DONALD M. THIEME
A Stratigraphic and Chronometric Investigation of the Alluvial Deposits of the North Branch of the Susquehanna River
(Under the Direction of ERVAN G. GARRISON)

An allostratigraphic unit, the Wyoming Valley formation, is proposed for the alluvial deposits which underlie the first terrace in the North Branch of the Susquehanna River valley. The lower bounding surface is a contact with outwash or ice-contact stratified drift at the base of the alluvial terrace. Four members are distinguished within the Wyoming Valley formation on the basis of buried soils which formed on former terrace surfaces. The members are traced through 23 stratigraphic sections in the 250 km study area on the basis of field observations, thin section photomicrographs, and laboratory analyses of grain size, soil chemistry, clay mineralogy, and magnetic susceptibility. A total of 139 radiocarbon dates constrain the age of bounding surfaces within the allostratigraphic framework. Eighty-nine of the radiocarbon dates are for samples of charred wood or nutshell from prehistoric pit features, while fifteen are for samples from geologic contexts beneath or spatially separated from any of the cultural occupations. The bounding discontinuities of the Wyoming Valley alloformation are argued to result from environmental changes which are evident in independent records from the surrounding region.

INDEX WORDS: Geoarchaeology, Alluvium, Holocene, Stratigraphy, Radiocarbon, Pennsylvania, Susquehanna

A STRATIGRAPHIC AND CHRONOMETRIC INVESTIGATION OF THE ALLUVIAL DEPOSITS OF THE NORTH BRANCH OF THE SUSQUEHANNA RIVER

by

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A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2003

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January 2003

ACKNOWLEDGMENTS

This dissertation is the fruit of an education which began with a broad liberal arts base, progressed through archaeology as one of the four fields of anthropology, and culminated in earth science. In hindsight I might have been wise to acquire more mathematical skills and laboratory knowhow while I was younger. However, my scholarly abilities and inclinations were nourished by several early mentors. Here I would particularly credit Bryan G. Norton of the Georgia Institute of Technology, George J. Gumerman of the Arizona State Museum, Jeffrey S. Dean of the Tree Ring Laboratory at the University of Arizona, and F. E. Smiley of Northern Arizona University. My appreciation of the diversity of human society and its environmental circumstances clearly reflects my parents, Darius L. Thieme of Fisk University and Mary S. Thieme of Gulf Coast Community College.

Aside from passing encounters with paleoenvironmental studies in archaeology, my initial exposure to geomorphology was at Southern Illinois University at Carbondale.

I flunked the last course taught by Dale F. Ritter and then retook and passed an equally demanding course under R. Craig Kochel. Geomorphological concepts and field techniques are an essential component of cultural resources management, of which I have been a devoted practitioner nearly since its inception. Much of the data reported in this dissertation was collected during deep testing of Susquehanna River alluvium for buried archaeological sites. My first fieldwork in Pennsylvania was in the summer of 1993 as an

assistant to Joseph Schuldenrein, president of Geoarcheology Research Associates and visiting scholar at New York University.

I began my program of study at the University of Georgia in the fall of 1993 under Norman Herz and Ervan Garrison. The program in the UGa Department of Geology is unique, and I believe the crop of graduates will make significant contributions to both archaeology and earth science in the years ahead. I had to work hard to make up for a lack of preparation in some areas, and I maintained a demanding schedule of consulting work along with my responsibilities as a teaching assistant. In addition to the archaeological geology and shallow geophysics courses taught by Herz and Garrison, I benefited immensely from the fluvial geomorphology course taught in the Department of Geography by David Leigh and the soil morphology course taught in the Department of Crop and Soil Sciences by Larry T. West. The clay mineralogy course taught by Paul Schroeder was also extremely beneficial, and it was thanks to Paul and David Leigh that I was finally able to interpret my laboratory results and develop the stratigraphic framework that is presented.

Although I had several interesting ideas for a dissertation project, I became obsessed with the North Branch of the Susquehanna River after Schuldenrein and I conducted a geomorphological study of the Wyoming Valley levee raising project area in the spring of 1995. While we obtained some significant results published in a regional archaeology journal, there were geographical and fiscal constraints as well as problems in obtaining results from other contract-funded studies. I ultimately moved to northeastern Pennsylvania in order to conduct fieldwork funded by mapping grants from the

Pennsylvania Geological Survey. Duane Braun of Bloomsburg University and Jon Inners of the survey took an active interest in my project and provided me with limited travel funds from 1997 until 2000, when I returned to Athens to complete my dissertation and defend it.

Archaeologists are more cautious scientists than their portrayal in popular fiction would suggest, and they can be extremely protective of data which are useful to other branches of science. Many of the radiocarbon dates and stratigraphic details presented in Chapter 4 were obtained through correspondence and negotiations as opposed to active fieldwork, but in many ways this was the greater intellectual challenge. While most researchers are appropriately credited in the text, I would single out James Herbstritt of the Pennsylvania Historical and Museum Commission and Jamie McIntyre of the Pennsylvania Department of Transportation. Both of these individuals have a personal stake in the completion of this study, recognizing their implications for finding even more significant stratified archaeological sites in the future.

Ervan Garrison supervised the writing of this dissertation, sometimes through written correspondence or email while I was living in Pennsylvania. The text definitely evolved through "punctuated equilibrium," as opposed to slow and gradual progress toward fulfillment of my initial conception. The staff at the Department of Geology at UGa were always helpful and patient in assisting me both on campus and while I was in the field. It is in large part thanks to Pat Hancock, Beatriz Stephens, and Mary Crowe that any of us ever graduate and move on to more productive employment in industry or academic positions.

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CHAPTER 1

INTRODUCTION

The following dissertation reports the results of a stratigraphic and chronometric investigation of the alluvial deposits of the North Branch of the Susquehanna River. The central hypothesis is that the alluvial deposits are separated from glacial outwash by a regional stratigraphic boundary, designated as Discontinuity I. Four additional discontinuities or bounding surfaces are hypothesized to exist within the alluvial deposits. By tracing these bounding surfaces within 23 stratigraphic sections, the deposits have been subdivided into four member-level allostratigraphic units.

The lower bounding surface for the alluvial deposits has been traced at the land surface by mapping the first terrace landform. Both the terrace (T-1) and the active floodplain (T-0) were mapped for the valley reaches from the Pennsylvania/New York state border downstream to the juncture of the North and West Branches of the Susquehanna River at Northumberland (see **Figure 1)**. Stratigraphic sections, borings, and archaeological sites discussed in the text are provenienced with UTM grid coordinates taken from U.S.G.S. 7.5 minute topographic maps as well as elevation above mean sea level (MSL) and distance upstream of the river mouth in Chesapeake Bay.

The discontinuities or bounding surfaces between member-level units identified in this study are consistent in their stratigraphic position and have been hypothesized to represent regional environmental forcing. Eustatic sea level rise, tectonic uplift, and

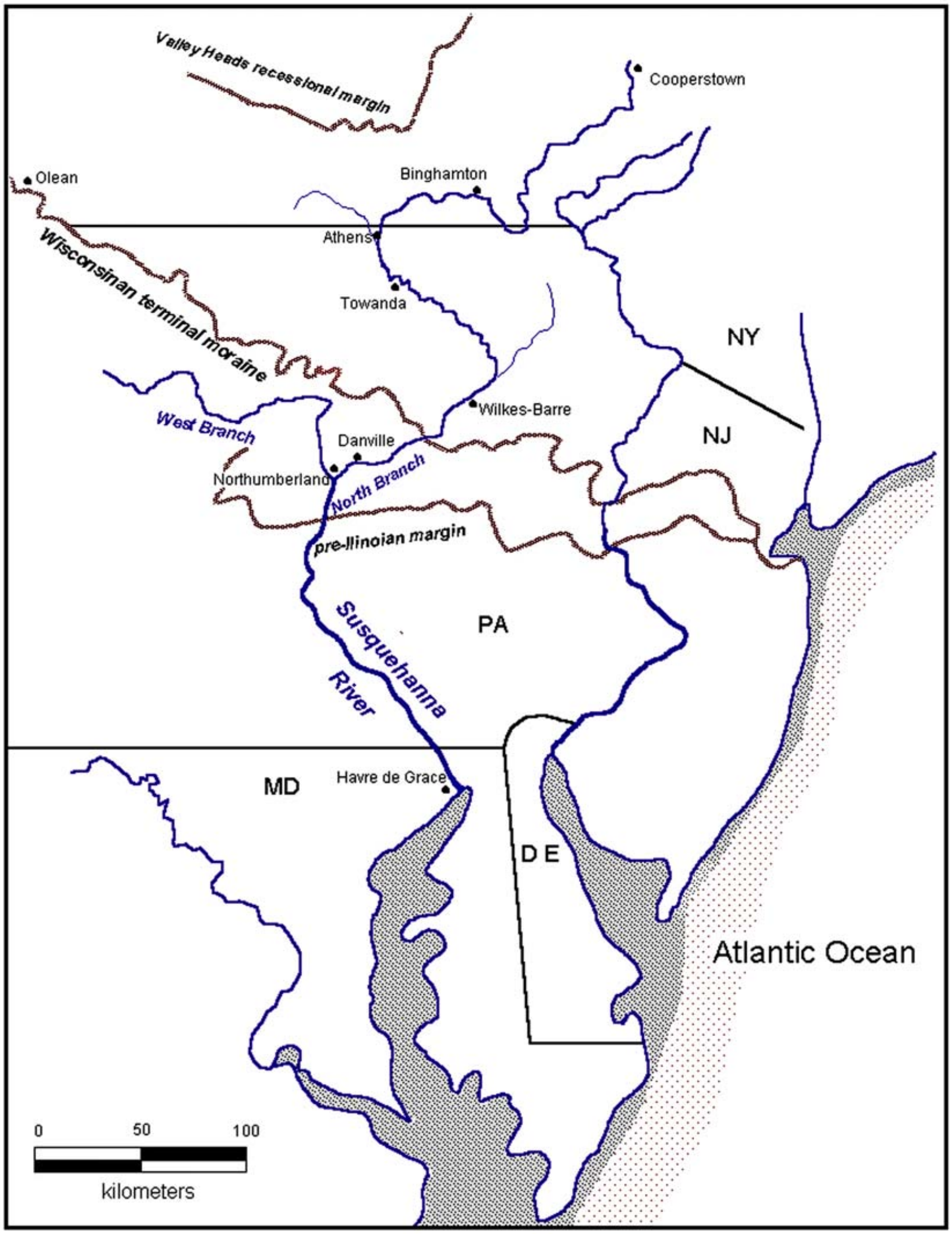


Figure 1: General location of the North Branch of the Susquehanna River study area

changes in climate, vegetation, or land use are among the external forcing variables that were considered as possible causes. However, the member-level units and their bounding surfaces were identified independent of any inferred genesis, following the applicable stratigraphic codes (NACSN, 1983; Salvador, 1994).

The methods employed in this study are reviewed in **Chapter 2.** Archaeological sites were investigated to obtain both age constraints and representative stratigraphic sections. Because the objective of the investigation is to relate the physical stratigraphy to regional environmental change, the study sample also includes some contexts where humans are not known to have disturbed the sediments. Areas beyond the limits of the known archaeological sites were targeted with both cutbank sections and auger borings spanning the 250 km field area.

Chapter 3 summarizes the existing stratigraphic framework and regional context. The North Branch of the Susquehanna River valley has several geographic and geologic features in addition to the stratified archaeological sites which make it particularly suitable for the present study. One of the most significant of these features is the late Wisconsinan terminal moraine, which crosses the river just upstream of Berwick (km 254) at the downstream end of the study area. The sediments released directly from the ice, and the outwash deposited by meltwater as the glacier retreated northward, have already been mapped for most of the study reaches by previous workers (Hollowell, 1973; Inners, 1978, 1981; Kehn et al., 1966; Peltier, 1949; Sevon and Braun, 1997). Outwash is typically identifiable below an unconformity at the base of the alluvium using lithologic criteria such as the size of clasts and their derivation from distant bedrock outcrops or glacial troughs.

Features of the river valley which are inherited from Pleistocene glaciation are discussed in some detail because these affect the alluvial stratigraphy, and the lower bounding surface in particular. The rebound of the continental crust following the most recent deglaciation accounts for much of the height of outwash deposits above modern river grade and is also a factor considered when explaining the thickness and distribution of the Holocene deposits. Tectonic forcing is otherwise unlikely on millennial or submillennial time scales for rivers draining the Atlantic slope (Gardner, 1989; Pazzaglia et al., 1998). Eustatic sea level has not reached elevations which would affect the Susquehanna River baseflow upstream of the 30 m falls at Conewingo, Maryland (km 19) since the last interglacial (oxygen isotope stage 5e) at the latest and probably back to the Miocene epoch at least five million years ago (Pazzaglia and Gardner, 1993).

In addition to straddling the limit of late Wisconsinan glaciation, the study area straddles a physiographic and phytogeographic transition between the oak-rich deciduous forests of the Ridge and Valley province to the south and the more mixed coniferous or deciduous forests of the Appalachian Plateaus province to the northeast (Berg et al., 1989; Braun, 1964; Briggs, 1999; Gaudreau, 1988; Way, 1999). Because the observed ecotone has a physiographic as well as climatic basis, it is likely to have been a place where the forest composition changed, regardless of which tree species were dominant in the canopy (Delcourt and Delcourt, 1981, 1984; Gaudreau, 1988; Watts, 1983).

The location of the study area in the midlatitude eastern United States is further significant in that proximity to the Atlantic Ocean has an effect on the storms which deliver precipitation to the drainage basin (Namias, 1973; Rossi, 1999; Whitaker and Horn, 1984). Weather records have been maintained in northeastern Pennsylvania since the early 19th century, and the river discharge has been measured by three U.S.G.S. gaging stations since the early 20th century. Climate patterns which affect the amount and type of precipitation are briefly summarized in **Chapter 2** and then discussed in more detail in **Chapter 6**.

Five possible discontinuities in the river's alluvial deposits are identified and then tested against the results of field and laboratory studies in separate chapters on archaeological chronology (**Chapter 4**) and stratigraphy (**Chapter 5**). Prehistoric settlement occurred during more than one cultural phase at several stratified archaeological sites in the study area. The phases when settlement occurred were contemporaneous to the extent that this can be determined from a total of 139 radiocarbon dates. Fifteen of the dates are from geologic contexts beneath or spatially separated from the cultural occupation levels, and most of these geologic dates fit in gaps between these successive episodes of prehistoric settlement.

Chronological models of the sort presented in **Chapter 4** are the natural outcome of working with alluvial deposits which include prehistoric archaeological contexts. Applicable stratigraphic codes dictate, however, that each unit or boundary be described and correlated between sites on the basis of observable physical characteristics which are independent of both genesis and the inferred time span of the deposit (NACSN, 1983, p.

866). Of the five possible discontinuities identified in **Chapter 4**, only four correspond to unconformities which can be recognized in stratigraphic sections or borings independent of the age constraints provided by artifact typologies and radiocarbon dates on the archaeological sites.

In **Chapter 5**, the alluvial deposits which underlie first terrace (T-1) surfaces and overlie outwash or ice-contact stratified drift in the North Branch of the Susquehanna River valley are grouped into the Wyoming Valley formation. The formation is an allostratigraphic unit composed of four members, not all of which are present in all of the stratigraphic profiles investigated. The members are distinguished primarily on the basis of the buried soils which formed on former terrace surfaces at their upper boundary. There are also important, although not statistically significant, differences with respect to lithofacies represented. Ten lithofacies are described using field observations, thin section photomicrographs, and laboratory analyses of grain size, soil chemistry, clay mineralogy, and magnetic susceptibility.

Chapter 6 concludes the dissertation, presenting several possible explanations for each of the discontinuities identified in the allostratigraphic framework. Certain fundamental forces such as episodic tectonic uplift and eustatic sea level change are definitely known to play only a limited role in the genesis of late Quaternary deposits in the upper reaches of rivers draining the Atlantic slope. Of the remaining possible driving forces, no single prime mover can explain any of the discontinuities. Several events evident in independent records of late Quaternary environmental change coincide with each discontinuity. These events are argued to explain the punctuated sedimentation and intervals of soil formation which allow the alluvial deposits to be subdivided in an allostratigraphic framework.

CHAPTER 2

METHODOLOGY

Testing the two core hypotheses about alluvial deposits in the North Branch of the Susquehanna River valley required the use of research methods and techniques which belong to several earth science subdisciplines. The methods that were used can be grouped into 1.) those used for basic identification and mapping, 2.) those used to establish the more detailed stratigraphic framework, 3.) those used to constrain the age of the deposits, and 4.) those used to understand the general pattern or genesis of the stratigraphic record. The present chapter will discuss these four general groups or arrays of methods and techniques in this order.

IDENTIFICATION AND MAPPING

The initial research task was simply to identify and map the alluvial deposits. Existing maps of topography, geology, and soils covering various parts of the study area (see **Figure 2**) were brought to a common scale using Adobe PHOTOSHOP™ and other graphics programs running under Microsoft WINDOWS™ on an IBM-compatible personal computer.

Alluvium and other Quaternary deposits had been mapped previously for the Bloomsburg and Mifflinville quadrangles and part of the Catawissa quadrangle (Inners,

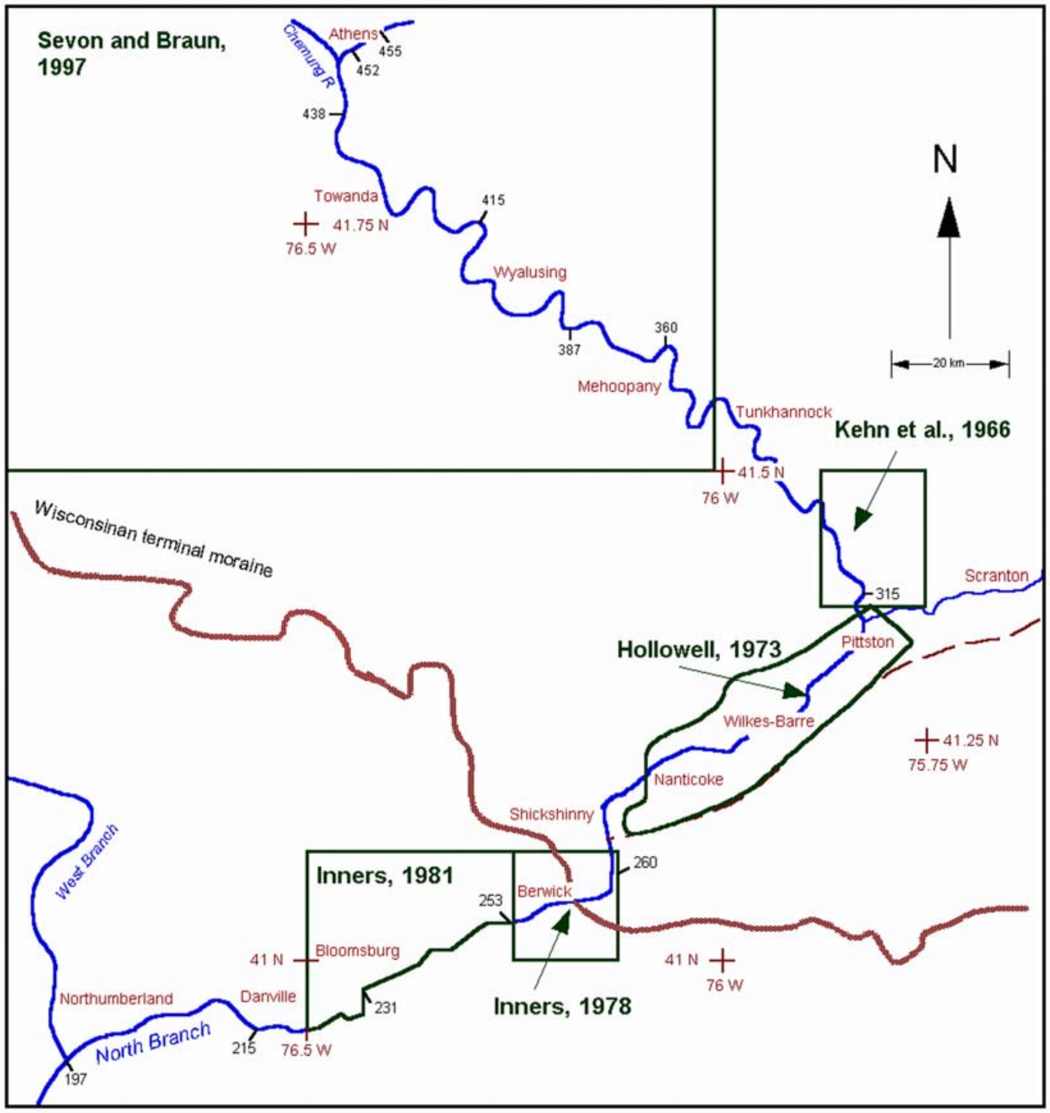


Figure 2: Areas covered by previous geologic mapping of Quaternary deposits in the North Branch of the Susquehanna River valley

1981), the Berwick quadrangle (Inners, 1978), the Wyoming Valley (Hollowell, 1973), the Ransom quadrangle (Kehn et al., 1966), and the Towanda 30-by-60 minute quadrangle (Sevon and Braun, 1997). Terraces of gravelly late Pleistocene outwash were mapped by Peltier (1949) along both branches of the Susquehanna River through all of Pennsylvania. For most of the present study area, however, only Peltier's longitudinal profiles giving relative terrace elevations have survived.

The U.S. Department of Agriculture (USDA) county soil surveys are one of the most useful sources for preparation of geomorphic maps (Birkeland, 1999, p. 31). In the North Branch of the Susquehanna River valley, the Holocene alluvium can generally be identified based on soils which show minimal profile development into discrete soil horizons (see **Table 1**). Specifically, most of the areas mapped with Udifluvent soils in Northumberland, Montour, and Bradford counties and with Fluvent soils in Lackawanna and Wyoming counties represent floodplain (T-0) landforms flanking the river channel. These soils have dark brown (7.5YR3/2) to brown (10YR4/3) surface horizons rich in organic matter (A horizons) overlying stratified alluvial parent material (C horizons).

The first terrace (T-1) landforms which were the primary focus of the present investigations were previously described as the "Mankato" periglacial terrace by Peltier (1949). Fluvent soils with A-C profiles are also found on these surfaces in some areas. More typically, however, the soils formed on T-1 surfaces have at least one cambic (Bw) horizon within the upper meter of the profile. These soils are mapped with the Pope series in Luzerne, Lackawanna, Wyoming, and Bradford counties, with the Linden series in Northumberland, Montour, Luzerne, and Bradford counties, with the Basher series in

Table 1: Soil Series formed in the Alluvial Deposits of the North Branch of the Susquehanna River

Series	Profile Characteristics	Reference
	Northumberland County (km 197-215)	
Udifluvents	A-C, dark brown (7.5YR3/2) to brown (10YR4/3) surface hoirzon over lighter-colored sediment, all textures possible	Eckenrode, 1985b, p. 90
Linden	Ap-Bw-C, dark brown (10YR3/3) silt loam over reddish brown (5YR4/4) silt loam over brown (7.5YR4/4) fine sandy loam, well-drained	Eckenrode, 1985b, p. 87
Barbour	A-Bw-C, reddish brown (5YR3/3-4/4) fine sandy loam over brown (7.5YR5/4) sand, well-drained	Eckenrode, 1985b, p. 75-76
Basher	A-Bw-C reddish brown (5YR3/3-4/4) silt loam over sand and gravel, moderately well-drained,	Eckenrode, 1985b, p. 76
Holly	Ap-Bg-Cg, dark grayish brown (10YR4/2) silt loam over gray (N5/0-6/0) silty clay loam over gray (N5/0) gravelly loamy sand	Eckenrode, 1985b, p. 84
	Montour County (km 215-231)	
Udifluvents	A-C, dark brown (7.5YR3/2) to brown (10YR4/3) surface horizon over lighter-colored sediment, all textures possible	Eckenrode, 1985a, p. 83
Linden	Ap-Bw-C, dark brown (10YR3/3) silt loam over reddish brown (5YR4/4) silt loam over brown (7.5YR4/4) fine sandy loam, well-drained	Eckenrode, 1985a, p. 80

Table 1: Soil Series formed in the Alluvial Deposits of the North Branch of the Susquehanna River

Series	Profile Characteristics	Reference
Basher	A-Bw-C, reddish brown (5YR3/3-4/4) silt loam over reddish gray (5YR5/2) loam over stratified sand and gravel, moderately well-drained	Eckenrode, 1985a, p. 69-70
Holly	Ap-Bg-Cg, dark grayish brown (10YR4/2) silt loam over gray (N5/0-6/0) silty clay loam over gray (N5/0) gravelly loamy sand	Eckenrode, 1985a, p. 77-78
Fluvaquents	A-C, very dark brown (10YR2/2) over light brownish bray (10YR2/2) sediment of any texture	Eckenrode, 1985a, p. 75
	Columbia County (km 223-253)	
Middlebury	A-C, dark grayish brown (10YR4/2) silt loam over dark brown (7.5YR4/4) silt loam over brown (7.5YR5/4) gravelly sandy loam	Parrish, 1967, p. 113-114
Tioga	A-C, very dark grayish brown (10YR3/2) silt loam over dark brown (10YR3/3) coal silt over reddish brown (5YR4/4) sandy clay loam over brown (7.5YR5/4) gravelly silty clay loam	Parrish, 1967, p. 117
Barbour	A-C, reddish brwon (5YR3/4-4/3) gravelly loam over dark reddish brown (5YR3/4) gravel, well-drained	Parrish, 1967, p. 102
Basher	A-C, dusky-red (2.5Y3/2) fine sandy loam over red (2.5YR4/6) loamy sand, moderately well-drained	Parrish, 1967, p. 102

Table 1: Soil Series formed in the Alluvial Deposits of the North Branch of the Susquehanna River

Series	Profile Characteristics	Reference
	Luzerne County (km 253-315)	
Pope	Ap-Bw-C, dark reddish gray (10YR4/2) silt loam over dark brown (10YR4/3) silt loam over brown (10YR5/3) loam, well-drained	Bush, 1981, p. 36-37
Linden	Ap-Bw-C, dark reddish gray (5YR4/2) silt loam over reddish brown (5YR4/3) very fine sandy loam over reddish brown (5YR4/3) very gravelly sand, well-drained	Bush, 1981, p. 26
Basher	A-Bw-C, dark greddish brown (5YR3/2-4/4) loam over reddish gray (5YR5/2) gravelly sand, moderately well-drained	Bush, 1981, p. 11-12
Holly	A-Bg-Cg, dark gray (10YR4/1) over light brownish gray (10YR6/2) over gray (10YR5/1) silt loam, poorly drained	Bush, 1981, p. 20
	Lackawanna and Wyoming Counties (km 315-387)	
Fluvents	A-C, very dark brown (7.5YR3/2) to dark brown (7.5YR4/4) over lighter-colored sediment, all textures possible	Eckenrode, 1982, p. 83

Table 1: Soil Series formed in the Alluvial Deposits of the North Branch of the Susquehanna River

Series	Profile Characteristics	Reference
Pope	Ap-Bw-C, dark brown (10YR3/3) over yellowish brown (10YR5/4) sandy loam, well-drained	Eckenrode, 1982, p. 89
Holly	Ap-Bg-Cg, dark gray (10YR4/1) silt loam over grayish brown (10YR4/2-6/2) sandy loam over gray (2.5Y5/2) gravelly loamy sand, poorly drained	Eckenrode, 1982, p. 84
	Bradford County (km 315-387)	
Udifluvents	A-C, very dark brown (5YR2/2) to dark brown (10YR4/4) over lighter-colored sediment, all textures possible	Grubb, 1986, p. 65
Pope	Ap-Bw-C, dark grayish brown (10YR4/2) silt loam over brown (10YR5/3) loam over dark brown (10YR4/3) loamy sand, well-drained	Grubb, 1986, p. 64
Linden	Ap-Bw-C, dark brown (7.5YR3/2) silt loam over dark reddish brown (5YR3/3) fine sandy laom over reddish brown (5YR4/3) sandy loam, well-drained	Grubb, 1986, p. 59
Holly	Ap-Bg-C, dark grayish brown (10YR4/2) silt loam over light brownish gray (10YR6/2) silt loam over grayish brown (2.5Y55/2) loam, poorly drained	Grubb, 1986, p. 58-59

Northumberland, Montour, Columbia, Luzerne, and Bradford counties, and with the Barbour series in Northumberland and Columbia counties. The Middlebury and Tioga series are mapped on T-1 surfaces in Columbia county, but this is an older survey and these series are now used primarily in New York state rather than Pennsylvania.

Poorly drained soils are mapped with the Holly series throughout the study area with the exception of Columbia county. Some of the more linear poorly drained areas at the valley margins represent paleochannels or flood chutes, and there are also several irregularly shaped flood basins or slackwater ponds. The infilled former bed of the North Branch Canal is also characterized by poorly drained soils. The canal bed was traced the length of the study area, in part in order to distinguish it from other geomorphic features of interest.

Tens of meters of relief typically separate the T-1 landform mapped in the present study from the older surfaces underlain by glacial outwash. Soils formed in sandy outwash sediment are mapped with the Wyoming series in Northumberland, Montour, Luzerne, Lackawanna, and Wyoming counties. The more gravelly soils are mapped with the Chenango series in Columbia, Luzerne, and Bradford counties. The Alton series is used for extremely gravelly soils in Bradford county. Although the soil surveys state the parent material as glacial outwash for all of these series, younger gravelly deposits do occur within the mapped boundaries.

Topography was used to identify the landforms underlain by glacial deposits. A great deal has already been written about their chronology and stratigraphy, and the most recent studies were given priority in labeling the surfaces evident on the digital topographic map files. For some reaches, the most detailed descriptions are still the riverlogs in Peltier (1949). Peltier's logs are quite accurate with respect to the number of geomorphic surfaces, and his terms were retained as opposed to numbering the terraces T-2, T-3, etc... Many of the discrepancies with respect to the glacial landforms indicated on previous maps relate to 20th century construction and quarry impacts as opposed to geological interpretation.

Peltier's log is in river miles, and the distances in kilometers given in this dissertation are equivalent for the larger towns and bridges along the river channel. Cross-shaped tick marks have been placed on the digital map files at distances measured using a map wheel on printed versions of the digital files. Due to the meandering pattern of the channel and bedrock valley, the river distances are only accurate to the nearest 500 m. The UTM grid coordinates measured for the locations of archaeological sites, cutbank sections, and borings should be accurate to the nearest 100 m (Lounsbury and Aldrich, 1986, p. 33-40; U.S. Army, 1987).

The U.S. Geological Survey (USGS) 7.5 minute topographic maps use a contour interval of 20 feet (6 m), meaning that many of the minor scarps separating T-1 from T-0 are not shown. As discussed above, the county soil survey maps were the primary source used for mapping the terrace. Topography was used as a fall back when several interpretations were possible from the soils map. Field visits were made to most of the terraces mapped as well, and proiles were surveyed in the field using a hand level at four locations of particular interest.

FIELD METHODS AND STRATIGRAPHIC DESCRIPTION

The field investigations for this dissertation began in the spring of 1995 with a study of archaeological sites impacted by raising the levees in the Wyoming Valley (Schuldenrein and Thieme, 1997). The excavations at the Conrail (36LU169) and Harding Flats (36WO55) sites were also visited during the course of these studies to identify buried soils and alluvial lithofacies with which prehistoric cultural materials are associated. As the theoretical objective evolved of relating the physical stratigraphy to regional environmental change, fieldwork expanded to include contexts where humans are not known to have disturbed the sediments. In order to maximize coverage within the study area, field descriptions of stratigraphy have also been extracted from the extensive Quaternary geological literature and archaeological contract reports.

All told, a total of 18 cutbank profiles and 57 borings with hand auger or Giddings hydraulic probe (Giddings Machine Company, 2002; Hodgson, 1978, p. 12-16) were examined. Each of these vertical profiles was partitioned into soil horizons in the field, according to the criteria in Soil Survey Staff (1984, 1993, 1997). Soil horizons are identified on the basis of physical attributes including color and texture as well as the structure developed in a sediment as it weathers. Because most soil processes operate from the vegetated land surface downward, soil horizons tend to parallel the surface topography when they form and may or may not parallel depositional layers in the parent material (Birkeland, 1999, p. 2-3).

In the present investigations, soil horizons were designated by capital letters denoting master horizons (A, B, C, E, etc...), lower case letters referring to more specific characteristics (Bw, Bt, etc...), and Arabic numerals subdividing a horizon as needed (AB1, AB2, etc...). The general rule followed was to subdivide a horizon for sampling purposes if it was more than 30 cm thick. The sediment texture of each horizon was recorded in classes, e.g. silt loam, fine sandy loam, silty clay loam, and so forth (Birkeland, 1999, p. 10-11; Soil Survey Staff, 1993). The soil texture classes are based on the proportion of sand-, silt-, and clay-sized particles within the inorganic soil fraction that is less than 2 mm, but there are field criteria for making reliable estimates. Color was recorded moist using the Munsell chart.

The structure of each soil horizon was characterized in terms of the shape and size of its “peds,” or clod-like soil aggregates (Birkeland, 1999, p. 12). Where structure was poorly developed or not present, more attention was paid to sedimentological attributes such as bedforms and depositional sorting within a horizon (Reineck and Singh, 1986). Boundaries between horizons were characterized in terms of both distinctness and topography (Birkeland, 1999, p. 356), with particular attention being paid to boundaries which define the top of buried soils in each profile.

In many cases, the buried soils represent more extensive weathering of the alluvial sediment than is exhibited at the surface on either T-0 or T-1. Films of clay on ped faces were described in terms of thickness and how continuous they appeared. This pedogenic clay was formed by the weathering of minerals such as mica and feldspar in the alluvial sediment when it was exposed on a terrace surface. Soil horizons with this property are referred to as "argillic" and designated with a lower-case "t" following the upper-case horizon term, "Bt" for example (Soil Survey Staff, 1997). Another characteristic property of well-developed soils in Pennsylvania is increased density combined with cracking. Horizons with this property are referred to as "fragic" or "fragipans" (Lindbo and Veneman, 1989; Soil Survey Staff, 1997) and designated with a lower-case "x." It is not uncommon for both of these weathering attributes to be present in a single horizon, which is then referred to as a Btx horizon.

Soil series which have fragic or argillic horizons have been mapped within the study area, but only on glacial deposits tens of meters above the T-1 surface. The buried soils identified in stratified alluvium during the present investigations occur at depths which were not investigated by soil scientists until very recently (Birkeland, 1999, p. 321-322; Buol, 1994; Gerrard, 1992). Because buried soils are often modified from their original appearance at the soil surface, they cannot always be classified with the systematic USDA soil taxonomy (Birkeland, 1999, p. 341). Following the methods of description used for soil survey does make some comparisons possible, however, and may indicate the relative importance of the known soil-forming factors.

At locations where cutbanks were profiled, and in exposures on at least two of the archaeological sites, it was possible to describe primary bedforms and lateral changes in sediment texture which are key to identifying lithofacies within the deposits (Miall, 1996, p. 99-130). For locations where only a few borings were made or stratigraphy of older excavations has been reported by previous workers, only the extremely general distinction can be drawn between gravelly beds, sandy beds, and muds (Friedman and

Sanders, 1978, p. 70). Nonetheless, even this coarse subdivision of the deposits contributes information which is crucial to the stratigraphic framework developed in **Chapter 5**.

SEDIMENTOLOGY AND OTHER LABORATORY ANALYSES

Sediment texture can be estimated in the field with sufficient accuracy to distinguish soil horizons (Soil Survey Staff, 1984, 1993, 1997) and to characterize the roughness of a river channel bed (Kellerhals and Bray, 1971; Leopold et al., 1964, p. 188-195). With practice, clay percents estimated by pressing a "ribbon" of moist soil between the thumb and forefinger will be within five percent of values measured in the laboratory by hydrometer (Buoyocos, 1962) or pipette (Indorante et al., 1990; Soil Survey Staff, 1996) methods. Field measurements of coarse particles can be used to generate statistical measures such as the median diameter (D_{50}) of bed material (Kellerhals and Bray, 1971; Kondolf, 1997; Leopold, 1970; Rice and Church, 1996; Wolman, 1954). These in turn provide general estimates of both bed roughness and the material which is moving as "bedload" by sliding, rolling, or bouncing on or very near the river bed (Knighton, 1998, p. 127; Leopold et al., 1964, p. 180; Ritter et al., 1995, p. 197; Southard, 2000, p. 170).

In the present investigations, bed material in the active river channel and gravels from stratigraphic contexts were counted in size categories using the method described by Wolman (1954). A steel caliper accurate to the nearest 0.1 mm was used to measure the b-axis of at least 100 gravel clasts selected approximately at random within a radius

Figure 3: Steel caliper measurement of gravel clast exposed during low water level on the riverbank at Forty Fort, Pennsylvania

of one meter on gravel bars exposed during low water levels at six locations in the active channel during the late summer of 2000 (see **Figure 3**). The locations studied were in the reaches between Shickshinny (km 274) and Mehoopany (km 367). More extensive studies using the same method have been conducted on rivers in central Pennsylvania by Brush (1965) and in southeastern Pennsylvania by Pizzuto et al. (2000). The gravels measured from subsurface stratigraphic contexts were collected in the 8th Street Bridge Replacement work area in Wyoming (km 306). The samples were from over four meters below the present land surface in two of the five backhoe trench excavations.

Sedimentological observations and laboratory results are reported in several previous studies of the valley's Quaternary deposits. These are used where applicable for developing the stratigraphic framework in **Chapter 4**. Darton (1914) compiled all the boring logs available at that time from the coal mines to show the thickness of outwash and till over bedrock in the Wyomng Valley from Pittston (km 310) downstream to Nanticoke (km 289). Peltier (1949) made pebble counts of outwash gravel throughout the North Branch valley. Clasts derived from nonlocal lithologies were noted in the present study for corroboration of Peltier's results and as a general indication of probable transport by glacial meltwater. Kehn et al. (1966) differentiated alluvial deposits from outwash in mapping the Ransom 7.5 minute quadrangle, noting that the gravel clasts are not as large in the alluvium and there is a lower percentage of igneous and metamorphic rocks. Hollowell (1973) provides graphic logs for approximately 500 borings in the Wyoming Valley using general categories such as "gravel," "sand," "clay," "clay and sand," etc.

Particle size distributions are reported by Inners (1978) for thirteen samples collected while mapping the Berwick quadrangle (km 252-267). Distributions for samples from Olean outwash in the North Branch valley near Mifflinville (km 246) and Catawissa (km 228) are also reported from subsequent mapping downstream (Inners, 1981). The distributions are presented graphically as cumulative percent coarser (Inners, 1978, p. 24) or percent finer (Inners, 1981, p. 106) than increments in the Udden-Wentworth or "standard" grade scale (Friedman and Sanders, 1978, p. 63-66; Udden, 1914; Wentworth, 1922). Since the silt and clay are grouped together as particles finer than 1/16 mm (0.62 mm) in diameter, the samples were evidently just wet-sieved (ASTM, 1963; Day, 1965; Gale and Hoare, 1991, p. 86-92).

Inners' plots use a logarithmic axis for the ordinate whereas a linear axis would be used if the same values were in phi units (Krumbein, 1936; Krumbein and Pettijohn, 1938, p. 76-90). Phi is calculated as the negative logarithm of the diameter in base 2 ($-\log_2 D$), converting the Udden-Wentworth increments into integer values. Cumulative particle size distributions in phi units are presented by Hayes et al. (1981) for ten samples from stratified archaeological sites in the Susquehanna Steam and Electric Station (SES) project area (km 262-264). The silt/clay break is shown at 8 phi (0.004 mm) whereas this is usually placed at 9 phi (0.002 mm) by either pipette or hydrometer analysis (Day, 1965; Gale and Hoare, 1991). Histograms, also in phi units, are presented by East et al. (1988) for 32 samples from two columns at the Catawissa Bridge site (36CO9). The graphic mean, median, standard deviation, and skewness (Friedman and Sanders, 1978, p. 70-81) were calculated for the site 36CO9 samples as well.

In the report on the excavations at the Gould Island archaeological site (36LU105), sediment texture is reported in general categories such as gravel, sand, or mud for each of 20 alluvial strata without laboratory particle size analysis (Weed and Wenstrom, 1992). A column of ten samples from the Falls Bridge site (36WO56) were wet-sieved by personnel of John Milner Associates (Kingsley et al., 1995) and reported in USDA particle size increments. The USDA grade scale makes fewer subdivisions of the fine sand- to silt-sized particles than does the Udden-Wentworth scale (Krumbein and Pettijohn, 1938, p. 78; Soil Survey Staff, 1984), which may be appropriate given that these alluvial deposits have probably been mixed by soil processes.

In the present study, methods of soil chemical analysis as well as particle size measurements were used to analyze a total of 22 samples from two stratigraphic type sections. Results have been presented in a previous report to the U.S. Army Corps of Engineers on the Wyoming Valley levee raising project (Schuldenrein and Thieme, 1997). All analyses were conducted at the University of Georgia Agricultural and Environmental Services Laboratory (AESL, 2002). The hydrometer method (Buoyocos, 1962) was used to measure the percent sand, silt, and clay. Organic matter content was measured with the Walkley-Black method (Allison, 1965, p. 1372-1376; Walkley, 1947; Walkley and Black, 1934). The pH was measured on a slurry prepared with a solution of 0.01 N $CaCl_2$ (Schofield and Taylor, 1955).

The elements P, K, Ca, Mg, Mn, Zn, and Fe were measured with inductively coupled plasma atomic emission spectrometry (ICP-AES). Solutions were prepared with the Mehlich I "double acid" (0.05 N HCl + 0.025 N H_2SO_4) extraction method (Mehlich, 1948, 1973) and introduced to the ICP torch as aqueous aerosol (Boumans, 1987; Soltanpour et al., 1982; Thompson and Walsh, 1989). The inductively coupled plasma thus formed, the ICP, is maintained by inductive heating of the flowing gas. Argon is generally used as a "carrier" gas to convey the sample to the plasma. The emission spectra are analyzed as the sample is vaporized.

The only other soil chemistry data available from stratified alluvial deposits in the study area are for the Gould Island archaeological site (Weed and Wenstrom, 1992, p. 163). Values for organic matter, soil pH, and the elements P, N, K, Ca, and Mg are plotted for eight samples from a single stratigraphic column. Although the laboratory methods are not specified, the range of values obtained is generally comparable to that obtained for the Wyoming Valley deposits in the present study.

Both particle size and soil chemistry are reported by Engel et al. (1996) for soils formed in glacial deposits and alluvium at locations on the West Branch of the Susquehanna River at Muncy and on the main stem downstream of Harrisburg. Both the total Fe measured with lithium metaborate dissolution (Medlin et al., 1969) and the extractable Fe, Al, and Mn by the citrate-bicarbonate-dithionite (CBD) method (Janitzky, 1986; Mehra and Jackson, 1960; Thurman et al., 1992) are presented in graphs. Extractions with CBD are more widely used in soil chronosequence studies (Bilzi and Ciolkosz, 1977; Ciolkosz et al., 1971, 1993; Foss and Segovia, 1984; Leigh, 1996; Levine and Ciolkosz, 1983; Markewich et al., 1987, 1989; Markewich and Pavich, 1991) than are the more recent extraction methods developed for ICP analysis. Values for both total Fe and CBD extractable Fe reported by Engel et al. (1996) are an order of magnitude above any of the values obtained with the Mehlich I extraction and ICP analysis in the present study.

Percent clay and clay mineralogy are widely used for soil chronosequence studies (Bilzi and Ciolkosz, 1977; Engel et al., 1996; Markewich et al., 1987, 1989; Markewich and Pavich, 1991). The whole soil mineralogy and the mineralogy of the less than 0.002 mm (2 μm) fraction were analyzed by x-ray diffraction (XRD) in the present study. The less than 2 μm fraction was separated by wet sieving and centrifugation (Hathaway, 1956). The weight percents of the fractions separated for XRD analysis were compared with those obtained by hydrometer for the two previously reported stratigraphic sections. Several more horizons were also studied which are key to defining members of the Wyoming Valley alloformation.

Powder mounts with approximately random orientation were prepared from the whole soil (< 2 mm) of each horizon and scanned from 3 to 70 degrees 2-theta using the SCINTAG XDS-2000 diffractometer in the Department of Geology at the University of Georgia. Experimental parameters included CoKα radiation, 2°/4° divergence slits, 0.5°/0.3° receiving slits, and a scan rate of 1° 2-theta per minute. The clay samples were sedimented to infinite thickness on glass petrographic slides and air-dried. Treatments included Ca-, Mg-, and K-saturation, followed by ethylene glycol solvation and heating to 300°C and 500°C.

Fourteen large (5 x 7.5 cm) and six standard (2.5 x 4.5 cm) petrographic thin sections were prepared from samples of soil or rock collected during the course of the present study. All of the thin sections were prepared by National Petrographic Services of Austin, Texas (National Petrographic Services, 2002). The rock samples include both local lithologies and a granite cobble from glacial outwash. One sample from a prehistoric archaeological pit feature at the Conrail site (36LU169) was thin-sectioned as well as fourteen fist-sized blocks of soil. The soil blocks were collected according to procedures described by Courty et al. (1989).

Each of the thin-sections was scanned on a flatbed scanner as well as examined under 4x, 10x, and 20x magnification on an Olympus Bx40 petrographic microscope. The scanned images as well as several views in both plane-polarized and cross-polarized light are presented for each thin section in **Appendix 2**. There are a total of 94 JPEG digital files, several of which are also used as figures in both **Chapter 3** and **Chapter 5**. Brief descriptions of the thin sections in **Appendix 2** make limited use of the specialized terminology of Bullock et al. (1985). The primary objective was identification of pedogenic clay and sesquioxide phases as well as microscopic correlates of macroscopic features observed in the field and the hand samples. The detrital components are also compared with the rock sample thin sections in terms of mineralogy, particle size, and sorting.

The magnetic susceptibility (χ) was measured for a total of 54 samples of rock, soil, or sediment collected during the course of the present study. Magnetic susceptibility is the ratio of the intensity of magnetization induced in a substance to the intensity of the magnetizing field to which it is subjected (Dalan and Banerjee, 1998, p. 6; Gale and Hoare, 1991, p. 202; Mullins, 1977, p. 224). All of the measurements in the present study were made on the alternating field bridge in the Department of Geology at the University of Georgia. The UGa bridge has been calibrated using MnF_2 salts, MnO_2 salts, and magnetite standard samples. Three measurements were made per sample and the bridge was zeroed between measurements. The three measurements typically differed by less than 0.5 x 10^{-5} SI, and the median value is reported to the nearest 0.1 x 10^{-5} SI.

The magnetic susceptibility analyses included samples spanning the range of depositional environments in the river valley. The primary objective was to characterize the buried soils formed on bounding surfaces in the alluvial deposits. Events or processes known to enhance magnetic susceptibility in soils include burning (LeBorgne, 1960; Tite and Mullins, 1971), plowing (Clark, 1992; Oldfield et al., 1979), topsoil erosion (Brown, 1992; Dearing et al., 1985, 1990; Oldfield et al., 1979), bacterial fermentation associated with organic matter decay (Dalan and Banerjee, 1998; LeBorgne, 1960; Maher, 1986; Mullins, 1977, p. 240-242), cultural intrusions (Clark, 1992; Dalan and Banerjee, 1998; Linford, 1994), and possibly climatic warming (Maher and Thompson, 1992, 1995a, 1995b; Tite and Linington, 1975; Verosub et al., 1993). Measurement using the UGa bridge was simple, inexpensive, and non-destructive.

RADIOCARBON DATING AND ARCHAEOLOGICAL AGE CONSTRAINTS

As noted in **Chapter 1**, the age of a deposit should ideally play no role in its formal stratigraphic description, unless it is actually being used to define part of the geologic time scale (NACOSN, 1983; Salvador, 1994). Nonetheless, age relationships are fundamental to building a stratigraphic framework based on individual outcrop descriptions or boring logs. Radiometric ages for bodies of rock and sediment and for included particles such as charred plant parts greatly improve the resolution of stratigraphy, and of Holocene alluvial stratigraphy in particular. Archaeological contexts are typically ideal repositories of particles for radiocarbon dating and tend to occur on "planes" or former land surfaces within alluvial strata (Brown, 1997; Waters, 1992). Prehistoric artifacts obtained from reliable stratigraphic contexts can also serve a function very similar to the "index fossils" used in the biostratigraphy of sedimentary rocks (Ferring, 2001, p. 89-90).

Stratified archaeological sites in the alluvial deposits of the North Branch of the Susquehanna River valley have produced 89 radiocarbon dates on samples of charred wood or nutshell from prehistoric pit features. There are another 35 dates from contexts somewhat less likely to represent *in situ* or "primary" cultural refuse (Schiffer, 1987). Many of the archaeological sites are referred to by archaeologists with common place names (e.g. Gould Island, Mifflinville Bridge). Each site has also been assigned a unique number in the state site files (e.g 36LU169). The number "36" represents the state of Pennsylvania and is followed by a two-letter abbreviation for the county (e.g. "LU" for

Luzerne County). The final numbers identify the site and are assigned in consecutive order by the Pennsylvania Historical and Museum Commission in Harrisburg

Radiocarbon dating is based on the decay of radiogenic ^{14}C to ^{14}N by beta decay, as described by the following equation (Faure, 1986, p. 388-389):

$$^{14}\mathbf{C} \Rightarrow {}^{14}\mathbf{N} + \beta^{-} + \nu + \mathbf{Q} \tag{1}$$

where β^{-} **= negatively charged beta particle (emitted electron)**
ν **= antineutrino**
$\mathbf{Q}$ **= end point energy of 0.156 MeV**

Radiocarbon dates are derived either from measurements of the beta decay "activity" of ^{14}C in a sample (gas proportional or liquid scintillation laboratories) or from directly counting atoms for each of the isotopes of carbon (accelerator mass spectrometry or AMS). In the gas proportional laboratories, such as the efficient and inexpensive Beta Analytic, Inc. facility, the sample is prepared to carbon dioxide and then sometimes to methane or acetylene (Aitken, 1990, p. 61). Preparation to benzene or some other liquid for scintillation counting, which was used in the University of Georgia laboratory prior to its recent upgrade to AMS, can make it possible to measure older samples (Long and Kalin, 1992a, 1992b; McCormac et al., 1993). In the AMS method, the sample is usually converted to a graphite pellet (Aitken, 1990, p. 76-78; Dickin, 1997, p. 360-372).

Seven radiocarbon dates were obtained for samples collected during the fieldwork for the present dissertation. Five of these were measured with gas proportional counting by Beta Analytic, Inc. These were samples collected in the portion of the fieldwork associated with the Wyoming Valley levee raising project. Of the remaining two dates, one is a liquid scintillation measurement by the Center for Applied Isotope Studies (CAIS) at the University of Georgia. The second of these samples was prepared to carbon dioxide gas at CAIS and submitted to the accelerator facility at the University of Arizona for AMS radiocarbon dating.

In the database of 139 radiocarbon measurements for samples from North Branch of the Susquehanna River alluvium, the "±" error values range from 35 up to 200 years. These are a function of the volume of gas or solid analyzed, the amount of carbon available to measure, and the length of time that counting is performed (Aitken, 1990, p. 78-81; Taylor, 2000, p. 87). Samples cannot be reliably dated if they are over 40,000 years old since the ^{14}C approaches background values in most of the extraction lines used to prepare the samples to carbon dioxide gas (Aitken, 1990, p. 81-82; Taylor, 2000, p. 88). When an early date is reported for a sample from Pennsylvania, one immediately suspects contamination with Paleozoic coal, "old carbon" which has no measurable amount of radiogenic ^{14}C.

Radiocarbon is incorporated into the cells of living organisms as they exchange carbon dioxide with the atmosphere. There are three isotopes of carbon, of which ^{12}C is by far the most abundant. The ratio of ^{14}C to ^{12}C in the reservoir from which the carbon initially derived must be known or estimated in order to calculate the sample age based on the laboratory measurement. When the radiocarbon dating method was first developed by Willard Libby (1955), this initial ratio was set to that typical of the modern atmosphere, assuming that the global "carbon exchange reservoir" is well mixed and any fluctuations through time have been insignificant relative to the amount of ^{14}C lost to decay. It has since been shown that both of these assumptions are incorrect. Significant "fractionation" of carbon isotopes occurs within the atmosphere and the biosphere (Aitken, 1990, p. 62-64; Bradley, 1999, p. 61-62; Herz and Garrison, 1998, p. 121), and the rate of ^{14}C production in the upper atmosphere has varied through time (Aitken, 1990, p. 66-72; Bradley, 1999, p. 62-68; Dickin, 1997, p. 364-366; Herz and Garrison, 1998, p. 121).

Biological fractionation occurs due to differences in the uptake of carbon isotopes from the exchange reservoir by the organism which supplied the material to be dated. In radiocarbon dating, fractionation problems are most acute when working with shell and other samples from marine and nearshore contexts (Little, 1995; Mangerud and Gulliksen, 1975; Olsson, 1983; Taylor et al., 1996, p. 657-658). For terrestrial plant carbon, minor corrections sometimes need to be made for differential uptake of ^{14}C by plants with different metabolic pathways (Bender, 1971; Park and Epstein, 1960; Smith and Epstein, 1971). To do so, however, the proportions of ^{13}C and ^{12}C have to be measured and this is not done routinely in gas proportional laboratories such as Beta Analytic, Inc. The $^{13}C/^{12}C$ ratio is normalized to $\delta^{13}C$ by subtraction from the value for the Pee Dee belemnite (PDB) standard (Craig, 1957). Fractionation effects previously reported for samples from eastern North America include anomalously young ages from C4 pathway plants such as maize (Conard et al., 1984; Hall, 1967; Little, 1999) and some grasses (Smith, 1973, p. 42). Measurement of all three carbon isotopes can also be used to identify anomalously old ages due to contamination by carbonate bedrock or marine submergence (Lini et al., 1995; Ridge et al., 1999).

The "conventional" age of a sample in "radiocarbon years" is calculated compared to C3 pathway wood at zero years before present (BP), where the "present" is set to the year AD 1950. If freshly cut in 1950, wood should have emitted 13.6 beta particles per gram of carbon or, equivalently, contained 1.5 parts of ^{14}C to a billion parts of ^{12}C (Aitken, 1990, p. 61-66; Stuiver and Polach, 1977). The exchange reservoir was actually perturbed during the 20th century by outputs of fossil carbon, which is depleted in ^{14}C, and by radiation from above-ground nuclear weapons testing, which increased the rate of radiocarbon production. Wood grown in A.D. 1950 consequently contained three percent less ^{14}C than samples grown in 1850, prior to the Industrial Revolution (Suess, 1955). Wood grown in 1960 and for several years following, on the other hand, is anomalously enriched in ^{14}C due to the neutrons released by nuclear weapons testing (Aitken, 1990, p. 71).

Because of the effect of these man-made perturbations on 20th century samples, an artificial standard is used in most beta decay analyses. This is an oxalic acid prepared by the U. S. National Bureau of Standards from sugar beets, with ^{14}C equivalent to values in the late 19th century and $\delta^{13}C$ of -19±1 (Aitken, 1990, p. 93-94). The "conventional" age is actually calculated using an older, incorrect value for the half-life of radiocarbon, 5,568 years (Aitken, 1990, p. 93; Taylor et al., 1996, p. 656-657).

The resulting "half-life based offset" is one cause of the deviation of "radiocarbon years" from "calendar years" which is corrected for using curves based on dendrochronology (Becker, 1993; Kromer and Becker, 1993; Ralph et al., 1973, 1974; Stuiver and Reimer, 1993; Stuiver et al., 1986, 1998; Suess, 1970), varve counting (Strömberg, 1985; Stuiver, 1970; Stuiver et al., 1986; Tauber, 1970), counting of ice-core laminations (Hammer et al., 1986), and uranium-series dating of fossil corals (Bard et al., 1990, 1993; Stuiver et al., 1998). Only a three percent error is introduced into conventional radiocarbon years by using the old, "Libby" half-life, while deviations approaching ten percent are introduced by fluctuations in the carbon exchange reservoir.

In **Chapter 4**, the entire suite of radiocarbon dates for the alluvial deposits of the North Branch of the Susquehanna River is calibrated to calendar years using the program CALIB 4.1 of Stuiver et al. (1998). This is the chronometric aspect of the present investigations since heretofore geologists and geomorphologists have reported and discussed radiocarbon dates and Quaternary chronology in uncalibrated or "radiocarbon" years (Haynes, 1991, 1993; Holliday, 2001, p. 12; Knox, 1976, 1983, 1995; Waters, 1992, p. 77-86; Waters and Haynes, 2001). Many archaeological compilations are also in radiocarbon years, although others (e.g. Herbstritt, 1988) follow the misleading practice of subtracting radiocarbon years from A.D. 1950 to obtain a putative "calendar year." Errors stemming from this practice are discussed by Custer (1996, p. 23-27) for eastern North American prehistory in general, while the implications of calibration for dating Paleoindian sites in particular have been discussed by Batt and Pollard (1996) and Fiedel (1999).

Calibration of the radiocarbon timescale began as an expedient means to solve empirical discrepancies with the results of other dating methods (Aitken, 1990, p. 99-

101; Taylor, 2000, p. 95). Pioneering efforts in the early 1970's were made at the Museum Applied Science Center for Archaeology (MASCA) of the University of Pennsylvania (Ralph et al., 1973, 1974). While the MASCA corrections were heralded as "revolutionary" by at least one Old World archaeologist (Renfrew, 1973), archaeologists working in eastern North America were cautioned to refrain from calibration until a "single best method" was agreed upon (Stuckenrath, 1977). Stuckenrath's caution may have been warranted since it was only in the 1990's that we began to understand the fundamental processes which underlie the divergence of radiocarbon years from calendar years.

The existence of the secular variations in ^{14}C activity has been conclusively proven by now using samples independently dated by multiple methods (Bard et al., 1993; deVries, 1958; Ralph and Stuckenrath, 1960; Ralph et al., 1973, 1974; Stuiver, 1970; Suess, 1965, 1970). Either the rate of ^{14}C production or the total amount of carbon in the atmosphere or both have varied compared to the oceans, the biosphere, and the lithosphere (Aitken, 1990, p. 62; Sternberg, 1992, p. 99-106; Stuiver et al., 1991). The mechanisms responsible for the variations as well as the global or regional timing of those variations are subjects of ongoing research (Bard et al., 1990, Damon et al., 1978; Sternberg, 1992; Stuiver et al., 1991; Peng and Broecker, 1992). A correlation with the sunspot cycle and geomagnetic events such as the "Maunder minimum" of the Little Ice Age (Stuiver, 1965; Stuiver and Braziunas, 1989; van Geel et al., 1999, p. 334) appears to explain some but not all of the variations.

The changes associated with the advance and retreat of continental ice sheets during the late Pleistocene had particularly significant effects on the distribution of carbon isotopes among the different parts of the carbon exchange reservoir (Bard et al., 1990; Peng and Broecker, 1992; Stuiver et al., 1991; van Geel et al., 1999). In addition to external forcing by parameters of the earth-sun geometry (Imbrie et al., 1993), ice sheet growth appears to have been driven by strong internal feedbacks since incoming solar radiation was reflected more strongly from surfaces covered with snow and ice (Bradley, 1999, p. 24-28) and sea ice curtailed the inputs from the North Atlantic Ocean which drive the global ocean circulation (Peng and Broecker, 1992, p. 85-90).

Analyses of carbon isotope ratios for both benthic and planktonic foraminifera show that carbon sequestered in the late Pleistocene abyssal ocean bottom water became depleted in ^{14}C (Peng and Broecker, 1992; Shackleton et al., 1988). Such "reservoir changes" apparently reinforced the effects of increased ^{14}C production due to lower solar activity, magnetic field strength, or both (Mankinen and Champion, 1993; Sternberg, 1992) resulting in over 3,000 years of divergence at the last glacial maximum (Bard et al., 1990; Stuiver et al., 1998). During deglaciation, carbon ventilated from bottom water to the atmosphere probably contributed to the irregular relationship of radiocarbon years to calendar years (Duplessy et al., 1992; Edwards et al., 1993).

Abrupt jumps in atmospheric ^{14}C at the Pleistocene-Holocene boundary and during the late Holocene are discussed in **Chapter 6** as one of many proxy records of climate change. The effect on radiocarbon chronology is that these intervals need to be shrunk down in order to fit into the calibrated time scale. Samples whose radiocarbon age differs by hundreds of years thus have the same calibration intercept, whereas multiple intercepts are typical for each radiocarbon date during the broad mid-Holocene hump when ^{14}C production was relatively constant.

Multiple radiocarbon measurements of tree rings for calibration purposes exemplify the general case where it is known prior to submitting samples for dating that the same object or event is being dated. This is Case I using the terminology of Ward and Wilson (1978), where it is appropriate to "pool" two or more dates by calculating the mean and standard deviation in radiocarbon years prior to calibration. This can now be done using the program OxCal written by Bronk Ramsey (1999) and is the procedure used by Haynes (1991, 1993) to pool the radiocarbon dates for the Clovis archaeological culture.

A more conservative procedure for testing the contemporaneity of radiocarbon dates was used in the present investigations, one which is suitable to the Case II phenomena of Ward and Wilson (1978). The reported standard errors as well as the dates were calibrated to calendar years prior to calculating the total time span for error estimates at two standard deviations (2-sigma). This procedure is the one recommended by Bronk Ramsey (1999) for most problems in stratigraphy and cultural chronology. While the results may not fully capture the relative rates of change in cultural or environmental phenomena, the alternative procedure essentially ignores the error inherent in the original laboratory measurements.

STRATIGRAPHIC CORRELATION AND INTERPRETATION

An allostratigraphic framework is developed in **Chapter 5** in order to correlate the alluvial deposits in the North Branch of the Susquehanna River valley and interpret their stratigraphic sequence. Allostratigraphic units are mappable, stratiform rock bodies defined and identified on the basis of bounding discontinuities (NACSN, 1983). Whereas uniform lithic characteristics are necessary for lithostratigraphic correlation, allostratigraphic units commonly include several different lithologies. Whereas chronostratigraphic units are by definition regionally synchronous, the bounding discontinuities used to subdivide deposits in an allostratigraphic framework may be somewhat time-transgressive. In general, neither age nor genesis should play a role in the definition of an allostratigraphic unit.

Bounding discontinuities identified in the North Branch sequence are of two types. There are a few lithologic contacts, such as the change from cobbly gravel beds in meltwater-derived deposits to ripple-bedded or fining-upward sandy alluvium. Most of the subdivisions that are made within the alluvial deposits, however, are based on the consistent stratigraphic position of buried soils. The buried soils define former terrace surfaces.

Where each upper boundary emerges to become a geomorphic surface, an allostratigraphic framework may mirror a previous terrace chronology or "morphostratigraphic" framework (e.g. Autin et al., 1991; Pazzaglia et al., 1998). The alloformation is a formal unit recognized in the North American stratigraphic code

(NACSN, 1983), however, whereas morphostratigraphic units are not. This is because the deposits are fully characterized between bounding discontinuities and a type locality is designated for each allostratigraphic unit. Morphostratigraphic units, on the other hand, were named after one or more geomorphic surfaces (Cotton, 1940, 1958; Frye and Leonard, 1952, 1954, 1963; Frye et al., 1948; Mackin, 1937; Willman and Frye, 1970).

Allostratigraphy is particularly suited to alluvial deposits, in which several distinct lithologies are deposited in each sedimentary cycle (Autin, 1992; Lewin, 1978). A lithostratigraphic interpretation will subdivide deposits that represent lateral changes in depositional environment. Deposits which differ significantly in both age and genesis may also be combined into a single heterolithic unit. The latter approach here serves as something of a null hypothesis against which to test the success or failure of the subdivisions made in **Chapter 5**. In general, an allostratigraphic framework provides the maximum amount of information on valley chronology and evolution (Autin, 1992). Allostratigraphy demands meter-scale stratigraphic descriptions that encompass all of the bounding surfaces.

Stratigraphers refer to the types of sediment associated with specific depositional environments as lithofacies (Pirrie, 1998). Ten lithofacies are described in **Chapter 5** from the North Branch alluvial deposits using field observations, thin section photomicrographs, and laboratory analyses of grain size, soil chemistry, clay mineralogy, and magnetic susceptibility. Changes in the alluvial lithofacies deposited at 23 locations within the North Branch of the Susquehanna River valley (see **Figure 4**) are reconstructed from cutbank profiles or borings. Lithofacies changes can be considered to represent gradual changes in depositional environments by substituting space for time, a principle known as "Walther's Law" (Nichols, 1999, p. 64; Pirrie, 1998, p. 399).

A bounding unconformity is a break in the stratigraphic column where the spatial displacement in depositional environments is large and environmental change was relatively rapid as opposed to gradual. "Stable" floodplains in which soil development occurs at the upper boundary of an alluvial package in this sense mark major changes within the river valley environment. This must be particularly true for the buried soils which are more strongly weathered than the soils formed at the present land surface.

The soils and buried soils described in this study form a "chronosequence" spanning at least 10,000 years. Seventy two soils have been described all told from the 23 profiles. Soils with "fragic" or "argillic" properties, as defined by Soil Survey Staff (1997), are found in buried soils but not in modern soils formed in alluvium. Cambic (Bw) subsoil horizons and stratic (A-C) profiles do occur at the top of some of the earliest and stratigraphically deepest of the alluvial packages, however. A statistical comparison with a contingency table (Fisher, 1970, p. 85-92; Snedecor and Cochran, 1989, p. 125-127) is used in **Chapter 5** to demonstrate the controlling influence of time relative to the other soil forming factors (Birkeland, 1999, p. 141).

Subdivisions within the alluvial deposits are presented in **Chapter 5** as members of the Wyoming Valley alloformation. It is hypothesized that the discontinuities

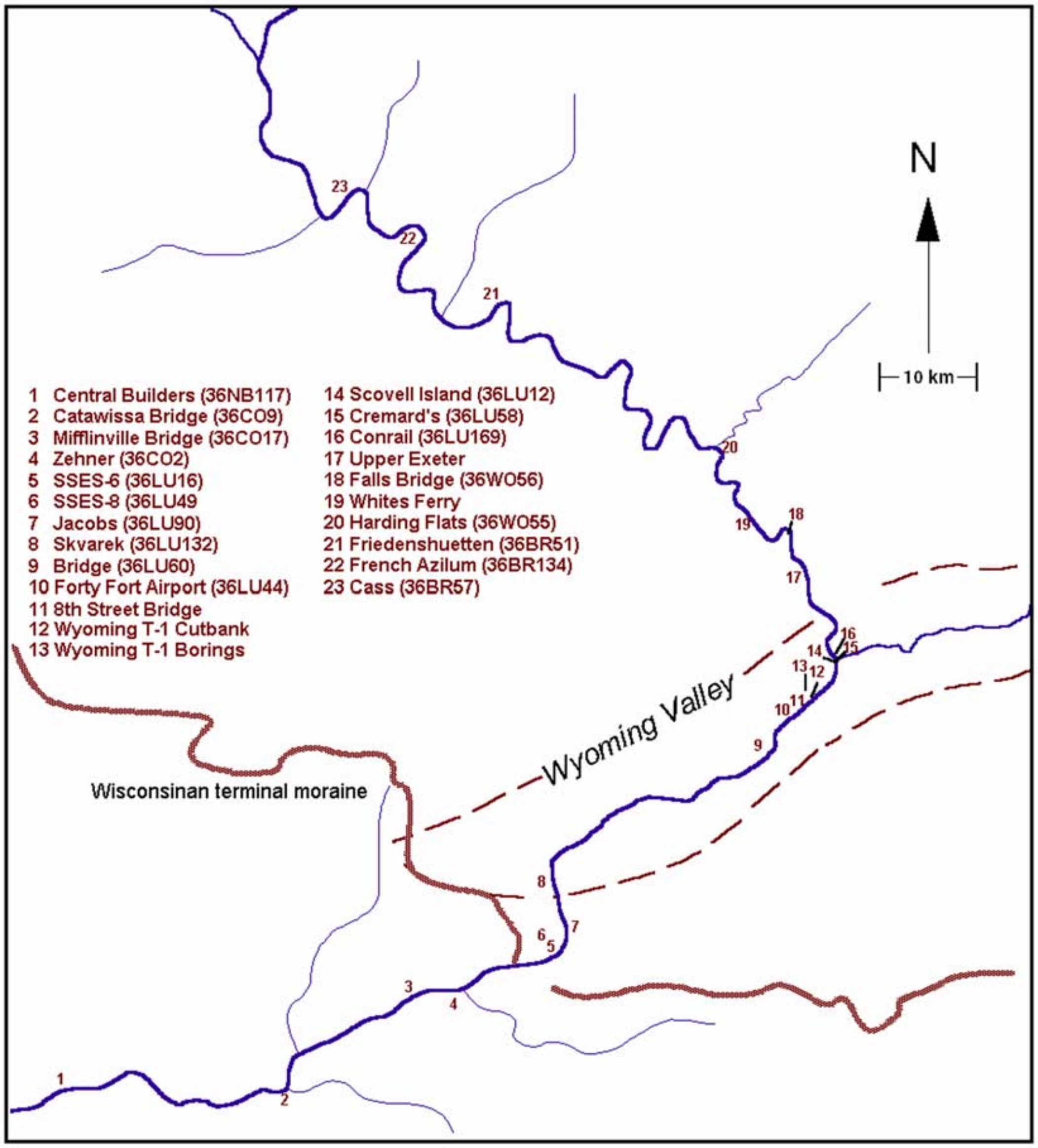


Figure 4: Map of the North Branch of the Susquehanna River valley showing the 23 locations at which the alluvial stratigraphy has been described from cutbank profiles or borings

bounding these members are equivalent to gaps in the radiocarbon chronology of prehistoric occupations on stratified archaeological sites. This chronological model is developed independently in **Chapter 4**, and the definition of allomembers in **Chapter 5** is independent of the age constraints.

The most reliable age estimates for the bounding discontinuities are the 15 radiocarbon dates for geologic contexts beneath or spatially separated from cultural occupations within the valley. The large "window" covered by each of these estimates may be narrowed by additional dating with radiocarbon or with other methods such as optically stimulated luminescence (Aitken, 1998; Wallinga et al., 2001). Many samples of plant material collected during the fieldwork for this dissertation have yet to be dated. These are indicated on the profile drawings. It is possible that unconformities bounding the members of the Wyoming Valley alloformation are somewhat time transgressive. This is permitted by the stratigraphic code and it is certainly true in many cases of the boundaries of biostratigraphic units (NACSN, 1983, p. 862).

Genesis is also considered an inappropriate basis for defining allostratigraphic units (NACSN, 1983, p. 866). Nonetheless, allostratigraphy is premised upon the existence of valley-wide or "allogenic" forcing. Strong external controls must determine both the distribution of lithofacies and the amount of time they are exposed at the surface for soils to form. In many respects, therefore, allostratigraphy can be considered an extension to nonmarine lithologies of the main principles of the sequence stratigraphy approach developed for clastic sedimentary rocks in passive margin depositional basins.

Of the five possible discontinuities identified on the basis of the radiocarbon chronology, the two which are most recognizable in the stratigraphic record are also the best dated. These are the Pleistocene-Holocene boundary (Discontinuity I) and the base of deposits which result from disturbance by Euroamerican land use practices (Discontinuity V). The other three discontinuities are marked by buried soils. The morphology of the buried soils is characterized using thin-sections as well as field descriptions.

FLUVIAL GEOMORPHOLOGY

Alluvial stratigraphy is the material representation of a river floodplain evolving over a geologic time frame. The most immediately accessible information pertaining to the genesis of an alluvial stratigraphic record is obtained by analysis of the channel and floodplain of the present river. Such an "actualistic" approach to the interpretation of alluvial deposits implements the basic uniformitarian assumption introduced by Hutton (1788) and Lyell (1833). Channels are assumed to conform to physical first principles such that their width, depth, and slope are adjusted to provide the velocity which transports the sediment supplied by the drainage basin (Knighton, 1998, p. 153-162; Ritter et al., 1995, p. 224-228).

In the following chapter, the channel form and channel pattern are described for 23 river cross sections and related to driving forces including valley slope, drainage basin area, and discharge. Discharge has been measured by the USGS gages at Towanda, Wilkes-Barre, and Danville for over 100 years. The year 1913 is the first for which continuous records are available at all three gaging stations. The computer program RIVER (Dowd, 2001) was used to calculate the recurrence interval of floods over the period of record. RIVER implements the Weibull method (Dalrymple, 1960; Dunne and Leopold, 1978, p. 305-313; Thomas, 1987) with daily peak discharges downloaded from the internet (USGS, 2002). Lognormal, Gumbel Type I, Gumbel Type III, and Pearson Type III models can be used to fit a regression line to the distribution of discharge versus the recurrence interval. The anomalously large flood of 1973 triggered by Tropical Storm Agnes causes skew in the distribution for all three of the study area gaging stations. The skew was eliminated by using the years 1913-1971 for the flood frequency calculation.

The discharge which just fills the river channel, the "bankfull" flood, is thought to be the most effective or "channel-forming" discharge (Knighton, 1998, p. 162-167; Wolman and Miller, 1960). The flood with a 1.5 year recurrence interval ($Q_{1.5}$) is the value which is most typical of the bankfull flood, particularly in humid mid-latitude drainage basins (Dunne and Leopold, 1978, p. 315). There are also field indicators of the bankfull channel, such as the height of the valley flat, the first prominent bench, or the streamside limit of perennial vegetation (Dunne and Leopold, 1978, p. 610-613; Williams, 1978a). The $Q_{1.5}$ values were compared with several of these field indicators and with the downstream increase in drainage basin area for gaging stations in the study area.

Field surveys of channel cross-sections (Harrelson et al., 1994; Pen et al., 2001) are recommended for precise understanding of the forces which shape the channel and transport sediment in natural rivers. Field surveys were not part of the present study, although some of the reaches where the archaeological sites are found were surveyed during the course of construction projects. The width and slope of the bankfull channel were measured off of USGS topographic maps, the latter by rolling a map wheel between points crossed by 20 foot contour lines.

In spite of admittedly large measurement errors, the 23 channel cross sections do provide a rational physical model of the river throughout the reaches studied. The fundamental "continuity" equation (**2**) relates discharge to the width and depth of the cross-sectional area of flow as follows:

$$\mathbf{Q} = \boldsymbol{w} * \boldsymbol{d} * \boldsymbol{v} \qquad (\mathbf{2})$$

The $Q_{1.5}$ depth at each cross section was calculated from the measured channel width, holding velocity constant. Previous studies of the hydraulic geometry of natural rivers (Carlston, 1969; Leopold and Maddock, 1953; Leopold et al., 1964) have found only small increases in velocity in the downstream direction. No overall increase or decrease in velocity was found in the USGS long-distance travel-rate determination along the North Branch from Binghamton downstream to Harrisburg (Carlston, 1969, p. 506-507).

Flow depths calculated from the continuity equation are geomorphologically significant in that they approximate the maximum height of flood scour or deposition. A better approximation of the area within which river energy is contained and applied to sediment transport is obtained, however, by calculating the hydraulic radius (*R*):

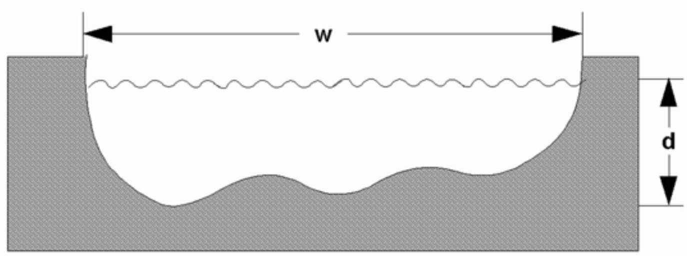
$$R = \frac{A}{P} = \frac{w * d}{w + 2d} \tag{3}$$

Figure 5 illustrates the calculation of *R* as the ratio of the cross-sectional area (*A*) to the wetted perimeter of the river channel (*P*). Values for *R* were calculated from the modeled $Q_{1.5}$ depths. Hydraulic radius (*R*), channel slope (*S*), and bed roughness (*n*) together determine flow velocity, according to the Manning equation (**4**):

$$V = k \frac{R^{2/3} S^{1/2}}{n} \tag{4}$$

where k = 1 for metric units

k = 1.49 for English units



A (cross-sectional area) = **w * d**

P (wetted perimeter) = **w + 2d**

H (hydraulic radius) = $\frac{A}{P} = \frac{w * d}{w + 2d}$

Figure 5: Idealized river cross-section showing the calculation of the hydraulic radius (*R*)

Within the error limits of the data obtained from the topographic maps and gaging records, the Manning equation was used to estimate the resistance to flow exerted by the channel bed. The calculated values for bed roughness (n) indicate the range of variation in slope, channel geometry, and the caliber of the bedload. There are many uncertainties uncertainties in the model, however, owing both to measurement error and to the initial assumption of smoothly increasing discharge in order to calculate the $Q_{1.5}$ depth and hydraulic radius. A simpler measure of downstream changes in channel form is the ratio of channel width to depth (w/d). The width/depth ratio was calculated for each $Q_{1.5}$ channel cross-section. Spatial variations in w/d within the study area are particularly relevant to the interpretation of channel changes recorded by the alluvial stratigraphy. Furthermore, the percentage of silt and clay in the wetted channel perimeter (M) is empirically correlated with the width/depth ratio according to the following equation developed by Schumm (1960):

$$w/d = 255\ \mathrm{M}^{-1.08} \qquad (5)$$

Values for M are predicted from the channel form at each of the 23 cross-sections. These compare favorably with the texture of the alluvium in the channel banks, although the bed roughness is better estimated from the Manning equation. For the reaches from Mehoopany (km 367) downstream to Shickshinny (km 271), it was also possible to use the field measurements of bed material in the active river channel. The pebble counts for five channel cross-sections were used to calculate the relative roughness (R/D_{84}), a ratio of the hydraulic radius to the diameter of the 84th percentile in the clast size distribution (Bathurst, 1993; Hey, 1979). From this ratio, it is further possible to derive the Darcy-Weisbach friction factor (ff) for resistance to flow (Knighton, 1998, p. 101-103).

The empirical formula for the Darcy-Weisbach factor developed by Wolman (1955) is presented below as equation (**6a**). The equation has been simplified (ASCE, 1963), and the simpler form presented as equation (**6b**) was used to calculate values reported in **Chapter 3**. The two forms of the equation yield the same results if hydraulic radius (*R*) is used in place of mean depth (*d*) in equation (**6a**).

$$\frac{1}{\sqrt{ff}} = 2 \log \frac{d}{D_{84}} + 1.0 \qquad (\mathbf{6a})$$

$$\frac{1}{\sqrt{ff}} = 0.82 \ \ln \frac{4.35\,R}{D_{84}} \qquad (\mathbf{6b})$$

The bed roughness, channel slope, and the composition and dimensions of the channel banks are all independent variables with respect to estimating the velocity and depth attained by individual flood events. Over a geologic time frame, however, these are all dependent variables which will be adjusted to one another in a "graded" longitudinal profile (Knighton, 1998, p. 154; Schumm and Lichty, 1965). Previous studies have found that the rivers of the glaciated Northeast are far from graded in that neither bed material size nor channel slope decrease smoothly along the downstream axis (Brakenridge et al., 1988; Brush, 1961; Carlston, 1968; Patton, 1988; Pizzuto, 1992). While this generalization holds true for the North Branch of the Susquehanna River as well, adjustments toward an equilibrium condition nonetheless appear to have occurred in response to Quaternary environmental change.

The channel dimensions have been shown to adjust primarily to discharge at the bankfull stage (Knighton, 1998, p. 162-167; Wolman and Miller, 1960). Extreme floods which recur less frequently than the bankfull flood may nonetheless do significant geomorphic work in terms of transporting sediment into the river floodplain (Knighton, 1998, p. 295-302; Lewin, 1978). One useful measure for comparing floods of varying recurrence at a reach is their unit stream power (ω):

$$\omega = \frac{\gamma \boldsymbol{Q} \boldsymbol{S}}{\boldsymbol{w}} \qquad \textbf{(7)}$$

where γ is the specific weight of water (ρg) = 1 g cm^{-3}

The unit stream power increases with discharge up to the point where floodwaters spread across the valley flat (Baker and Costa, 1987; Magilligan, 1992). The unit stream power at $Q_{1.5}$ was calculated for each of the 23 channel cross-sections. Without detailed field surveys of each cross-section, however, it was not possible to calculate unit stream power at discharges above bankfull (e.g. Magilligan, 1992). For the reaches in the vicinity of the USGS gaging stations at Towanda, Wilkes-Barre, and Danville, the unit stream power was estimated for the 5-, 10-, and 50-year floods and for the peak event triggered by Tropical Storm Agnes.

The drop in unit stream power as flow goes overbank both explains and predicts the deposition of floodplain alluvium (Allen, 1970, p. 136-140; Knighton, 1998, p. 141-148). Entrainment of particles, on the other hand, is a function of shear stress (τ) exterted within the volume defined by the hydraulic radius:

$$\tau = \gamma \boldsymbol{R} \boldsymbol{S} \qquad \textbf{(8)}$$

Bed shear stress was calculated for each $Q_{1.5}$ channel cross-section. For the reaches in the vicinity of the three USGS gaging stations, it was also possible to estimate the flood magnitude necessary to transport gravels as large as the D_{50} and D_{85} values recorded in the pebble counts. Field survey of channel cross-sections would be necessary to accurately model bedload transport in the North Branch of the Susquehanna River.

The bed shear stress equation (**8**) is closely related to the following theoretical equation for the Darcy-Weisbach factor:

$$\mathbf{ff} = \frac{\mathbf{8\,g}\,\boldsymbol{R}\,\boldsymbol{S}}{\boldsymbol{v}^2} \qquad \textbf{(6c)}$$

where g = acceleration due to gravity = 0.8 m s^{-1}

While theoretically elegant, lack of field measurements of width, depth, slope, or velocity precludes the use of equation (**6c**) except as a cross-check on the estimates obtained using equation (**6b**) and the pebble counts. Generally consistent values obtained from all of the above mechanical equations strongly suggests that the channel dimensions and channel pattern are in fact controlled by the ability of the bed and banks to resist the shear stress exerted by bankfull flows (Knighton, 1998, p. 205-236; Ritter et al., 1995, p. 212-223). The other important control, of course, is sediment supply.

Previous studies have found that multiple-thread (braided) channels tend to occur in reaches with abundant coarse bed material, erodible banks, highly variable discharge, and steep valley slopes (Knighton, 1998, p. 231-232). Leopold and Wolman (1957) characterized the geomorphic threshold from a braided to a meandering channel pattern in terms of channel slope, while Schumm (1963) characterized the same threshold in terms of sediment texture. Both braided and meandering reaches are included in the sample of 23 cross-sections for the present study, and the variation in channel pattern has been examined with reference to the hydraulic principles summarized above. There is evidence in the alluvial stratigraphy for several valley-wide changes in channel pattern, and this is one way in which the analysis of the channel and floodplain of the present river has been used to help in explaining the discontinuities in the stratigraphic record.

The sinuousity (s) of single-thread channels in the vicinity of each cross-section was measured off of the USGS topographic maps as the ratio of channel length to valley length (Ritter et al., 1995, p. 213; Schumm, 1963). Sinuosity values less than 1.5 are traditionally considered to characterize straight as opposed to meandering river channels.

Incised or entrenched meanders controlled by bedrock or terraces of glacial outwash and alluvium are very characteristic of certain reaches of the North Branch of the Susquehanna River valley (Itter, 1938; Leopold et al., 1964, p. 308-317). These were distinguished from "freely" meandering reaches in the present study on the basis of low sinuosity and the lack of floodplain (T-0) surfaces.

The simple tripartite classification of rivers as braided, meandering, or straight is not adequate for every task in the analysis of river form and function. A more elaborate classification has been developed by Rosgen (1994) which distinguishes channels on the basis of their degree of entrenchment, slope, and width/depth ratio, as well as their sinuosity. Each of the 23 channel cross-sections in the study area was assigned to one of nine categories in the Rosgen classification.

As noted by Miller and Ritter (1996), the Rosgen categories do not have much geomorphological meaning except as a shorthand notation for measurements made with standard methods. While the transitions between straight, meandering, and braided channels have been shown to occur at geomorphic thresholds (Leopold and Wolman, 1957; Schumm, 1963), the boundaries between the Rosgen categories seem arbitrary. Rosgen evidently varies the category boundaries to fit the range in a particular dataset, appealing to a "continuum concept" which may not be appropriate for all of the variables included in his classification. Problems encountered in attempting to classify reaches in the North Branch of the Susquehanna River valley thus relate to flaws in the classification itself as well as to the limitations of an analysis based on USGS topographic maps as opposed to field survey.

