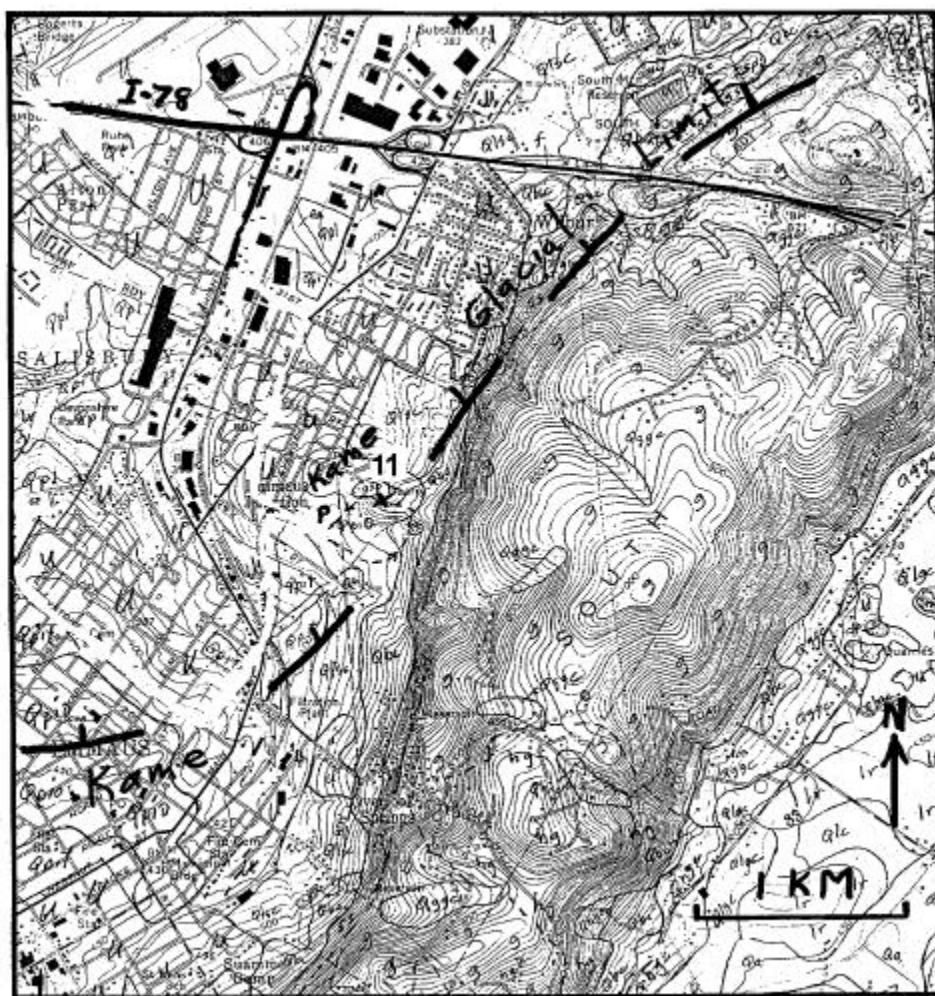


Figure 48. Surficial geologic map of the central western part of the Allentown East 7.5-minute quadrangle. Number 11 is the Conference Stop. Map units: ca – coaly alluvium; f – fill; g – granitic gneiss bedrock; gp – granite or granitic gneiss pit; hg – hornblende gneiss bedrock; ld – limestone and/or iron ore dump; lp – limestone and/or iron ore pit; lr – limestone bedrock; sgp – sand and gravel pit; ss – sandstone bedrock; ssp – sandstone pit; u – urban land; Qa – alluvium; Qat – alluvial terrace; Qbc – boulder colluvium; Qggc – colluvium derived from granitic gneiss; Qgsc – colluvium derived from granitic gneiss and sandstone; Qhgc – colluvium derived from hornblende gneiss; Qlc – colluvium derived from limestone; Qlgc – colluvium derived from limestone and gneiss; Qlsc – colluvium derived from limestone and sandstone; Qpio – pre-Illinoian outwash; Qpit – pre-Illinoian till; Qpl – pre-Illinoian lag; Qsc – colluvium derived from shale and slate; Qssc – stony colluvium derived from gray sandstone; Qst – strath terrace.

This deposit at Emmaus Junction is separated by a broad, shallow valley from the remainder of the kame sand and gravel underneath Emmaus (Figure 48). The Emmaus deposit

remnant caps a large oval shaped hilltop. Earlier workers (Williams, 1917) called the deposit the Emmaus drumlin because of its landform. The form is not the result of glacial activity, but rather, long term post-glacial periglacial and fluvial erosion.

Williams (1893,1917) described outcrops of clay rich material (Packer Clay) that he thought represented the deposits of Glacial Lake Packer. Leverett (1934) thought that the material was glacial till. A few outcrops examined in this project, within the proposed area of Lake Packer, did have a clay rich, very sparsely stony upper layer 1-2 m thick. The clayey material probably represents lake sediments that have been "homogenized" by long term cryoturbation, bioturbation, and mass wasting of the material as the entire mass of glacial deposits have been "let down" by dissolution of the underlying carbonates.

- Leave Stop 11. TURN RIGHT** onto Alpine Street.
- 0.1 20.0 **Stop Sign.** Proceed straight ahead to next **Stop Sign** and proceed straight ahead across Evergreen Street.
- 0.1 20.1 **Stop Sign. TURN RIGHT** onto Dalton Street.
- 0.6 20.7 **Stop Light. TURN LEFT** onto 31st Street.
- 0.3 21.0 **Stop Light. TURN RIGHT** onto Lehigh Street.
- 0.2 21.2 **TURN RIGHT** onto Interstate 78 East and PA Route 309 South. The route ahead passes through South Mountain and rocks of the Reading Prong.
- 1.6 22.8 Outcrops on left of Reading Prong crystalline rocks.
- 1.1 23.9 PA Route 309 exits right to the Saucon Valley. Proceed straight ahead on I 78.
- 4.5 28.4 View ahead of valleys underlain by carbonate rocks and hills composed of crystalline rocks of the Reading Prong.
- 1.9 30.3 **EXIT RIGHT** at Exit 21 to Hellertown.
- 0.4 30.7 **Stop Light. TURN LEFT** onto PA Route 412 South. As the exit ramp approaches the stop light, the view ahead is of South Mountain, site of Stop 13.
- 0.1 30.8 **TURN LEFT** onto Cherry Lane.
- 0.5 31.3 **Stop Sign. TURN LEFT** onto Easton Road.
- 2.9 34.2 Cross Lower Saucon Road. Easton Road becomes Raubsville Road.
- 1.6 35.8 **Intersection.** Proceed straight ahead onto Steely Hill Road. Raubsville Road turns left.
- 0.5 36.3 **TURN LEFT** onto Stouts Valley Road.
- 1.0 37.3 **Stop Sign. BEAR LEFT** across Durham Road following Stouts Valley Road. Lovely stone house on left is typical example of many in the area constructed of crystalline rocks from the Reading Prong.
- 0.5 37.8 **Stop Sign.** Proceed straight ahead.
- 0.5 38.3 **Stop Sign.** Proceed straight ahead. Cross Spring Hill Road.
- 0.5 38.8 **Stop Sign. TURN LEFT** onto Red Bridge Road.
- 0.6 39.4 **Stop Sign. TURN LEFT** onto PA Route 212 East.
- 0.4 39.8 **Stop Sign. TURN RIGHT** onto PA Route 611 South at Durham Furnace. Across the road is Durham Furnace Lock 21 of the Delaware Canal. Delaware River is beyond that. Outcrops ahead on right of Reading Prong crystalline rocks.
- 0.6 40.4 Outcrops of red rocks of the Mesozoic Basin on right and ahead. Contact of Mesozoic and crystalline rocks is in the covered interval.
- 1.2 41.6 **TURN LEFT** onto PA Route 32 South.
- 1.8 43.4 Indian Rock Inn on the right.

0.3 43.7 **TURN RIGHT** onto Narrows Hill Road.
0.4 44.1 **TURN LEFT** onto Ringing Rocks Road.
0.9 45.0 **TURN LEFT** into Ringing Rocks Park.
STOP 12. RINGING ROCKS BLOCK FIELD
Leaders: W. D. Sevon and Gary Fleeger

INTRODUCTION

Ringing Rocks is a locality well known because of the acoustic properties of some of the diabase rocks on the block field (Figure 49). There are other significant items related to this locality: the well exposed and diverse character of the hornfels underlying the diabase sill; the waterfalls developed on the hornfels; the shape and topographic position of the original diabase sheet and its possible relationship to ancient topography; and the character and origin of the block field. This locality is maintained as a small park owned and administered by the Bucks County Parks Department.



Figure 49. View down the Ringing Rocks barren block field. The field has a slope of 7-9°.

BEDROCK GEOLOGY

Bedrock comprising the rocks in the block field and presumably the surface around the field is diabase of the Coffman Hill diabase sheet (Drake and others, 1967). The diabase is medium to coarse grained, dark gray to nearly black and is composed largely of grayish-green calcic plagioclase and green augite. "Thin sections show normal ophitic texture, with large patchy augite grains molding around and enclosing small, haphazardly oriented laths of labradorite. The two minerals are present in nearly equal proportions, making up perhaps 98 percent of the typical rock. Minor constituents are some coarse magnetite grains of irregular shape and a few patchy grains of secondary biotite and chlorite." (Montgomery, 1956) The Coffman Hill diabase correlates with the York Haven diabase that is earliest Jurassic in age.

Dip and strike symbols on the geologic map of Drake and others (1967) indicate that the underlying hornfels and stratigraphically lower rocks of the Brunswick Formation into which the diabase was intruded dip towards the center of the circular diabase sheet at inclinations generally less than 10°. Much of the surface in the area of Ringing Rocks is covered with either boulder colluvium (Qbc) or stony colluvium (Qdsc) derived from diabase (Figure 50) (Braun, 1996a,c). This cover makes it difficult in places to be certain that the underlying bedrock is really diabase

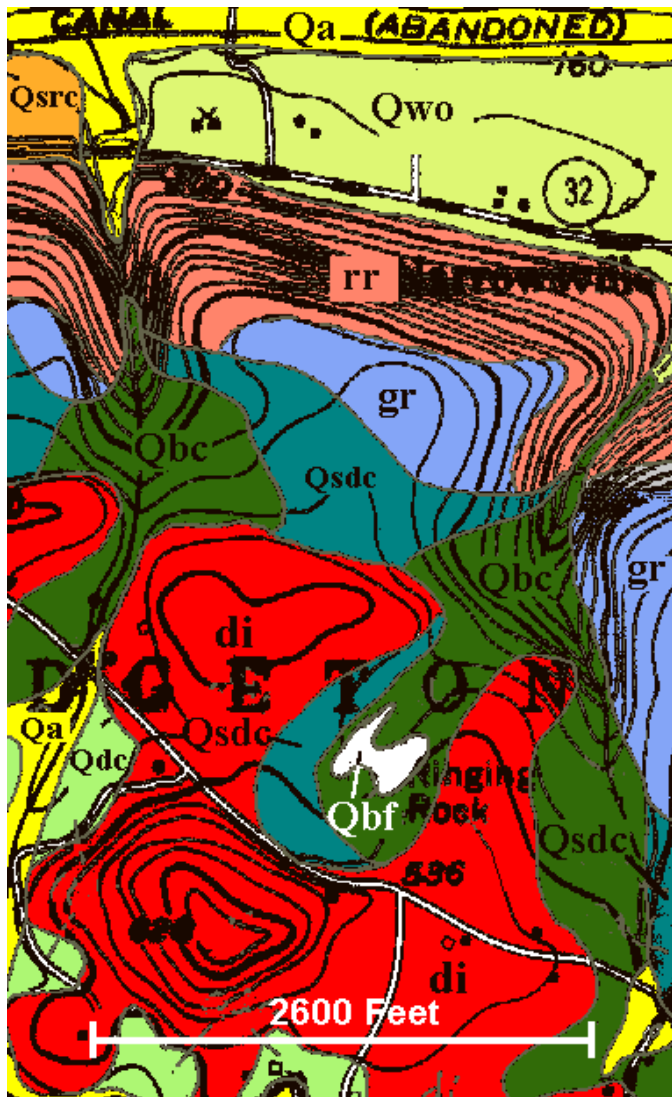


Figure 50. Surficial geology of the Ringing Rocks block field area. Taken from Braun (1996c).

Qbf – boulder field; **Qbc** – boulder colluvium; **Qsdc** – stony diabase colluvium; **Qdc** – diabase colluvium; **Qsrc** – stony sandstone colluvium; **Qa** – alluvium; **Qwo** – Wisconsinan outwash; **rr** – shale and sandstone bedrock; **gr** – gray hornfels; **di** – diabase bedrock

the diabase was intruded the surface was undergoing erosion, not deposition. Which direction the eroding streams were flowing is totally unknown, but to the northwest is most probable because the Atlantic Ocean was not yet opened and the known major highland source area was to the southeast.

The Coffman Hill diabase sheet was intruded into sedimentary rocks of the Brunswick Formation and heat from the intrusion caused thermal metamorphism of rocks close to the margin of the intrusion. These metamorphosed rocks are called hornfels, a fine grained rock com-

and we suspect that in places the diabase has been mapped where it really doesn't exist as bedrock. However, that aspect was not investigated for this trip.

The Coffman Hill diabase sheet is part of a larger, formerly continuous diabase sheet that once connected westward with the Haycock diabase sheet (Drake and others, 1967), and eastward with similar sheets in New Jersey. This diabase was a continuous, undulating sheet that rose and fell with some regularity. Bradley (1965) suggested that such undulating magmatic surfaces were controlled by surface topography at the time of intrusion. Meyboom and Wallace (1978) elaborated on this and presented illustrations that seem particularly relevant to the Coffman and Haycock Hills area. Meyboom and Wallace (1978) indicate that magma in a closed system rises to an isobaric compensation surface and the geometry of that surface is largely controlled by the thickness of the overburden. Thus, the surface of the intrusion is depressed where the overburden is thickest while the surface rises where the overburden is thinnest, thus creating an undulating surface (Figure 51).

It would appear then that diabase sheets centered on Coffman Hill, Quakertown, and Pennsburg (Figure 51) were intruded into areas of thick overburden, possibly hills, while the intervening areas, PA Route 412 and Northeast Extension Pennsylvania Turnpike (Figure 51), were areas of thin overburden, possibly river valleys. If the isobar control of undulation is correct, then it would appear that when