The model of the North Branch of the Susquehanna River channel developed in this dissertation is limited because the fieldwork effort was primarily directed toward the description of alluvial stratigraphy. Better measurement will obviously increase our ability to explain the channel dimensions using factors which affect discharge and sediment supply. No matter how detailed the data obtained on the modern channel, however, an actualistic model will be significantly different from the channel which existed prior to Euroamerican settlement. Direct and indirect impacts of human activity on the river channel are particularly evident in the reaches where the three gaging stations are located. These impacts are examined in **Chapter 6** in order to explain the last of the stratigraphic discontinuities identified in **Chapter 5**.

SYNOPTIC METEOROLOGY

In order to understand the genesis of the relict channels and floodplains archived within the North Branch alluvial terrace (T-1), it was necessary to first investigate the meteorological causes for floods which transport sediment into the present floodplain. Most floods are generated by "synoptic" patterns in the atmosphere, patterns with dimensions between 10 and 1000 km (Djuric, 1994, p. 10-13). Synoptic causes were identified for floods occurring between 1957 and 1996 using NOAA "reanalyses" of the height of the 250, 500, and 850 millibar pressure contours (NOAA, 1999). The results are presented in **Appendix 2**, and the causes identified include hurricanes, extratropical or "wave" cyclones, frontal systems, and isolated convective storms. Snowmelt also played a role in many of the late winter or spring floods, but this is not as easy either to forecast or to "backcast" (Dunne and Leopold, 1978, p. 465-490; U.S. Army Corps of Engineers, 1956, 1960).

Based on the synoptic reanalyses and other meteorological studies, causes were inferred for all floods above the $Q_{1.5}$ recorded at the three study area gaging stations as well as for historic floods dating back to the late 18th century. Such a historical perspective can indicate some of the limitations in flood frequency curves when extrapolated to time frames beyond the period of gaging (Hirschboeck, 1988; Knox, 1984, 1988, 1993). The calculation of flood recurrence probabilities assumes a population of floods for which there has been no significant change in river-basin characteristics or climatic conditions, a stationary stochastic process (Chow, 1964, p. 8-9). If the processes responsible for extreme events change over time, this "stationarity" assumption is violated and there is more than one population of floods.

Spatial variation in the effects of synoptic causes is another problem with the extrapolation of flood probabilities beyond the period of record (Eagleson, 1972; Rodriguez-Iturbe and Valdes, 1979; Troch et al., 1994). Latitudinal variation occurs along the downstream axis of the North Branch of the Susquehanna River, in particular. The North Branch straddles a break in relief at the Allegheny Front, where the westerlies in the upper atmosphere tend to bend to the north (Djuric, 1994, p. 175-177; Whittaker and Horn, 1981, 1984). Flood magnitudes triggered by specific events were examined for USGS gaging stations at Conklin (km 581), Waverly (km 455), and Harrisburg (km 105) as well as the three stations in the study reaches. Variability between tributary catchments and the trunk valley was also identified in the study area from the magnitude of specific events relative to the $Q_{1.5}$ for the gaging station at the mouth of Tunkhannock Creek (km 349).

Differences in the magnitude of events triggered by snowmelt as opposed to tropical storms were used as the basis for an experimental "nested" frequency analysis (Brown, 1991, 1996; Bevan, 1993) of floods in the study area. The results may not be sufficiently reliable to be used in mapping flood hazards, but they do indicate different flood populations which would have been affected differently by long-term environmental change. Previous studies of the South Platte River, Arkansas River, and Colorado River basins in Colorado (Elliott et al., 1982) and the Salt River valley in central Arizona (Hirschboek, 1987) have also partitioned late winter and spring floods caused by snowmelt from other extreme events.

PALEOCLIMATOLOGY

Over the geologic time frame within which alluvium has been deposited by the North Branch of the Susquehanna River, flood events varied in frequency due to changes in climate. Climate is a generalization of the regional weather phenomena which actually trigger most floods (Fairbridge, 1967; Lydolph, 1985). What we know about past climate is even more general, being based either on "proxy" data or on quantitative simulation models.

Paleoclimatic proxy data are obtained through the study of natural phenomena which are climate-dependent, and which incorporate into their structure a measure of this dependency (Bradley, 1999, p. 1). Models used in paleoclimatology range from relatively simple mathematical expressions of hydrological, chemical, and biological processes to computer models of atmospheric and coupled atmospheric-oceanic circulation. Paleoclimate models compensate for our inability to observe the past directly, but they also improve our understanding of present-day processes through the simulation of past climate conditions (Bradley, 1999, p. 471-472). Processes characteristic of the Quaternary period are well enough understood that some models have been extended to simulate "icehouse" and "greenhouse" conditions on Earth deep in the geologic past (Frakes et al., 1992; Otto-Bliesner, 1996). Possible future conditions have also been simulated in response to concerns about climate changes caused by anthropogenic inputs of CO_2 and other greenhouse gases (Schneider, 1992).

Biological and geochemical proxy data indicate that the Earth's surface began to cool between 3 and 2.5 million years ago, toward the end of the Pliocene epoch (Raymo, 1992; Stanley, 1993). Causal factors variously emphasized by competing models include earth-sun geometry (Berger, 1978; Imbrie et al., 1993; Shackleton, 1995), Himalayan uplift (Ruddiman and Kutzbach, 1989; Ruddiman and Raymo, 1988), sea-floor spreading (Ruddiman and McIntyre, 1981), feedbacks from the buildup of ice-sheets at both poles (Kutzbach and Guetter, 1986; Shackleton, 1995), and feedbacks from changes in vegetation and weathering rates on continental surfaces (Prentice et al., 1992; Ruddiman et al., 1986). For the purposes of the present study, glacial-interglacial cycles are simply assumed to be characteristic of the Quaternary period and forced at least in part by changing earth-sun geometry (Bradley, 1999, p. 35-48; Williams et al., 1998, p. 73-106).

The Earth travels an elliptical path around the sun, the magnitude of the ellipse being referred to as its **eccentricity** (see **Figure 6**). The eccentricity was shown by Milankovitch (1941) to increase and then decrease in a cycle lasting approximately 95 ky. The Earth's axial tilt, or **obliquity**, also varies. The obliquity cycle period is approximately 41 ky. Eccentricity increases the relative intensity of the seasons, which has an opposite net effect in terms of temperature in each hemisphere. Obliquity increases summer radiation receipts at high latitudes (Bradley, 1999, p. 35). The season of the year when the Earth is nearest the sun also varies with the Earth's wobble about its own axis, or **precession**. The precession cycle period is approximately 23 ky.

The global changes in eccentricity, obliquity, and precession cause only miniscule changes in the total amount of energy received from the sun, but in combination they have a very pronounced effect on the geographical distribution and seasonal timing of solar insolation. Approximately one million years ago, in the middle Pleistocene, a nearly regular cycle between warm and cool climate states evolved with a period of 100 ky (Imbrie et al., 1993). The best evidence for this cycle comes from the oxygen isotope ratios in the shells of foraminifera found in marine sediments (Shackleton, 1977; Shackleton and Opdyke, 1973), while its association with glaciation at the poles is recorded by oxygen isotope ratios and other parameters measured in the ice cores (Dansgaard et al., 1971; Jouzel et al., 1987). These long-term proxy records of global Quaternary climate change are now accepted by most Earth scientists as reliable baselines to use in correlating short-term millennial- to decadal-scale records and records of regionally specific environmental change.

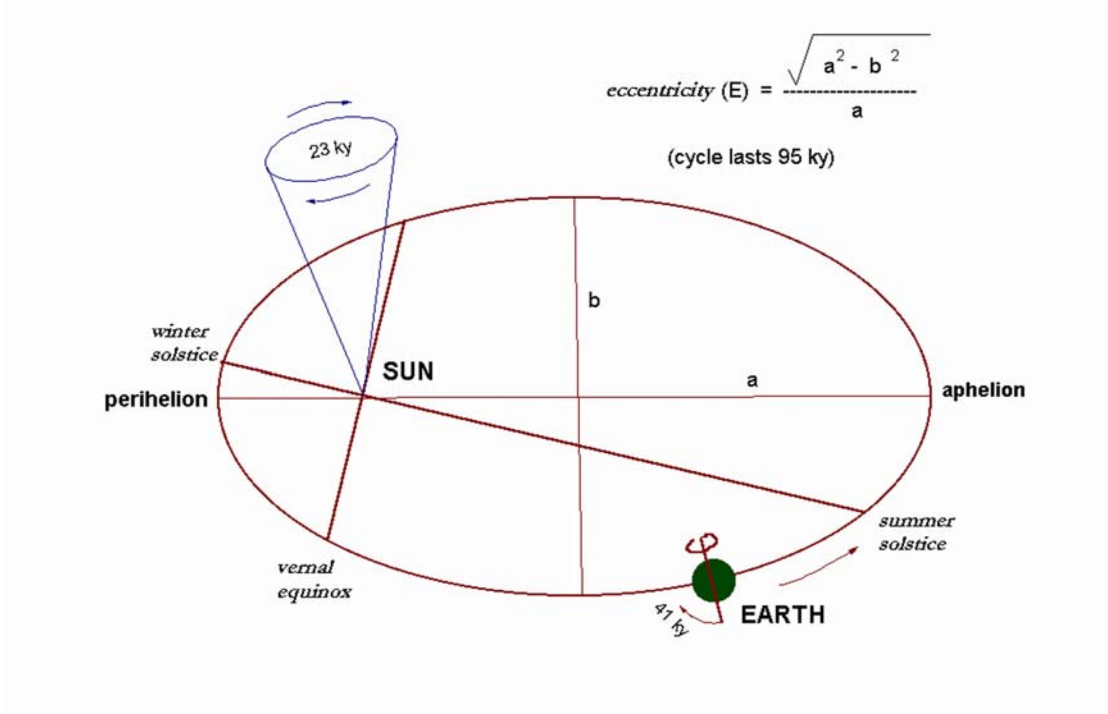


Figure 6: Schematic diagram of the Earth's orbit around the Sun, showing the eccentricity, obliquity, and precession parameters thought to drive the Quaternary glacial-interglacial cycle

Radiocarbon Abundance

Another proxy record of long-term environmental change mentioned earlier in this chapter is the irregular relationship of radiocarbon years to calendar years. These "secular variations" in ^{14}C activity appear to correlate with the sunspot cycle and geomagnetic events such as the "Maunder minimum" of the Little Ice Age (Stuiver, 1965; Stuiver and Braziunas, 1989; p. 334). The most recent calibration of the radiocarbon time scale uses both tree-ring measurements and corals dated by uranium series methods (Bard et al., 1990; Stuiver et al., 1998; van Geel et al., 1999).

Over 3,000 years of divergence of radiocarbon years from calendar years occurs at the last glacial maximum, and this may be too large to have been caused entirely by solar activity or magnetic field strength. A competing model presented by Peng and Broecker (1992) emphasizes "reservoir changes." In particular, it has been suggested that carbon depleted in ^{14}C was sequestered in the late Pleistocene abyssal ocean bottom water and then released in episodic "burps" (Peng and Broecker, 1992, p. 85-90; Shackleton et al., 1988). Mechanisms involving ocean circulation have also been suggested for probable abrupt cooling events at ~8.2 ka and ~2.8 ka (^{14}C yr BP), which also appear to have been periods when the atmosphere was comparatively enriched in ^{14}C (Stuiver et al., 1991; van Geel et al., 1999). Proxy evidence for both of these secular variations in ^{14}C abundance was obtained in the present study through calibration of several of the ^{14}C measurements in the suite of 139 radiocarbon dates from the North Branch alluvial deposits.

Pollen and Vegetation Change

Pollen, plant macrofossils, and other remains of past vegetation provide proxy records pertaining to both global and regional climatic variation. Regional environmental change is typically the most important when explaining the stratigraphy of alluvial deposits (Knox, 1983, 1985; Maddy et al., 2001). In eastern North America, the effects of postglacial climate change can be seen in the sequence of pollen zones originally defined by Deevey (1939, 1943, 1951). Deevey's herb (T) zone represents tundra vegetation of the late Pleistocene epoch and is succeeded by the spruce (A), pine (B), and oak (C) zones of the present, Holocene interglacial.

Figure 7 shows the locations for twelve postglacial bogs or lakes in the region surrounding the present study area from which pollen cores have been obtained in independent palynological studies (Barnosky et al., 1988; Cotter and Crowl, 1981; Cotter et al., 1986; Peteet et al., 1990, 1993; Watts, 1979). The age of regional vegetation changes is constrained by a total of 23 radiocarbon dates for samples from five of the pollen cores. Although both tundra and spruce parkland vegetation have been inferred on the basis of the basal herb (T) and spruce (A) zone assemblages, these may very well have no modern analogs (Overpeck et al., 1992). For explanation of the alluvial discontinuities, abrupt, millenial-scale fluctuations such as the Younger Dryas event at ca. 11.2 ka (^{14}C yr BP) represent particularly significant changes in regional climate and vegetation.

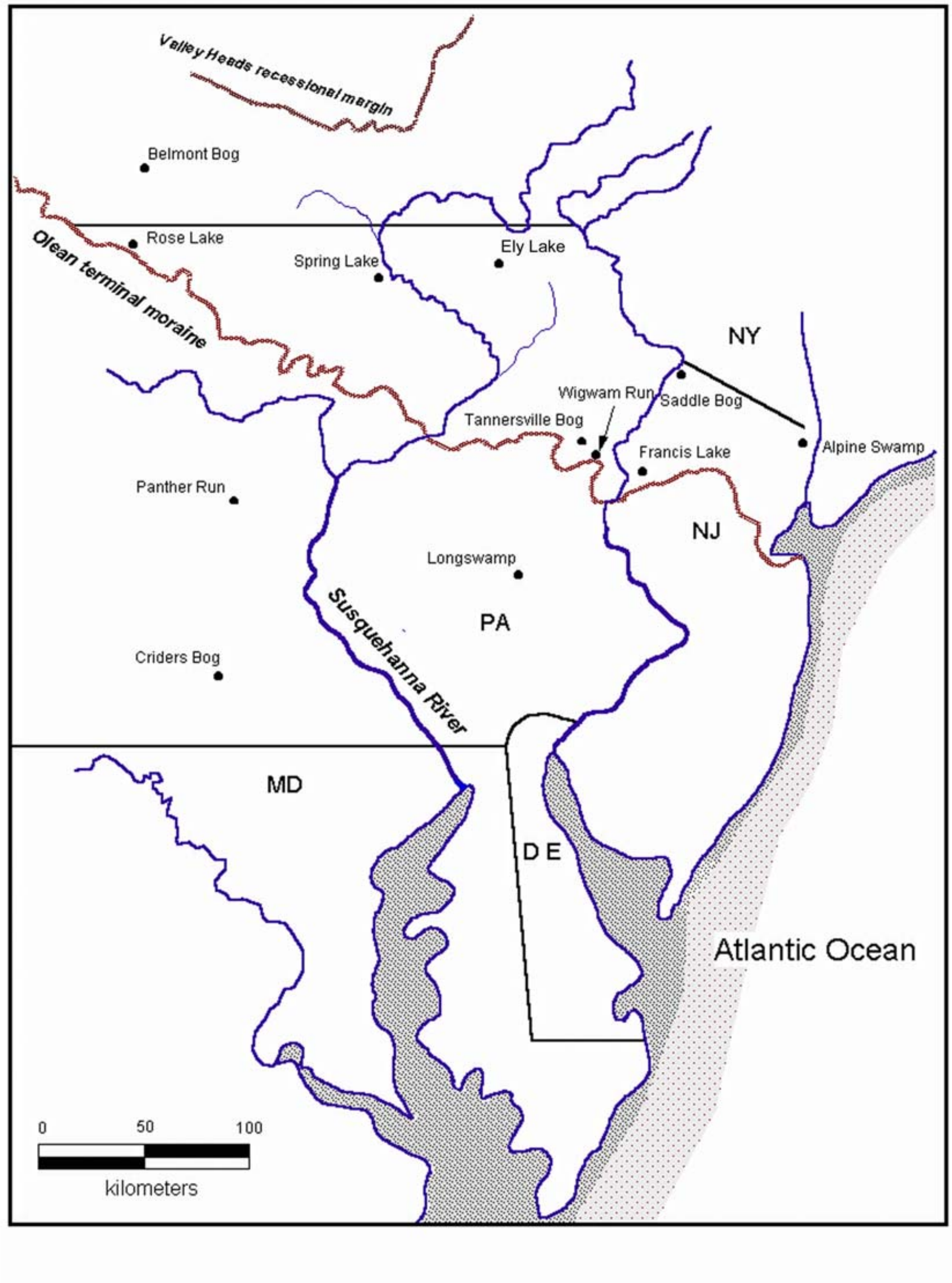


Figure 7: Map of the study area showing the location of pollen cores taken from postglacial bogs or lakes

Most of the inferences about regional vegetation change in the present study are based upon the results of other researchers reported in published literature. One important issue in the interpretation of Holocene pollen spectra from northeastern Pennsylvania is the importance of the "ecotone" or transition zone proposed by Gaudreau (1988, p. 241) at the physiographic boundary between the Ridge and Valley and Appalachian Plateaus. Immigrations of hemlock (*Tsuga*), beech (*Fagus*), hickory (*Carya*), and chestnut (*Castanea*) crossed this ecotone in sequence, gradually changing the composition of the mixed coniferous and deciduous forests of the Northeast.

Some or all of the above migrant species may have grown in the river floodplains. Relatively few studies have been reported to date of pollen from North Branch alluvium, but preliminary results indicate this to be a productive line of inquiry. In all of the cores from postglacial bogs or lakes, there is an abrupt decline in the percentage of *Tsuga* pollen ca. 4.8 ka (^{14}C yr), equivalent to ca. 5.5 ka cal BP. This abrupt environmental change in the middle part of the Holocene epoch appears to follow rather than precede an important discontinuity in the North Branch alluvial deposits. It nonetheless seems to be an important variable for explaining the deposits which overlie the discontinuity. The abundance of ragweed (*Ambrosia* sp.) and grass (graminae) pollen in historic sediment represents an equally significant deforestation event which explains the very abrupt discontinuity between prehistoric and historic alluvium in most of the stratigraphic profiles.

Tree-Ring Width Chronologies

Tree-ring widths can provide proxy evidence of very high-frequency, decadal- to annual-scale climate change (Cook et al., 1992; Fritts, 1976; Stahle, 1996). The strongest relationships between ring widths and climate occur where or when trees are under physiological stress. This is one reason why the pinyon, juniper, and Ponderosa pine chronologies are so detailed for the semiarid southwestern United States (Dean and Robinson, 1976). Preservation of the wood used for construction of prehistoric dwellings has also helped improve sample size. In the southeastern United States, bald cypress ring widths have proven sensitive to droughts which dropped water levels in cypress bogs and swamps (Stahle et al., 1988; Stahle and Cleaveland, 1992).

The best candidate for a tree species in northeastern forests with ring widths sensitive to Holocene climate change has turned out to be the Eastern hemlock (Cook, 1991; Cook and Cole, 1991). A total of 42 hemlock tree-ring chronologies, typically 300 or more years in length, were reported by Cook and Cole (1991, p. 274). Each chronology is obtained from 15 to 30 trees on a site by standardizing the ring width measurements to indices with a mean of 1 and uniform variance (Fritts, 1976). This makes it possible to reliably estimate climatic factors affecting tree growth, with the Palmer Drought Severity Index (Palmer, 1965) being one common measure in addition to mean annual or seasonal precipitation or temperature.

One unfortunate casualty of the statistical manipulations in dendroclimatology is any low frequency, multidecadal to centennial climate signal. As in the statistical analysis of flood recurrence intervals, "stationarity" is assumed in the average response of tree growth to the key climatic factors. Tree-ring chronologies from the Potomac River drainage basin were found by Cook and Jacoby (1983) to reliably predict gaged streamflow in July through September. The calibrated streamflow response function was used to reconstruct periods of drought back to 1730. Tree-ring chronologies are not yet available from the present study area, but there are old-growth hemlock stands from which they could be developed (Cook, 2002). Synoptic analyses of 19^{th} century flood events in the present study corroborate the relationship inferred by Cook and Jacoby (1983, p. 1670) between large amplitude, persistent wet and dry periods and sea surface temperatures in the North Atlantic Ocean.

Lake Sediments

Lake sediments provide a number of proxy records in addition to windborne pollen. Core transects which delineate the size and thickness of former lakestands have been used to reconstruct the lake levels at intervals whose age is constrained by radiocarbon dates (Harrison, 1989; Webb et al., 1993a). Periods which were wetter or drier than the present have been compared with the climate inferred from the pollen records. The most detailed comparisons have been made for lakes in New England. Several of the Finger Lakes in New York state have also provided multiple proxy records of Holocene climate and vegetation change (Anderson et al., 1997; Dwyer et al., 1996; Mullins, 1998).

The relative rise and fall in the level of Owasco Lake was reconstructed using radiocarbon-dated cores with facies identifed on the basis of sedimentology and the habitat preferences of lacustrine mollusks and ostracodes (Dwyer et al., 1996). Two long cores from Cayuga Lake were more homogeneous in sedimentary lithofacies but contained variable amounts of calcite, thought by Mullins (1998) to have been precipitated at a faster rate when summers were warmer in the middle part of the Holocene.

Stable isotope analyses of carbonate and other organic materials precipitated in freshwater lakes are based on principles already worked out in studies of foraminifera tests and ice cores. Relative changes in ^{18}O and ^{13}C of ostracod shells from Lake Erie were studied by Fritz et al. (1975). The climate changes indicated by the stable isotope analyses were consistent with an independent pollen record from the same sediments and with stratigraphic evidence for rising lake level after a postglacial erosional hiatus. The measurements of ostracod shells are less reliable as a proxy for the magnitude of changes in regional temperature, because these are affected by the lake volume and water chemistry as well as the isotopic composition of atmospheric precipitation.

General Circulation Models (GCMs)

Regional weather phenomena are connected with one another by the circulation of atmospheric mass and energy above the surface of the Earth. Long-term climate change must consequently represent significant change in the pattern of atmospheric circulation. The simplest models directly relate mean temperature to the changes in solar insolation predicted by Milankovitch forcing (Budyko, 1969; Sellers, 1969; Gunn, 1991, 1994, 1997). For example, Gunn assumes that global mean temperature regulates the average annual position of the jet stream at the boundary between polar and equatorial air masses (Gunn, 1994, p. 72). The position of the jet stream in turn supposedly controls the amount of rainfall in any given region, with mid-latitude climates tending to "jump" rapidly between three primary states: hot and dry, warm and wet, or cool and dry. A shift of the jet stream toward the equator during the warmest part of the Holocene, the Hypsithermal, has also been proposed in several model interpretations of North American proxy data (e.g. Forman et al., 1995; Dwyer et al., 1996).

While all models are simplifications of reality, the global energy balance models fail to include many features of both the continents and the oceans which determine "boundary conditions" for Holocene climate change. The model developed by the members of the Cooperative Holocene Mapping Project (COHMAP) is in some ways more empirical, although the flow between grid cells is driven by simple equations that satisfy the principles of mass and energy conservation (COHMAP Members, 1988, p. 1044). COHMAP used the Community Climate Model (CCM) of the National Center for Atmospheric Research (NCAR) to simulate the climate in North America for the months of January and July at 18 ka, 12 ka, 9 ka, and 6 ka BP

The Community Climate Model is a 40 x 48 grid of cells with 7.5 degrees of longitude and about 4.4 degrees of latitude (Kutzbach and Ruddiman, 1993, p. 13; NOAA, 1999). The present study area is in the grid cell centered at 42.2°N/75°W. Each model run reports a total of 62 values of meteorological variables at the surface and at the 850 mb, 500 mb, and 250 mb levels in the atmosphere. Paleoenvironmental proxy data were used to prescribe the following "boundary conditions" for each time slice:

orbitally determined insolation, mountain and ice-sheet orography, atmospheric trace-gas concentrations, sea-surface temperatures, sea-ice limits, snow cover, albedo, and effective soil moisture (COHMAP members, 1988, p. 1044; Kutzbach and Ruddiman, 1993, p. 14-20).

Figure 8 illustrates the changes in boundary conditions which drive the COHMAP GCM simulations. The critical boundary condition from 18 ka to 9 ka was the retreat of the Laurentide ice sheet (Ice). The solar insolation in the summer months (S_{JJA}) reaches a maximum at 9 ka, at which point the insolation in the winter months (S_{DJF}) is at a minimum. The warming of the oceans lags approximately two thousand years behind the solar insolation changes. Recent studies (Bond et al., 1997; Marchitto et al., 1998) have suggested that changes in sea-surface temperatures driven by the ocean circulation became increasingly important after 9 ka.

Teleconnections

General circulation models are an essential tool for understanding past and present climate. The models help to explain a number of statistical relationships which have been observed between weather phenomena separated by great distances. Such relationships between synoptic-scale patterns which are not in direct physical contact are known as "teleconnections" (Angstrom, 1935). For eastern North America, one teleconnection which definitely affects the path and intensity of winter storm tracks as well as precipitation and runoff is the North Atlantic Oscillation (NAO). The NAO was

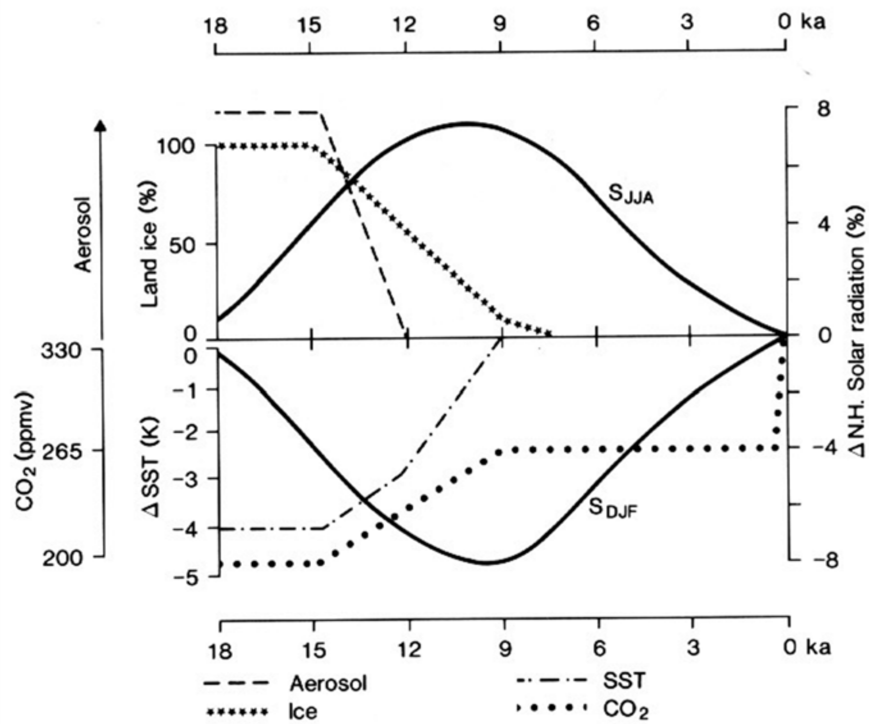


Figure 8: Boundary conditions for the COHMAP simulations of the last 18 ky using the NCAR Community Climate Model

first defined by Walker and Bliss (1932) as the difference between normalized mean winter (DJF) pressure anomalies at Ponta Delgadas, Azores, and Akureyri, Iceland (Rogers, 1984, p. 2000).

Positive numerical values of the NAO are associated with strong east-west (zonal) flow in the region between the stations while negative values are associated with weakened zonal flow. The NAO appears to explain an observed "seesaw" between winter temperatures in Greenland and northern Europe (Burroughs, 1992, p. 46-49; Van Loon and Rogers, 1978) since high NAO-index winters are unusually warm in northern Europe and cold in Greenland while the reverse is true in low NAO-index winters. Values for the NAO index, redefined as the difference between the normalized sea level pressure over Gibraltar and the normalized sea level pressure over Southwest Iceland, have recently been calculated back to 1823 by Jones et al. (1997) using early instrumental data. The NAO index values were compared with gaged floods which are summarized in the following chapter. Several previous studies have also suggested that proximity to the Atlantic Ocean influences the storms which deliver precipitation to northeastern Pennsylvania (Namias, 1973; Rossi, 1999; Whitaker and Horn, 1984).

Another teleconnection described by Walker and Bliss (1932), the Southern Oscillation (SO), has recently received considerable attention because of its apparent connection with the "El Niño" phenomenon in the eastern Pacific Ocean. Walker's original definition of the SO was based on the difference in pressure observations at Santiago, Honolulu and Manila, and those at Jakarta, Darwin and Cairo, together with figures for the temperature in Madras, rainfall in India and Chile, and the Nile flood

(Burroughs, 1992,   p. 48-50). A high in the South Pacific above Tahiti typically corresponds to a low over northern Australia which strongly affects summer rainfall there (Rogers, 1984, p. 2000; Williams et al., 1998, p. 166). In the opposite case, drought conditions prevail over a large portion of the Australian continent.

Atmospheric mass is thus apparently exchanged along the complete circumference of the globe in tropical latitudes. The El Niño phenomenon is one aspect of the ENSO (El Niño/Southern Oscillation) in that equatorial sea-surface temperature in the Pacific is relatively high when the South Pacific high is weak, as is equatorial rainfall (Julian and Chervin, 1978). ENSO forcing has been suggested to account for high frequency climatic variability worldwide, including events in Chesapeake Bay (Cronin et al., 2000) and in New England proglacial lakes (Rittenour et al., 2000).

The ENSO appears to be far removed from the mechanisms known to generate historic floods in the North Branch of the Susquehanna River, and neither El Niño nor La Niña events have been hypothesized to be primary causes for discontinuities in the present stratigraphic framework. Recent models do suggest that El Niño events may influence the predominant state of the NAO and other mechanisms which are identifiable from the synoptic reanalyses (Alexander et al., 2002; Hoerling and Kumar, 2002). Nontheless, an empirical investigation found that the impact of past El Niño events on the weather in Pennsylvania was neither strong nor systematic (Forbes et al., 1999).

Gulf Stream and Atlantic Ocean atmospheric effects

Recent paleoclimate models incorporate more feedbacks from ocean circulation than were accomodated in the COHMAP simulations. One prominent synoptic pattern in ocean circulation which is closely coupled with the atmosphere over eastern North America is the Gulf Stream. This is the western limb of a "subtropical gyre" which encircles the becalmed Sargasso Sea (Pedlosky, 1990). Water actually converges on the Sargasso Sea, then sinks and begins to return just below the surface back to the north and south. As it does, it is turned to the right by the Coriolis force, resulting in the observed encircling currents such as the Gulf Stream.

The strength of the Gulf Stream varies through time and this affects the atmospheric circulation on the North American continent as well as the ocean circulation in the North Atlantic. The subtropical high often seen at approximately 20°N latitude, for example, is associated with positive surface and subsurface heat content anomalies in the shallow waters fed by the Gulf Stream. The warm, salty waters of the Gulf Stream are also key to the formation of North Atlantic Deep Water (NADW). As shown in **Figure 9**, a "conveyor belt" in the world's oceans begins when these waters cool and sink between Greenland and Norway (Broecker, 1995, 1997, 1998). Due to the known linkages of these mechanisms with atmospheric circulation within the period of meteorological records in the study area, they have been considered as primary candidates for environmental changes that could generate discontinuities in the stratigraphic record.

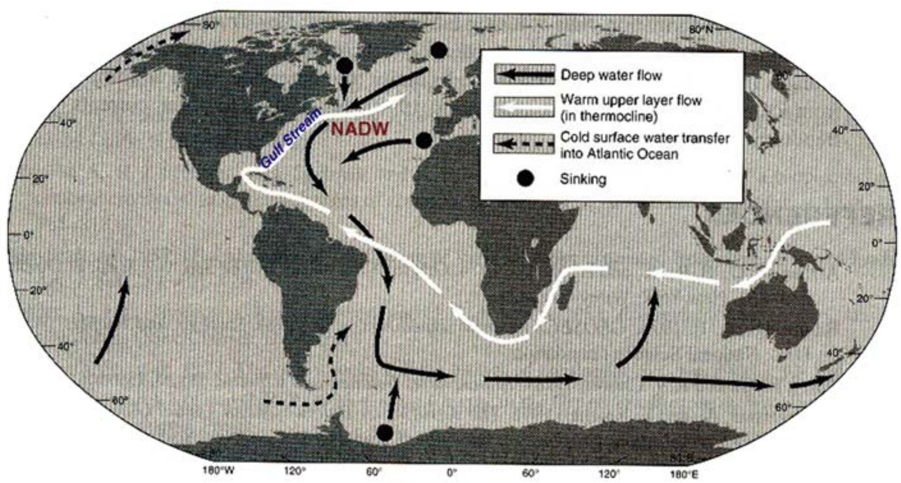


Figure 9: The thermohaline circulation or global "conveyor belt" of oceanic deep water currents (after Broecker, 1997)

Pacific/North America (PNA) pattern

The most direct relationship between a synoptic pattern and the regional atmospheric circulation in eastern North America is that between the Pacific/North America (PNA) pattern and the trough of low pressure east of the Allegheny Front. In its purest form, the PNA consists of four cells forming an arc stretching from the central Pacific to the Gulf of Alaska, into Alberta, and continuing southeastward across the United States to the eastern Gulf of Mexico (**Figure 10**). This is not technically a "teleconnection" since the cells are in direct physical contact.

According to Lins et al. (1990, p. 21), the PNA is the primary determinant of winter weather for most of the North American continent. Relatively wet troughs over the eastern United States and southeastern Canada are associated with relatively dry longwave ridges over the western United States and southwestern Canada, and vice versa. Strong PNA conditions of pronounced Rossby waves in the westerlies should correlate with a weakened NAO, since the NAO is characterized by zonal flow across the Atlantic Ocean (Burroughs, 1992, p. 46-47; Wallace and Gutzler, 1981). The inferences made through comparison of flood events with the values calculated for the NAO index in the present study may therefore have implications for the strength of the PNA as well. Over the Holocene epoch as a whole, the strength of the PNA could thus be affected by the Gulf Stream and by rapid changes in the sea surface temperature of the North Atlantic Ocean.

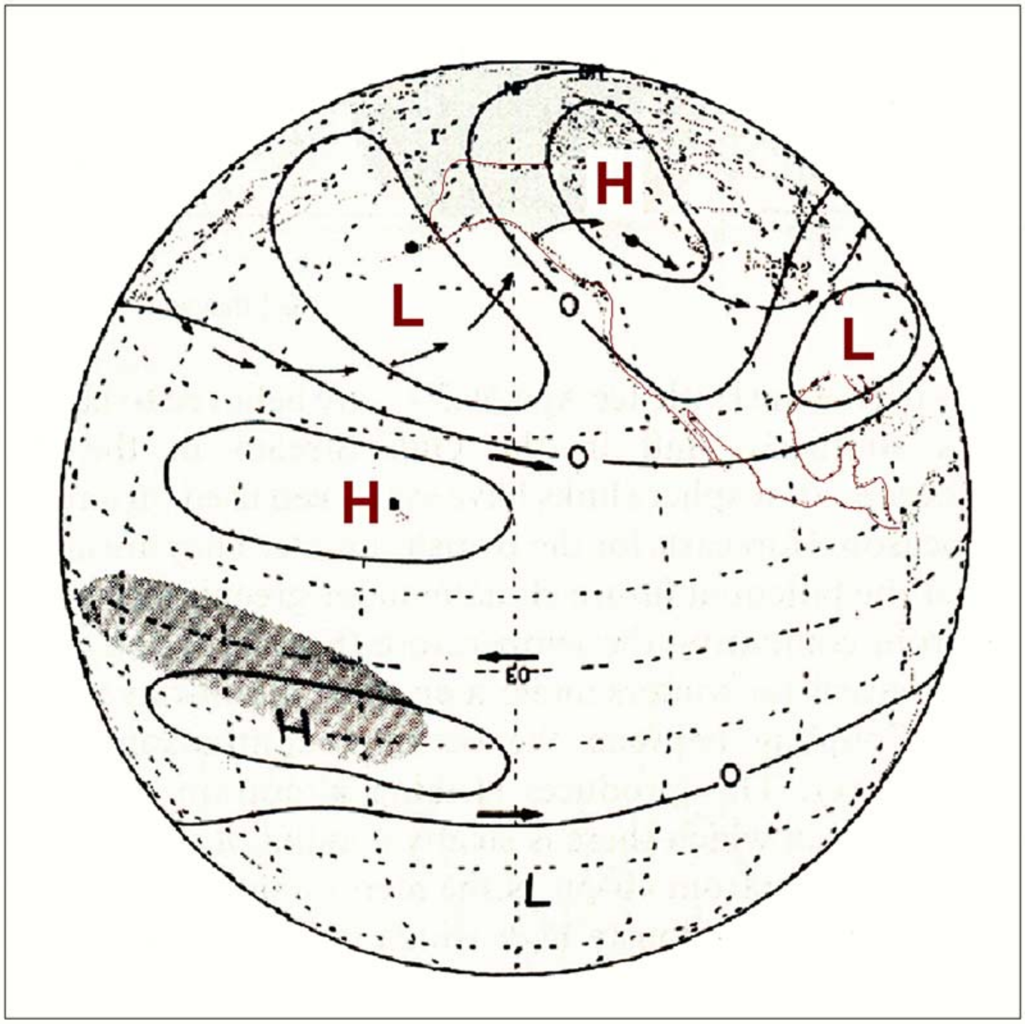


Figure 10: The Pacific/North America (PNA) pattern of atmospheric circulation

METHODOLOGICAL STRENGTHS OF MULTIDISCIPLINARY RESEARCH

The methods summarized above are derived from several distinct subdisciplines of the earth sciences. By employing several separate lines of attack, it is hoped that the results obtained in this study can be analytically separated from the core hypotheses. Such methodological independence contributes scientific objectivity and enables an assessment of the relative support for multiple working hypotheses (Chamberlin, 1890).

Multidisciplinary research is most effective when driven by strong hypotheses which have specific empirical implications but far-reaching theoretical consequences (Platt, 1964). Statement of "null" or alternative hypotheses to that confirmed in the study helps guard against biased interpretation of results (Popper, 1968). In confirming the core hypothesis that physical discontinuities exit in the North Branch alluvial deposits, a null hypothesis of a heterolithic unit encompassing all of the alluvium is also entertained. This would in fact be what is typically identified as "Quaternary alluvium" on state geological maps. The present study aims to go beyond the merely practical goal of mapping the alluvium, however. Mapping was undertaken in order to contribute to fundamental understanding of a large river basin and its response to external forcing (e.g. Blum and Tornqvist, 2000; Maddy et al., 2001).

The allostratigraphic framework developed in **Chapter 5** effects an accomodation between the geologist's focus on bedforms and changes in sediment texture and the pedologist's focus on soil structure and weathering geochemistry. It is hoped that this will serve as a model for the stratigraphic interpretation of river deposits represented in the rock record. Allostratigraphy separates the identification and description of stratigraphic discontinuities from inferences regarding the age or genesis of the deposits. This is not due to a lack of interest in either chronology or long-term environmental change, but simply a device which permits multiple working hypotheses to be entertained. Hypotheses which should be considered when attempting to explain bounding unconformities identified in alluvial deposits include global climate change, vegetation change, plate tectonics, eustatic sea-level fluctuations, and deforestation or other human land use impacts.

CHAPTER 3

STUDY AREA GEOLOGY, GEOMORPHOLOGY, AND HYDROLOGY

The study area for the present dissertation extends for 250 km along the North Branch of the Susquehanna River in northeastern Pennsylvania (see **Figure 11**). The North Branch originates near Cooperstown, New York and is the larger of the two branches of the Susquehanna which join at Northumberland, Pennsylvania (km 197). The combined drainage basin area of 75,000 km^2 is the largest for rivers which drain the Atlantic Slope of the North American continent. All of the study area was glaciated during the Pleistocene, more than half of it by the most recent, Wisconsinan ice sheet. The relative importance of the various forces which drive valley alluviation can be anticipated in large part from the study area's location in the glaciated upper reaches of a large sedimentary basin.

BEDROCK GEOLOGY OF THE RIVER VALLEY

The upstream reaches of the study area are in the Appalachian Plateaus physiographic province (Berg et al., 1989; Briggs, 1999), with slightly folded Devonian sedimentary rocks of the Lock Haven and Catskill formations. The North Branch channel trends predominantly southeast across the strike trend of the elongate ridge crests locally referred to as the "Endless Mountains." Samples were collected from one outcrop of the

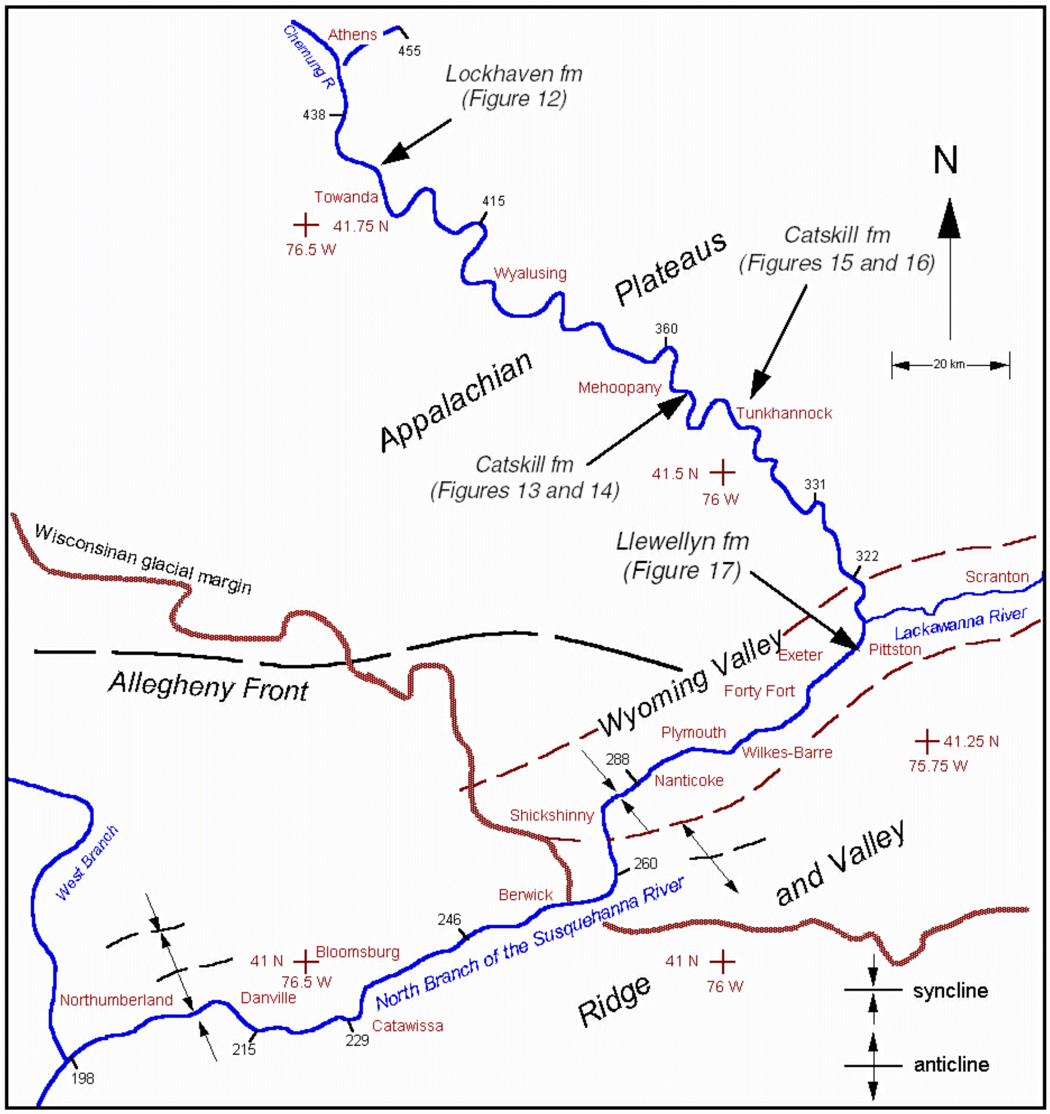


Figure 11: Map of the North Branch of the Susquehanna River valley showing prominent physiographic features, locations of modern towns, and bedrock sampling units

Lock Haven and two of the Catskill in order to identify clastic sedimentary particles in the alluvium which are derived from these local lithologies.

The Lock Haven formation outcrop was on the left bank of the river 2.5 km upstream of Towanda (km 430). The flat-lying beds of gray or greenish gray fine-grained sandstone are part of a tidally-influenced facies in the Catskill Delta (Berg et al., 1980; Sevon and Woodrow, 1985) with some extremely muddy beds. In thin section (**Figure 12**), the framework consists of subangular to subrounded quartz clasts which average 0.1-0.2 mm in diameter. Muscovite laths with pink (2^{nd} order) birefringence parallel the bedding planes seen in the hand sample, and most of the matrix filling intergranular voids also appears to consist of silt- or clay-sized mica.

The Catskill formation first outcrops in the North Branch of the Susquehanna River valley at Wyalusing (km 399). The Catskill is currently undivided in northeastern Pennsylvania but has been divided in the downstream reaches of the present study area into the Duncannon, Sherman Creek, and Irish Valley members (Sevon and Woodrow, 1985; Inners, 1978). The outcrop sampled in the river channel a kilometer downstream of Mehoopany (km 367) is planar-bedded, fine-grained sandstone with parting lineations (**Figure 13**). When examined in thin section (**Figure 14**), the detrital framework can be seen to consist of subangular quartz (>80%) from 0.1-0.5 mm in diameter along with some blocky clasts that are probably potassium feldspar (<5%).

Most of the opaque grains in the Catskill are detrital iron oxides (5-10%) but there are also oblate particles that are probably fecal pellets. There are fewer euhedral muscovite grains (<5%) than in the Lock Haven, and micaceous material has

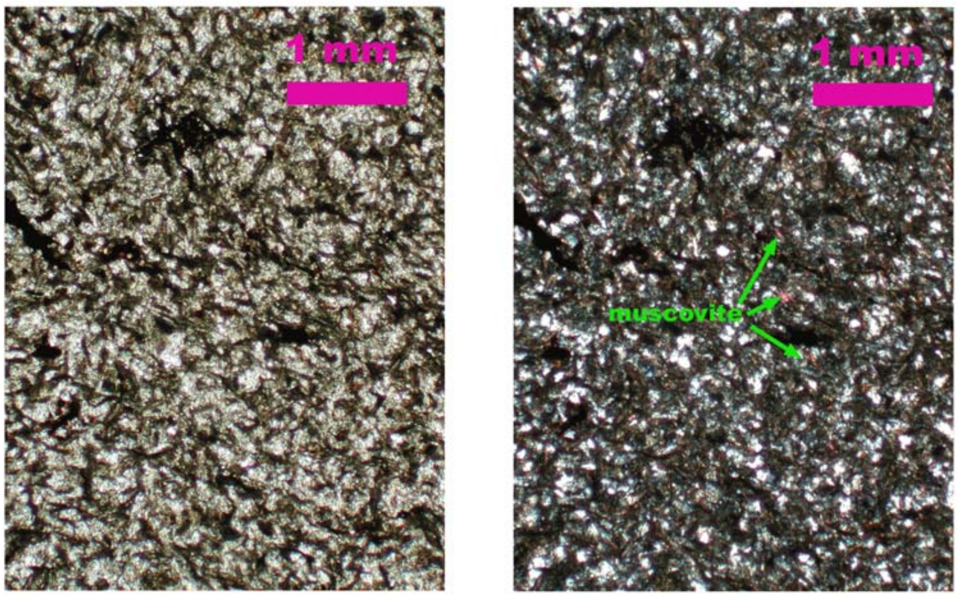


Figure 12: Thin-section photomicrographs in PPL (left) and XPL (right) of a sample of the Lock Haven formation collected on the left bank of the North Branch of the Susquehanna River 2.5 km upstream of Towanda, Pennsylvania

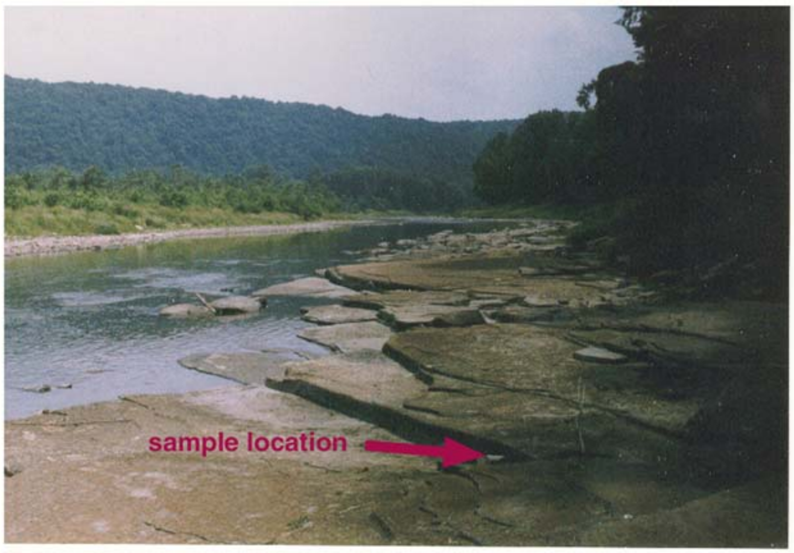


Figure 13: Catskill formation sandstone exposed in the river channel a kilometer downstream of Mehoopany, Pennsylvania

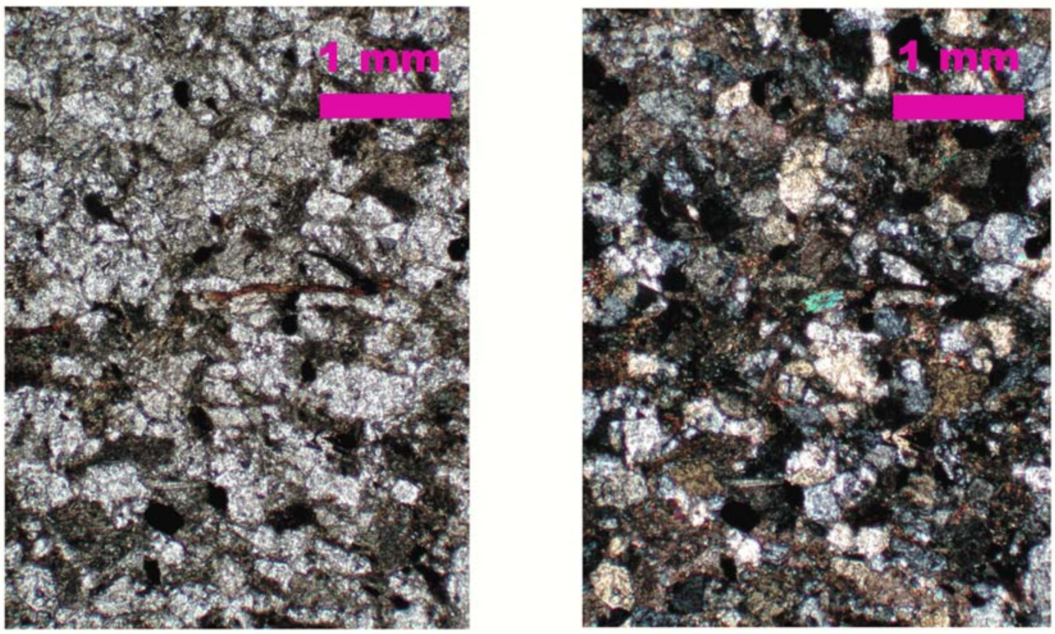


Figure 14: Thin-section photomicrographs in PPL (left) and XPL (right) of the sample of the Catskill formation collected from the river channel a kilometer downstream of Mehoopany

recrystallized within many of the planar voids subparallel to bedding. Limpid yellow clay cementing the entire framework is particularly prevalent in the upper half of the field of view, above the planar contact defined by muscovite laths. The clay cement may be a product of subaerial weathering, and was definitely added after the initial deposition of the sand sheet in a floodplain or delta setting (Woodrow, 1985). Chert cement fills most of the lower right hand corner of the field of view in **Figure 14**.

In the outcrop of Catskill sampled along S.R. 92 northeast of Tunkhannock (see **Figure 15**), low-angle crossbeds are visible as well as hackly fracture suggesting soil formation. The quartz framework grains are better sorted and more rounded than in the other Catskill sample. Muscovite laths are aligned with bedding below the planar contact in the middle of **Figure 16**. The contact may mark the top of a fining-upward trend in the deposit, although both the mica and clay could have been precipitated in response to pressure during diagenesis

Sedimentary lithologies also characterize the Ridge and Valley physiographic province (Berg et al., 1989; Way, 1999), which the river enters upon passing through the water gap at Pittston (km 311). The bedrock is more strongly folded, with local displacement along thrust faults (Faill and Nickelsen, 1999; Gillmeister, 1997; Inners, 1981). The folds strike northeast-southwest, with two downwarped synclines (Wyoming Valley, Northumberland-Catawissa) separated by an upwarped anticline (Berwick) The river generally parallels the strike, with the exception of short jags where it has cut "water gaps" through the resistant rocks (Reif, 1993; Sevon, 1986). At Pittston, for

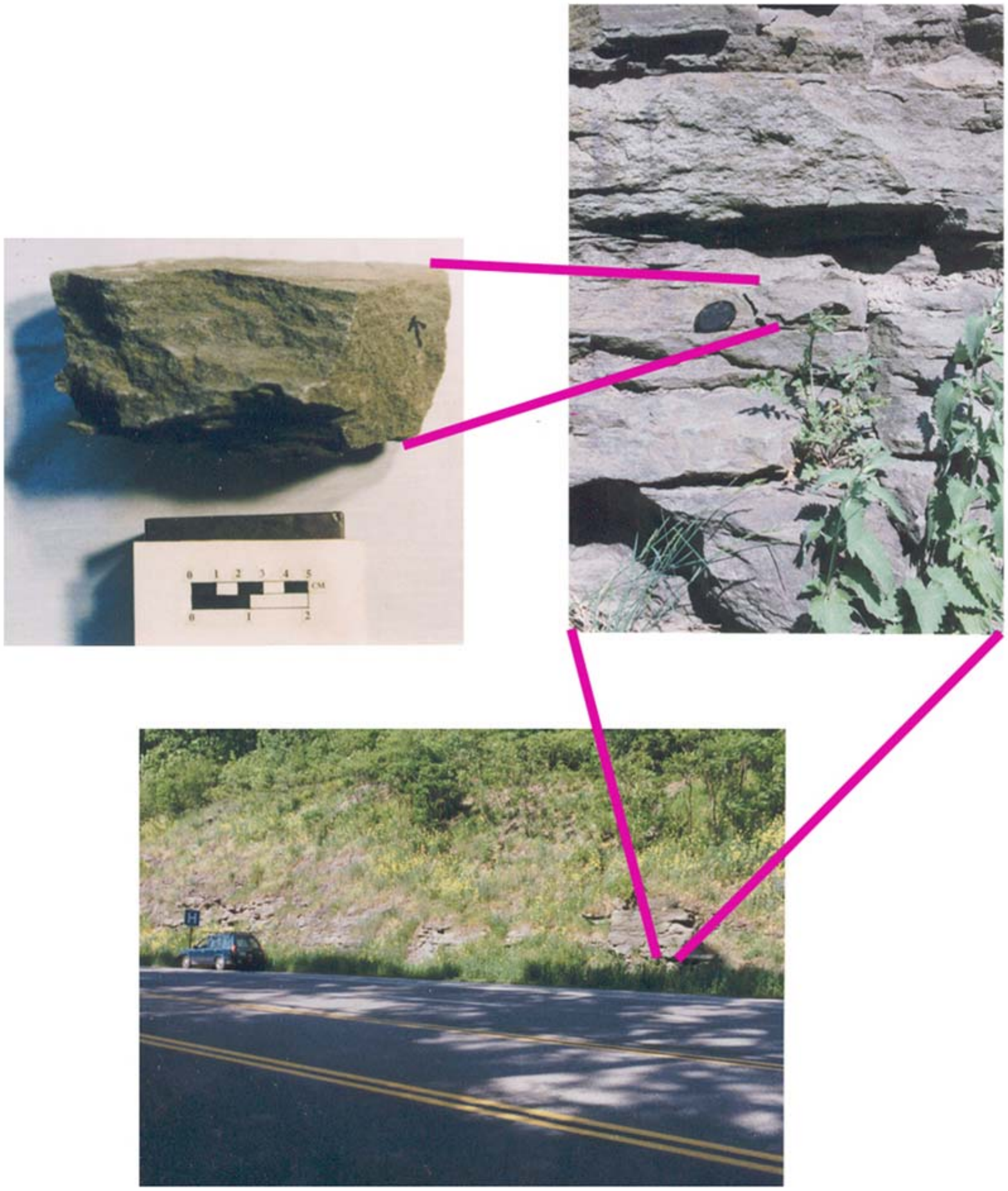


Figure 15: Catskill formation outcrop sampled on SR 92 northeast of Tunkhannock, Pennsylvania

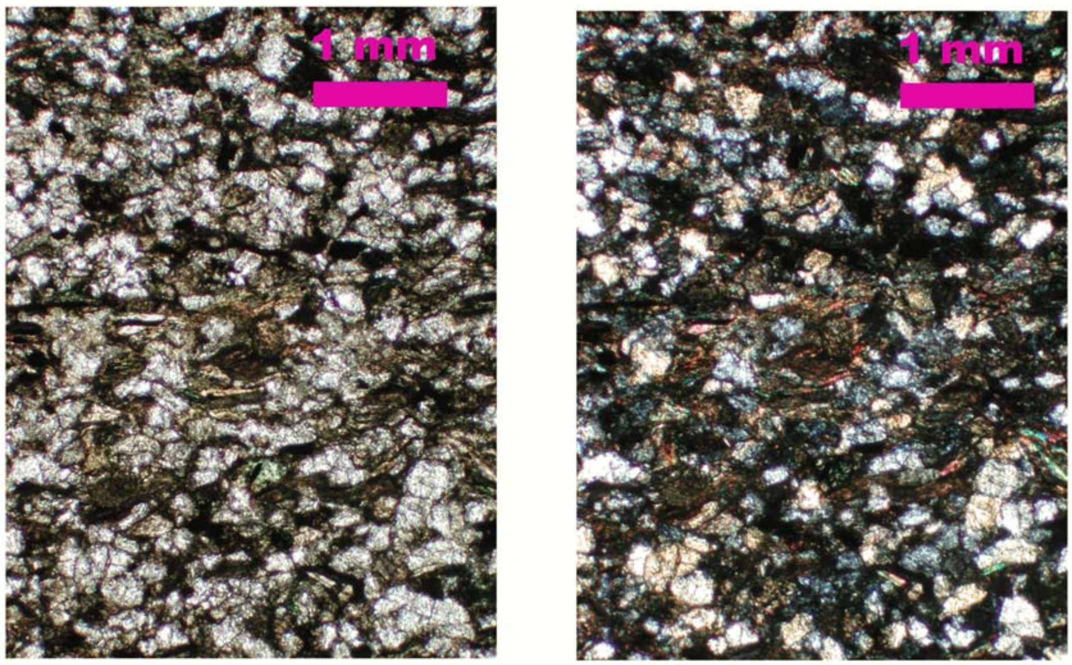


Figure 16: Thin-section photomicrographs in PPL (left) and XPL (right) of the sample of the Catskill formation collected from the outcrop on SR 92 northeast of Tunkhannock, Pennsylvania

example, the valley cuts the Pocono, Mauch Chunk, and Pottsville formations and then flows on the Llewellyn through Wilkes-Barre (km 299).

A sample of the Llewellyn formation was collected on the left bank of the river at Pittston. Photomicrographs of a thin-section prepared from the sample (**Figure 17**) show a much coarser texture to the initial deposit, with quartz and feldspar clasts ranging from 0.4 to 1.0 mm in diameter. There is very little pore space, and what there is has been filled with opaque to dark brown iron oxide cement. A euhedral muscovite lath in the upper left corner of the field of view has both pink and light blue (2^{nd} order) birefringence in cross-polarized light.

The river course from the Pittston water gap downstream to Nanticoke (km 290) follows the southwesterly trend of the canoe-shaped Wyoming Valley syncline (Gillmeister, 1997). These relatively straight reaches are known as the "Wyoming" Valley after an historic Native American village on the site of modern Wilkes-Barre. At Nanticoke the river snakes back across the syncline's northwestern limb, passing from the Llewellyn to the Pottsville, Mauch Chunk, and Pocono until it finally abuts a southeast dipping slope of Devonian Catskill formation red mudstones and gray sandstones (Berg et al., 1980; Braun et al., 1989, p. 77-79).

A right angle bend at Shickshinny (km 272) directs the channel southward through the core of the Wyoming Valley syncline once again. Ridge crests known locally as Penobscot Mountain east and Lee Mountain west of the North Branch valley are the topographic expression of the resistant lithologies on the southeastern limb of the syncline. The south-trending "water gap" continues through the adjoining Berwick

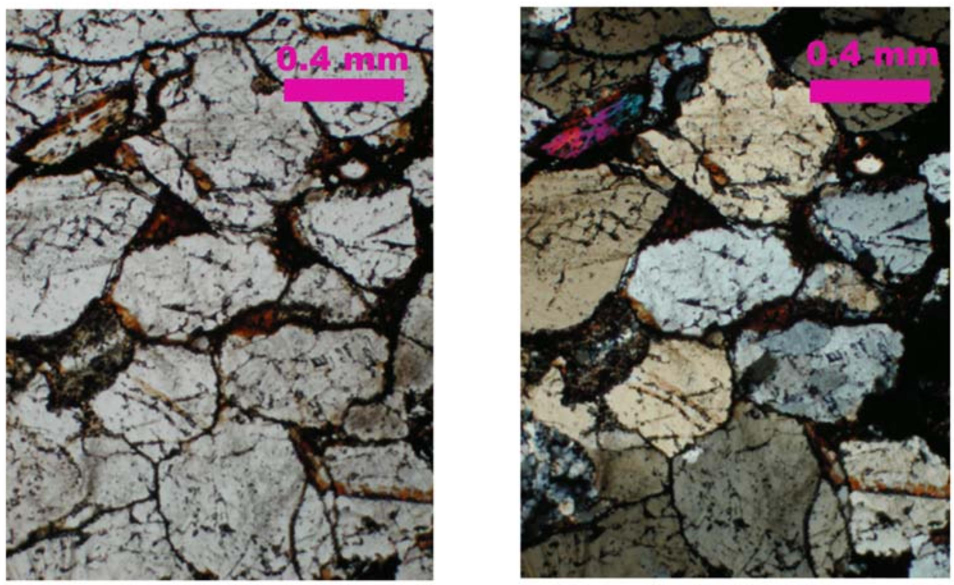


Figure 17: Thin-section photomicrographs in PPL (left) and XPL (right) of the sample of the Llewellyn formation collected on the left bank of the North Branch of the Susquehanna River at Pittston, Pennsylvania

anticline across Catskill beds which have been divided into the Duncannon, Sherman Creek, and Irish Valley members in order of increasing age (Sevon and Woodrow, 1985; Inners, 1978). Whereas the average channel width is less than 200 m through the gap, both channel and valley widen abruptly as they bend to follow the southeastern limb of the breached anticline downstream of Wapwallopen (km 261).

From this "Bell Bend" at Wapwallopen downstream to Bloomsburg (km 234) the North Branch channel trends southwesterly through a "lowland" eroded down to Upper Silurian to Middle Devonian shales and carbonates on the south limb of the Berwick anticline. More resistant Upper Devonian sandstones and siltstones of the Catskill and Trimmers Rock formations form the valley walls, dipping to the north on the north side of the river and to the south on the south side (Inners, 1978, p. 4; Braun and Inners, 1988a, p. 106-112). The ridge to the north is called Lee Mountain while Nescopeck Mountain lies to the south. Local relief is typically 90-120 m in comparison to nearly 200 m in the Wyoming Valley and 250 m in the reaches from Tunkhannock to Pittston.

The river trends due west downstream of Berwick (km 254), crossing from the Mahantango to the Marcellus, Onondaga, Keyser, and finally the Silurian Tonoloway and Wells Creek formations near the core of the Berwick anticline. Braun (1988a, 1994a) attributes the abrupt southward bend below Bloomsburg to the capture of a meltwater channel from one of at least two glaciations prior to the Wisconsinan advance. If Braun is correct, the course of the North Branch from here downstream to Catawissa (km 229) is less than a million years old.

The westward-trending reach downstream of Catawissa occupies a valley which continues east along Catawissa Creek and then across a low divide to a small tributary of Nescopeck Creek. The age of the stream which incised this valley and the capture of its lower reaches by the North Branch of the Susquehanna River have yet to be worked out in detail. It is probably early- to mid-Pleistocene or older, and the present divide is suggested by Braun (1988a, 1994a) to be filled with detritus from the Illinoian (oxygen isotope stage 6) glaciation.

The North Branch valley bends to the north at Danville (km 217), crossing from the Catskill to the Trimmers Rock, Mahantango, Onondaga, Keyser, Tonoloway, Wells Creek, Bloomsburg, Mifflintown, and finally Clinton group rocks toward the core of the Berwick anticline. While the structural valley trend would continue due west on less resistant shale and carbonate lithologies at the core of the Berwick anticline, the river instead bends to the southwest to work its way back onto resistant Catskill formation beds where it joins the West Branch at Northumberland (km 197). The Shermans Creek and Irish Valley members of the Catskill formation are at the core of what Inners (1981, 1988a) refers to as the "Northumberland-Catawissa" syncline.

The North Branch/West Branch juncture is the downstream limit of the area investigated in the present study. The main stem valley below Northumberland traverses several prominent water gaps in the Ridge and Valley upstream of Harrisburg (km 88) then proceeds across the northeast-trending "Great Valley" Triassic rift and the Piedmont physiographic province before entering the Coastal Plain.

THE SUSQUEHANNA VALLEY SEDIMENTARY BASIN

The North Branch valley reaches studied in the present dissertation represent the upstream portion of a sedimentary basin which extends downstream across Chesapeake Bay onto the Atlantic continental slope. Factors affecting the supply, transport, and deposition of sediment in an idealized river basin vary along the downstream axis as shown in **Figure 18**. While sediment is obviously supplied, transported, and deposited in each of the three "zones," the position along the valley axis nonetheless determines the dominant process (Schumm, 1977, p. 1-5).

For most of the Holocene epoch, the falls at Conowingo, Maryland (km 19) have divided the transport-dominated river valley (Zone 2) from a steep bedrock gorge leading to the Chesapeake Bay depositional basin (Zone 3). The first version of Chesapeake Bay formed as early as oxygen isotope stage 11 (~400 ka) when rising sea level drowned the ancestral Susquehanna channel, depositing the Omar formation shelly beds (Colman and Mixon, 1988; Colman et al., 1990; Mixon, 1985; Poag, 1985). Emergence and submergence occurred in step with subsequent Pleistocene glacial-interglacial cycles.

The last deglaciation may have had indirect effects on the study reaches in that the regional climate was probably affected by changes in ocean currents and sea surface temperatures accompanying Holocene sea level rise (Bond et al., 1997; Chapman and Shackleton, 1998; Duplessy et al., 1992). Since the existing estuary volume would have contained upwards of 100 m of postglacial sea level rise, however, it should not have affected base level in the study reaches (Bloom, 1983; Pazzaglia, 1993; Pazzaglia and Gardner, 1993). Even with the additional 60 m or more projected if the polar ice caps

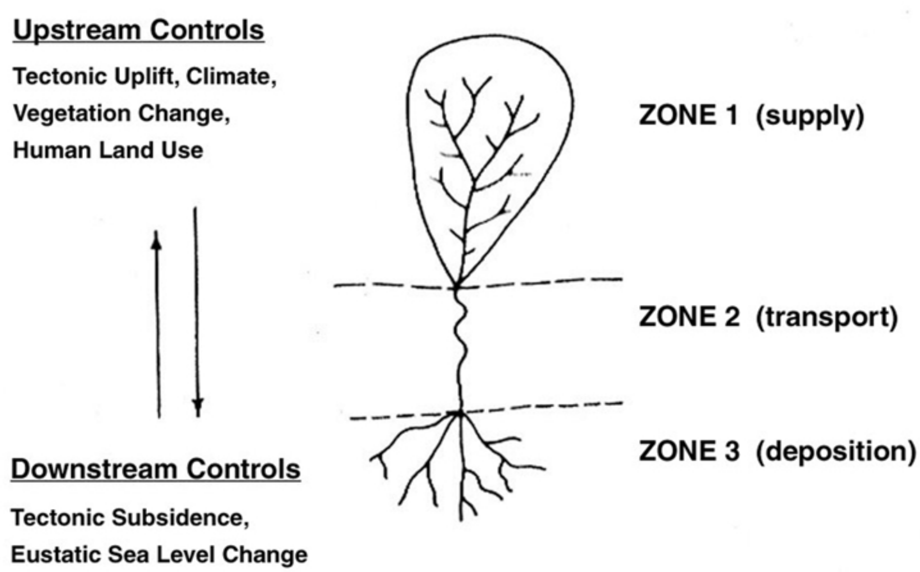


Figure 18: Controls on Supply, Transport, and Deposition of Sediment in an Idealized River Basin (after Schumm, 1977, p. 3)

were to melt (Goudie, 1992, p. 213), mean sea level would still be at least 30 m below river base level at Conowingo.

The vertical separation of the Susquehanna River valley from its depositional basin is the historical result of the tectonics of the continental margin, including the probable impact of a large bolide in the late Eocene (Gardner, 1989; Poag, 1985, 1999; Poag and Sevon, 1989). The 30 m falls above Conowingo, Maryland have a slope of 0.0015 below which the channel flattens rapidly as it passes through a bedrock gorge and enters the Chesapeake Bay (Thompson, 1990; Pazzaglia, 1993). Over the entire longitudinal profile (**Figure 19**) the average slope is 0.0005 but steeper reaches occur at prominent nickpoints between Waverly and Towanda (s = 0.0006), just above Harrisburg (s = 0.0006), and between Falmouth and Marietta (s = 0.0009).

The relief shown on **Figure 19** totals 365 m, but less than 120 m of that change in channel elevation occurs within the study area of the present dissertation. In general, tectonic forces have played only a limited role in the erosion of material from interior drainage basins (Zone 1) and transport or storage of alluvial sediment within the North Branch of the Susquehanna River valley (Zone 2). While crustal uplift rates average 6 mm/yr based on vertical leveling (Brown, 1978; Brown and Oliver, 1976), there is uncertainty regarding the extrapolation of these short-term rates to geological time scales. The study area is by no means earthquake prone, and the observed seismic activity may be caused by several plate tectonic mechanisms. The most probable mechanisms are spreading at the mid-Atlantic ridge (Zoback and Zoback, 1980), "drag" on that spreading

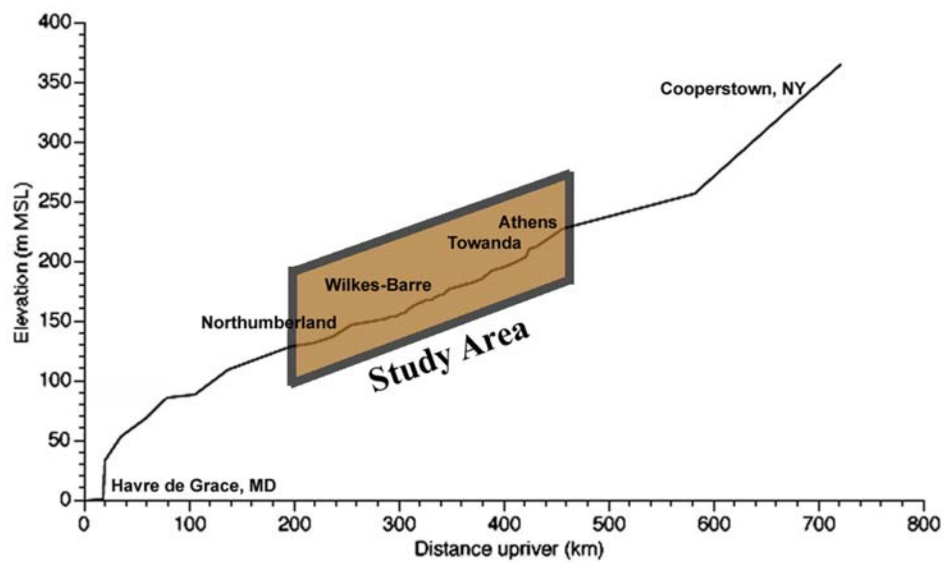


Figure 19: Longitudinal profile of the Susquehanna River from its mouth at Havre de Grace, Maryland to its headwaters near Cooperstown, New York

from the underlying aesthenosphere (Fletcher et al., 1978), and reactivation of northeast-trending Paleozoic faults (Bollinger, 1973; Mixon and Newell, 1977; Prowell, 1988; Seeber and Armbruster, 1981, 1988). More hypothetical mechanisms include landward propagation of northwest-trending fractures on the sea floor (Sykes, 1978) and the reactivation of "failed arms" of the mid-Atlantic rift (Burke and Dewey, 1973).

On very long geological time scales, isostatic uplift rates are related to rates of continental denudation (Ahnert, 1970; Pavich, 1985). Denudation rates derived from saprolite ages estimated with cosmogenic nuclide inventories range from 2.2-5.3 m/my (Pavich, 1985, 1989; Pavich et al., 1989). Much lower rates of 0.03-1.5 m/my were derived from apatite fission tracks by Zimmerman (1977) while much higher rates of 10-150 m/my were derived for the Susquehanna valley itself from sediment thickness offshore (Braun, 1989; Poag and Sevon, 1989). Even the highest of these rates is an order of magnitude less than the crustal uplift estimates from vertical releveling (Brown, 1978; Brown and Oliver, 1976; Brown et al., 1980, 1981; Gardner, 1989; Gardner et al., 1987), so some of the plate tectonic mechanisms probably do play a role in uplift-driven denudation. There is no strong evidence, however, for anomalously high rates in the study region or for specific episodes which might coincide with stratigraphic discontinuities during the Holocene epoch.

GLACIOISOSTASY, OUTWASH TERRACES, AND MORPHOSEQUENCES

The Laurentide ice sheet itself represented a significant source of tectonic disturbance during the Quaternary period. Northeastern Pennsylvania was glaciated at least three times, and ice sheet margins have been mapped from morainal debris of the pre-Illinoian (> 800 ka), Illinoian (OIS 6-8 or ca 300-130 ka), and Wisconsinan (OIS 2 or 60-20 ka) advances (Braun, 1994b, 1997; Crowl and Sevon, 1980, 1999). During the Wisconsinan advance, the ice depressed the crust up to 150 m and caused a peripheral bulge extending for at least 100 km beyond the ice front (Andrews, 1970; Broecker, 1966; Isachsen et al., 2000, p. 175-177; Peltier, 1981; Walcott, 1972).

The ice sheet began its retreat from the late Wisconsinan terminal moraine at 18 ka according to Crowl and Sevon (1980), while a slightly earlier date for deglaciation may be indicated by 29 radiocarbon dates greater than 20 ka obtained from outwash deposits at Port Washington on Long Island by Sirkin (Sirkin, 1986; Sirkin and Stuckenrath, 1980). The crust rebounded rapidly as the ice sheet retreated, and this "glacioistostatic" rebound helps to explain why the terminal moraine was so deeply incised and the outwash sand and gravel is found at successively lower terrace levels. The best constraints on rebound rates have been obtained from uplifted shorelines of the Great Lakes. At Port Huron, for example, the glacial Lake Maumee shoreline was uplifted 20 m in less than two thousand years (Farrand, 1962). This corresponds exactly to the rate of 10 mm/yr proposed by Brown and Oliver (1976) for episodic as opposed to average uplift (the 6 mm/yr rate).

The prominent outwash grades at approximately 20, 15, and 10 meters were mapped in a previous study by Peltier (1949) and identified with stillstands of the ice sheet where it built recessional moraines. Peltier referred to the highest and oldest late Wisconsinan deposits as "Olean" after the town of that name in the Salamanca Reentrant, which is the only portion of New York state that was not glaciated during the late Wisconsinan. In the North Branch valley, the frontal kame or head of outwash for the Olean deposits extends for approximately three kilometers between Wapwallopen and Berwick, Pennsylvania. As described by Braun and Inners (1988b, 1994), steeply dipping foresets of an ice-contact delta change abruptly up-section to openwork gravels, marking the height of the spillway for the proglacial lake in these valley reaches (see **Figure 20**).

Valley outwash at Berwick was attributed by Peltier (1949) to the retreat from the "Binghamton" and "Valley Heads" ice margins further north (see **Figure 21**). In his detailed mapping of the Berwick quadrangle, Inners (1978) found that these deposits were not sufficiently distinctive in lithology or bedforms to be mapped separately from the Olean outwash. The "Mankato" terrace grade shown on **Figure 21** is underlain by the Holocene alluvial deposits which are the subject of the present dissertation. Radiocarbon ages less than 10 ka disprove the proposed periglacial origin for the landforms Peltier assigned to the "Mankato."

The "Valley Heads" recessional margin at the southern end of the Finger Lakes has been tightly dated to ~14 ka (Muller, 1965; Muller and Calkin, 1993). Valley Heads outwash was funneled into the North Branch valley through the Chemung and Chenango Rivers. Neither the distance which the Valley Heads sand and gravel were transported down valley nor the age and distribution of pre-existing outwash deposits are presently well understood. Detailed mapping at 1:24,000 scale will have to be completed to enable reliable correlation between valleys. Peltier (1949) placed the "Binghamton" recessional margin at Milan (km 446), as shown in **Figure 22**. Recent mapping by Sevon and Braun

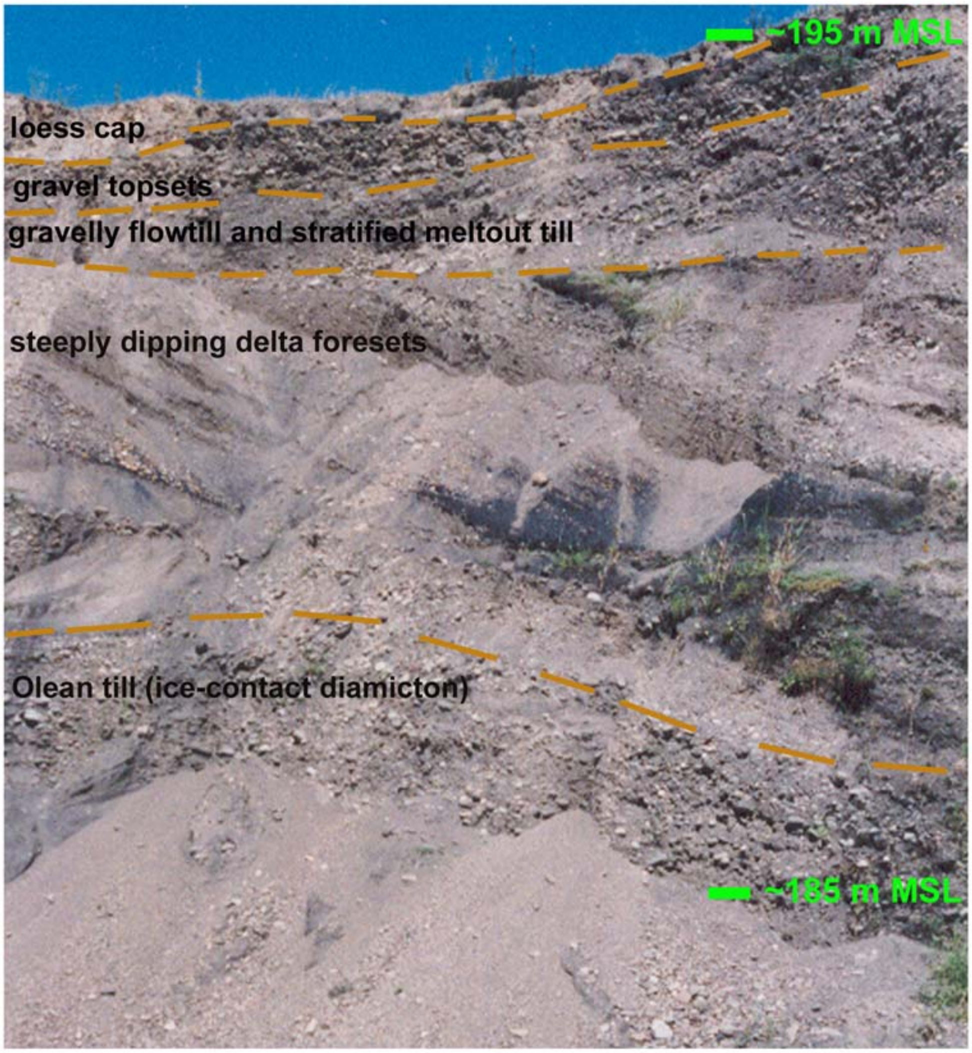


Figure 20: The Olean frontal kame deposits at Bell Bend on the right bank of the North Branch of the Susquehanna River upstream of Berwick, Pennsylvania

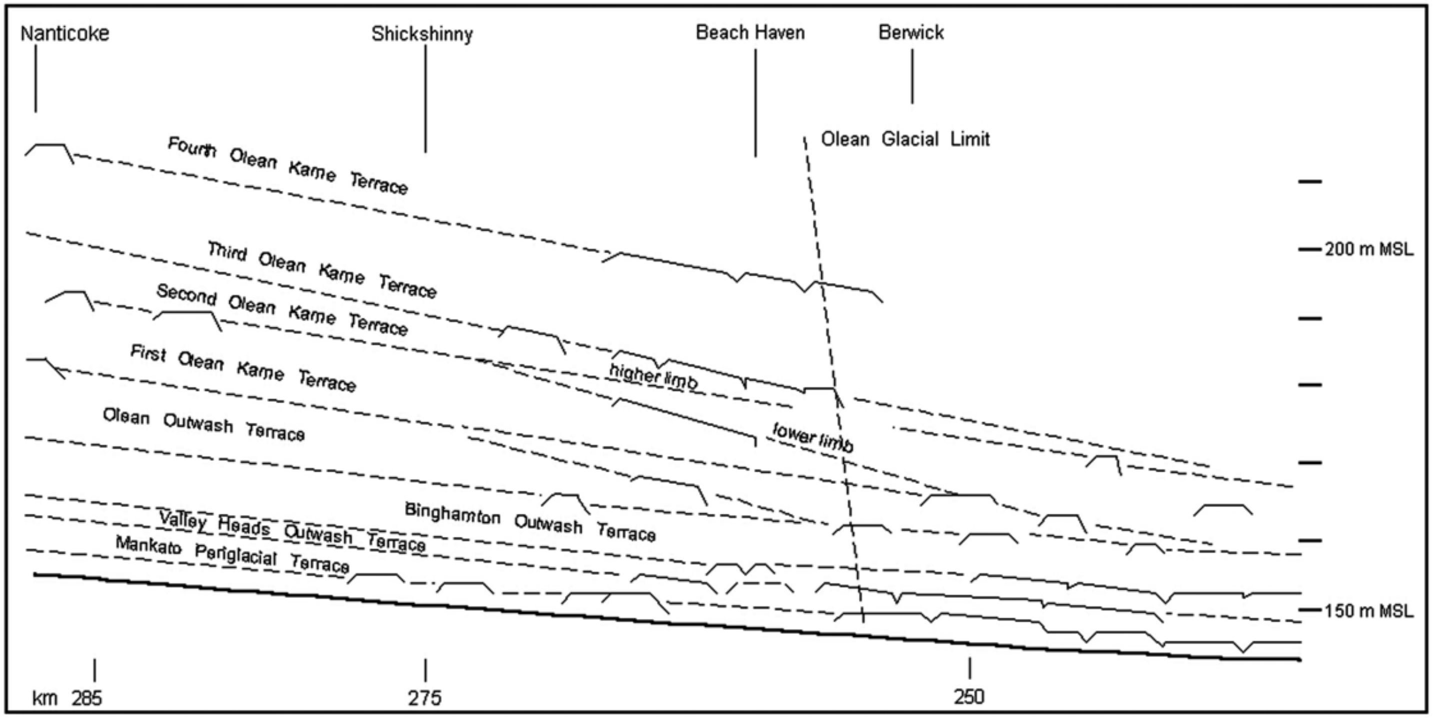


Figure 21: Peltier's terrace profiles and projected grade lines near Berwick, Pennsylvania

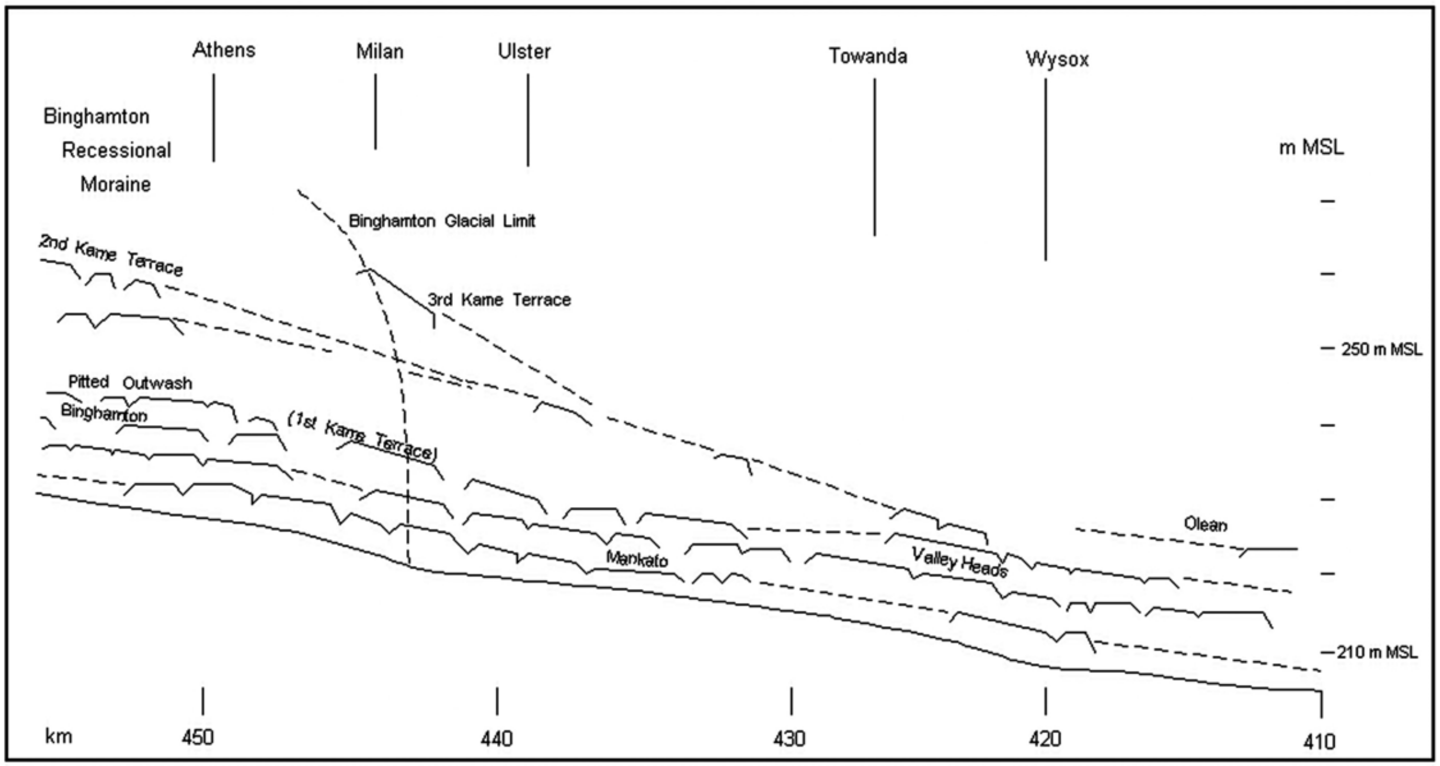


Figure 22: Peltier's terrace profiles and projected grade lines near Milan, Pennsylvania

(1997) indicated that the more likely location is further downstream, at Quicks Bend (km 393). The ice-contact sand and gravel (ISG) on the right bank are part of a nearly continuous moraine extending up the valley of Wyalusing Creek to the east and along Sugar Run valley to the west.