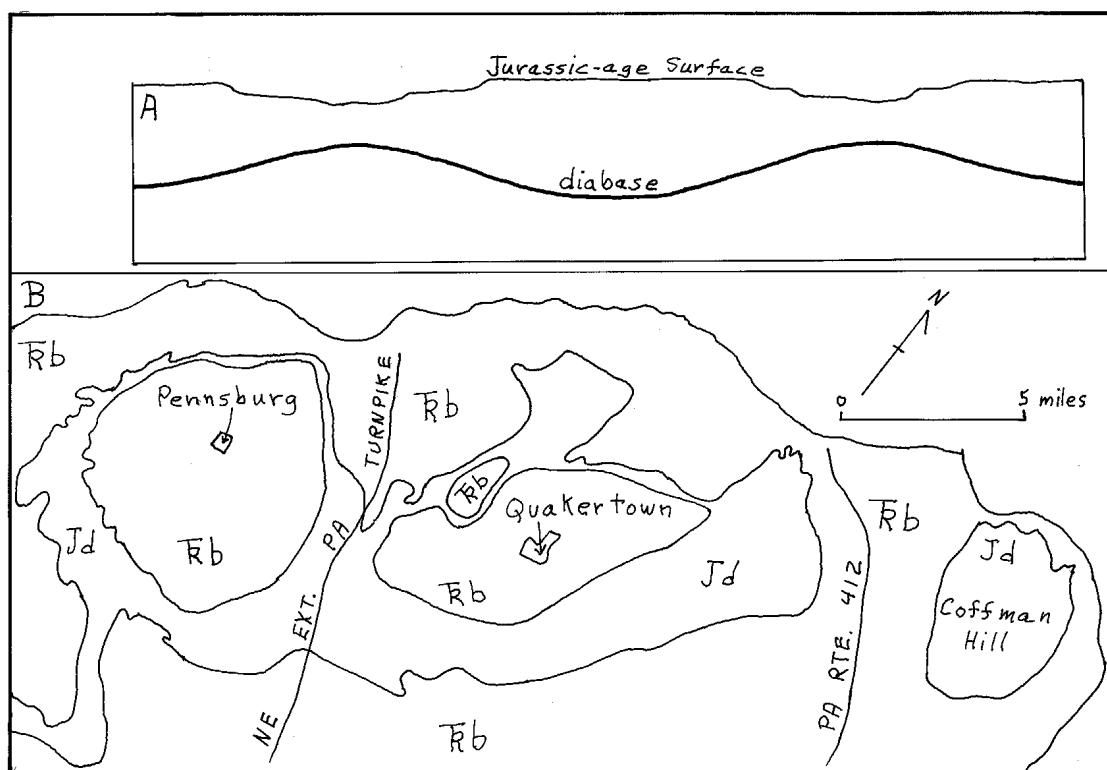


Figure 51. Illustration of the theoretical relationship between undulating compensation surface of intruded diabase, paleo-Jurassic surface, and the occurrence of diabase in eastern Pennsylvania. **A.** This diagram, redrawn and simplified from Meyboom and Wallace (1978) shows the diabase undulating compensation surface response to paleo-surface topographic highs and lows. Isobars are not included for purpose of simplification. **B.** Geologic map of part of the Mesozoic basin in eastern Pennsylvania. Redrawn and simplified from Berg and others (1980). Note the close correspondence between the areas where diabase is totally or partly eroded (PA Rte. 412 and NE Extension Pennsylvania Turnpike) and the highs in the compensation surface shown in part A. Meyboom and Wallace (1978) are to be commended for anticipating the scale of the 1980 Geologic Map of Pennsylvania in their diagram. Jd = diabase; Trb = Brunswick Fm.

posed of a mosaic of equidimensional grains without preferred orientation. Hornfels associated with the Coffman Hill diabase are well exposed east of the Ringing Rocks block field (Figure 50) in a ravine directly below a large waterfall (Figure 52). According to Montgomery (1956), the base of the diabase is very near the top of the steep, west bank overlooking a waterfall near the head of the ravine. The hornfels extend vertically below the diabase for about 200 ft. This exposure allows viewing of the effect of thermal metamorphism on different sedimentary rock types.

The following general description of the hornfels at this site is abstracted from Montgomery (1956). The brown red color of the unmetamorphosed sedimentary rocks changes to gray and near black in the hornfels. Four rock types make up different hornfels. Calcareous siltstone loses its brown-red color more readily than any other type. This is replaced with clots and streaks of dark ferrous oxide through which are abundant tiny grains of quartz, feldspar, muscovite, and calcite. When fully metamorphosed, this rock becomes gray hornfels with calcite missing and granules of pale green hornblende in its place. Siltstone becomes a gray-white hornfels. It lacks hornblende and contains much quartz. This hornfels is very quartzitic, extremely

tough, and is the rock that forms the waterfalls. The calcareous mudstone becomes a dense, flinty, gray-black hornfels with crude prisms of pale green hornblende scattered through a dense mat of minutely crystalline sericite. Shale goes to dark gray cordierite-bearing hornfels. The cordierite crystals are crudely formed and the outer rims of some crystals are much altered to chlorite and muscovite. Tiny magnetite grains occur as inclusions in the cordierite crystals. The groundmass is a dense mat of finely-crystalline sericite.

THE WATERFALLS

The waterfalls (Figure 52) is an excellent place to view several features. The lip of the waterfalls and the streambed surface upstream from the waterfalls are on hornfels developed from siltstone of the Brunswick Formation. It is a very hard, quartzitic rock and is that material closest to the intruded diabase. Three other hornfel variations described previously occur in exposures below the lip of the waterfalls. The surface above the waterfalls is a dip slope that dips 11° at 234° azimuth. This dip slope continues beyond the well-defined right bank and underlies the adjacent woodland slope. The left bank is defined by large diabase blocks that presumably inhibit down-dip migration of the stream. The rock floored streambed is 35 ft wide immediately above the waterfalls and gradually narrows upstream until it is covered by block field. Extremely prominent in the rock is a fracture cleavage with spacing of 0.5-4 inches and orientation of 263° azimuth and 84° N dip. This fracture cleavage controls the orientation of the waterfalls face. Another variably spaced fracture has an orientation of 345° azimuth and 90° dip.

Of considerable interest are the 11 troughs (Figure 53) eroded into the riverbed surface at intervals above the lip of the falls. The troughs are oriented parallel with the fracture cleavage and occur on the lower part of the dipping streambed surface. The troughs are up to 25 inches deep and are generally less than 24 inches wide in the deepest part of the trough. Most of the troughs have parts, particularly on the upslope part of the streambed that are wider, up to 16 ft, and shallower, generally less than 12 inches.

What is the origin of these troughs? This stream has a drainage-basin area of $\sim 1.8 \text{ mi}^2$. Even though infiltration into the subsurface may be inhibited by the hard hornfels and diabase



Figure 52. Waterfalls and streambed surface developed on gray, quartzitic hornfels. Arrows point to three troughs.



Figure 53. A trough eroded into streambed composed of quartzitic hornfels. Note prominent fracture cleavage. This trough is number 5 upstream from the lip of the large waterfalls. The trough is 16 inches deep at its deepest part and 15-25 inches wide. Scale divided into 10 cm intervals, here and in Figures 54, 55, 56, 58, and 59.

thus contributing to runoff during heavy rainfall events or during significant, rapid snowmelt events, it is doubtful that really large flows occur. The answer is interpreted to occur at the last upstream trough (number 11), 155 ft upstream from the lip of the falls. Here a trough is forming at the base of a 4-ft high waterfalls that marks a knickpoint in the streambed. We suggest that each trough represents a place where a waterfalls stabilized long enough to cause erosion of a trough in the streambed. Widening of some of the troughs may have occurred at a later time. Erosion of the troughs is obviously enhanced by the fracture cleavage and the bedding which allow the hard rock to be broken into small transportable pieces. Even in the dry summer of 1999 when there was no waterflow in the stream, all of the troughs contained water. This suggests that water would be present during the winter and that freeze-thaw activity could contribute to disintegration of the resistant rock.

If this hypothesis is correct, then what about the areas between troughs? Presumably the migrating waterfalls moved sufficiently rapidly between trough positions that no troughs were formed. Another question is, how long has the process been operating to produce the 11 troughs? We suspect for a long period of time. Some evidence for this occurs in the first two troughs above the main waterfalls. These are the only troughs that do not extend to the left bank of the streambed.

The first trough ends 7 ft from the left bank; the second, 4 ft. We suggest that that part of the left bank has been eroded since the two troughs were formed. Considering the size of the materials composing the bank, this erosion is probably either slow or catastrophic or both.

THE BLOCKFIELD

Ringling Rocks block field consists of blocks of diabase that vary considerably in size and shape and rest in the field in general disarray (Figure 49). The block field is generally considered to be the barren part upon which there is no vegetation. However, this is but a small part of the total block field. There is a considerable area upslope and adjacent to the barren part where the areas between blocks are filled with fine-grained matrix (Qbc of Braun, 1996c; Figure 50). This part of the block field supports thick woodland cover. The block field ends abruptly on the west side of the barren field (Figure 50) where there is a slope change and the slope rises gently to the west. The downslope end of the barren field (Figure 50) is fairly abrupt in a shallow drainageway that connects downslope with the ravine below the waterfalls. At this end the

blocks quickly decrease in number and the field tapers to an end. Most striking is the margin of the narrow northern part of the barren field, the narrow barren limb that is separated from the main barren field by a thin strip of vegetation. This margin is very steep and drops abruptly several feet. In the waterfalls area, the eastern margin of the covered block field is marked by the ravine below the waterfalls and the riverbed above. The covered block field crosses the stream more than 200 ft upstream from the waterfalls and continues eastward for an unknown distance.

Blocks in the field range in size from less than a foot to more than 6 ft in long dimension. According to Psilovikos and Van Houten (1982) the common range of long axes is: large boulders, 5-6 feet; medium boulders, 3-4 feet; and small boulders, 1-2 feet. Although some of the blocks are equidimensional, most are not and each has definite long, intermediate, and short axes. Tabular blocks are probably the most common. Many of the blocks are curved in a fashion suggestive of a block that may have spalled off the original bedrock source. Blocks vary from well rounded to quite angular, although most blocks have some rounding of their angular edges.

Weathering of the blocks varies depending on position in the block field. Blocks in the woodland areas generally appear more rounded than those on the barren field, often have sharply defined cracks, and are darker brown in color which may have some relationship to degree of weathering. Some of these blocks appear to be exfoliating. Blocks on the surface of the barren field vary with regard to degree of weathering. The uppermost surfaces of the uppermost rocks in the most exposed places on the barren-field surface appear to have the thinnest weathering rind and also are a lighter gray color. These blocks tend to be those with the best ringing qualities. The uppermost, most exposed surface of these blocks tends to be relatively smooth in contrast to the underside of the same block that is often fairly rough. This is interpreted to mean that weathered material from the uppermost surface is removed more rapidly than that from the undersurface. In general, blocks in the barren field have surfaces that look fresher than blocks in woodland areas.



Figure 54. Block of diabase that has separated into 4 pieces since emplacement on the barren block field. Scale is 1 m long.

A number of the large blocks have separated into two or more pieces since the time of their emplacement in the barren field (Figure 54). This is readily recognizable because the shapes of the adjacent pieces match perfectly. In all cases the edges of these pieces are at least slightly rounded by weathering. This suggests that the separation occurred a long time ago and that the blocks have been in their position for an even longer period of time.

A moderate number of blocks have pitted surfaces (Figure 55) that were attributed by Psilovikos and Van Houten (1982) to weathering of the diabase while resting on the surface of the barren field. These pits are polygonal in shape, generally 1-2 inches in diameter, and up to 1 inch deep. These surfaces have every conceivable orientation within the field. On sloping surfaces that culminate at the top of well-exposed blocks, these pits appear to become less well defined towards the top of the block as though weathering on the barren field is destroying them rather than creating them. We suggest that the pits were formed by weathering in some other environment than that of the present field and that the weathering precedes transport. This hy-

pothosis is supported by a block in the center of the trail to the waterfalls that has a pitted surface that becomes less well defined toward the top end of the boulder and better defined towards the bottom that is buried in soil.

A number of interesting features occur on the barren field. Opferkessel-like pits occur on flat surfaces of blocks of some blocks (Figure 56). These presumably are solution pits that have formed since the blocks were transported and exposed on the barren field. A number of relatively flat and sloping surfaces have narrow, shallow, channel-like features suggestive of fluvial erosion (Figure 57). One small pothole occurs in a block that almost certainly has been transported since the pothole formed (Figure 58). Some blocks have a surface with well-defined polygonal, v-shaped grooves (Figure 59) that may be related to cooling of the diabase. Other features probably



Figure 56. Opferkessel-like solution pits on surface of diabase.

occur that are yet to be recognized.

The origin of Ringing Rocks block field is not 100 percent certain. Peltier (1959) suggests that the field is an in situ collection of blocks from which matrix material was removed by running water. He cites their existence in a small, shallow drainage-way as evidence for the mechanism of matrix removal. We have some trouble with that hypothesis because of the extremely small catchment area for the water. Gibbons and Schlossman (1970) adhere to a simple story of block field or felsenmeer (literally “stone seas”) development by freezing and thawing that breaks up bedrock and gradually heaves the rock fragments to the surface. Fine-grained material is flushed away by slope wash and vegetation is not established. Psilovikos and Van Houten (1982) propose a two stage origin. They hypothesize that the blocks represent corestones produced by weathering of diabase. The corestones are surrounded by fine-grained matrix that is also the product of weathering. These corestones were then exhumed during late Cenozoic dissection of an old lowland



Figure 55. Diabase block with pitted surface that appears to be in the process of destruction by weathering at the top of the boulder.



Figure 57. Block of diabase with small channels that appear to have been formed by water erosion.

surface (the Harrisburg peneplain?) and subsequently moved downslope by periglacial creep and solifluction during the Pleistocene. We suggest that blocks accumulated through a process of scarp retreat of the front of the diabase sheet and that, in addition to accumulation of blocks at the base of the scarp, there has also been gravity-driven movement of the blocks under the influence of periglacial climate during the Pleistocene. The fluvial-appearing channels and the pothole suggest that significant fluvial activity may have affected some of these blocks prior to transport. Could the Delaware River once have flowed across this area?

Thus, Ringing Rocks block field constitutes an accumulation of some thickness (actual is unknown) and appears to have accumulated at least in part by gravity-driven periglacial activity. This presents a small problem in that the block field is at a rather low elevation, 460-520 ft amsl, and has an unfavorable orientation. Other low gradient block fields and steep sloped block talus deposits occur at higher elevations and/or in orientations more favorable to periglacial activity, i.e., south-facing slopes. Fritz and Meirding (1989) analyzed block field locations throughout the length of the Appalachians and their work indicates that block field accumulation at the Ringing Rocks latitude ($\sim 40^{\circ}30'$) should be at an elevation of at least 1,000 ft amsl, not half that. Some argument can be made that proximity to Late Wisconsinan ice (~ 15 miles) could have contributed to block field development, but how much is unknown. A more probable possibility is that Ringing Rocks block field was formed during the pre-Illinoian glaciation when glacial ice was much closer (4 miles). If the block field were formed during the pre-Illinoian and had a lot of associated fine-grained matrix, that matrix could have been eroded during subsequent glacial or interglacial intervals to produce the field we see today.

Possible evidence for the scenario presented above occurs at the waterfalls. On the southwest side of the ravine, slightly downstream from the waterfalls scarp, there is a pile of diabase blocks on the valley bottom that have accumulated by falling over the scarp to form almost a talus cone. Presumably these blocks were carried to the edge of the scarp by periglacially-driven gravity movement. When that movement occurred is an important question. Assuming that the waterfalls is retreating headward at some slow rate, it had already passed the site of the block accumulation prior to its development. We suggest that the blocks moved down and over



Figure 58. Small block of diabase with pothole that was not formed in its present position.

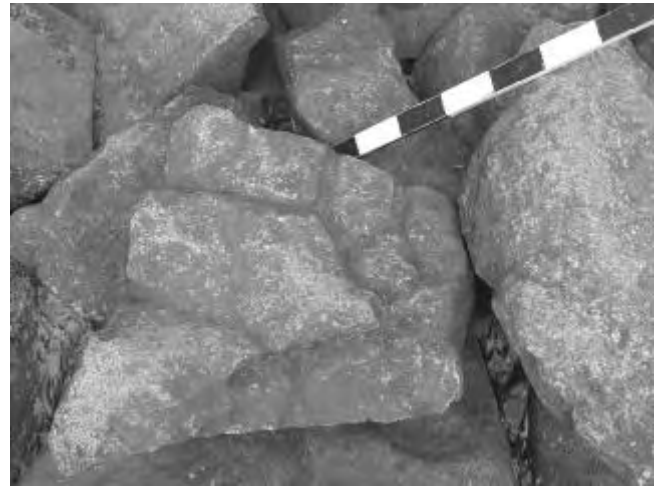


Figure 59. Block of diabase with v-shaped polygonal furrows.

the scarp during pre-Illinoian periglacial conditions and that the main waterfalls retreat was earlier, possibly during older glacial episodes.