Aside from relative elevation of the terrace grades, the deposits from the three suggested ice margins (Olean, Binghamton, Valley Heads) differ to some extent in clast composition. Local sedimentary lithologies predominate in the Olean, and only five percent of the clasts traveled more than eight kilometers according to Coates (1976, p. 65). Anthracite coal is also prevalent downstream of the Wyoming Valley, particularly in the deposits at the terminal moraine.

The Binghamton gravel contains pebbles and cobbles of gneiss and other erratics from the Mohawk Valley and the Adirondack Mountains (Peltier, 1949, p. 18). Twenty five percent of Binghamton clasts traveled more than 80 km according to Coates (1976, p. 65). A higher proportion of blue limestone pebbles, a shallower depth of leaching (~1.5 m), and a shallower weathering profile (~20 cm) distinguish the Valley Heads from gravels of the earlier, higher terraces according to Peltier (1949, p. 81). Limestone clasts are not found downstream of the Wyoming Valley, however, which Peltier attributed to the naturally low pH of waters draining coal-bearing lithologies.

Three representative clasts collected from an outwash terrace upstream of Mehoopany are shown in **Figure 23**. A pink granite cobble typical of the Binghamton outwash was collected from a kame terrace downstream of Falls. A thin-section was prepared from the cobble, with views in both plane-polarized and cross-polarized light

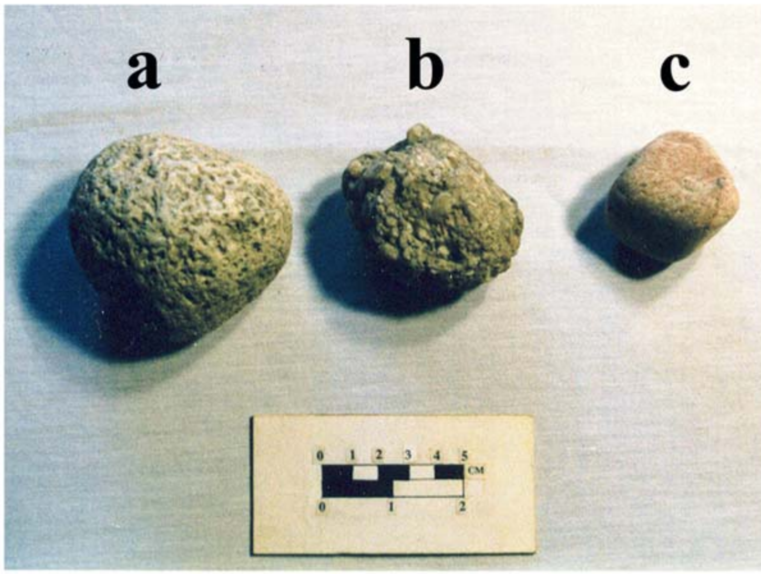


Figure 23: Clasts of quartzite (a), quartz pebble conglomerate (b), and pink granite (c) collected from the T-2 outwash terrace on the right bank of the North Branch of the Susquehanna River approximately two kilometers downstream of Mehoopany

shown in **Figure 24.** Even in the most far-traveled outwash, erratic clasts account for at most five percent of the gravel beds (Braun, 1988b, 1994b). Quartzite, quartz pebble conglomerate, and chert are more common and occur in much higher percentages than they do in more recent alluvial gravels (Kehn et al., 1966, p. 34-35; Peltier, 1949).

In the maps of the North Branch of the Susquehanna River valley presented as **Appendix 1** of the present dissertation, the terms Olean, Binghamton, and Valley Heads have been retained for areas mapped by Peltier (1949) which have not yet been remapped by other investigators. As explained in **Chapter 2**, most of the outwash terraces were delineated purely on the basis of topographic contours and soil surveys. Terms such as "Olean/Binghamton," "Binghamton/Olean," and "Binghamton/Valley Heads" are used where the topographic contours define fewer than three terrace grades but some meltwater flooding occurred during deglaciation.

Ice-contact deposits mapped by Sevon and Braun (1997) at Quicks Bend (km 393), Wyalusing (km 399), Standing Stone (km 418), Wysox (km 424), Ulster (km 441), and Milan (km 446) must somehow be incorporated into any reconstruction of the late Pleistocene stratigraphic architecture. The "morphosequence" approach developed in New England (Koteff, 1974; Koteff and Pessl, 1981; Stone et al., 1998) shares much in common with the allostratigraphic framework of the present study. Genesis is used in defining mapping units for glacial deposits, however, whereas allostratigraphic units must be defined independent of genesis. As pointed out by Bridge (1993a) with reference to alluvial deposits, mapping and field description should be kept separate from genetic interpretation to the extent possible.

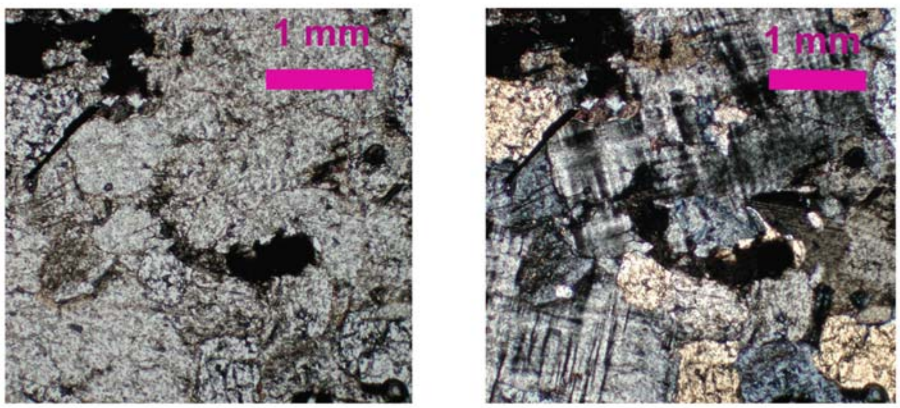


Figure 24: Thin-section photomicrographs in PPL (left) and XPL (right) of a granite cobble collected from a kame terrace on the left bank of the North Branch of the Susquehanna River two kilometers downstream of Falls

CHANNEL FORM AND BED MATERIAL

Although geologic history indicates that a variety of specific events have shaped the North Branch of the Susquehanna River channel, it is fundamentally a physical entity governed by universal processes of fluid mechanics and sediment transport. At a given valley cross-section, the channel width, depth, and slope provide the velocity which transports the sediment supplied by the drainage basin (Knighton, 1998, p. 153-162; Ritter et al., 1995, p. 224-228). In planform, channel meanders and braiding around floodplain islands represent typical responses to discharge, slope, and sediment supply controls.

Measurements by the USGS near their three gaging stations (Schaffstall, 2002) and valley profiles drawn from the 7.5 minute topographic maps provide a rational physical model of 23 channel cross-sections. At each of their three cross-sections, the USGS has correlated the stage or height of the water column with river discharge in a "rating curve" (Dunne and Leopold, 1978, p. 594-598). For the other cross-sections, I have assumed that discharge varied smoothly between the gaging stations in order to estimate the height of flows recurring every 1.5 years on average ($Q_{1.5}$). Because they provide the best data on river channel dimensions, each of the USGS cross-sections will now be discussed in some detail. The locations and dimensions of the other 20 cross-sections are summarized in **Table 2**.

The USGS gaging station at Towanda is just downstream of the U.S. 6 bridge. The surveyed channel cross-section (**Figure 25**) is actually at the James Street bridge, one mile (1.6 km) upstream of the gaging station. From a steep bluff of Lock Haven

Table 2: Cross-Sections of the North Branch of the Susquehanna River channel

Location Name	km upriver	Valley Width (m)	Relief	Channel Slope (m/m)	Channel Width (m) *	Channel Depth (m) *	Hydraulic Radius (m)	Channel Pattern	Rosgen	Sinuosity	w/d
Sayre	452.0	4000	265	0.0006	200	4.0	3.8	entrenched	F4	1.15	50.0
Milan	446.0	1500	259	0.0006	200	6.0	5.7	braided	D4	1.20	33.3
Towanda	430.0	1000	225	0.0005	247	4.9	4.7	braided	D4	1.04	50.4
Wysox	425.0	2000	195	0.0006	200	6.0	5.7	meandering	C4	1.30	33.3
French Azilum	413.0	1300	230	0.0005	250	6.3	6.0	braided	D4	1.10	39.5
Friedenshuetten	396.0	1100	174	0.0004	200	6.5	6.1	entrenched	F4	1.20	30.8
The Neck	361.0	800	348	0.0005	180	7.3	6.8	entrenched	F4	1.10	24.7
Tunkhannock	349.0	1100	250	0.0005	200	6.6	6.2	entrenched	F4	1.30	30.3
Whites Ferry	338.0	1600	268	0.0004	200	6.6	6.2	entrenched	F4	1.05	30.3
Falls	331.0	1700	198	0.0005	250	5.3	5.1	entrenched	F4	1.10	47.2
Upper Exeter	325.0	600	195	0.0003	300	4.4	4.3	entrenched	F4	1.20	67.9
Coxton Yards	314.0	1300	302	0.0004	200	6.6	6.2	entrenched	F4	1.20	30.1
Forty Fort Airport	304.0	2800	277	0.0003	250	5.3	5.1	meandering	C4	1.50	46.9
Wilkes-Barre	299.0	9000	311	0.0003	244	6.6	6.3	entrenched	F5	1.30	37.0
Nanticoke	289.0	1900	283	0.0002	340	4.5	4.4	meandering	C5	1.40	75.6
Shickshinny	271.0	500	244	0.0002	200	7.0	6.5	entrenched	F4	1.10	28.6
Gould Island	265.0	1100	130	0.0002	340	4.2	4.1	braided	D4	1.30	80.8
Mifflinville Bridge	246.0	1800	146	0.0006	213	7.2	6.8	braided	D5	1.19	29.4
Bloomsburg	232.0	2000	165	0.0003	350	4.7	4.5	entrenched	F5	1.20	75.1
Catawissa Bridge	228.0	1200	116	0.0003	450	3.7	3.6	entrenched	F5	1.10	122.0
Danville	217.0	900	232	0.0001	450	5.3	5.2	meandering	C5	1.40	85.1
Central Builders	202.0	1500	107	0.0001	500	5.2	5.1	entrenched	F5	1.20	96.7
Northumberland	197.0	2200	123	0.0001	600	4.4	4.4	braided	D5	1.20	135.4

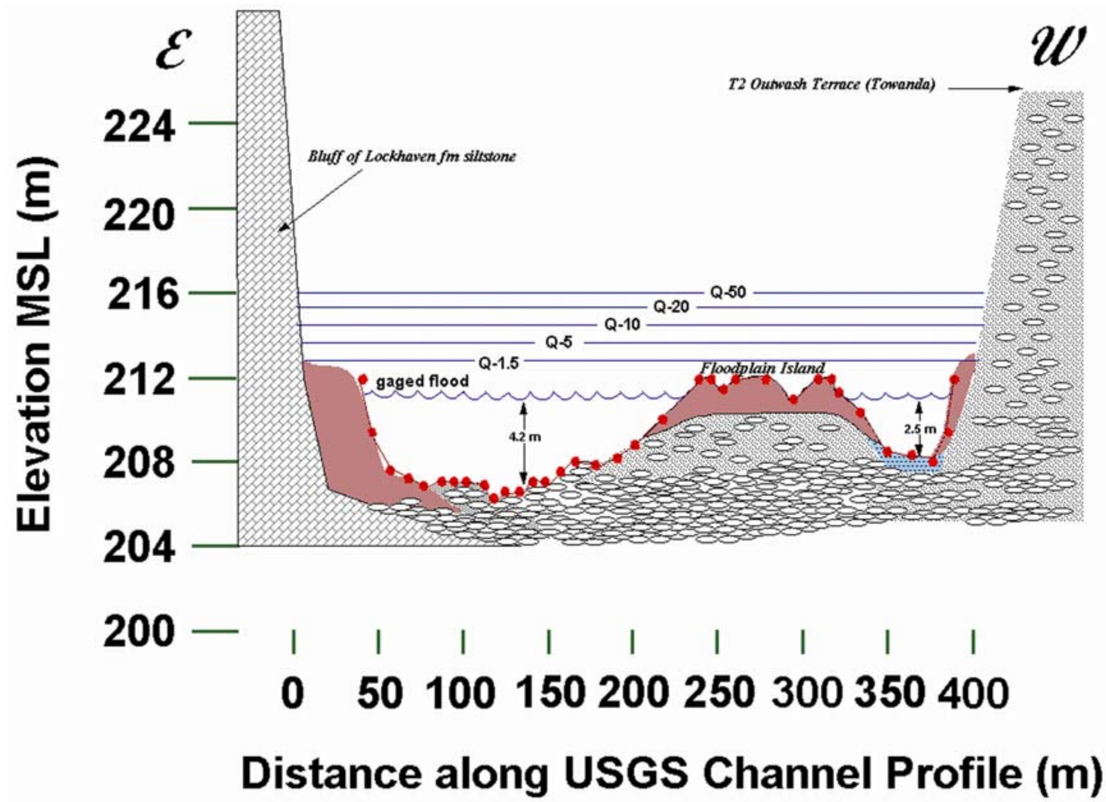


Figure 25: Cross-section of the North Branch of the Susquehanna River channel at Towanda, Pennsylvania (from data provided by Schaffstall, 2002)

siltstone on the east, it crosses the wider (198.1 m) of two channels to a floodplain island. The narrow (73.2 m) channel between the island and the town of Towanda was formerly part of the North Branch Extension Canal (Petrillo, 1986, p. 73-95). The canal here entered slackwater impounded behind a crib dam. The dam was located in the vicinity of the present U.S. 6 bridge, and well-preserved wooden timbers were excavated from the river bed near the former dam location when the bridge was being constructed in 1985 (Petrillo, 1986, p. 238). West of the canal remnant in the channel cross-section, the town of Towanda sits on a grade of 225 m MSL. The 225 m grade was mapped as ice-contact sand and gravel (ISG) by Sevon and Braun (1997) and this designation is also used in **Appendix 1**.

On the day that the cross-section was prepared (May 22, 2000), a discharge of 1,594 m^3s^{-1} was accomodated by the two channels at a mean velocity of 1.79 ms^{-1}. Substituting the discharge (Q) and velocity (v) into the continuity equation (**2**), the cross-sectional area ($w * d$) should be 890.5 m^2. The measured areas are 832 m^2 for the larger channel and 183 m^2 for the canal remnant. More sluggish discharge in the considerably shallower (2.5 m deep) smaller channel probably accounts for the discrepancy between the sum of the measured cross-sectional areas and the value predicted with the continuity equation.

The width of 247 m reported in **Table 2** is for the undivided channel downstream of the U.S. 6 bridge. Although the river is significantly narrower at the gage, the gage height measurements do appear to closely approximate the mean channel depth at both locations. For the discharge of 1,594 m^3s^{-1} accomodated by the surveyed channel cross-section, the rating curve gives a gage height of 3.6 m (11.8 ft). The 1.5 year flood ($Q_{1.5}$) for the years 1913-1971 has a magnitude of 2,525 m^3s^{-1} (89,183 cfs) and occurs at a gage height of 4.9 m (16.18 ft). There would have to be a significant increase in velocity, from 1.59 ms^{-1} to 2.08 ms^{-1}, for the $Q_{1.5}$ to occur at a depth of 4.9 m in both the divided (317 m) and undivided (247 m) cross-sections. At the surveyed cross-section (**Figure 25**), the $Q_{1.5}$ would fully submerge the floodplain island, but even the 50 year flood (Q_{50}) would still be nearly ten meters from flooding the grade of the town (225 m MSL).

The USGS cross-section at the Pierce Street bridge in Wilkes-Barre (**Figure 26**) has an irregular bed in its western half, and both banks have been artificially contoured as part of the Wyoming Valley levee system. Wilkes-Barre is on the left bank, built on a terrace (T-2) standing at 167 m MSL. The T-2 elevation is between 10 m and 15 m above the base level of the river, and has been mapped as outwash by Hollowell (1973) and as "Valley Heads/Binghamton" outwash in **Appendix 1**.

The channel follows a straight, southwesterly course for two kilometers past Wilkes-Barre. Such straight segments typically occur where the channel is entrenched into bedrock and glacial deposits. In the Wyoming Valley, the long straight segments combine to form several large bends, or "entrenched meanders" (Braun, 1983; Leopold et al., 1964, p. 308-317; Thornbury, 1965; Shepherd, 1972). Just upstream of the cross-section at the Pierce Street bridge, outcrops of Llewellyn sandstone bedrock and culm piles reach elevations of at least 183 m MSL, or 30 m above river base level (Schuldenrein and Thieme, 1997, p. 59-63).

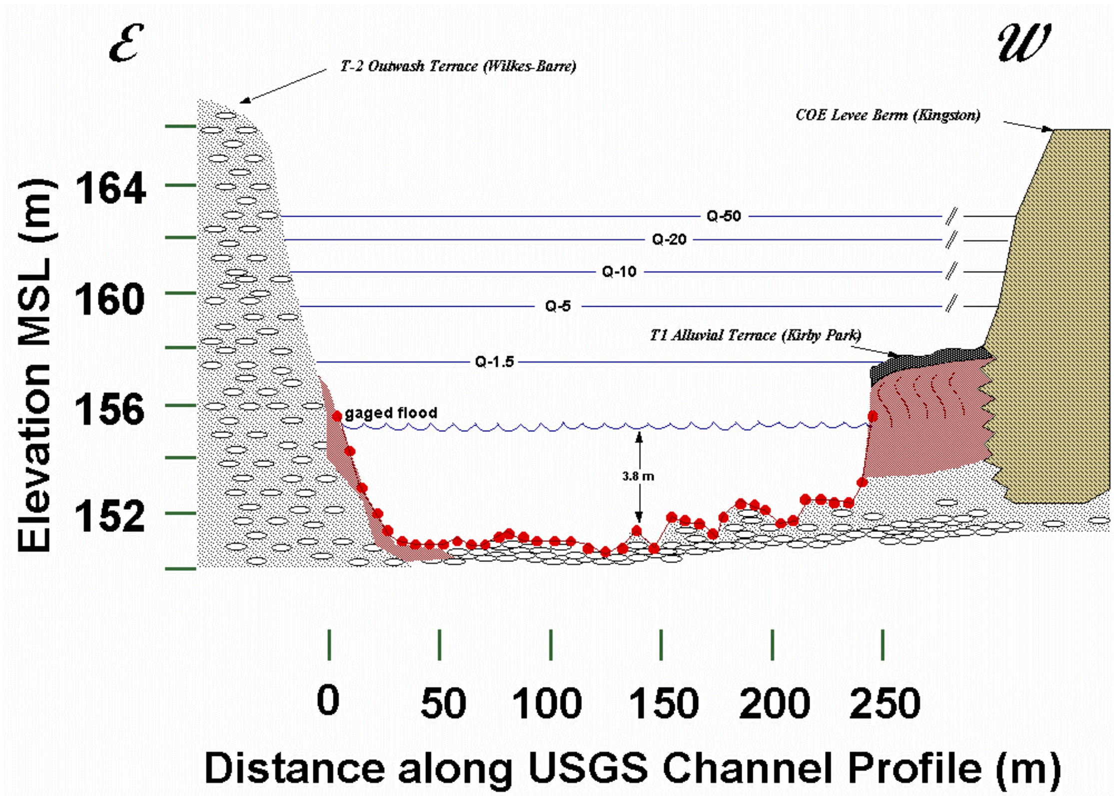


Figure 26: Cross-section of the Susquehanna River channel at Wilkes-Barre, Pennsylvania (from data provided by Schaffstall, 2002)

On the right bank, opposite Wilkes-Barre, a Holocene alluvial terrace at ~158 m MSL occurs between the river and the berm designed to protect the town of Kingston. The most recent (1976-1983) versions of the Pittston and Kingston 7.5 minute topographic maps show the berm elevation at 164 m MSL. The U.S. Army Corps of Engineers has raised the berm at least a meter since the maps were last revised. The town of Kingston is built on outwash and an alluvial fan deposited at the mouth of Toby Creek. Maximum elevations of 165 m MSL are at approximately the same grade as the T-2 outwash terrace in Wilkes-Barre on the other side of the river.

The Wilkes-Barre cross-section was prepared on February 14, 2002, and the measured discharge of 906 m^3s^{-1} had a mean velocity of 0.99 ms^{-1}. Whereas the continuity equation would predict a cross-section of 915 m^2, the measured cross-section was 924.2 m^2. The areas of reduced velocity were probably on the west, where the channel has a rougher bottom.

At Wilkes-Barre, the $Q_{1.5}$ for 1913-1971 has a magnitude of 2,860 m^3s^{-1} (101,015 cfs). According to the rating curve, the $Q_{1.5}$ gage height would be 6.6 m (21.7 ft), a flow just barely contained by the bank of the T-1 alluvial terrace. The T-1 is flooded by the Q_5 event, and the velocity predicted using equation (**2**) falls off between the Q_5 (4,615 m^3s^{-1}) and Q_{50} (6,307 m^3s^{-1}) events as flow spreads across the T-1 grade. Although Wilkes-Barre was flooded by both the 1936 and 1972 events, these are such extreme floods that it is difficult to estimate their recurrence probability using the gaging records. The geomorphic significance and meteorology of such large floods are discussed in the following section of this chapter.

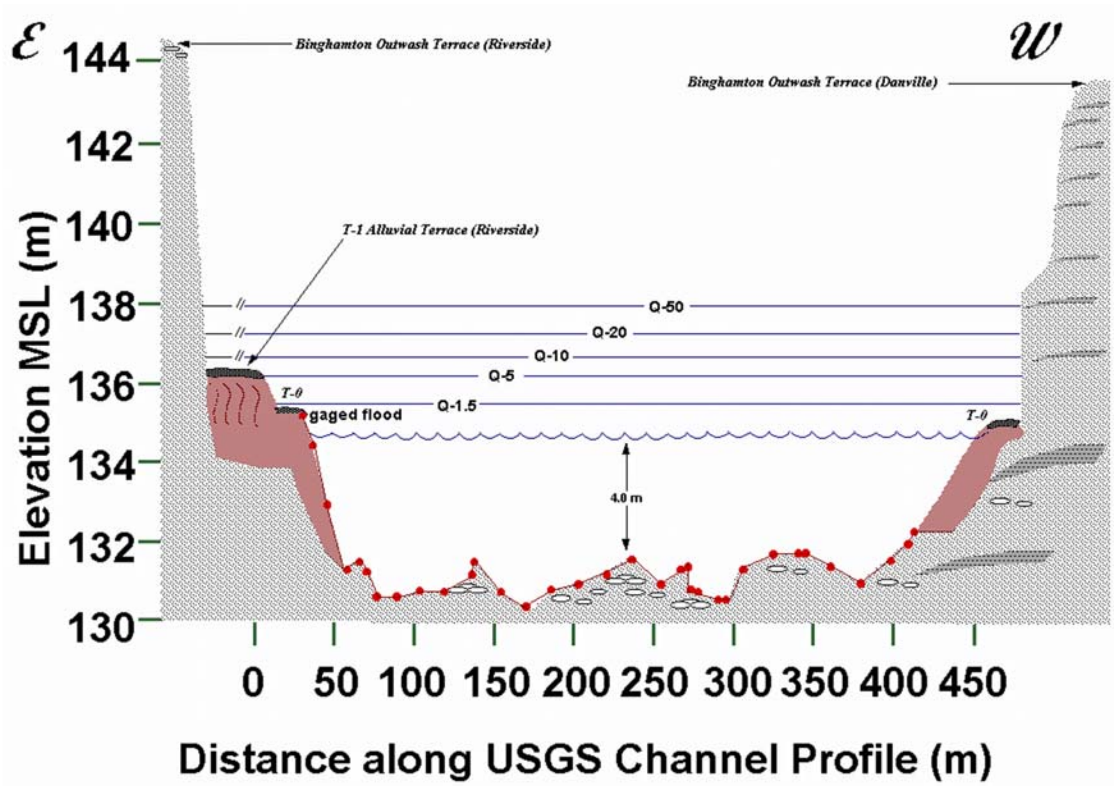


Figure 27: Cross-section of the Susquehanna River channel at Danville, Pennsylvania (from data provided by Schaffstall, 2002)

The USGS cross-section at Danville (**Figure 27**) follows the S.R. 54 bridge across a northwest-trending channel on the upstream side of a large bend. The bend appears to have formed as the channel was entrenched into glacial deposits. Stepped terrace grades on the left bank at 152 m and 145 m MSL are mapped as Olean and Binghamton outwash in **Appendix 1**, following Peltier (1949). The S.R. 54 roadbed runs along the left bank on a T-1 alluvial terrace at ~136 m MSL prior to crossing the river to Danville. The T-1 also occurs on the right bank upstream of Danville, but it pinches out between the narrow (50 m wide) floodplain and the Binghamton outwash terrace at the bridge. Downstream of Danville, Mahoning Creek has built an alluvial terrace just upstream of where it enters the river.

On the day that the cross-section was prepared (March 28, 2002), a discharge of 2,248 m^3s^{-1} was accomodated by a channel 397 m wide with a mean depth of four meters. According to the latest rating curve, the gage height should have been 4.4 m at this discharge. The measured velocity of 1.45 ms^{-1} is just slightly larger than the value of 1.41 ms^{-1} obtained by substituting the width and depth into the continuity equation (**2**). In a 1.5 year flood event, the velocity should drop to 1.32 ms^{-1} as floodwaters spill across the T-0 and the channel widens to 450 m. The same channel width contains the flood with a five year recurrence interval for the years 1913-1971.

The T-1 grade at 136 m MSL and the S.R. 54 roadbed would be inundated by the 10 year flood, with a magnitude of 5,521 m^3s^{-1}. In a 20 year flood, the channel would be 650 m wide and 8.1 m deep. Even the 50 year flood at Danville fails to overtop the Binghamton or Olean outwash terraces. Significant floods have occurred, however, as waters backed up at the mouth of Mahoning Creek and in the remnants of the North Branch Canal which have been redesigned for storm sewers in the town.

The model cross-sections presented in **Table 2** are for a $Q_{1.5}$ event which varies smoothly along the downstream river axis. The two independent variables are the channel width, as measured from the 7.5 minute topographic maps, and the gaged discharge values for Towanda (2,525 m^3s^{-1}), Wilkes-Barre (2,860 m^3s^{-1}) and Danville (3,143 m^3s^{-1}). Since these are only two of the four variables in the continuity equation (**2**), we are unable to fully predict the channel dimensions at ungaged reaches. Assuming constant velocity, while mathematically elegant, results in unrealistic channel depths (>8 m) for narrow reaches.

The solutions presented in **Table 2** result from constraining velocity to a "minimum variance" ranging from 1.21 to 2.14 ms^{-1}. As initially presented by Langbein and Leopold (1964), the concept of minimum variance is central to the development of most subsequent quantitative geomorphological models (e.g. Chang, 1979; Williams, 1978b). The predicted channel depths range from 3.7 to 7.3 meters for a $Q_{1.5}$ event on the North Branch of the Susquehanna River. Although no individual flood may have had these precise dimensions at each of the reaches studied, these are the best available estimates for the volume of flowing water at an event which recurs every 1.5 years on average.

The 23 cross-sections were used to develop a physical model of the channel using the equations for unit stream power (w) and bed shear stress (t) presented in the

Table 3: Unit Stream Power, Bed Shear Stress, and Bed Roughness (n) for the 23 Channel Cross-Sections

Location Name	km upriver	1.5 year flood	Velocity	Channel Width (m)	Channel Depth (m)	Hydraulic Radius	Channel Slope (%)	Unit Stream Power (W/m^2)	Bed Shear Stress (N/m^2)	Manning's n
Sayre	452.0	2468.75	1.57	200	4.00	3.8	0.060	0.74	0.23	0.038
Milan	446.0	2484.09	2.07	200	6.00	5.7	0.060	0.75	0.34	0.037
Towanda	430.0	2525.00	2.08	247	4.91	4.7	0.050	0.51	0.24	0.030
Wysox	425.0	2537.78	2.11	200	6.00	5.7	0.060	0.76	0.34	0.036
French Azilum	413.0	2568.47	2.10	250	4.88	4.7	0.050	0.51	0.23	0.030
Friedenshuetten	396.0	2611.94	2.01	200	6.50	6.1	0.040	0.52	0.24	0.033
The Neck	361.0	2701.43	2.06	180	6.50	6.1	0.050	0.75	0.30	0.036
Tunkhannock	349.0	2732.12	2.07	200	7.30	6.8	0.050	0.68	0.34	0.038
Whites Ferry	338.0	2760.24	2.09	200	6.59	6.2	0.040	0.55	0.25	0.032
Falls	331.0	2778.14	2.10	250	6.61	6.3	0.050	0.56	0.31	0.036
Upper Exeter	325.0	2793.48	2.11	300	5.30	5.1	0.030	0.28	0.15	0.024
Coxton Yards	314.0	2821.61	2.12	200	4.42	4.2	0.040	0.56	0.17	0.024
Forty Fort Airport	304.0	2847.18	2.14	250	6.65	6.3	0.030	0.34	0.19	0.027
Wilkes-Barre	299.0	2860.00	1.78	244	5.33	5.1	0.030	0.35	0.15	0.029
Nanticoke	289.0	2894.51	1.72	340	6.59	6.3	0.020	0.17	0.13	0.028
Shickshinny	271.0	2956.63	2.11	200	7.00	6.5	0.020	0.30	0.13	0.023
Gould Island	265.0	2977.33	2.08	340	4.21	4.1	0.020	0.18	0.08	0.017
Mifflinville Bridge	246.0	3042.90	1.97	213	7.24	6.8	0.060	0.86	0.41	0.044
Bloomsburg	232.0	3091.22	1.89	350	4.66	4.5	0.030	0.26	0.14	0.025
Catawissa Bridge	228.0	3105.02	1.87	450	3.69	3.6	0.030	0.21	0.11	0.022
Danville	217.0	3143.00	1.32	450	5.29	5.2	0.015	0.10	0.08	0.027
Central Builders	202.0	3194.76	1.24	500	5.17	5.1	0.015	0.10	0.08	0.029
Northumberland	197.0	3212.02	1.21	600	4.43	4.4	0.015	0.08	0.07	0.027

preceding chapter. The unit stream power was calculated using equation (**7**) with the slope (*S*) in percent (%) as opposed to fractional units (m/m). As presented in **Table 3**, all of the values are less than one watt per square meter (W/m^2). Values less than 10 W/m^2 are typical of stable channels formed by vertical accretion of fine-grained alluvium and infrequent channel avulsion (Knighton, 1998, p. 146). The bed shear stress values predicted using equation (**8**) range from 0.07 to 0.41 newtons per square meter (N/m^2).

The hydraulic radius (*R*) was used to calculate the bed shear stress. Substituting the mean depth changes only a few of the larger values, a difference of no more than 0.02 N/m^2. Both unit stream power and bed shear stress decrease along the downstream river axis. As noted by Magilligan (1992, p. 375), this trend is predictable from the decrease in slope which accompanies increasing discharge in downstream hydraulic geometry. Increasing channel depth will increase bed shear stress, however, where the other dimensions are constant. Predicted $Q_{1.5}$ depths greater than 5.5 meters would produce zones of particularly high shear stress between Sayre and Towanda, at Wysox, at "The Neck" above Tunkhannock, and at Mifflinville.

All of the stream power values appear somewhat low for the caliber of the bed material and wide, shallow channel. The roughness coefficients calculated with the Manning equation (**4**) more clearly indicate these characteristics of the channel. Nine of the values for Manning's *n* are greater than 0.035, indicating a winding channel, rocky bed, or variable channel dimensions. There are also ten values less than 0.025, however, typical of rivers in "fair condition with some growth (Chow, 1964; Ritter et al., 1995,

p. 195)." The Manning's *n* values were calculated with metric units and the slope in proportional units (m/m) rather than percent.

Width/depth ratios are presented in **Table 2.** Because the only field measurements of either width or depth were made at the three USGS gaging stations, it is not appropriate to infer any pattern from these numbers. The downstream increase in channel width, although irregular, is typical for a river of this size (Leopold and Maddock, 1953). Based on the range from 24.7 to 135.4 for *w*/*d*, there should be from two to twelve percent silt and clay (M) in the wetted channel perimeter using equation (**5**). The values predicted for Towanda (4.5 %) and Wilkes-Barre (8.0 %) are only slightly lower than those obtained in limited laboratory analyses reported in **Chapter 5**. The predicted value for Danville (3.5%) is much too low, as are the low values for the wider downstream reaches in general. Width/depth ratios appear more useful in comparing channel dimensions between rivers than between reaches, at least for the river which is the subject of the present study.

By far the best estimates of channel bed material and bed roughness are those obtained from the pebble counts, summarized in **Table 4**. The median diameter (D_{50}) is presented as well as the diameter of the particle which is coarser than 84 percent of the distribution sampled, D_{84}. While the D_{50} is a useful measure of the bedload transported by a river (Bagnold, 1977; Leopold et al., 1964, p. 188-195; Pizzuto et al., 2000), the D_{84} is the most accepted measure of bed roughness (ASCE, 1963; Hey, 1979; Limerinos, 1970; Simons and Richardson, 1966). The actual resistance to flow can also be calculated from the ratio of the hydraulic radius to the D_{84} (R/D_{84}). Values obtained for this ratio are

Table 4: Pebble Count Statistics for Gravel Bars and Stratigraphic Contexts, North Branch of the Susquehanna River valley

Location	km upriver	D_{50} (mm)	D_{84} (mm)	*R*	$\frac{R}{D_{84}}$	ff
North Mehoopany, right bank, creekmouth gravel bar	367	35	80	6.6	82.5	0.043
Tunkhannock, left bank, riverside gravel bar	349	40	64	6.6	103.12	0.039
Cremard's gravel pit, left bank, shoreline opposite Scovell Island	314	22	40	6.7	166.25	0.034
West Pittston, right bank, shoreline opposite Scovell Island	312	18	36	6.7	183.33	0.033
8th Street Bridge in Wilkes-Barre, right bank, TR 4, > 4 m bs	306	10	25	NA	NA	NA
8th Street Bridge in Wilkes-Barre, right bank, TR 1, > 4 m bs	306	16	38	NA	NA	NA
Forty Fort Airport, right bank shoreline	304	16	35	5.3	151.43	0.035
Shickshinny Boat Launch, right bank shoreline	271	45	85	6.5	82.35	0.043

presented in **Table 4** as well as the Darcy-Weisbach friction factor (ff), derived using equation (**6b**). Although the bed consists of quite coarse gravel in most of the reaches sampled, the resistance to a flow of 1.5 year recurrence is not particularly high. This is because the effect of grain roughness is drowned out as the depth of flow increases to the $Q_{1.5}$ and greater flood magnitudes (Knighton, 1998, p. 103).

As a cross-check on the bed roughness estimates based on pebble counts, values for the Darcy-Weisbach friction factor (ff) were independently calculated using equation (**6c**). The values for Tunkhannock (0.057), Coxton Yards (0.043), Forty Fort Airport (0.026), and Shickshinny (0.023) overlap the range of the estimates in **Table 4**. The ff estimates based on hydraulic geometry decrease down the valley axis, predominantly controlled by channel slope. The estimates based on pebble counts are more likely to indicate the actual resistance to flow, since they are based on direct field measurements. Further support for the values presented in **Table 4** was obtained by independently estimating Mannings n from the R/D_{84} values (Limerinos, 1970). The n values estimated with Limerinos' empirical formula range from 0.022 to 0.025, falling in the range of the lower group of values estimated from hydraulic geometry (**Table 3**).

CHANNEL PATTERN AND CONSTRAINTS ON CHANNEL CHANGE

The North Branch of the Susquehanna River traverses a meandering bedrock valley. It is not self-formed as is the case for alluvial rivers and most flume experiment channels. The channel pattern is dominated by the sort of entrenched meanders discussed above with reference to the cross-section at the Wilkes-Barre gaging station. Resistance to flow is therefore unlikely to be simply a product of the factors of channel form and bed material size discussed above. As has been shown by several previous studies in similar geologic settings (Brush, 1961; Cenderelli and Cluer, 1998; Leopold et al., 1960; Tinkler and Wohl, 1998), both flow velocity and rates of sediment transport are affected by variations in planform channel pattern and sedimentary bedforms.

At the 23 cross-sections examined in the present study, the channel pattern varies from a nearly straight, entrenched pattern (Falls, Wilkes-Barre), to an island braided pattern (Towanda, Gould Island), to a freely meandering one (Nanticoke, Danville). **Table 2** and **Table 3** report values for serveral variables found in previous studies to determine channel pattern (Lane, 1957; Leopold and Wolman, 1957; Schumm, 1963). Contrary to what was found by Schumm (1963), there is little or no correlation with the width/depth ratio. This may be because of inaccuracy in the depth estimates based on the continuity equation, although some depths are independently constrained by stream gaging.

None of the sinuosity values measured off of the 7.5 minute topographic maps are greater than 1.5, meaning that the reaches designated as "meandering" in **Table 2** are just barely sinuous enough to qualify as such (Knighton, 1998, p. 207; Ritter et al., 1995, p. 212-213). The large arcuate bends at locations such as "The Neck" upstream of Tunkhannock (**Figure 28**) actually represent some of the least sinuous reaches, because the channel simply follows meanders in the bedrock valley (Leopold et al., 1964, p. 18-22). The radius of curvature (r_c) and the wavelength (λ) were measured for seven bedrock meanders on the Towanda, Wyalusing, Laceyville, and Meshoppen quadrangles. When

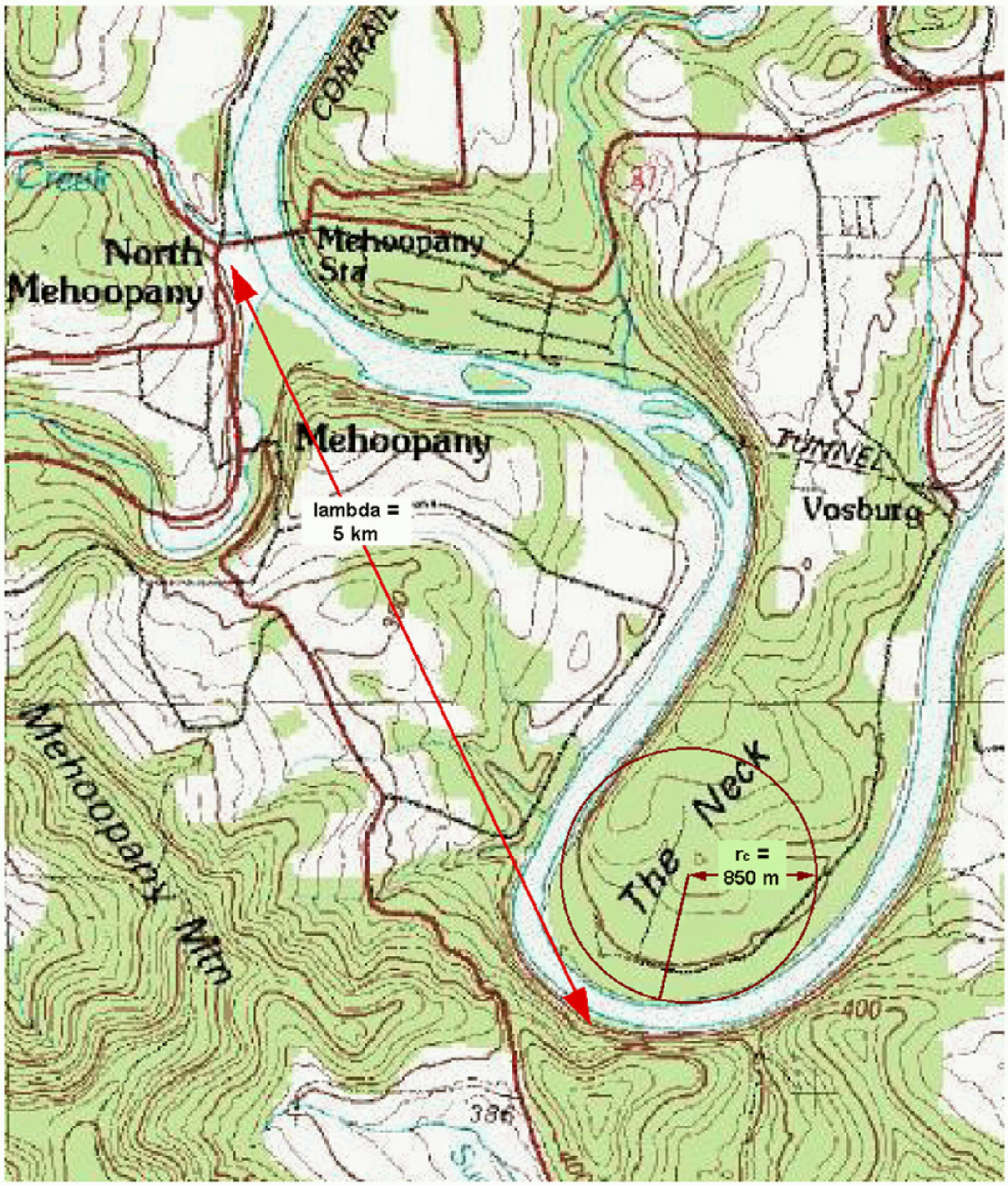


Figure 28: Bedrock meander at "The Neck" on the Meshoppen 7.5 minute topographic map

substituted into the following equations, the λ values suggest that these meanders were carved by a channel similar in width to that of the present North Branch of the Susquehanna River but conveying greater bankfull discharges.

$\lambda = 10.9\ w^{1.01}$ (Leopold and Wolman, 1957) (9)

$\lambda = 62\ Q_{bkf}^{\ 0.47}$ (Ackers and Charlton, 1970) (10)

$\lambda = 30\ Q_{bkf}^{\ 0.5}$ (Dury, 1965) (11)

The measured λ values range from three to five kilometers. The bankfull width should range from 260-432 meters according to equation (9), which is similar to the range of widths estimated for the $Q_{1.5}$ at the 23 channel cross-sections in the present study. The two equations relating λ to bankfull discharge (Q_{bkf}) give very different results. Bankfull discharge of the river responsible for the bedrock meanders would range from 3,842-11,391 m^3s^{-1} according to equation (10), and from 10,000-27,778 m^3s^{-1} according to equation (11). The equation (10) values are within the range of floods that have occurred on the North Branch of the Susquehanna River within the period of historic record. The equation (11) values would suggest a very different river, with much deeper and faster flows.

Regardless of the geologic origin of these bedrock meanders, they now play a significant role in both sediment transport and routing of discharge during extreme floods. Large meanders such as the bend at French Azilum (km 415) are characterized by a large radius of curvature (r_c = 1.3 km) in proportion to the channel width (w = 0.25 km) The ratio r_c/w decreases as bends become tighter and serves to index the increasing potential to erode the channel and banks opposite a bend. Maximum erosion occurs in the range of $2 < r_c/w < 3$, while below this range erosion decreases and subsequent adjustments tend to reduce curvature (Hickin, 1974; Knighton, 1998, p. 226-228). Of seven meanders studied, the lowest r_c/w was 3.0 for Quicks Bend (km 393).

According to Chitale (1973), meanders in wide, shallow channels will travel downstream rather than increase in curvature since stream power is maximized downstream of the apex of each bend. In the study area, both rock-cut bluffs and outwash terrace scarps are prevalent downstream of valley meanders on the opposite bank. Resistance from these obstacles generally precludes significant downstream migration, so that meanders have shifted at most a few hundred meters. Extreme flood discharges would probably be accomodated by channel avulsion (Ritter et al., 1995, p. 239-240; Smith et al., 1989), were it not for the construction of levees to constrain the channel to its present configuration.

The spacing of meanders and other features in alluvial environments is thought to be regular, with a dimension of $2\pi w$ suggested by Yalin (1971, 1992) and revised to $4\pi w$ by Hey (1976). The $2\pi w$ dimension would have a range of 0.9-2.8 km and the $4\pi w$ dimension a range of 1.8-5.6 km in the study area. The mechanical basis for this is a regular pattern of alternating regions of high velocity that develops under turbulent flow. Such regions are maintained or become more pronounced when discharge increases beyond bankfull stage. It will be argued in **Chapter 6** that the regular spacing of regions of turbulent flow represents a plausible hypothesis for the discontinuous distribution of deposits from large flood events in the North Branch of the Susquehanna River valley.

CLASSIFICATION AND EXPLANATION OF CHANNEL PATTERN

In **Table 2**, the 23 cross-sections are each assigned to one of the categories from the channel pattern classification developed by Rosgen (1994). These categories should in principle be derivable from the ranges for quantifiable variables presented in the same table. For example, channel types C4-C5 (meandering) have sinuousities greater than 1.4, while the channel slopes should be less than 0.02 (%). By the latter criterion, only the Nanticoke and Danville cross-sections would be meandering according to the Rosgen classification. Because of such inconsistencies between the natural clustering of values for measured variables and the arbitary class limits in the classification, Rosgen in fact suggests that it be applied flexibly (Rosgen, 1994, p.181). Unfortunately, the Rosgen classification thereby runs the risk of being applied *ad hoc* to suit the purposes of a particular study.

Rosgen follows Schumm (1963) in the importance attached to the width/depth ratio (*w*/*d*) for distinguishing braided (D4-D5) from meandering (C4-C5) channel patterns. In the present study, three cross-sections in which an island braided pattern is known to occur have widths that are too narrow, according to Rosgen's criteria, relative to their estimated depths. The cross-sections at Milan, French Azilum, and Mifflinville have *w*/*d* values less than 40 reported in **Table 2**, even though they include floodplain islands.

An interesting aspect of the Rosgen classification, which initially suggested its application in the present study, is the provision it makes for the unique properties of entrenched channels. Entrenched channels are defined as channels with values less than 1.4 for the entrenchment ratio, a ratio of the flood-prone width to the bankfull channel width. Rosgen defines the flood-prone width as the width of a channel twice as deep as the bankfull channel. The flood-prone dimensions are also suggested to be those of the 50-year flood (Rosgen, 1994, p. 182-183).

The "twice bankfull depth" rule-of-thumb has nothing to recommend it in terms of either theory or practical implications. For the three USGS gaging stations on the North Branch of the Susquehanna River, all of the Q_{50} depths are a good bit less than twice the $Q_{1.5}$ depths (see **Table 5**). It seems preferable to use gaging records where they are available. Soil mapping criteria of the sort used in the present study could also be helpful in defining areas prone to frequent flooding. The ratios of widths at Q_{50} to widths at $Q_{1.5}$ are 1.3 for both Towanda and Wilkes-Barre and 1.6 for Danville. The Danville reach had already been classified as having a meandering channel pattern using other criteria. No attempts were made to calculate the Rosgen "entrenchment ratio" for ungaged reaches.

The results of applying the Rosgen classification in the present study suggest it to be so elaborate that many channel types will be found in any river as large as the North Branch of the Susquehanna. It is therefore of limited utility for making comparisons between large rivers. Problems with applying the criteria consistently in order to plan stream restoration projects in specific reaches have already been noted by other authors (Kondolf et al., 2001; Miller and Ritter, 1996). Pebble counts are recommended to differentiate cobble-bed (C3, D3, and F3) from gravel-bed (C4, D4, and F4) reaches (Rosgen, 1994, p. 183-184). These do not apply to the bank component of channel material, however, and some alternative method must be used to identify channels formed in sand, silt, or clay. How soil mapping should be used for this purpose is not explained.

The data on channel dimensions and channel pattern presented above were obtained with a view toward understanding causal mechanisms at work over varying timescales. This explicit theoretical approach is very different from the sort of "extrapolation and prediction" which is supposed to be possible on the basis of the Rosgen classification. Rather than attempt to scale variables on an *ad hoc* basis to arrive at a predetermined classificatory result, the objective has been to identify those which are dependent and adjust to a channel-forming discharge. The discharge with a recurrence interval of 1.5 years ($Q_{1.5}$) does appear to approximate the channel-forming discharge for the North Branch of the Susquehanna River. This cannot be simply assumed, however, in identifying a bankfull stage at ungaged channel reaches (Kondolf et al., 2001).

Over intervals less than the channel-forming recurrence interval (10^{-2} - 10^{0} yr), discharge can be considered to be an independent variable (Knighton, 1998, p. 263; Ritter et al., 1995, p. 7; Schumm and Lichty, 1965). While the channel dimensions also remain fixed at each cross-section, each river has a slightly different rate of increase in width, depth, and velocity along the downstream axis (Leopold and Maddock, 1953). Width increases irregularly as a power function of discharge ($Q_{1.5}$) with an exponent, *b*, of approximately 0.38 in the present study reaches (**Figure 29**). The correlation is weak

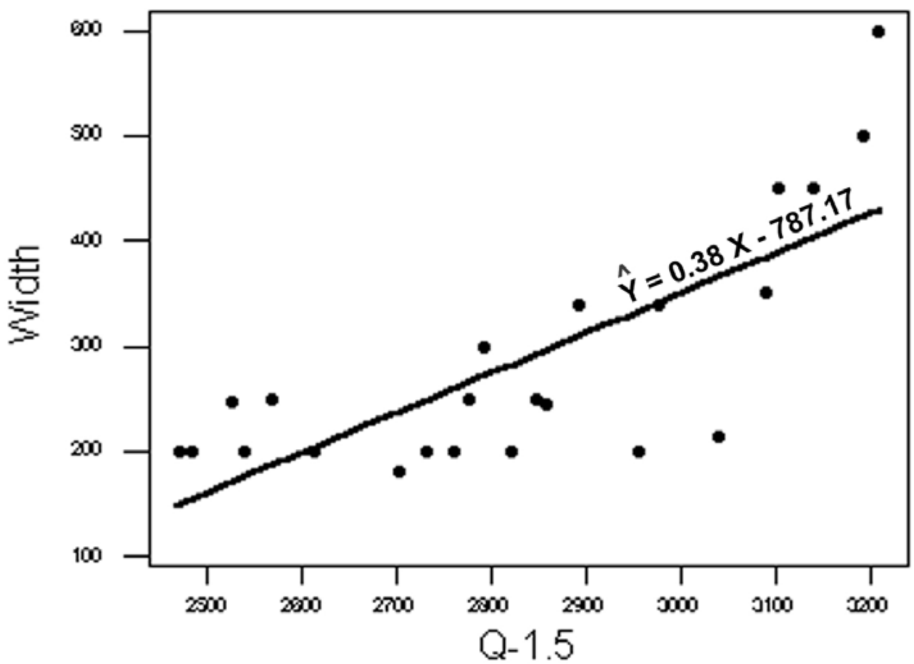


Figure 29: Correlation of channel width with increasing discharge (Q1.5) in the North Branch of the Susquehanna River

($r^2 = 0.59$) but no weaker than correlations used in the initial studies of hydraulic geometry (Brush, 1961; Leopold and Maddock, 1953). The value for *b* is considerably lower than previously reported values of 0.55 for a sample of 16 Pennsylvania streams (Brush, 1961) and 0.50 for midwestern streams (Leopold and Maddock, 1953, p. 26). Neither depth nor velocity show much correlation with discharge. This may be due to the indirect method of estimating these values, but it also probably represents the effects of entrenchment and bed irregularities detailed above.

At discharges less than bankfull, peak velocities occur at "rapids." These are reaches where the slope increases across an irregular channel bottom. A graded river channel may still have such irregularities, but they will be submerged by a discharge that fills the channel cross-section. This results in a constant slope or energy grade line at bankfull discharge.

If the channel bottom of the North Branch of the Susquehanna River were carefully mapped from a boat, it would presumably show many irregularities due to scour and fill adjustments of the channel bed. Velocities measured with a current meter could be extremely varied for flows disrupted by gravel bars and floodplain islands. Once these features have been submerged beneath the energy grade line, however, the velocity should remain within the relatively narrow range (1.2 - 2.2 ms^{-1}) estimated in **Table 2** from the USGS gaging records. In the wide reaches between Danville (km 217) and Northumberland (km 197), bedforms on the sandier channel bottom may also contribute to the shallow depth (< 5 m) and low velocity (< 2 ms^{-1}).

Direct field measurements would significantly revise many of the values presented for hydraulic variables in **Table 2** and **Table 3**. The indirect methods are appropriate given the available gaging records, however. The present use of the continuity equation is similar to its use by Brush (1961) to estimate velocity in Pennsylvania rivers. Brush's estimates ranged from 1.1-2.5 ms^{-1} for Little Juniata River and from 1.0-4.2 ms^{-1} for Bald Eagle Creek at the 2.3 year recurrence interval. These are the two largest rivers that Brush studied in terms of drainage basin area. The slightly higher velocities are probably due to the channel slopes being at least an order of magnitude greater than any of those in **Table 2**. The use of the 2.3 year rather than the 1.5 year recurrence interval may also be significant, since velocity increases with discharge at-a-station as well as along the downstream axis (Leopold and Maddock, 1953).

Rivers become "graded" through adjustments occurring at timescales that encompass all of the time since the retreat of the Laurentide ice-sheet (10^2 - 10^4 yr). Adjustments to deglaciation and Holocene environmental change are indicated by channel pattern changes in many alluvial rivers (Schumm, 1977, p. 164-171; Schumm and Brakenridge, 1987, p. 224-228; Starkel, 1983). In addition to stratigraphic evidence of former channel patterns, adjustments made under different environmental conditions may be indicated by channel dimensions which differ from those typical for the channel-forming discharge (Dury, 1954, 1965; Leigh and Feeney, 1995). Quaternary environmental change is one quite plausible explanation for the occurrence of an island braided pattern in reaches of the North Branch of the Susquehanna River for which the width/depth ratio is outside the range indicated by Schumm (1963).

Other variables, particularly channel slope, do control the occurrence of braided river channels. Leopold and Wolman (1957) found, in their study of 58 rivers worldwide, that meandering and braided streams were separated by a threshold defined by slope and discharge (see **Figure 30**). With a bankfull discharge of 3000 m^3s^{-1}, the threshold slope would be 0.0005 for the North Branch of the Susquehanna River. Channel slopes equal to or greater than this occur at Milan, Towanda, French Azilum, and Mifflinville where there is a braided channel. The threshold appears to be particularly effective in this case because the slope does not decrease smoothly along the downstream axis. This indicates that the river is not completely at grade, even after adjusting through what is considered to be "graded" time (Schumm and Lichty, 1965).

The Leopold-Wolman slope threshold is part of Schumm's model for river metamorphosis (Schumm, 1969), although Schumm emphasized channel dimensions and channel material in his work on braiding in alluvial rivers (Schumm, 1968; Schumm and Lichty, 1963). Slopes are gradually reduced through erosion or increased through tectonic uplift and knickpoint migration. The channel-forming discharge can also change over graded time, as a result of changes in vegetation or the frequency and magnitude of precipitation-causing storms. Long-term changes in effective precipitation will be proposed in **Chapter 6** of the present dissertation as plausible explanations for river adjustments evident in the stratigraphic framework developed in **Chapter 5**. These

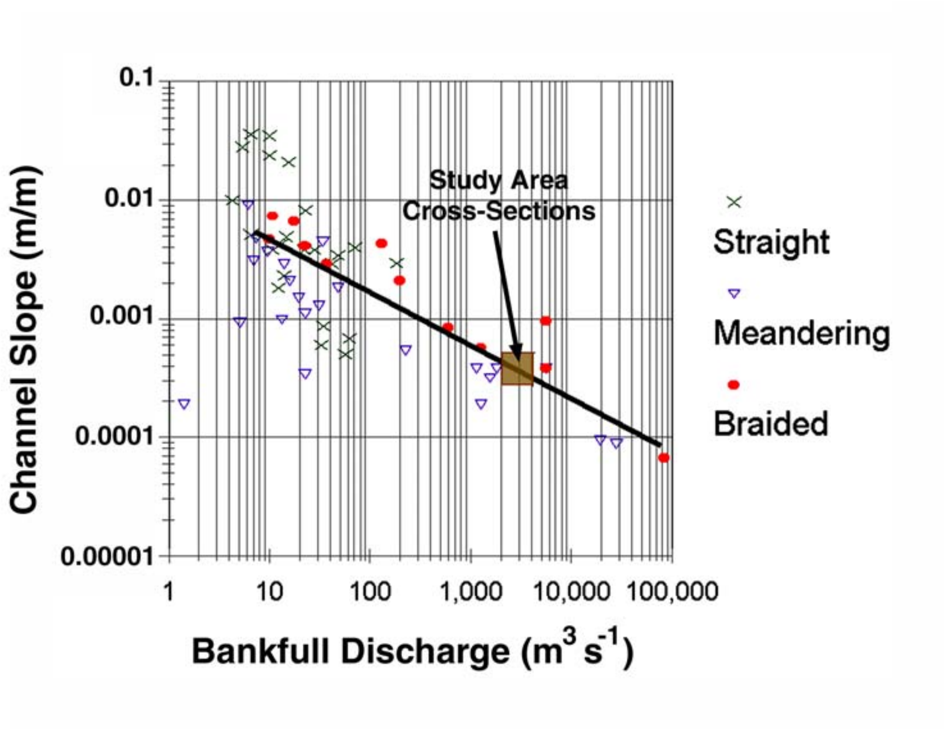


Figure 30: Position of the Study Area on the Threshold between Meandering and Braided River Channels defined by Leopold and Wolman (1957)

long-term changes are plausible given what is known about the meteorological causes and hydrological outcome of extreme floods within the historic period of record.

LARGE FLOODS AND FLOOD FREQUENCY

Recurrence intervals for floods at the Towanda, Wilkes-Barre, and Danville gaging stations are plotted in **Figures 31-33** on the basis of the gaging records for 1913-1971. **Table 5** presents the width, depth, and velocity for the $Q_{1.5}$, Q_5, Q_{10}, Q_{20}, and Q_{50} flood recurrence intervals at each gaging station. These were obtained by plotting the gaged channel depths on the surveyed cross-sections presented in **Figures 25-27**.

Years prior to 1913 were not included in the flood frequency analyses because this is the first year for which daily discharge records are available at all three gaging stations. The years following 1971 were excluded because the flood of 1972 triggered by Hurricane Agnes is both an extreme statistical outlier and a meteorological anomaly among 20th century floods. Statistical flood frequency analyses are subject to large errors in forecasting flood recurrence because of fluctuations in precipitation-causing storm events (e.g. Knox, 1984) as well as human impacts on drainage basin hydrology (Wohl, 2001, p. 101-125). Both land use history and the meteorology of individual flood events were investigated in some detail in the present study.

Floods were observed by Euroamerican settlers as early as the late 18th century on the North Branch of the Susquehanna River (Hoyt and Langbein, 1955, p. 429). Prior to that, the Native American inhabitants are reported to have expected serious floods about once every fourteen years (Stranahan, 1993, p. 119). The first recorded flood occurred on

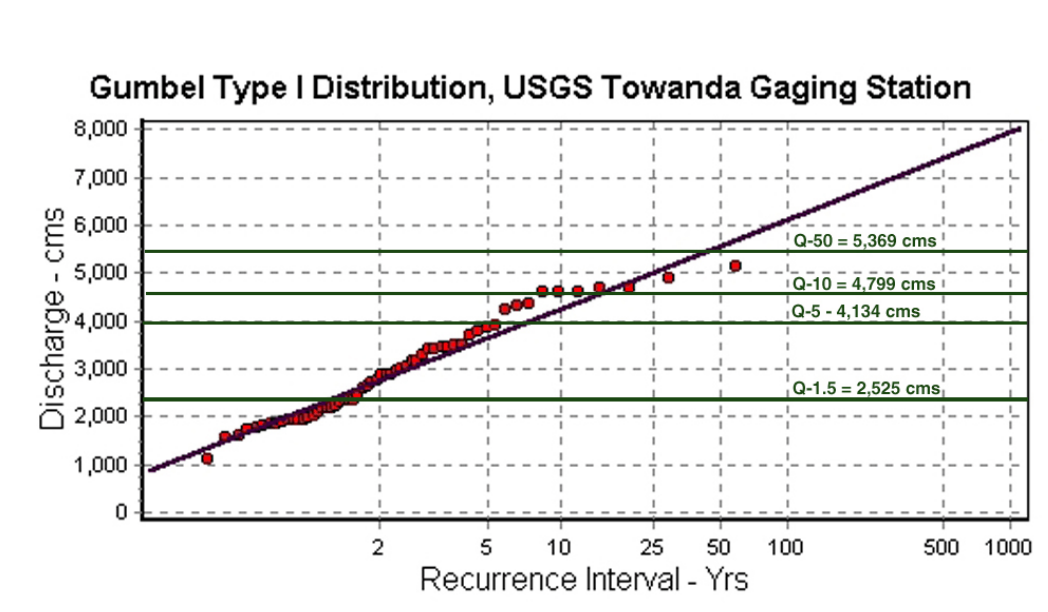


Figure 31: Flood frequency curve for the Towanda gaging station based on records for 1913-1971

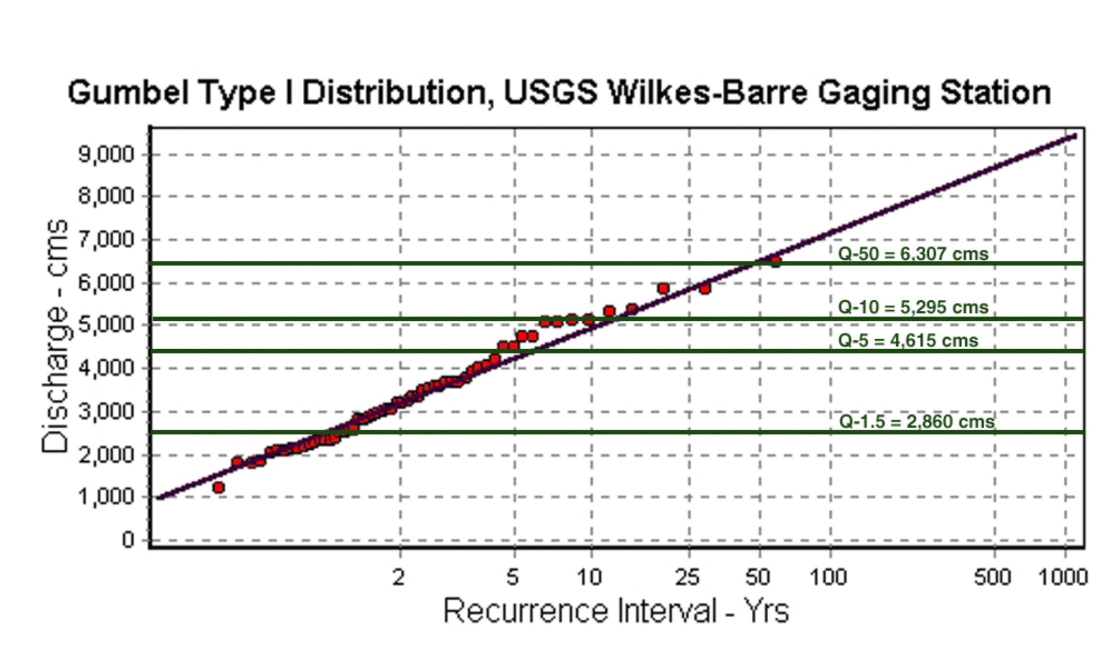


Figure 32: Flood frequency curve for the Wilkes-Barre gaging station based on records for 1913-1971

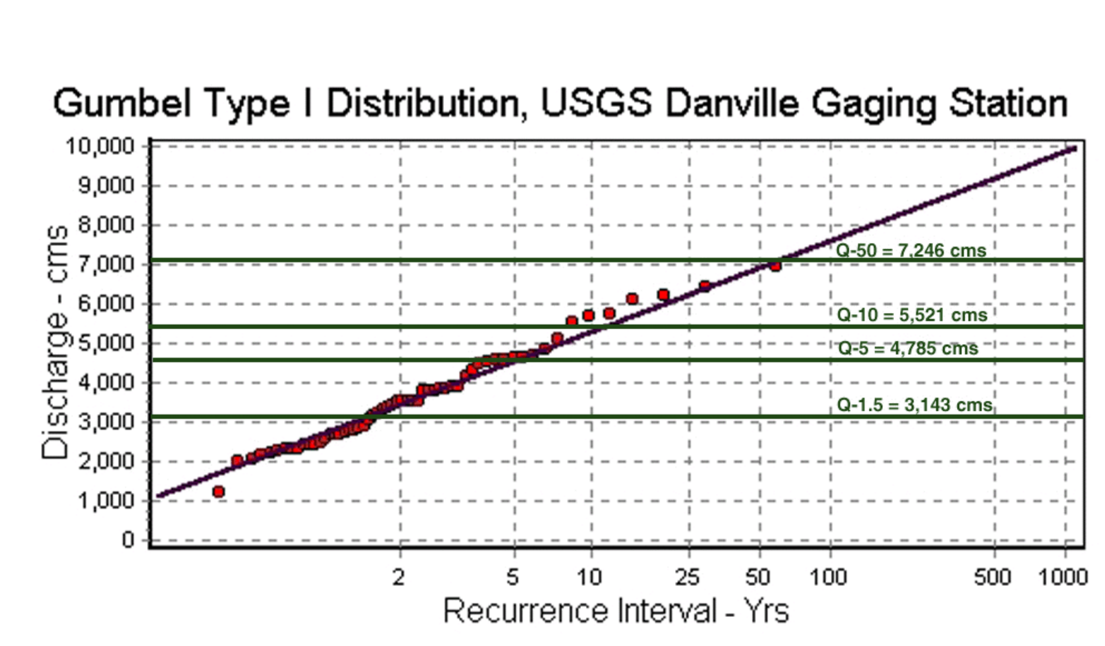


Figure 33: Flood frequency curve for the Danville gaging station based on records for 1913-1971

Table 5: Discharge, Width, Depth, and Velocity for Floods at the Towanda, Wilkes-Barre, and Danville Gaging Stations up to the 50-year recurrence interval

USGS Gaging Station at Towanda (km 430)

	Q-cfs	Q-cms	v (m)	w (m)	d (m)	A (m^2)
Gaged	56,300	1,594	1.79	247	3.6	890
$Q_{1.5}$	89,183	2,525	1.60	317	4.9	1,553
Q_5	146,012	4,134	1.60	380	6.8	2,584
Q_{10}	169,501	4,799	1.60	389	7.6	2,958
Q_{20}	175,258	4,962	1.60	403	7.7	3,101
Q_{50}	189,633	5,369	1.60	414	8.1	3,356

USGS Gaging Station at Wilkes-Barre (km 299)

	Q-cfs	Q-cms	v (m)	w (m)	d (m)	A (m^2)
Gaged	32,000	906	0.99	241	3.8	916
$Q_{1.5}$	101,015	2,860	1.78	244	6.6	1,610
Q_5	163,002	4,615	1.80	302	8.5	2,564
Q_{10}	187,019	5,295	1.77	305	9.8	2,989
Q_{20}	204,750	5,797	1.76	310	10.6	3,286
Q_{50}	222,763	6,307	1.75	325	11.1	3,604

USGS Gaging Station at Danville (km 219)

	Q-cfs	Q-cms	v (m)	w (m)	d (m)	A (m^2)
Gaged	79,400	2,248	1.45	397	4.0	1,588
$Q_{1.5}$	111,011	3,143	1.32	450	5.3	2,385
Q_5	169,006	4,785	1.56	450	6.8	3,060
Q_{10}	195,002	5,521	1.26	600	7.3	4,380
Q_{20}	230,295	6,520	1.24	650	8.1	5,265
Q_{50}	255,929	7,246	1.19	700	8.7	6,090

October 5, 1786, and is known as the "pumpkin" flood because of its destruction and entrainment of that agricultural crop. A discharge of 5,351 m^3s^{-1} at Wilkes-Barre has been estimated for the pumpkin flood (USGS, 2002). That would only be a 10-year flood using the frequency curve in **Figure 32**.

The USGS. has estimated discharge at Wilkes-Barre for four other early floods prior to the first systematic gaging. A discharge of 5,719 m^3s^{-1} is reported for April, 1807. A discharge of 2,695 m^3s^{-1} is reported for July, 1809. A discharge of 4,983 m^3s^{-1} is reported for May 14, 1833. By far the most significant 19th century event occurred on March 17th (St.Patrick's Day) of 1865. The depth of 10.1 m (33.1 ft.) would represent a discharge of 6,569 m^3s^{-1} using the modern rating curve, and a 50-year flood using the frequency curve in **Figure 32**.

Many of the large floods during the 19th century were related to deforestation and other deleterious land use practices. Timber harvest throughout the catchment had depleted forest land as early as 1840 (Petrillo, 1986, p. 142; Russell, 1997; Russell et al., 1993, p. 108-129). The rapidly increasing price of charcoal stimulated the experimentation with alternative heat sources such as anthracite coal. The effects of deforestation on flood hydrology are manifest in the present environment by a linear relationship between forest cover and sediment yield (Williams and Reed, 1972).

Particularly good records are available for events which affected the construction of the North Branch Canal, beginning in 1830 (see **Table 6**). Many of the disastrous events along the canal occurred in winter or spring months, and these are probably related to cold regional climate at the end of the Little Ice Age (Grove, 1988; Lamb,

Table 6: Chronology of floods and other events impacting the North Branch Canal, 1830-1865

Year	Events
1832	January ice jam at Shickshinny, dam at Nanticoke undermined. Spring freshet shattered the western side of the dam and carried away the guard lock.
1839	April 13 freshet carried away the dam across the Lackawanna and the Mill Creek aqueduct in the Wyoming Valley.
1854	Heavy rains in May caused a slide along the canal in Wilkes-Barre. June 27 floods caused a landslide at Shickshinny.
1857	November 11 flood on the Chemung River closed that canal.
1864-65	River choked with ice from December 20 to March.
1865	March 17-18 was the worst flood in Wilkes-Barre in previous history. The canal was underwater from Nanticoke Dam downstream to Northumberland.

1982). Large snowmelt or ice-jam floods also occur in the interval 1830-1865 on the Connecticut River at Hartford and the Ohio River at Pittsburg (Hoyt and Langbein, 1955, p. 55-57).

Floods were gaged at Wilkes-Barre beginning in 1891, at Towanda beginning in 1893, and at Danville beginning in 1900. Discharges greater than bankfull were recorded on January 1, 1891 and April 4, 1892 at Wilkes-Barre, and in 1893 (May 4-5), 1895 (April 10), and 1896 (March 31 - April 1) at both Towanda and Wilkes-Barre. An anomalous fall flood on November 28, 1900 gaged at both Wilkes-Barre and Danville was followed by a return to consistent spring floods gaged at all three stations for 1902 (March 2-3), 1903 (March 24-25), 1904 (March 9-27), and 1905 (March 26). The flood of 1904 resulted in part from the occurrence of a tremendous ice gorge that blocked the river from near Danville upstream to Berwick. At least six bridges were carried away when the gorge finally broke, including those at Berwick, Mifflinville, and Catawissa (Inners, 1981, p. 92).

Gaged floods which exceeded the bankfull stage are a mixed population in terms of meteorological cause. Synoptic scale "reanalyses" for events between 1957 and 1996 (Kalnay et al., 1996; NOAA, 1999) implicate hurricanes, extratropical or "wave" cyclones, frontal systems, and isolated convective storms (see **Appendix 2**). Snowmelt has played a key role in many of the late winter or spring "freshets" and this is not easy either to forecast or to "backcast" (Dunne and Leopold, 1978, p. 465-490; U.S. Army Corps of Engineers, 1956, 1960).

By partitioning the flood populations based on meteorological cause, more reliable estimates may be made of the recurrence for specific types of event (Brown, 1991, 1996; Bevan, 1993). Late winter and spring floods caused by snowmelt have been successfully partitioned from other extreme events in previous studies of the South Platte River, Arkansas River, and Colorado River basins in Colorado (Elliott et al., 1982) and the Salt River valley in central Arizona (Hirschboeck, 1987). Namias (1973) and Hirschboeck (1988, p. 35-37) also previously diagnosed the causes of the flood of June 1972 on the North Branch of the Susquehanna River.

The flood of June 1972 triggered by Tropical Storm Agnes was among the most destructive floods in United States history, costing more than 48 deaths and 1.5 billion dollars in Pennsylvania, 117 deaths and 3.1 billion dollars in the United States as a whole

(Bailey et al., 1975, p. 83). The measured discharges of 9,060 m^3s^{-1} at Towanda, 9,768 m^3s^{-1} at Wilkes-Barre, and 10,277 m^3s^{-1} at Danville are around three times larger than the mean annual flood for 1913-1971. The channel form may still be adjusting to its impact in many reaches, although Stevens et al. (1975) suggest that rivers typically adjust to a flood up to ten times larger than the mean annual within 100 years. The gaged discharges are within "maximum likelihood" limits defined from previous extreme floods for a given drainage basin area by Hoyt and Langbein (1955, p. 59-61).

The anomalous magnitude of the Agnes event is evident from the annual flood series for the Wilkes-Barre gaging station (**Figure 34**). The river channel widened to over two kilometers in reaches on the Wilkes-Barre quad mapped by Flippo and Lenfest (1973). The gaged flood depth of 12.4 m converts to a pool elevation of 168.5 m MSL. Flippo and Lenfest mapped up to the 170 m (560 ft.) contour on the basis of field indications. Bailey et al. (1975, p. 76) documented erosion on the edge of the Forty Fort cemetery as well as deposition of up to 50 cm of overbank sediment which was sand-sized or finer.

Although only a few other floods within the period of record were triggered by tropical storms, certain meteorological features make it possible to relate the flood of June 1972 to a larger set of events. In particular, Atlantic Ocean sea-surface temperatures (SSTs) affected the zones favorable to generation and movement of cyclones and anticyclones during the 1972 event (Namias, 1973). Air-sea heat exchange and oceanic advection led to colder than normal water in northerly latitudes of the North Atlantic,

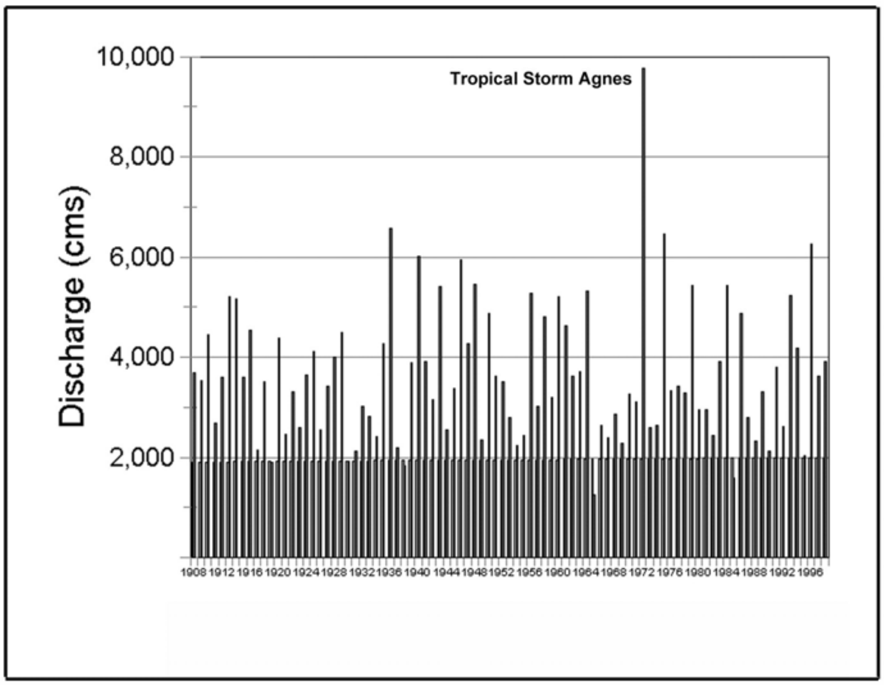


Figure 34: Annual flood series for the Wilkes-Barre gaging station

warmer than normal surface waters in the mid-Atlantic, and especially warmer than normal water off the eastern seaboard of the United States in June of 1972 (**Figure 35**). This "meridional gradient" in SSTs was mirrored by strengthened meridional upper air flow, encouraging the rapid formation and movement of synoptic waves in the westerlies.

Agnes reached tropical storm intensity on June 16th in the Caribbean Sea and started to curve northward, heading straight toward the Florida Panhandle. It became a hurricane while in the Gulf of Mexico and made landfall on June 19th (**Figure 36**). Thereafter it weakened so that it was no longer a hurricane and became embedded between a ridge and a trough in the upper air flow, effectively constituting an "extratropical cyclone" (Djuric, 1994, p. 167-168). This "steering" of the storm's path took it across the populous and industrially developed mid-Atlantic coast to north-central Pennsylvania, where it stalled for almost 24 hours and was fed by moist air flowing from the abnormally warm western Atlantic.

Although rainfall amounts of up to 350 mm were gaged within the study area during the storm event (Bailey et al., 1975, p. 54), monthly rainfall only totaled 178 mm at the Scranton-Wilkes Barre airport station and the June total was less than that for May (Earth Info, Inc., 1994). The center of the storm track was considerably west of the North Branch valley so that more rainfall and flooding occurred along the Chemung River than the Susquehanna upstream of their juncture. The peak discharge of 3,285 m^3s^{-1} on the Chemung River at Waverly, New York has a recurrence interval of 40 years while that on the Susquehanna River at Binghamton has a recurrence interval of only two years. The discharge of 750 m^3s^{-1} on the Susquehanna at Conklin, New York was less than the

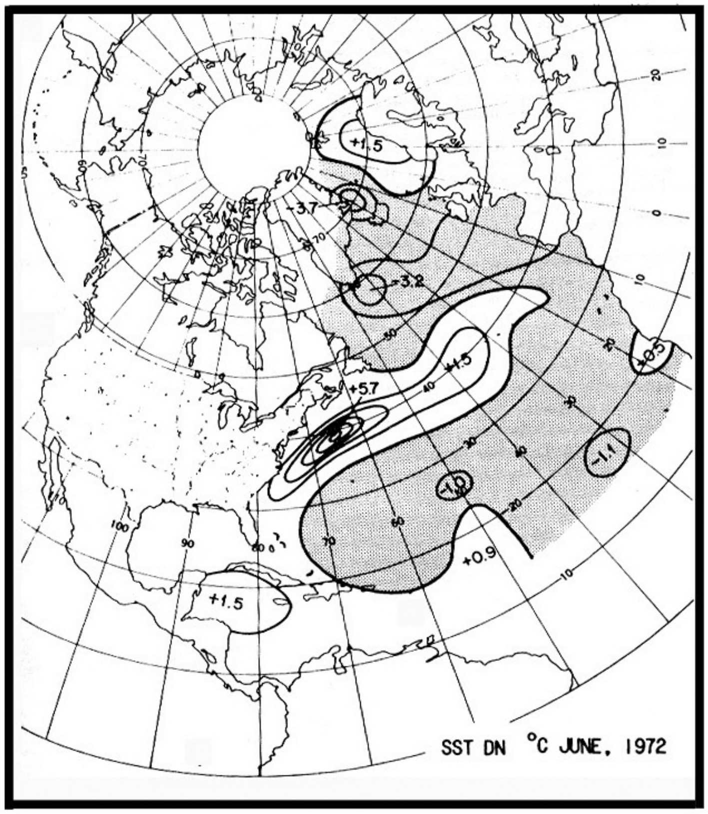


Figure 35: Sea Surface Temperature (SST) departures from normal for June 1-26, 1972

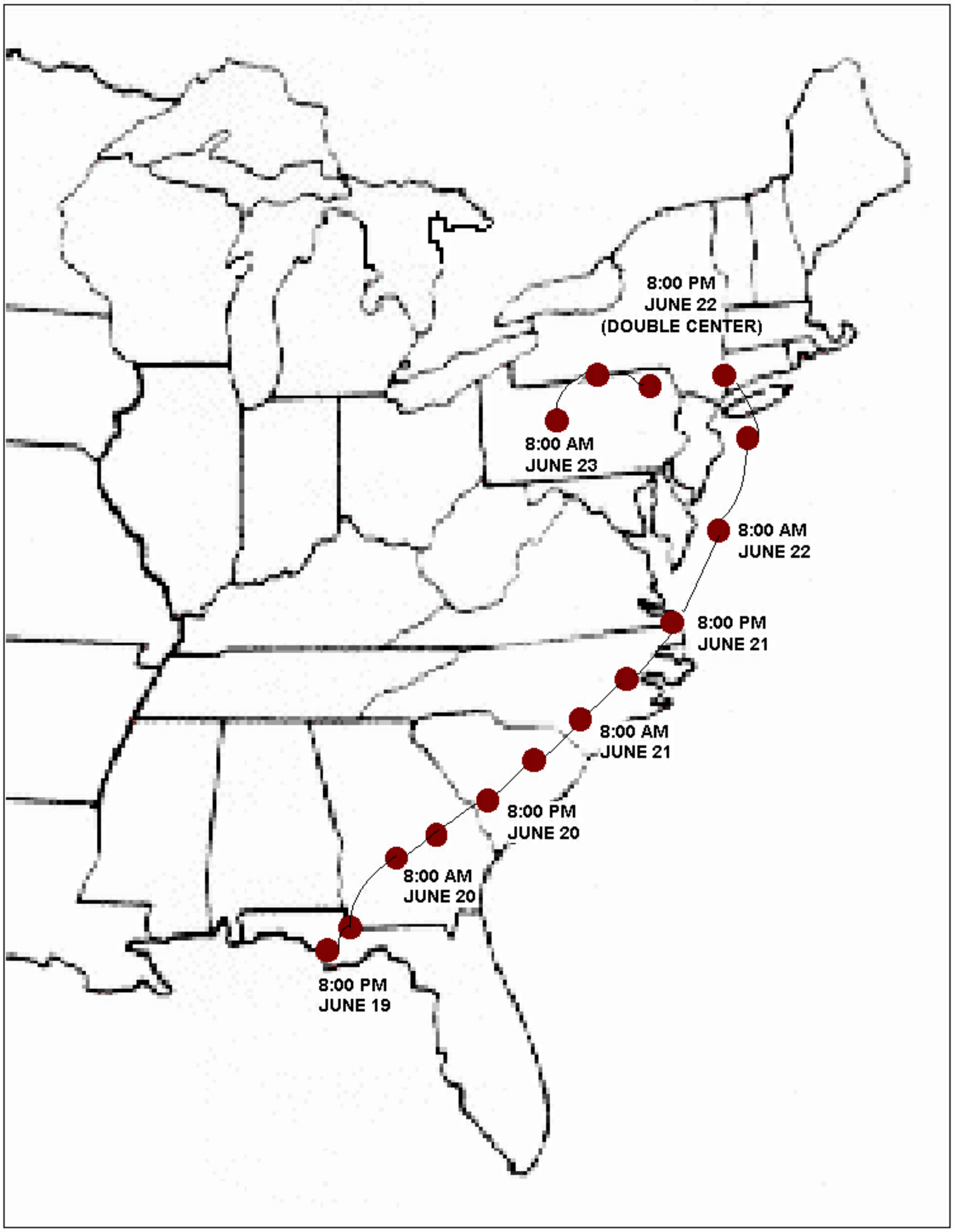


Figure 36: Track of Hurricane Agnes through the northeastern United States in June, 1972

bankfull and approximately equivalent to the mean annual flood. Flooding also appears to have been less severe in tributary valleys, although relatively few gaging stations are located on tributaries. At Tunkhannock Creek, for example, the June flood does not even count as an annual peak for 1972.