ORIGIN OF ACOUSTIC PROPERTIES

The origin of the acoustic properties of Ringing Rocks was first investigated by Fass and Flocks (1966) who ascertained that the ringing is the result of a complex interaction of primary and beat frequencies with the primary frequency apparently related to the length of the major acoustic axis.

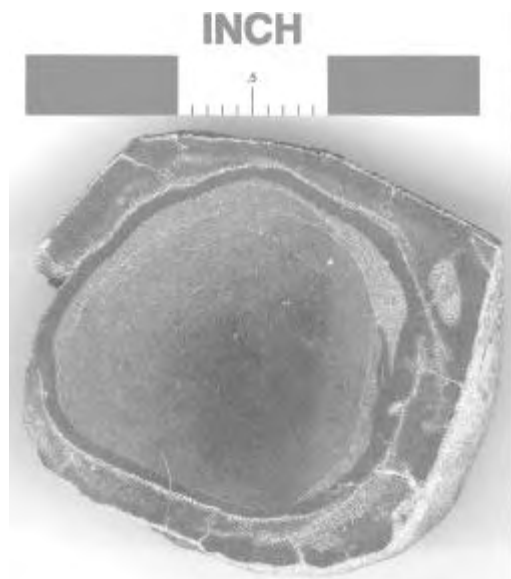


Figure 60. Polished section of a diabase cobble showing several zones of weathering. Outer light rim is the usually rusty red weathering rind. Other shades of light and dark relate to other zones of weathering. Thin sections have not been prepared for this rock so it is unknown whether or not the central dark area is weathered or unweathered. It probably is weathered.

The acoustic-axis length is apparently controlled by the shape of the rock and the point of impact of the hammer. Gibbons and Schlossman (1970) further studied the ringing and ascertained that it is related to tension in the rocks. They found that the near surface of a ringing rock is weathered sufficiently that the pyroxene has been completely changed to montmorillonite. Montmorillonite occupies more space than the original pyroxene and creates an expansion of the outer shell of a ringing rock and a corresponding tension in the core. The strain resulting from the tension raises the resonant frequency of the ringing rock. Do not be deceived by the thin rusty brown weathering rind that appears on most pieces of diabase. Weathering in these rocks is complex and goes much deeper than the surface weathering rind. Figure 60 shows the complexity of weathering within a small piece of diabase. The actual changes in mineralogy of that piece are not known because thin sections have not been prepared. However, the weathering fronts and subtle changes in color indicate that alteration has occurred. Equal or greater weathering complexity is probable at Ringing Rocks. Rocks that have good ringing qualities are very evident on the block field because of the discoloration imparted by much pounding in the same area of a specific rock.

This pounding has removed some of the rusty brown surface weathering so that a lighter gray surface color stands out in contrast to the non-pounded remainder of the rock.

Gibbons and Schlossman (1970) also noted the clear relationship between ringing rocks in the most open areas of the barren block field and the non-ringing rocks in woodland areas as well as marginal areas of the barren block field that receive some shade during the day. This is very evident on the north margin of the block field where there is an expanse of many feet that lacks matrix, but where considerable shade exists from overhanging trees and lichens cover variable amounts of the blocks. The shade and lichens prevent rapid evaporation of water and the blocks weather deeper (differently?) than those in the open area of the barren field. These blocks do not ring. We note also that many of the rocks in the most open area of the barren field do not ring, particularly those that are beneath the upper surface of the field. It would appear that even some shading by adjacent rocks is sufficient to enhance moisture conditions and increase weath-

ering to the point that ringing does not occur. The balance between weathering-enhanced ringing qualities and too much weathering is apparently very delicate.

We agree with previous investigators that vegetation is slowly encroaching upon the field and will someday cover it completely and end the ringing of the rocks. However, that event will not occur for many generations yet to come. The process involves shading by trees along the margins of the barren field, accumulation of leaves and other organic materials in the interstices between blocks, and lichen growth on the blocks. The organic materials gradually create a mat that aids in accumulation of wind blown dust and particles derived from rock surface disintegration. In time small plants will find adequate material in which to root and these will be followed by trees as encroachment proceeds.

- | | | |
|---|------|---|
| | | Leave Stop 12. TURN RIGHT onto Ringing Rocks Road. |
| 0.9 | 45.9 | Stop Sign. TURN LEFT onto Narrows Hill Road. |
| 3.2 | 49.1 | Stop Light. TURN LEFT onto PA Route 611 South and then immediately
TURN RIGHT onto Church Hill Road. |
| 1.6 | 50.7 | Stop Sign. TURN RIGHT onto PA Route 412 North. |
| 4.8 | 55.5 | Stop Sign. TURN LEFT following PA Routes 412 North and 212 West. |
| 2.0 | 55.7 | Road Fork. TURN RIGHT following PA Route 412 North. |
| 3.8 | 59.5 | Stop Light. TURN LEFT onto Walnut Street. |
| 0.5 | 60.0 | Stop Sign. Proceed straight ahead. |
| 0.1 | 60.1 | Stop Sign. TURN RIGHT onto Meadows Road. |
| 0.5 | 60.6 | Stop Sign. TURN LEFT onto Friedensville Road. |
| 0.3 | 60.9 | Stop Light. TURN RIGHT onto South Mountain Drive. |
| 0.9 | 61.8 | Pass under Interstate 78. |
| 0.1 | 61.9 | Stop Sign. Proceed straight ahead. |
| 0.9 | 62.8 | Road Fork. BEAR RIGHT and continue around bend and enter Lehigh University Mountain Top Campus. |
| 0.2 | 63.0 | Road Fork. BEAR RIGHT. |
| 0.1 | 63.1 | TURN RIGHT into parking lot at Iaccoca Hall. |
| STOP 13. LEHIGH VALLEY LANDSCAPE OVERVIEW. | | |
| Leader: Dru Germanoski | | |

THE LANDSCAPE

This stop takes advantage of the Stabler Tower at the Lee Iacocca Business Center at Lehigh University's Mountaintop Campus on the crest of South Mountain. South Mountain is a local geographic name not to be confused with the South Mountain Section of the Blue Ridge Physiographic Province located in southcentral Pennsylvania. This campus was formerly Bethlehem Steel's research campus and employed research geologists including mineralogists and coal petrologists in the 1970's. The Tower affords a fabulous view of erosion surfaces that have been interpreted as peneplains produced by multiple cycles of uplift and erosion. In fact, the landscapes viewed from this stop provide a view of three of the four classic peneplains identified in the central Appalachians: the Schooley peneplain, the Harrisburg peneplain, and the Somerville peneplain (Davis, 1889; Davis and Wood, 1890; Campbell, 1903, 1933). Before providing an interpretation of the origin of the landforms visible from this vantage point I will first point out the salient attributes of the landscape beginning with a description of the South Mountain stop site, followed by a view to the north, and then turning clockwise 360 degrees.

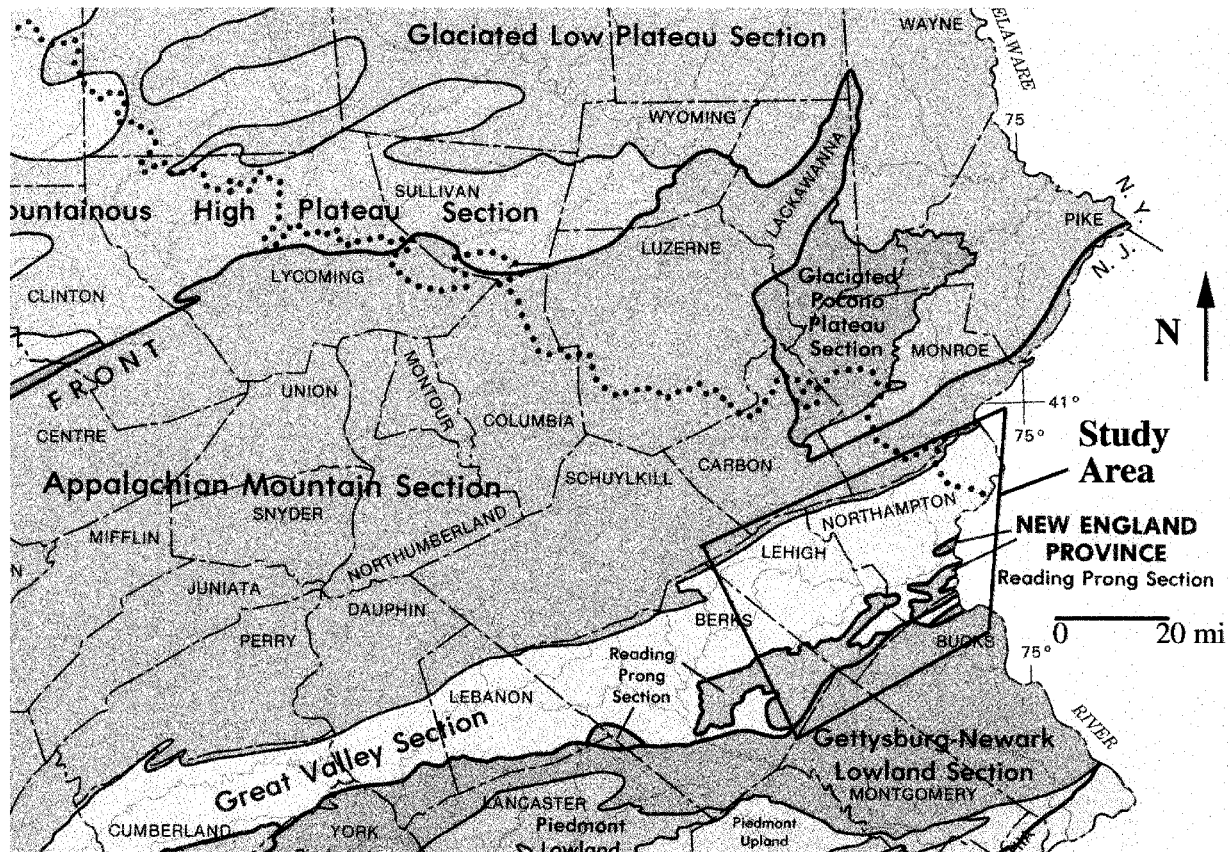


Figure 61. Location map showing the physiographic provinces and sections represented in the study area (from Berg and others, 1989).

South Mountain, the site of Stop 13, is shown on Figure 61 as the northernmost oval segment of the New England Province, Reading Prong Section. South Mountain is a large fault-bounded basement block composed of Middle Proterozoic rocks of the Byram Intrusive Suite including hornblende granite and associated biotite granite and micropertithic, microantiperthitic alaskite (Lyttle and Epstein, 1987), and granite gneiss. The Byram Suite includes bodies of amphibolite, potassic feldspar gneiss, gneissoid granite, and granitic gneiss with hornblende and/or biotite (Lyttle and Epstein, 1987). South Mountain is one of the most prominent landforms in the region and has been mapped as a discrete landform by Sevon (1999). Sevon describes the landform as “a single, northeast-southwest trending ridge that rises abruptly 300 to 500 ft (90 to 150 m) above the surrounding lowland. Slopes of 30-50% are common, particularly on the south side. The hilltop is rounded and generally 1,000 ft (305 m) or more wide. Incipient valleys are poorly developed and long lengths of smooth slopes occur” (Sevon, 1999). Slopes are mantled with boulder colluvium (Braun, 1996a). South Mountain reaches a maximum elevation of 1,042 ft amsl (318 m) at the Big Rock 2 tower in Salisbury Township (Allentown East quadrangle) and an elevation of over 910 ft (277 m) at Stop 13.

The view to the north shows the Great Valley and the southernmost portion of the Appalachian Mountain Section of the Ridge and Valley Province. Blue Mountain, the even-crested ridge forming the horizon to the north (Figure 62) was believed by Davis (1889) to be the remnant of “a general lowland of denudation, a wide area of faint relief.” This surface of low relief was believed to be a peneplain that Davis named the Schooley peneplain (Davis and Wood,

1890). In essence, this presumably formerly flat surface served as the cornerstone for Davis' geographical cycle (Davis, 1899). Blue Mountain has a maximum elevation of 1,660 ft (506 m) amsl in this area, and an average elevation of 1,496 ft (456 m) amsl excluding the areas adjacent to the two major water and two major wind gaps in the ridge. The deep water gap in Blue Mountain that is visible directly north from the Stabler Tower marks the position of the southward flowing Lehigh River. The Lehigh flows south from the water gap through Allentown and Bethlehem, and where it encounters South Mountain at the base of the slope we're standing on, the river turns eastward and flows to its confluence with the Delaware River at Easton. The eastward-flowing segment of the Lehigh River is visible to the north-northeast just over the horizon of the near-slope of South Mountain.



Figure 62. Photograph of three of the principal “surfaces” described in the manuscript. Blue Mountain forms the skyline. The label, “Slate Surface” is on the escarpment that separates the higher slate surface from the carbonate surface in the near view. In terms of peneplains described by earlier workers, Blue Mountain is a remnant of the Schooley peneplain, the slate surface is a remnant of the Harrisburg partial peneplain, and the carbonate surface is part of the Somerville partial peneplain. Photo taken from Chestnut Hill in Easton, PA looking north.

The remnants of the Bethlehem Steel blast furnaces and administrative buildings are located on the south shore of the river. Bethlehem Steel employed 30,000 people in the mid-1900's, but by 1996 “the Steel” as it is known locally, employed only 2,400 people. The Steel announced in January, 1997 that an additional reduction to 1,500 personnel would occur and coke and steel-making ended at this legendary plant shortly thereafter. This plant is legendary because it is the point of origin of the Bethlehem Steel giant and also because this plant produced

much of the structural steel used to construct the nation's great bridges and skyscrapers throughout the first 75 years of this century. The former administrative buildings are now the site of "The Learning Center" a children's science and engineering learning center, and the steel infrastructure will be the future site of a Smithsonian Institution museum of heavy industry. The site is also of supreme importance at the moment because it may very well become a model of brown-field re-development projects.

The prominent surface immediately south of Blue Mountain is underlain by the Martinsburg slate and shale and will be referred to here as the Martinsburg surface for simplicity. I hasten to add that I am not trying to give a formal title to this surface by using this designation. This surface has been designated as the Slate Hills Region by Sevon (1999). The surface extends from the base of Blue Mountain approximately seven miles to the south. The escarpment that separates this surface from the carbonate surface to the south as viewed from the Stabler Tower is marked by the cement manufacturing plants visible at the base of the escarpment in the middle distance. The Martinsburg surface can easily be traced over a hundred miles along strike to the southeast and also tens of miles into New Jersey to the northeast. Figure 62 shows a view of this surface taken from Chestnut Hill in Easton, PA approximately 10 miles (16 km) to the northeast of Stop 13. The Martinsburg surface is a broad to rolling upland surface heavily dissected by streams and rivers. The average elevation of this surface measured along a topographic profile parallel to strike has an average elevation of 559 ft (170 m) amsl with a standard deviation of 121 ft (37 m). This surface has been designated the Harrisburg peneplain by Campbell (1903) and although he attempted to change the formal designation to the Chambersburg surface at a later date (1933), most subsequent literature retains the Harrisburg nomenclature. This partial peneplain was believed to have formed in the middle Tertiary (Davis, 1889; Ashley, 1930).