Despite its catastrophic impact on the Susquehanna River valley and other populated areas in the northeastern United States, Agnes was never a "major" hurricane with windspeeds over 50 ms^{-1} (Elsner and Kara, 1999, p. 137-164). Hurricane Eloise was both a more significant and a more typical tropical cyclone system with flood impacts in the study area. Peak discharges of 6,257 m^3s^{-1} at Towanda and 6,455 m^3s^{-1} at Wilkes-Barre were gaged on September 27, 1975 and a discharge of 7,276 m^3s^{-1} was gaged on September 28, 1975 at Danville.

Both tropical and extratropical cyclones form more frequently and track more rapidly toward the northeastern United States during late summer and fall months. This is because there is a stronger contrast between the cool, dry air originating at high latitudes and the warm, humid air of the tropics, resulting in a strengthened and more southerly polar front (Djuric, 1994, p. 167-183; Elsner and Kara, 1999, p. 34-36). Eleven of the 108 annual flood peaks between 1891 and 1998 at Wilkes-Barre occurred in August through November (see **Figure 37**) and cyclogenesis along the polar front played a role in most of these events (Elsner and Kara, 1999; NOAA, 1999). Particularly significant were the flood of November 17, 1926 with a discharge of 3,426 m^3s^{-1} gaged at Wilkes-Barre and the flood of October 21, 1927, with a discharge of 3,992 m^3s^{-1}.

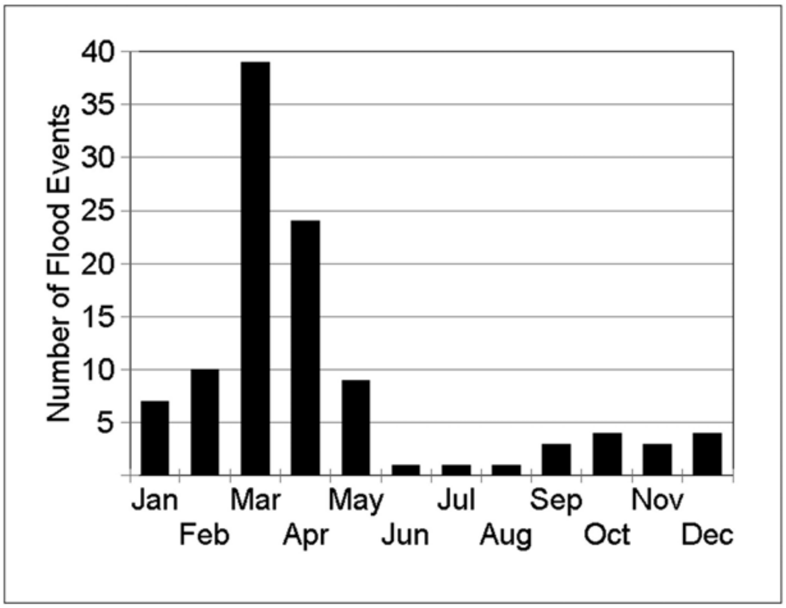


Figure 37: Distribution within the calendar year of peak annual floods recorded at Wilkes-Barre between 1891 and 1996

Regionally significant floods occurred in the Delaware River valley during August, 1955 in response to hurricanes Connie and Diane (Chapman and Sloan, 1955; Namias and Dunn, 1955) but these storms never tracked westward to deliver precipitation in the study area. Flooding did occur on September 24, 1938 at Wilkes-Barre when a cyclone tracked westward after causing catastrophic floods in the Connecticut River valley (Elsner and Kara, 1999, p. 151; Jahns, 1947, p. 63-64). A discharge of 1,758 m^3s^{-1} was gaged at Wilkes-Barre but this was not even a peak annual flood at Towanda or Danville.

Figure 37 shows late winter to early spring floods to be the most prevalent type of even within the period of record, and these are also some of the largest in terms of discharge. Prior to the Hurricane Agnes event, for example, the March 1936 floods were the greatest on record at all three gaging stations. It was in response to these floods that the United States Congress enacted the National Flood Control legislation and the Army Corps of Engineers built the 20 kilometer long system of levees between West Pittston and Plymouth in the Wyoming Valley (Stranahan, 1993, p. 127).

The March 1936 floods occurred after the very cold preceeding winter froze the ground, followed by unusually heavy snowfalls in January and February (Barrows, 1948, p. 121-122; Grover, 1937). Heavy rainfall from cyclonic storms on March 9-13 and March 16-19 coincided with unseasonably high temperatures to cause very high runoff. The peak discharges were 5,323 m^3s^{-1} at Towanda, 6,569 m^3s^{-1} at Wilkes-Barre, and 7,078 m^3s^{-1} at Danville. These exceeded all previous discharges since the St. Patrick's Day flood of 1865, which was similar in terms of meteorological cause. The gaged flood

Table 7: Snowmelt Flood Discharges recorded at the Tunkhannock Creek and Wilkes-Barre Gaging Stations

	Tunkhannock Creek	Wilkes-Barre
March 10, 1964	699	5,323
April 16, 1983	643	3,907
March 16, 1986	750	4,807
April 2, 1993	617	5,238
January 20, 1996	858	6,257
Q_{maf}	404	3,570
Q_{bkf}	323	3,029

All values are in m^3s^{-1}.

depth of 10.1 m at Wilkes-Barre corresponded to a pool elevation of 166.2 m MSL, the intended containment of the initial 11 m high Wyoming Valley levee.

The annual flood series for the gaging station on Tunkhannock Creek (**Figure 38**) records almost exclusively snowmelt events and can therefore be used to partition the series at Wilkes-Barre and the other gaging stations in the trunk stream valley. Of five extreme events gaged at Tunkhannock Creek since 1960 all but one resulted in greater than bankfull discharges at Wilkes-Barre (**Table 7**). There is only a weak correlation, however, between the flood magnitudes. The floods of March 10, 1964 and April 2, 1993 would be 10-year floods on the North Branch of the Susquehanna River using Figure 32. The floods of April 16, 1983 and March 16, 1986 were large magnitude on Tunkhannock Creek but would only be 2-year floods in the trunk stream valley.

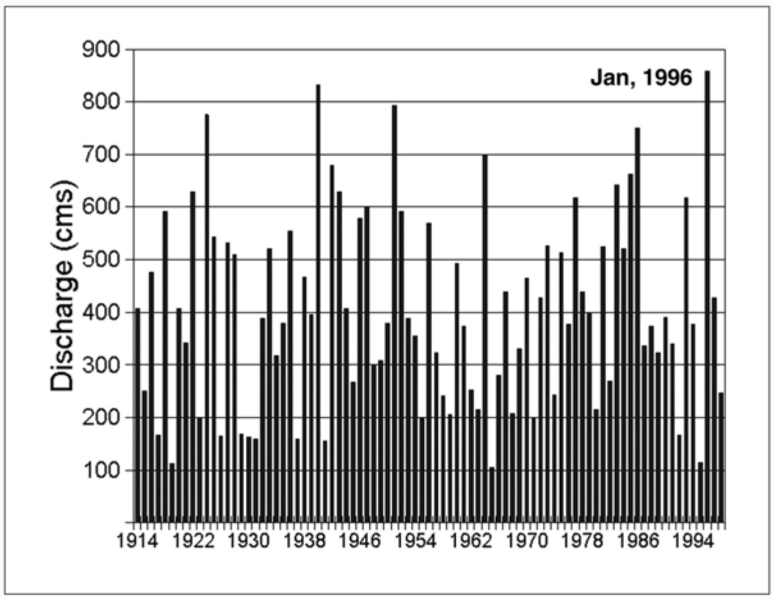


Figure 38: Annual flood series for the Tunkhannock Creek gaging station

The most recent snowmelt flood occurred in 1996 when strong southerly winds and dewpoints reaching over 50°F melted the snowpack in advance of intense frontal rains on January 19th and 20th (Leathers et al., 1999; SRBC, 1996). Although a relatively modest discharge of 3,624 m^3s^{-1} was gaged at Wilkes-Barre, the discharge at the Tunkhannock Creek gaging station is more than twice the mean annual flood. If confined within its banks to a channel only 60 m wide, the gaged discharge of 858 m^3s^{-1} would correspond to a flow velocity of 2.4 ms^{-1} and this high velocity was apparently maintained downstream below Tunkhannock at least to Pittston (km 311).

Using nine extreme events whose genesis has been detailed above, we can hypothetically partition the frequency of floods caused by snowmelt and tropical storms within the study area (**Figure 39**). Events in which tropical storms track through the study area probably recur no more frequently than once every 50 years. Tropical storms do play a role, however, in the meteorological conditions responsible for other frontal and extratropical cyclonic precipitation events.

While the largest snowmelt floods on record do not exceed 8,000 m^3s^{-1} these are the most common event, exceeding the bankfull discharge once every two years on average. As mapped in **Appendix 1**, Holocene alluvial deposits do not occur above the heights of the maximum snowmelt floods, approximately 219 m MSL at Towanda, 166 m MSL at Wilkes-Barre, and 140 m MSL at Danville. Snowmelt also plays a crucial role in flooding along high gradient tributary streams such as Tunkhannock Creek, and snowmelt floods are therefore a likely mechanism to deliver sediment into the trunk stream valley as well as to deposit it overbank on natural levee surfaces.

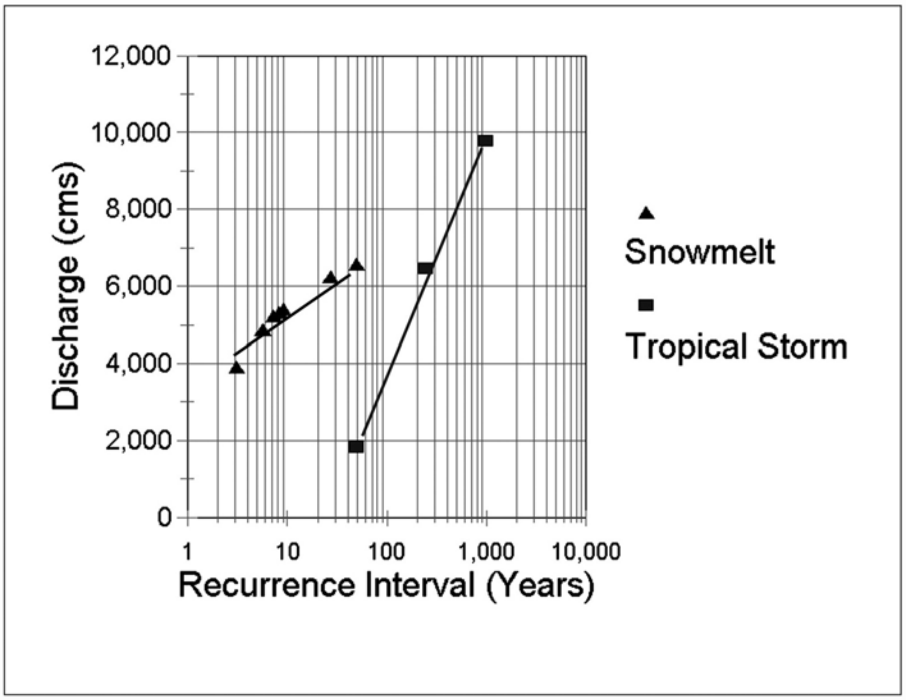


Figure 39: Hypothetical "nested frequency" of snowmelt and tropical storm flood events, North Branch of the Susquehanna River at Wilkes-Barre

CHAPTER 4

CULTURE HISTORY AND RADIOCARBON CHRONOLOGY

This chapter summarizes the sequence of prehistoric cultures in the North Branch of the Susquehanna River valley and develops a regional chronology based on radiocarbon dates from both cultural and natural contexts. The present dissertation represents one of many recent collaborations between Quaternary geologists and archaeologists (e.g. Holliday, 1997; Mandel, 1992; Waters, 1990). Archaeologists are interested in alluvial deposits, in particular, because they provide stratigraphic contexts for prehistoric cultures. Rates of alluvial sedimentation determine how artifacts and cultural features are buried in alluvial strata (Ferring, 1986, 1992; Waters, 1992), making collaboration with geologists quite beneficial to archaeologists.

As the present dissertation will show, collaboration with archaeologists can contribute considerably to geological studies of recent alluvial strata. Artifact typologies and radiocarbon dates on cultural pit features provide us with valuable age constraints on landforms mapped at the surface. Subsurface stratigraphic relationships are also often evident in the exposures on archaeological sites. Observations at several sites in the North Branch of the Susquehanna River valley stimulated the hypothesis of traceable unconformities which is tested in subsequent chapters of this dissertation.

The stratigraphic framework developed in **Chapter 5** has units which are defined independent of the age constraints provided in the present chapter. Nonetheless, radiocarbon dates are used to constrain the age of unconformities which bound the units in the stratigraphic framework. The unconformities actually appear to coincide with gaps or "discontinuities" in the sequence of dates from cultural contexts. It will be argued in **Chapter 6** that most of these age gaps not only correspond to unconformable contacts in the alluvial stratigraphy but also represent episodes of rapid change in the regional climate or vegetation of eastern North America.

CULTURE HISTORY

The valley of the North Branch of the Susquehanna River attracted Native American settlement beginning at the close of the Pleistocene epoch, approximately 13,000 to 10,000 years ago (13-10 ka). During the Paleoindian Period of the prehistoric cultural sequence, the valley was a major north-south route for both people and large game animals (Funk, 1993a, p. 299). Remains of mastodon and other extinct Pleistocene fauna dating to the period have been reported by Coates et al. (1971) and Barnosky et al. (1988). While no *in situ* Paleoindian materials have been excavated to date, there have been many surface finds, particularly on the outwash terraces (Orlandini, 1996, p. 12-13; Royer, 1963; Shaffer et al., 1990, p. 35; Wymer, 1999).

The time range from ~10-3 ka has been subdivided into Early, Middle, and Late Archaic Periods by archaeologists working in the eastern United States (e.g. Carr, 1998a, 1998b; Custer, 1996, p. 133-216). Construction of circular, dome-shaped, bark-covered houses on several sites in Pennsylvania is indicated by patterns of postmolds, the remnant stains of decayed posts (Kent, 1980, p. 25). In the study area itself, sites typically consist of artifact scatters around pits used for storing and processing food. The tool kit includes pecked and polished grooved-stone axes, pestles and mullers for crushing and grinding nuts and seeds, atlatl weights for spear-throwing sticks, and chipped-stone drills, knives, scrapers, and spearpoints. Chronological distinctions between the three major periods and more specific local phases of the prehistoric cultural sequence are based primarily on stylistic and functional changes in the chipped-stone spearpoints or knives (see **Figure 40**).

The interval from 3.8-2.8 ka is locally designated the Terminal Archaic or Transitional Period in Pennsylvania archaeology (Kent, 1980, p. 26-27; Witthoft, 1953). The period is marked by two characteristic artifact forms: broad-bladed (e.g. Susquehanna and Perkiomen Broadspear) PPKs and soapstone (steatite) vessels. Both forms are widely distributed and probably represent an "interaction sphere" within which other economic or ceremonial behaviors were shared (Caldwell, 1965; Struever, 1964).

The more elaborate and substantial material culture from the Terminal Archaic Period is paralleled by the occurrence of relatively large (5000-10,000 m^2) base camps distributed on first terraces of the major river valleys (Carr, 1998a, p. 85; Ritchie and Funk, 1973, p. 72; Witthoft, 1953). Terminal Archaic base camps were excavated at the following alluvial terrace sites in the study area: Mifflinville Bridge, Susquehanna Steam and Electric Station (SES), Gould Island, Jacobs, Skvarek, Cremard, Falls Bridge, and

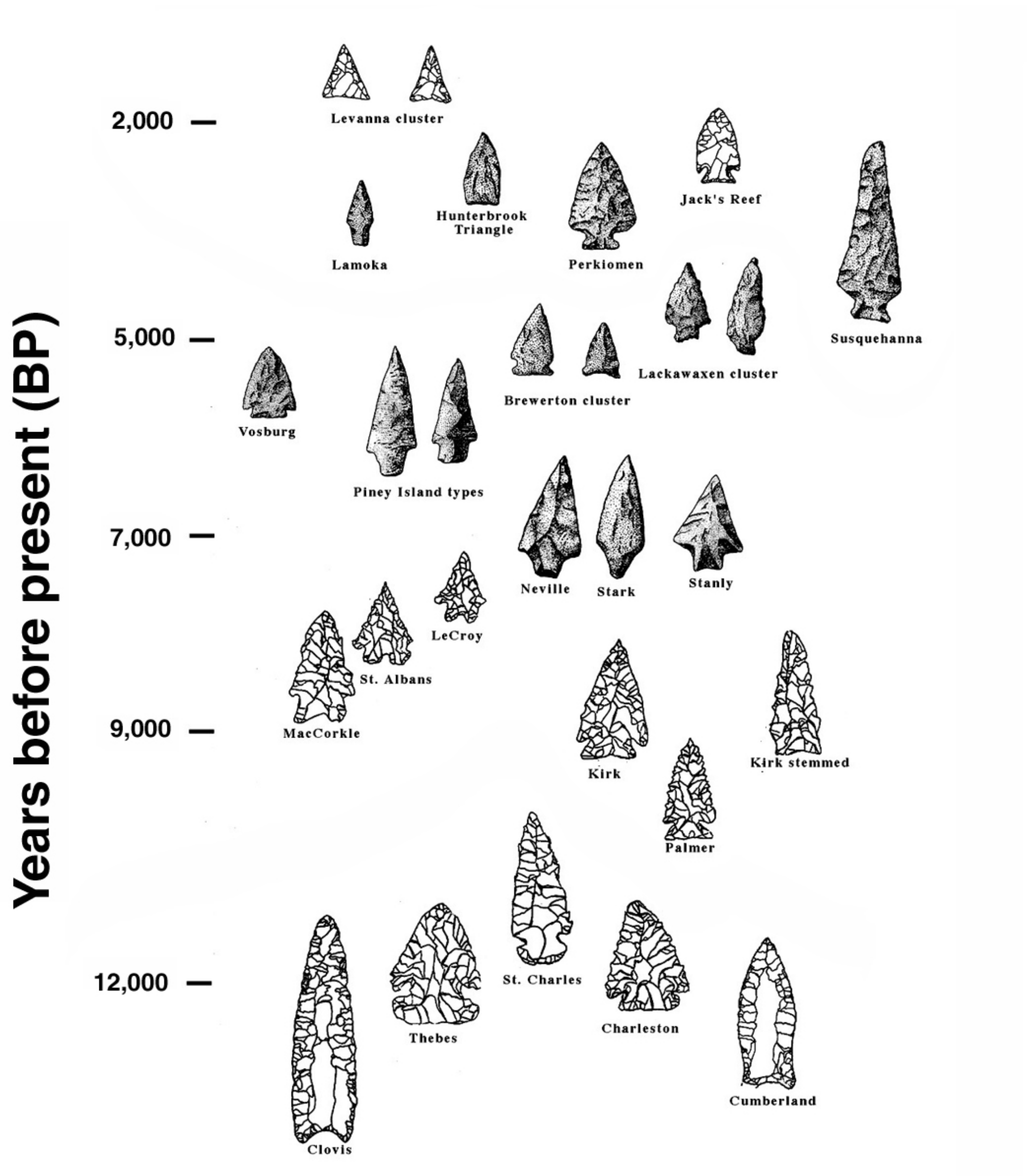


Figure 40: Styles of chipped stone projectile points or knives (PPKs) for northeastern Pennsylvania (after Carr, 1998a, 1998b; Custer, 1996)

Harding Flats (see **Table 8**). The general locations of these sites are shown on **Figure 41** along with other key archaeological sites used to develop the stratigraphic framework of this study.

The Woodland Period of Northeastern prehistory begins locally at ~2.8 ka (800 BC) and is defined by the first appearance of ceramics and, in many areas, horticulture (Custer, 1996, p. 217). Between 800 BC and AD 800 aboriginal ceramics show a gradual progression from thick-walled, crude, poorly made to thin-walled, well made, and sometimes elaborately decorated vessels (see **Figure 42a-d**). Several native species are known to have been domesticated prior to 2 ka in areas east of the Mississippi River (Smith, 1992; Wymer, 1992, 1993; Yarnell, 1993). The only examples so far reported from Pennsylvania are the squash, *Cucurbita pepo* (Hart and Asch Sidell, 1996, 1997), and little barley, *Hordeum* sp. (King, 1999). Several excavations in the study area have encountered Early or Middle Woodland components, but these have provided little information on house type or village plan.

Carbonized kernels of *Zea mays* are first found on villages of the Clemson Island and Owasco cultures, which date ca. AD 800-1300 (Hart, 1999a; Lucy, 1991b; Ritchie, 1969, p. 272-300; Stewart, 1990, 1994). Isotopic analyses of skeletal samples from the study area (Herbstritt et al., 1997) and the surrounding region (Vogel and Van der Merwe, 1977) further confirm the consumption of maize and other C4 pathway plants by Late Woodland people. The recent proposal by Snow (1995) of a northward migration of these early agriculturalists up the Susquehanna into New York receives some tentative support from both the radiocarbon chronology and the stratigraphic studies in the present

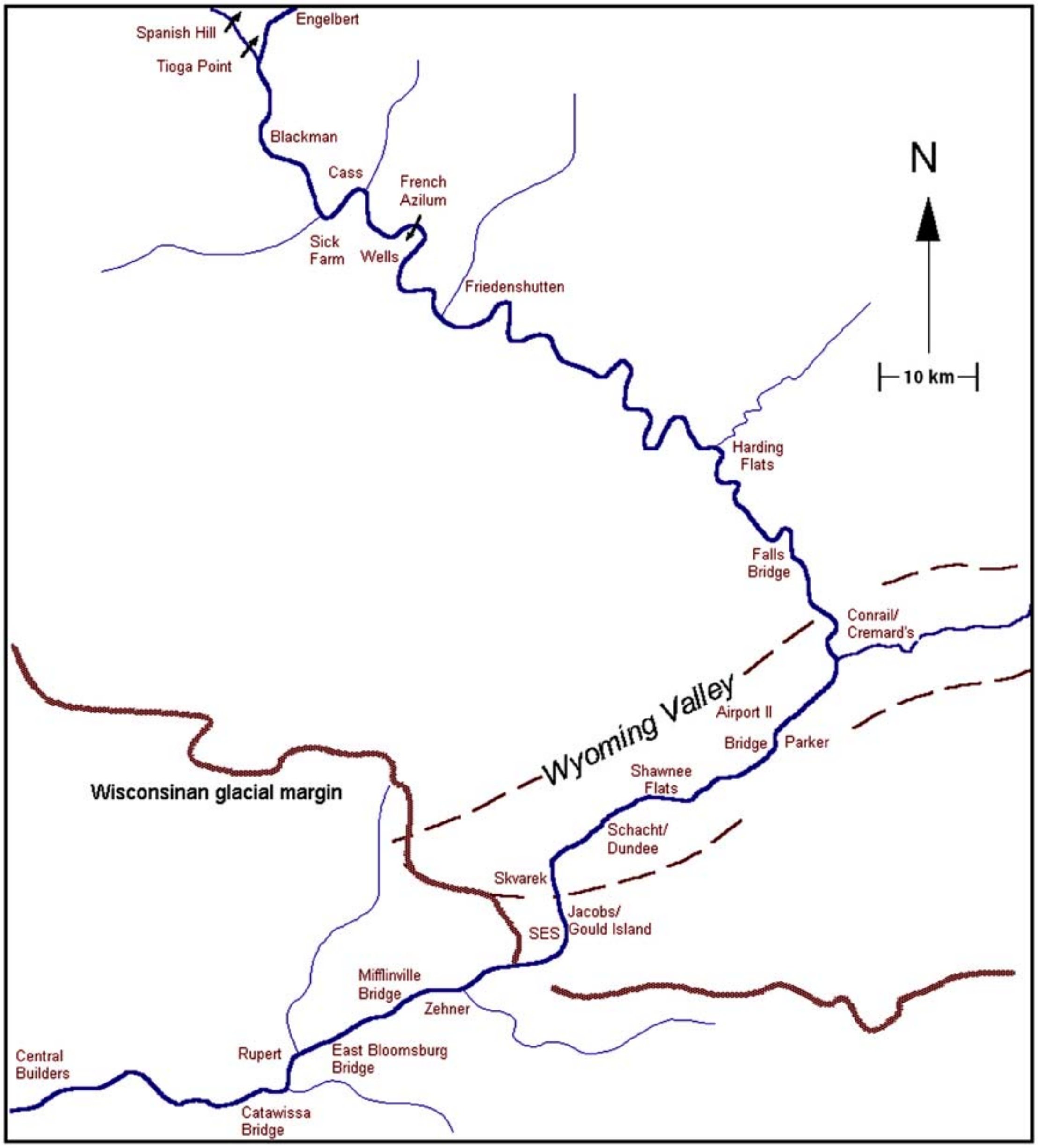


Figure 41: Map of the study area showing locations of key archaeological sites

Table 8: Archaeological Sites in the North Branch of the Susquehanna River valley

			ARCHAIC				WOODLAND			PROTO-OR
Site Name	PASS #	PALEO	E	M	L	T	E	M	L	HISTORIC
Fort Augusta	36NB71									X
Central Builders	36NB117		X	X						
Cherokee Golf Course	36NB72	X								
Catawissa Bridge (Oskohary)	36CO9							X	X	?
Rupert	36CO3			?	X	X	?			
East Bloomsburg Bridge	36CO10			?	X	?	?	X		
Zehner	36CO2							X	X	
Mifflinville Bridge	36CO17			X	X					
SES-3	36LU15				X					
SES-6	36LU16							X	X	
SES-8	36LU49				X	X				
SES-10	36LU50				X					
SES-11	36LU51								X	
SES-13	36LU17				X	X				
Knouse (Wapwallopen)	36LU43									X
Gould Island	36LU105				X	X	X	X	X	
Jacobs	36LU90				X	X	X			
Skvarek	36LU132			X	X	X	X	X	X	
Shawnee Flats	36LU39								X	
Wadham Creek	36LU128								X	
Schacht	36LU1								X	
Dundee	36LU11								X	

			ARCHAIC				WOODLAND			PROTO-OR
Site Name	PASS #	PALEO	E	M	L	T	E	M	L	HISTORIC
Bead Street	36LU54								X	X
Fort Wyoming (Wyomink)	NA									?
Wermuth	36LU2								X	
Bridge	36LU60			?	X				X	
Sarf	36LU3									X
Rusbar	36LU4								X	
Parker	36LU14							?	X	
Forty Fort Cemetery	36LU13							?	X	
Forty Fort Ossuary	36LU77								X	
Airport I	36LU44								X	
Airport II	36LU45								X	
Unnamed?	36LU47								X	
8th Street Bridge	Unknown			?	X				?	
Anastasi	36LU80							X		
Scovell Island	36LU12				X	X	?	?	X	
Cremards	36LU58		X	X	X	X	X	X	X	
Conrail	36LU169	X	X	X	X	X	X	X		
Falls Bridge	36WO56			X	X	?	?	X		
Harding Flats	36WO55				X	X	X	X	X	
Friedenshutten	36BR80							?	X	X
Wells	36BR59								X	
Wysox Flats	36BR56								X	
Unnamed	36BR75								X	
Pipher	36BR55								X	

			ARCHAIC				WOODLAND			PROTO-OR
Site Name	PASS #	PALEO	E	M	L	T	E	M	L	HISTORIC
Cass	36BR57								X	X
Strickland	36BR76								X	X
Wilson	36BR58								X	X
Sick Farm	36BR50								X	X
North Towanda (Newtychanning)	36BR41								X	X
North Towanda Flats	36BR44								X	X
Blackman	36BR83								X	X
Hornbrook1	36BR85								X	
Unnamed	36BR86								X	
Vought1	36BR84		X	?	X	?				
Unnamed	36BR99		X	?	X	?				
Murray Farm	36BR5								X	X
Tioga Point Farm	36BR3							X	X	X
Murray Garden	36BR2								X	X
Abbe-Brennan	36BR42									
Spanish Hill	36BR27				?					
Foot of Spanish Hill	36BR28								X	

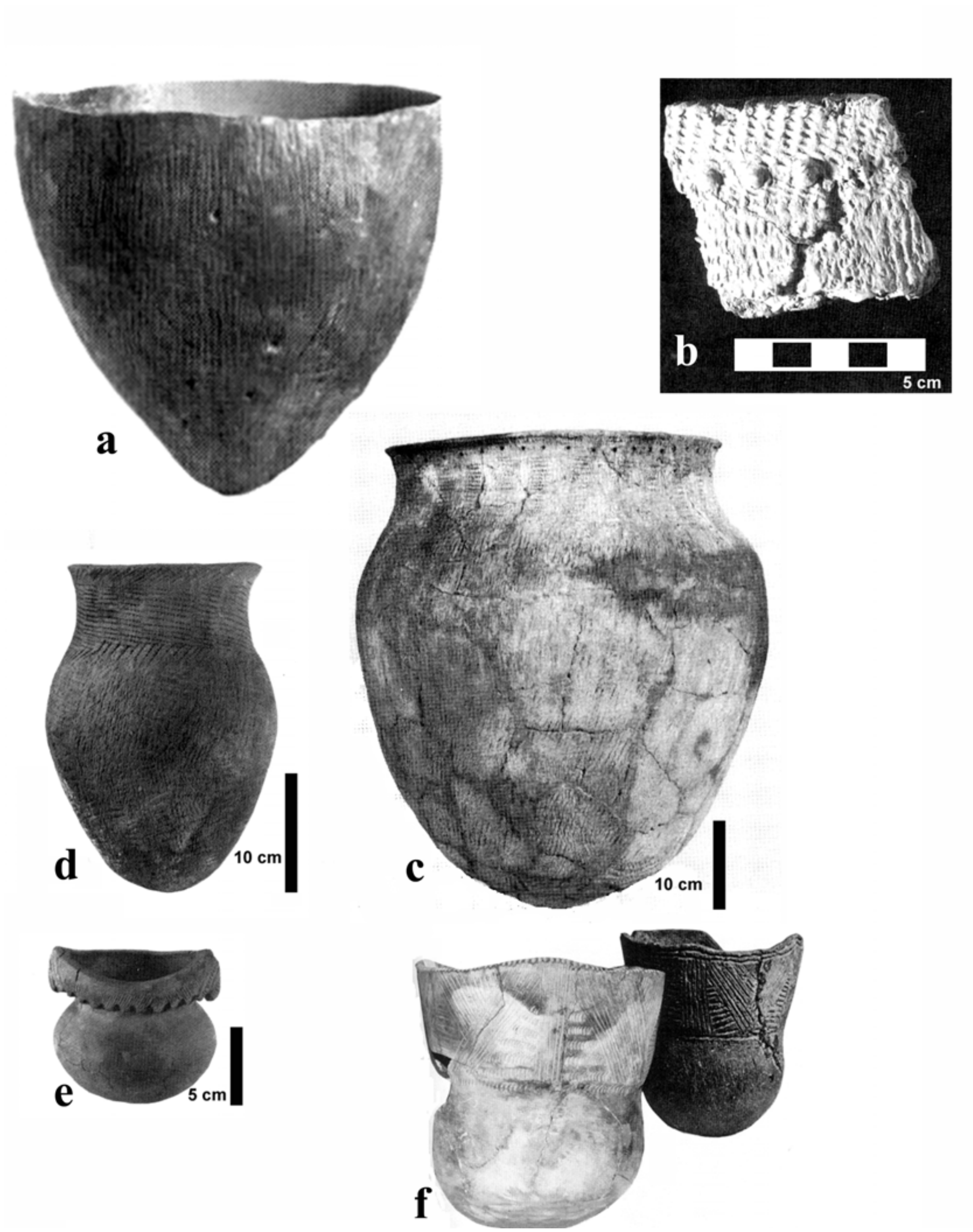


Figure 42: Types of prehistoric pottery manufactured in northeastern Pennsylvania: a) Early Woodland conical vessel (Kent, 1980, p. 28); b) Clemson Island noded rim decoration (Stewart, 1994, p. 119); c) Clemson Island vessel with punctate rim decoration (Orlandini, 1996, p. 149); d) Owasco (Kent, 1980, p. 34); e) Wyoming Valley collared (Kent, 1980, p. 34); f) Susquehannock Schultz incised (Kent, 1993, p.113).

dissertation. Equally rapid cultural change could probably result, however, from the diffusion of horticultural practices through seasonally mobile Middle Woodland societies without a long-distance migration (Stewart, 1998).

Snow's use of ceramic vessel attributes to identify the Clemson Island and Owasco horticulturalists as "northern Iroquois" is particularly problematic, as noted by Funk (1997, p. 26). Construction of "longhouse" dwellings would make the case more convincing, but the postmold patterns excavated to date suggest that Clemson Island houses were oval structures approximately 5 m in diameter (Adovasio et al., 1988; Garrahan, 1990, p. 5-6; Stewart, 1994, p. 164-170). One possible exception is an oblong postmold pattern approximately 11.2 x 5.5 meters excavated on the Clemson Island/Owasco village at the Forty Fort Airport (Garrahan, 1990, p. 6). Perhaps the earliest longhouse is the one at the Roundtop site, just upstream of the present study area in south central New York. The longhouse at Roundtop dates to approximately AD 1150-1200 (Ritchie and Funk, 1973, p. 183-186).

The Clemson Island and Owasco are succeeded by the Wyoming Valley (AD 1400-1550) and Proto-Susquehannock (ca. AD 1500) cultures in the North Branch of the Susquehanna River valley (Lucy and McCracken, 1985; Smith, 1973; Sweeney, 1966; Witthoft, 1969). The Wyoming Valley culture was a localized manifestation with the following traits identified by Smith (1973, p. 50-51):

(1) grit-tempered, incised pottery (**Figure 42e**)
(2) year-round settlement in large towns surrounded by elaborate earthern and timber stockades and entrenchments traversed by dirt causeways.

(3) bark-covered longhouses, rounded and domed sweathouses, semi-subterranean "keyhole" structures.

(4) bell, basin, straight-walled, and slit-trench pits

Shell-tempered vessels with incipient collars and incised decorations occur as a minor ware in the Wyoming Valley culture assemblages as well as in the McFate-Quiggle assemblages from central and western Pennsylvania (Kent, 1993, p. 118-121). The Proto-Susquehannock ceramics from Bradford County, on the other hand, have vessel forms and design motifs which are more typical of later Susquehannock wares such as Schultz incised (**Figure 42f**). As noted by Kent (1993, p. 15), most Proto-Susquehannock archaeological contexts lack stratigraphic integrity or at least require better stratigraphic documentation. The villages do appear to have been smaller than those of the Wyoming Valley culture, with less elaborate architecture.

The historic Susquehannock cultural groups have been conclusively identified as makers of shell-tempered Schultz incised pottery (Kent, 1993, p. 15-18). Scraps of European brass and brass beads were found in association with this pottery at six sites in Bradford County (Witthoft, 1969, p. 29). Both Witthoft and Kent concur that the Susquehannock began to abandon their small villages on the North Branch around AD 1570. They settled in a single large community at the Schultz site (36LA7) on the lower Susquehanna shortly before AD 1575 (Kent, 1993, p. 19). Witthoft (1969, p. 35) attributed the migration to pressure from the developing League of the Iroquois. Hunter (1969, p. 13), on the other hand, suggested that they were drawn south by the opportunities of trade with the Dutch. Custer (1996, p. 307-308) notes a correlation with the onset of the Little Ice Age, AD 1600-1850, and possible reduction in corn yields.

After the migration of the Susquehannock peoples south, the Iroquois claimed the study area but they established few of their own permanent villages. Instead, they actively encouraged settlement by tribes such as the Delaware, Nanticoke, Shawnee, Conoy, Tutelo, Mahican, and Mohegan who had been displaced by the European colonies to the south and east. This is referred to as the "Refugee Phase" by Custer (1996, p. 315-318). The sites typically consist of ephemeral scatters of 18th century colonial artifacts, particularly items of adornment or personal items such as pipes, strike-a-lites, and pipe tongs (e.g. Kent, 1993, p. 389). Native American "towns" identified by Kent et al. (1981) with archaeological sites on the North Branch of the Susquehanna include Shamokin (Delaware, Iroquois, Tutelo), Oskohary (Delaware, Conoy, and Tutelo), Wapwallopen (Delaware), Shickshinny, Mocanaqua, Candowsa (Delaware), Adjouquay (Iroquois), Tunkhannock (Delaware), Wyalutimink, Wysox (Delaware), Towanda (Delaware), Newtychanning (Iroquois), Tioga (Iroquois, Mahican, Shawnee, and Delaware), and Tutelo Town (Tutelo).

The village at the juncture of the North and West Branches of the Susquehanna, Shamokin, became a veritable "capital" for Native Americans in Pennsylvania prior to its abandonment in 1756 (Kent, 1993, p. 100). It was the headquarters of Shickellamy, an Iroquois of the Cayuga tribe who acted as a regional "overlord." After his visit in 1745, the missionary David Brainerd described upwards of fifty houses and near three hundred persons occupying both the left (Sunbury) and right (Northumberland) banks of the river as well as Packers Island between them. Beads, coins, iron tools, worked brass, pipes, and other objects which may relate to Shamokin were recovered from mixed contexts during excavations in Sunbury (Nichols, 1980). Brainerd also described a more typical village of twelve houses upstream at the mouth of Wapwallopen Creek which he visited on October 5, 1744 (Kent, 1993, p. 102).

Euroamerican colonization accelerated rapidly following the purchase of the Wyoming Valley in 1754 from a small number of Iroquois chiefs by John Henry Lydius, representing the Susquehanna Company of Connecticut (Lottick, 1992, p. 37; Zbiek, 1994). Despite threats from Teedyuscung, chief of the Delawares, as well as the Pennsylvania authorities and the Iroquois confederacy, Connecticut Yankees began constructing a settlement on the left bank of the river near Mill Creek in 1762. They built three small blockhouses, cleared land, and planted crops before returning to Connecticut. In the spring of 1763, chief Teedyuscung was killed when his cabin caught fire, and most of the Native Americans in the Wyoming Valley moved on (Lottick, 1992, p. 43; Zbiek, 1994). The settlers came back to an almost unoccupied valley, but were massacred by a Delaware war party soon after their return.

Late 18th century fortification of the North Branch valley by conflicting Euroamerican interests was commonly justified as a response to the Native Americans, who became key participants and casualties in the ensuing political conflicts. The one brief exception to the military approach to the Native American "problem" was the Moravian mission, Friedenshütten, founded in 1763 at the town of Wyalutimink, or Wyalusing. Some two hundred Native Americans moved west with pastors Ettwein and

Roth when they abandoned the mission in 1772. Queen Esther's Town opposite Tioga Point was the last major town, with upwards of seventy log and plank houses according to Lottick (1992, p. 63). This town was abandoned in 1778 in advance of Sullivan's March, which was largely a response to Esther Montour's own victory in the "Wyoming Massacre" conflict.

RADIOCARBON CHRONOLOGY

A total of 139 radiocarbon dates have been reported to date for samples from the alluvial deposits of the North Branch of the Susquehanna River (see **Table 9**). Only fifteen of the samples dated are from geologic contexts beneath or spatially separated from the cultural occupation levels on archaeological sites. Of the remaining 124 dates, there are 89 on samples of charred wood or nutshell from prehistoric pit features. Three dates are associated with the housefloor at the Parker Site (Smith, 1973, p. 42), two are associated with bone clusters in the Airport II ossuary (Herbstritt et al., 1997), one with midden exposed by topsoil mining in the Shawnee Flats (36LU28), and one was obtained from smudge residue on a ceramic vessel off of the Harding Flats site (36WO55). Most of the remaining 28 cultural dates represent charcoal concentrations provenienced only by general excavation level. Ten of the dates provenienced by excavation level are from the Catawissa Bridge site (36CO9). The Catawissa Bridge dates may have feature associations that have yet to be reported (East et al., 1988).

Table 9: Inventory of Radiocarbon Dates for Samples from the North Branch of Susquehanna River Valley

Km	Site/Location	Provenience	14-C yr	Lab No.	Material	Affiliation	Reference
BRADFORD COUNTY							
454	Chemung T-2	3.5 mbs	13,320±200	Y-2619	mastodon bone	Periglacial	Coates et al., 1971
437	Blackman (36BR83)	Fea. 40	410±60	Beta-20200	charred wood	Proto-Susquehanno	McCracken and Lucy, 1989
410	Wells (36BR59)	Fea. 6, 135 cmbs	970±100	I-2488	charred wood	Owasco	Lucy and McCann, 1983
410	Wells (36BR59)	Fea. 6, 127 cmbs	880±100	I-2489	charred wood	Owasco	Lucy and McCann, 1983
WYOMING COUNTY							
349	Harding Flats (36WO55)	Trench A, gravels	5880±50	Beta-114049	sediment	Geological	East, 1998
349	Harding Flats (36WO55)	Trench H, Fea. 179	3970±60	Beta-115640	charred wood	Late Archaic	East, 1998
349	Harding Flats (36WO55)	Trench I, Fea. 183	3660±60	Beta-116274	charred wood	Late Archaic	East, 1998
349	Harding Flats (36WO55)	Block 6, gravels	3560±50	Beta-115641	sediment	Geological	East, 1998
349	Harding Flats (36WO55)	Fea. 288	3410±110	Beta-120811	charred wood	Terminal Archaic	East, 1998
349	Harding Flats (36WO55)	Fea. 182	3340±60	Beta-116273	charred wood	Terminal Archaic	East, 1998
349	Harding Flats (36WO55)	Block 3, Stratum 16	2490±50	Beta-105521	sediment	Geological	East, 1998
349	Harding Flats (36WO55)	Block 6, Fea. 186	2470±50	Beta-116275	charred wood	Early Woodland	East, 1998
349	Harding Flats (36WO55)	Block 3, Fea. 1	1720±80	Beta-83813	charred wood	Middle Woodland	East, 1998
349	Harding Flats (36WO55)	Block 6, Fea. 45	1500±60	Beta-121892	vessel smudge	Middle Woodland	East, 1998
349	Harding Flats (36WO55)	Block 6, Fea. 323	1450±70	Beta-121905	charred wood	Middle Woodland	East, 1998
349	Harding Flats (36WO55)	Block 6, Fea. 108	1420±70	Beta-114050	charred wood	Middle Woodland	East, 1998
349	Harding Flats (36WO55)	Block 6, Fea. 112	1360±60	Beta-114051	charred wood	Middle Woodland	East, 1998
349	Harding Flats (36WO55)	Block 6, Vessel 63	1200±40	Beta-121906	charred wood	Middle Woodland?	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 32	1150±60	Beta-116124	charred wood	Undefined LW	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 27	1150±70	Beta-121904	charred wood	Undefined LW	East, 1998
349	Harding Flat (36WO55)	Block 1, Fea. 147B	1120±60	Beta-114052	charred wood	Undefined LW	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 169	1010±60	Beta-115639	charred wood	Undefined LW	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 31	1000±60	Beta-105520	charred wood	Undefined LW	East, 1998

Km	Site/Location	Provenience	14-C yr	Lab No.	Material	Affiliation	Reference
WYOMING COUNTY (CONTINUED)							
349	Harding Flats (36WO55)	Block 1, Fea. 128	990±70	Beta-121895	charred wood	Undefined LW	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 4-1	980±50	Beta-121888	charred wood	Undefined LW	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 28	970±60	Beta-121889	charred wood	Undefined LW	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 4-2	950±80	Beta-83814	charred wood	Owasco	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 63	940±60	Beta-121894	charred wood	Owasco	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 26	890±50	Beta-105519	charred wood	Owasco	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 30	820±50	Beta-121890	charred wood	Owasco	East, 1998
349	Harding Flats (36WO55)	Block 6, Fea. 187	790±60	Beta-121897	charred wood	Owasco	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 197	780±60	Beta-121898	charred wood	Owasco	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 9	710±70	Beta-105518	charred wood	Owasco	East, 1998
349	Harding Flats (36WO55)	Fea. 47	690±40	Beta-121893	charred wood	Owasco	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 35	610±60	Beta-121891	charred wood	Owasco	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 158	410±60	Beta-116125	charred wood	Undefined LW	East, 1998
349	Harding Flats (36WO55)	Block 1, Fea. 157	390±50	Beta-121896	charred wood	Undefined LW	East, 1998
349	Harding Flats (36WO55)	Block 6, Fea. 185A	230±60	Beta-117375	charred wood	Historic	East, 1998
331	Falls Bridge (36WO56)	Fea. 6, 106 cmbs	5570±60	UGa-7118	charred wood	Middle Archaic	Kingsley et al., 1995
331	Falls Bridge (36WO56)	100-110 cmbs	4705±50	UGa-7119	charred wood	Late Archaic	Kingsley et al., 1995
331	Falls Bridge (36WO56)	Fea. 3, 100 cmbs	4090±60	Beta-79357	charred wood	Late Archaic	Kingsley et al., 1995
331	Falls Bridge (36WO56)	Fea. 4, 100 cmbs	4630±50	UGa-7117	charred wood	Late Archaic	Kingsley et al., 1995
331	Falls Bridge (36WO56)	Fea. 2, 62 cmbs	1730±60	Beta-79356	charred wood	Middle Woodland?	Kingsley et al., 1995
LACKAWANNA COUNTY - - no reported dates							
LUZERNE COUNTY							
313	Conrail (36LU169)	Fea. 117	4850±90	Beta-93248	charred wood	Late Archaic	SPA, 1997
313	Conrail (36LU169)	Unreported	4180±90	Beta-82891	charred wood	Late Archaic	Griffiths, 1997

Km	Site/Location	Provenience	14-C yr	Lab No.	Material	Affiliation	Reference
LUZERNE COUNTY (CONTINUED)							
313	Conrail (36LU169)	Unreported	4060±70	Beta-131810	charred wood	Late Archaic	Griffiths, 1997
313	Conrail (36LU169)	Unreported	1590±70	Unreported	charred wood	Middle Woodland	Griffiths, 1997
313	Cremard (36LU58)	Ab13	9000±270	Unreported	charred wood	Geological	Herbstritt, 1990
313	Cremard (36LU58)	Ab16/Ab17	8690±240	Unreported	charred wood	Geological	Herbstritt, 1990
313	Cremard (36LU58)	Fea. 1, ca. 300 cm	4710±110	Unreported	charred wood	Late Archaic	Herbstritt, 1990
313	Cremard (36LU58)	Unreported	4810±110	Unreported	charred wood	Late Archaic	Herbstritt, 1990
313	Cremard (36LU58)	Unreported	4820±110	Unreported	charred wood	Late Archaic	Herbstritt, 1990
313	Cremard (36LU58)	2Ab, ca. 250 cm	2190±50	Unreported	charred wood	Middle Woodland	Herbstritt, 1990
312	Anastasi (36LU80)	Pit feature	1705±70	UGa-5386	charred wood	Middle Woodland	Herbstritt, 1988
308	Fort Wintermoot	B1, 5C2, 500 cm	2260±70	Beta-82387	charred wood	Geological	Schuldenrein and Thieme, 1997
307	Wyoming T-1 Slackwater	B2, 300 cm	9520±90	UGa-7816	small twigs	Geological	This manuscript
307	Wyoming T-1 Cutbank	6O, 500-520 cm	5310±70	Beta-82384	fine charcoal	Geological	Schuldenrein and Thieme, 1997
307	Wyoming T-1 Cutbank	2Ab, 110-115 cm	240±110	Beta-82383	fine charcoal	Geological	Schuldenrein and Thieme, 1997
304	Airport I (36LU44)	S1, 4Ab, 60-70 cm	1030±70	Beta-82386	fine charcoal	CI/Owasco	Schuldenrein and Thieme, 1997
304	Ossuary (36LU77)	Clusters XI-XII, 26.7 cm	1010±70	Beta-27648	charred wood	CI/Owasco	Herbstritt et al., 1997
304	Ossuary (36LU77)	Cluster VII, 15.2 cm	990±90	Beta-27647	charred wood	CI/Owasco	Herbstritt et al., 1997
304	Airport II (36LU77)	Fea. 41	970±40	PITT-392	charred wood	CI/Owasco	Garrahan, 1990
304	Airport II (36LU77)	Fea. 30	650±40	PITT-393	charred wood	Owasco	Garrahan, 1990
302	Parker (36LU14)	House basin	480±90	I-4880	charred log	Wyoming Valley	Smith, 1973
302	Parker (36LU14)	House basin	350±90	I-4881	charred log	Wyoming Valley	Smith, 1973
302	Parker (36LU14)	House roofing	250±90	I-4879	grass	Wyoming Valley	Smith, 1973
300	Bridge (36LU60)	Fea. 1, 50 cm	1170±70	Beta-82385	fine charcoal	CI/Owasco	Schuldenrein and Thieme, 1997
291	Shawnee Flats	Midden	1170±50	Beta-105632	charred wood	CI/Owasco	SPA, 1998
271	Skvarek (36LU132)	Fea. 20, 754 cm AE	4160±70	Beta-67304	charred wood	Late Archaic	AHC, 1994; Miller, 1998
271	Skvarek (36LU132)	Fea. 1, 820 cm AE	3190±80	Beta-67302	charred wood	Transitional	AHC, 1994; Miller, 1998
271	Skvarek (36LU132)	Fea. 1, 810 cm AE	2950±70	Beta-62884	charred wood	Early Woodland	AHC, 1994; Miller, 1998
271	Skvarek (36LU132)	Fea. 1, 810 cm AE	2810±60	Beta-67303	charred wood	Early Woodland	AHC, 1994; Miller, 1998

Km	Site/Location	Provenience	14-C yr	Lab No.	Material	Affiliation	Reference
LUZERNE COUNTY (CONTINUED)							
271	Skvarek (36LU132)	Fea. 1, 800 cm above	2060±80	Beta-62883	charred wood	Early Woodland	AHC, 1994; Miller, 1998
271	Skvarek (36LU132)	Fea. 9 = disturbance?	1440±70	Beta-62882	charred wood	Middle Woodland	AHC, 1994; Miller, 1998
266	Jacobs (36LU90)	Ab6, 8 AE	8150±140	Beta-43796	sediment	Geological	Weed and Wenstrom, 1992
266	Jacobs (36LU90)	Fea. 128, 8.97-8.82 AE	3860±160	Beta-44753	charred wood	Terminal Archaic	Weed and Wenstrom, 1992
266	Jacobs (36LU90)	Fea. 116, 8.715 AE	3850±80	Beta-24611	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Jacobs (36LU90)	Fea. 112, 8.83 AE	3780±60	DIC-3328	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Jacobs (36LU90)	Fea. 133, 8.81-8.54 AE	3750±170	Beta-44752	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Jacobs (36LU90)	Fea. 135, 8.685-8.47 AE	3680±70	Beta-44751	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Jacobs (36LU90)	Fea. 133, 8.81-8.54 AE	3650±70	Beta-44750	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Jacobs (36LU90)	Fea. 135, 8.685-8.47 AE	3610±100	Beta-27297	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Jacobs (36LU90)	Fea. 136, 8.655 AE	3520±70	Beta-26667	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Jacobs (36LU90)	Unreported	3520±70	Beta-44211	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Jacobs (36LU90)	Fea. 128, 8.97-8.82 AE	3160±100	Beta-44212	charred wood	Terminal Archaic	Weed and Wenstrom, 1992
266	Jacobs (36LU90)	Ab1, Fea. 131	2280±90	Beta-43793	charred wood	Early Woodland	Weed and Wenstrom, 1992
266	Jacobs (36LU90)	Ab1, Fea. 131	2180±70	Beta-27296	charred wood	Early Woodland	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Unreported	>37,000	Beta-23884	Coal?	Geological	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Ab3, no depth reported	5990±110	Beta-24447	sediment	Geological	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 22A, 17.19 AE	4070±90	Beta-23565	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 59, 18.12 AE	4070±90	Beta-27472	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 48, 18.58 AE	3800±70	Beta-27469	charred wood	Terminal Archaic	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 48, 18.58 AE	3750±110	Beta-23883	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 58, 18.08 AE	3740±60	Beta-28752	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 23, 18.18 AE	3720±70	Beta-28214	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 3, 18.25 AE	3620±100	Beta-42663	charred wood	Late Archaic	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 3, 18.25 AE	3250±90	Beta-23881	charred wood	Terminal Archaic	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 49, 18.56 AE	3190±70	Beta-43673	charred wood	Terminal Archaic	Weed and Wenstrom, 1992

Km	Site/Location	Provenience	14-C yr	Lab No.	Material	Affiliation	Reference
LUZERNE COUNTY (CONTINUED)							
266	Gould Island (36LU105)	Unreported	3150±60	Beta-23310	charred wood	Terminal Archaic	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 49, 18.56 AE	3040±100	Beta-27470	charred wood	Terminal Archaic	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 16, 18.63 AE	2350±70	Beta-23564	charred wood	Terminal Archaic	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 50, 17.19 AE	2330±70	Beta-28751	charred wood	Early Woodland	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 22B, 17.17 AE	2150±60	Beta-27468	charred wood	Early Woodland	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 57, 16.25 AE	1330±110	Beta-27471	charred wood	Middle Woodland	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 30, 16.48 AE	1170±160	Beta-23314	charred wood	Clemson Island	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 32, 16.20 AE	1100±50	Beta-23882	charred wood	Clemson Island	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Unreported	980±70	Beta-23313	charred wood	CI/Owasco	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 55, 16.50 AE	900±50	Beta-28216	charred wood	CI/Owasco	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 41, 17.55 AE	870±60	Beta-24199	charred wood	CI/Owasco	Weed and Wenstrom, 1992
266	Gould Island (36LU105)	Fea. 54, 16.30 AE	690±200	Beta-42665	charred wood	CI/Owasco	Weed and Wenstrom, 1992
264	SES-8 (36LU49)	STT-9, 195 cmbs	3970±105	Beta-1800	charred wood	Late Archaic	Hayes et al., 1981
264	SES-8 (36LU49)	STT-9, 190 cmbs	3485±95	Beta-1799	charred wood	Late Archaic	Hayes et al., 1981
264	SES-6 (36LU16)	B1, 75 cmbs	2000±130	Beta-1801	charred wood	Middle Woodland	Hayes et al., 1981
261	Little Wapwallopen	CB1, ~70m east of river	35,570±4,500	UGa-7426	Coal?	Geological	This manuscript
COLUMBIA COUNTY							
246	Mifflinville Bridge	Basal Gravels	9060±100	Beta-37856	charred wood	Basal gravel	Wall, 1998
246	Mifflinville Bridge	Level 15	7900±60	Beta-114822	charred wood	Middle Archaic	Wall, 1998
246	Mifflinville Bridge	Level 15	7890±70	Beta-84329	charred wood	Middle Archaic	Wall, 1998
246	Mifflinville Bridge	Level 14	7890±50	Beta-114823	charred wood	Middle Archaic	Wall, 1998
246	Mifflinville Bridge	Level 12, Fea. 29	7850±70	Beta-114825	charred wood	Middle Archaic	Wall, 1998
246	Mifflinville Bridge	Fea. 27	7230±60	Beta-84327	charred wood	Middle Archaic	Wall, 1998
246	Mifflinville Bridge	Fea. 22	4140±120	Beta-114821	charred wood	Late Archaic	Wall, 1998
246	Mifflinville Bridge	Fea. 12	3900±80	Beta-84321	charred wood	Late Archaic	Wall, 1998

Km	Site/Location	Provenience	14-C yr	Lab No.	Material	Affiliation	Reference
COLUMBIA COUNTY (CONTINUED)							
246	Mifflinville Bridge	Fea. 13	3670±50	Beta-84324	charred wood	Late Archaic	Wall, 1998
246	Mifflinville Bridge	Fea. 21	3630±120	Beta-84325	charred wood	Late Archaic	Wall, 1998
246	Mifflinville Bridge	Fea. 17	3430±140	Beta-84323	charred wood	Late Archaic	Wall, 1998
246	Mifflinville Bridge	Fea. 30b	2800±60	Beta-114824	charred wood	Late Archaic?	Wall, 1998
235	East Bloomsburg Bridge	N 55/W 60	1480±70	Beta-25270	charred wood	Middle Woodland	Kardas and Larrabee, 1988a
228	Catawissa Bridge	Not reported	1455±45	PITT-8	charred wood	Middle Woodland	East et al., 1984
228	Catawissa Bridge	Not reported	1365±50	PITT-76	charred wood	Middle Woodland	East et al., 1984
228	Catawissa Bridge	Not reported	1280±35	PITT-11	charred wood	Middle Woodland	East et al., 1984
228	Catawissa Bridge	Not reported	1040±45	PITT-12	charred wood	Clemson Island	East et al., 1984
228	Catawissa Bridge	Not reported	1030±70	DIC-3151	charred wood	Clemson Island	East et al., 1984
228	Catawissa Bridge	Not reported	995±55	PITT-74	charred wood	Clemson Island	East et al., 1984
228	Catawissa Bridge	Not reported	795±75	PITT-77	charred wood	Clemson Island	East et al., 1984
228	Catawissa Bridge	Not reported	610±85	PITT-75	charred wood	Undefined LW	East et al., 1984
228	Catawissa Bridge	Not reported	550±35	PITT-10	charred wood	Undefined LW	East et al., 1984
228	Catawissa Bridge	Not reported	480±60	PITT-9	charred wood	Undefined LW	East et al., 1984
MONTOUR COUNTY - - no reported dates							
NORTHUMBERLAND COUNTY							
202	Central Builders	Tr. 1, Fea. 8, 260 cmbs	9165 +210/-205	A-10053	charred wood	Early Archaic	Baker, 1993

Using the terminology of Ward and Wilson (1978), there are relatively few examples in **Table 9** of "Case I," where it was known prior to the laboratory measurement that the same object or event was being dated. It was therefore necessary to test the contemporaneity of the dates in each probable "Case II" cluster, even those from a single feature or component on a stratified site. The test statistic (*T*) derived from the χ^2 distribution was used (Ward and Wilson, 1978, p. 21-24), as implemented in OxCal by Bronk Ramsey (1999). If we reject the null hypothesis that the uncalibrated dates come from a different object or represent different "events," then OxCal can be used to average them and compute a single age estimate in calibrated calendar years. As discussed by Long and Rippeteau (1974, p. 206), Batt and Pollard (1996, p. 425-429), and Bronk Ramsey (1998, p. 462), however, such averaging is not always appropriate, even for those "Case II" clusters where it can be justified statistically.

One Case II cluster which is particularly well delimited comes from the early Middle Archaic occupation at the Mifflinville Bridge site (36CO17). A pooled age estimate of 7885±30 BP (8,933-8,543 cal BP) was obtained using Oxcal for the four oldest cultural dates (see **Figure 43**). Both the geological date obtained on a large log from the basal gravels and the date for Feature 27 failed the contemporaneity test and must be considered to represent different "events" in the formation of site 36CO17. The cluster at 8.9-8.5 ka dates the occurrence of bifurcate base (MacCorkle, St. Albans, and LeCroy) and Kirk stemmed projectile points or knives (PPKs). These PPK styles are at their peak frequency in regional assemblages within the same time window (see **Figure 40**).

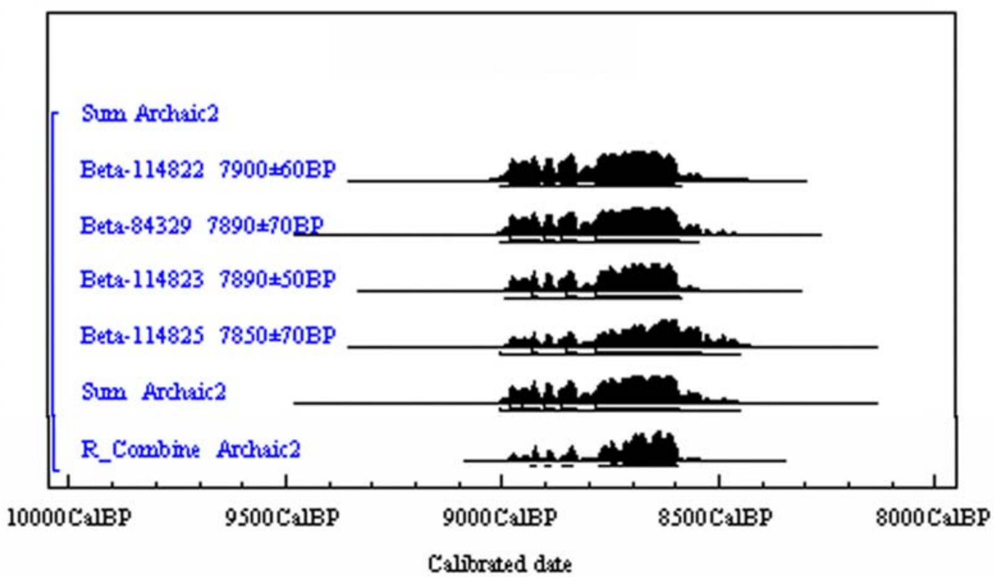


Figure 43: Oxcal averages for four radiocarbon dates from the early Middle Archaic occupation at the Mifflinville Bridge site (36CO17)

Temporally diagnostic artifacts, as well as nondiagnostic assemblages in good stratigraphic context, indicate the presence of earlier components at several other alluvial terrace sites in the study area. A cluster of Early Archaic dates can be constructed using the uncalibrated date of 9165 +210/-205 BP (A-10053) from Feature 8 at the Central Builders site and two dates from the excavations at the Cremards site (**Figure 44**). The cluster mean of 8977±136 BP (10,427-9,678 cal BP) is statistically valid in that all three dates pass the Oxcal contemporaneity test.

More than a statistical justification is required, however, to infer the contemporaneity of the widely separated hunter-gatherer camps in which PPK styles such as Palmer and Kirk corner-notched were manufactured and deposited in archaeological contexts. Issues of appropriate statistical methods for averaging and calibration have been raised previously in criticisms of C. Vance Haynes' radiocarbon chronology for the Clovis and Folsom cultures (Batt and Pollard, 1996; Taylor et al., 1996). Haynes et al. (1984) averaged 44 AMS radiocarbon dates to obtain an estimate of 11.2-10.9 ka (uncalibrated), which calibrates to 13,090-12,867 BP in calendar years (Batt and Pollard, 1996, p. 424).

Over and above the statistical issues, it would seem important to obtain independent archaeological confirmation for contemporaneous occupation by a single band-level society, both for Clovis and for the various Archaic cultures dated using radiocarbon. Hunter-gatherer band territories have previously been proposed as far back as the Early Archaic in the prehistory of eastern North America (Anderson and Schuldenrein, 1983; Daniel, 1995; Stewart and Cavallo, 1991). These are speculative

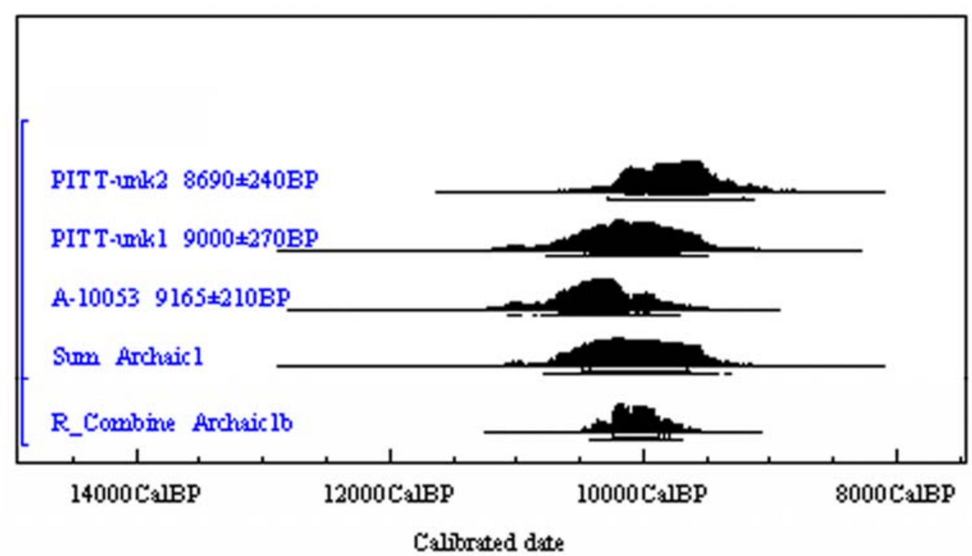


Figure 44: Oxcal averages of three radiocarbon dates for Early Archaic archaeological contexts in the North Branch of the Susquehanna River sequence

models, however, based on ethnographic analogy, physiographic boundaries, and differences in the raw materials used to manufacture stone tools. Artifacts from the Late Archaic Period and younger do provide clear evidence for cultural style boundaries (Custer, 1996; Ritchie, 1969; Witthoft, 1953). Not by coincidence, Late Archaic archaeological contexts are some of the first for which correlation was attempted through averaging of radiocarbon dates (Long and Rippeteau, 1974).

Figure 45 plots all 139 radiocarbon dates from the North Branch of the Susquehanna River alluvial deposits. The width of each bar represents one standard deviation (1-sigma) either side of the date after calibration. The abundance and density of Late Archaic and Terminal Archaic components is immediately evident by the "plateau" trend consisting of 34 Late Archaic and eleven Terminal Archaic dates. While the river valley was occupied continuously along this plateau, some of the individual sites have more than one discrete occupation separated by culturally sterile alluvium.

The Vosburg style of PPK commonly occurs in the earliest components of the Late Archaic Period. The radiocarbon date cluster shown in **Figure 46** represents Vosburg components at the Cremards and Falls Bridge sites. The cluster has one principal intercept spanning 5,480-5,410 cal BP (3,530-3,360 BC) and a second, minor intercept spanning 5,580-5,550 BP (3,630-3,600 BC). Averaging radiocarbon dates from this interval is complicated by an irregular relationship between radiocarbon years and calendar years, possibly due to abrupt climate change (Stuiver et al., 1991; Van Geel et al., 1998, 1999).

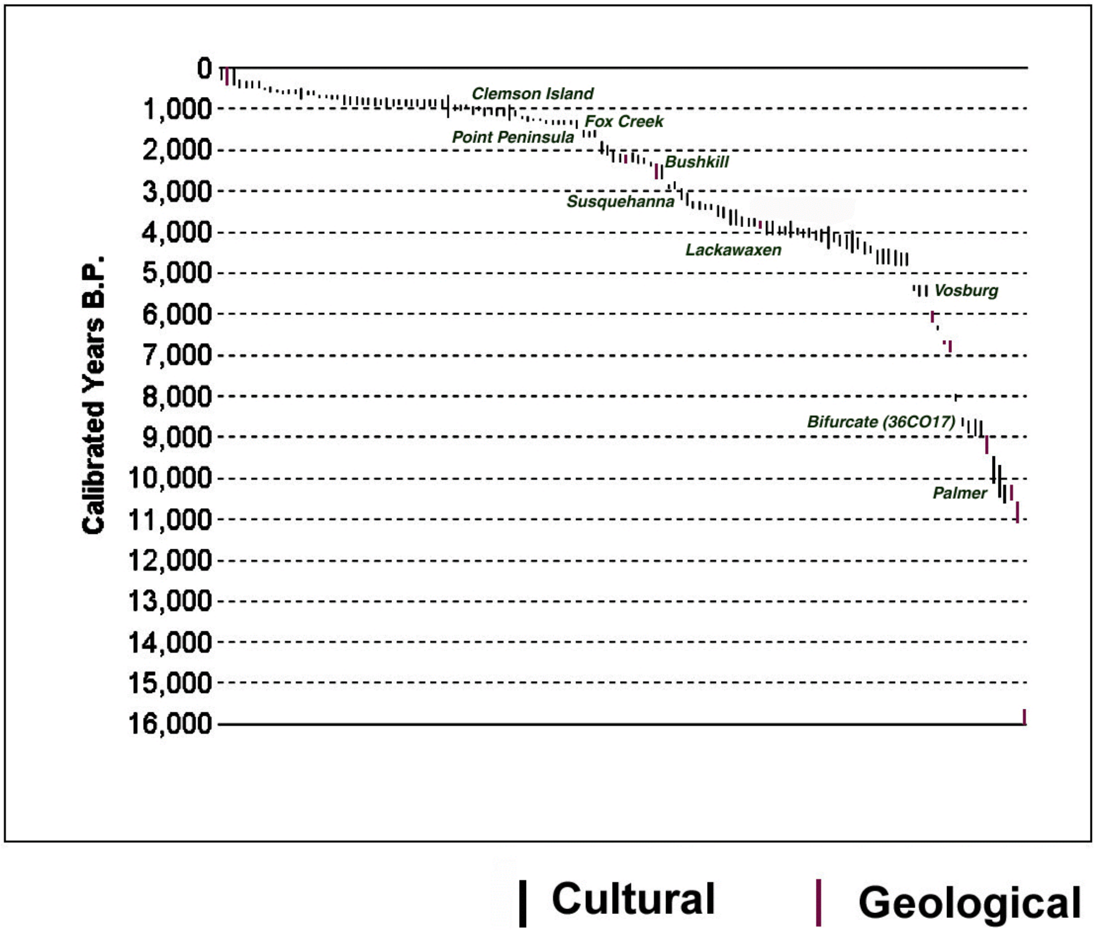


Figure 45: Radiocarbon dates from geological and archaeological contexts in the North Branch of the Susquehanna River valley (calibrated years before AD 1950 using Stuiver et al., 1998)

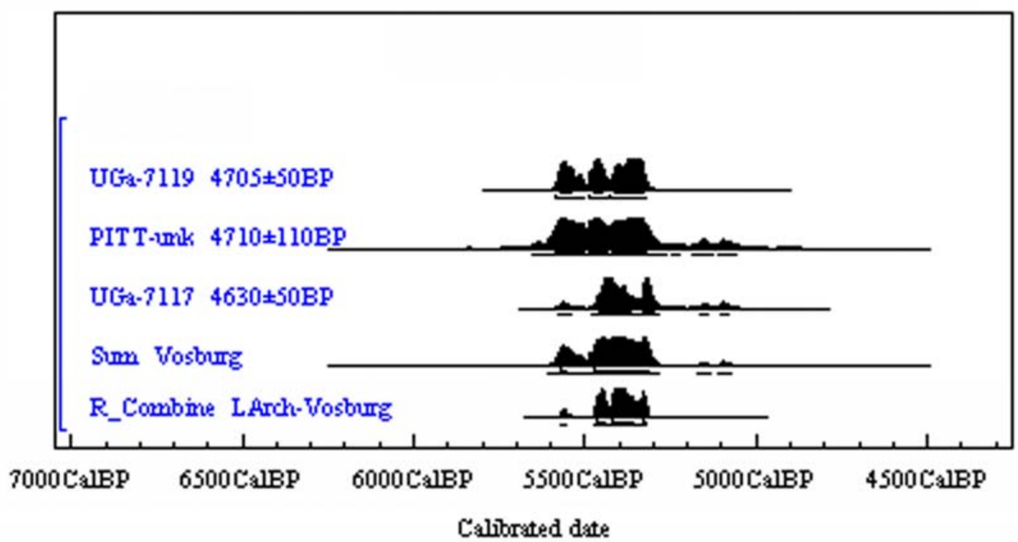


Figure 46: Oxcal averages of four radiocarbon dates for Late Archaic (Vosburg) archaeological contexts in the North Branch of the Susquehanna River valley

The primary result of calibrating radiocarbon dates from prehistoric sites in eastern North America is that the entire span of occupation is lengthened from approximately ten thousand to at least thirteen thousand years. Certain periods, such as the Early Archaic and Late Archaic, are also lengthened as shown in **Figure 47**. Because these are periods when the overall production of ^{14}C was high and irregular, however, calibration does not always improve our ability to resolve or correlate the components on individual sites.

One of the more laterally extensive and complex areas of Late Archaic occupation in the North Branch of the Susquehanna River valley is on Gould Island (36LU105). Weed and Wenstrom (1992) reported seven radiocarbon dates for samples of wood charcoal from pit features, although one of these was thought to be Terminal Archaic based on the associated artifacts. The five youngest of these seven dates pass the Oxcal contemporaneity test, with a pooled age estimate of 3737±34 BP (uncalibrated). Averaging of these five dates is shown in **Figure 48**, implying that the charcoal in these pit features came from trees which died between 4230 and 3980 BP in calibrated calendar years.

Late Archaic through Terminal Archaic radiocarbon dates from the nearby Jacobs site (36LU90) on the left bank of the river are similarly distributed. A tight cluster of four dates estimated to span 3960-3730 BP (2010-1880 BC) is preceded by five outliers which fail the Oxcal contemporaneity test. Features 33 and 35 each produced one date which falls in the cluster and one which is anomalously old. The age estimate for the cluster

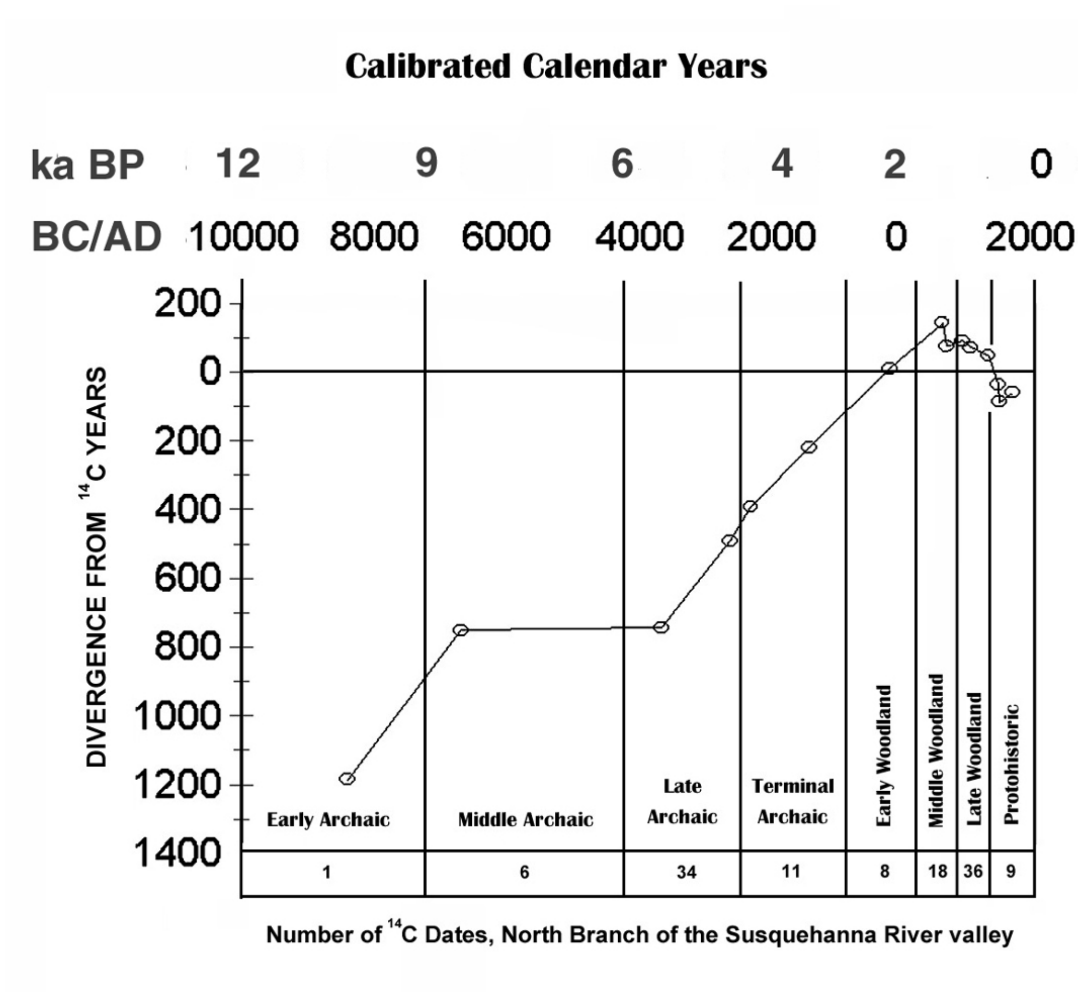


Figure 47: Effects of Radiocarbon Date Calibration on the Prehistoric Cultural Chronology for the North Branch of the Susquehanna River valley

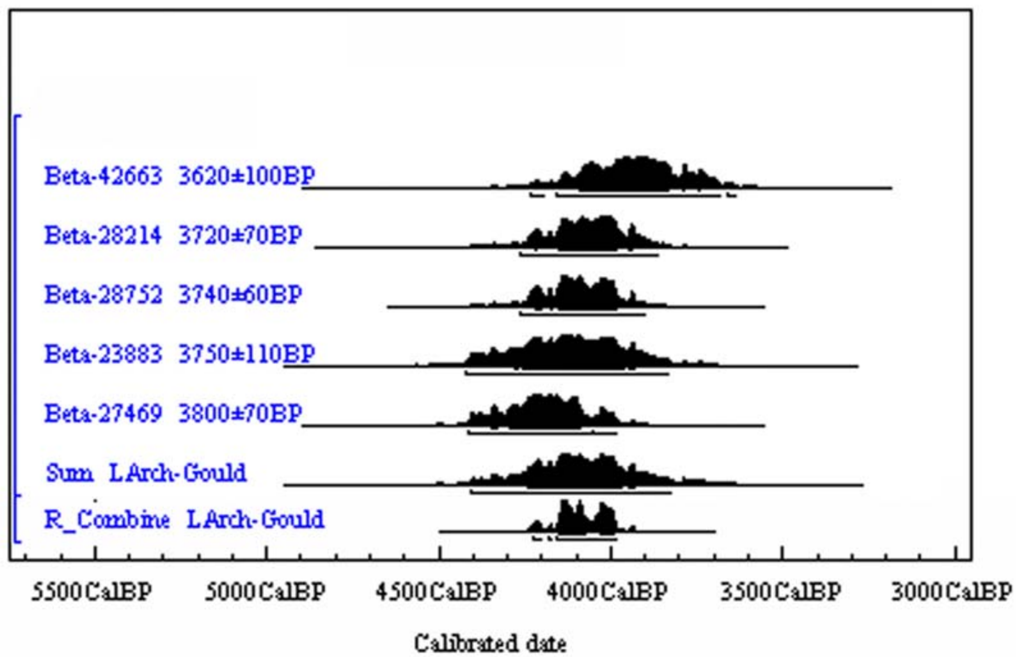


Figure 48: Oxcal averages for five radiocarbon dates from the Late Archaic (Lackawaxen) occupation of Gould Island (36LU105)

overlaps with the Terminal Archaic period as traditionally defined (Kent, 1980, p. 26-27; Witthoft, 1953). A younger outlier from Feature 128 also clearly dates a Terminal Archaic context.

Most of the sites in the study area with Late Archaic and Terminal Archaic components have complex stratigraphy. Intrasite chronologies sometimes imply very long occupations which are hard to reconcile with a seasonally mobile settlement pattern. In some cases, this is because occupations shifted laterally across a floodplain more rapidly than their traces were buried by overbank flooding (e.g. Hayes et al., 1981). This does not explain, however, the occurrence of dates on the same feature which are as much as 900 years apart in radiocarbon years (Miller, 1998; Weed and Wenstrom, 1992). Rather than actual long-term use of habitation areas and excavated pits (i.e. sedentism), some of this "noise" in intrasite chronologies may be due to cultural patterns of wood use and the environmental conditions in northeastern forests during this period.

Cultural practices involving the use of driftwood, dead-standing, or downed trees may help explain some anomalously old dates for Late Archaic and Terminal Archaic pit features. A much larger but similarly distributed set of radiocarbon dates from the early agricultural Lolomai Phase in northeastern Arizona, for example, was found to include "old wood" which expanded the apparent site occupation span as much as five-fold (Smiley, 1998b). The Lolomai Phase sites were in a semiarid setting where the mean age of deadwood on the forest floor should be somewhat older than in the humid floodplain forests of northeastern Pennsyvlania (Smiley, 1998b, p. 52). Wood obtained from driftwood, dead-standing, or downed trees may nonetheless be considerably older than the human gathering and burning events on prehistoric sites which archaeologists wish to date (Bonnichsen and Will, 1999; Ferguson, 1969, 1971; Schiffer, 1982, 1986, 1987; Smiley, 1998b).

As discussed briefly above, the averages presented for radiocarbon dates in the present dissertation are only as historically accurate as our definition of the cultural events or objects we are dating (Dean, 1978, 1993; O'Brien and Lyman, 1999; Smiley, 1998a, 1998c; Stein, 1990, 2000). The choice of a statistical method is important in that events roughly comparable in duration to the "phases" of traditional culture history (McKern, 1939; Willey and Phillips, 1958, p. 22) result from combining the 2-sigma ranges for radiocarbon dates with the "Sum" procedure in Oxcal (Bronk Ramsey, 1999). Much shorter time spans result from averaging dates using the "R_Combine" procedure, and this was the procedure used in the above analyses as well as in previous analyses of the peopling of the Americas (Batt and Pollard, 1996; Haynes, 1991, 1993; Haynes et al., 1984; Meltzer, 1995). Averaging of radiocarbon dates has also been used to analyze the first use of pottery (e.g. Sassaman, 1993).

The present analyses presume the accuracy of the relative chronology developed by Pennsylvania archaeologists for changes in prehistoric material culture. Radiocarbon dates from archaeological contexts were averaged in order to systematically compare cultural and geological events whose traces are preserved within the same alluvial deposits. Pooled dates in radiocarbon years for twelve key events or phases are presented in **Table 9** as well as calibrated ranges in years AD or BC using both Oxcal averaging procedures.

Table 10: Calibration of Pooled Radiocarbon Dates for Key Phases or Events in the Cultural Chronology of the North Branch of the Susquehanna River valley

"Event" Horizon	n	Combined ^{14}C age[1] using Oxcal R_Combine	Calibrated 95% date range[2] (AD/BC)	Summed date range[2] using Oxcal SUM (AD/BC)
Protohistoric	8	467±20	AD 1412-1552	AD 1306-1641
Corn[3]	15	721±15	AD 1272-1298	AD 1040-1440
Corn[4]	5	971±26	AD 1000-1160	AD 880-1260
Clemson Island	7	1148±18	AD 780-980	AD 650-1040
Fox Creek	7	1366±20	AD 642-688	AD 430-870
Point Peninsula	8	1494±23	AD 530-640	AD 240-690
Bushkill	5	2380±28	400-200 BC	800 BC - AD 1
Susquehanna	9	3229±27	1600-1420 BC	1950-1100 BC
Lackawaxen	3	4132±41	2880-2570 BC	2900-2490 BC
Vosburg	3	4668±35	3630-3360 BC	3700-3100 BC
Bifurcate	4	7885±30	7000-6640 BC	7050-6500 BC
Kirk	3	8977±136	8477-7728 BC	8834-7345 BC

[1]Errors in radiocarbon ages are given as one standard deviation.

[2]Date ranges are given as two standard deviations.

[3]Conservative estimate of the first corn. Cluster includes Roundtop site AMS date.

[4]Cluster includes charcoal date for a feature containing corn at the St. Anthony site.

The difference between results obtained using the two procedures for averaging dates is well illustrated by the Terminal Archaic ("Susquehanna Broadspear") sample in the present study (see **Figure 49**). Nine dates were averaged, representing the following five sites: Mifflinville Bridge, Gould Island, Jacobs, Skvarek, and Harding Flats. The pooled mean for the nine dates is 3229±27 BP. Using the Oxcal R_Combine average would imply a relatively short occupation event spanning 3550-3370 BP (1600-1420 BC). However, the contemporaneity test is failed by two of the nine dates, for Gould Island Feature 16 and Mifflinville Bridge Feature 30b. The longer time span of 1950-1100 BC obtained using the Oxcal Sum procedure may be a more appropriate estimate for the historical phenomenon referred to as "Terminal Archaic" by archaeologists.

Components dating after AD 500 are qualitatively different from the rest of the North Branch archaeological sequence, with sherd-rich middens overlying postmold patterns that represent dwellings occupied most of the year. This increased considerably the amount of organic material available for radiocarbon dating by archaeologists. Over half of the 123 prehistoric cultural dates in **Table 8** are derived from Middle Woodland, Late Woodland, or Protohistoric contexts. More rapid rates of change in material culture are also generally characteristic of sedentary societies and of ceramic as opposed to lithic industries. This means that it is definitely appropriate to use the shorter age estimates from **Table 9**, based on averaging dates with the Oxcal procedure R-Combine (Bronk Ramsey, 1999).

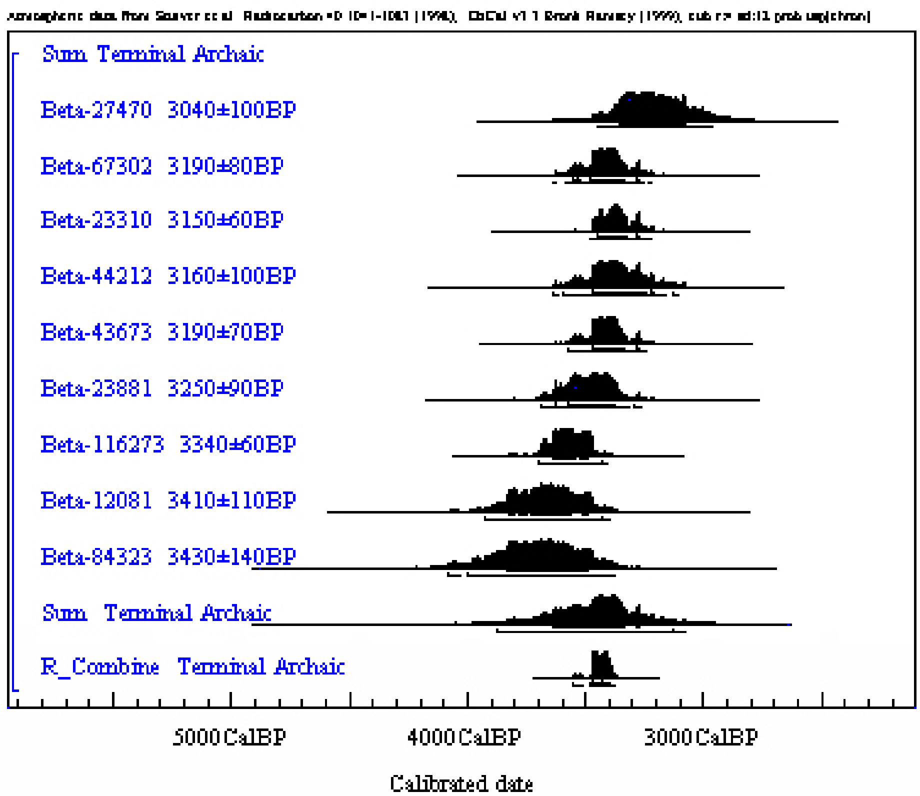


Figure 49: Oxcal averages for nine radiocarbon dates from Terminal Archaic components in the North Branch of the Susquehanna River valley

Point Peninsula and Fox Creek can both be considered Middle Woodland phenomena, although neither manifests the strong ceremonialism and interregional exchange identified with this period in the midwestern or southeastern United States. Radiocarbon dates indicate Point Peninsula components at the Catawissa Bridge site (36CO9), the East Bloomsburg Bridge site (36CO10), the Skvarek site (36LU132), Anastasi (36LU80), Conrail (36LU169), and Harding Flats (36WO55). **Figure 50** shows the cluster of eight dates around an average range of 1414-1311 BP (AD 536-639). This is contemporaneous with both Adena and Hopewell, and some possible Adena items have been recovered by amateurs following topsoil mining in the Wyoming Valley (Orlandini, 1996, p. 74-75)

. Plant remains including apparently undomesticated *Zizania aquatica* (wild rice) and *Chenopodium* sp. (goosefoot) as well as apparently domesticated *Hordeum* sp. (little barley), *Cucurbita pepo* (squash) and *Zea mays* (corn) were reported from Stratum III at the Catawissa Bridge site (36CO9) by King (1999, p. 19-20). These are the only well-dated paleoethnobotanical remains reported to date from the alluvial deposits of the North Branch of the Susquehanna River. The occurrence of *Zea mays* appears anomalously old, and is dated only by apparently associated charcoal. Paleoethnobotanical results for flotation samples from well-dated Fox Creek features at the Harding Flats site (36WO55) have yet to be reported.

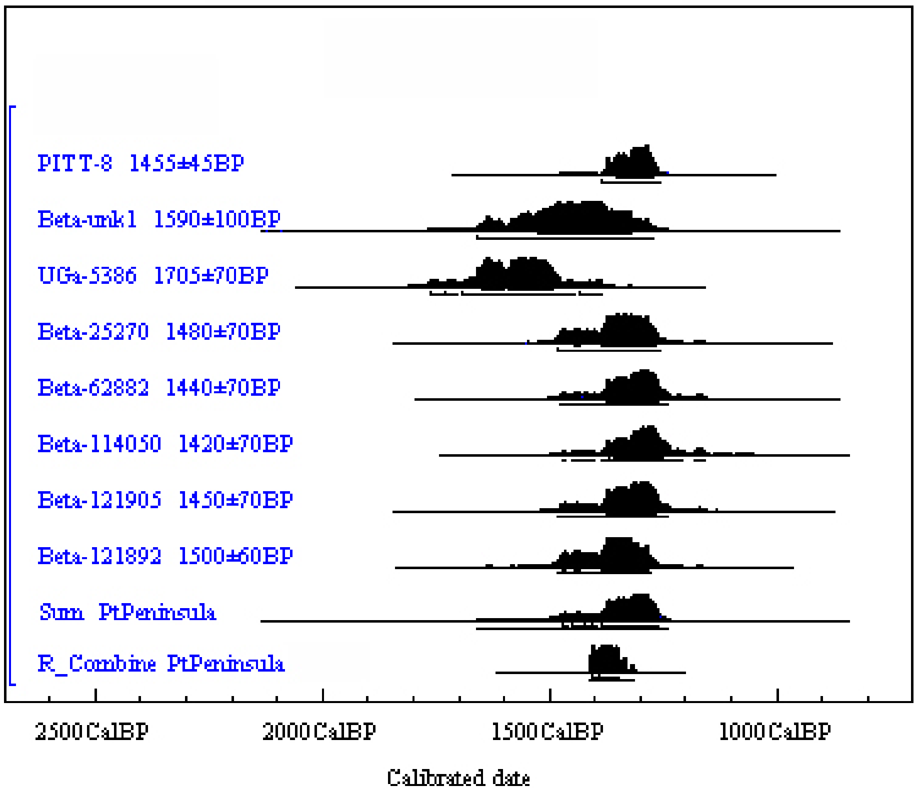


Figure 50: Oxcal averages for eight radiocarbon dates from Point Peninsula archaeological contexts in the North Branch of the Susquehanna River valley

The "folk" named for Clemson Island in the central Susquehanna River valley just upstream of the mouth of the Juniata River are the supposed "first farmers" of the prehistoric sequence in Pennsylvania (Kent, 1980, p. 33; Snow, 1995; Stewart, 1994, 1998). In New York state, components with cordmarked pottery and Levanna triangular projectile points which are roughly contemporaneous with the earliest Late Woodland components in Pennsylvania were assigned by Funk (1993a, p. 290) to the Hunter's Home Phase. Recent excavations at the Broome Tech site (Knapp, 1998) near the juncture of the Chenango River with the Susquehanna at Binghamton exposed a sizeable Hunter's Home component for which paleoethnobotanical results have also yet to be reported. The earliest evidence for maize agriculture along the Susquehanna at this point comes from three features (6, 17, and 20) at the St. Anthony site in the central valley near Lewisburg, Pennsylvania dated by associated charcoal (Stewart, 1994, p. 59-62). The date of 950±80 B.P. (Beta-22813) from Feature 17 clusters with the four radiocarbon dates from the Forty Fort Airport sites in the Wyoming Valley (**Figure 51**), passing the Oxcal contemporaneity test and suggesting that maize horticulture was being practiced from AD 1000-1160.

Early Owasco occupations at the Wells site (36BR59) and the Harding Flats site (36WO55) were apparently contemporaneous with these Clemson Island components downstream and may also eventually yield evidence of early agriculture. Recently, however, an extremely conservative estimate of a late 13th century introduction of maize has been proposed for the upper Susquehanna River valley by Hart (1999b) based on his redating of the Roundtop site west of Binghamton (Ritchie and Funk, 1973, p. 173-194).

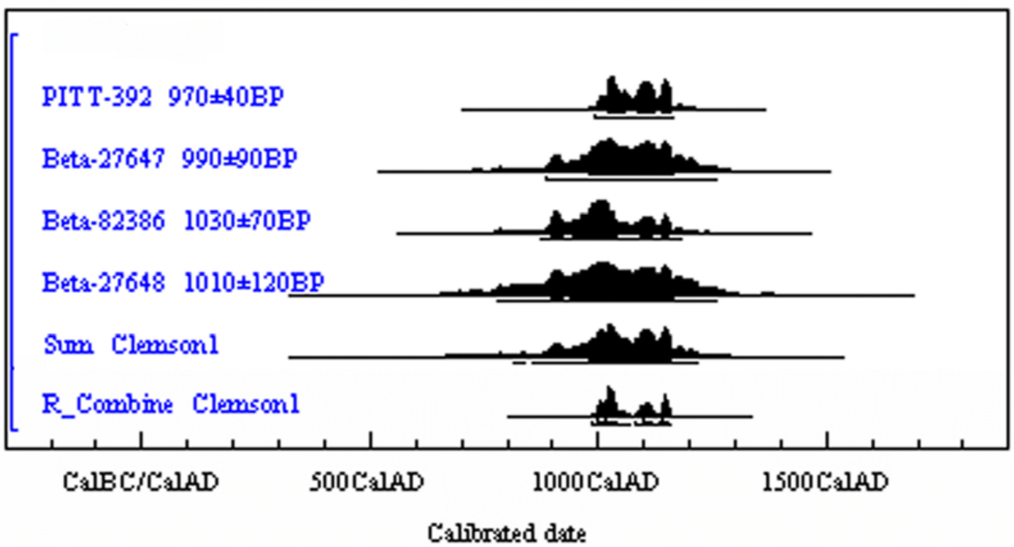


Figure 51: Oxcal averages for the earliest possible prehistoric maize cultivation, during the time of the Clemson Island culture

AMS ^{14}C dates on maize kernels from Roundtop Features 35 and Feature 235 cluster with dates from Features 6 and 20 at the St. Anthony site, with dates from six features at the Harding Flats site, and with dates from the Airport II, Gould Island, and Catawissa Bridge sites. The pool of fifteen contemporaneous radiocarbon dates from horticultural village sites (**Figure 52**) clearly demonstrates that significant changes had been wrought on Susquehanna valley landscapes by the late 13th century AD. Late prehistoric deforestation for swidden farming is discussed in **Chapter 6** as one plausible explanation for a discontinuity in the allostratigraphic framework.

The ability to date Middle and Late Woodland archaeological contexts using radiocarbon improves every year as standard deviations are reduced and sampling issues addressed through the increased use of AMS methods (Hart, 1999b; Hart and Asch Sidell, 1996, 1997). As shown in **Figure 53**, the shape of the calibration curve also influences the precision of the age estimates. Only minor spikes in ^{14}C abundance are in the part of the curve used for calibrating the date of 970±40 B.P. on Feature 41 at the Airport II site (36LU77). The gentle hump in the curve between AD 1000 and 1300 may be related to above average temperatures during the Medieval Warm Period (Damon and Jirikowic, 1993; Lamb, 1965, 1982), although the global significance and meteorological explanation for such an event have recently been called into question (Bradley, 1999, p. 447; Hughes and Diaz, 1994). Oxygen isotope ratios from ice cores have been considered by some analysts (Dansgaard et al., 1975; Johnsen et al., 1970; Thompson et al., 1995) to record warmer temperatures during this period.

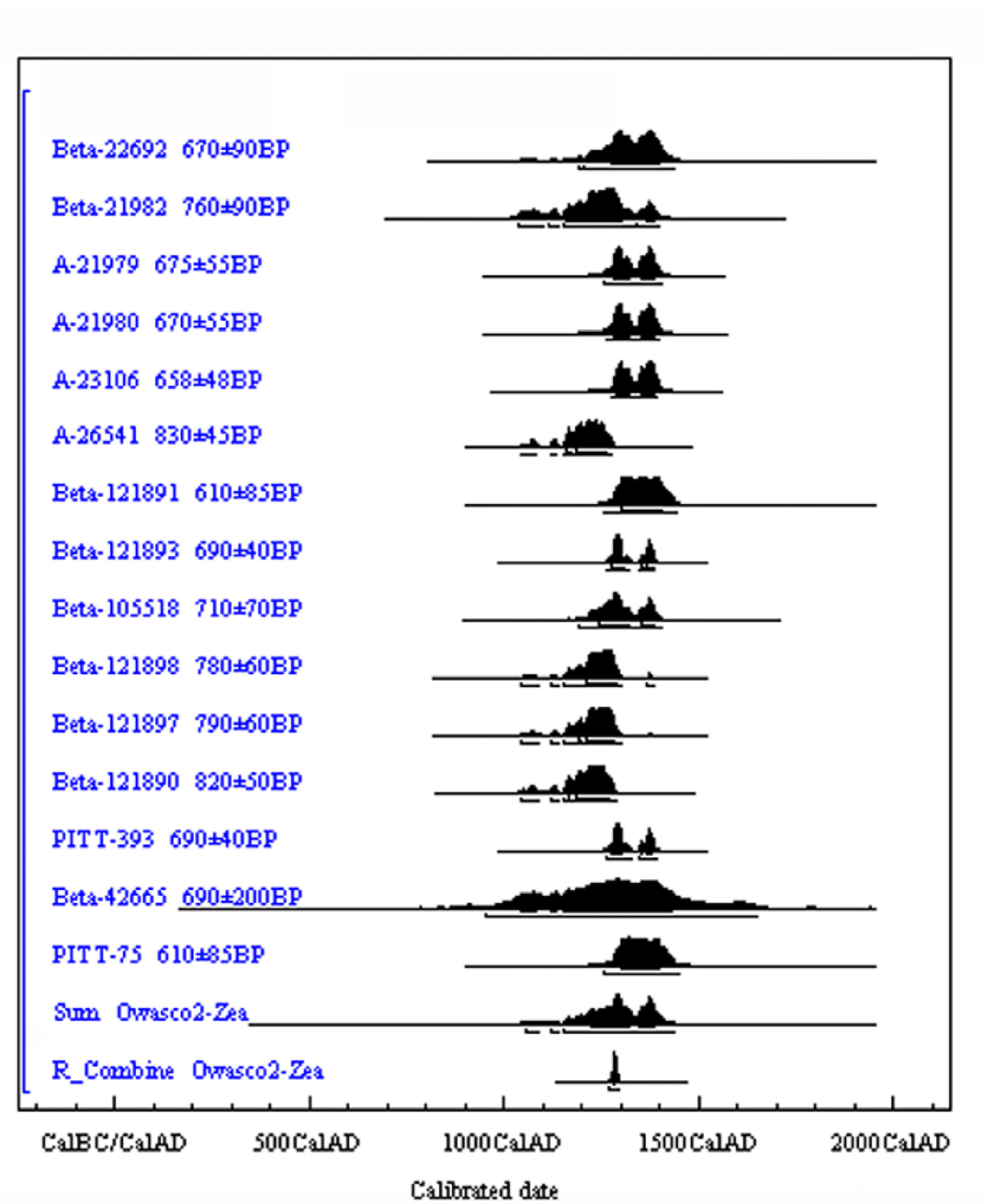


Figure 52: Pool of fifteen radiocarbon dates for early Owasco contexts associated with prehistoric maize cultivation in the North Branch of the Susquehanna River valley

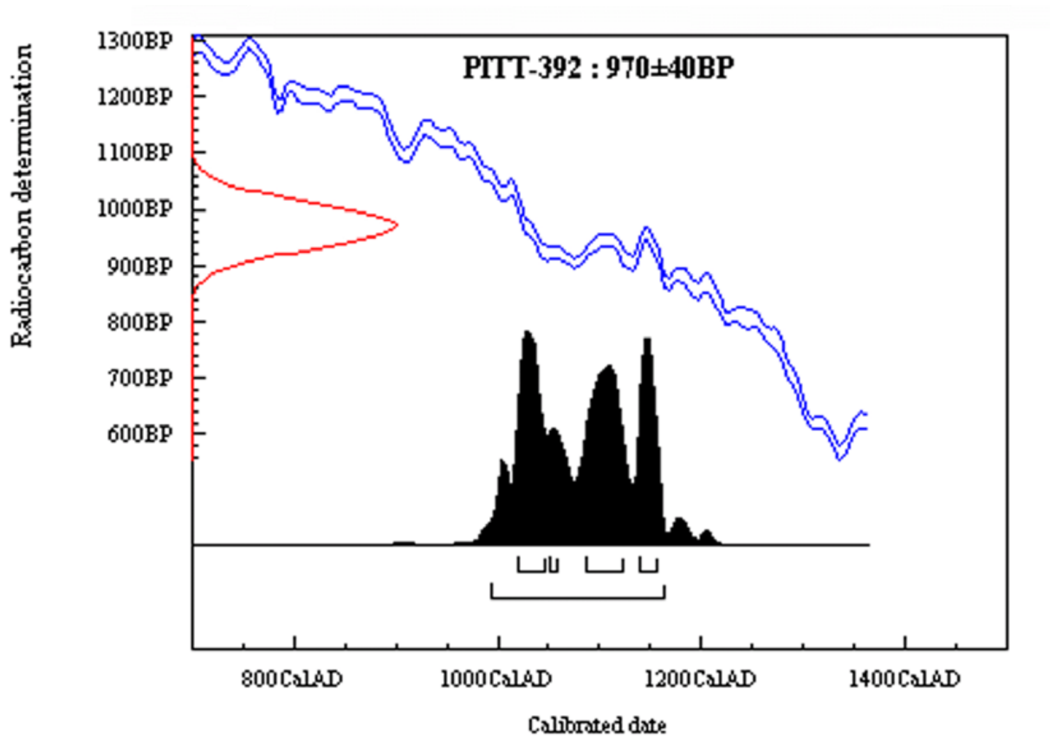


Figure 53: Calibration of the date of 970±40 BP on Feature 41 at the Airport I site (36LU77)

As shown by **Figure 47**, Middle and Late Woodland contexts actually calibrate younger than their estimated age in radiocarbon years, while most Protohistoric contexts are slightly older. Overlap occurs in the archaeological record at only a few sites, particularly the Catawissa Bridge site (36CO9) and the Harding Flats site (36WO55). Relatively few dates have been reported from Protohistoric archaeological contexts, and the seven measurements pooled to the interval AD 1412-1552 in **Table 9** are associated with heterogeneous ceramic assemblages (Kent, 1993, p. 109-110; Lucy, 1959, 1971).

Averaging the cluster of eight Protohistoric radiocarbon dates would indicate that occupations may have occurred at the Engelbert site near Nichols, New York, at the Blackman site (36BR83), at the Parker site (36LU14), and at the Harding Flats and Catawissa Bridge sites within the span of a single generation (1-sigma range). Alternatively, opting for the longer AD 1306-1641 interval obtained using the Sum procedure would make it more probable that some of these sites were inhabited in series as the Susquehannock migrated south to found their large villages near modern Lancaster.

The fact that identical radiocarbon determinations were actually obtained for the Blackman and Harding Flats sites and for the Parker and Catawissa Bridge sites does argue for contemporaneity. However, this is a highly problematic portion of the radiocarbon timescale. **Figure 54** shows the calibration curve for 600 years bracketing the date of 410±60 B.P. on Feature 40 at the Blackman site (36BR83). There are spikes in ^{14}C abundance during the 14th century, early 16th century, late 17th to early 18th centuries, and a plateau extending through the entire 19th century. Samples from these

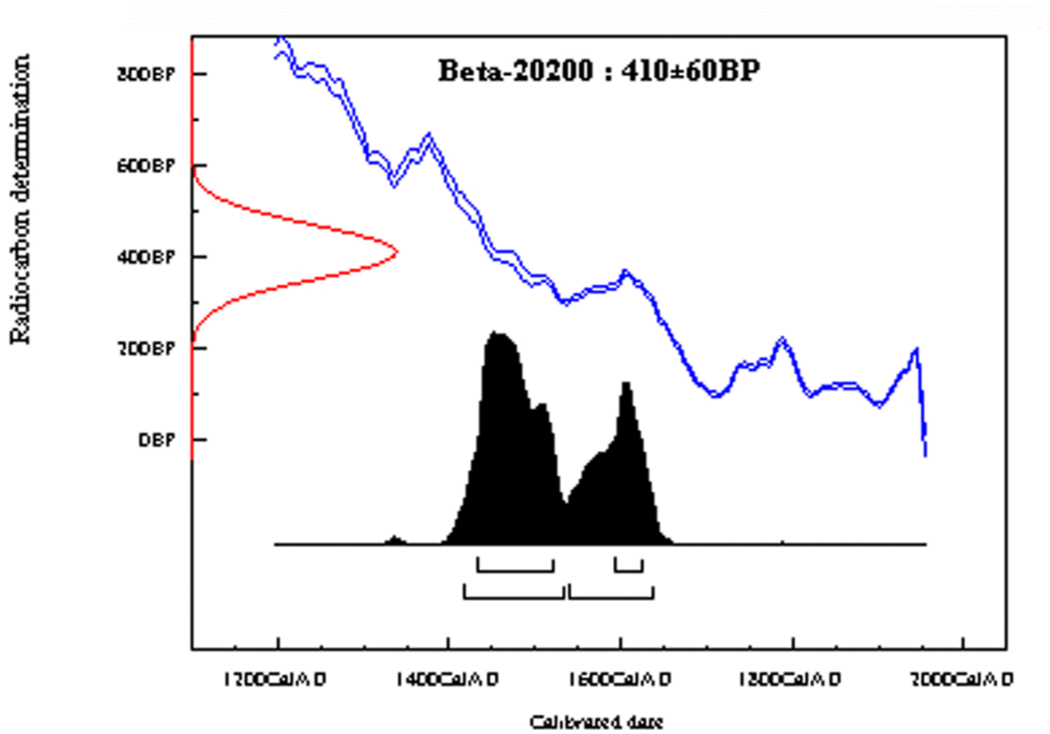


Figure 54: Calibration of the date of 410±60 BP on Feature 40 at the Blackman site (36BR83)

intervals will date too young, and the late 17th to early 18th century "Maunder minimum" spikes in particular resulted in samples having so much initial radiocarbon that they are essentially undateable due to common intercepts with 20th century tree rings (Damon and Jirikowic, 1993; Stuiver and Braziunas, 1989; van Geel et al., 1999).

Dateable materials other than wood charcoal are more common on the later sites, including thatch from roofs as well as maize kernels and other cultigens (e.g. Smith, 1973). If dates are to be obtained using a method other than AMS, it is very important to have the $\delta^{13}C$ measured. The $\delta^{13}C$ correction may be up to 80 radiocarbon years, and thus can affect the selection of calibration intercepts for the most recent portion of the chronology. In spite of these complications in radiocarbon dating due to fractionation and reservoir effects during the past four or five centuries, precision of a century or less has been achieved in the regional chronology through the use of historical records to shed light on archaeological findings (e.g. Kent, 1993; Snow, 1994; Witthoft, 1969).

GEOLOGICAL DATES AND CULTURAL CHRONOLOGY

Fifteen of the dates reported in **Table 8** represent samples from geological contexts beneath or spatially separated from the cultural occupation levels on archaeological sites. Nine of these dates are associated with stratigraphic contexts which represent the local equivalent for one of five discontinuities traced through the alluvial deposits in the following chapter. The geological dates are summarized in **Table 10** along with estimates of the time span within which each discontinuity occurred. One date

Table 11: Calibration of Pooled Radiocarbon Dates for Alluvial Discontinuities in the North Branch of the Susquehanna River valley

Discontinuity	Individual ^{14}C ages[1]	Summed date range[2] using OxCal SUM (calibrated B.P.)	Geologic Age and Characteristics of the overlying member of the Wyoming Valley formation
I	9520±90 9060±100 8150±140	11,250-8,650	Early Holocene ("Boreal"): reworked outwash gravel; slackwater clay; coarse, poorly sorted sand (sometimes ripple-bedded); strongly developed (Bt or Btx) buried soils (Central Builders member)
II	5990±110 5880±50 5570±60 5310±70	7,150-5,850	Mid-Holocene ("Atlantic"): fine to medium sand with some silt locally; fining-upward and well-sorted; deposition at rates up to 10 cm/100 yr (Wyoming member)
III	2490±50 2260±70	2,750-2,100	Late Holocene ("Sub-Boreal"): medium to coarse sand (sometimes ripple-bedded), woody detritus, particularly common at tributary mouths and island margins
IV[3]	1030±70	A.D. 887-1162	Late Holocene ("Neo-Atlantic"): stratic floodplain soils, medium to coarse sand with particulate charcoal, scour marks (Forty Fort member)
V[3]	240±110	A.D. 1468-1899	Early Historic ("Little Ice Age"): medium to coarse sand (sometimes ripple-bedded), woody detritus, thinly laminated sediment near canal pools containing coal silt (Nanticoke member)

[1]Errors in radiocarbon ages are given as one standard deviation.
[2]Date ranges are given as two standard deviations.
[3]Only a single determination available. 2-sigma age range reported as calendar years AD.

reported in Table 10 comes from a buried soil (“Ab6") horizon that appears to be considerably above the basal discontinuity for the Holocene alluvium. Only the other two dates in this cluster were pooled to estimate the age of the discontinuity. The discontinuity time span estimates were obtained by combining the 2-sigma ranges for the dates (Oxcal Sum procedure).

With the exception of the buried soil date, the dates for Discontinuities I-III all came from basal alluvium directly overlying glacial outwash. This shows the considerable range in age as well as lithic characteristics of deposits overlying this contact. As discussed in **Chapter 2**, the variation could be accomodated in a single, time-transgressive, heterolithic unit rather than attempt to identify discrete packages within the alluvium. Such a reconstruction would not provide as much information for the archaeologists who is attempting to explain or predict the occurrence of prehistoric cultural material. Nor would it be possible to identify causes in Quaternary environmental change for adjustments in channel morphology and sediment transport of the sort discussed in **Chapter 3**.

While the earliest geological dates are all for culturally sterile sediment, they do overlap the range for early cultural dates obtained from the Central Builders and Cremards archaeological sites. This suggests that the environmental conditions represented by the earliest discontinuity (Discontinuity I) were not severe enough to prevent hunter-gatherer use of floodplain settings or remove its archaeological traces. The younger dates for basal contacts, on the other hand, show little overlap with the prehistoric cultural occupations. This can be seen graphically in **Figure 45**, the geological dates falling in relatively large gaps between the clusters of cultural dates. One discontinuity (Discontinuity II) occurred between the early Middle Archaic and the Late Archaic, and another discontinuity (Discontinuity III) occurred between the Terminal Archaic and the Middle Woodland.

Events represented by the geological dates are responsible for some variation in the form of the T-1 surface as well as for the buried surfaces from which the dates were obtained. While **Appendix I** maps all of the Holocene deposits together as one T-1 surface, there are local differences in elevation. In the Wyoming Valley, landforms constructed by Late Holocene sedimentation typically stand from one to three meters above river grade, contrasting with considerably higher surfaces underlain by sediments deposited during the Early to Middle Holocene (Schuldenrein and Thieme, 1997; Thieme and Schuldenrein, 1998). The Late Holocene surface designated as T-1a in the Wyoming Valley has stratigraphic equivalents in the North Branch Lowland and other wide valley reaches, as discussed in the following chapter.

The ages obtained for geological samples from the North Branch alluvial deposits roughly correspond to the environmental periods defined in the Blytt-Sernander pollen chronology for western Europe (Sernander, 1919; Godwin, 1975, p. 455-472). There are well-founded objections to the use of the terms from this chronology for paleoenvironmental reconstruction in the Americas (Davis. 1983; Wright, 1996a). The terms are placed in quotation marks in the present dissertation in recognition of these objections. Apparently synchronous changes in climate on both sides of the Atlantic Ocean are discussed further in **Chapter 6**. Pollen records have been relied upon for the explanation of the stratigraphic discontinuities because both vegetation and the storm events which supply stream discharge are in the final analysis controlled by regional climate.

CHAPTER 5

ALLOSTRATIGRAPHIC FRAMEWORK FOR THE HOLOCENE ALLUVIAL DEPOSITS

In this chapter, the alluvial deposits of the North Branch of the Susquehanna River are grouped into an unconformity-bounded stratigraphic unit, the Wyoming Valley formation. Four members of the formation are described, each of which includes several lithofacies. The members are distinguished primarily on the basis of buried soils. Each of the buried soils formed on one of a series of former terrace surfaces stacked up within the T-1 landform, which is mapped in **Appendix 1**.

After the members of the Wyoming Valley formation have been defined, they will be used to reconstruct a complete stratigraphic record for the study area, beginning at its downstream end and traveling upvalley. Discontinuities bounding the members will be traced through a total of 23 stratigraphic sections, spanning over 200 kilometers along the river between the Central Builders property just upstream of Northumberland (km 202) and the Cass site at the mouth of Wysox Creek (km 423). Although the definition of the members is independent of both age and genesis, their age is well-constrained by the chronology based on calibrated radiocarbon dates.

Bracketing ages for each member of the Wyoming Valley formation are presented at the conclusion of this chapter. These estimates were obtained using dates from cultural contexts to supplement those from geological contexts which date the basal discontinuities (Table 11). The cultural dates that are used can all be securely positioned relative to the lower and upper boundary of the appropriate member in the stratigraphic column.

CENTRAL BUILDERS MEMBER

The Central Builders member of the Wyoming Valley formation rests unconformably on beds of coarse gravel. This lower bounding surface has been recognized in previous surficial mapping, where the gravel deposited by glacial meltwater is distinguished from the valley alluvium (Hollowell, 1973; Inners, 1978, 1981; Sevon and Braun, 1997). One key indicator for the underlying gravel is the presence of clasts derived from lithologies not found in northeastern Pennsylvania (e.g. granite, gneiss, quartzite, banded ironstones). Gravel clasts may also be up to a meter in diameter, larger than would be transported by modern floods.

One of the rare exposures of the disconformable contact between the Central Builders member and the outwash gravel occurs in a cutbank of Cayuta Creek (**Figure 54**). Cayuta Creek is a tributary which enters the North Branch of the Susquehanna River from the northwest (right bank) at Sayre (km 452). This is just upstream of the juncture of the Chemung River with the North Branch at Athens (km 447). The Central Builders deposits are somewhat more fine-grained in this exposure than in the other sections, and the silt-sized material may represent represent windblown loess which was reworked by overbank floods (Peltier, 1949).

Figure 55: Disconformable contact between the Central Builders member and coarse gravel in the cutbank on Cayuta Creek in Sayre, Pennsylvania (km 452)

Table 12: Lithofacies identified in the Alluvial Deposits of the North Branch of the Susquehanna River valley

Lithofacies	Occurrence	Description
channel sand and gravel	Central Builders (c), Wyoming (r), Nanticoke (r)	Discoidal pebbles and cobbles of local sandstone and siltstone. Matrix is predominantly medium sand with somewhat coarser and more poorly sorted sand characteristic of the Central Builders member. Colors range from olive yellow (2.5Y6/6) to brown (10YR5/3).
slackwater silt and clay	Central Builders (r), Wyoming (r)	Mucky silt containing abundant preserved plant parts. Clay settling deposits can exhibit laminar bedding but are also commonly bioturbated and discolored by water table fluctuations. Colors range from very dark gray (2.5Y3/1) to gray (N6/1).
peat	Central Builders (r), Wyoming (r)	Deposits composed predominantly of plant parts and organic matter in varying stages of decomposition. Peats mostly represent buried floodplain forest swamps, although some freshwater marsh peats also occur. The term "peat" is reserved for deposits consisting of leaves, stems, and flowering parts as opposed to woody detritus containing large branches and tree trunks.
overbank sand and silt	Central Builders (r), Wyoming (c), Forty Fort (r), Nanticoke (c)	Silt loam, loam, or fine sandy loam textures at the top of the former floodplain. Deposit may grade up section from somewhat coarser textures at the base. Degree of ped development depends on age and is diagnostic of each member. Colors range from very dark grayish brown (10YR3/2) to brown (7.5YR5/4), depending upon content
massively bedded sand	Central Builders (r), Wyoming (c), Forty Fort (c)	Well-sorted to moderately well-sorted, with a range of at most 4 phi. Nearly pure quartz with some quartz-rich rock fragments and less than 10% mica. Massive bedding indicates submergence of former terrace surface beneath at least a meter of floodwaters. Color ranges from

Lithofacies	Occurrence	Description
lamellar sand and silt	Central Builders (r), Wyoming (c), Forty Fort (c)	Textures range from loam to loamy sand, with an abundance of fine sand most characteristic. Lamellae are redder in color and more clayey than interlamellae. Colors of 10YR4/3-5/4 typify sand with 7.5YR or 5YR hues in the lamellae.
stratic sand and charred organics	Forty Fort (c)	Sets of quartzose sand alternate with thin A-horizon rooting zones. Dark (1oYR3/3-4/3) A horizons contain abundant wood charcoal and may have been produced by
thinly laminated sand	Wyoming (r), Forty Fort (r), Nanticoke (c)	Heterolithic sand containing organic particles and abundant mica. Well-sorted to moderately well-sorted with a range of at most 4 phi. Laminations are very thin (<1 mm) with contrasting colors of brown (10YR4/2-4/3) and yellowish brown (10YR5/4). Commonly occurs in "natural levee" landscape positions of the modern floodplain.
laminar sand with anthracite particles	Nanticoke (c)	Sets of quartzose sand alternate with sets composed almost entirely of anthracite particles. Anthracite particles range from coarse angular sand to fine silt. Wood charcoal and other organic particles may also be included. Contrasting colors are typically black (10YR2/1) or yellowish brown (10YR5/4).
woody detritus	Central Builders (r), Wyoming (c), Forty Fort (r), Nanticoke (c)	Deposits composed predominantly of tree branches, stems, and leaves in varying states of decomposition. Whole trunks encountered in the Nanticoke member may represent the remains of historic log rafts.

(c) = common occurrence in this member of the Wyoming Valley formation.

(r) = rare occurrence in this member of the Wyoming Valley formation.

Three of the lithofacies defined in **Table 12** are found in the Central Builders deposits identified in the present study. The channel sand and gravel lithofacies is the most characteristic, although it is also the most difficult to observe. This lithofacies is typically buried by several meters of younger sediment and does not remain stable in profile. Because the sand and gravel were deposited in areas actively scoured by the river channel, they usually do not contain significant archeological contexts. Descriptions in the archaeological contract reports are brief, even those written by geologists or soil scientists (e.g Pollack and Petersen, 1992; Wagner, 1987).

Based on the descriptions that are available for the Central Builders archaeological site (36NB117) and several sites further upvalley, it appears that much of the sand and gravel were deposited by a river which occupied more than one channel. At site 36NB117, in particular, longitudinal bars of sand showing both planar and trough crossbedding were observed in the nine short trenches (ST-1 though ST-9) excavated on the T-1 between the archaeological site and the outwash grade. Both these bedforms and the generally coarser grain size suggest a braided channel pattern. As was shown through geomorphological analysis of 23 channel cross-sections in **Chapter 3**, braiding still occurs in some reaches of the modern river.

A slackwater lithofacies of silt, peat, and sometimes clay typically fills swales and relict channels at the valley margin in the wider valley reaches. Preservation is poor because this facies is found in areas which were often used for the bed of the North Branch Canal (Inners, 1988b; Petrillo, 1986). Where undisturbed, these deposits promise to provide pollen and plant macrofossil records of the changing vegetation on the valley floor. There is also potential to identify individual extreme floods by dating layers of coarser sediment within the generally fine-textured slackwater sediment (Baker, 1987; Knox, 1985, 1988, 1993; Kochel and Baker, 1988).

Where an overbank flood lithofacies occurs in the Central Builders member it is thin (<50 cm) and incorporated into the buried soil which defines the upper bounding surface. Textures range from silt loam to loamy sand, with the finer textures occurring primarily in reaches with siltstone, shale, or carbonate bedrock. Although there are deposits as thick as five meters from which the Central Builders member is missing entirely, it is typically found from two to four meters below surface and characterized by the most strongly developed buried soil in any given profile. The buried soil typically shows evidence of clay translocation (argillic or Bt horizon), pedogenic cracking and increased density (fragic or Bx horizon), or both of the above (Btx horizon).

The most strongly developed buried soils are found capping finer-textured sediments of the overbank flood lithofacies. Soils formed on channel sand and gravel deposits may be more weakly developed, with cambic (Bw) horizons, while those formed in the slackwater silt may be gleyed (Bg horizons). It is therefore necessary to trace the top of each lithofacies laterally to determine with which member of the Wyoming Valley formation it is associated. Buried soils with fragic or argillic horizons do appear to be sufficiently common to make the top of the Central Builders member recognizable in most valley reaches where it occurs. Independent age constraints can also be obtained from the remains of prehistoric occupations on the former terrace surfaces as well as from radiocarbon dating of included organic particles.

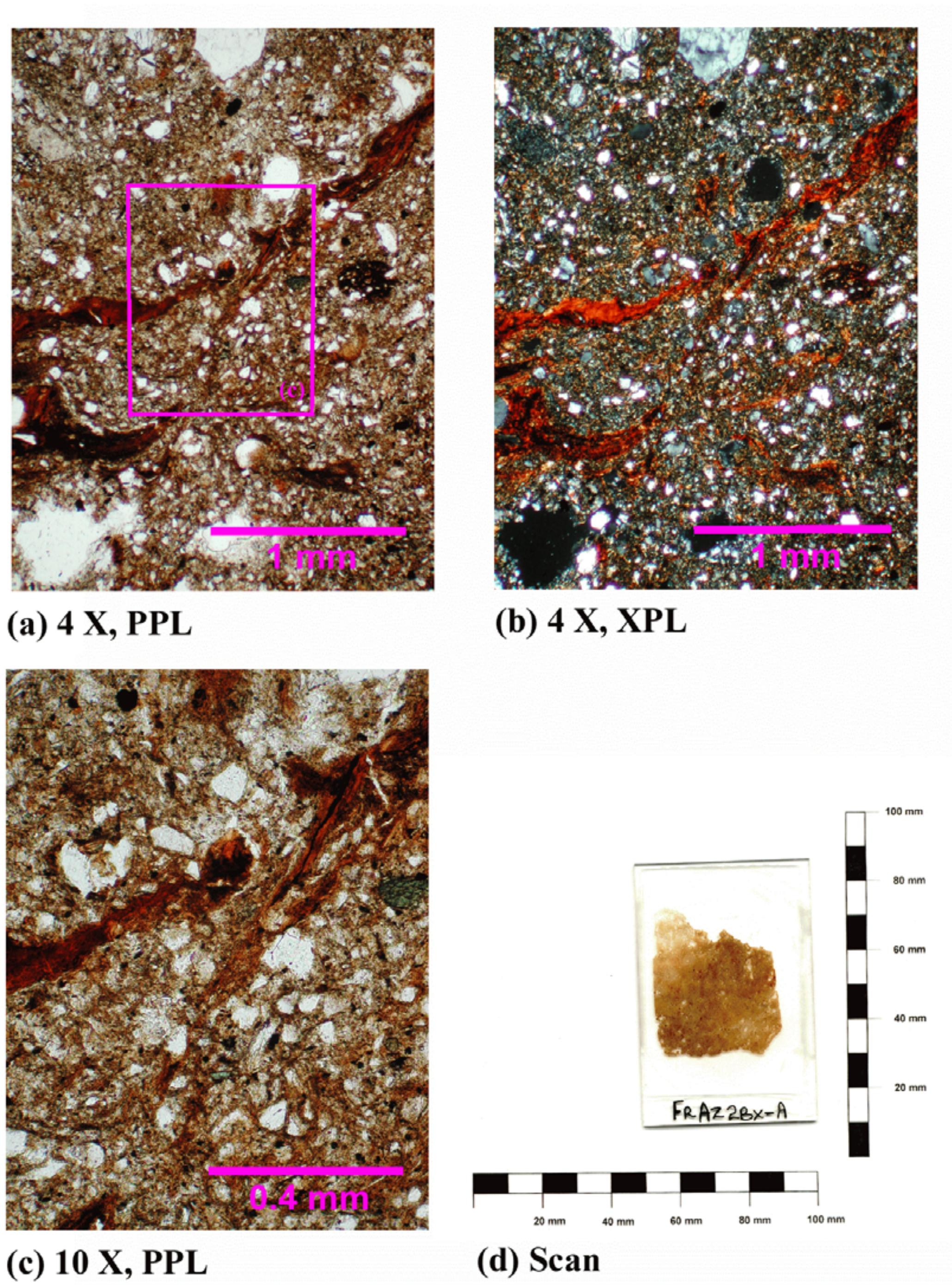
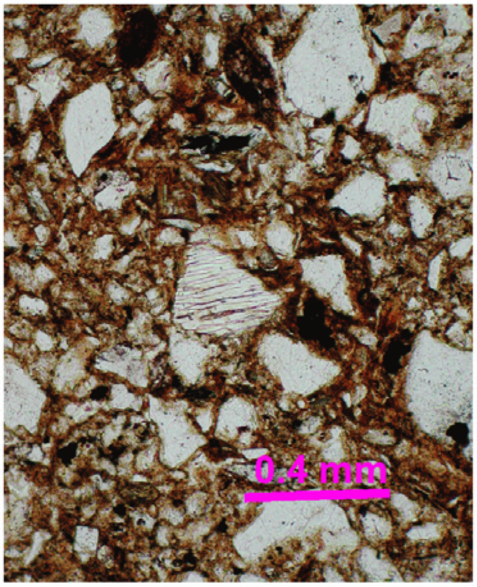


Figure 56: Photomicrographs (a,b,c) and scan (d) of a thin-section of the 2Bx horizon (fragipan) from Boring AT-2 at French Azilum. Inset view (a) shows the area of the 10X closeup view (c).

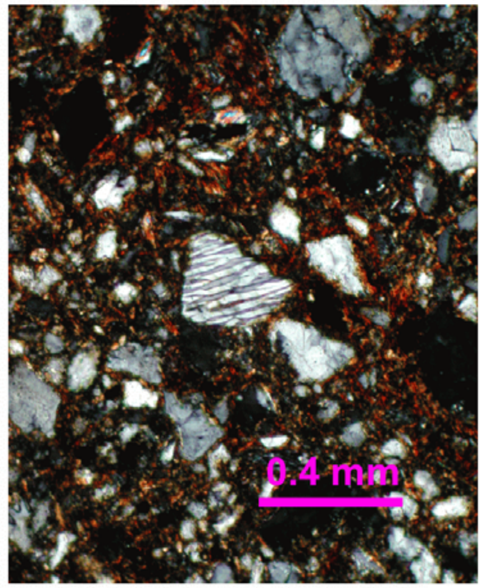
Two of the 20 thin-sections studied in the present dissertation represent buried soils formed at the top of the Central Builders member. The thin-section of the 2Bx horizon (fragipan) from Boring AT-2 at French Azilum (**Figure 56**) shows very well-developed ferriargillans (Grossman and Carlisle, 1969; Grossman et al., 1959a, 1959b; Lindbo and Veneman, 1989). The largest of the ferriargillans curves diagonally for a distance of over two millimeters across the field of view in image (a). The approximately horizontal alignment of the subangular to subrounded sand grains has been crosscut by this pedogenic feature.

Bright orange areas of higher birefringence within ferriargillans when viewed in cross-polarized light (b) typically indicate a more hydrous iron-rich phase (Grossman et al., 1959a; Stephen, 1960). As reported below, XRD analyses of the pedogenic clays from the Wyoming Valley formation indicate them to consist primarily of hydroxy-interlayered vermiculite (HIV). The 10 X closeup view of the French Azilum 2Bx (c) shows voids and passage traces entirely plugged with pedogenic clay, linked by films surrounding sand grains to form the continuous ferriargillan feature.

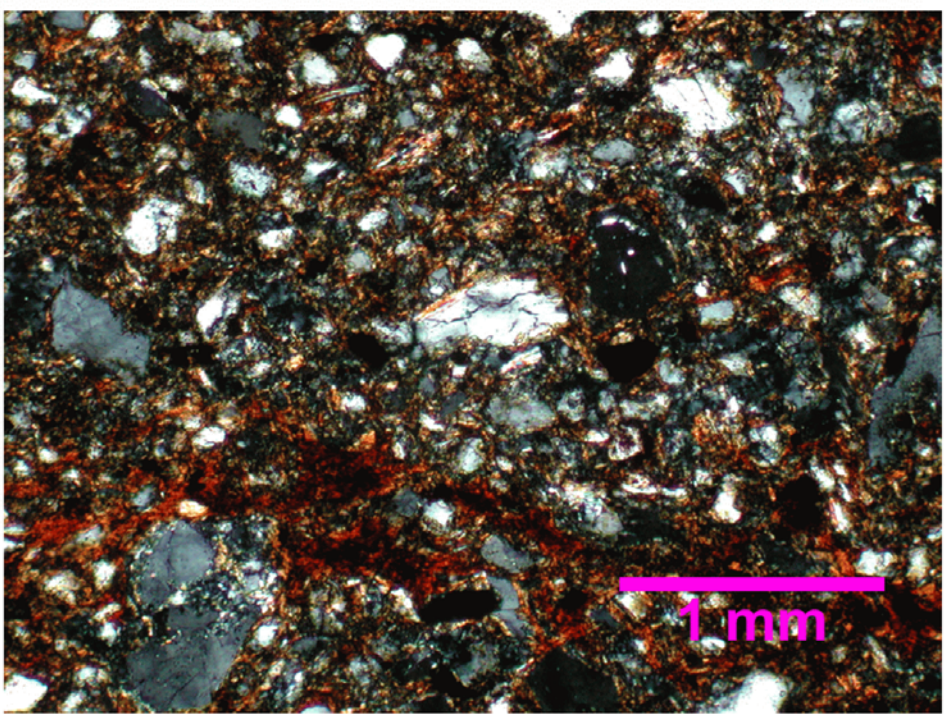
The thin-section of the 4Btx (fragipan) from Boring 1 on Scovell Island (**Figure 56**) shows that the soil formed in an immature, poorly sorted sand ranging from 0.1 to at least 0.5 mm in diameter. A relatively unweathered plagioclase feldspar clast can be seen in the center of the field of view at 10 X (a,b) as well as some very angular quartz clasts. The sample had a relatively high magnetic susceptibility, 7.85 x 10^{-5} SI, as reported in **Appendix 3**. Most of the coarser textured samples analyzed had high values, but in this case magnetite is probably among the iron-bearing minerals present. A bed of small



(a) 10 X, PPL



(b) 10 X, XPL



(c) 4 X, XPL

Figure 57: Thin-section photomicrographs of the 4Btx horizon (fragipan) from Boring 1 on Scovell Island (km 312)

Table 13: Particle Size Distribution for Column of 10 Samples from Hand Auger Boring at Falls Bridge Site (36WO56) from data reported by Kingsley et al. (1995)

Horizon	Depth	%Sa	%Si	%Cl	VCOS	COS	MS	FS	VFS	TEXTURE
2AB	150-200	75.7	11.5	12.8	0.00	0.79	10.02	29.09	35.81	VFSL
2Bt	200-250	62.7	20.0	17.3	0.00	1.06	8.32	25.59	27.72	VFSL
2BC	250-300	71.7	20.0	8.3	0.00	0.58	3.30	34.68	33.13	FSL-VFSL
2C1	300-350	63.7	22.7	13.7	0.00	1.24	8.10	25.74	28.61	VFSL
2C2	350-400	70.0	18.3	11.7	0.00	0.85	2.37	24.75	42.04	VFSL
3AB	400-450	64.0	24.0	12.0	0.00	0.67	4.20	30.07	29.07	FSL
3BE	450-500	75.0	10.7	14.3	0.04	0.55	3.40	30.45	40.33	VFSL
3Bt	500-550	64.7	17.5	17.8	0.00	0.36	3.93	29.77	30.64	VFSL
3C1	550-600	74.3	17.3	8.3	0.34	1.19	17.90	37.32	17.56	FSL
3C2	600-650	73.3	17.7	9.0	0.09	0.86	12.91	35.84	23.60	FSL

opaque grains less than 0.1 mm in diameter trends horizontally across the lower half of the field of view in both (a) and (b). The speckled fabric between the grains represents silt- to clay-sized mica (Bullock et al., 1985). In the cross-polarized image at 4 X magnification (c), a large ferriargillan can be seen to have formed by welding this same micaceous material into a continuous band.

Particle-size data for both the Central Builders member and the overlying Wyoming member were obtained by Kingsley et al. (1995) for samples from a hand auger boring at the Falls Bridge site (36WO56). The Central Builders member was buried four meters below surface, capped by a buried soil with an argillic horizon (3Ab-3BE-3Bt profile). As reported in **Table 12**, the Central Builders deposits at the base of the auger boring were only slightly coarser textured than the Wyoming member bed immediately beneath the Late Archaic occupation surface. All of the sample textures were either fine sandy loam or very fine sandy loam. Very coarse sand occurred in the 3C1 and 3C2 horizons only, and these two horizons also had particularly high percentages of medium sand (12-18 %). Unfortunately, it is not possible to describe sedimentary bedforms from an auger boring.

WYOMING MEMBER

The Wyoming member is the defining member for the Wyoming Valley formation, and it occurs in 19 of the 23 stratigraphic sections described in this chapter. The Wyoming typically fines upward from a disconformable contact either with a strongly developed buried soil at the top of the Central Builders or with outwash gravel in reaches which lack earlier Holocene deposits. Silt loam, loam, or sandy loam textures predominate, although coarser beds also occur as discussed below. Most Wyoming profiles fit the Allen stratigraphic model for the meandering stream facies (Allen, 1970, p. 140-146; Miall, 1996, p. 217-224; Nichols, 1999, p. 116-118). In the Allen model, textural fining corresponds to the gradual migration of the river channel away from a point bar at the apex of a meander loop.

The Wyoming disconformably overlies the Central Builders in twelve of the 19 sections in which it occurs. Six of the sections include a stratum of massively bedded sand immediately above the contact with the buried soil at the top of the Central Builders. Stratigraphically equivalent coarse sand and gravel occur at the base of several floodplain islands, Gould Island and Richards Island in particular. Massively bedded coarse to medium sand is thus a lithofacies of the Wyoming distinct from other overbank deposits which record the development of channel meanders. The discharges which deposited the sand at the base of the Wyoming were evidently greater than the bankfull stage for the underlying floodplain, marked by the buried soil at the top of the Central Builders.

The Wyoming member crops out as few as 50 centimeters below the present land surface on some of the higher T-1 landforms. Bioturbation by tree roots and burrowing organisms is typical of soils formed at its upper boundary. The degree of soil development is quite varied, with fragic (Bx) and argillic (Bt) horizons occurring as well as the cambic (Bw) horizons most typical of soils forming in conditions of rapid overbank deposition. The buried soil formed at the top of the Wyoming member in the Trench 5 profile at the 8th Street Bridge Project Work Area (**Figure 57**) has a thick

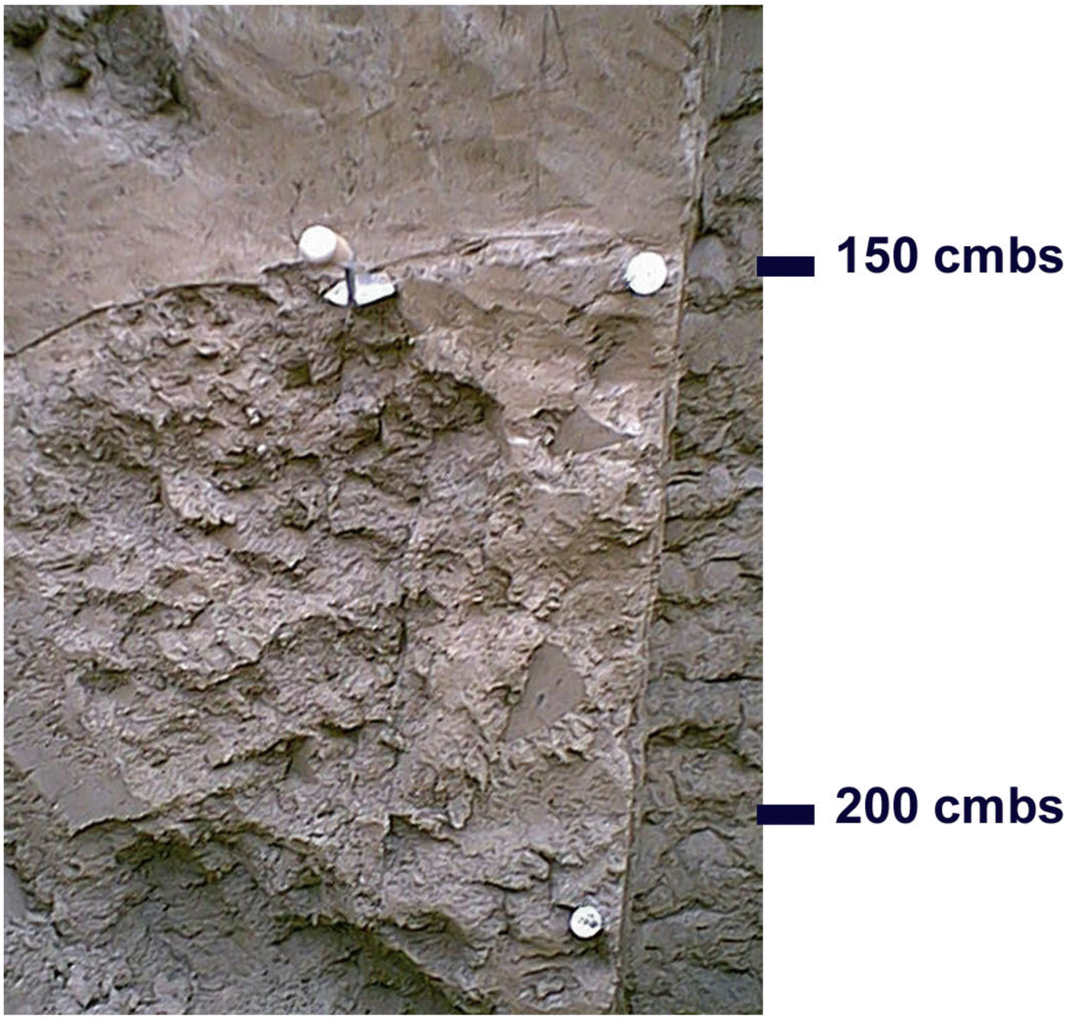
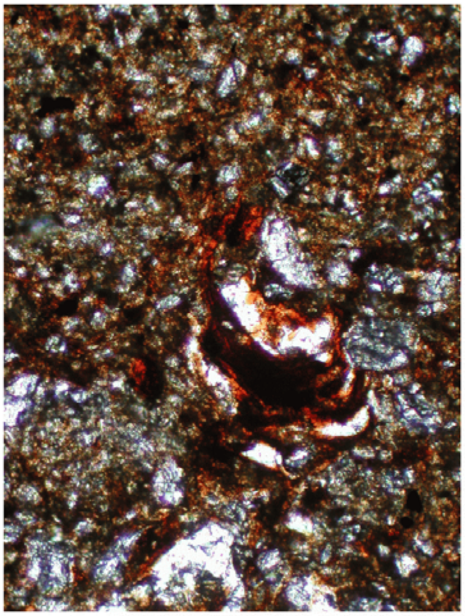
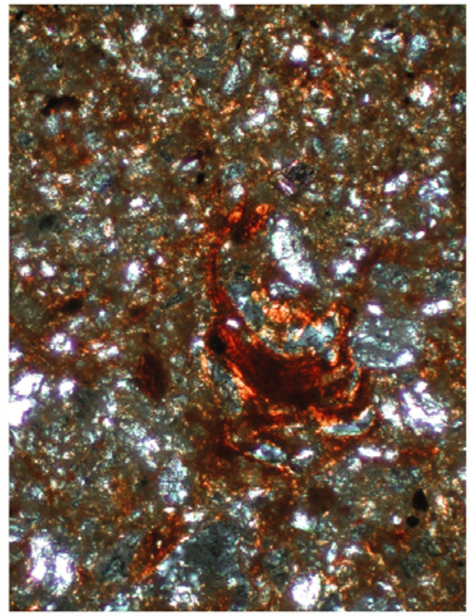


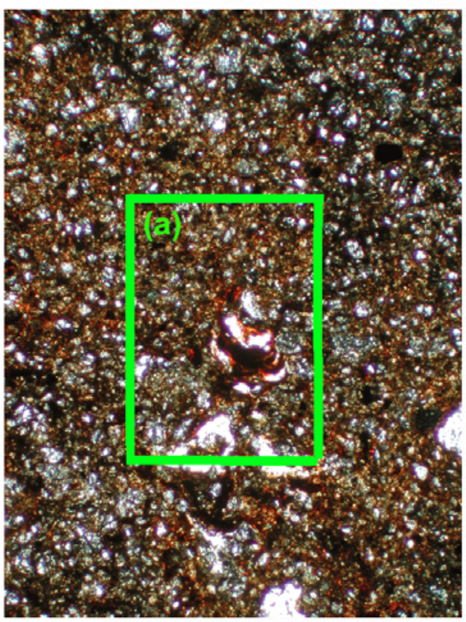
Figure 58: Profile of buried soil with cambic horizon at the top of the Wyoming member in Trench 5 at the 8th Street Bridge Project Work Area in Wyoming, Pennsylvania (km 306)



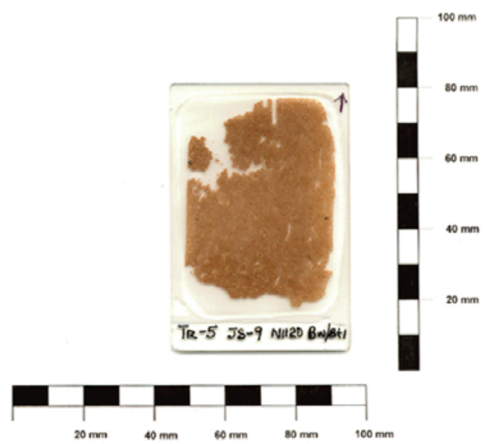
(a) 10 X, PPL



(b) 10 X, XPL



(c) 4 X, PPL



(d) Scan

Figure 59: Photomicrographs (a,b,c) and scan (d) of the thin-section of the Bw/Bt1 horizon in Trench 5 at the 8th Street Bridge Project Work Area in Wyoming in Wyoming, Pennsylvania (km 306). Inset view (c) shows the area of the 10X closeup views (a,b).

cambic horizon in which some portions were observed to have weak prismatic structure and discontinuous clay films. The horizon was therefore designated a Bw/Bt, which was corroborated by observation of both pedogenic clay and iron-bearing minerals in thin-section (**Figure 58**).

The photomicrographs of the 8th Street Bridge Project Area Bw/Bt1 horizon show abundant pedogenic soil "plasma" (Brewer, 1976; Kubiena, 1970, p. 112-114). The pedogenic minerals are disseminated throughout the clastic framework, however, as opposed to being concentrated along ped faces or in longitudinal cracks as occurs in soils that have had more time to form. The large void filled with bow-shaped laminae of bright orange birefringent clay in the closeup views (a,b) is clearly a burrow filled with "spreites" (Bullock et al., 1985, p. 102-103; Reineck and Singh, 1986, p. 162-165). In addition to the more disseminated soil plasma, the buried soils of the Wyoming member can be identified in thin-section by the abundance of passage traces, fecal material, and other evidence of active bioturbation. Such biological activity has been shown to increase the magnetic susceptibility because magnetotactic bacteria are also more active (Fassbinder et al., 1990; LeBorgne, 1955; Mullins, 1977). The sample from the 8th Street Bridge Bw/Bt1 horizon did have a relatively high magnetic susceptibility of 8.60×10^{-5} SI.

Lamellar sand and silt is listed as the third lithofacies of the Wyoming member in **Table 12**. Lamellae are bands of translocated iron and clay common in many alluvial deposits worldwide (Dijkerman et al., 1967; Foss and Segovia, 1984; Rawling, 2000).

Lamellae are here treated as a lithic characteristic based on research showing that they form soon after deposition, within at most a few hundred years in the eastern United States (Foss and Segovia, 1984). In the North Branch of the Susquehanna River valley, lamellae are most common in dynamic, low-lying floodplains where iron and clay move laterally in response to water table fluctuations (Dijkerman et al., 1967; Foss and Segovia, 1984; Rawling, 2000).

Lamellae occurred in the Wyoming member deposits at the 8th Street Bridge Project Work Area (**Figure 60**), riverward of the Trench 5 profile where the sample of the Bw/Bt1 horizon was collected. In thin-section (**Figure 61**), it is the "interlamellar" sediments which can be seen to be continuous horizontal features. The pedogenic clay and iron in the lamellae are very discontinuous blebs. Both bright orange (hydrous) and dark brown (oxidized) ferriargillans occur within each of the lamellae, as shown in views (a) and (b). A very high magnetic susceptibility value of 20.6 x 10^{-5} SI is reported for the lamellar C horizon sample from the 8th Street Bridge Project Work Area in **Appendix 3**.

One particularly important characteristic of the lamellar sand and silt in the Wyoming member is the abundance of conifer charcoal fragments. As shown in view (c), some of these are quite large. Based on personal communication with a botanist (Scott-Cummings, 2001), these fragments have been identified as American hemlock (*Tsuga canadensis*). As discussed further in **Chapter 6**, *Tsuga* suffered a severe blight at the approximate time of deposition of this charcoal-rich fine sandy alluvium.

Both particle size and soil chemistry data were obtained in the Wyoming Valley levee raising project study (Schuldenrein and Thieme, 1997) for samples from a river

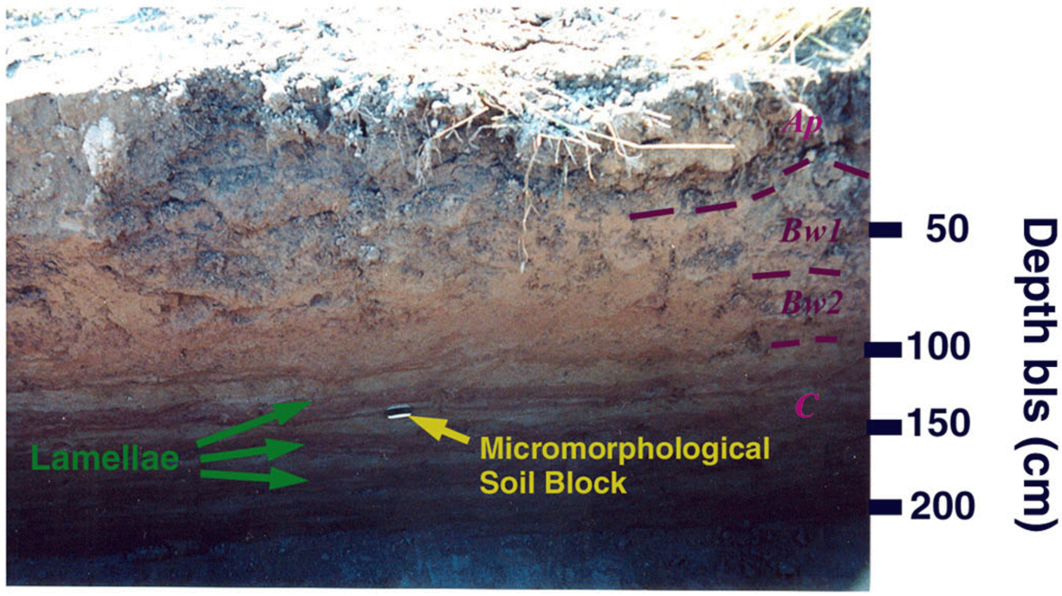


Figure 60: Lamellar sand and silt lithofacies in the Trench 5 south wall profile at the 8th Street Bridge Project Work Area in Wyoming, Pennsylvania (km 306)

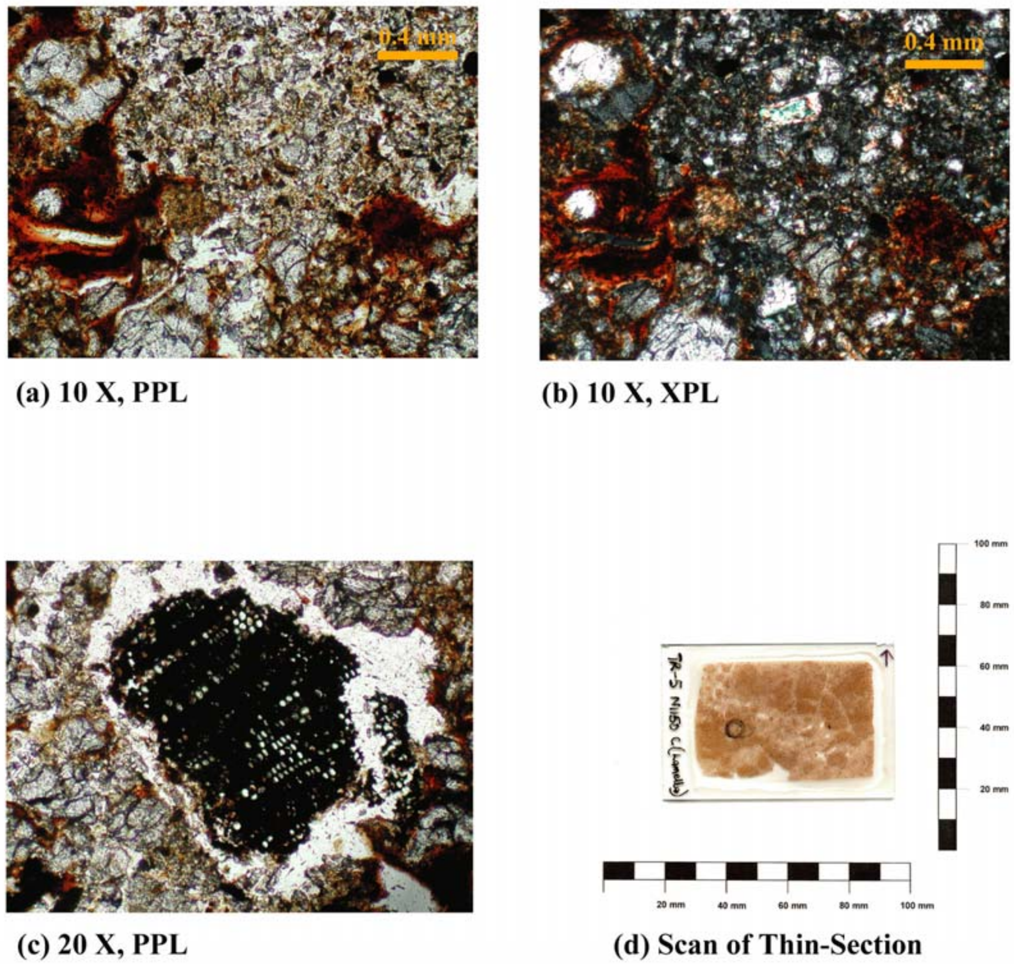


Figure 61: Photomicrographs (a,b,c) and scan (d) of the thin-section of lamellar sand and silt from the Trench 5 south wall profile at the 8th Street Bridge Project Work Area in Wyoming, Pennsylvania (km 306)

Table 14: Results of Laboratory Analyses for Column of 12 Samples
from the T-1 Cutbank at Wyoming, Pennsylvania

Horizon	**Depth**	**%Sa**	**%Si**	**%Cl**	**OM**	**pH**	**P**	**K**	**Ca**	**Mg**	**Zn**	**Mn**	**Fe**
2Ab	110-125	40.0	42.0	18.0	1.61	5.50	16.0	13.2	716.5	67.0	3.10	9.02	25.66
2Bw	140-160	30.0	52.0	18.0	0.54	5.70	9.5	18.7	662.0	85.1	0.39	5.45	49.16
2BE	220-240	54.0	36.0	10.0	0.20	5.40	6.8	16.4	433.5	49.9	0.48	3.90	39.39
3E	240-250	48.0	40.0	12.0	0.40	5.50	12.6	16.4	497.7	54.2	0.53	6.66	43.75
3EB	250-265	46.0	40.0	14.0	0.40	5.50	6.2	16.8	608.5	66.2	0.53	3.45	43.64
3BE	265-270	48.0	40.0	12.0	0.30	5.40	36.2	12.4	497.5	47.4	0.49	3.48	33.90
3Btx	270-290	42.0	44.0	14.0	0.34	5.40	17.2	13.3	449.2	50.3	0.49	2.08	35.46
4E	300-315	68.0	18.0	14.0	0.34	5.70	29.1	11.9	382.5	39.6	0.39	2.43	27.37
4Btx	340-360	42.0	50.0	8.0	1.88	5.60	33.6	14.4	723.5	119.5	0.79	2.63	33.86
5E	375-390	66.0	20.0	14.0	0.34	5.70	<1.0	<1.0	7.7	<1.0	<1.0	<1.0	<1.0
5Bg	400-420	48.0	38.0	14.0	0.34	5.80	40.7	12.7	582.0	90.6	0.68	4.98	41.73
5Bt	450-470	42.0	42.0	16.0	0.40	6.00	32.1	17.1	656.0	102.4	0.76	4.50	37.56

cutbank of the T-1 at Wyoming, Pennsylvania (km 307). The Wyoming member of the Wyoming Valley formation is represented by a type section of a little over two meters of alluvium in which three soils formed on top of one another (3E1 through 5Bt horizons). As reported in **Table 14**, all but one of the samples from the Wyoming member type section had more silt than is characteristic of the Central Builders member. The soil chemistry data indicate leaching and translocation of iron (Fe) and other mobile constituents, as discussed in detail below. Tree roots were responsible for much of the leaching, and several generations of forest vegetation succeeded one another as T-1 surfaces accreted during Wyoming member deposition.

X-ray diffraction analysis of the clay fraction of the 4Btx horizon in the Wyoming member type section showed it to consist predominately of illite, or soil mica (Fanning et al., 1989) along with hydroxy-interlayered soil vermiculite (Barnhisel and Bertsch, 1989; Douglas, 1989). The 10 angstrom phase on **Figure 62** is illite. The 14 angstrom phase must be vermiculite or chlorite since it failed to expand upon saturation with ethylene glycol (Moore and Reynolds, 1997). Destruction of the 14 angstrom phase upon step-heating of the Mg-saturated slide (**Figure 63**) demonstrates the presence of vermiculite as opposed to chlorite.

Because the parent sedimentary lithologies are similar for all of the members of the Wyoming Valley formation, the two clay mineral phases found in the 4Btx horizon of the Wyoming member type section can be presumed to be the most common in all of the buried soils. While the members cannot be identified solely on the basis of clay mineralogy, semi-quantitative analyses of the abundance of the two phases do make it

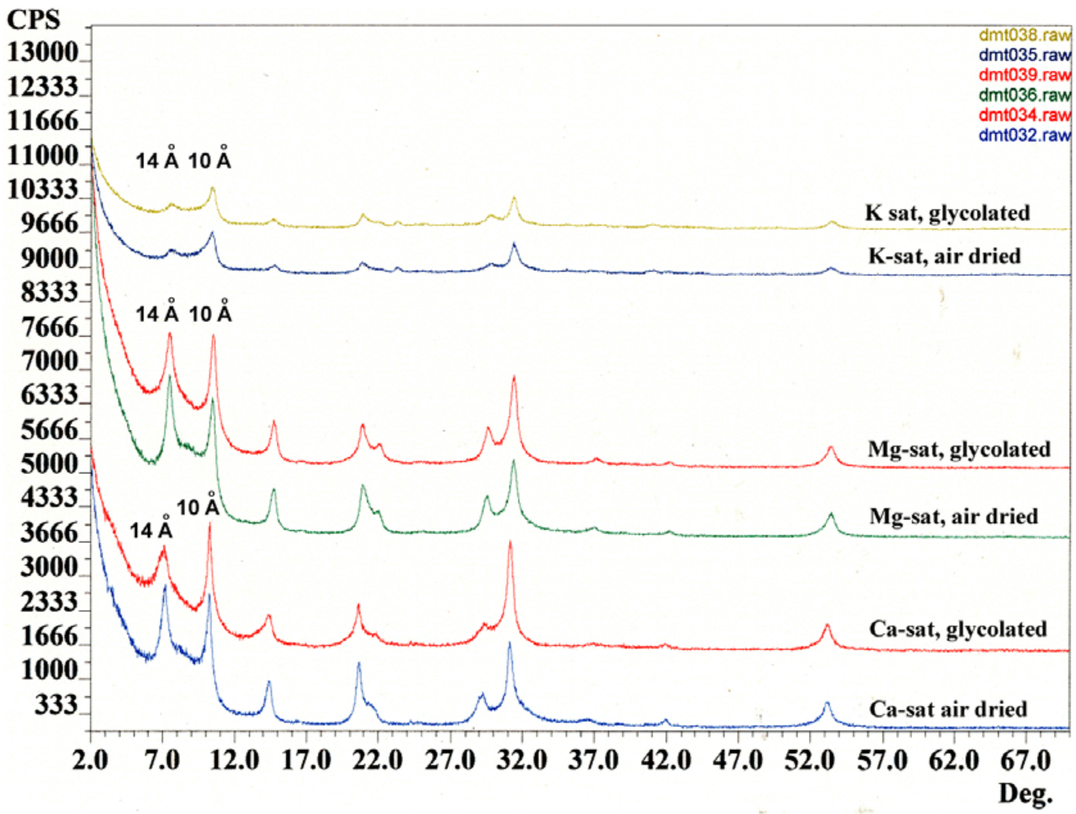


Figure 62: X-ray diffractograms of clay separates (< 2 microns) of the 4Btx horizon from the Wyoming member type section, saturated with K, Mg, and Ca, scanned in air-dried state and after glycolation

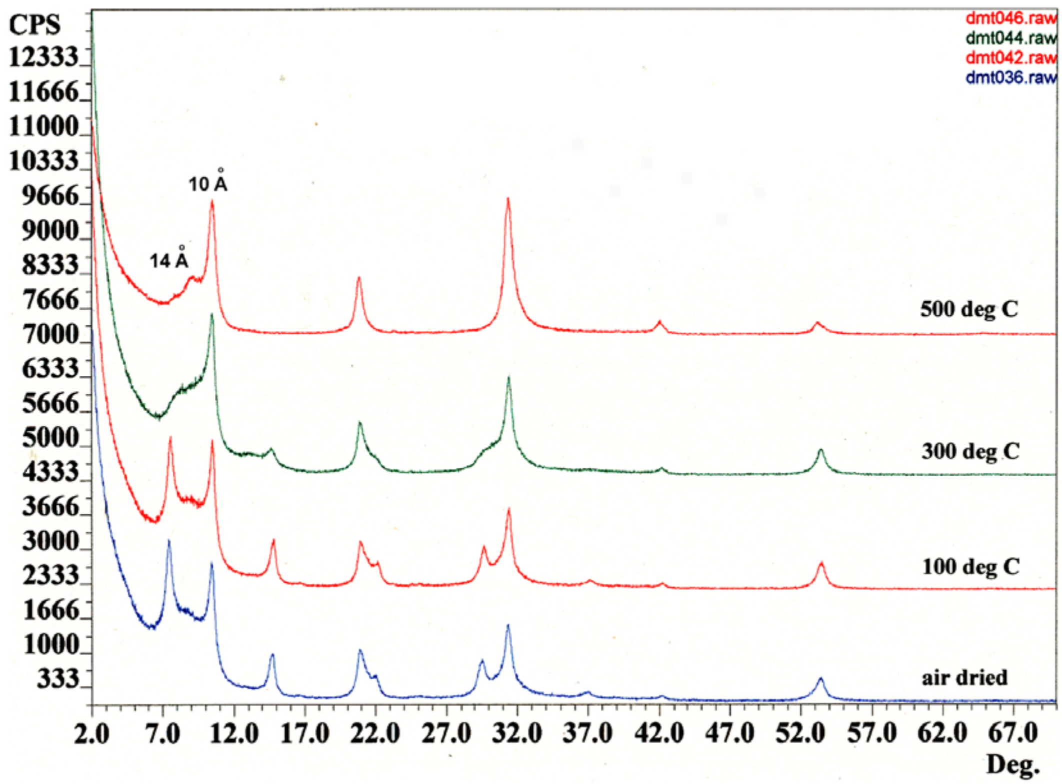


Figure 63: X-ray diffractograms of Mg-saturated clay separates (< 2 microns) from the 4Btx horizon of the Wyoming member type section, step-heated to 100, 300, and 500 degrees centigrade

possible to discriminate detrital from authigenic components. Combined with soil micromorphological study, the present analyses demonstrate that hydroxy-interlayered vermiculite is the primary authigenic phase formed in the ferriargillans of the Wyoming member.

Surfaces actively flooded during deposition of the Wyoming member are now at or just beneath the grade of the Holocene alluvial terrace (T-1). This means that at some point in time the earlier floodplain was abandoned, and the stratified archaeological sites provide age constraints on that landscape history. Most of the deposits underlying the T-1 surfaces mapped in **Appendix 1** belong to either the Wyoming member or the Central Builders member of the Wyoming Valley formation. The Wyoming member is somewhat more visible because it is found closer to the surface. Given the prevalence of the overbank sand and silt facies in the Wyoming, upstream erosion was probably supplying more sediment than could be transported out of the study reaches.

FORTY FORT MEMBER

The Forty Fort member is the least common of the four members of the Wyoming Valley formation, found only in particularly wide portions of the bedrock valley. The lower boundary of the Forty Fort member is a disconformable contact with either the Wyoming or the Central Builders. Based upon the type section exposed in a borrow pit at the Forty Fort Airport (see **Figure 64**), the basal discontinuity is marked by some scour which is probably due to channel avulsion. The Forty Fort member sediments are predominantly medium to coarse sand, massively bedded above the basal discontinuity as

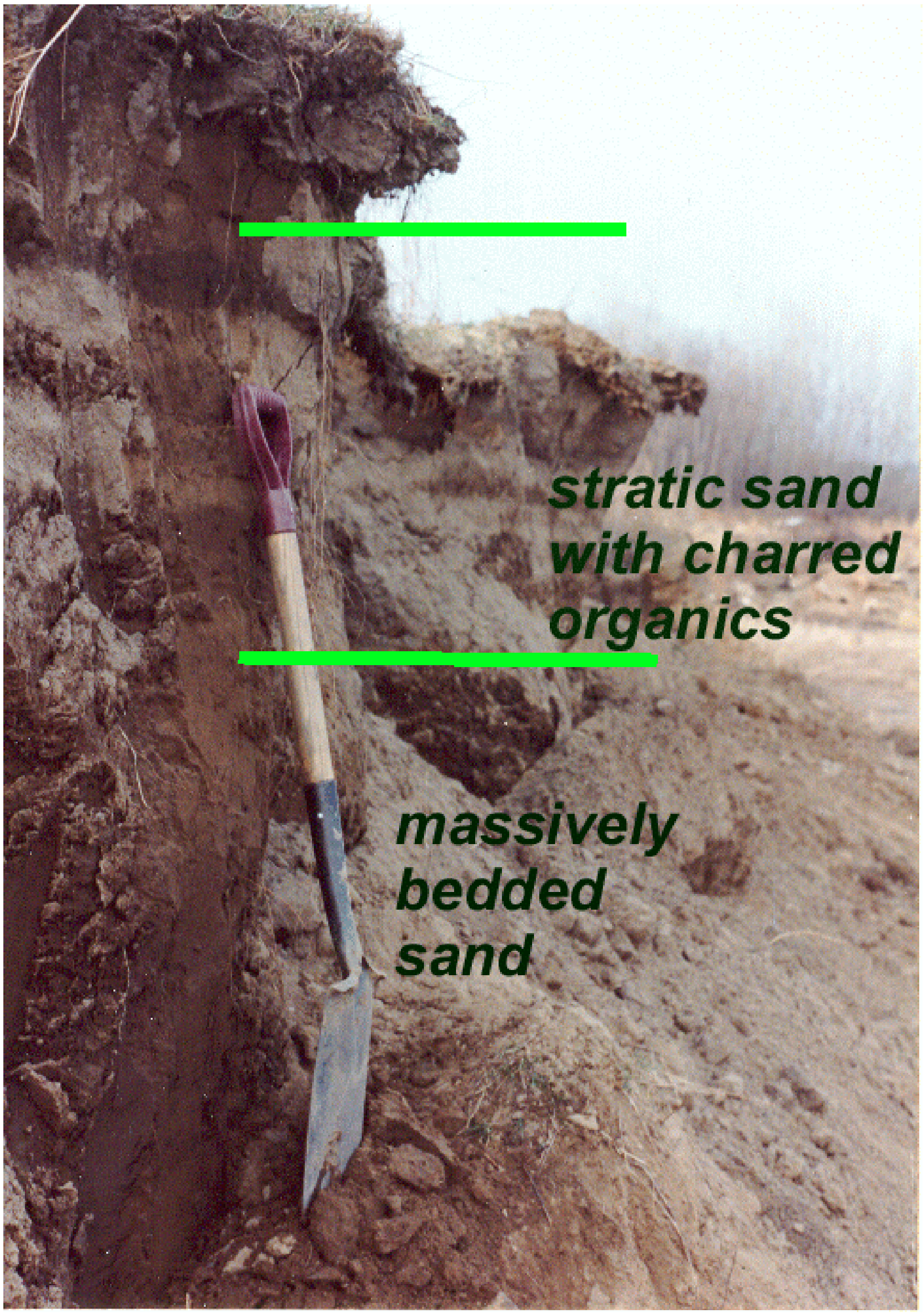


Figure 64: Type section of the Forty Fort member of the Wyoming Valley formation, the borrow pit at the Forty Fort Airport

Figure 65: Massively bedded sand lithofacies of the Forty Fort member at the base of the section in the borrow pit at the Forty Fort Airport in the Wyoming Valley

shown in **Figure 65**. Thin, discontinuous lamellae are also present, and lamellar sand and silt are reported for stratigraphically equivalent deposits elsewhere in the valley.

The stratic sand and charred organics lithofacies shown at the top of **Figure 64** is unique to the Forty Fort and occurs in nearly all alluvial deposits associated with late prehistoric agricultural villages in eastern Pennsylvania and adjacent New Jersey (Stewart, 1990; Wall and Stewart, 1996, p. 202-220). In terms of soil horizon nomenclature, there is a regular alternation of A or Ab horizons with the C horizon sands. Some of the coarser beds are over 80 % sand, based upon the laboratory results for Section 5 in the borrow pit at the Forty Fort Airport (**Table 15**). The 2Ab2 horizon, on the other hand, was 28 % muds (silt and clay).

The relative importance of climate change and human impact as factors in the deposition of the Forty Fort member of the Wyoming Valley formation are discussed in more detail in the following chapter. Specifically, it is hypothesized that localized disturbance of floodplain forests for swidden plots supplied much of the sediment of the stratic sand and charred organic matter lithofacies. Charcoal clasts several millimeters in diameter occur in the Forty Fort member sediments over a kilometer away from any of the actual late prehistoric village sites. There was a Forty Fort member deposit in the 8th Street Bridge Project Work Area, for example, over a kilometer upstream of the Clemson Island/Owasco villages at the Forty Fort Airport.