The cities of Allentown and Bethlehem, marked by the high-rise buildings and urbanized areas visible in the near ground from the Stabler Tower, are constructed on carbonate lowlands called the Somerville partial peneplain (Campbell, 1903). This surface extends from the cement manufacturing plants (visible at the base of the escarpment in the middle distance) which typically mark the position of the Jacksonburg cement rock at the top of the Cambro-Ordovician carbonate sequence, to the northern base of South Mountain. The carbonate surface and the escarpment that separates the carbonates from the shale and slate belt is also clearly visible in Figure 62. The carbonate lowland is designated the Lebanon Lowland Region by Sevon (1999). This surface has an average elevation of 387 ft (118 m) amsl with a standard deviation of 73 ft (22 m) measured along a strike-parallel topographic profile of the Lehigh Valley region. The carbonate surface is underlain by the Cambro-Ordovician carbonates of the Allentown, Jacksonburg, and Leithsville Formations, and the Beekmantown Group. The carbonate surface is typical of karst terrain; low relief, low drainage density, closed depressions, and sinkholes (Kochanov, 1986). Virtually all of the major drainages that cross this surface originate in non-carbonate terrains and then flow across the carbonates.

A view to the northeast of the Stabler Tower reveals an elongate rounded hill that rises approximately 200 ft (61 m) above the low-relief surface of the carbonate terrain to an elevation of 598 ft (182 m) above mean sea level. This rounded hill is known as the Camelhump. The Camelhump is a fault-bounded basement block of Middle Proterozoic potassic feldspar gneiss, with a thin slice of Hardyston quartzite along the southeastern flank (Lyttle and Epstein, 1987).

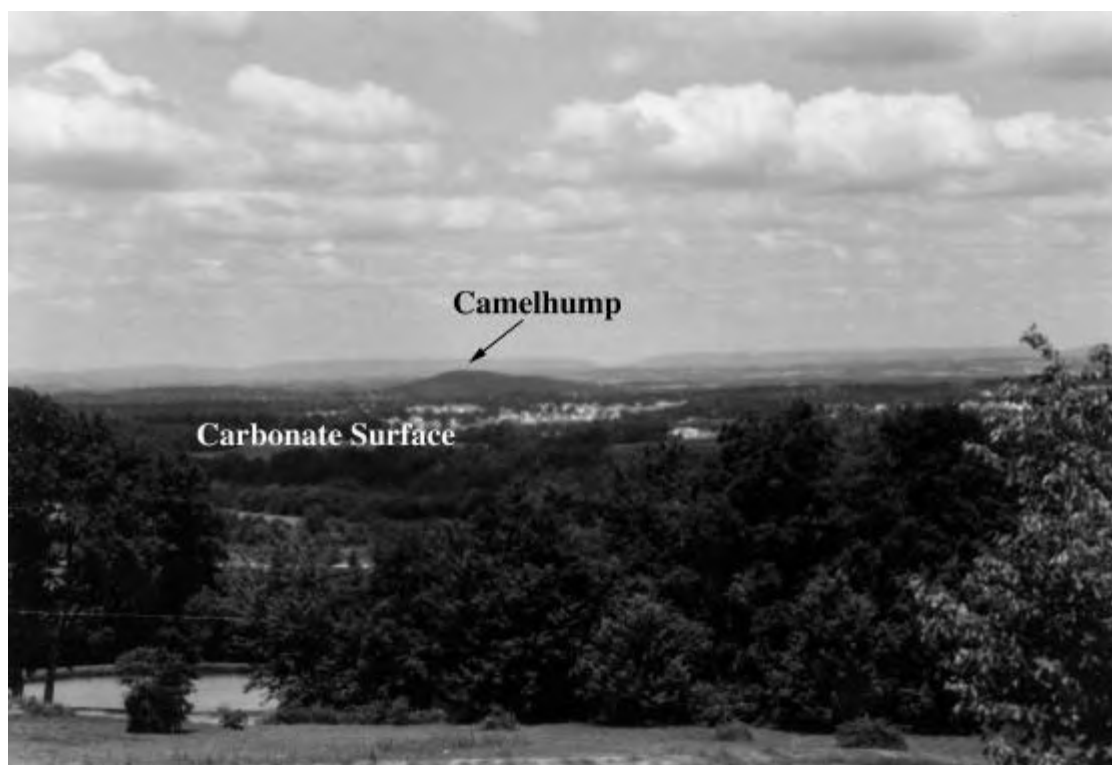


Figure 63. Photograph of the Camelhump, a fault-bounded basement block composed of Middle Proterozoic potassic feldspar gneiss and a lesser amount of Hardyston Quaartzite (Lyttle and Epstein, 1987). Camelhump is surrounded by less resistant carbonates. Blue Mountain is visible forming the skyline in the far distance. Photo taken from the northwest flank of Gaffney Hill east of Hellertown, PA looking north.

Turning east-northeast following the strike of South Mountain, Green Hill is the hill visible across Saucon Creek marked by the active landfill. The landfill is currently a private commercial operation after serving for decades as the City of Bethlehem's landfill. The landfill was sold to an independent commercial company in 1998. Farther east along this ridge-line is a rolling mountain-top surface composed of Gaffney Hill [1,016 ft (310 m) amsl; Nazareth quadrangle], Hexenkopf Hill [920 ft (280 m) amsl; Easton quadrangle], and Morgan Hill [800 ft (244 m) amsl; Easton quadrangle]. Morgan Hill is underlain by the Middle Proterozoic Byram Intrusive Suite including hornblende granite and associated biotite granite (Lyttle and Epstein, 1987). Gaffney and Hexenkopf Hills are underlain by Middle Proterozoic rocks of the Hexenkopf Complex consisting of hornblende-augite-quartz-andesine gneiss, epidote-augite-hornblende-plagioclase gneiss, and quartz-garnet-augite hornfels (Lyttle and Epstein, 1987). These hills are mapped as part of the Saucon Hills Area by Sevon (1999). The view to the southeast, sweeping southward from the Stabler Tower shows more of the Saucon Hills Area. To the southeast across the Saucon Valley are prominent ridges including Kirchberg [1,006 ft (307 m) amsl], Focht [811 ft (247 m) amsl], Swoveberg (850+ ft (259+ m) amsl), and Kohlberg [981 ft (299 m) amsl] Hills. More directly south across Saucon Valley are isolated hills including Church Hill [580 ft (177 m) amsl] and Saucon Hill [660 ft (201 m) amsl], with the skyline in the background formed by the more areally massive Flint Hill [1,000 ft (305 m) amsl] and The Lookout [911 ft (278 m) amsl] (all on the Hellertown quadrangle). Gazing southwest to west completing the 360 degree sweep, the skyline is formed by Applebutter Hill [858 ft (262 m) amsl] and then to the

west-southwest the skyline is formed by the extension of South Mountain (Allentown East quadrangle). Kirchberg, Focht, Swoveberg, Kohlberg, Church, and Saucon Hills are fault-bounded Middle Proterozoic basement rocks, primarily of the Byram Intrusive Suite and Cambrian Hardyston Quartzite, and Applebutter and Flint Hills are underlain by Triassic-age quartz conglomerates (Lyttle and Epstein, 1987). The Lookout is underlain by Jurassic-age diabase (Lyttle and Epstein, 1987).

The Saucon Valley is underlain by Cambro-Ordovician carbonates of the Leithsville and Allentown Formations and the Beekmantown Group. The Saucon Valley exhibits typical karst topography similar to that described in the Great Valley carbonates north of South Mountain. Saucon Valley is drained by Saucon Creek and its tributaries from southwest to northeast where the Saucon Creek passes through a gap between South Mountain and Green Hill to its confluence with the Lehigh. A tongue of pre-Wisconsinan glacial ice prograded into the Saucon Creek drainage at least to the southwest end of Hellertown, blocking the drainage of this valley to the northeast (Braun, this volume). Braun, following work of Leverett (1934) has mapped an ice-marginal lake in this valley called Glacial Lake Saucon. The evidence for this proglacial lake is the lack of a topographic outlet to the south and ice-marginal deposits, other evidence of an ice tongue prograding into the valley blocking the basin outlet, and clean clay deposits, presumably lacustrine, that have been mapped in the valley (Braun, personal communication; 1996a). I have encountered thick (100+ ft), clean, clay deposits in a water well drilled at the base of South Mountain in the Summit Lawn community in the center of the Allentown East quadrangle that certainly appeared to be lacustrine in origin. I have also been informed by a developer of clay deposits that have been encountered at a development site along Seidersville Road (just west of the intersection of South Mountain Drive and Friedensville Road, mile 60.9 on Road Log) that were so clean (well-sorted) that they were suitable for lining a floodwater detention pond.