Table 15: Results of Laboratory Analyses for Column of 10 Samples from Section 5 in the Borrow Pit at the Forty Fort Airport

Horizon	**Depth**	**%Sa**	**%Si**	**%Cl**	**OM**	**pH**	**P**	**K**	**Ca**	**Mg**	**Zn**	**Mn**
Ap	10-20	68.0	22.0	10.0	0.87	6.00	121.0	52.0	793.0	109.6	3.39	9.78
CE	30-40	82.0	10.0	8.0	0.47	6.10	47.8	24.4	443.2	57.6	0.72	3.08
EC	45-50	88.0	8.0	4.0	0.07	6.30	38.6	19.3	454.7	54.2	0.55	2.40
2Ab1	60-65	84.0	10.0	6.0	0.47	6.50	38.4	23.0	577.5	50.0	0.61	2.29
2Ab2	70-75	72.0	20.0	8.0	0.87	6.40	26.1	21.6	734.5	41.6	0.54	2.75
2AB	85-95	76.0	16.0	8.0	0.40	6.70	28.9	24.9	531.5	31.4	0.45	3.30
2Bw1	110-120	60.0	28.0	12.0	0.47	6.80	29.9	18.4	771.0	49.0	0.63	2.45
2Bw2	130-140	64.0	26.0	10.0	0.54	7.00	29.3	13.0	707.0	47.5	0.55	1.96
3C1	160	52.0	34.0	14.0	0.87	6.80	27.6	14.6	944.0	68.9	0.69	2.75
3C2	160-170	70.0	22.0	8.0	0.54	7.00	30.9	10.3	642.0	48.6	0.74	1.82

NANTICOKE MEMBER

The Nanticoke member is more widespread in occurrence than the Forty Fort, but it is more diverse in composition and bedforms. The most characteristic lithofacies of the Nanticoke member is a laminar sand with anthracite particles introduced by mining in the Wyoming Valley and transport by barges along the North Branch Canal. The Nanticoke member deposits of this lithofacies may be several meters thick, particularly in reaches where the river was impounded behind crib dams and coal was loaded onto the barges. Laminar coal sand is also very common at both the upstream and downstream end of floodplain islands or in the abandoned bed of the canal itself.

The type section for the Nanticoke member is a terrace composed of sediment deposited by slackwater impounded upstream of the crib dam at Nanticoke, Pennsylvania (km 290). The terrace stands at least three meters above river grade, with over two meters of thinly laminated sand from the period that the canal was in operation (**Figure 66**). In thin-section, the anthracite particles are completely opaque and extremely angular (**Figure 67**). Quartz or quartzose sandstone clasts make up less than 50 % of the sediment, much of which is instead limpid yellow to brown clay and silt-sized clumps of mud. There are a few bright orange ferriargillans filling voids at the bedding plane which trends diagonally across the upper half of the field of view.

The Nanticoke may rest directly upon glacial outwash, and many of these basaldeposits often consist of the woody detritus lithofacies (see **Table 12**). Wood charcoal and other fine organic matter are also key constituents of the thinly laminated

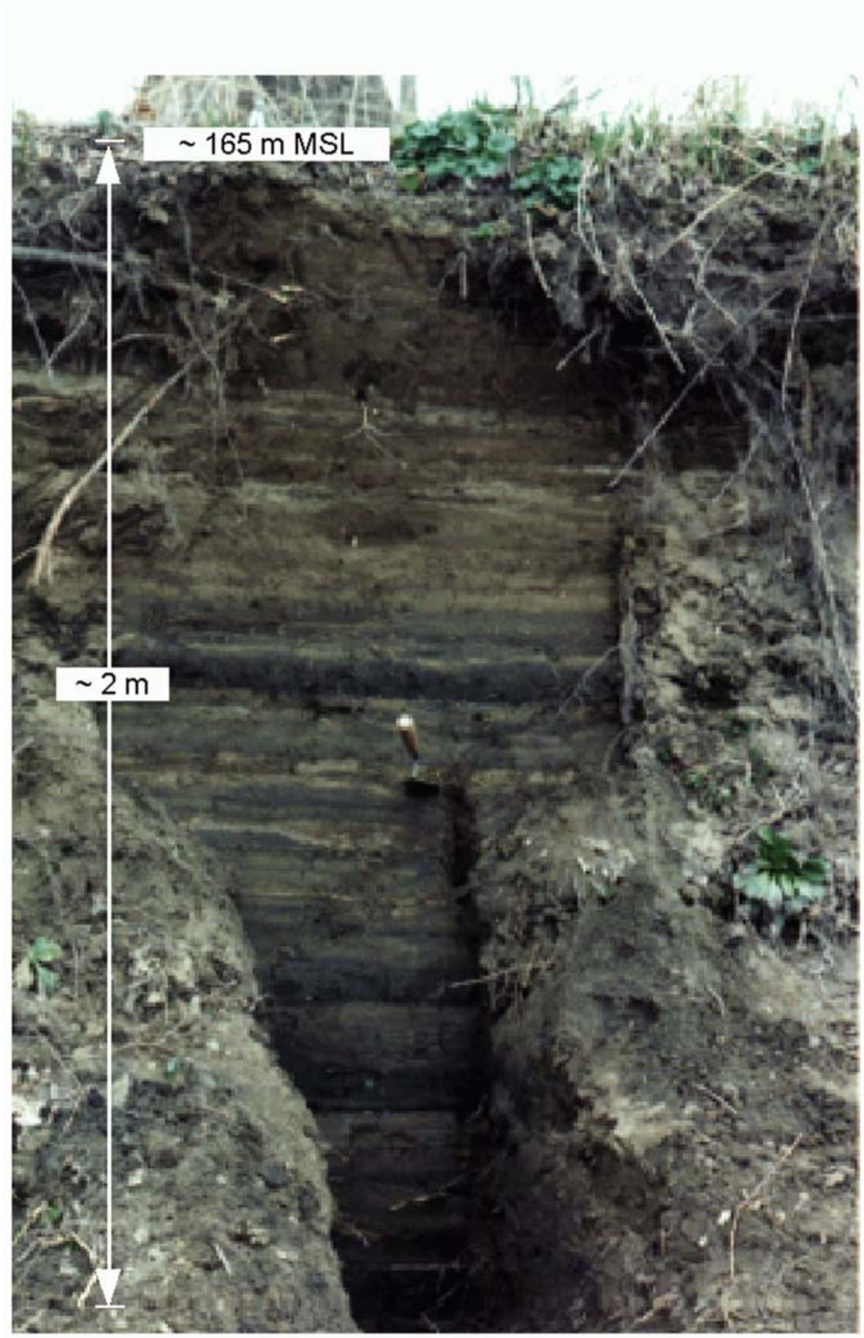


Figure 66: Laminar sand with anthracite particles exposed in terrace built by North Branch Canal slackwater pool upstream of the crib dam at Nanticoke (km 290)

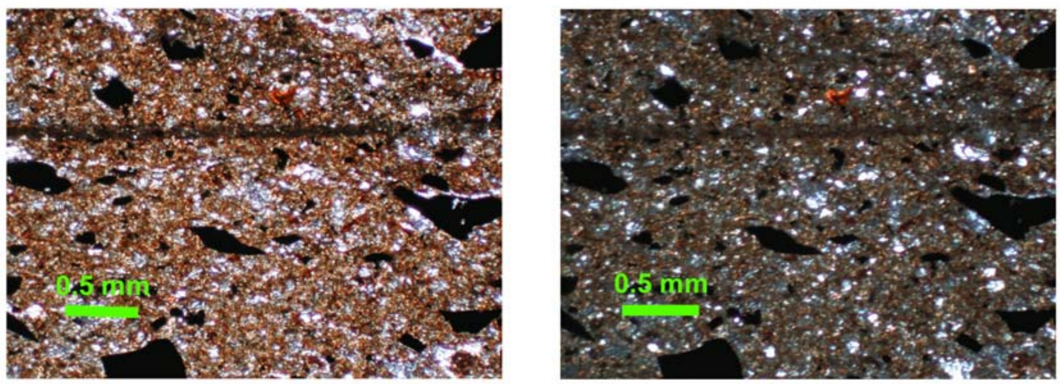


Figure 67: Photomicrographs in PPL (left) and XPL (right) of the thin-section of the laminar sand with anthracite particles from the terrace built by the Nanticoke slackwater pool

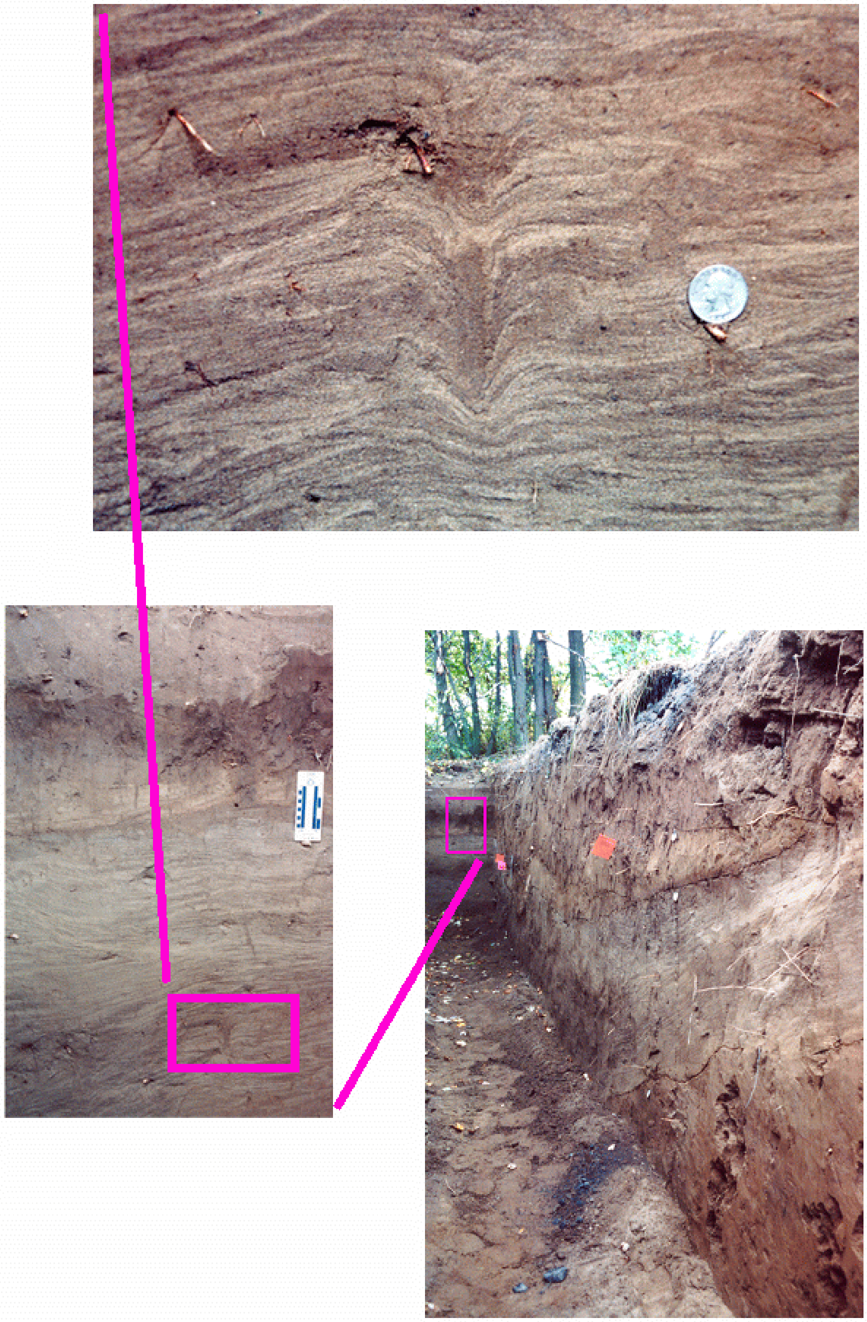


Figure 68: Thinly laminated sand lithofacies of the Nanticoke member exposed in the east wall (riverbank) of Trench 5 at the 8th Street Bridge Project Work Area in Wyoming, Pennsylvania (km 306)

sand lithofacies. The thinly laminated sand is frequently found in natural levee accumulations, where it typically overlies either the Wyoming or the Central Builders. **Figure 68** illustrates an exposure of the thinly laminated sand in Trench 5 at the 8th Street Bridge Project Area in Wyoming. A fine sandy to silty loam overbank lithofacies also occurs in the Nanticoke member as well as in the Forty Fort and the Wyoming.

All of the Nanticoke member lithofacies outcrop at the modern land surface, typically beneath a thin organic mat (O horizon) or an A horizon up to 20 cm thick. In the most urbanized reaches, the Nanticoke is sometimes mantled by municipal solid waste or leaf mulch dumped along the river banks. The overbank lithofacies deposits are thickest in local depressions, particularly those from old topsoil mines and gravel pits. Topsoil is mined from both the Wyoming and the Forty Fort members of the Wyoming Valley formation, while gravel is extracted primarily from glacial outwash.

TERRACE MAPPING, SOILS, AND STRATIGRAPHIC DISCONTINUITIES

The alluvial deposits of the North Branch of the Susquehanna River occur beneath either T-1 or T-0 surfaces, as mapped in **Appendix 1** for the reaches from Northumberland (km 202) upstream to Athens (km 452). The T-1 landform was mapped based on topographic contours and the USDA county soil surveys, while the bank height and $Q_{1.5}$ flood magnitudes were used to define the T-0. Aside from a few reaches where topsoil mining and other bank modifications have increased the area inundated by a bankfull flood, the T-0 deposits consist entirely of the Nanticoke member of the Wyoming Valley formation. The stratigraphy beneath the T-1 is more complex, and at least three of the members of the Wyoming Valley formation (Central Builders, Wyoming, and Nanticoke) have been observed to rest directly upon glacial outwash at the base of the terrace.

The Central Builders and Wyoming members make up the bulk of the T-1 deposits, and the discontinuities which bound them will now be traced through 23 stratigraphic sections summarized in **Table 15**. These are Discontinuities I-III for which tentative age constraints were presented in **Table 9**. Both Discontinuity I and Discontinuity II may be represented as a lower bounding surface where alluvium sharply overlies the outwash gravel. Discontinuities II and III are most typically represented by buried soils formed at the upper bounding surface of either the Central Builders member (Discontinuity II) or the Wyoming member (Discontinuity III).

Because of limited sample size, the characterization of the buried soils is admittedly qualitative. Soils formed in alluvium deposited after Discontinuity III do show significant differences in profile characteristics compared to the combined sample of soils formed at the top of either the Wyoming or the Central Builders (**Table 16**). No soils with fragic or argillic characteristics were found in deposits younger than Discontinuity III, and the cells for soils with cambic, fragic, and argillic characteristics were therefore grouped together in order to perform a 2 x 2 contingency table analysis (Fisher, 1970, p. 85-92; Snedecor and Cochran, 1989, p. 125-127) . Compared against stratic profiles, $\chi^2 = 19.8$ ($p<0.005$) in a one-tailed test for soils formed in sediment deposited before and after Discontinuity III.

Table 16: Representation of Soils and Discontinuities in Stratigraphic Sections, North Branch of the Susquehanna River Alluvial Deposits

Section Name	Site #	km upriver	Surface Elev.	River grade	Top of Section	Base of Section	SOILS	DISCONTINUITIES (Elev. MSL)
Central Builders	NB11	202.0	134	130	134.0	132.0	1 Fragic, 2 Cambic	I @ 132; II @ 133; III @ 133.7
Catawissa Bridge	CO9	228.0	143	138	143.0	138.0	1 Cambic, 1 Stratic	II @ 138.5; III @ 141; IV @ 142
Mifflinville Bridge	CO17	246.0	144	140	144.0	141.0	1 Cambic, 1 Stratic	I @ 141.25; II @ 142.8; III @ 143.5; IV @ 143.7
Zehner	CO2	253.0	146	141	146.0	142.0	2 Argillic, 1 Cambic	I @ 142; II @ 143; III @ 144.5
SSES-6	LU16	264.0	151	148	151.0	149.0	2 Cambic	III @ 149; IV @ 150; V @ 150.5
SSES-8	LU49	264.0	151	148	151.0	148.0	2 Cambic	II @ 148; III @ 151
Jacobs	LU90	266.0	153	147	153.0	147.0	2 Argillic, 1 Cambic, 3 Stratic	I @ 149; II @ 150; III @ 152
Skvarek	LU13	271.0	158	149	158.0	149.0	2 Argillic, 1 Stratic	I @ 152.5; II @ 154; III @ 156; IV @ 157
Bridge	LU60	300.0	160	157	160.0	158.0	1 Cambic	III @ 158; IV @ 159.5
Forty Fort Airport	LU44	304.0	163	160	163.0	161.0	1 Cambic; 3 Stratic	III @ 161.3; IV @ 162.0; V @ 162.4
8th St. Bridge	NA	306.0	165	161	165.0	161.0	1 Argillic; 1 Stratic	II @ 163; III @ 164; IV @ 164.5
Wyoming T-1 CB	NA	307.0	166	161	166.0	161.0	1 Argillic; 2 Fragic; 1 Cambic; 1 Stratic	II @ 161; III, IV @ 164; V @ 164.8
Wyoming T-1 B-2	NA	307.0	166	161	166.0	163.0	1 Cambic	I @ 163; V @ 165
Scovell Island	LU12	312.5	167	161	167.0	163.0	1 Fragic; 2 Cambic; 2 Stratic	I @ 163; II @ 165; III @ 165.7
Cremard's	LU58	313.0	168	161	166.0	161.0	1 Argillic; 3 Cambic; 2 Stratic	I @ 161; II @ 162.5; III @ 165.5; IV @ 165.7
Conrail	LU16	313.0	168	161	168.0	162.3	4 Cambic; 2 Stratic	I @ 162.3; II @ 164.7; III @ 167
Upper Exeter	NA	325.0	170	165	169.0	167.0	2 Cambic	III @ 168.5
Falls Bridge	WO56	331.0	174	168	174.0	168.0	2 Argillic; 1 Cambic	I @ 168; II @ 172; III @ 173; IV @ 173.7
Whites Ferry	NA	338.0	176	171	176.0	173.0	1 Fragic; 2 Cambic; 2 Stratic	II @ 174; III @ 175
Harding Flats	WO55	349.0	180	175	180.0	175.0	1 Cambic; 1 Stratic	II @ 176; III @ 177; IV @ 178; V @ 179.5
Friedenshuetten	BR81	396.0	204	198	204.0	201.0	2 Cambic	III @ 203.5
French Azilum	BR13	413.0	208	202	208.0	204.0	1 Fragic; 1 Cambic	I @ 204; II @ 207
Cass	BR57	424.0	215	210	215.0	210.2	3 Stratic	III @ 214

Table 17: Morphology of Soils formed in Alluvium deposited before and after **Discontinuity III** (2,750 - 2,100 cal BP), North Branch of the Susquehanna River valley

	Stratic	Cambic	Fragic	Argillic	Totals
After **Discontinuity III**	18	10	0	0	28
Before **Discontinuity III**	6	21	6	11	44
Totals	24	31	6	11	72

The present use of buried soils to define stratigraphic bounding surfaces demonstrates the benefits of describing and dating the soils formed in Susquehanna River alluvium rather than relying upon the ages attributed to geomorphic surfaces by Peltier (1949) and other early studies of the valley. A previous study of soils on terrace surfaces flanking the West Branch of the Susquehanna River (Engel et al., 1996) concluded that the degree of soil development was not sufficient to establish definitive age constraints on Susquehanna River alluvium. Discrete levels of B horizon development within the past 10,000 years have been identified, however, in other recent chronosequences for the eastern United States (Foss and Segovia, 1984; Leigh, 1996; Markewich and Pavich, 1991).

Based on the interpretation of the buried soils described for 16 of the 23 stratigraphic sections summarized in **Table 16**, the Central Builders and Wyoming

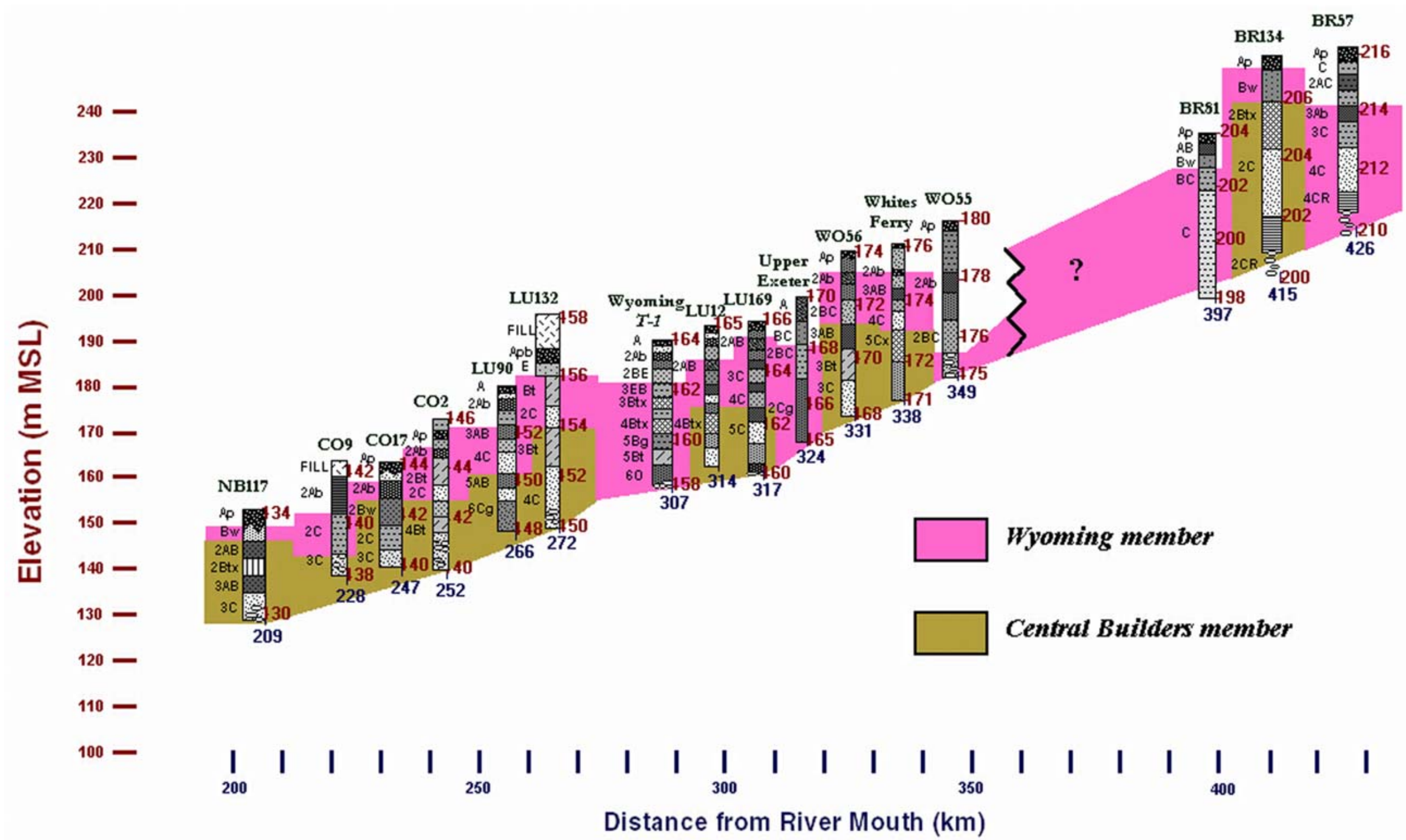


Figure 69: Composite Longitudinal Profile of the Alluvial Deposits of the North Branch of the Susquehanna River showing the members of the Wyoming Valley formation represented in 16 stratigraphic columns

members are traced for over 200 kilometers along the valley axis in **Figure 69**. The x-axis represents the distance upvalley in kilometers, while vertical exaggeration is used to show the relative position of each profile and the two allostratigraphic units. Locations which represent archaeological sites are indicated with a two letter abbreviation for the county (NB, CO, LU, WY, or BR) followed by the number as recorded consecutively at the Pennsylvania Historical and Museum Commission (PHMC) in Harrisburg. The number "36" representing Pennsylvania in an alphabetical list of states is also generally prefixed when archaeological site numbers are used in this dissertation.

Data were obtained during the course of this study from a total of 50 archaeological sites, 18 cutbank profiles, and 57 borings with hand auger or Giddings Rig. The sections used to develop the allostratigraphic framework simply represent the locations where the most complete profiles were described in the most detail. The strengths and limitations of the stratigraphic record as a whole will be evident from the following descriptions of each study location.

THE CENTRAL BUILDERS SITE (36NB117)

Site 36NB117 is on the right bank of the river seven kilometers upstream of Northumberland, Pennsylvania (km 202) on property owned by Central Builders, Incorporated. T-1 and T-0 landforms are mapped for these river reaches on **Figure 70**. The archaeological contexts are in deposits underlying the T-1, which stands at approximately 134 m MSL or four meters above the active river channel.

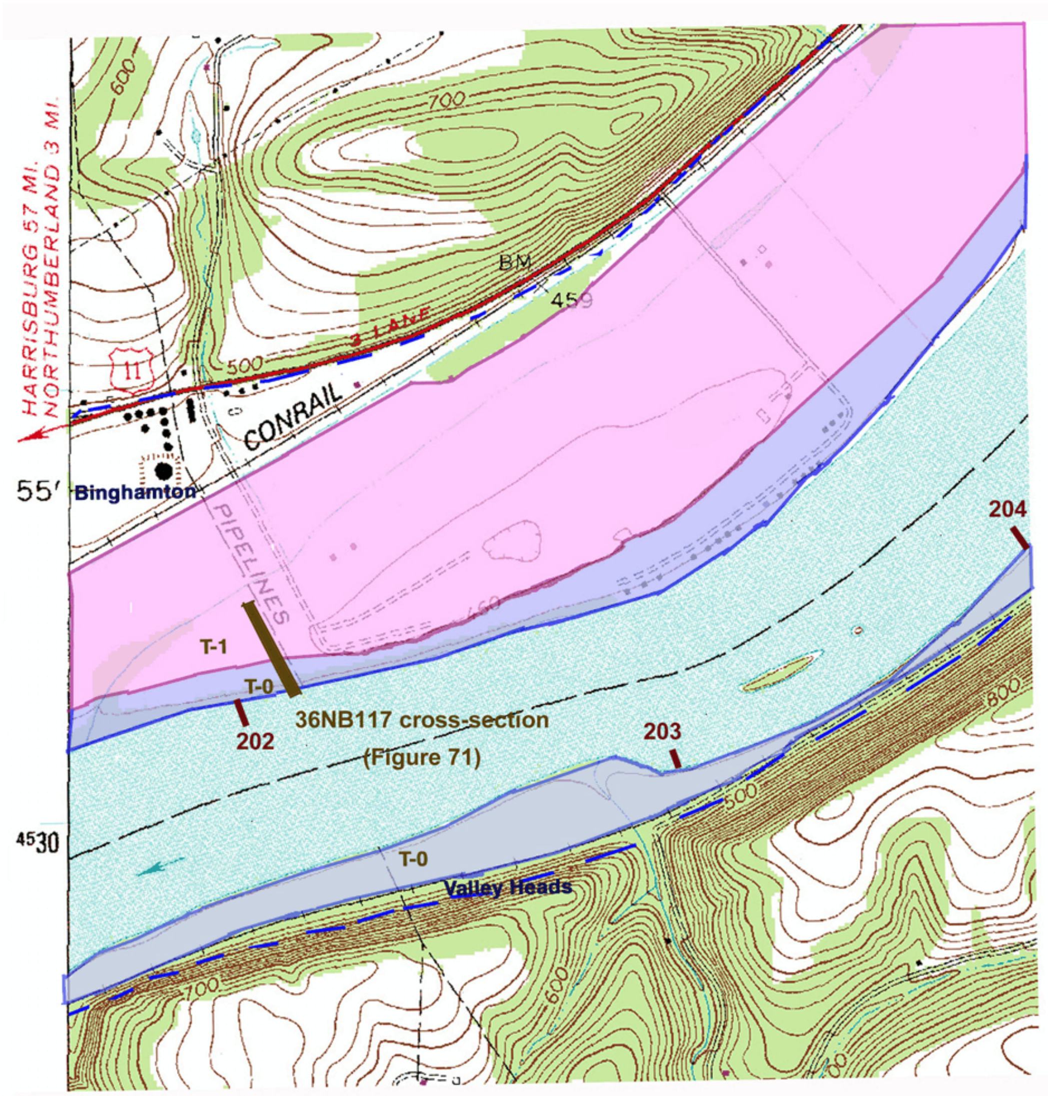


Figure 70: Part of the Riverside quadrangle USGS 7.5' Topographic Map showing landforms mapped in the vicinity of the Central Builders site (36NB117)

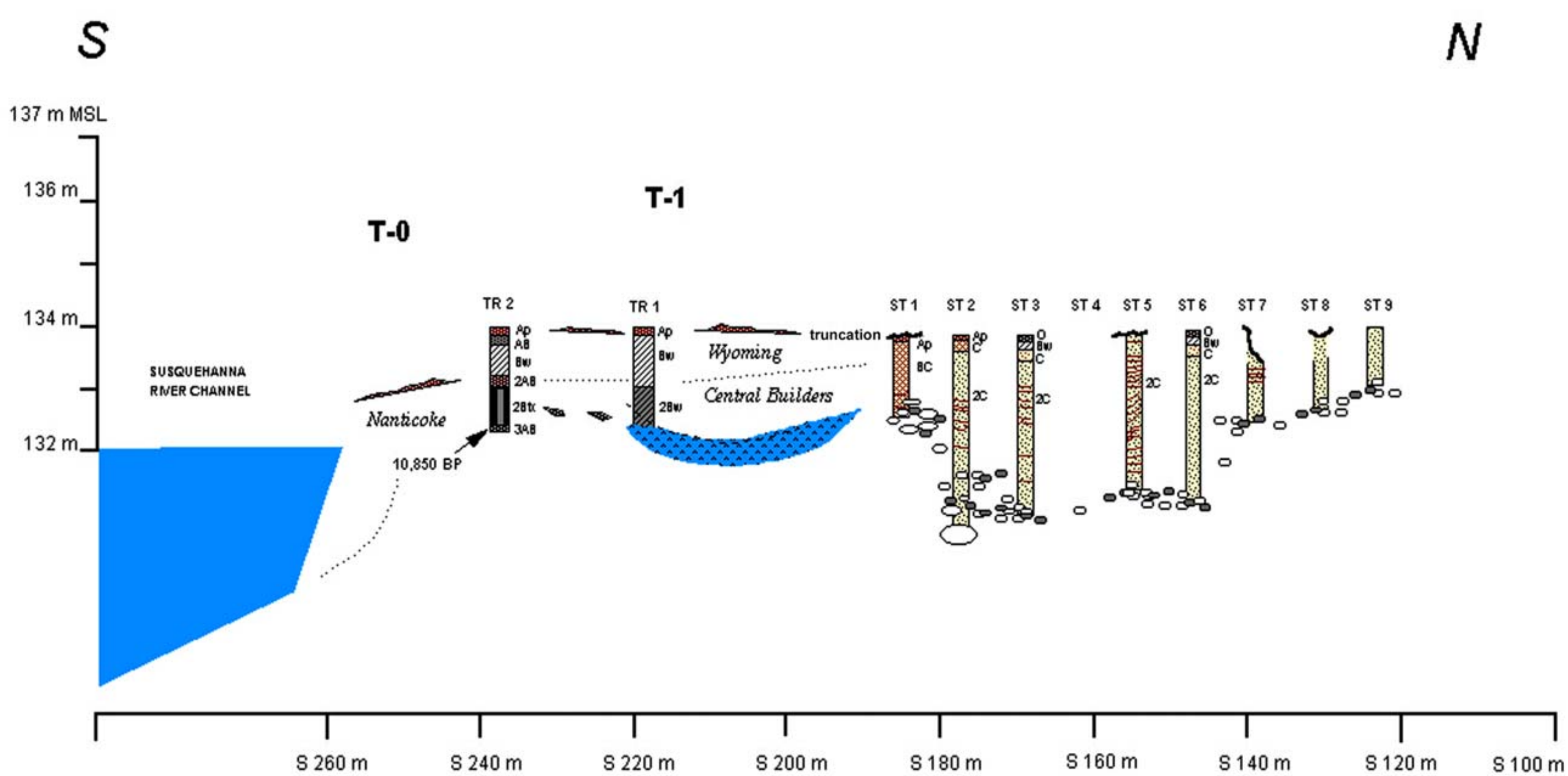


Figure 71: Schematic cross-section of the Cetnral Builders site (36NB117) upstream of Northumberland, Pennsylvania

Figure 71 shows the stratigraphy described when the site's deposits were tested by archaeologists from the Pennsylvania Historical and Museum Commission (PHMC). The test excavations included two deep hand-excavated trenches (Trench 1 and Trench 2) and nine small backhoe cuts (ST-1 through ST-9). An Early Archaic component was encountered approximately 2.6 m below surface in Trench 2 (Baker, 1993; Carr, 1998b, p. 51-52), represented by a rhyolite corner-notched projectile point or knife (Kirk, Palmer, or Charleston type on **Figure 14**). The point was associated with Feature 8, a hearth containing wood charcoal dated to 9165 +210/-205 BP (A-10053), which calibrates to 11,070-9,699 BP at 2-sigma (Stuiver et al., 1998). The date of 10,850 BP shown on **Figure 70** is the midpoint of the middle calibration intercept.

The Early Archaic component at Central Builders was found in the upper 20 cm of a buried soil (3AB horizon). The 3AB horizon was in turn overlain by another strongly developed soil with fragic properties (2Btx horizon). The 2Btx occurred in both Trenches 1 and 2, and its fragic properties included coarse prismatic peds, polygonal cracks, firm consistence, and a brittle manner of failure (Soil Survey Staff, 1997, p.l 15; Witty and Knox, 1989).

A thin 2AB horizon capped the 2Btx at Trench 2, defining the top of a buried ridge approximately 1.2 m below the present terrace surface. The Early and Middle Archaic artifacts and pit features at site 36NB117 were either on or within this ridge feature. High-energy stream channel sands and gravels which preserved no intact prehistoric contexts were found landward of this feature in the area tested by nine short trenches, ST-1 through ST-9. Longitudinal bars of sand with both planar and trough crossbedding are shown in detailed profiles of these trenches on file at the PHMC.

The lower bounding surface of the Central Builders member at site 36NB117 (Discontinuity I) is no younger than the date of 11,070-9,699 cal BP for Feature 8. The 2AB horizon marks the contact between the Central Builders member and the overlying Wyoming member of the Wyoming Valley formation (Discontinuity II). The presence of a buried soil means that this is a disconformable contact marking an interval when there was little or no floodplain deposition. Because the cultural materials were sparse and of less interest to the archaeologists, no independent age constraints were obtained on the upper stratigraphy at this site. During a brief field visit to site 36NB117 in 1999, I noted anthracite particles in the sediments recovered from an auger boring on the T-0. This is the basis for the identification of the Nanticoke member on the schematic cross-section (**Figure 71**).

CATAWISSA BRIDGE (36CO9) AND RUPERT (36CO3)

The next stratigraphic section moving upvalley along the x-axis on **Figure 69** is from the site excavated prior to the replacement of the S.R. 42 bridge over the river at Catawissa (km 228). The bridge construction impacted prehistoric site 36CO9 in the southwest quadrant of the work area. The site was reported by Struthers and Barrett (1982), and test excavations resulted in a finding of eligibility to the National Register of Historic Places (Struthers, 1983). Mitigation of adverse impact was accomplished through data recovery excavations by the University of Pittsburgh Cultural Resource Management Program (East et al., 1984, 1988).

Five "occupational episodes" were identified at site 36CO9, all of which were contained within two of the fourteen strata described as lithostratigraphic units by Jack Donahue in the University of Pittsburg interim report (East et al., 1988, p. 73-74). The ten radiocarbon dates reported by Herbstritt (1988) have a combined 2-sigma range of 450-2450 BP in ^{14}C years, or AD 500-1500 in calibrated calendar years (Stuiver et al., 1998). Three of the five occupational episodes are represented by discrete living floors within Stratum IV, a buried A (2Ab) soil horizon within a stratic profile.

Using a vertical exaggeration of 1:3, I have prepared a schematic drawing (**Figure 72**) which depicts the position of the Middle to Late Woodland living floors at 141.0-141.8 m MSL within the T-1 alluvial terrace opposite the mouth of Catawissa Creek. The living floors at site 36CO9 were defined by tracing artifact concentrations and cultural pit features along relatively continuous surfaces (East et al., 1988, p. 73). A floor was identified at the contact between the 2Ab (Stratum IV) and underlying 2BC (Stratum III) horizons, and one additional floor was identified 10 cm beneath the top of the 2BC (East et al., 1984, p. 12). A moderate degree of subsoil development is indicated for this horizon by its description as "compact" with light-yellowish brown to light reddish-briwn color. The use of "C" in the "2BC" designation indicates the preservation of primary depositional bedding, including these two Middle Woodland living floors.

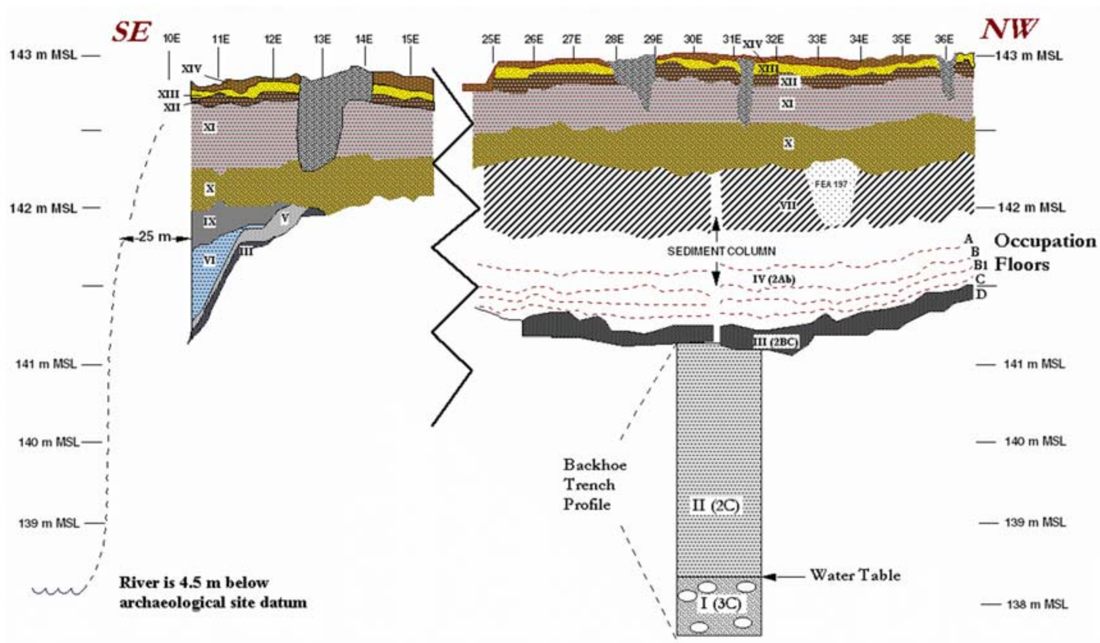


Figure 72: Schematic stratigraphy showing the position of the site 36CO9 occupation floors within the T-1 alluvial terrace opposite the mouth of Catawissa Creek (km 228)

At least 90 cm of culturally sterile alluvium were hand excavated beneath the lowest occupation floor in one 2 x 2 m unit at site 36CO9 (East et al., 1984, p. 121). A backhoe trench was also excavated down to culturally sterile sandy gravel (Stratum I) at five meters below surface, or 138 m MSL, capped by light gray clay (Stratum II). The gravel was saturated with groundwater, which it was probably perching. The deepest part of the excavation was still over a meter above river grade. Unfortunately, no organic material suitable for radiocarbon dating was recovered from the basal deposits at site 36CO9.

Although no buried soil was described for the upper bounding surface, the basal sandy gravel (Stratum I) is assigned to the Central Builders member of the Wyoming formation on Figure 69. Light gray clay (Stratum II) is assigned to the Wyoming member. This is particularly plausible in light of the more typical Wyoming member deposits which occur only three kilometers upstream at Rupert (km 231). Excavations by Dee Anne Wymer of Bloomsburg University at site 36CO3 recovered rhyolite debitage, Brewerton PPKs, and other Late Archaic cultural materials from overbank silt and fine sandy loam at depths from 50-150 cm below the surface ot a T-1 landform.

Strata III and IV at site 36CO9 were Forty Fort member deposits, which rarely occur outside of the Wyoming Valley. The fine textures reported for samples from living floors IVA and IVB are somewhat atypical of the Forty Fort, making this an example of the overbank sand and silt as opposed to the stratic sand and charred organic particles lithofacies. The median grain size increases abruptly from 7 f (7.8 microns) in Stratum IV to 4 f (63 microns) in Stratum VII. The standard deviation of the particle size distribution is also higher for the sandier Stratum VII bed. Euroamerican artifacts such as wire nails and bottle glass were recovered from Strata VI, VII, X, XI, XII, and XIV during the archaeological excavations. Anthracite coal particles were identified in Strata XI and XIV, and they can be assigned to the Nanticoke member of the Wyoming Valley formation.

Possible Protohistoric archaeological contexts are indicated at site 36CO9 by ceramics with Susquehannock affinities (East et al., 1984, p. 12) and by two radiocarbon dates (PITT-9 and PITT-10) with calibration intercepts in the 15th century. This reach of the North Branch of the Susquehanna River valley may have been one of the last areas occupied by the Susquehannock peoples prior to their migration to the lower Susquehanna valley (Kent, 1993, p. 19).; Members of the Tutelo, Conoy, and Delaware also reportedly settled at the village of Oskohary on the opposite bank from site 36CO9 during the 18th century (Kent et al., 1981).

THE MIFFLINVILLE BRIDGE SITES (36CO15, 16, 17, and 18)

A little less than 20 km further upstream, replacement of the S.R. 2028 bridge impacted archaeological sites on both sides of the river at Mifflinville (km 247). All four of the sites were multicomponent, and the styles of PPK recovered in the excavations indicate Early Archaic, Middle Archaic, Late Archaic, and Woodland occupations (Wall et al., 1990, p.32). At the sites on the left bank (36CO15, 16, and 18), most of the artifacts were associated with a relict plowzone buried by half a meter of industrial fill.

The archaeological contexts were not ordered stratigraphically, and the Holocene alluvium was relatively thin (<1 m) over the underlying outwash gravel.

Site 36CO17 was on the right bank of the river in both the northeast and northwest quadrants of the bridge replacement project (Wall et al., 1990). Three meters of Holocene alluvium containing stratified archaeological contexts were excavated beneath the surface of the T-1 landform. A large, uncarbonized log of deciduous wood collected from the base of one of two backhoe trenches was radiocarbon dated to 10,496-9,910 cal BP (2-sigma range). This is another minimum age for the base of the alluvial deposits, the disconformable contact between the Wyoming Valley formation and glacial till or outwash. The overlying sediments were relatively fine-grained compared to the coarse sandy textures typical of the Central Builders member.

A buried soil (2Bw horizon) marked the upper bounding surface of the Central Builders member at site 36CO17. Radiocarbon dates suggest an age of 8,933-8,593 cal BP for the buried soil, although no PPKs or other diagnostic prehistoric artifacts were recovered from these levels of the site (Levels 14-15). Three pit features in the overlying deposits of the Wyoming member did contain both dateable charcoal and PPKs. Feature 22 contained a Poplar Island PPK, one of the Late Archaic "Piney Island" types shown on **Figure 40**. The associated radiocarbon age is 4,968-4,299 cal BP (Beta-114821). Features 18 and 21 represent a Terminal Archaic Period component with Lamoka and Susquehanna Broadspear PPKs and charcoal dates of 4,148-3,841 cal BP (Beta-84324) and 4,146-3,728 cal BP (Beta-84325).

The contacts for the Wyoming and Central Builders members at the Mifflinville Bridge site are shown in the third of the 14 stratigraphic columns on **Figure 69**. A second buried soil (2Ab horizon) from 0.3 to 0.6 m below the T-1 surface caps the Wyoming member deposits. This buried soil formed on the same surface which was intruded by Features 18 and 21. Some Early Woodland cultural material was recovered below the plowzone, including a single potsherd. The Forty Fort member is not represented, and the uppermost sediments belong either to the Nanticoke member or to more recent (20^{th} century) industrial disturbance.

THE ZEHNER SITE (36CO2)

Five kilometers upstream of site 36CO17, Nescopeck Creek joins the North Branch of the Susquehanna River from the southeast. A Bloomsburg University fieldschool under the supervision of Dee Anne Wymer excavated several Middle and Late Woodland house basins on a site immediately downstream of the creekmouth. Site 36CO2, the Zehner site, is at least 200 m from the active river channel on a T-1 landform which stands approximately five meters above river grade, or ~146 m MSL.With the assistance of a field school student, Renee Knecht, I performed a hand auger boring to a total depth of 3.7 m below the T-1 surface. **Figure 73** illustrates the stratigraphy of the boring.

The T-1 has been mapped in **Appendix 1** as an old alluvial fan of Nescopeck Creek following Inners (1978, Plate 2), but the members of the Wyoming Valley formation can nonetheless be identified on the basis of buried soils at upper bounding

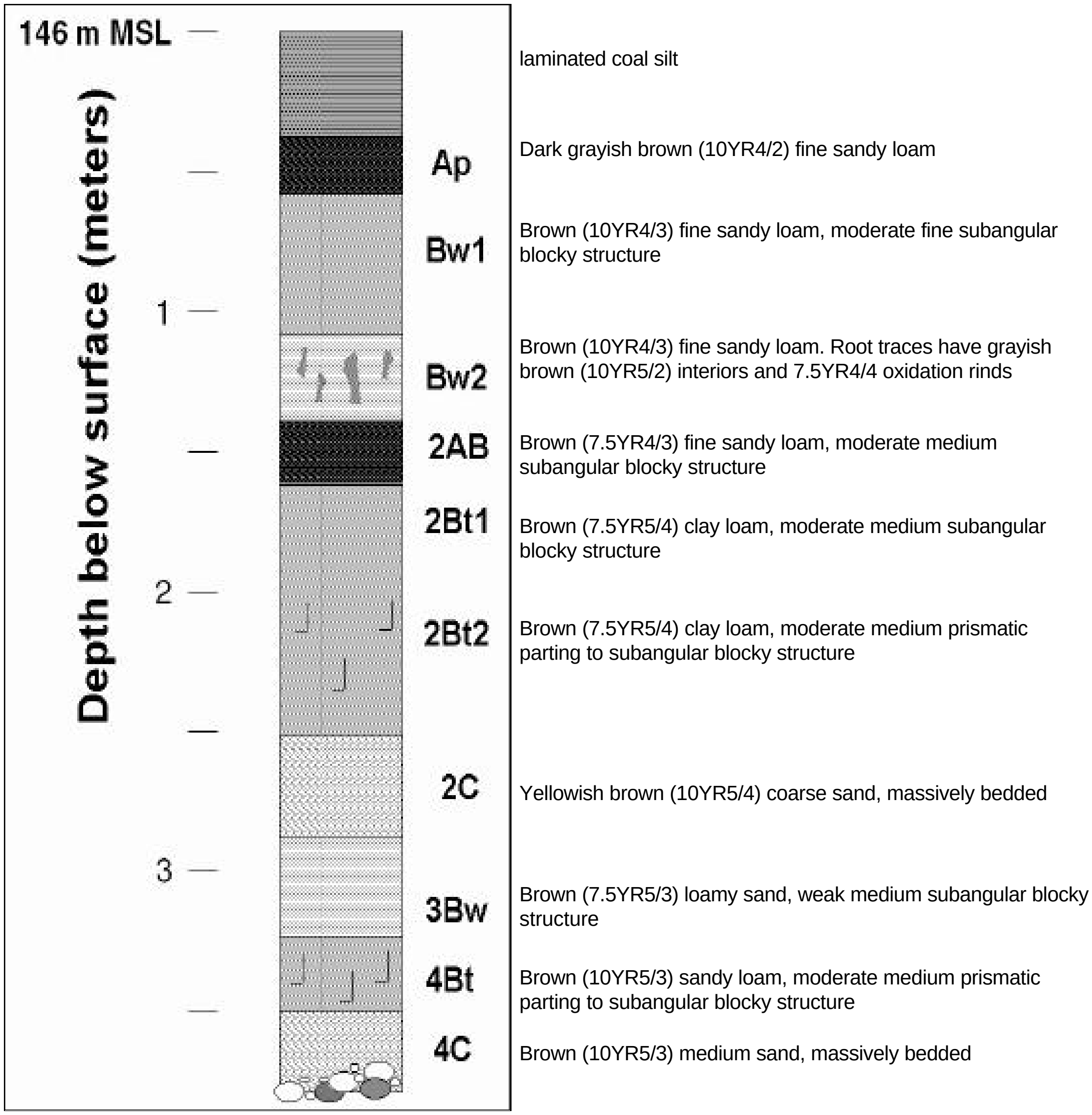


Figure 73: Stratigraphy of hand auger boring at the Zehner site (36CO2)

surfaces. The Middle and Late Woodland components are in a moderately well developed(Bw) subsoil, which is capped by up to 50 cm of laminar silt with anthracite particles. This upper deposit belongs to the Nanticoke member, while the bioturbated fine sand and silt below the Woodland living floors are overbank deposits of the Forty Fort member. All of these sediments were deposited by river floods, and they contained no gravel splays or sand lenses which would be characteristic of alluvial fan deposits.

The upper boundary of the Wyoming member of the Wyoming Valley formation is marked by a buried soil (2Ab-2Bt1-2Bt2) formed on a relict terrace ~1.5 m below surface. There are thin, discontinuous clay films on the faces of the peds in the 2Bt1 and 2Bt2 horizons. No prehistoric artifacts or features were recovered from the buried soil, but the Bloomsburg University fieldschool did not attempt to sample to this depth with their test units. The contacts for the Wyoming member and for the underlying Central Builders member at site 36CO2 are shown in the fourth of the 16 stratigraphic columns in **Figure 69**.

A coarse sand bed approximately 20 cm thick occurs occurs immediately beneath the 2Bt2 horizon in the site 36CO2 boring, representing a high-energy discharge, which appears to have scoured the surface sediment of an earlier buried soil (3Bw horizon). The well-developed 3Bw horizon is in turn welded to the top of an extremely well-developed subsoil with medium-sized prismatic peds and continuous clay films (4Bt horizon). These horizons formed at the upper bounding surface of the Central Builders member (Discontinuity II). The auger was refused by resistant gravel at ~3.8 m below surface. This is the lower boundary of the Central Builders member (Discontinuity I). The underlying deposit is either glacial outwash or an alluvial fan deposit which reworked the outwash.

THE "SUSQUEHANNA RIVERLANDS" OF PENNSYLVANIA POWER AND LIGHT

On the right bank of the river, less than ten kilometers upstream of the late Wisconsinan terminal moraine at Berwick (km 256), are the "Susquehanna Riverlands" and the Steam Electric Station (SES) of Pennsylvania Power and Light (**Figure 74**). Construction on the plant began in 1973 and it was in commercial operation by 1973 (Inners, 1988b). Cultural resources investigations of the project area were conducted by Commonwealth Associates, Inc. (Hayes et al., 1981; Schuldenrein et al., 1981). Eight archaeological sites were identified in stratified alluvium of the river terrace (**Table 18**), only three of which had been previously reported.

The age of the occupations found on upper bounding surfaces suggest that the T-1 landform accreted laterally between the Late Archaic Period and the Late Woodland Period. Sites 36LU15 and 36LU50 were on an older landform defined by a 1-2 m scarp or ridge slope approximately 80-100 m from the active river channel. Late Archaic occupations were shallowly buried approximately 3-5 m above river grade. At site 36LU49, a buried surface sloping toward the river was traced with backhoe trenches. Charcoal samples from a rock hearth feature excavated at 1.7 mbs in trench STT-9 were dated to 4,815-4,094 cal BP (Beta-1800) and 3,984-3,477 cal BP (Beta-1799).

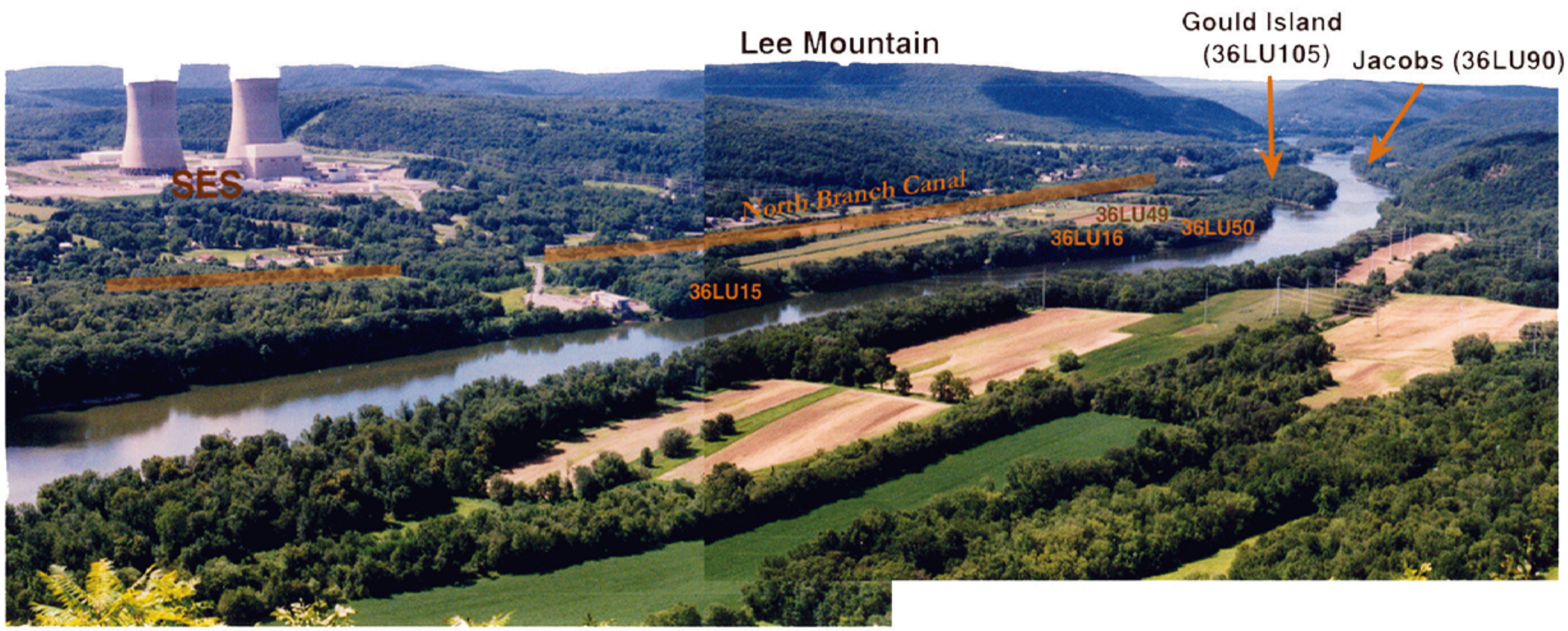


Figure 74: The North Branch Lowland between Gould Island (km 206) and the Susquehanna Steam and Electric Station (km 264)

Table 18: Archaeological Sites identified in the Alluvial Terrace at the Susquehanna Steam Electric Station (km 264)

Site	Field Number	Components
36LU15	SES-3	Late Archaic
36LU16	SES-6	Middle/Late Woodland
36LU49	SES-8	Late Archaic-Terminal
36LU50	SES-10	Late Archaic
36LU51	SES-11	Late Woodland
36LU17	SES-13	Late Archaic-Terminal Archaic
36LU52	SES-14	Undetermined
36LU48	SES-16	Historic

The younger date from the rock hearth in trench STT-9 agrees with the Terminal Archaic affiliation suggested by the steatite bowl sherd found in the feature. A similar feature was found buried over three meters below surface in trench STT-8, eight meters riverward of STT-9 (Hayes et al., 1981, p. 178). The alluvial deposits beneath the Late or Terminal Archaic occupations on the older T-1 landform at the Susquehanna SES are here assigned to the Wyoming member of the Wyoming Valley formation. The younger and slightly lower lying T-1 surfaces riverward of sites 36LU15 and 36LU50 are underlain by deposits of the Forty Fort member. Middle to Late Woodland occupations are indicated for these surfaces by the diagnostic artifacts recovered from sites 36LU51 and 36LU16.

Limited test excavations at site 36LU51 suggest that archaeological contexts are confined to the upper 50 cm (Hayes et al., 1981, p. 127-131). The diagnostic artifacts recovered include a Madison triangular projectile point and quartz-tempered pottery sherds without visible surface decoration. The archaeological contexts at site 36LU16 were more deeply buried and more extensively tested due to their exposure by a drainage ditch excavated by the utility company (Hayes et al., 1981, p. 102-112). Two pit features were identified at depths of over 50 cmbs in profiles cut in the walls of the drainage ditch.

Charcoal from Feature B1 at site 36LU16 was radiocarbon dated to 2000±130 BP (Beta-1801), or 362 BC - AD 320 in calibrated calendar years (2-sigma range). The calibrated range overlaps both the Early and Middle Woodland Periods, but the investigators considered the date too early for the ceramics (Hayes et al., 1981, p. 111-112). The sherd exterior surfaces were decorated with nodes, punctates, and cord impressions, and these surface treatments are certainly not characteristic of Early Woodland types such as Vinette 1 or Point Peninsula (Custer, 1996; Kent, 1980; Ritchie, 1969). The local Middle Woodland pottery can be decorated, however, although very little of it had been excavated in the North Branch of the Susquehanna River valley when the report was written.

The silt loam textures determined by particle size analysis (Hayes et al., 1981) suggest that overbank flood deposition predominated in both the Wyoming and the Forty

Fort members at the Susquehanna SES. Mixing and addition of fines by soil formation and bioturbation were noted in the field descriptions, however. Due to such soil-forming processes, the texture of 12% sand, 68% silt, and 20% clay for the 2Ab horizon at STT-8 may not be representative of the unweathered Wyoming member alluvium. Slackwater deposits would also be expected locally in this wider valley reach. This could explain the 23% clay peak in the BC horizon at STT-8, overlying the buried soil at the top of the Wyoming member.

At site 36LU16, over 15 percent sand was found in the sediment capping the relict levee containing the Woodland pit features (Hayes et al., 1981, Figure V.b.7). I noted anthracite particles in a boring I performed on the site in 1998, so that this deposit can be assigned to the laminar sand lithofacies of the Nanticoke member. Sandy and poorly sorted sediment textures were noted in older deposits at the upstream end of the SSES alluvial terrace (Hayes et al., 1981, p. 194-195). Lateral variation in sediment textures may result from separation in the river's flow around Gould Island and through the narrow (<100 m) chute between the island and the alluvial terrace. Since the braiding and transport of coarse sediment appear to have been particularly prevalent during the deposition of the Forty Fort member, earlier archaeological contexts may have been eroded or reworked. At more distal floodplain locations such as site 36LU15 and 36LU50 on the other hand, deposition of finer-textured alluvium may have actually protected the archaeological contexts from later agricultural disturbance.

THE JACOBS (36LU90) AND GOULD ISLAND (36LU105) SITES

The Jacobs site (36LU90) and Gould Island (36LU105) are a little over three kilometers upstream of the Wisconsinan terminal moraine (km 261-263). Although the river is flowing almost due south and across strike, it has already entered the strike-parallel bedrock valley of the North Branch Lowland (**Figure 74**). Only two kilometers downstream of Gould Island (km 266), at the mouth of Wapwallopen Creek (km 264), the river bends west to follow the strike valley trend. The deep alluvial deposits in which these two stratified sites are found clearly result in part from local bedrock controls.

Archaeological investigations were conducted at sites 36LU90 and 36LU105 in 1987 and 1988 prior to the construction of the Transcontinental Gas Pipeline (Weed and Wenstrom, 1992; Weed et al., 1987). The Jacobs site (36LU90) is on the left bank of the river and the pipeline disturbance was confined to a right-of-way approximately 50 m (150 feet) wide. Fourteen radiocarbon dates were obtained (Weed and Wenstrom, 1992, Appendix D) only two of which are reported in Herbstritt (1988, p. 14). All of the samples dated were charcoal from cultural pit features with the exception of a geological sample of the "Ab6" horizon.

The "Ab6" geological sample from site 36LU90 was selected for dating by a consultant, Frank Vento. The sample was collected approximately a meter below the earliest cultural levels, or two meters below the surface of the six meter high T-1 landform. At this depth in the test unit profile, Vento observed what he interpreted to be a change from coarse, laterally accreted sand to finer-textured overbank flood deposits in the terrace stratigraphy. In terms of the present stratigraphic framework, this would probably be the contact between the Central Builders member and the Wyoming member of the Wyoming Valley formation (Discontinuity II). The present reanalysis suggests that this contact does indeed occur at this depth, although the date of 9,469-8,648 cal BP obtained for the "Ab6" sample (Beta-43796) would seem more appropriate for the lower portion of the Central Builders member. The date was obtained on dispersed organic matter in bulk sediment.

In 1998, I performed a hand auger boring approximately 200 m north of the pipeline at site 36LU90 in order to redescribe and possibly to date the alluvial deposits (**Figure 75**). I recorded six discrete packages of alluvium bounded by soils, and I collected a charred nutshell fragment from the "6AB" horizon, 290 cmbs. Radiocarbon dating of this undated sample would provide another valuable age constraint on the lower boundary of the Central Builders member (Discontinuity I), which is the regional equivalent for the Pleistocene-Holocene boundary of the geological time scale (Hageman, 1972; Harland et al., 1990). The upper boundary of the Central Builders member (Discontinuity II) is the most strongly developed buried soil, the 5AB-5B1-5B2 group of horizons at 200-250 cmbs. Moderate medium prismatic structure and thin continuous clay coats occur in the 5B1 horizon.

Based on correlation with the archaeological excavation profiles, the 3AB horizon at 80-100 cmbs in my hand auger boring represents the surface occupied during the Late Archaic and Terminal Archaic Periods. As noted in the previous chapter, there are problems with averaging the radiocarbon dates from these components due both to site formation factors (Schiffer, 1987; Smiley, 1998b) and abrupt climate change

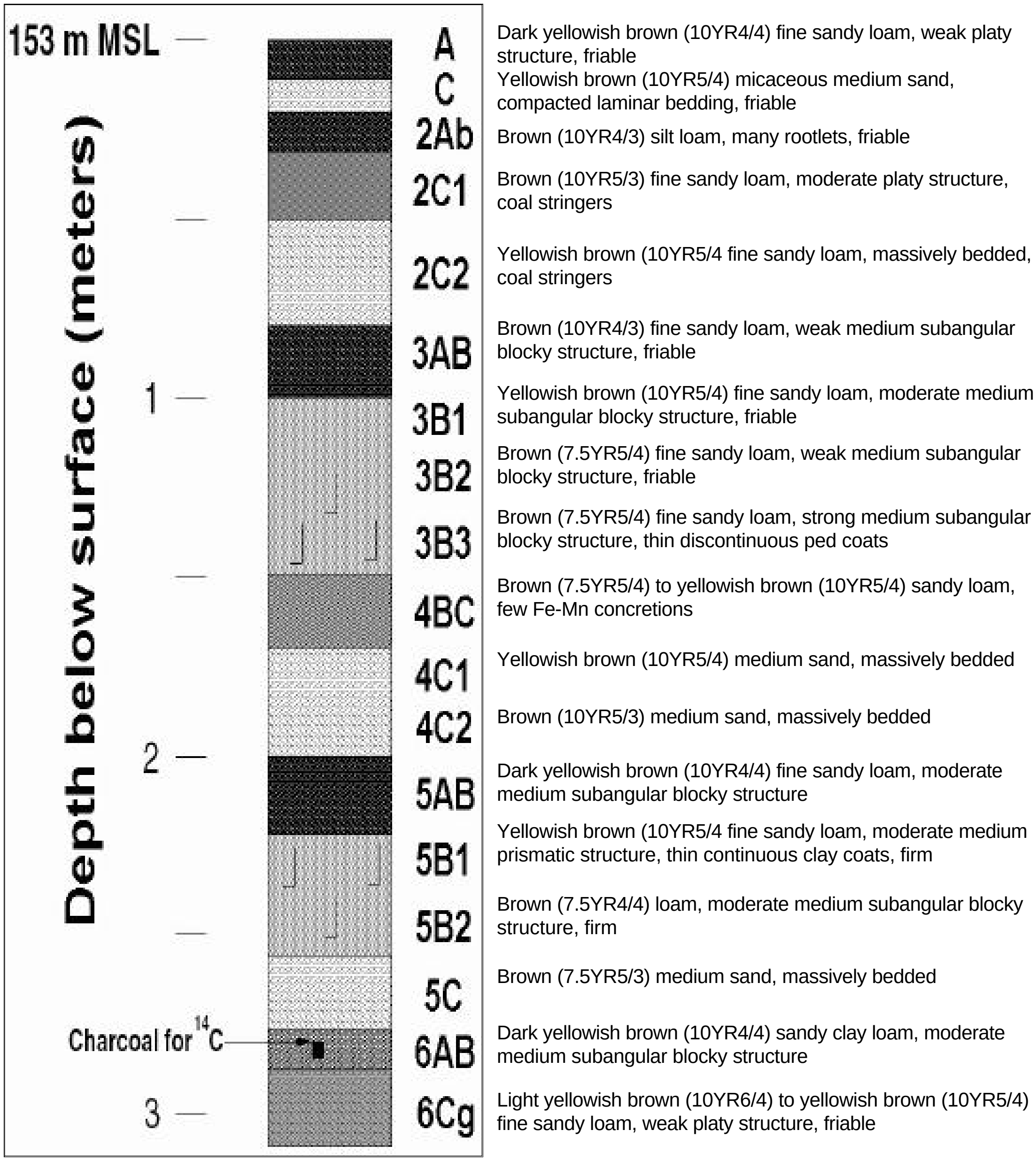


Figure 75: Stratigraphy of the hand auger boring at the Jacobs site (36LU90)

(Stuiver et al., 1991; Van Geel et al., 1998, 1999). The summed 2-sigma range for nine of the dates reported by Weed and Wenstrom (1992, Appendix D) spans 4,230-3,639 cal BP. This seems to be a good, precise estimate for the age of the soil formed at the upper boundary of the Wyoming member (Discontinuity III) in this location. The contacts at site 36LU90 for both the Wyoming and the Central Builders members of the Wyoming Valley formation are shown in the fifth of the 16 stratigraphic columns on **Figure 69**.

Similar cultural components to those at the Jacobs site were found on Gould Island (36LU105). The prehistoric archaeological contexts on Gould island were buried at variable depths beneath a blanket of coal sand and late Holocene flood deposits (Weed and Wenstrom, 1992, p. 161). The former are here assigned to the Nanticoke member, while the latter are Forty Fort member deposits which include the same stratic sand and charred organic matter lithofacies found in the Wyoming Valley at Forty Fort (km 302).

Twenty-three radiocarbon dates were obtained for site 36LU105. A basal date of 5990±110 BP on bulk sediment from 2.5 mbs near the center of the island calibrates to 7,160-6,552 BP at 2-sigma. This is an important age constraint on the lower boundary of the Wyoming member of the Wyoming Valley formation (Discontinuity II). It also demonstrates that some floodplain islands are constructed entirely of mid- to late-Holocene alluvium, as opposed to their previous interpretation as relict features of late Pleistocene or early Holocene braided rivers transporting coarse bedload (Itter, 1938; Segovia, 1989). As is true of the Jacobs site on the left bank of the river, the upper bounding surface for the Wyoming member (Discontinuity III) can be identified with the surface intruded by Late Archaic and Terminal Archaic pit features on Gould Island. As discussed in the preceding chapter, five radiocarbon dates from Gould Island indicate that the peak of the Late Archaic occupation occurred from 4,230-3,980 cal BP. Three of these dates are from contexts at the very top of the Wyoming member, from 100 percent of its thickness in the local stratigraphic column. These dates are used below to constrain the age of the upper boundary of the Wyoming member in the regional framework.

THE SKVAREK SITE (36LU132)

Only eight kilometers upstream of Gould Island, another significant and deeply stratified prehistoric archaeological site was found within the work area for replacement of the S.R. 239 bridge between Shickshinny and Mocanaqua (km 274). Archaic to Middle Woodland contexts were excavated by Archaeological and Historical Consultants, Inc. (1990, 1994) on the right bank of the river in the southwestern quadrant of the bridge replacement project. Named the Skvarek site after the landowner, site 36LU132 has also been summarized in a subsequent research article by Miller (1998).

The T-1 alluvial terrace surface stands slightly less than nine meters above river grade, or 158 m MSL, in the vicinity of the Skvarek site. The archaeological contexts were found in deposits from 6.6-8.4 m above river grade, or 155.6-157.4 m MSL (see **Figure 76**). A moderately well developed soil had formed within the well-sorted medium and fine sand in the cultural levels (Pollack and Petersen, 1992). Illuvial lamellae of translocated

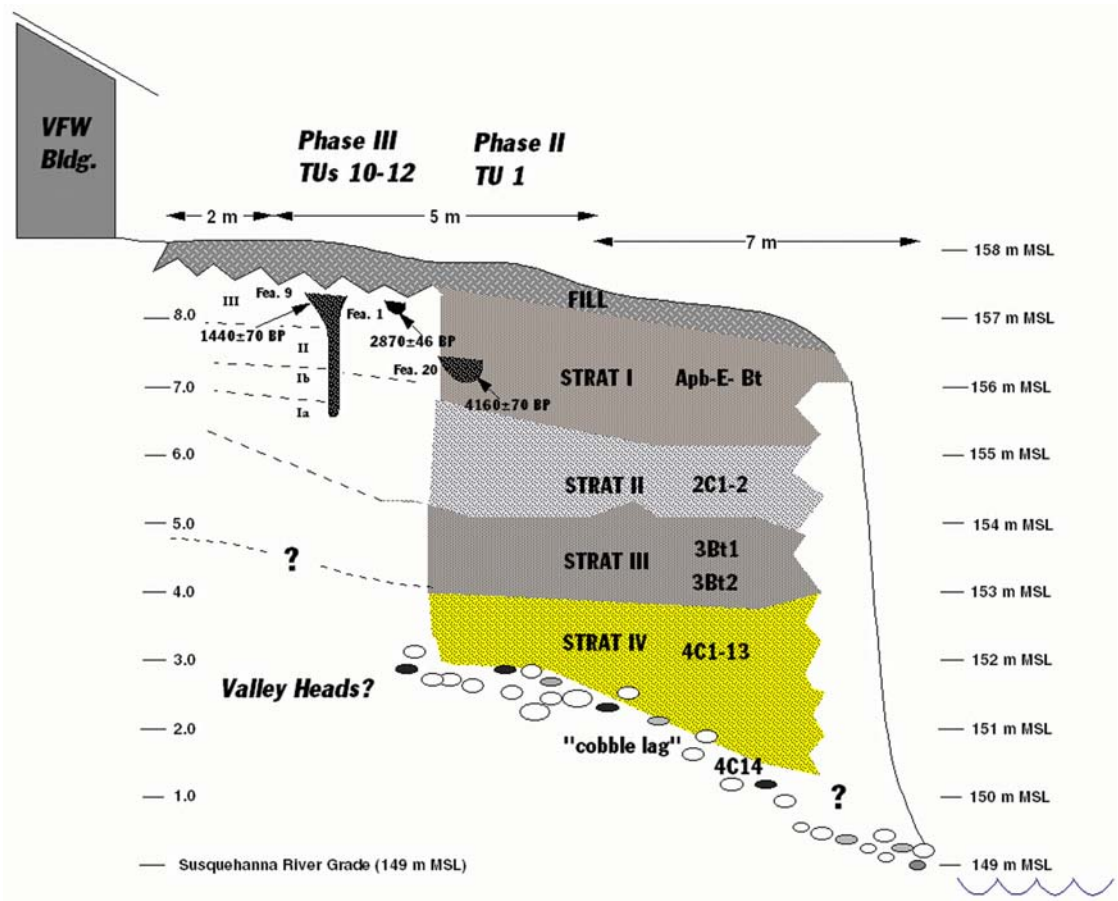


Figure 76: Schematic stratigraphy of the Skvarek site (36LU132) on the T-1 alluvial terrace downstream of Shickshinny (km 274). Radiocarbon dates are in uncalibrated ^{14}C years BP.

iron and clay were present as well as an argillic (Bt) horizon. Because the stratigraphic position of the buried soils was not effectively presented, the soil science studies were essentially ignored in the master site stratigraphy developed by the archaeologists (Miller, 1998). Strata were numbered up from the deepest level containing prehistoric artifacts, which was over six meters above the base of the T-1 alluvial deposits.

The archaeological strata are on the left side of **Figure 76**, while the larger Roman numerals to the right designate the unconformity-bounded packages of alluvium identified by Pollack and Petersen (1992) using soil horizon nomenclature. Strata III and IV of Pollack and Petersen (1992) together represent the Central Builders member of the Wyoming Valley formation. Stratum II and the lowermost horizon in Stratum I represent the Wyoming member. The upper bounding surface of the Wyoming member was overprinted by soil formation at the present land surface. Forty Fort member deposits were present but no thicker than 20 cm. The Nanticoke member deposits had been mixed with 20th century industrial debris and used as landfill to artificially raise parts of the terrace surface.

In the archaeological stratigraphy (Miller, 1998), the plow-disturbed sediments at the top of the terrace were referred to as Stratum "IIIc." Archaeological Stratum IIIc was described as a BAb horizon by Connors (1989, p. 130) and an Apb horizon by Pollack and Petersen (1992, p. 35). Middle and Late Woodland ceramics were found in both Stratum IIIc and in the upper portion of the underlying Stratum IIIb. There was also a large pit (Feature 9) which intruded from Stratum IIIc all the way to the base of the site excavation, Stratum I. A radiocarbon date of 1440±70 BP (cal AD 432-691) from charred plant remains in this pit feature was considered by Miller (1998) to pertain to Stratum IIIC.

Archaeological Strata IIIa and IIIb contained the remains of intensive Terminal Archaic settlement (Miller, 1998, p. 109-111). In particular, a fire-cracked rock concentration 3-5 m in diameter (Feature 1) provides evidence of recurrent seasonal use or perhaps even year-round sedentary settlement (Cavallo, 1988; Custer, 1984; Raber et al., 1998, p. 125). Three of the four radiocarbon dates on charcoal from Feature 1 cluster within the Terminal Archaic, from 1700-800 BC (3,650-2,750 BP) after calibration to calendar years (Bronk Ramsey, 1999; Stuiver et al., 1998). The fourth radiocarbon date of 2060±80 BP (uncalibrated) is considered problematical by the archaeologists since it is much younger than the other dates on the feature (Miller, 1999).

Shorter term occupation by more "residentially mobile" hunter-gatherers (Binford, 1980) is indicated by the Stratum II assemblage and preservation of three small hearths (Features 25, 28, and 29). A radiocarbon date of 4160±70 BP on charcoal from Feature 20 and a Lackawaxen PPK found during initial test excavations are in agreement in suggesting a Late Archaic affiliation. The archaeological Stratum II is from 7.5-7.7 m above river grade (see **Figure 76**) and thus should represent the argillic or "Bt" horizon of Stratum I as described by Pollack and Petersen (1992). This is the overprinted buried soil at the upper bounding surface of the Wyoming member (Discontinuity III) which was mentioned above. Archaeological Stratum I was part of this same buried soil and contained abundant lithic debitage and nine PPKs. Identification of a Vosburg corner-notched and a Brewerton eared-notched type indicate a date of at least 5000 BP and possibly as much as 6000 BP (see **Figure 40**) for the basal cultural levels at 6.64 m above river grade, or 155.6 m MSL.

Stratum I in the archaeological stratigraphy is still at least a meter above the base of the Wyoming member, and more than three meters above the basal contact with outwash gravel at the river bank. As shown in **Figure 76**, the gravel does appear to crop out closer to the surface at the landward side of the T-1. A bed of cobbles at 3.5 m above river grade (152.5 m MSL) in TU-5, for example, probably represent glacial outwash. The 2C1-2 and 4C1-2 horizons described by Pollack and Petersen (1992) consisted of heterolithic medium to coarse sand. This channel sand and gravel lithofacies is more typical of the Central Builders member than of the Wyoming member of the Wyoming Valley formation. The contacts for both members at the Skvarek site are shown in the sixth of the stratigraphic columns in **Figure 69**.

THE SHAWNEE FLATS (36LU39 and 128)

The Wyoming Valley itself begins upstream of the sharp bend in the bedrock valley between Shickshinny and Nanticoke (km 290). Upstream of Nanticoke but downstream of Plymouth (km 294), alluvial bottomland stretches for at least four kilometers along the right bank of the river. At least three village sites were reported on these "Shawnee Flats" by Christopher Wren (1914, p. 216-217), but most of the strata in which they were found have now been removed by topsoil mining. Subsequent use of the topsoil pits for disposal of mining spoils and municipal waste makes it extremely difficult to relocate any of the early excavations. The areas of topsoil mining are generally referred to as site 36LU39, but little provenience information is available for the numerous artifacts in private collections, including three whole vessels shown by Orlandini (1996, p. 138-161).

Prehistoric cultural material recently salvaged by a local amateur archaeologist from one of the active topsoil mines included cordmarked potsherds, triangular projectile points, and lithic debitage. Wood charcoal collected during this amateur excavation was dated to 1170±50 BP (Beta-105632) by the Society for Pennsylvania Archaeology Radiocarbon Dating Program (SPA, 1998). The calibrated age of AD 720-984 confirms the Clemson Island/Owasco cultural affiliation indicated by the ceramics. The deposits targeted for topsoil mining can probably be assigned to the Forty Fort member of the Wyoming Valley formation. The Forty Fort member is particularly rich in charred organic matter and other nutrients valuable as topsoil for gardening. Often the contact between the Forty Fort and underlying sediments can be recognized by the point at which the equipment operators stopped removing the "topsoil," as much as a meter below the T-1 surface.

Another amateur archaeologist, Russell Royer, reportedly found from 75 to 80 potsherds at the upstream end of the Shawnee Flats, near the mouth of Wadham Creek within the Plymouth town limits (km 294). A second site number, 36LU128, was assigned to this general location. I found that the deposits between the flood protection levee and the active river channel were too young to contain prehistoric cultural material (Schuldenrein and Thieme, 1997, p. 79). Piles of mine culm and municipal solid waste cap laminated sands and coal silts deposited from slackwater impounded behind the Nanticoke crib dam when the North Branch Canal was in operation. These slackwater sediments are the type section for the Nanticoke member of the Wyoming Valley formation as defined above. They outcrop along the riverbank for much of the Shawnee

Flats, and various other lithofacies of the Nanticoke member occur in many of the other stratigraphic sections examined in this chapter.

SCHACHT (36LU1) AND DUNDEE (36LU11)

A little over a kilometer upstream of Nanticoke (km 290), and approximately 400 m southeast of the river on the right bank of Warrior Creek, there was a stockaded village built by a late prehistoric group of the Wyoming Valley culture (Smith, 1973, p. 45-47; Orlandini, 1996, p. 120-122). The Schacht site (36LU1) was excavated by the Frances Dorrance Chapter of the SPA with some professional assistance from Jacob W. Gruber of Temple University and John Witthoft of the Pennsylvania Historical and Museum Commission. The stockade complex enclosed an area over 80 m on its long axis, less than a third of which was systematically excavated. The stockade itself measured over two meters from the innermost to the outermost lines and was surrounded by a ditch up to two meters deep. Excavations within the limits of the stockade revealed a single keyhole-shaped semisubterranean structure as well as numerous aligned postmolds defining rectangular, "longhouse" structures (Smith, 1973, p. 46-47).

Approximately 70 m downstream of the Schacht stockade complex along Warrior Creek, Leslie Delaney of Kings College excavated storage pits containing Wyoming Valley Culture materials between 1967 and 1971 (Smith, 1973, p. 47). The pits were at least a meter deep but the nature of the alluvial strata they intruded was not recorded nor is there any indication that the possibility of more deeply buried components was investigated. Delaney did not define any postmold patterns, and he therefore inferred that this "Dundee" site (36LU11) was a specialized storage facility functionally related to the Schacht stockaded village (Smith, 1973, p. 47). Sweeney (1966, p. 28) suggests the alternative possibility of an earlier, smaller settlement by the same cultural group.

Radiocarbon dates were not obtained for materials from either Schacht or Dundee, although the ceramics suggest an affiliation with the Wyoming Valley Culture materials from the Parker site (36LU14). As will be seen more clearly with reference to other late prehistoric sites, the alluvial strata they intrude do not typically belong to the Forty Fort member. In some cases these sites are actually on glacial outwash terraces, although the Schacht and Dundee locations are clearly T-1 landforms. The Wyoming member would be the most likely candidate, because it is the member which is most common throughout the river valley.

THE BRIDGE SITE (36LU60)

Although several prehistoric sites are recorded along the river in both Wilkes-Barre and Kingston, few of these have survived the 20th century construction of the Wyoming Valley levee system bordering the river (Schuldenrein and Thieme, 1997; Shaffer et al., 1990, 1991). One site which is still partially preserved is on the right bank upstream of Kirby Park in Kingston (km 298). Site 36LU60 is underneath the bridge abutment, where the Wilkes-Barre Connecting Railroad crosses the river (Orlandini, 1996, p. 123-125; Schuldenrein and Thieme, 1997).

According to Orlandini, the Bridge site was first exposed when the 1936 spring snowmelt flood undermined an alluvial terrace and caused it to slide toward the river

(Orlandini, 1996, p. 123). Roberts (1948, p. 52) also records a cave-in in the spring of 1944 over operations of the Lehigh Valley Coal Company which dropped a section of the new levee behind Church Street over a stretch of approximately a thousand feet. Since the levee has recently been raised, deposits riverward of the berm will probably be subjected to further erosion.

Stemmed and side-notched projectile points in private collections from the Bridge site (Orlandini, 1996, p. 124-125) point to repeated seasonal use beginning at least 5000 BP (Brewerton cluster) and perhaps as early as 7000 BP (Stanly and Neville types).
I found a local sandstone netsinker *in situ* in the fill of a cultural pit feature during my investigations for the Wyoming Valley levee raising (Thieme and Schuldenrein, 1998, p. 12; Schuldenrein and Thieme, 1997, p. 55). The prehistoric pit feature had unfortunately been previously disturbed by an amateur excavation, but I did obtain a radiocarbon date of 1170±70 BP (Beta-82385) on dispersed charcoal from the cultural fill. This date calibrates to AD 887 using Stuiver et al. (1998). A potsherd identified as Carpenter Brook cord-on-cord (Ritchie and MacNeish, 1949, p. 107-120; Ritchie, 1969, p. 290-294) recovered from a buried soil in a cutbank in another part of the site generally agrees with the radiocarbon date in suggesting a Clemson Island or Owasco occupation.

The sediments in which the Clemson Island/Owasco pit feature and ceramic artifacts were found at site 36LU60 are relatively coarse-textured overbank sand and silt. These are here placed in the Forty Fort member of the Wyoming Valley formation, although charred organic particles are less abundant than in the sections further upstream in the Forty Fort borrow pit. Deposits which belong to the Wyoming member probably occurred landward of the present site limits, in the area that has been disturbed by levee and bridge construction. The stratigraphy may in fact be inverted in some portions of site 36LU60 if deposits containing the Archaic points were displaced riverward by a slumping event.

THE FORTY FORT AIRPORT SITES

Some of the most intensive historic and prehistoric Native American settlement of the North Branch of the Susquehanna River valley occurred on the right bank of the river in the vicinity of Forty Fort, Pennsylvania (km 302). Late Woodland prehistoric settlement was concentrated between Abrahams Creek and the active river channel (Garrahan, 1990; Schuldenrein and Thieme, 1997, p. 77-78; Thieme and Schuldenrein, 1998, p. 4-8; Wren, 1914, p. 219). As illustrated in **Figure 77**, the low-lying alluvial terrace in this reach is presently used for a small private airfield. Archaeological remains from the Airport I (36LU44) and Airport II (36LU77) sites record late prehistoric villages affiliated with the Clemson Island and Owasco cultures.