EXPLANATION OF THE LANDSCAPE

I present a more detailed argument elsewhere in this guidebook (p. 9) that the landscape elements visible from the Stabler Tower result from the differential erosion of rocks having variable resistance to erosion. Figure 64 shows a topographic profile oriented perpendicular to strike, and running approximately north to south to include the major topographic elements through Stop 13. The profile shows a very close correspondence between geology and topography. Beginning from the north end and proceeding south, Chestnut Ridge is underlain by moderately resistant Devonian-age Palmerton sandstone, Aquishicola Creek valley is cut in the less resistant Bloomsburg Formation shale and siltstone, and Blue Mountain, the highest point along the profile is underlain by the super-resistant, quartzites and quartzite conglomerates of the Silurian-age Shawangunk Formation. Note that the lithologically dissimilar Chestnut Ridge and Blue Mountain summits are not accordant peneplain remnants. Peneplain enthusiasts would perhaps argue that they were once part of the same surface, but that Chestnut Ridge was subsequently lowered below the former peneplain surface by erosive forces that were more effective eroding the weaker sandstones. I believe the weaker sandstones were always more susceptible to weathering and erosion than the super-resistant Shawangunk quartzites and likely always held a lower place in the topography during the denudation of this landscape.

Returning to Figure 64 to continue the southward progression, the Martinsburg Formation (Harrisburg peneplain) holds a surface several hundred feet below the summit of Blue Mountain because the Martinsburg shale and slate are much less resistant to erosion than the quartzite. Note the deeply dissected, highly irregular nature of this surface that reflects significant fluvial incision. The slate/shale forms a distinct escarpment where it joins the soluble carbonates. The lowest

contiguous surface in the region is underlain by the soluble Cambro-Ordovician carbonates, because this rock type is most susceptible to solution weathering and erosion. Camelhump, South Mountain, and Church Hill, all Middle Proterozoic intrusive and/or gneissic metamorphic rocks, project above the carbonates because they are more resistant to weathering and erosion than the carbonates. Flint Hill and The Lookout are underlain by Triassic quartz fanglomerates and Jurassic diabase, respectively. These resistant rocks maintain mountains of high elevation because of their resistance to erosion. Data presented elsewhere in this volume (p. 9) suggests that variations in elevation among the Proterozoic basement rocks can be explained in part, by variation in resistance to erosion as a function of variations in area of outcrop. In short, isolated hills of resistant rock such as Camelhump, or Church Hill are eroded to lower elevations than similar lithotypes such as South Mountain because Camelhump and Church Hill are small in areal extent compared to South Mountain, and Flint Hill and The Lookout as well. I have described this occurrence as “exposed isolation” when a small block of resistant rock is surrounded by less resistant rocks. Conversely, small masses of less resistant rocks can be “protected” from erosion to some extent when surrounded by larger masses of more resistant rocks. Such an occurrence I have described as “protected isolation.” The valley between Flint Hill and the Lookout (Figure 64) is an example of a weak rock in “protected isolation.” In this case, the Lower Jurassic-Upper Triassic Brunswick Group siltstones and shales hold an elevation of approximately 750-800 ft (229-244 m) amsl when “protected” from erosion by the adjacent Flint Hill quartzite fanglomerate and The Lookout diabase. For comparison, the Brunswick Formation more typically holds elevations on the order of 500 ft (152 m) amsl when “unprotected” by adjacent masses of more resistant rock. Furthermore, the variations in elevation among the Proterozoic basement blocks likely reflect variations in mineralogy, fracture frequency, and perhaps differential metamor-

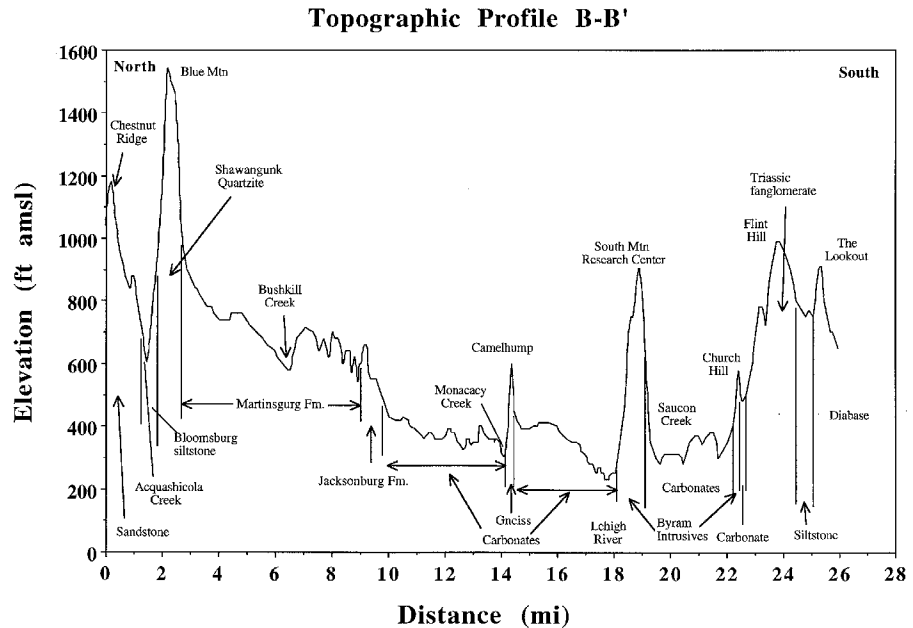


Figure 64. Topographic profile measured north to approximately normal to regional strike from the Wind Gap, PA to Hellertown, PA quadrangles. The profile begins in the Ridge and Valley Province and extends to the Gettysburg-Newark Lowland. Note the close correspondence between lithology and landforms.

phism. Relationships between lithology and susceptibility to weathering of the basement rocks are the focus of an ongoing investigation and nothing more definitive can be said at the present time about these relationships.

The well defined relationship between landform elevation and lithology leads me to conclude that the Lehigh Valley landform assemblage reflects differential erosion of rocks having mineralogically-controlled variable resistance to erosion, rather than sequences of peneplanation and partial peneplanation. Thus, these conclusions are much more similar to the conclusions of recent students of Appalachian landform evolution (Hack, 1960, 1975, 1980; Flint, 1963; Braun, 1989) than they are to the conclusions of early workers (Davis, 1889; Davis and Wood, 1890; Bascom, 1921; Knopf, 1923; Ward, 1930).

- 0.2 63.3 **Leave Stop 13. TURN LEFT** out of parking lot.
- 0.1 63.4 **Stop Sign.** Proceed straight ahead.
- 0.1 63.4 **BEAR LEFT** at road fork.
- 0.1 63.5 **Stop Sign.** Proceed straight ahead.
- 0.9 64.4 **Stop Sign.** Proceed straight ahead.
- 0.1 64.5 **TURN LEFT** onto Seidersville Road.
- 1.0 65.5 **Stop Sign. TURN LEFT** onto William Street.
- 0.2 65.7 **TURN RIGHT** onto Apple Street.
- 0.2 65.9 **Stop Sign. TURN RIGHT** onto Silvex Road.
- 0.4 66.3 **Stop Light.** Proceed straight ahead onto Interstate 78 West.
- 12.9 79.2 **BEAR RIGHT** at **Exit 15** onto PA Route 309 North.
- 2.5 81.7 **Stop Light. TURN RIGHT** onto Ridgeview Road and immediate **RIGHT** onto Bulldog Drive.
- 0.4 82.1 Parking lot of Days Inn. **End of 1999 Field Conference. Have a safe trip home. Come again next year for the gala FC2K festivities!!**