At the Airport II site (Garrahan, 1990), there were four house patterns, encircled by an oval stockade. Small fragments of charred wood from a deep cultural pit, Feature 41, were radiocarbon dated to 970±40 BP (PITT-392). The calibrated calendar date is AD 1029 using Stuiver et al. (1998). Riverward of the Airport II site (36LU77), I identified three buried soils within the upper meter of stratified alluvium in a borrow pit at site 36LU44 (see **Figure 78**). In this type section for the Forty Fort member of the Wyoming Valley formation, clear smooth contacts between Ab and overlying C horizons

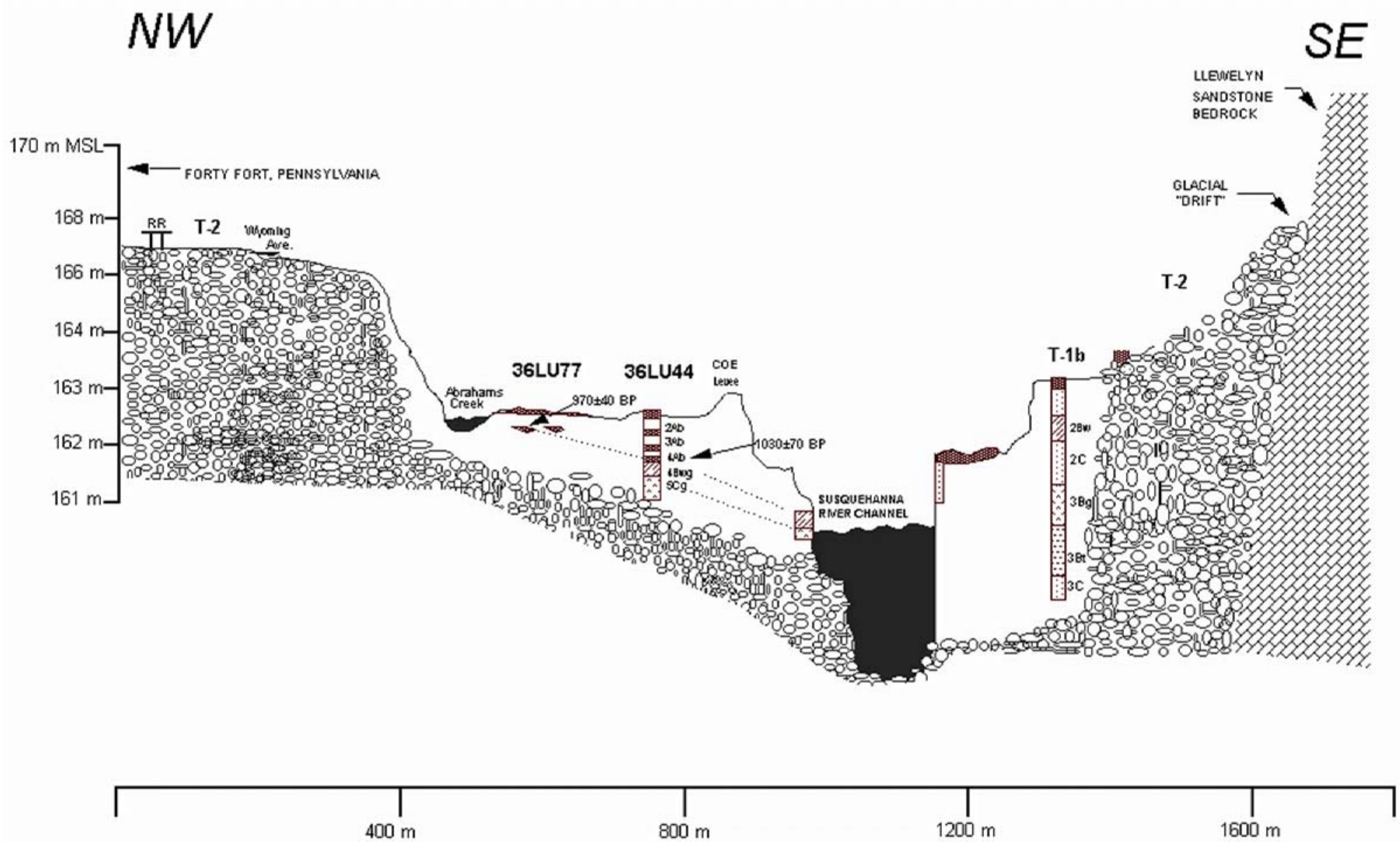


Figure 77: Schematic cross-section of the Wyoming Valley in the vicinity of the Airport I (36LU44) and Airport II (36LU45) archaeological sites at Forty Fort, Pennsylvania. Radiocarbon dates are presented in uncalibrated ^{14}C years.

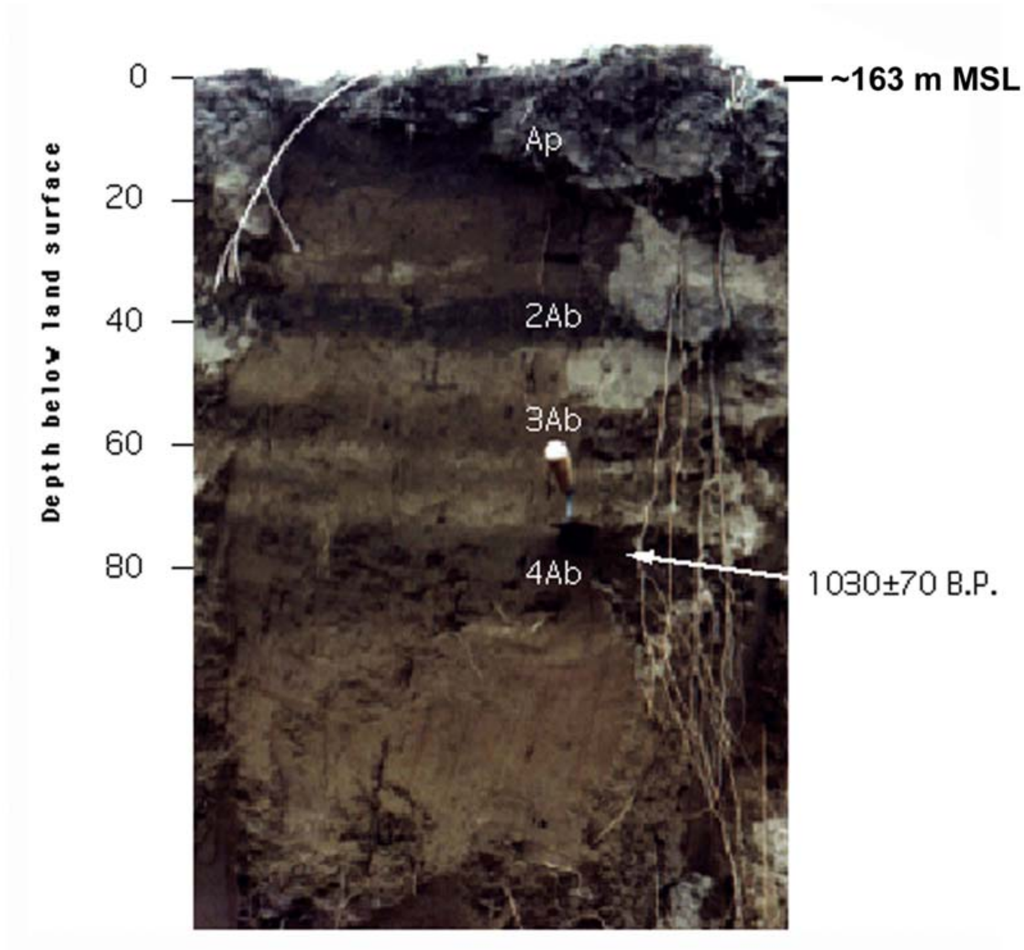


Figure 78: Section 1 in the Borrow Pit at Forty Fort, Pennsylvania (km 302). Radiocarbon date is in uncalibrated ^{14}C years.

are the result of episodic deposition or "stratic" profile development (Gerrard, 1992, p. 114-116). The sedimentation rate was too rapid for much soil formation to occur, whereas significantly longer periods of weathering are indicated by the cambic (Bw) or argillic (Bt) horizons which formed in the earlier members of the Wyoming Valley formation.

At the Forty Fort Airport sites, prehistoric cultural refuse was concentrated in the darker Ab horizons, adding to their thickness and lowering the Munsell color value. I obtained a radiocarbon date of 1030±70 BP (Beta-82386) for the 4Ab horizon in the borrow pit at the Airport I site (36LU44). The date calibrates to calendar year AD 1008 using Stuiver et al. (1998), and thus precedes the date of AD 1029 for Feature 41 at the Airport II site (36LU77) by less than the lifespan of a single human generation. Two further radiocarbon determinations, from an ossuary associated with the Airport II site (Herbstritt et al., 1997), fall in between these bracketing ages. Isotopic analyses of the ossuary skeletal samples indicate the consumption of C4 pathway cultigens such as maize by these individuals, matching similar results reported previously for skeletons from Owasco contexts in New York state (Vogel and Van der Merwe, 1977).

The Section 1 profile at site 36LU44 was unfortunately destroyed by earth moving before it could be sampled for analysis. A column of samples was analyzed from Section 5 in the same borrow pit, with results as presented in **Figure 79**. The lowest two samples in the section were from the massively bedded sand lithofacies of the Forty Fort member. The 3C1 sample was taken from one of several thin lamellae of translocated

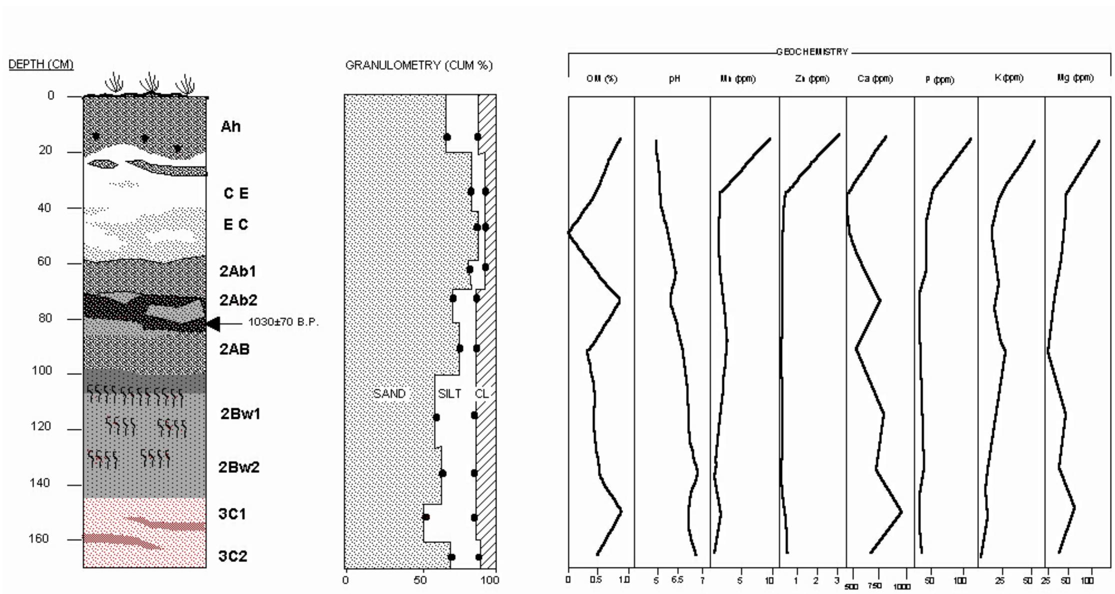


Figure 79: Composite physical and chemical stratigraphy of Section 5, Forty Fort Airport Site (36LU44). Radiocarbon date is in uncalibrated ^{14}C years.

iron and clay (Rawling, 2000; Soil Survey Staff, 1997, p. 31) while the 3C2 sample represents the tan, interlammelar sand. The 3C1 sample had slightly higher organic matter, Mn, Ca, K, and Mg than the 3C2 and contained 12% more silt and 6% more clay.

The upper portion of Section 5 in the borrow pit at site 36LU44 represents the stratic sand and charred organics lithofacies of the Forty Fort member. Organic matter peaks in the lower of two Ab horizons, which contained sufficient fine particulate charcoal for the radiocarbon date of AD 1008 (calibrated). The dated horizon was traced laterally across the borrow pit from Section 5, where it was the 4Ab and overlain by three horizons of organic enrichment. These are marginal buried soils using the criterion that they be "covered with a mantle 30-50 cm thick which is at least half the total thickness of the named diagnostic horizons in the underlying soil (Soil Survey Staff, 1997, p. 1)." As noted by Gerrard, however, alluvium-derived soils do not always conform to models based on weathering of a single parent material. Organic matter is carried in the alluvium as well as being added by vegetation growing at the surface.

PARKER (36LU14), RUSBAR (36LU4), SARF (36LU3), AND SITE 36LU10

On the left bank of the river, on the inside of the southward bend at Forty Fort (km 302), archaeological remains of large, late prehistoric villages were unearthed beginning with the construction of the North Branch Canal in the 1830's (Lottick, 1992, p. 17; Miner, 1845, p. 25-26; Smith, 1973, p. 45) and culminating with topsoil mining beginning in the 1950's (Smith, 1973, p. 6-7). The designation of four archaeological sites on the bend relates more to their fortuitous discovery than to well-defined boundaries between material remains or locations of past human activity. The most discrete and completely excavated of the four sites is the Parker site (36LU14) , situated approximately 370 meters from the river in a large topsoil mine just north of the abandoned Omalia homestead (Smith, 1973, p. 6). This is the type site for the Wyoming Valley culture with eight semisubterranean "keyhole" structures (Smith, 1976) enclosed by a stockade composed of five distinct lines of posts and an external ditch.

Radiocarbon dates of 650±40 BP (PITT-393) and 480±90 BP (I-4880) on logs from the floors of different semisubterranean structures are accepted as "bracketing" ages for the occupation of the Parker site by Smith (1973, p. 42). The combined two-sigma range for these two dates is AD 1410-1640 in calibrated calendar years (Bronk Ramsey, 1999; Stuiver et al., 1998), essentially contemporaneous with the Bradford County Proto-Susquehannock components discussed later in this chapter. Smith rejected his third date of 350±90 BP (I-4879) on grass from another structure, and this date is nearly indistinguishable from modern carbon with a two-sigma range from AD 1444-1952.

Although it had been less than 500 years since the Parker site was abandoned, the surface that its structures were excavated into was nonetheless buried by a meter or more of culturally sterile alluvium (Smith, 1973, p. 7-8). This layer of "yellow subsoil or alluvium" was stripped away with a front end loader to expose the midden stains and posthole patterns. While the deeper stratigraphy below the Wyoming Valley culture village was not systematically tested, Smith did observe it in places due to occasionally excessive stripping. In particular, he was surprised to find "what appeared to be a topsoil, but was actually an earlier layer of deposition" which must have been at least 1.5

mbs.This Ab soil horizon may mark the same floodplain surface on which the Clemson Island or Owasco villages were established across the river at the Forty Fort Airport sites.

Considerable disruption of basal Holocene stratigraphy actually occurred from beneath the Parker site, since it was situated on top of an abandoned underground coal mine. Robbing of the coal "pillars" supporting the roof of the mine caused large surface slumps which were filled with broken and burned mine and quarry stone known locally as "red dog" (Smith, 1973, p. 7-8). Coal-bearing sandstone bedrock may have been no more than two to three meters below the surface, stepping off as the alluvial deposits thickened toward the river. A site is shown riverward of the Parker site and referred to as Rusbar (36LU4) by Smith (1973, Figure 1), Rasson and Evans (1980), and Shaffer et al. (1990, p. 31). There are no published descriptions of artifacts from this site although it is characterized as "Late Woodland." It would seem just as likely that Rusbar represents a slightly older and stratigraphically deeper occupation than for there to have been a second Wyoming Valley culture village this close to the Parker site.

Site 36LU3 is further downstream around the bend from the Parker and Rusbar sites at the approximate location where Peter Sarf, a heavy equipment operator, unearthed a cache of wampum from the Refugee phase (Kent, 1970). Necklaces of shell, glass, and tubular brass beads were placed in a leather pouch and then sealed by two brass kettles jammed mouth-to-mouth. The wire-wound faceted glass beads indicate a date between 1700 and 1760 for the cache (Kent, 1970, p. 192). Mr. Sarf stated that he was excavating over two meters below the original land surface at the time he created the backdirt pile on which the cache was found. The fourth archaeological site on the bend, 36LU10, is shown by Rasson and Evans (1980) approximately equidistant between Rusbar (36LU4) and the Sarf cache (36LU3). There is even less information on associated artifacts and stratigraphy for site 36LU10 than there is for Rusbar.

8th STREET BRIDGE AND THE WYOMING MEMBER TYPE SECTION

The borough of Wyoming, Pennsylvania (km 307) is on the right or northwest bank of the river, five kilometers upstream of Forty Fort. The 8th Street Bridge crosses the river here from Plains Township on the northern outskirts of Wilkes-Barre, as shown in **Figure 80** on a portion of the Pittston quadrangle USGS 7.5' topographic map. The T-1 landform extends continuously along this bank of the river, and ranges from three to five meters above river grade.

I began my stratigraphic studies in this river reach during my initial study for the Wyoming Valley levee raising project (Schuldenrein and Thieme, 1997). More recently, the work area for the 8th Street Bridge Replacement was tested with five long backhoe trenches extending all the way from the river to the scarp of the T-2 (McIntyre, 2001). The T-2 is mapped as "Binghamton/Valley Heads outwash" on **Figure 80** and in **Appendix 1**. The relatively flat grade of the T-1 at Wyoming conceals a complex stratigraphy in which packages bounded by unconformities can be attributed to both the Wyoming and the Central Builders members of the Wyoming Valley formation.

The well-drained Pope series soil is mapped for most of the T-1 landform in Luze rne County by Bush (1981). There are several buried soils, however, in the T-1 profile I described at a river cutbank in Wyoming (**Figure 81**). The most strongly developed of

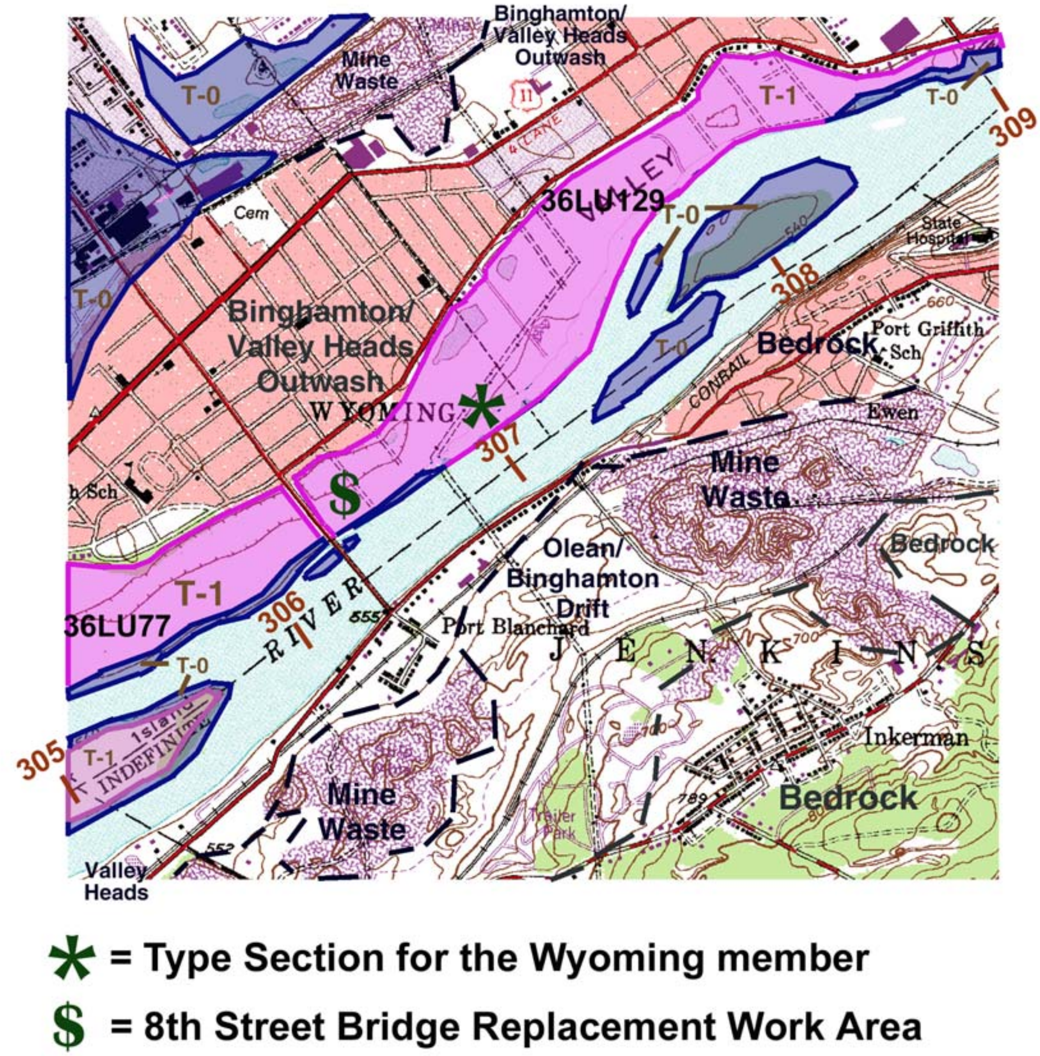


Figure 80: Part of the Pittston quadrangle USGS 7.5' Topographic Map showing landforms and archaeological sites mapped in the vicinity of Wyoming, Pennsylvania (km 306)

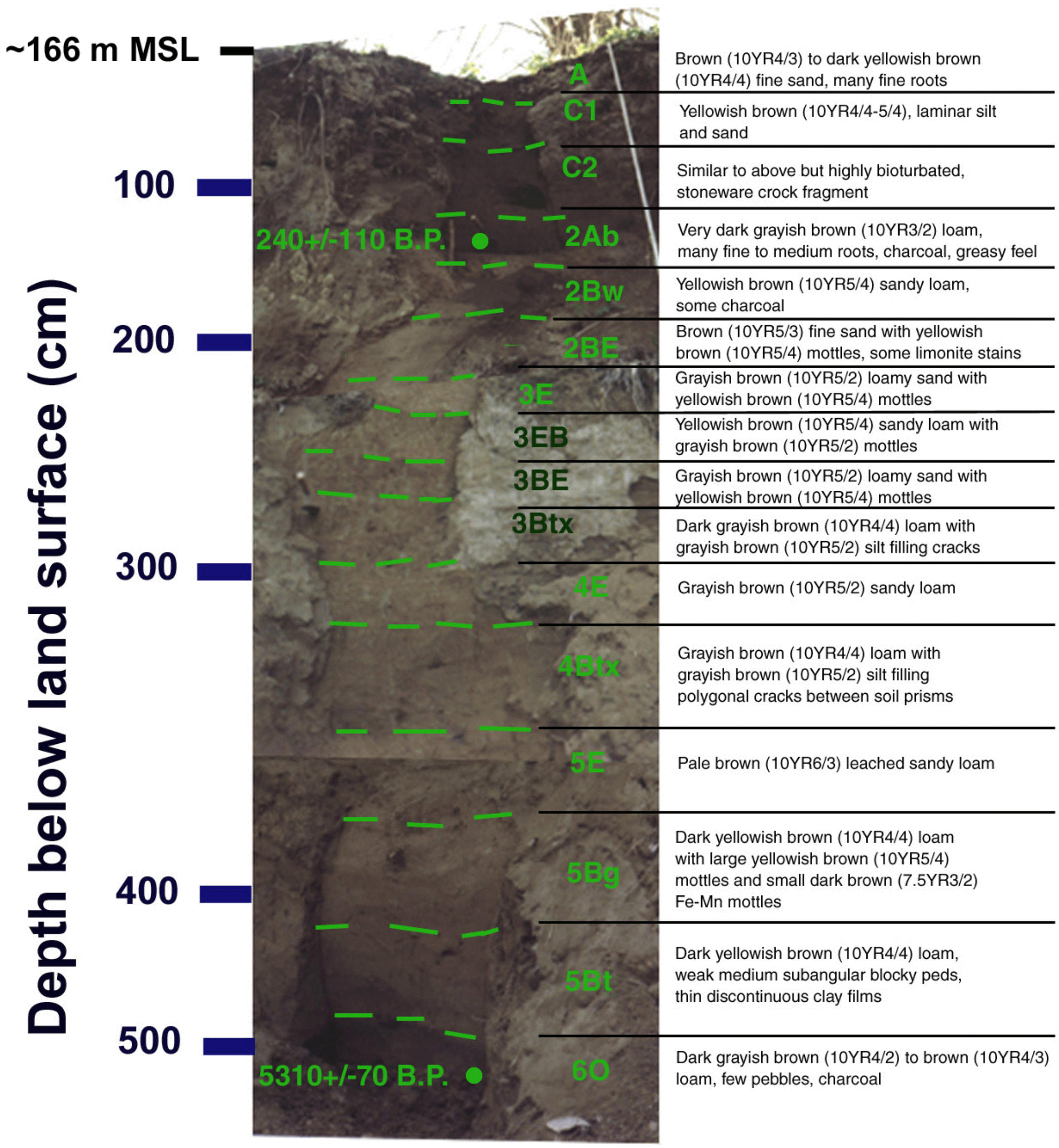


Figure 81: Profile of the T-1 Alluvial Terrace exposed in a river cutbank at Wyoming, Pennsylvania (km 307)

the buried soils originate beneath the upper meter used to define series for soil mapping. The uppermost buried soil, underlying the 2Ab horizon, is weakly developed and has undergone relatively little movement or translocation of soil material through the profile. The buried soils below the 2Bw in the Wyoming T-1 profile differ from alluvial soils mapped at the modern land surface in that they have undergone intense leaching and translocation of iron (Fe) and other mobile constituents. These buried soils and the sediments in which they formed are the type section for the Wyoming member of the Wyoming Valley formation and were described as such earlier in this chapter.

Stratigraphic information obtained from borings between the river cutbank and the T-2 scarp suggests that much of the T-1 formed as an island or longitudinal bar which was subsequently attached to the bank of the river. Regional vegetation records (Barnosky et al., 1988; Watts, 1979) suggest that such features in the river floodplain would have been continuously forested, so that each of the buried soils may represent a generation or more of trees. Leached, eluvial ("E") horizons can result from roots extracting nutrients upward as well as translocation of mobile elements downward in the soil profile (Buol et al., 1989, p. 118-119). Soil chemistry results presented in **Figure 82** show that the E horizons in the Wyoming T-1 profile are leached of most of the cations measured with ICP following Mehlich I extraction. The 4E in particular shows depletion in potassium, calcium, magnesium, zinc, and iron.

The 3Btx and 4Btx are "fragic" horizons, the "x" modifier meaning that they have become denser and more brittle as a result of soil formation (Soil Survey Staff, 1997, p. 30). Translocation of pedogenic clay (the "t" modifier) was identified in the field by

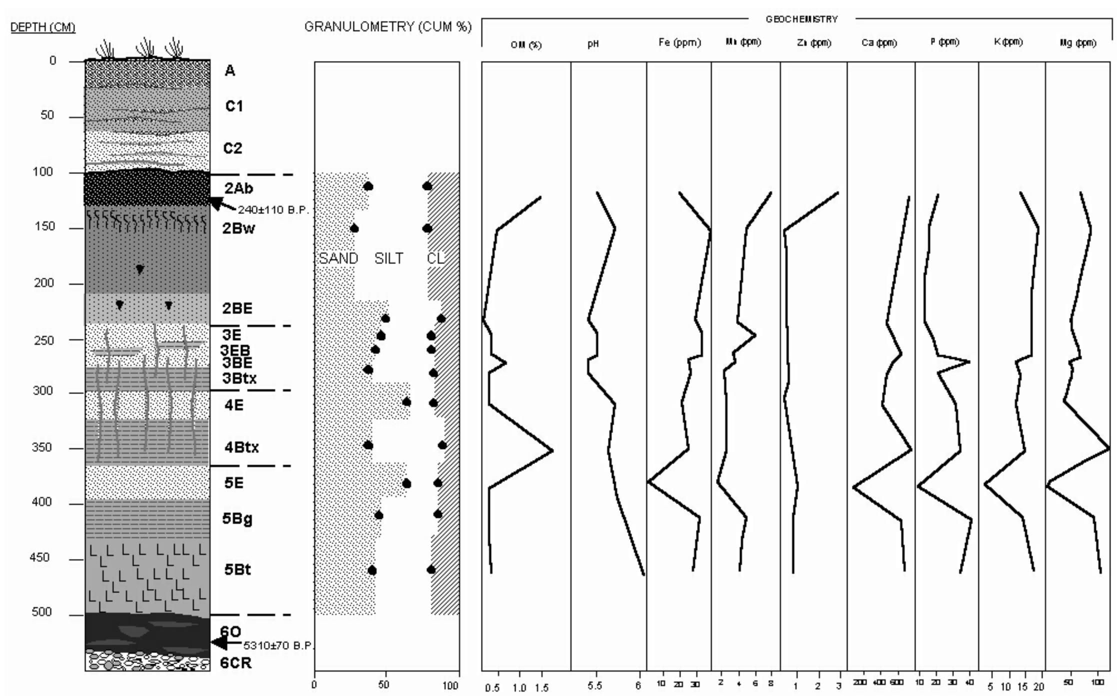


Figure 82: Composite physical and chemical stratigraphy of the T-1 Alluvial Terrace Cutbank at Wyoming (km 307)

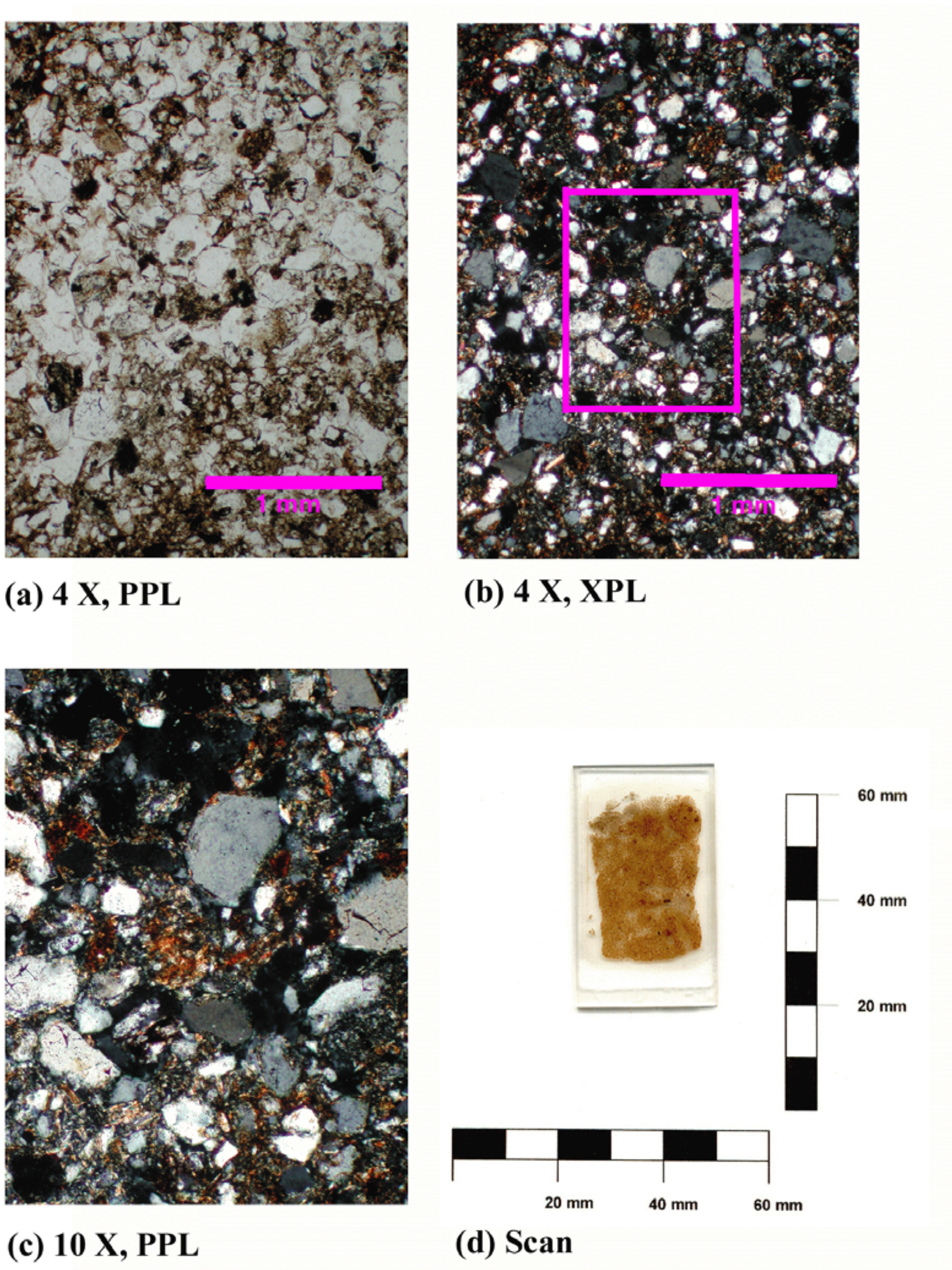


Figure 83: Photomicrographs (a,b,c) and scan (d) of the thin-section prepared from a sample of the 4Btx1 horizon in the Wyoming T-1 cutbank profile. Inset shows the area of the closeup view (c).

clay films on ped faces. The hydrometer results indicate a large increase in silt, but they actually show a decrease in the percent clay from the 4E to the 4Btx horizon. The presence of pedogenic clay as well as translocated silt is evident, however, in thin sections prepared from samples of two subdivisions of the 4Btx (4Btx1 and 4Btx2).

In **Figure 83**, there is no void space between the densely packed quartz and mica silt. In the lower half of the field of view, both fine mica and dusty brown clay increase abruptly in abundance. The inset view (c) is a closeup of the area along this textural boundary, and both fine mica laths and a brown clay material can be seen to fill the voids around subrounded quartz and iron oxide (opaque) clasts. The iron oxides are more abundant (10-20 %) and the overall grain size larger than in the Bw/Bt1 horizon from the 8th Street Bridge Work Area. The clay material also lacks the bright orange birefringence seen in that sample, and it fills much smaller voids.

Voids in the 4Btx horizon appear from the thin sections to be the result of shrinkage and expansion in the sediment rather than burrowing. Pedogenic cracking was observed in the field as a macroscopic property but was most evident in the thin section of the 4Btx2 horizon. The 2X view (c) shows a thin (0.2 mm) crack in which void space is still present. The "banded" texture seen in all three views of the 4Btx2 (**Figure 84**) is widely reported in previous studies of fragipans (Dumanski and St. Arnaud, 1996, p. 289; Goldberg, 1994; Harris, 1985, p. 220-222). It is the result of the preferential concentration of iron oxides and hydroxides in specific linear domains.

The x-ray diffractograms for clay separates (< 2 microns) of the 4Btx horizon in the Wyoming cutbank profile were presented above. In order to understand the processes

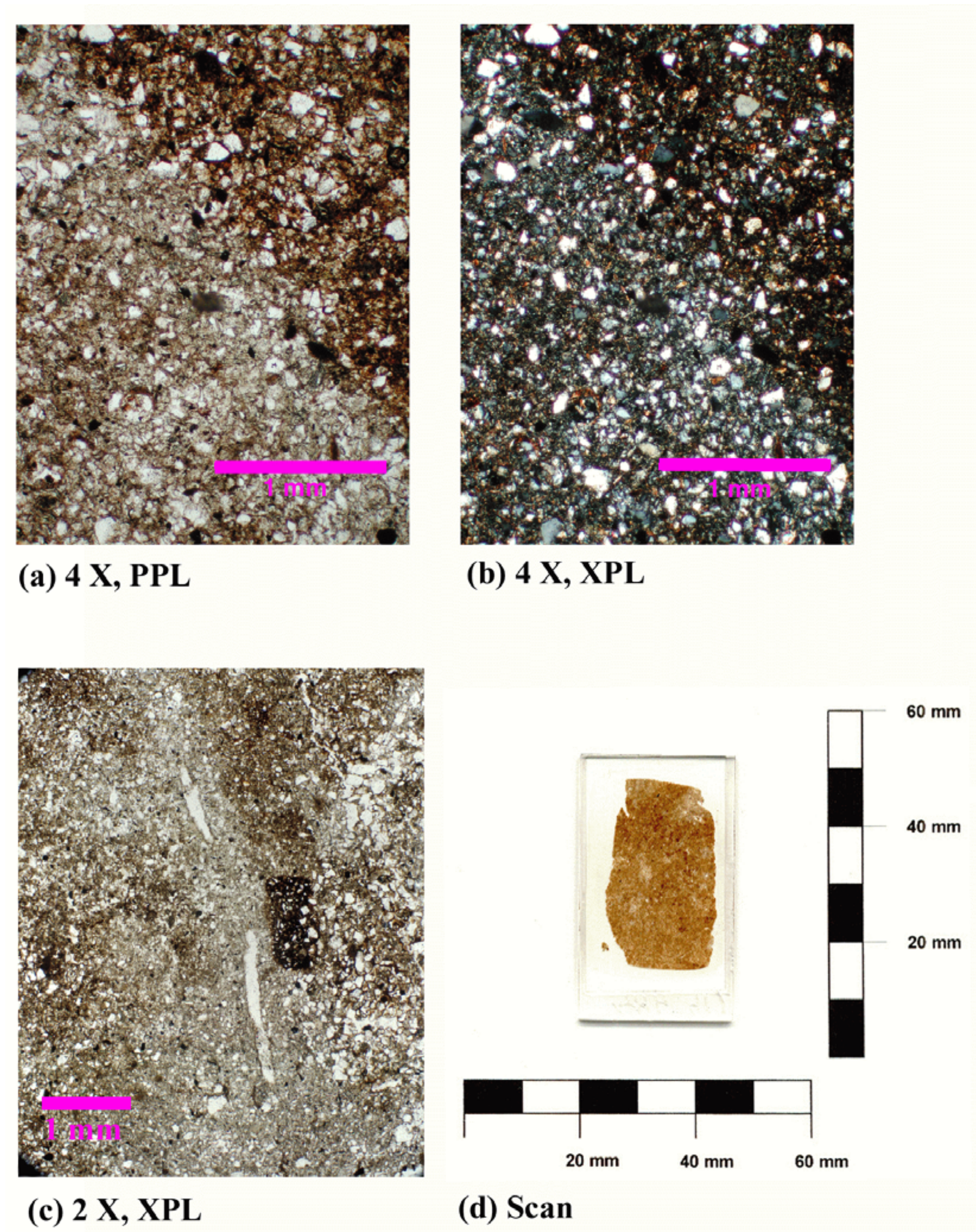


Figure 84: Photomicrographs (a,b,c) and scan (d) of the thin-section prepared from a sample of the 4Btx2 horizon from the Wyoming T-1 cutbank profile

of deposition and soil formation which produced the entire profile, x-ray diffraction was also used to analyze a column of twelve samples of the bulk sediment (ground to 10 micron average diameter). The same phases identified as illite (10 angstrom) and hydroxy-interlayered vermiculite (14 angstrom) in the clay mineral separates were present. Quartz was considerably more abundant, however, and could be used as an internal standard (Moore and Reynolds, 1997; Reynolds, 1989) to determine changes in the relative abundance of each clay mineral phase within the entire profile (**Figure 85**). The ratio of the 14 angstrom, hydroxy-interlayered vermiculite (HIV) to the 10 angstrom peak intensity was also calculated for each scan.

All three of the clay mineral ratios are highest for the 4Btx sample, corroborating the occurrence of pedogenic clay indicated by both field observation and micro-morphological analysis. Both the clay mineralogy and the soil chemistry results indicate that the horizons between the 3E (240 cmbs) and the 4Btx (360 cmbs) have been "welded" into a single profile. All of these horizons have contributed to the density of the 4Btx and its high values for phosphorous, potassium, calcium, magnesium, zinc, manganese, and iron. By the same token, the greater abundance of quartz indicated by x-ray diffraction for the 3BE and 5E horizons is consistent with their depleted K, Ca, Mg, Zn, Mn, and Fe values in the soil chemistry results.

The cutbank profile provides an ideal type section for the Wyoming member and the Wyoming Valley formation in general because it formed as the T-1 landform accreted in a location where there does not appear to have been intensive human occupation. However, the absence of prehistoric artifacts or pit features means that the age of the

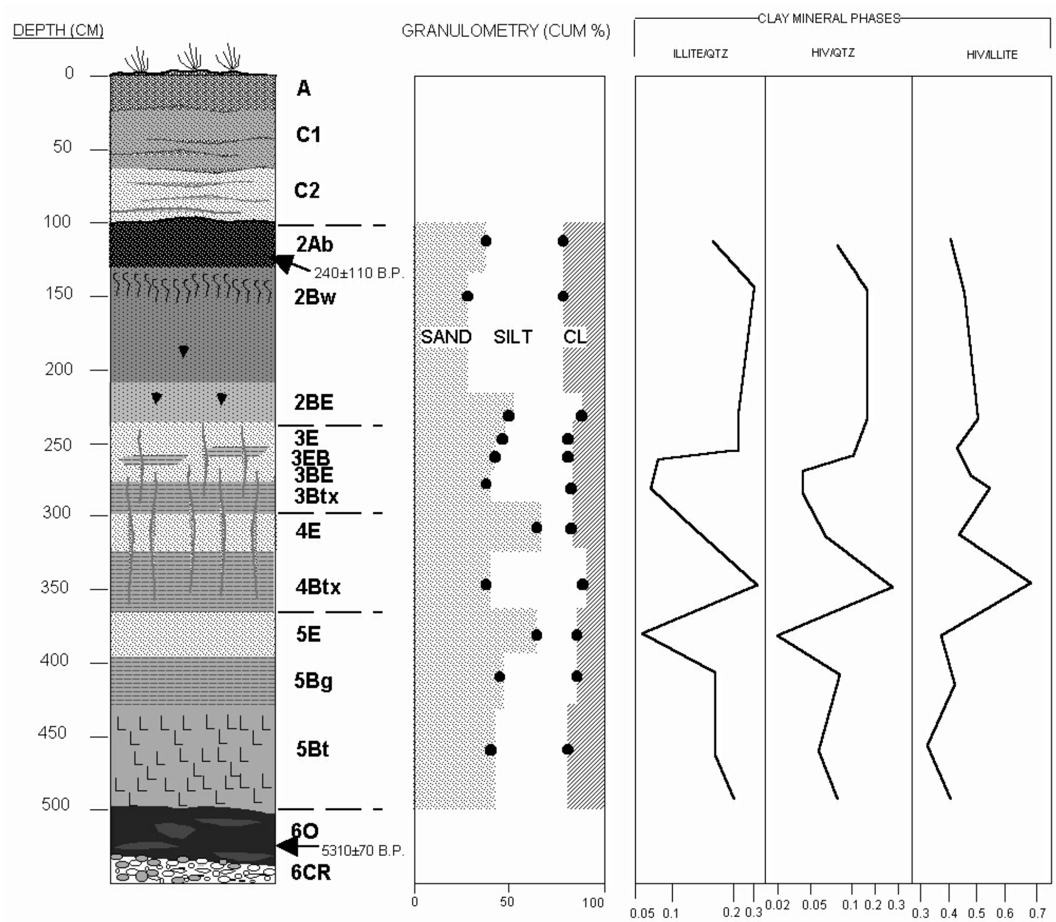


Figure 85: Clay mineral phases identified through x-ray diffraction analysis of twelve samples of bulk sediment from the Wyoming T-1 profile

upper boundary for the Wyoming member (Discontinuity III) is not as well constrained here as in other locations. The bounding surface is marked by a buried soil (3E-4Btx horizons) which has a relatively complex formation history compared to soils which formed in the same stratigraphic position in other locations. The 3E-4Btx buried soil is a fragipan whereas the top of the Wyoming member is more typically marked by buried soils with cambic (Bw) subsoil horizons. Approximately a kilometer downstream of the cutbank profile, the Bw/Bt1 horizon in the 8th Street Bridge Project Area formed in the same stratigraphic position on the same T-1 landform.

The stratigraphy underlying the T-1 surface at Wyoming was further examined with hand auger borings between the cutbank profile and the scarp of the T-2 outwash terrace. Boring B-1 was ~20 m from the T-2 scarp and B-2 was ~100 m further southeast toward the riverbank (see **Figure 86**). Basal gravels occurred at 70 cm below surface in B-1 and appear to dip gradually toward the river. Fine, pea-sized channel gravel was encountered at 300 cm below surface in B-2, overlain by a bed of very dark gray (2.5Y3/1) organic silt. Twigs collected from the silt were dated to 9,520±90 BP (UGa-7816) in radiocarbon years (11,200-10,550 cal BP), a measurement made at the University of Arizona accelerator laboratory.

The slackwater silt beneath this portion of the T-1 at Wyoming is assigned to the Central Builders member based upon the fact that it is onlapped ("crosscut") by the Wyoming member overbank sand and silt described at the cutbank. The radiocarbon dates are consistent with this interpretation and corroborate the inferences based upon the bounding surfaces. The dark gray silt at the base of boring B-2 was approximately 20 cm

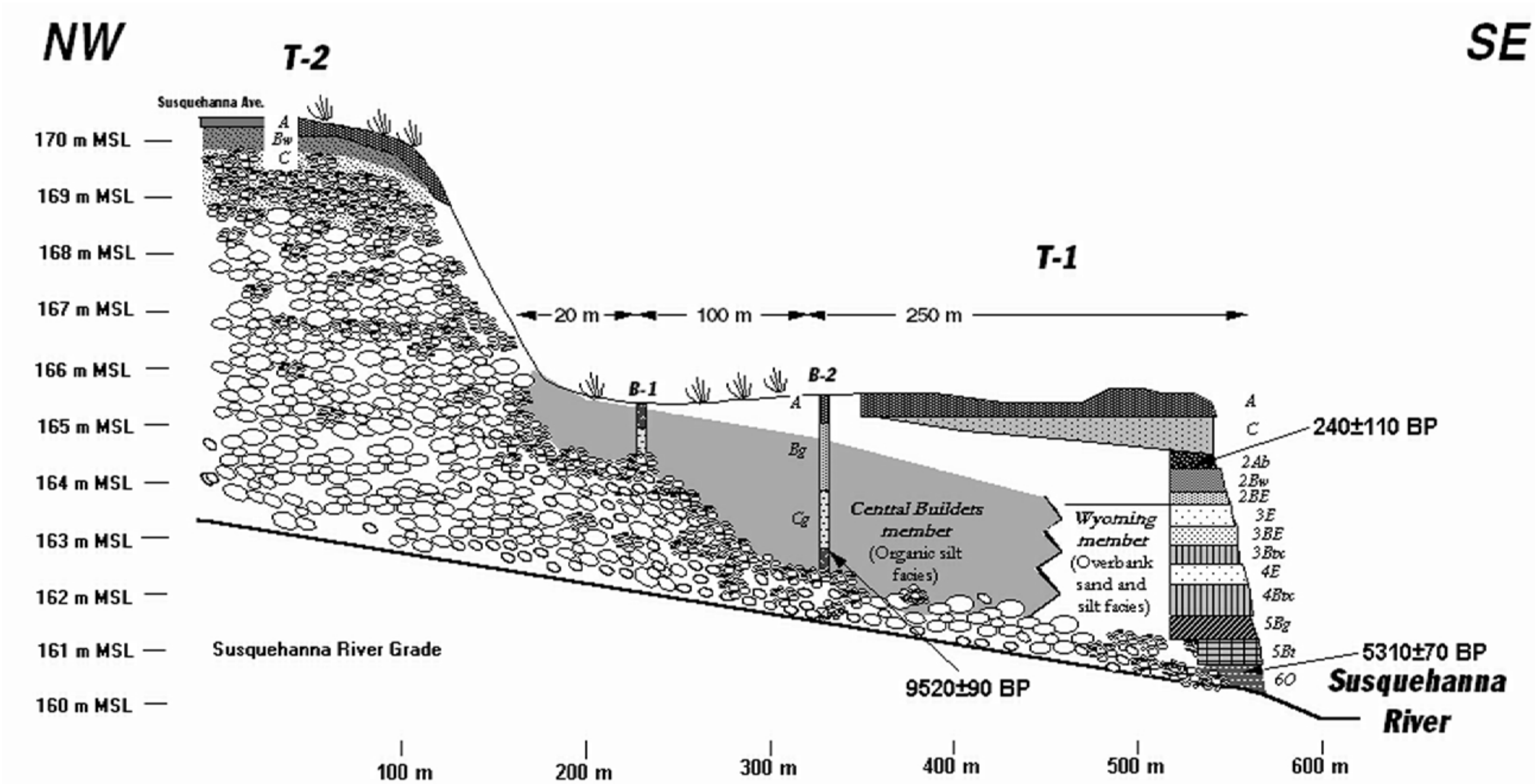


Figure 86: Stratigraphic transect of the T-1 at Wyoming, Pennsylvania showing unconformities bounding the members of the Wyoming Valley formation and the basal contact with glacial outwash

thick and contained abundant woody detritus. The overlying sediment was a dark gray (2.5Y4/1) clay with much smaller pockets of more decayed organic matter. Bedding appears to have been disturbed by root action up to approximately 140 cm below surface, where thin laminar bedding was observed in dark grayish brown (2.5Y4/2) clayey silt described as a Cg soil horizon.

The Bg horizon formed in the Central Builders member slackwater silt and clay has moderately well-developed platy structure parting to weak fine subangular blocky peds. The field at Wyoming in which boring B-2 was made was plowed or cleared of vegetation several times during the years that fieldwork was conducted but does not appear to have been planted, presumably because of poor drainage. A thin lens of dessicated plant remains found at the base of the brown (10YR5/3) to yellowish brown (10YR5/4) Ap horizon suggests an intermittent wetland drained for agricultural use.

SCOVELL ISLAND (36LU12)

Scovell Island is immediately opposite the mouth of the Lackawanna River, where it joins the North Branch of the Susquehanna at Pittston, Pennsylvania (km 312). **Figure 87** shows the landforms mapped on this portion of the Pittston quadrangle USGS 7.5' topographic map. Scovell Island is fan-shaped and has consequently been thought to be composed at least in part of glacial outwash (Braun, 1997; Hollowell, 1973; Itter, 1938). Gravel beds along its banks include erratics such as pink granite, gneiss, and quartzite. Based on the stratigraphy observed in a hand auger boring in the center of the island (**Figure 88**), as well as in cutbanks on its upstream side, Scovell Island consists

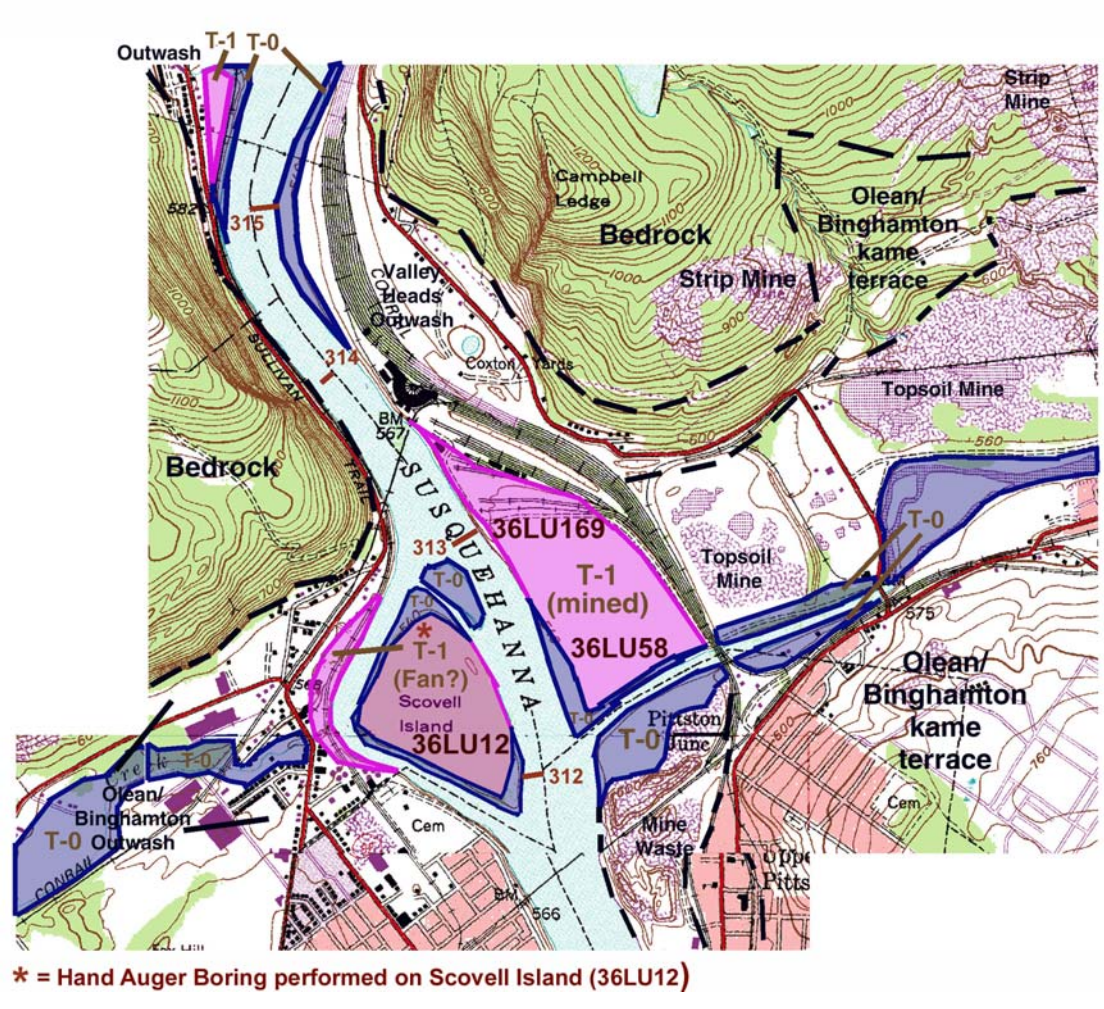


Figure 87: Part of the Pittston quadrange USGS 7.5' topographic map showing Scovell Island (36LU12) and the Cremards (36LU58) and Conrail (36LU169) sites

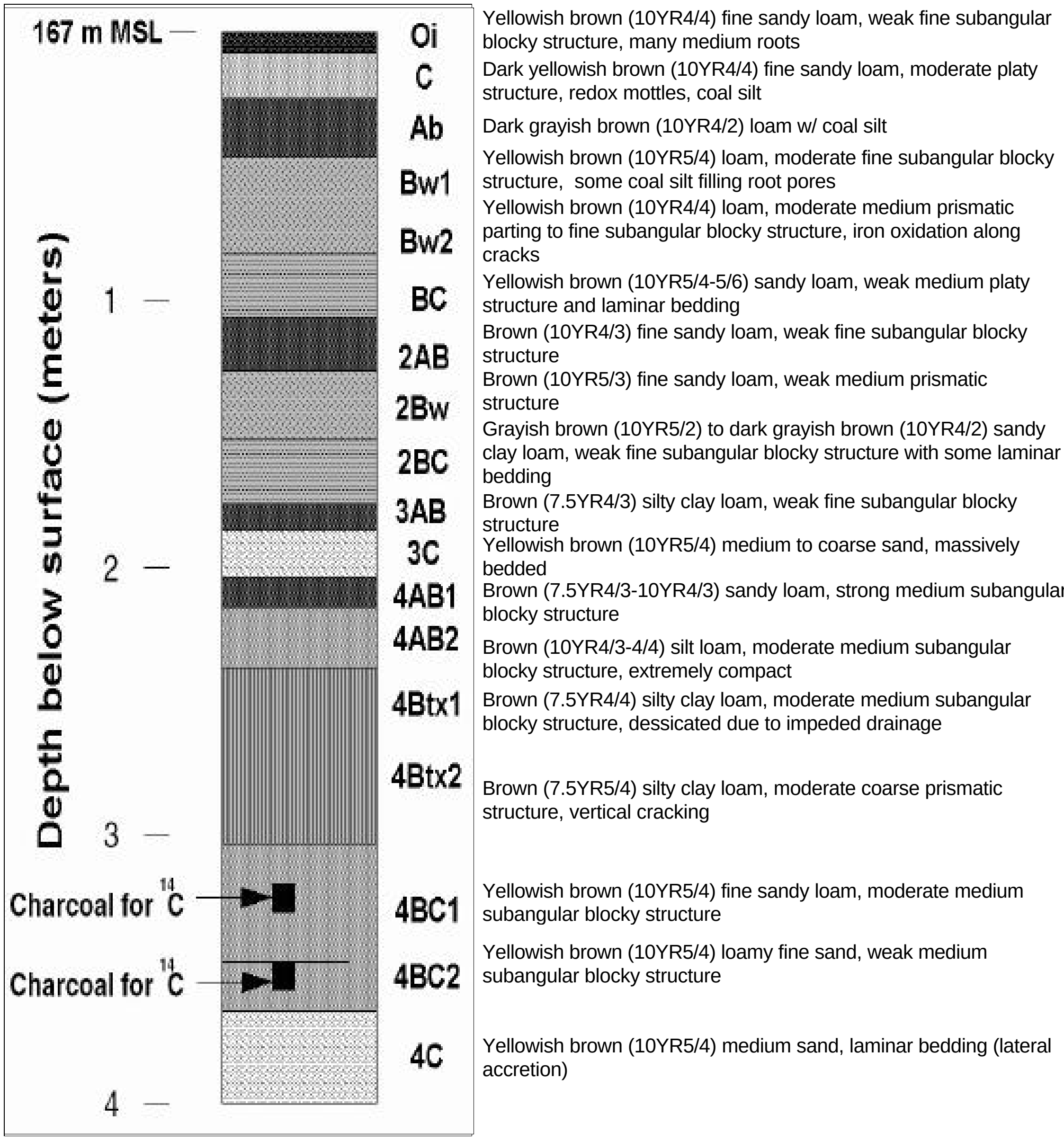


Figure 88: Stratigraphy of the hand auger boring on Scovell Island (36LU12)

almost entirely of Holocene alluvium. This is further corroborated by evidence of prehistoric occupations dating back at least to the Late Archaic period (Brown et al., 1986; Orlandini, 1996).

The Scovell Island hand auger boring reached a total depth of 4 mbs, at which point loose medium sand was falling out of the auger bucket. This cannot have been more than a meter above the lower boundary of the Central Builders member (Discontinuity I), as shown on **Figure 69**. Until the charcoal samples from the 4BC horizon are dated, the age of the basal discontinuity at Scovell Island can be estimated from the dates obtained downstream. Geological samples collected from the boring at Wyoming and the basal levels of the Mifflinville Bridge site (36CO9) have a combined 2-sigma range of 11,160 - 10,578 cal BP. Discontinuity I is the regional equivalent of the Pleistocene-Holocene boundary of the geological time scale (Hageman, 1972; Harland et al., 1990).

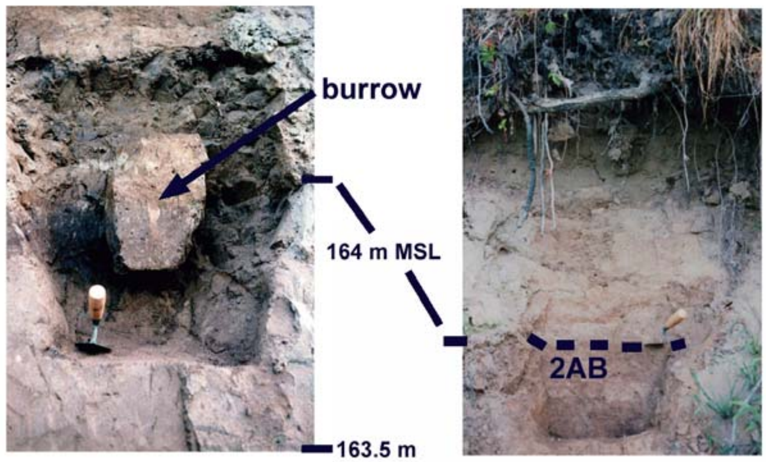
The Central Builders member is capped by the most strongly developed buried soil in the hand auger boring on Scovell Island. This buried soil is nearly a meter thick and includes all of the horizons from the base of the boring up to the 4AB1 horizon originating at 200 cmbs. The 4Btx horizon of this buried soil was described from thin-section in the definition of the Central Builders member at the beginning of this chapter. Soils developed in the overlying sediments have cambic (Bw) as opposed to argillic and fragic (Btx) subsoil horizons.

The sediments between the 2AB and 4AB1 horizons in the boring at the center of Scovell Island are here assigned to the Wyoming member of the Wyoming Valley formation. The observed textures are coarser than those described at the type section.

A basal sand bed similar to that described above also occurred in the Wyoming member deposits that I described downstream at both the Jacobs site (km 266) and the Zehner site (km 253). The upper meter of the boring at the center of Scovell Island contains packages assigned to the Forty Fort member (Ab-Bw1-Bw2-BC horizons) and the Nanticoke member (Oi-C horizons) based on lithic characteristics as well as bounding surfaces.

The Central Builders member pinches out away from the center of Scovell Island, and it was not observed in any of the profiles examined in eroding cutbanks on the upstream side of the island (**Figure 89**). The buried soils which outcrop here represent the soil formed at the upper bounding surface of the Wyoming member. This is typically a weakly developed soil with a cambic (Bw) subsoil horizon. It may also be very bioturbated, as seen previously in the thin-section of the Bw/Bt1 horizon from the 8th Street Bridge Replacement in Wyoming.

In one of the cutbanks on the upstream side of Scovell Island, there was a textbook example of a worm burrow infilled with clayey feces or "spreites" (Bullock et al., 1985, p. 102-103; Reineck and Singh, 1986, p. 162-165). In thin-section (**Figure 90**), bow laminae of dusty brown clay were seen in both plane-polarized and cross-polarized light. Fecal pellets and fungal sclerotae provide additional evidence of bioturbation in the thin-section. Such microscopic evidence of soil biota appears to coincide with the macroscopic concentration of prehistoric human activity between this point in the stratigraphic column and the present land surface. Similar features due to bioturbation were observed at any rate in the thin-sections prepared from cultural activity areas at the



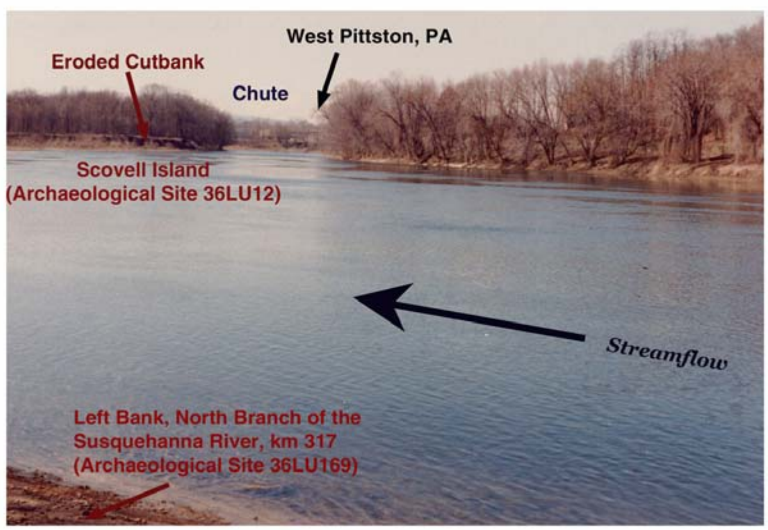


Figure 89: Eroded cutbank profiles on the upstream side of Scovell Island and the buried soil (2AB horizon) sampled for micromorphological analysis

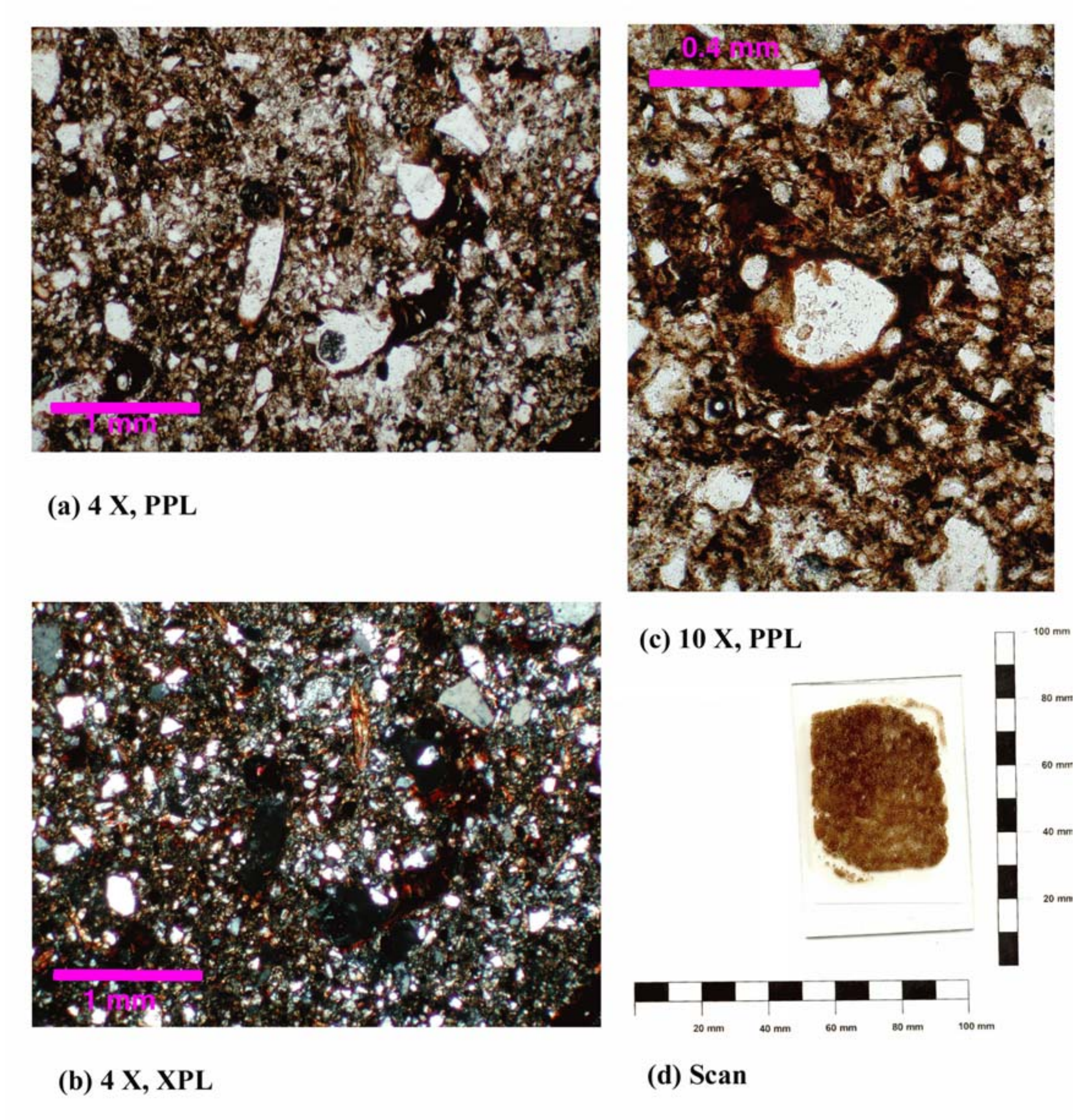


Figure 90: Photomicrographs (a,b,c) and scan (d) of the thin-section prepared from a sample of the 2AB horizon collected from a cutbank on the upstream side of Scovell Island (km 312)

Conrail site (36LU169) upstream of Scovell Island as well as the 8th Street Bridge Replacement Project downstream at Wyoming.

THE CREMARD'S (36LU58) AND CONRAIL (36LU169) SITES

Sites 36LU58 and 36LU169 are both located at the juncture of the Lackawanna River with the North Branch of the Susquehanna, as shown in **Figure 87**. Cremards (36LU58) is a large topsoil mine on the point of land between the two rivers, while Conrail (36LU169) is a relatively undisturbed parcel of land between the topsoil mine and the Coxton railyards. The Frances Dorrance Chapter of the Society for Pennsylvania Archaeology (SPA) has conducted most of the excavations on these two sites, and several of its members have large and relatively well-documented artifact collections.

Deep stratigraphic tests at site 36LU58 were supervised by James Herbstritt (1990), who is currently on the staff of the PHMC. A total of 22 "incipient" buried soils were identified in more than six meters of Holocene alluvium by Frank Vento, a geologist who consulted for Herbstritt at the time (see **Figure 91**). Most of these carefully documented texture and color differences within the profile do appear to represent stratigraphic contacts. Similar banding features can also be caused, however, by lateral and vertical translocation of iron, clay, and dissolved carbon (Birkeland, 1999, p. 113-114; Rawlings, 2000). In the Cremards profile, twelve of the 22 "Ab" horizons (Ab4, Ab5, Ab6, Ab7, Ab8, Ab12, Ab13, Ab14, Ab15, Ab19, Ab20, and Ab21) were less than 5 cm thick and crenulated in appearance. These are unlikely to represent organic matter

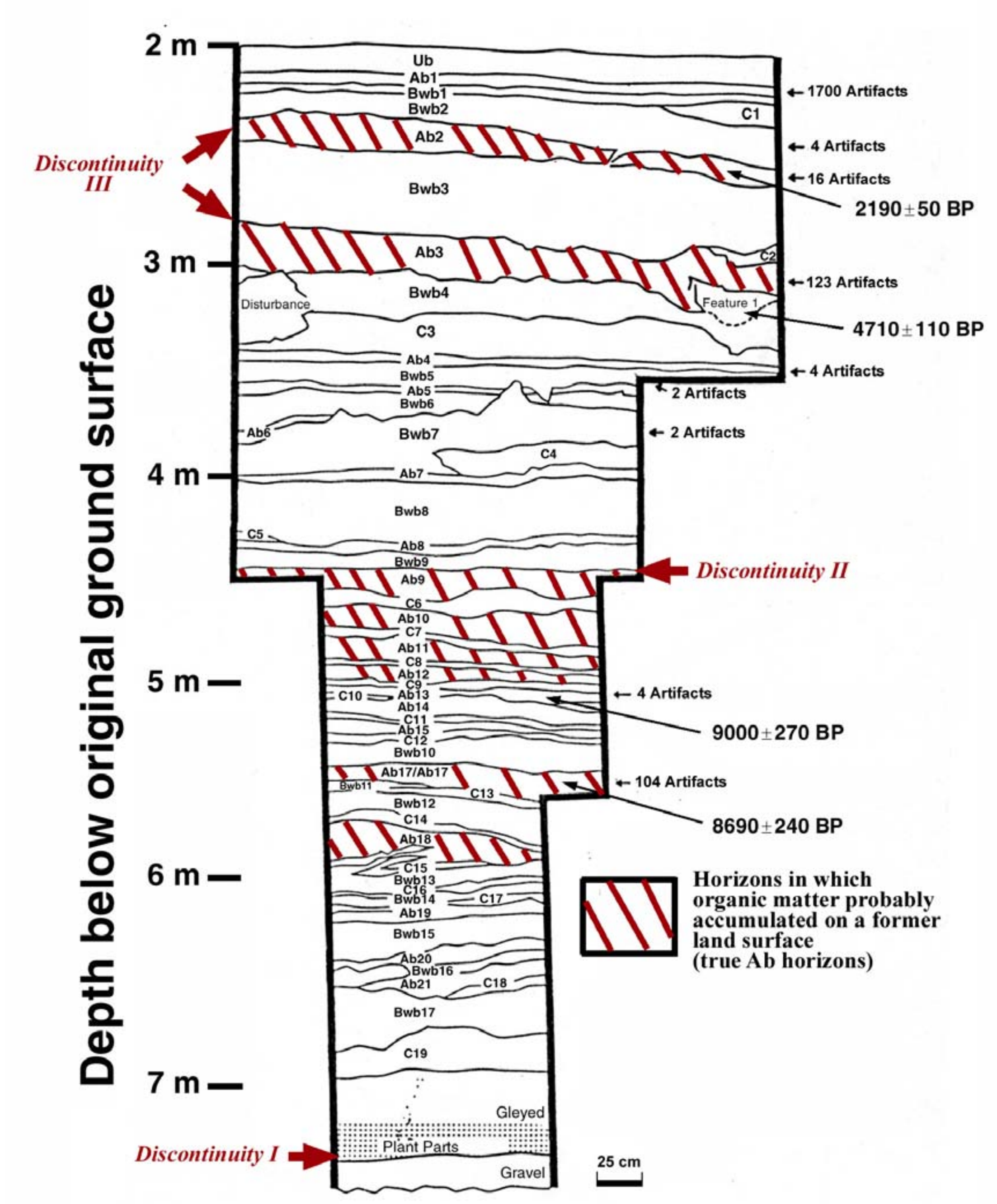


Figure 91: Stratigraphic column at the Cremards site (after Vento and Rollins, 1989). Radiocarbon dates are in uncalibrated ^{14}C years BP.

which accumulated at the earth's surface as topsoil (A) horizons, although they apparently did contain abundant plant material and charcoal as well as intrusive cultural deposits.

Three of the discontinuities which have been traced in the present study can be identified in the Cremards site stratigraphic column. The base of the excavation was a disconformable contact between slackwater deposits of the Central Builders member of the Wyoming Valley formation and outwash gravel (Discontinuity I). Unfortunately, a radiocarbon date has not yet been obtained on this contact. There are two dates from the overlying deposits. A date of 8690±240 B.P. was obtained for the buried soil designated as "Ab16/Ab17," and a date of 9000±270 B.P. for the thin crenulated band designated as "Ab13." The combined 2-sigma range for these dates is 10,272-9,492 cal BP. Both dates were associated with an Early Archaic cultural component, which featured bifurcate base (MacCorkle, St. Albans, and Lecroy on **Figure 40**) and Kirk stemmed PPKs.

Two factors probably contributed to the absence of a strongly developed buried soil at the top of the Central Builders member in the Cremards site profile. First of all, the predominance of slackwater deposition and the episodic nature of that deposition precluded the type of weathering which results in fragic or argillic subsoil horizons. Many of the horizons at Cremards were similar to the gleyed ("Bg" and "Cg") subsoil horizons described downstream at Wyoming in deposits of equivalent stratigraphic position and age. For those intervals and in those discrete areas where the land surface was stable, the intensity of human occupation itself also seems to have affected the soil properties.

The Wyoming member at the Cremards site is represented by sediments between the horizons designated as "Ab9" and "Ab3." The cambic ("Bwb") horizons designated within this interval are typical of this member of the Wyoming Valley formation. As discussed later in this chapter, the upper boundary of the Wyoming as defined by morphology of buried soils occurs at a contact which appears to be somewhat older than the age for Discontinuity III initially proposed in the radiocarbon chronology. In general, Late Archaic through Terminal Archaic occupations are commonly found in the soils formed on this bounding surface.

At the Cremards site, the horizon designated "Ab3" contained Late Archaic (Vosburg) cultural material, but the T-1 accreted over 50 cm more before the initial deposition of sediments which can be assigned to the Forty Fort member. Unfortunately, as is so often the case in the Wyoming Valley, the uppermost, organic-rich sediment on this site was mined for toposoil before the stratigraphy could be carefully described. Both Middle Woodland and Clemson Island/Owasco cultural components were present.

The Wyoming and Forty Fort member deposits thin upvalley between Cremards (36LU58) and the Conrail site (36LU169). Whereas the buried soil containing the Early Archaic component was over four meters below the land surface at Cremards, similar cultural materials were found from two to four meters below surface at Conrail. **Figure 92** presents the stratigraphic column that I described from the profile shown in **Figure 93**. The 4AB horizon was the most strongly developed buried soil in the profile, marking the top of the Central Builders member. It should therefore correlate with the horizon

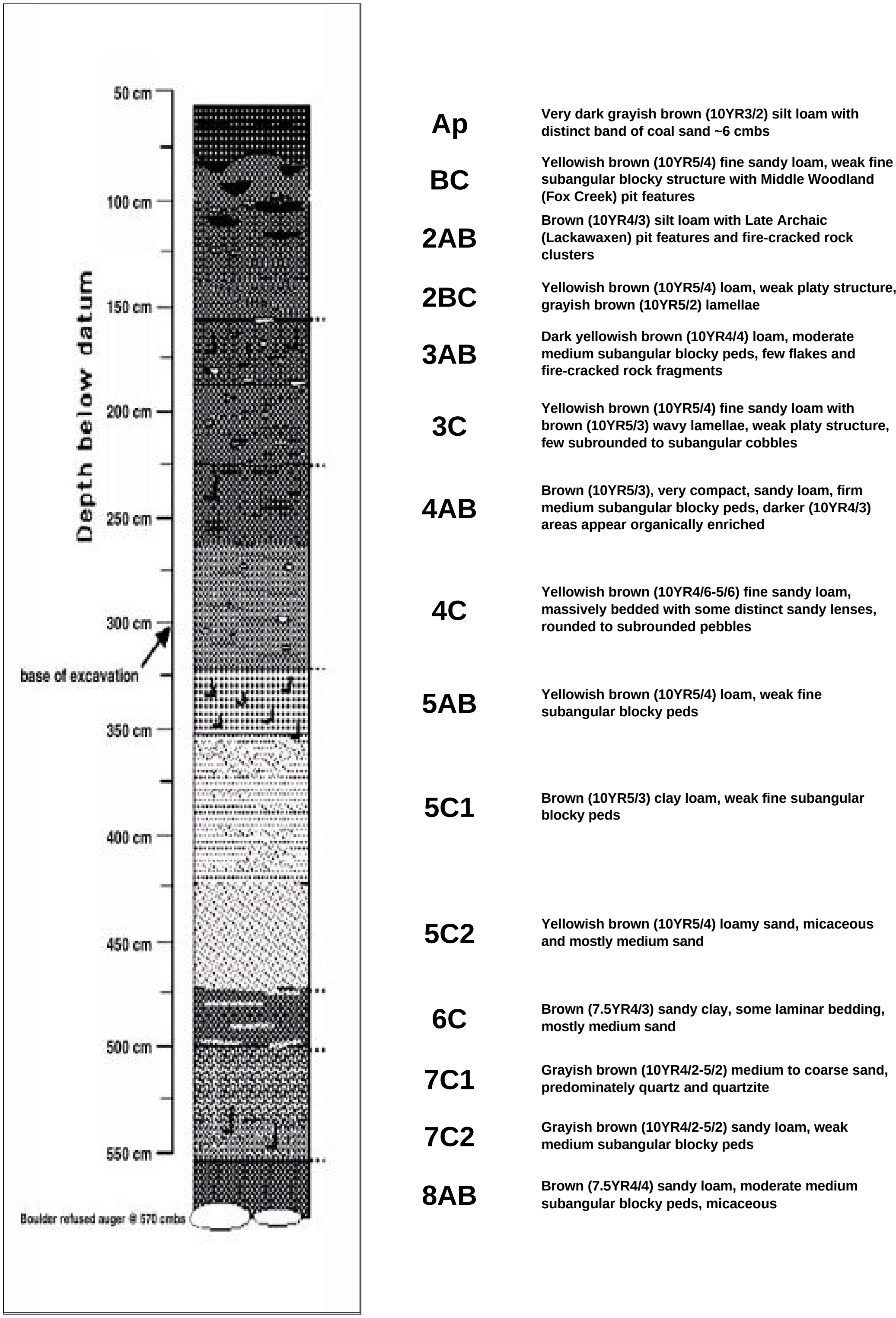


Figure 92: Master stratigraphy for the Conrail site (36LU169)

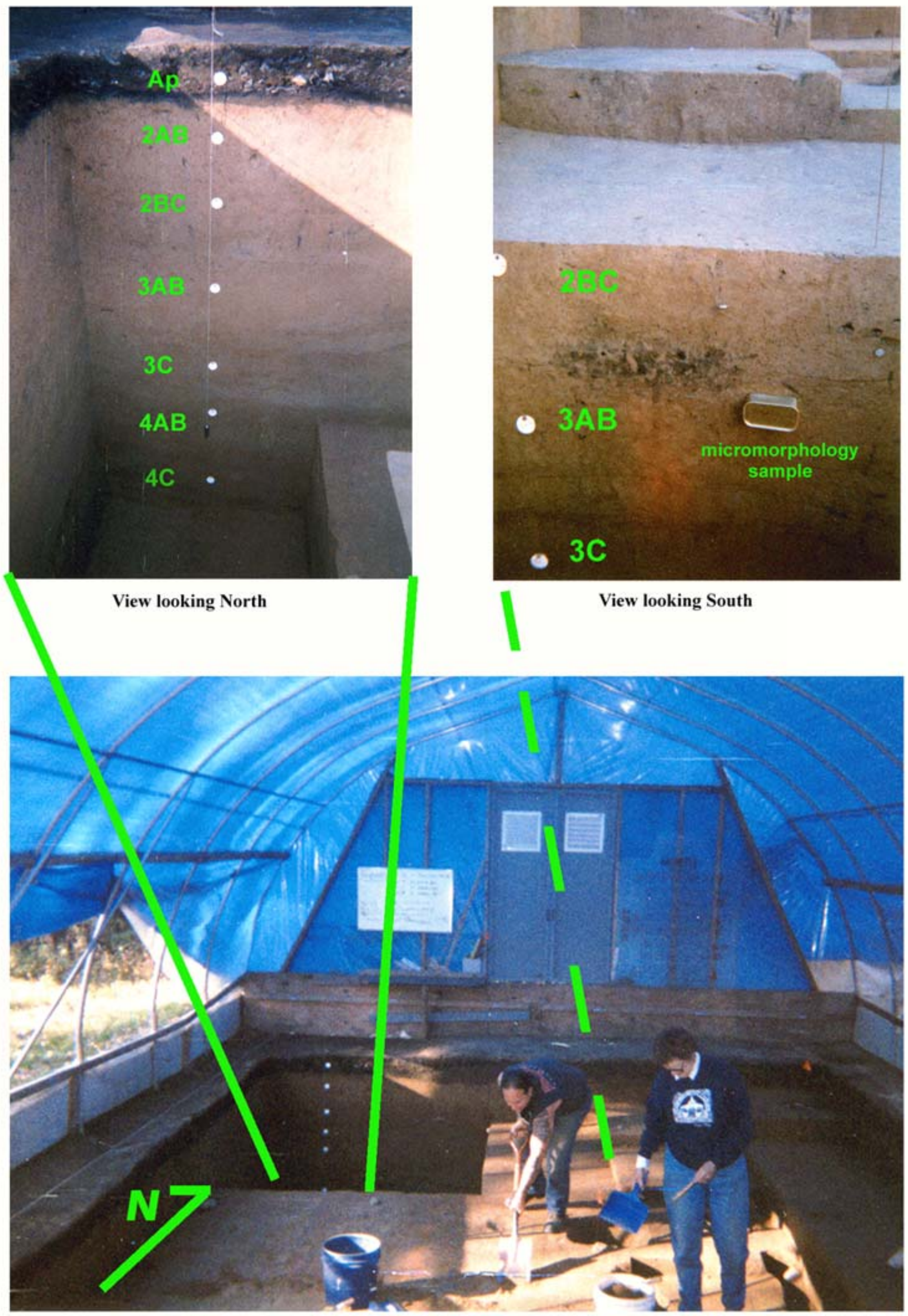


Figure 93: Block excavation at the Conrail site (36LU169) showing the master stratigraphy profile and the sample of the 3AB horizon collected for micromorphological analysis

designated as "Ab9" in the Cremards site profile, which is consistent with the Early Archaic cultural materials found in both profiles at this depth.

The top of the Wyoming member at Conrail is marked by the buried soil which consits of the 2AB and 2BC horizons. At least three Late Archaic occupations occurred as the sediment from which this soil formed was being deposited. Assemblages containing Vosburg, Brewerton, and Lackawaxen PPKs were found in stratigraphic order on living floors, as shown in **Figure 94**. The floors could not be differentiated as soil horizons or natural levels in the profile, although their compaction allowed them to be followed by the excavators. Samples were collected for thin-section analysis from both the 3AB horizon beneath the Late Archaic occupations and from Feature 187, a prehistoric pit containing charred plant material (**Figure 95**).

The thin-section of the 3AB horizon (**Figure 97**) exhibits a spongy texture characteristic of bioturbated soils with a high mud content (Beckmann and Geyter, 1967; Bullock et al., 1985). Small voids were found throughout the parent sediment, but these have been filled with dusty brown clay, hydrous iron compounds characterized by bright red birefringence, excreta (peloids), and fungal sclerotae. A burrow backfilled with bright red to brown clayey spreites is shown in the 10X closeup view (c).

The same spongy texture is evident in the thin-section of the Feature 187 sample. Up to 20% of the sediment in the pit fill consists of wood charcoal, and some grains are over 1 mm in diameter. The larger grains are rimmed with iron and clay precipitates, and this sediment has also been extensively burrowed. A burrow backfilled with bright red to brown clayey spreites can be seen in the upper left corner in views (a) and (b). View (c)

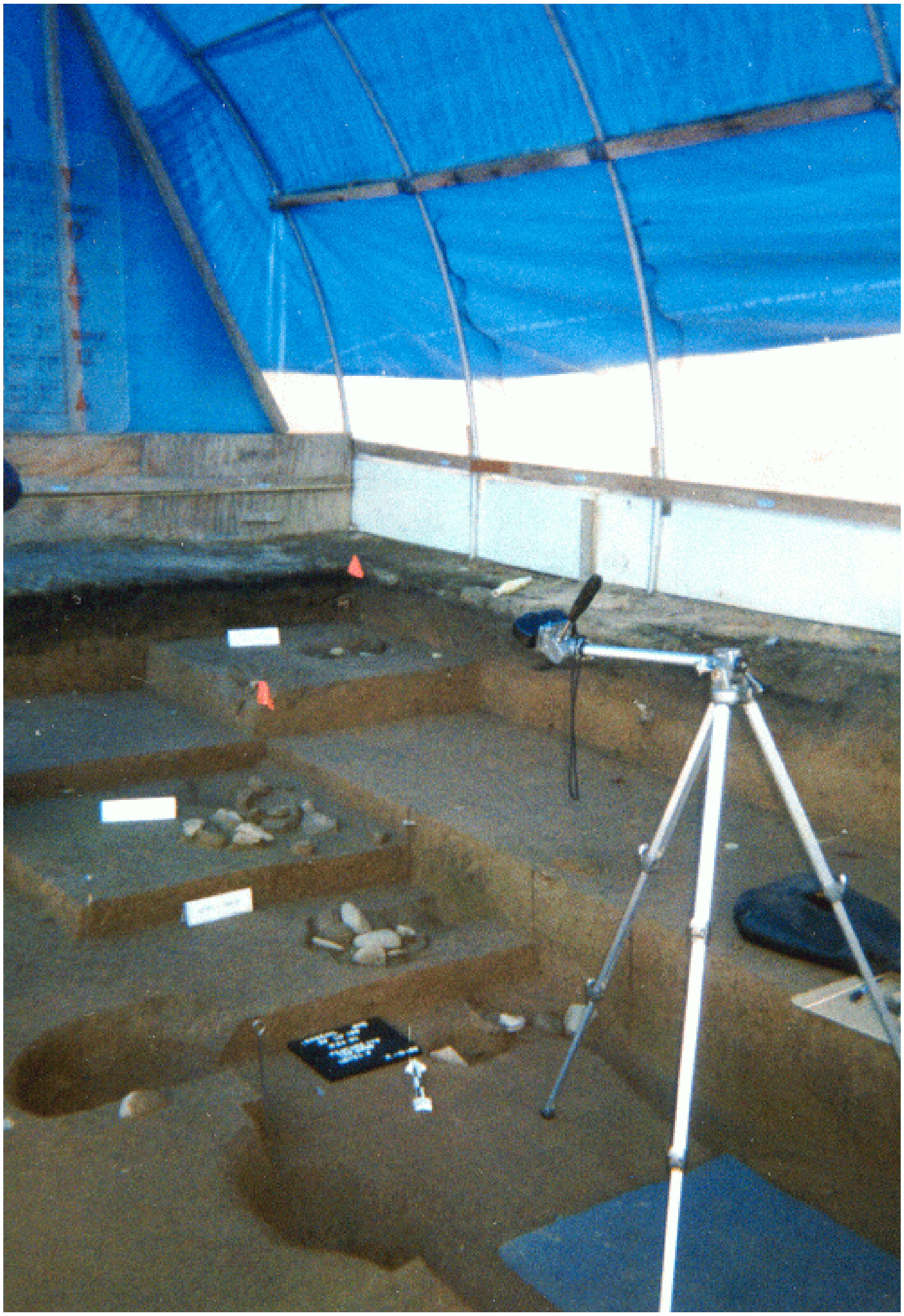


Figure 94: Late Archaic pit features in stratigraphic order on living floors in the block excavation at the Conrail site (36LU169)

Figure 95: Vosburg style PPK *in situ* on a Late Archaic living floor in the 2BC horizon at the Conrail site (36LU169)

Figure 96: Sample collected for thin-section micromorphology from Feature 187 at the Conrail site (36LU169)

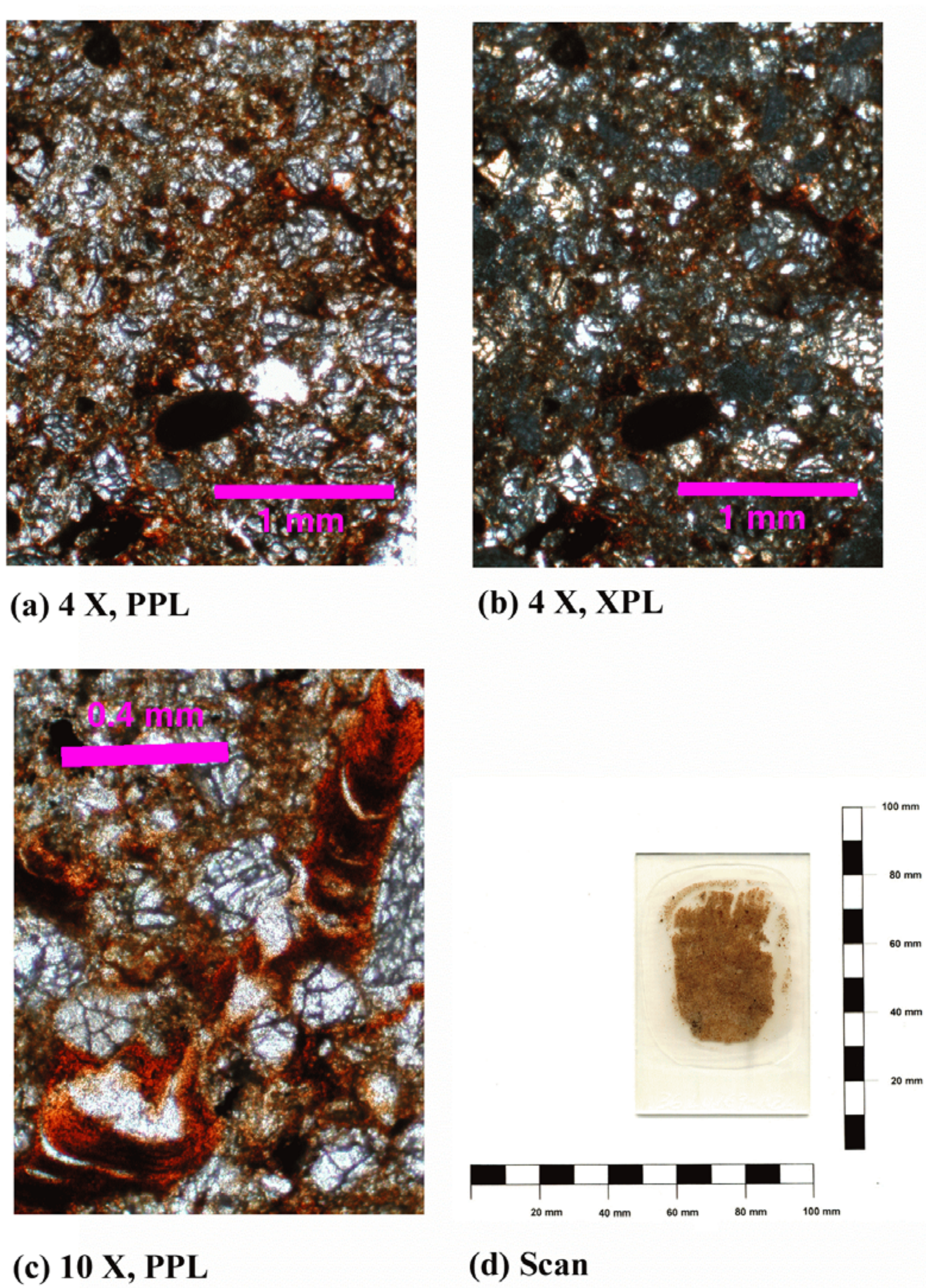


Figure 97: Photomicrographs (a,b,c) and scan (d) of the thin-section prepared from a sample of the 3AB horizon at the Conrail site (36LU169)

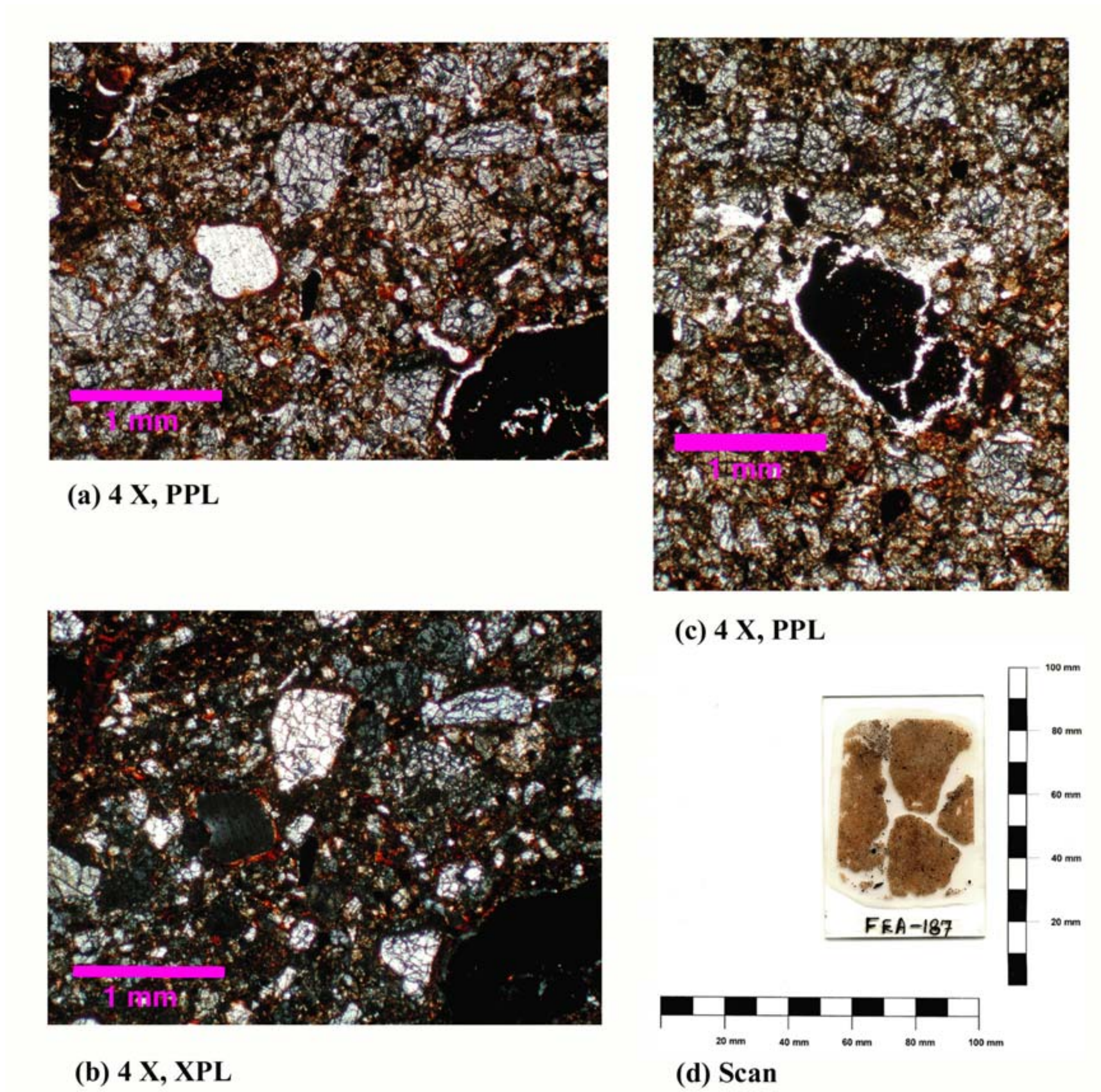


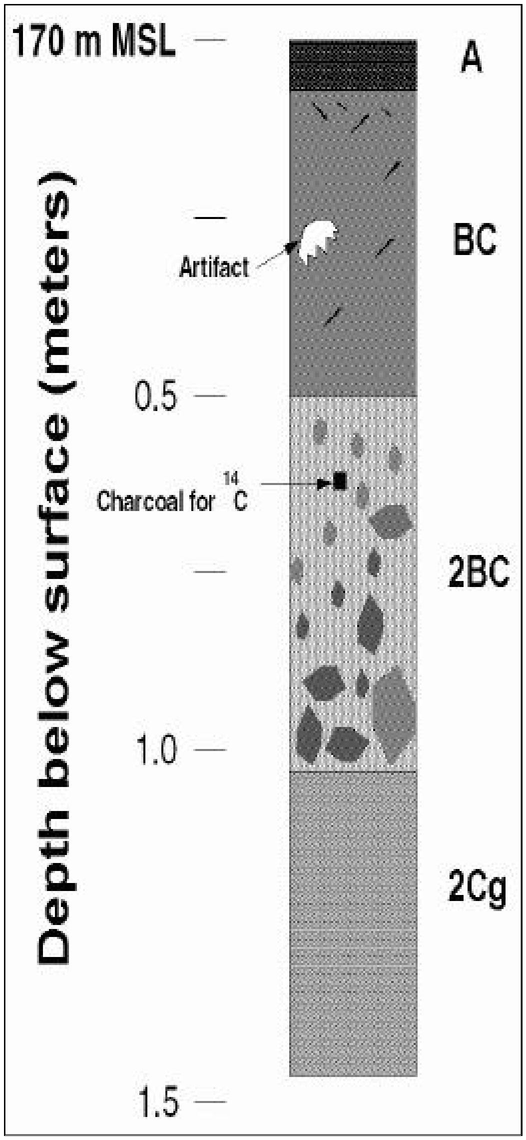
Figure 98: Photomicrographs (a,b,c) and scan (d) of the thin-section prepared from Feature 187 at the Conrail site (36LU169)

shows the change to a more opaque spongy matrix which occurs near the base of the pit, where it intruded the underlying 3AB horizon.

Grading of site 36LU169 truncated it down to a Middle Woodland component before the archaeological excavations began. The Middle Woodland component was also reported to occur at Cremards within the "Ab2" buried soil horizon (Vento and Rollins, 1989). The radiocarbon date of 2190±50 BP on wood charcoal from the "Ab2" calibrates to 385-112 BC in calendar years. This is actually an Early Woodland date, falling in the range for "Bushkill" cultural materials such as Vinette I ceramics (see **Table 10**). The grading and topsoil mining at both Cremards and the Conrail site removed deposits which are of the appropriate age to be assigned to both the Forty Fort and Nanticoke members of the Wyoming Valley formation (Griffiths, 1997; Orlandini, 1996). A section of the North Branch Canal also traversed the T-1 just northeast of the Conrail site. The original railroad tracks were put in on the same right-of-way after the canal bed had been filled in.

UPPER EXETER (km 325)

Upstream of the Wyoming Valley, the river follows bedrock meanders and the alluvial terrace consists of discontinuous segments spaced several kilometers apart or on opposite banks. One such segment occurs on the right bank on the Ransom quadrangle USGS 7.5' topographic map, between kilometers 323 and 326 counting upstream from the river mouth. I described and sampled the profile shown in **Figure 99** where the T-1 is incised by a small tributary upstream of the Mountain View cemetey in Upper Exeter.



A: Brown (10YR5/3) fine sandy loam, weak fine granular structure, many fine to medium roots

BC: Dark grayish brown (10YR4/2) to brown (10YR4/3) fine sandy loam, moderate fine platy parting to fine subangular blocky structure, scattered plant parts, prehistoric lithic artifact

2BC: Dark yellowish brown (10YR4/4) loam with coarse prominent dark brown (10YR3/3) mottles increasing with depth

2Cg: Brown (10YR5/3) loamy sand with fine grayish brown (10YR5/2) redoximorphic mottles

Figure 99: Stratigraphy of the T-1 segment exposed at Upper Exeter (km 325) exposed by tributary incision

The Wyoming member of the Wyoming Valley formation is clearly present at Upper Exeter, given the predominant fine sand and silt texture. I have placed the top of the Wyoming (Discontinuity III) at the contact of the BC with the 2BC horizon (see **Figure 69**). At least a meter of the Wyoming is present, although the basal contact with outwash gravel could not be obeserved in this cutbank exposure.

THE FALLS BRIDGE SITE (36WO56)

Less than ten kilometers upstream of Upper Exeter, at Falls (km 331), the replacement of the S.R. 92 bridge impacted prehistoric site 36WO56 on the right bank T-1 of the North Branch of the Susquehanna River (see **Figure 100**). The T-1 stands at 174 m MSL, approximately six meters above river grade at 168 m MSL (Kingsley et al., 1995, p. 3). Middle Archaic, Late Archaic, and possible Terminal Archaic components occurred from 80-120 cmbs, and there was a Middle Woodland component between the surface and approximately 65 cmbs. Five radiocarbon dates were obtained on charred wood, four of which were from pit features. The Falls Bridge site radiocarbon chronology combined with the artifact assemblages suggests episodic occupation prior to 5000 BP, intensive utilization during the Late Archaic Period, and finally a brief occupation at some point between AD 240 and 400.

Figure 101 shows the results of the particle size analyses for a column of ten samples from a hand auger boring at the base of the archaeological excavations. These results were previously reported in the beginning of this chapter (**Table 13**). The boring reached a total depth of 6.5 mbs, where outwash gravel was encountered at the base of

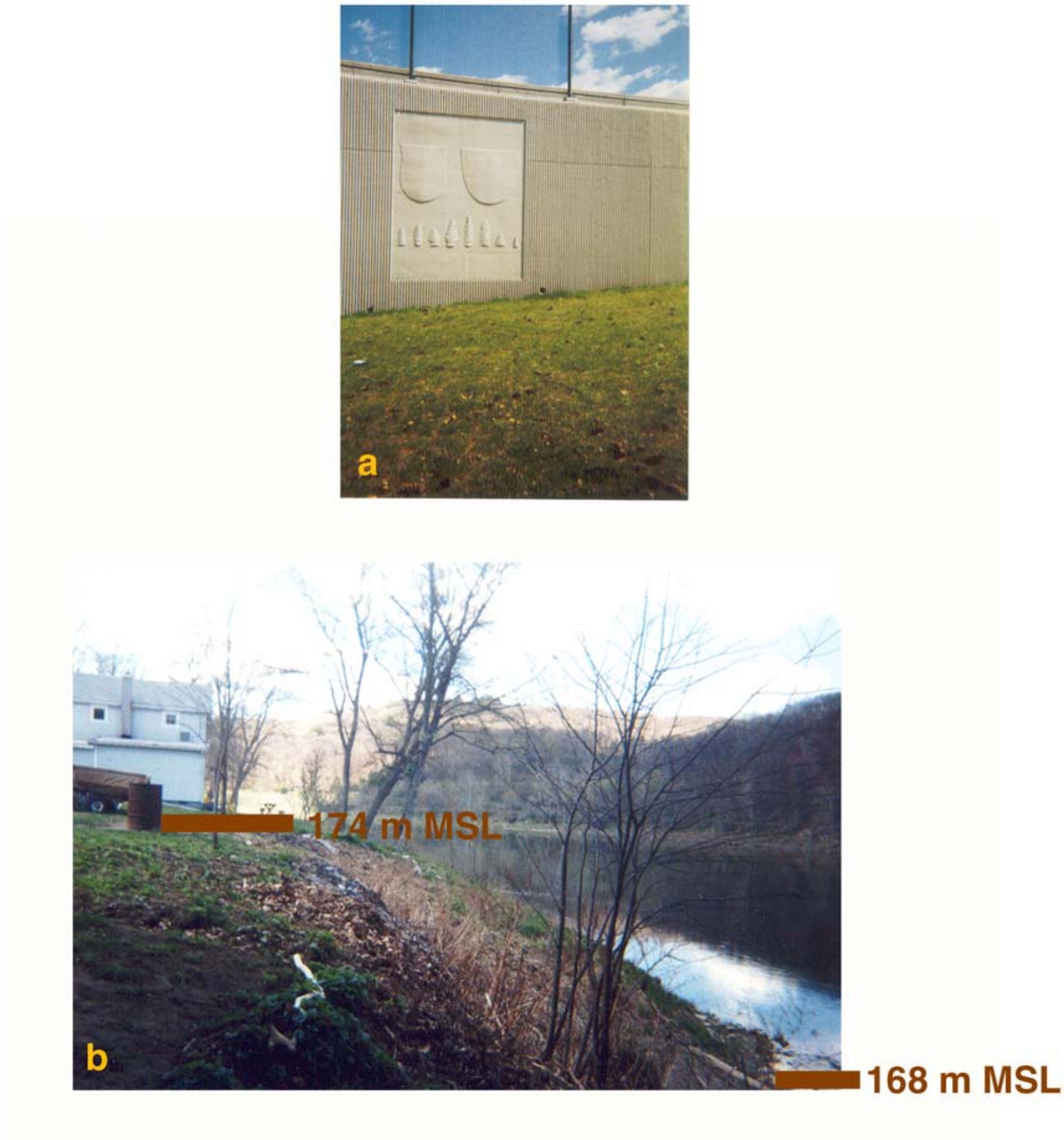


Figure 100: The Falls Bridge site (36WO55) after completion of the S.R. 92 bridge over the North Branch of the Susquehanna River. View (a) looking south. View (b) looking north along the surface of the T-1 landform.

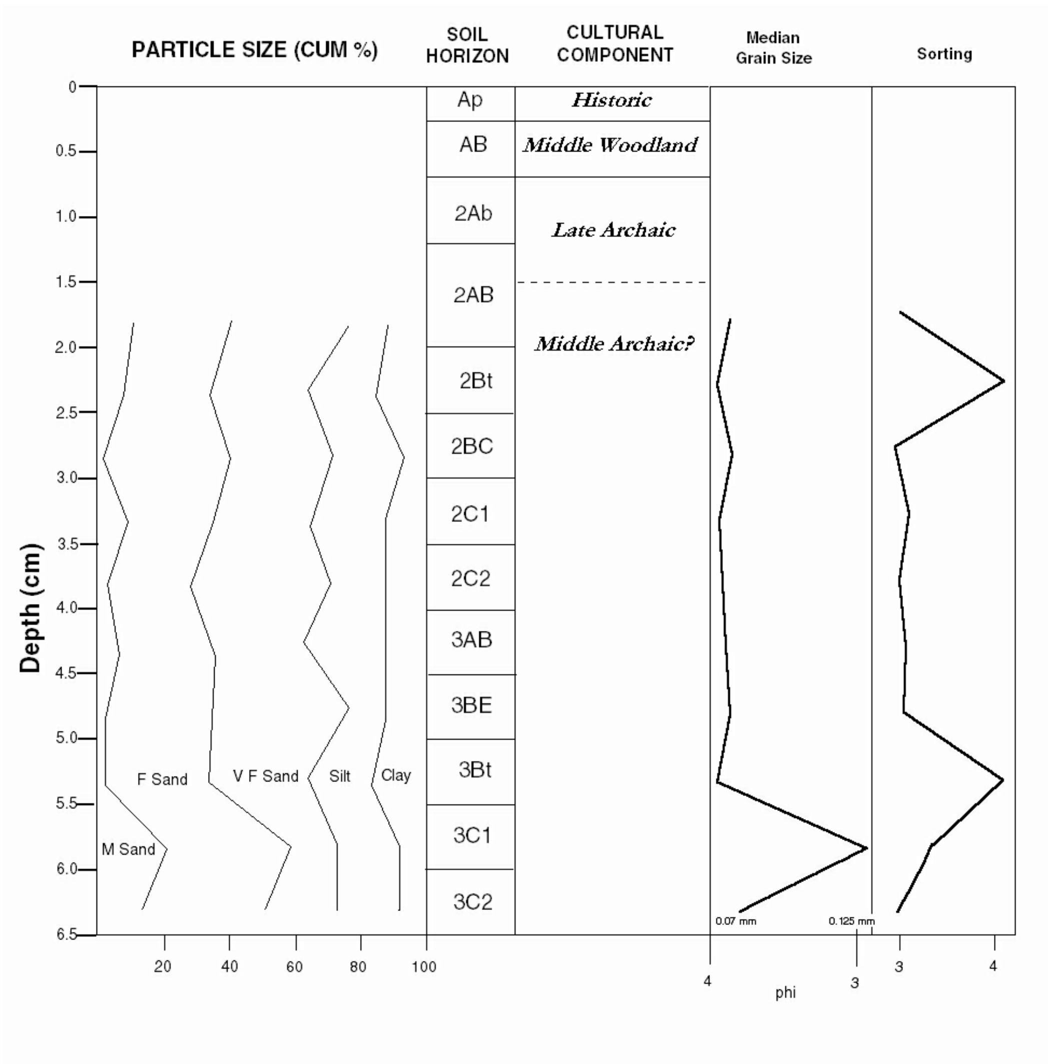


Figure 101: Particle size of the Holocene alluvial deposits underlying the archaeological contexts at the Falls Bridge site (36WO56)

the alluvial deposits. This contact represents Discontinuity I in the present allostratigraphic framework, and the overlying, coarse-textured sediment with a strongly developed buried soil is typical of the Central Builders member of the Wyoming Valley formation.

Rapid changes in the energy of the flowing water which deposited the sediment are suggested by the abrupt increase in the abundance of medium and fine sand, as well as the greater median grain size of the 3C1 horizon. Coarse sand was also abundant in the 3C1, and very coarse sand only occurred in the 3C1 and 3C2 horizons. A clay increase of ten percent occurs from the 3C1 to the 3Bt. The clay increase causes the sediment in both the 2Bt and the 3Bt horizons to appear more poorly sorted using the graphic sorting index of Friedman and Sanders (1978).

The 3AB horizon marks the upper bounding surface of the Central Builders member and Discontinuity II in the present allostratigraphic framework. The horizons above the 3AB horizon, up to the 2Ab horizon which contained the Late Archaic cultural material, are here assigned to the Wyoming member of the Wyoming Valley formation. The texture in these sediments is more uniform, which may be due to greater bioturbation as well as to less variation in depositional energy. The Bt horizon in the Wyoming member "sequum" at site 36WO56 was previously described by Wagner (1987), who correctly estimated these deposits to be from 3000 to 4000 years old.

The upper boundary of the Wyoming member was only 65 cm below the present land surface at Falls Bridge. This is Discontinuity III in the present allostratigraphic framework. Above this bounding surface on these older T-1 segments, overbank floods rarely overtopped the river banks. Relatively coarse-textured flood drapes of either Forty Fort member or Nanticoke member sediment mark very large discharges as well as greater supply of sediment by erosion during these intervals of alluvial deposition.

WHITES FERRY (km 338)

Only seven kilometers upstream of Falls, a T-1 segment again occurs on the right bank of the river at Whites Ferry (km 338). The T-1 stands at 176 m MSL, approximately five meters above river grade (see **Figure 102**). I described and sampled the upper three meters of the alluvial deposits with a hand auger boring, as shown in **Figure 103**. The basal contact with outwash gravel (Discontinuity I) is at some undetermined depth between the base of my boring and the elevation of the gravel exposed along the river bank.

The buried soils at Whites Ferry have weakly developed (Bw) subsoil horizons, although the density increased considerably in the lowest horizon sampled, designated as 5Cx. The horizons from the base of the boring up to the 4Ab horizon, at approximately 180 cmbs, are here assigned to the Central Builders member of the Wyoming Valley formation. The Wyoming member is represented by the horizons from the 4Ab (Discontinuity II) up section to the 2Ab horizon at 80 cmbs (Discontinuity III). Age constraints could be obtained on the bounding surfaces in the Whites Ferry section by dating the samples of charred plant material which I collected from the 2Ab and 5C2 horizons in the hand auger boring.

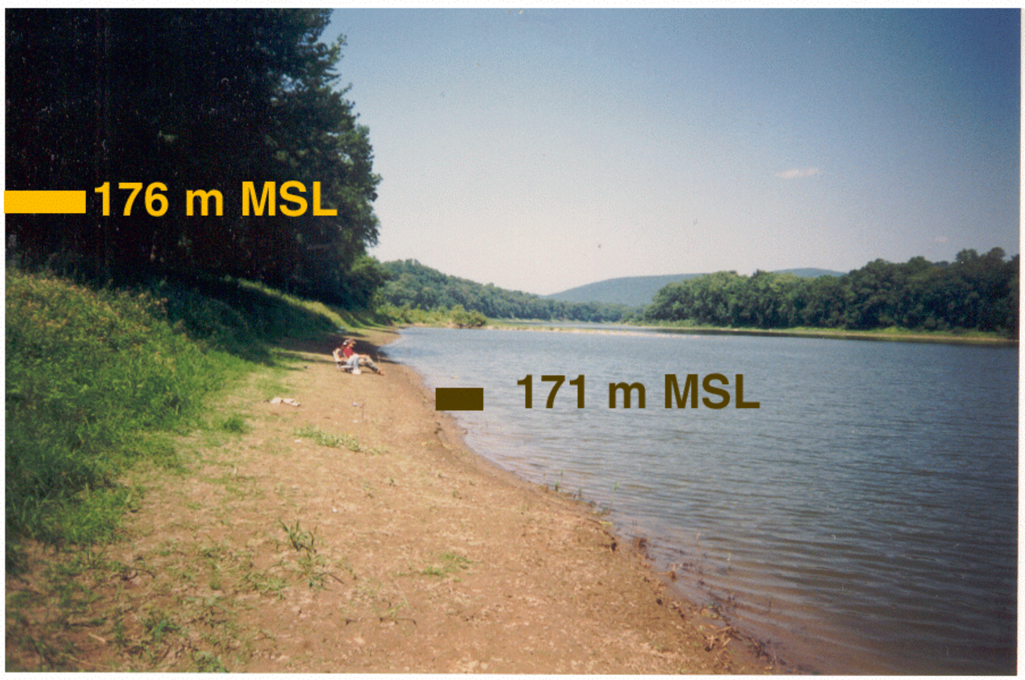


Figure 102: The T-1 segment on the left bank of the North Branch of the Susquehanna River at Whites Ferry (km 338)

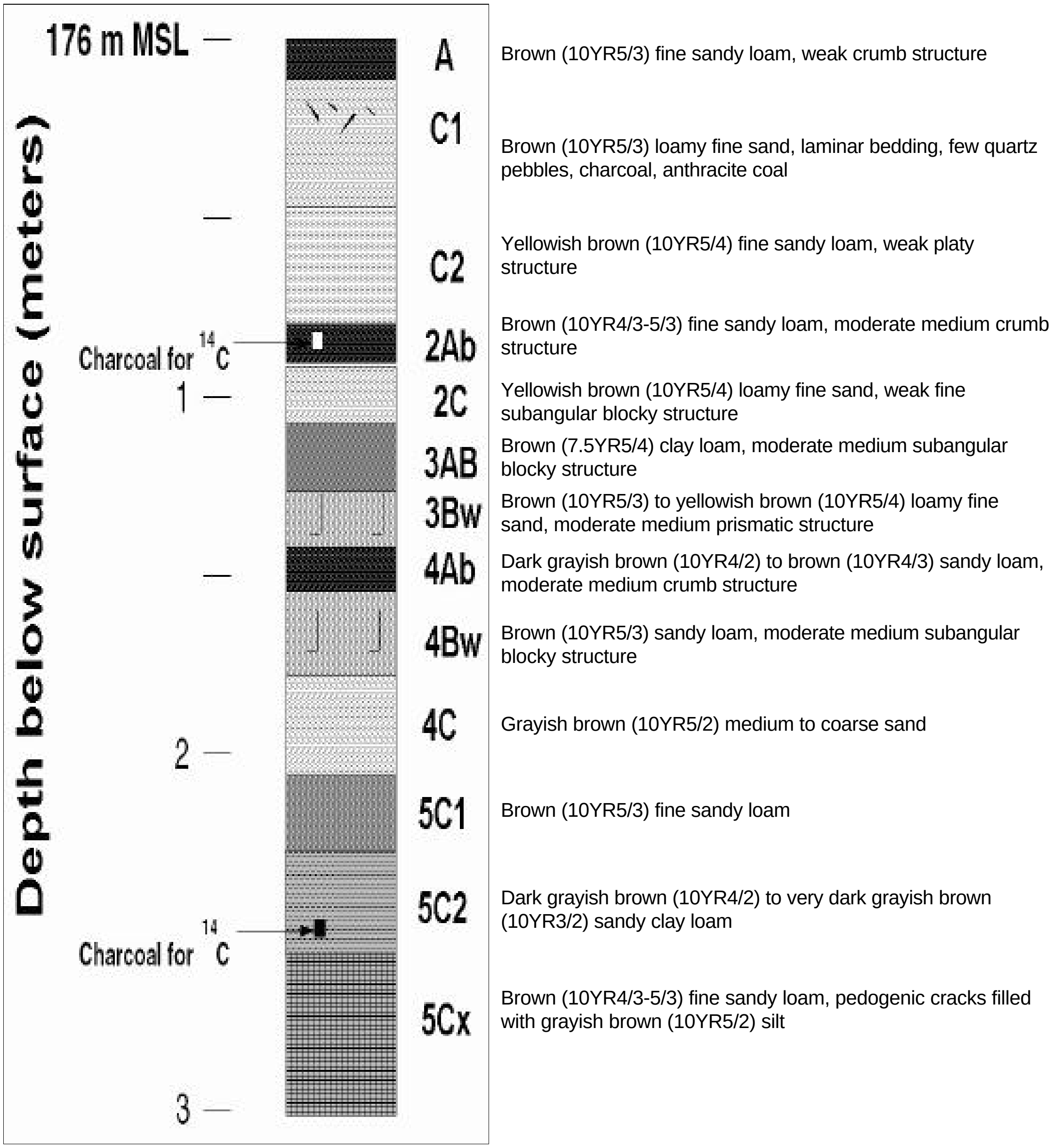


Figure 103: Stratigraphy of the T-1 remnant at Whites Ferry (km 338)

THE HARDING FLATS SITE (36WO55) AT THE MOUTH OF TUNKHANNOCK CREEK

Tunkhannock Creek enters the North Branch of the Susquehanna River from the left bank just downstream of the town of Tunkhannock, Pennsylvania (km 349). The town and the creek both take their name from a Delaware town which was occupied from 1749 to 1758 (Kent et al., 1981). Archaeological traces of this "Refugee phase" town have not been conclusively identified, but they may be represented by early historic materials on two of the seven archaeological sites impacted by the recent construction of the S.R. 6 bypass of Tunkhannock.

The site on the right bank of Tunkhannock Creek, 36WO9, was relatively shallow and most of the prehistoric to protohistoric materials were in mixed contexts containing 19th and 20th century materials as well (LBA, 1991; Skelly and Loy, 1995). The largest and most significant of the sites containing prehistoric cultural material was the Harding Flats site (36WO55) on the left bank of Tunkhannock Creek. The prehistoric occupations at Harding Flats also continue downstream along the left bank of the North Branch of the Susquehanna River (see **Figure 104**).

Harding Flats was a particularly complex and challenging archaeological site because a relatively late (Owasco culture) component was buried more than a meter below the surface in one area while much earlier (Late Archaic through Middle Woodland) components occurred much closer to the surface elsewhere on the site. The latter components were encountered relatively late in the project and were on the T-1 of

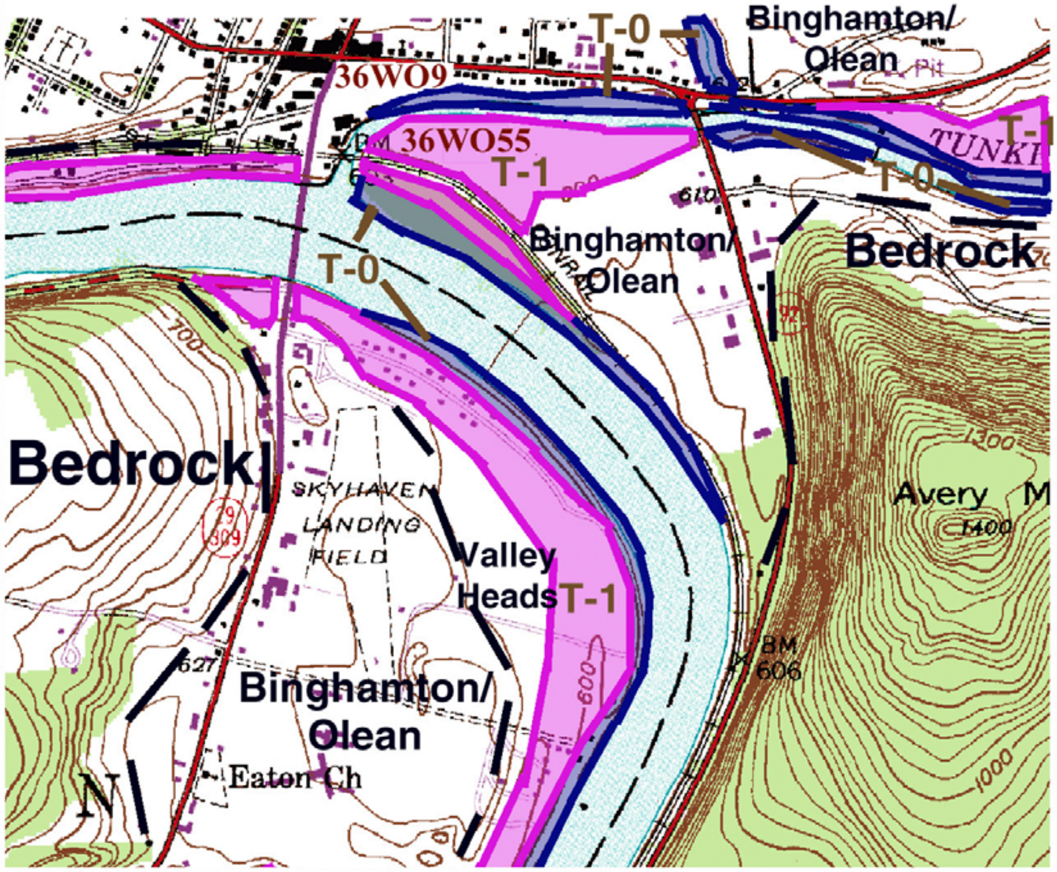


Figure 104: Part of the Tunkhannock quadrangle USGS 7.5' topographic map showing landforms mapped in the vicinity of the Harding Flats site (36WO55)

the North Branch of the Susquehanna River. Most of the Owasco culture occupation, on the other hand, was immediately adjacent to Tunkhannock Creek.

The landforms at the juncture of Tunkhannock Creek with the river owe their unique stratigraphic architecture to shifts in both the creek and the river channel through time. Tunkhannock Creek has a much steeper gradient, falling from 195 m to ~178 m MSL within ten kilometers in its lower reaches. This is more than twice as steep as the average gradient of 0.0005 for the river channel, as presented in **Chapter 3**. One reason for the steep gradient is that the creek follows a sluiceway cut by local meltwater and the discharge from glacial lake Great Bend during the late Pleistocene (Braun, 1999; Braun et al., 1999; Inners et al., 1999). The creek still receives very large flood disccharges, particularly during spring snowmelt events.

Buried channels and terrace landforms defined during the archaeological excavations show that the Tunkhannock Creek channel has shifted progressively upstream to the northwest across the Harding Flats. A terrace grade variously referred to as "T-2" and "T-1b" (Skelly and Loy, 1995) stands approximately five meters above the active channel of Tunkhannock Creek. Along the riverbank, the terrace segments stand closer to river grade and have been recontoured, most recently by the railroad and by the North Branch Canal back in the 19th century.

The generalized profile presented in **Figure 69** illustrates the deep deposition from the time of the Owasco occupation to the present. At least a meter of this upper T-1 alluvium represents the Forty Fort member of the Wyoming Valley formation. A basal deposit no thicker than 50 cm overlying coarse gravel beds derived from local lithologies has been assigned to the Wyoming Valley formation.

Radiocarbon dates of 5880±50 BP (cal 6850-6552 BP) and 3560±50 B.P. (cal 3980-3694 BP) were obtained on organic sediment immediately overlying the channel sand and gravel in former channels of Tunkhannock Creek. These ages pertain to local channel changes in Tunkhannock Creek, but the first date also coincides with Discontinuity II in the allostratigraphic framework for the alluvium of the river valley. The later date may represent the local equivalent of Discontinuity III, depending on whether the top of the Wyoming member or the base of subsequent deposits is used as the stratigraphic reference.

FRIEDENSHÜTTEN

As shown in **Figure 69**, there is a gap of nearly 50 km in the bedrock-controlled reaches of the Appalachian Plateaus in which the alluvial deposits beneath the T-1 landform have yet to be investigated. The first location upstream of Tunkhannock where I was able to obtain access to describe profiles was the location of Friedenshutten, a mission founded by Moravians in 1763 (Delaney, 1973; Kent, 1993, p. 103-104; Kent et al., 1981). A commemorative obelisk on the "Binghamton/Olean" outwash terrace two kilometers downstream of the modern town of Wyalusing (km 399) marks the supposed site of the mission (see **Figure 105**). The marker at the site summarizes the history of this last major residence of Delaware Indians on the North Branch of the Susquehanna River as follows:

Figure 105: Site of the Moravian mission, Friedenshütten, as marked by an obelisk on the "Binghamton/Olean" outwash terrace two kilometers downstream of Wyalusing

FRIEDENSHUETTEN

Moravian mission founded at Wyalusing Indian town, 1763, by Zeisberger, who built a model Indian town. Abandoned in 1772 when pastors Ettwein and Roth led some 200 Indians to the mission of Friedensstadt on the Beaver River.

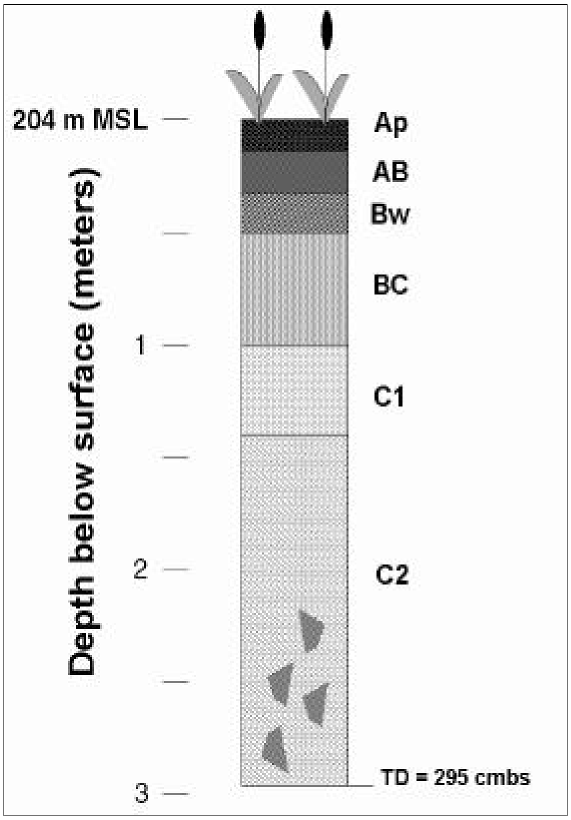
Leslie Delaney excavated with a King's College field school in the vicinity of the obelisk at what he referred to as the "Biggins-McCarty site." The original site number for Friedenshütten was 36BR81, but Delaney used this number for what he referred to as the "Schultz-Franklin site" on the alluvial terrace flanking the river. He then assigned a new number, 36BR80, to the "Biggins-McCarty" area marked by the obelisk (Delaney, 1973). Unfortunately, the number 36BR80 was already being used for another site in Bradford County. At present, "Biggins-McCarty" and "Schultz-Franklin" must be considered to be two activity areas within a single large site, 36BR81.

The field with the obelisk is approximately 500 m north of the river. Here, Delaney found historic artifacts which convinced him and Barry Kent (1993, p. 104) that he had found the site of the Moravian mission to the Delawares. At the "Schultz-Franklin" area, on the other hand, Woodland materials were encountered in what appears to have been an intact alluvial deposit. The latter site was described as "quite complex in that it had suffered soil erosion and silt depositing over periods of flooding for hundreds of years (Delaney, 1973, p. 33)." Delaney claimed to be able to distinguish upper (Owasco) and lower (Clemson Island) components within the stratigraphy, but no tabulations of ceramic attributes were reported and no radiocarbon dates were obtained.

A local amateur archaeologist, Rowland Smith, has subsequently excavated in the same area and found a much earlier assemblage, characterized by Vosburg and Brewerton style PPKs.

Site 36BR81 is situated on one of the higher T-1 remnants in the upper valley reaches, standing approximately 6-7 m above river grade. Because floods rarely overtopped the high terrace bank, relatively little deposition occurred above the soil which formed at the upper bounding surface of the Wyoming member of the Wyoming Valley formation. The exposure of this soil at or near the terrace surface also means that the Late Archaic through Late Woodland components are found on essentially the same landform, often in mixed contexts. A profile of the T-1 alluvium is shown in **Figure 106**, based on a hand auger boring approximately 500 m upstream of site 36BR81. This is the same profile represented in **Figure 69**, in which the Wyoming member is over a meter and a half thick and overlain by less than 50 cm of subsequent overbank alluvium.

The T-1 continues upstream of site 36BR81 on the left bank of the river for at least two kilometers to the mouth of Wyalusing Creek. Several gullies are incised up to three meters into the terrace, impounding runoff during storm events. A boring with a hand auger in the base of one such gully immediately northwest of site 36BR81 encountered dark grayish brown (10YR4/2) silty clay containing abundant woody detritus at over two meters below surface. This is interpreted as a deposit which resulted from historic deforestation, representing the woody detritus lithofacies of the Nanticoke member of the Wyoming Valley formation.



Yellowish brown (10YR5/4) silt loam, loose, friable

Brown (10YR5/3) silt loam, compact, moderate medium platy structure

Yellowish brown (10YR5/4) silt loam, moderate coarse platy parting to fine subangular blocky structure

Yellowish brown (10YR5/4) silt loam, moderate medium subangular blocky

Yellowish brown (10YR5/4) silt loam, weak fine subangular blocky structure

Brown (10YR5/3) silty clay, massively bedded

Brown (10YR4/3) redox mottles

Wet sandy clay refused the auger

Figure 106: Stratigraphy of hand auger boring approximately 500 m upstream of site 36BR81 (Friedenshutten) near Wyalusing

FRENCH AZILUM (36BR134) AND THE WELLS SITE (36BR59)

Eighteen kilometers further upstream, and only sixteen kilometers downstream of Towanda (km 431), I was able to conduct limited excavations at the historic site of French Azilum. This was a small town in a large bend on the right bank of the river which was established in 1793 by refugees from the French Revolution. Archaeological traces of the town are designated as site 36BR134 and include stone foundations for a log structure purportedly built for Marie Antoinette and her son and heir to the French throne, Charles Dauphin (Bradford County, 2001).

Although Marie Antoinette followed her husband, King Louis XVI, to the guillotine in October, 1793, French Azilum continued to be occupied into the early 19th century (Binghamton University, 2001). Descendants of a few of the original settlers still live in this part of Bradford County, but not one of the more than fifty structures erected in the town remains standing today. The LaPorte house, built in 1836 by one of the descendant families, stands on the northern portion of the old town on property owned by the Pennsylvania Historical and Museum Commission (PHMC).

Most of French Azilum appears to have been built on the "Olean/Binghamton" outwash surface (T-2) which stands 12-20 m above river grade, or 212-220 m MSL. Numerous stone foundations were found on the T-2 during excavations in 1976 by Steven Warfel of the PHMC. The absence of artifactual and structural remains at the surface on the lower-lying T-1 alluvial terrace motivated Warfel to excavate a series of shallow backhoe trenches, none of which encountered prehistoric or historic cultural materials. Field schools have been conducted at the Madame de Sibert house on the T-2 since 1999 by Binghamton University. I examined the excavations at the conclusion of fieldwork in 1999 and noted erratic clasts such as pink granite and quartzite among the basal gravels. I also walked the riverbank, finding stone walls which have been attributed to a flour mill, and performed two auger tests on the T-1.

Figure 107 is a schematic cross-section based on my 1999 observations and interpretation of the topographic contours. The scalloped appearance of the T-1/T-2 boundary on the bend probably results from severe erosion in the 19th century, possibly related to land-use practices at French Azilum itself. Additional investigations would be required to determine if positive or negative features predominate in the scalloped areas. That is to say, lobes of colluvium may extend out on top of older Holocene alluvium on the T-1, or, alternatively, gullies may have been incised into the outwash. It is also possible that both processes occurred.

Both of my auger borings on the T-1 encountered a 2Bx soil horizon from 80-100 cmbs capped by fine sandy loam overbank flood deposits. The 2Bx horizon is here considered to represent the top of the Central Builders member of the Wyoming Valley formation. The thin-section prepared from a sample of this horizon was presented in the definition of the Central Builders member at the beginning of this chapter. Pedogenic cracking was noted in hand sample, while the thin-section showed abundant ferriargillans filling cracks, passage traces, and other voids.

Alluvial deposits do not occur all the way to the base of the T-1 at French Azilum. The alluvium is probably deeper on the mid-channel islands opposite French Azilum bend, as shown in **Figure 107**. At Hagerman's Island (36BR53), cultural materials of

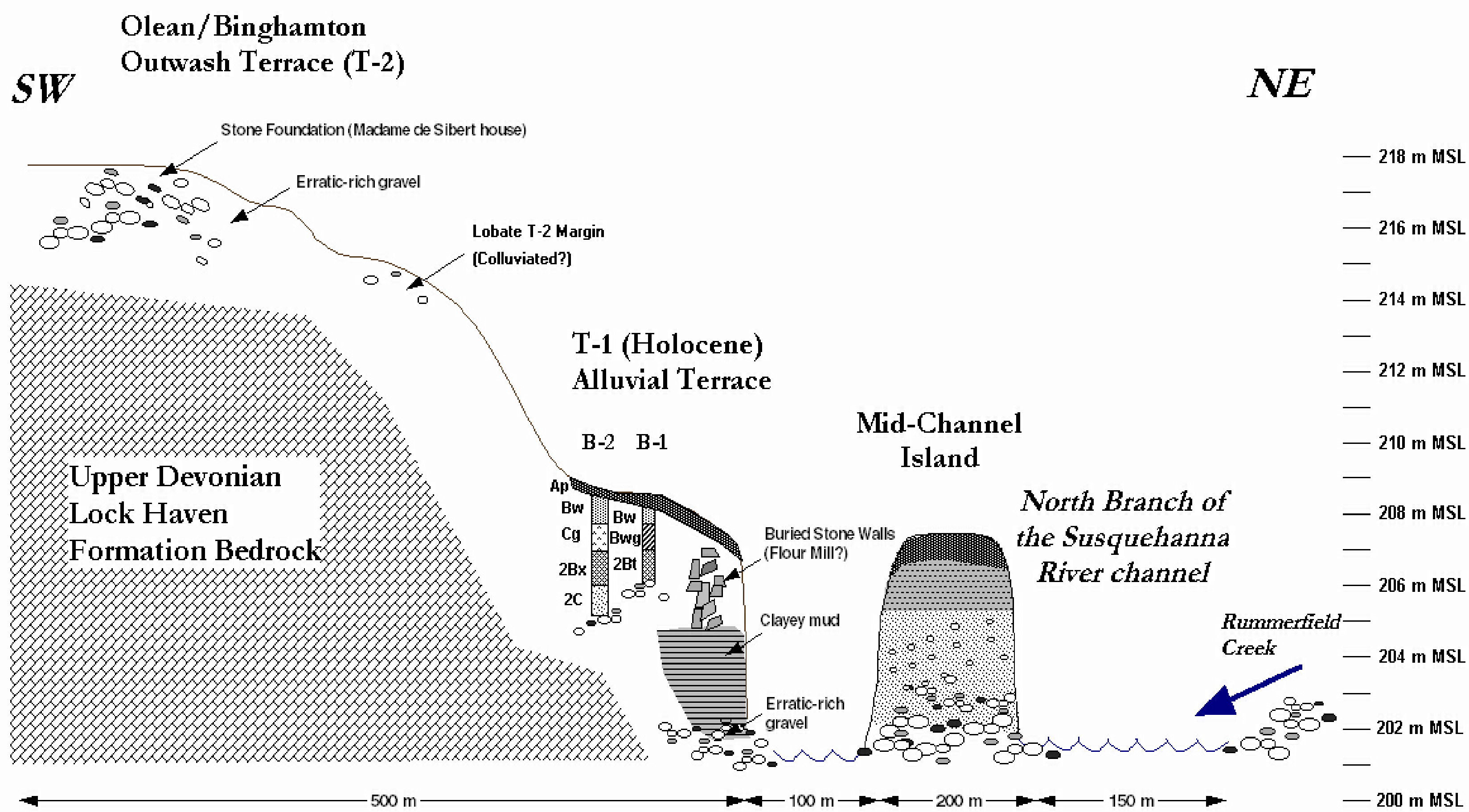


Figure 107: Schematic cross-section of French Azilum bend on the North Branch of the Susquehanna River

probable Late Archaic affiliation have been found by amateur archaeologists. Lamoka, Brewerton, and Susquehanna Broadspear PPKs have also reportedly been found in the fields north of the PHMC property at prehistoric site 36BR54.

The upper meter of alluvium underlying the T-1 at French Azilum is here assigned to the Wyoming member on **Figure 69**. Forty Fort member deposits occur locally, however, in association with small Owasco settlements. Four kilometers downstream of the old French Azilum town center on the same side of the river, excavations at the Wells site (36BR59) by the Andaste Chapter of the Society for Pennsylvania Archaeology in 1961 encountered ten prehistoric pit features in an area of approximately 40 m^2 (Lucy and McCann, 1983). Radiocarbon dates of 970±100 B.P. and 880±100 B.P. were obtained on charred wood from Feature 6, a large pit which originated at 127 cmbs and also contained calcined bone and sherds identified as Clemson Island punctate and Carpenter Brook cord-on-cord (Herbstritt, 1988, p. 6; Lucy and McCann, 1983, p. 4). Projectile points found on the site were of the Levanna PPK style and made from Onondaga chert, probably quarried from cobbles in the glacial outwash. The calibrated 2-sigma range for the two dates from Feature 6 at site 36BR59 is AD 998-1255.

THE MOUTH OF WYSOX CREEK AND THE CASS SITE (36BR57)

Closer to Towanda on the opposite side of the river from French Azilum, there is a complex of four prehistoric archaeological sites (36BR55, 36BR56, 36BR75, and 36BR139) where Wysox Creek joins the river (see **Figure 108**). Owasco ceramics

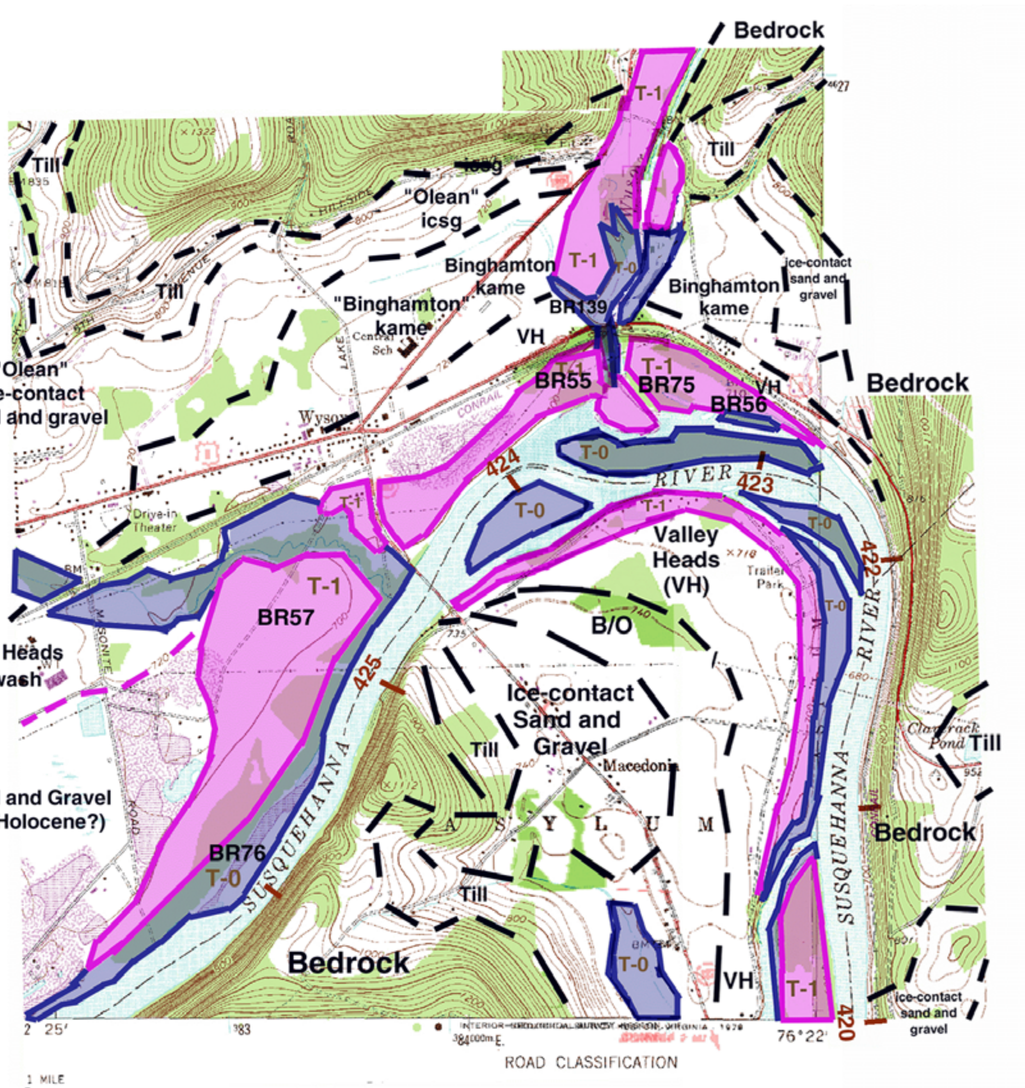


Figure 108: Part of the Towanda quadrangle USGS 7.5' topographic map showing landforms and archaeological sites at the mouth of Wysox Creek

collected from the Wysox Flats (36BR56) downstream of the creek juncture are described by Lucy (1959, 1971). The Owasco village apparently continues upstream to the bank of the creek. The Pipher site (36BR55) is on the right or upstream bank of Wysox Creek, while site 36BR75 is on the left or downstream bank. A historic Delaware town is reported at Wysox by Kent et al. (1981) but none of the archaeological sites is reported to have either a Proto-Susquehannock or Refuge Phase component.

Site 36BR139 was upstream of the mouth of Wysox Creek in the area that was impacted by construction of the present S.R. 6 bridge over the creek. Extensive shovel testing in the northwest quadrant of the bridge right-of-way (Lewis et al., 1989) recovered chert debitage but no temporally diagnostic artifacts. From 132 to 164 cm of dark brown (10YR3/3) silty loam were encountered in the floodplain (T-0) along the creek whereas a more strongly developed soil profile occurred on the T-1 to the west.

All of the prehistoric artifacts found at site 36BR139 were in the T-1 deposits. The T-1 grade is approximately 213 m MSL, at least a meter above the T-0 and three meters above creek grade. The prehistoric artifacts were mixed with historic debris in dark yellowish brown (10YR4/4) silt loam sediment which had all been plowed, although it extended up to 30 cm below surface. A clear wavy contact defined the top of a brown (10YR5/3) clay loam subsoil, which was probably a 2Bt horizon formed in considerably older alluvial deposits. Basal gravels were encountered at 152 cmbs.

Approximately a kilometer upstream of the mouth of Wysox Creek, immediately southwest of the S.R. 187 bridge, the river is joined by another small creek, Laning Creek. There is a boat launch managed by the Pennsylvania Fish and Boat Commission at the mouth of the creek. On its upstream or west bank, the creek has incised the T-1 deposits near the area referred to as the Cass (36BR57) and Strickland (36BR76) sites (Lucy and McCracken, 1985, p. 22; Witthoft, 1969, p. 31). **Figure 109** illustrates the stratigraphy for approximately five meters of Holocene alluvium capping basal gravels which are imbricated as a result of current directed down the North Branch of the Susquehanna river channel. Based upon the profiles with cambic (Bw) subsoil horizons, the four meters of sediment beneath the 2AC horizon at 100 cmbs were assigned to the Wyoming member of the Wyoming Valley formation.

Less than 500 m northwest of the Laning Creek cutbank, Witthoft excavated five Proto-Susquehannock cache pits after they were scraped by a bulldozer at the Cass site (36BR57). These cache pits appear to have been on a much older terrace surface standing from six to nine meters above river grade, or 214-218 m MSL. Glacial outwash fans were deposited when Laning Creek and Wysox Creek valleys functioned as meltwater sluiceways and a thin (20-30 cm) cap of windblown loess was also described in this area by Peltier (1949). According to Lucy and McCracken (1985, p. 22), the Cass site (36BR57) was on a "hilltop" but Proto-Susquehannock pottery has also been found at the Strickland site (36BR76) on the "flats" below it. These "flats" presumably denote much younger T-1 alluvial deposits stretching from Laning Creek for at least two kilometers upstream and possibly as far as the Wilson site (36BR58) at the East Towanda Fairgrounds (Kent, 1993, p. 304). Additional stratigraphic investigations in this area would be extremely helpful in assessing the potential for buried archaeological sites.

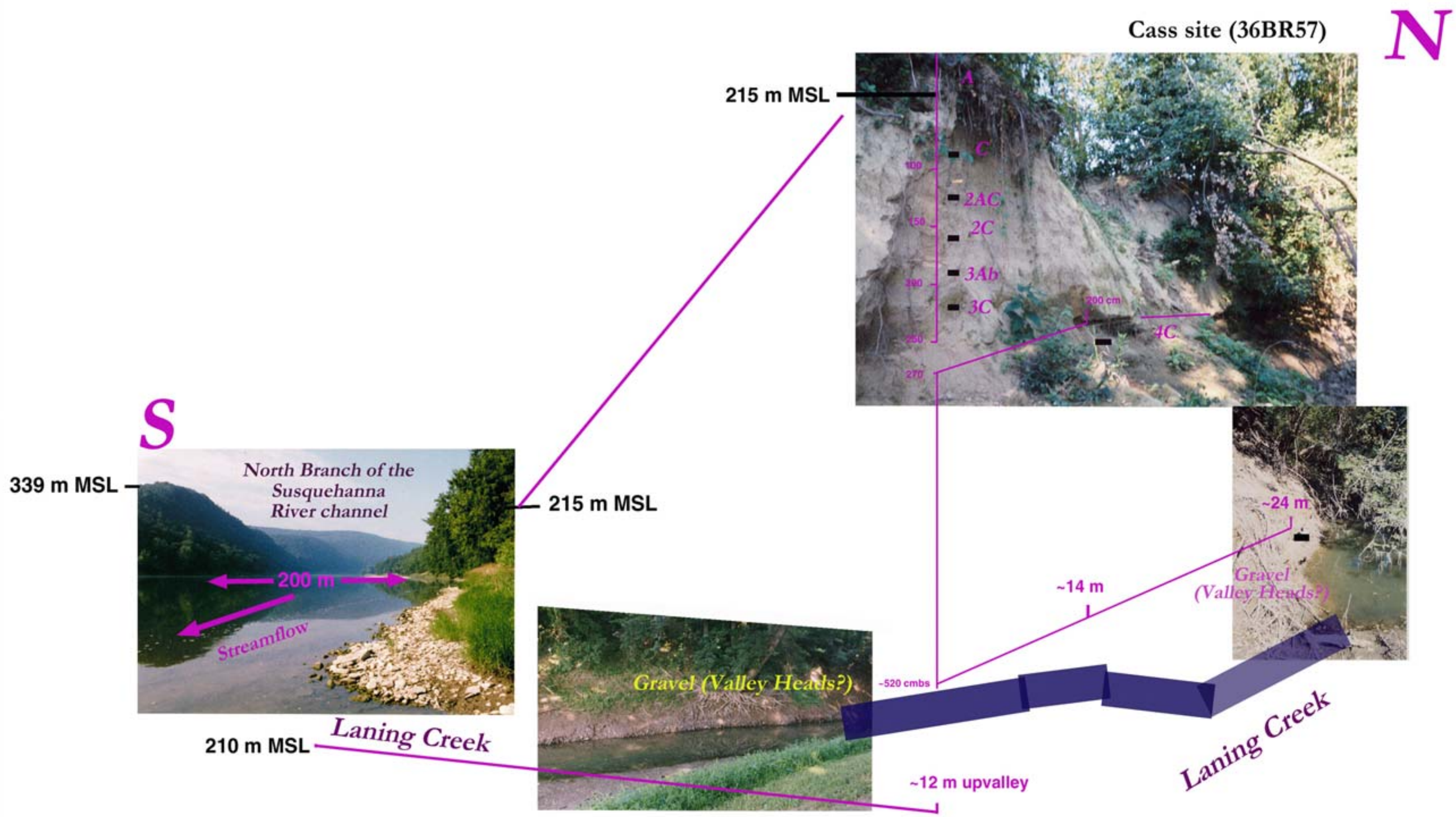


Figure 109: Stratigraphy of the west bank of Laning Creek at the Cass site (36BR57)

SUBDIVISION OF ALLUVIUM UPSTREAM OF SITE 36BR57

The profile at the Cass site (**Figure 109**) is the last for which alluvial deposits have been described in sufficient detail to be assigned to specific members of the Wyoming Valley formation. Archaeological sites in stratified alluvium have been reported in the reaches near Towanda (km 430), and upstream at least as far as the juncture with the Chemung River at Tioga Point (km 447). The T-1 and T-0 have also been mapped for all of these reaches in **Appendix 1**. I anticipate that the alluvium can be subdivided once the bounding unconformities have been described on the basis of stratigraphic trenches or borings. The sites discussed in the remaining sections of this chapter would be ideal locations for such investigations, assuming that permission can be obtained from landowners and the appropriate authorities.

WOODLAND AND PROTOHISTORIC SITES IN TOWANDA

At Towanda (km 430), the North Branch of the Susquehanna bedrock valley narrows to less than a kilometer with inset glacial deposits leaving less than half of that for use by the Holocene river channel. Areas with more space for alluvial deposition do occur at the mouth of Sugar Creek in North Towanda and at the mouth of Towanda Creek in South Towanda (see **Figure 110**). These areas also appear to have been favored for Native American settlement. Site 36BR41 in North Towanda is identified as the Iroquois town of "Newtychanning" by Kent et al. (1981). Nearby, at site 36BR44, numerous prehistoric burials were unearthed during canal construction in 1860 (Kent, 1993, p. 298). The Delaware town of Towanda was near the mouth of Towanda Creek

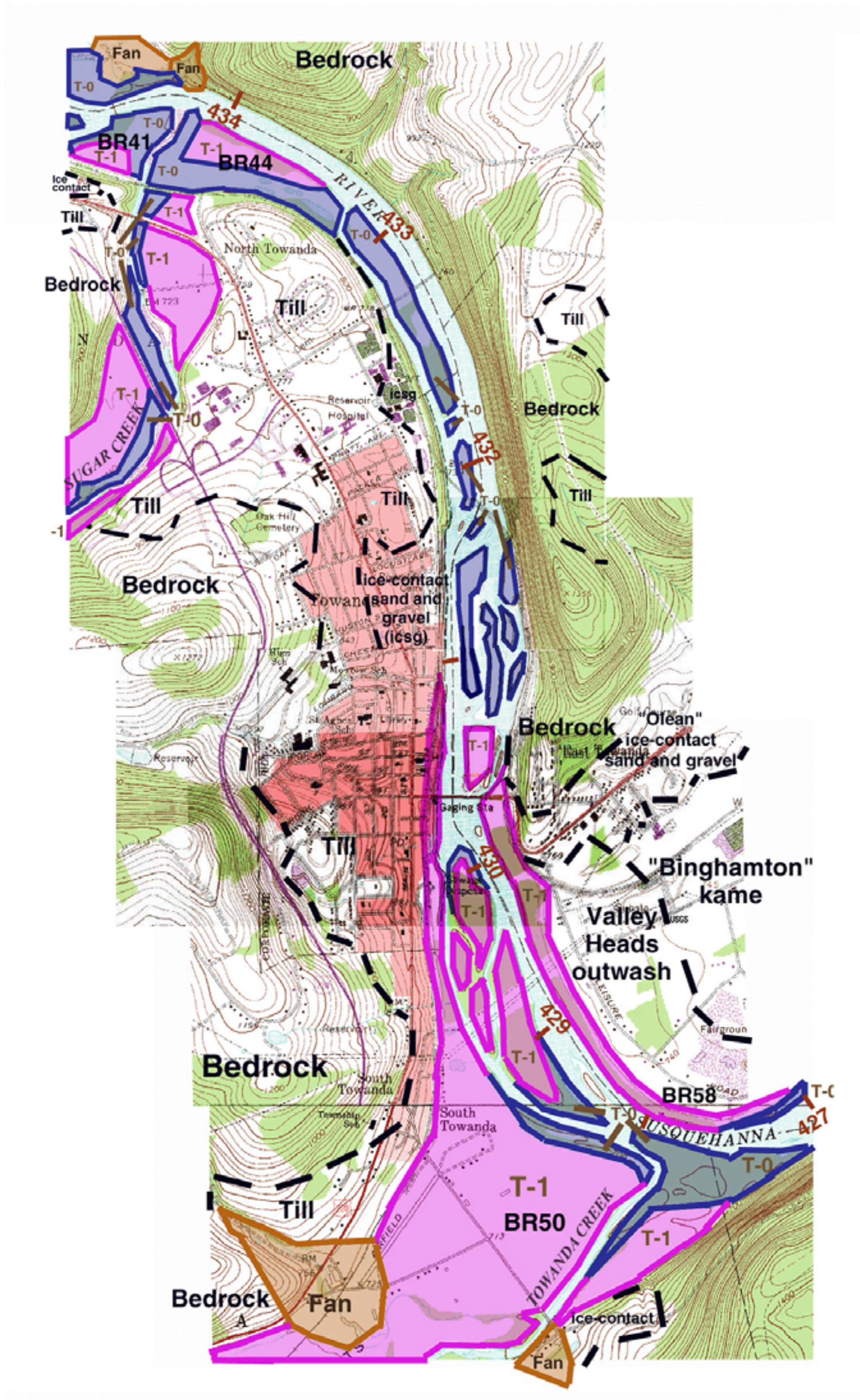


Figure 110: Part of the Towanda quadrangle USGS 7.5' topographic map showing landforms and archaeological sites at the mouths of Sugar Creek and Towanda Creek

(Kent et al., 1981, p. 10) on the same "South Towanda Flats" as the multicomponent Sick Farm site (36BR50).

The Sick Farm site (36BR50) had a late prehistoric component identified by Witthoft (1969, p. 32) as Proto-Susquehannock. Witthoft excavated a rectangular house over seven meters long, superimposed over five other periods of Late Woodland construction. The nature of the alluvial deposits beneath these relatively late components is not reported, nor is there any indication that they were investigated for more deeply buried cultural materials. Deep testing has been performed on at least one recent project for the Pennsylvania Department of Transportation in Towanda (Baublitz et al., 1994; Wagner, 1994), but that was in an area of upland terrain and glacial landforms.

The T-1 deposits at the mouths of Sugar Creek and Towanda Creek are here assigned to the Wyoming Valley formation. Bounding surfaces within the formation and the contact with underlying glacial deposits have yet to be defined. In their mapping of the Towanda quadrangle, Sevon and Braun (1997) suggested that meltwater was impounded in both of these tributary valleys. The proglacial lakes extended to the upper reaches and may have spilled through Lycoming Creek into the West Branch of the Susquehanna River valley.

BLACKMAN (36BR83) AND OTHER SITES NEAR HORNBROOK

Four kilometers upstream of Towanda, on the apex of another gentle bend in the bedrock valley, conclusive evidence of Proto-Susquehannock occupation has been unearthed at the Blackman site (36BR83). Two burials were initially excavated by an amateur archaeologist, Elwin Gillette. Each of these contained a shell-tempered Schultz incised pot (Kent, 1993, p. 305; Lucy and McCracken, 1985, p. 6). Professional excavations were conducted in 1975 by Ira Smith and James Herbstritt of the PHMC, exposing forty pit features and two rows of postmolds which define a palisade (Lucy and McCracken, 1985, p. 6-7). The pits were dug into gravelly outwash and lined with marsh grass. The site sits on a Valley Heads outwash terrace (T-2) and the surface soil is mapped as the Alton series (Grubb, 1986). The T-2 stands from 12-15 m above river grade, or 225-230 m MSL. The burials and features were presumably exposed by erosion along the terrace scarp.

In addition to shell-tempered Proto-Susquehannock pottery, grit-tempered Owasco pottery and Levanna triangular projectile points characterize the site 36BR83 assemblage. A radiocarbon date of 410±60 BP was obtained on charcoal from a large circular pit, Feature 40 (McCracken and Lucy, 1989). The calibration of this date to calendar years was discussed in **Chapter 4**. It overlaps at 2-sigma with the slightly older date of 490±100 BP obtained from a context containing smelted copper trade items as well as Schultz incised pottery at the Engelbert site near Nichols, New York (Elliott and Lipe, 1970). The eight Protohistoric dates from the study area have a combined range of AD 1412-1552 if averaged to a single date (OxCal R_Combine procedure), or AD 1306-1640 if their ranges are summed (OxCal Sum procedure).

Site 36BR83 probably has several components which predate the Late Woodland and Proto-Susquehannock components. Rhyolite debitage and steatite bowl fragments have been found in surface collections, and these are most typical of Transitional and

Late Archaic assemblages. Neither the adjacent sites 36BR84 and 36BR99 on the same T-2 landform nor sites 36BR85 and 36BR86 on the lower-lying T-1 surface have yet been professionally investigated. Private collections reportedly contain Kirk and Brewerton projectile points from these sites, suggesting that buried Archaic components may be found within the T-1 alluvium. Wyoming Valley formation deposits are thus present at this location, although they cannot yet be assigned to a particular member.

TIOGA POINT, QUEEN ESTHER'S FLATS, AND SPANISH HILL

The point of land where the Susquehanna is joined by the Chemung River (km 451) was the site of a village occupied by Iroquois, Mohicans, Shawnee, and Delaware from 1751 to 1760 (Kent et al., 1981, p. 11). The Tioga Point Farm site (36BR3) encompasses most of this village area (see **Figure 111**). The site numbers (36BR)48, 49, 51, 52, and 61 have also been used for portions of Tioga Point during the long history of archaeological research in the area.

The summary of Tioga Point by Lucy and Vanderpoel (1979) follows Peltier (1949) in assigning it a late Pleistocene meltwater origin with Holocene deposition limited to a "veneer" or "terracette" along its outer margin. As can be seen from the depth of Holocene deposits in most of the archaeological sites discussed above, the age and depositional history of T-1 landforms rarely accord with this model proposed by Peltier for the "Mankato" terrace. Peltier correctly notes that both of the confluent streams contributed to local terrace deposition (Peltier, 1949, p. 86), and the Chemung River

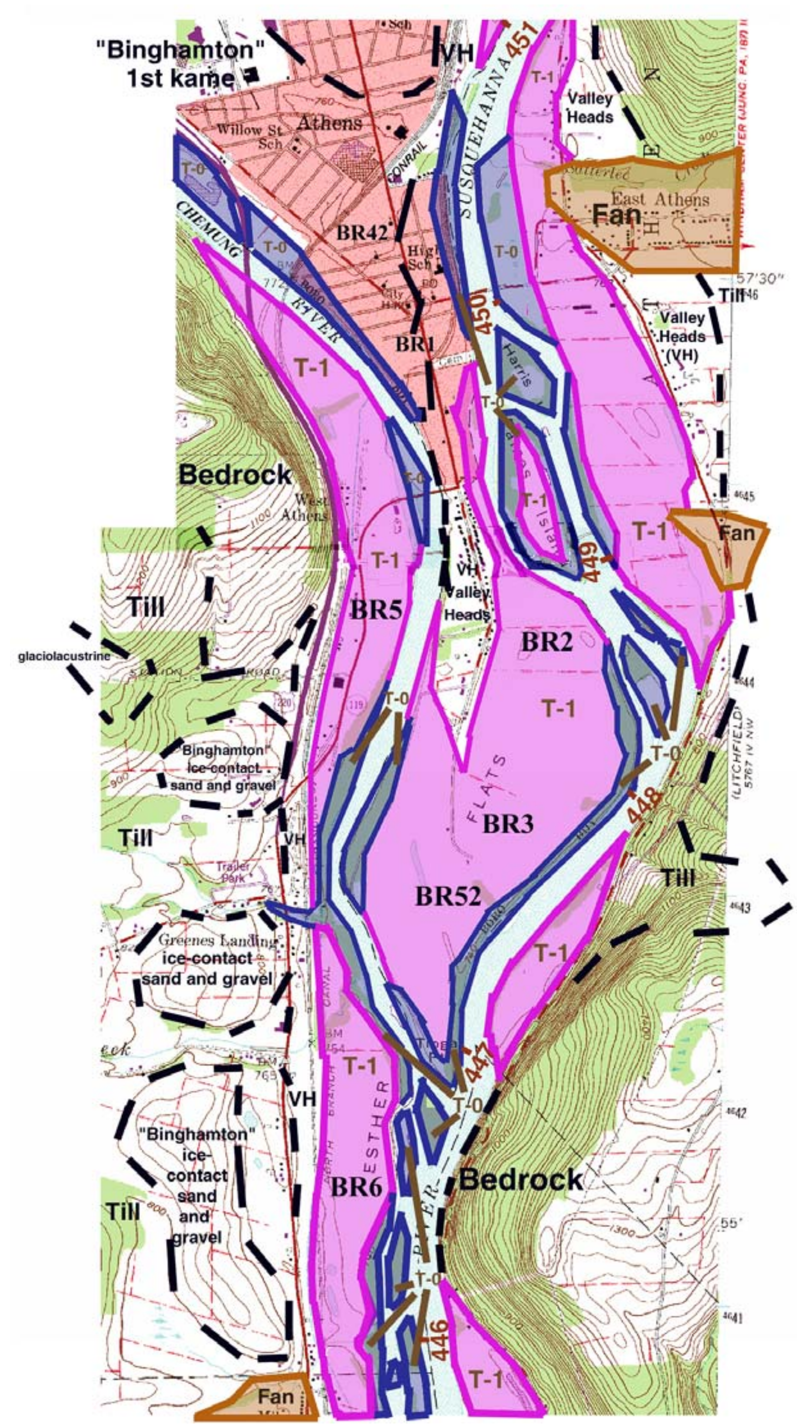


Figure 111: Part of the Sayre quadrangle USGS 7.5' topographic map showing landforms and archaeological sites in the vicinity of Tioga Point

channel actually appears to have carried considerably more meltwater than the Susquehanna during the late Pleistocene (Sevon and Braun, 1997).

One of the earliest archaeological discoveries in Pennsylvania is in fact from Tioga Point, where Native American burials were unearthed by General Sullivan's troops stationed there in 1779 (Murray, 1908, p. 196). Sporadic discoveries continued throughout the 19th century, and in 1883 pots were collected by Harrison Wright for the Wyoming Valley Historical and Geological Society from site 36BR3. Wright also collected the Murray Farm site (36BR5) at Queen Esther's Flats on the west bank of the Chemung River and the Murray Garden site (36BR2) north of Tioga Point in the town of Athens. Photographs of these pots were published by Christopher Wren (1914) along with his own discoveries from the Wyoming Valley. The local Tioga Point Museum was founded in the late 1890's to house the trove of Native American artifacts that were being unearthed. Burials were actually disturbed in 1897 during construction of the Spaulding Memorial Library, which still houses this museum in Athens.

Louise Welles Murray, a local patrician, personally excavated at the Murray Garden site (36BR2) and the Ahbe-Brennan site (36BR42) within the Athen's town limits at the turn of the century (Muray, 1896, 1908, 1921). Professional archaeological research began in 1916, when the Heye Museum launched its Susquehanna River Expedition (Custer, 1986; Moorehead, 1938). A major objective of the expedition was tracing the extent and origins of the Susquehannock tribe, or "Andaste" as they were called by the Huron and the French. Pursuant to this objective, extensive excavations were conducted in the area of the Chemung and Susquehanna confluence. The

Susquehanna River Expedition excavations were supervised by Alanson Skinner, although the work is often credited to Warren K. Moorehead. Skinner excavated a series of long trenches on Queen Esther's Flats at the Murray Farm site (36BR5) as well as burials variously tallied at 57 (Kent, 1993, p. 300; Moorehead, 1938, p. 50) and 38 (Custer, 1986, p. 54). Pottery from these excavations was later analyzed by James B. Griffin (1929). Several components seem to be present, ranging from Owasco (AD 800-1300) to Proto-Susquehannock (AD 1300-1500) and possibly also including Contact or "Refugee Phase" materials.

Skinner's Susquehanna River Expedition party also undertook extensive test excavations on top of the drumlinoid "Spanish Hill" feature approximately six kilometers north of Tioga Point along the Chemung River on the Pennsylvania/New York state border. Local lore has associated this feature with the fortress of "Carantouan" supposedly encountered by Champlain's scout Etienne Brule in 1615 (Stacy, 1996, p. 10; McCracken, 1985). The archaeological excavations by Skinner and subsequently Griffin (1931) and Cowles (1933) provide no evidence to support this hypothesis. Spanish Hill is designated as site 36BR27 because Griffin did find a surface scatter of nondiagnostic artifacts on top. Cowles found evidence for an Owasco hamlet at the foot the hill (site 36BR28). Subsequent excavations at site 36BR28 by the PHMC in 1967 and again in 1972 suggest that the Owasco site may have been palisaded (Kent, 1993, p. 301).

The stratified alluvial sites at the Chemung River confluence have yet to be systematically tested. The discovery by amateur archaeologists Leroy Vanderpoel and others were integrated with previous work by Charles Lucy (Lucy, 1991a; Lucy and Vanderpoel, 1979). John Witthoft also visited and made surface collections on Tioga Point while he was state archaeologist. Witthoft commented that a discrete Middle Woodland site occurred along the Susquehanna on the eastern side of the peninsula (Lucy and Vanderpoel, 1979, p. 1). **Figure 111** shows a T-1 surface here, inset against a central T-2 ridge of gravelly outwash. The lateral and vertical contacts with the outwash deposits still need to be defined as well as the bounding discontinuities within the Wyoming Valley formation itself.

The ceramics found in sites on Tioga Point provided much of the data to support Lucy's hypothesis that grit-tempered ("Owasco") and shell-tempered ("Proto-Susquehannock") pottery were in fact used contemporaneously on villages along the North Branch of the Susquehanna River. According to Lucy (Lucy and McCracken, 1985; McCracken and Lucy, 1989), the shell-tempered wares are rarely found outside of burial contexts. At Tioga Point, Vanderpoel excavated a burial with a shell-tempered Schultz incised pot nested within a grit-tempered Richmond incised pot (Lucy and McCracken, 1985, p. 11; McCracken and Lucy, 1989, p. 16). This burial offering vividly symbolizes the emergence of the historic Susquehannock culture out of the pan-Iroquoian Owasco culture base.

The Proto-Susquehannock components at Tioga Point (36BR3), Blackman (36BR83), and Cass (36BR57) seem to have in common a location on gravelly T-2 landforms which were slightly higher in elevation and perhaps better for defensive purposes, particularly when palisaded. In each case, these landforms have also been subject to considerable erosion, and this may have actually been triggered by the site's occupants. Erosion of portions of the original settlements may also have led to an underestimation of the typical settlement size by Barry Kent (1993, p. 297-298). Kent notes that his population estimate of 500 Susquehannocks for the twenty sites in Bradford County prior to AD 1550 seems to be too small for the total tribe which later relocated to the lower Susquehanna valley.

SUMMARY OF THE ALLOSTRATIGRAPHIC FRAMEWORK

The Wyoming Valley formation is an unconformity-bounded stratigraphic unit (alloformation) which includes all of the alluvial deposits of the North Branch of the Susquehanna River overlying the basal contact with glacial till or outwash. This chapter has described the deposits in 23 stratigraphic sections, nineteen of which are on prehistoric archaeological sites. The sections span over 200 km of the reaches between the Pennsylvania/New York state border and the juncture of the West and North Branches of the Susquehanna River.

Excavations at the archaeological sites have provided exposures at which to identify and trace discontinuities which bound the four members of the Wyoming Valley formation defined at the beginning of this chapter. These discontinuities are hypothesized to be the result of regional enviromental change. It was consequently necessary to perform borings and describe cutbank exposures in a number of settings where people are not known to have disturbed the sediments (Frederick, 2001; Stein, 2001). The type section for the Wyoming member in the Wyoming Valley (km 307) is one such setting as also are the cutbank section at Upper Exeter (km 325) and the boring at Whites Ferry (km 338). At the archaeological sites themselves, the majority of my fieldwork consisted of describing deposits which were beneath or adjacent to the contexts containing prehistoric pit features or artifact concentrations.

Figure 69 traces the lower three of the five discontinuities which bound the members of the Wyoming Valley formation. Each of these discontinuities represents an interval of nondeposition. Based on the single age estimate available for the top of the glacial deposits, from three to five thousand years elapsed during Discontinuity I. The deposition of the Central Builders member began by 10,600 cal BP, based on the dates obtained from basal Holocene geological contexts at Mifflinville Bridge (36CO17) and the boring in slackwater deposits on the T-1 at Wyoming.

The top of the Central Builders member has been identified in sixteen of the 23 stratigraphic sections, using either a buried soil or a lithofacies change. The surfaces on which the soils with fragic or argillic horizons were forming would have been locations available for settlement by Early Archaic and Middle Archaic hunter-gatherers. To date only three Early Archaic components and six Middle Archaic components have been found in stratified contexts within the study area. The present allostratigraphic framework should contribute significantly toward the discovery of additional components.

On **Figure 112**, the basal dates for Mifflinville Bridge and the Wyoming T-1 slackwater deposits are plotted relative to dates for nine other contexts which can be placed by thickness of the Central Builders member in the regional stratigraphic column.

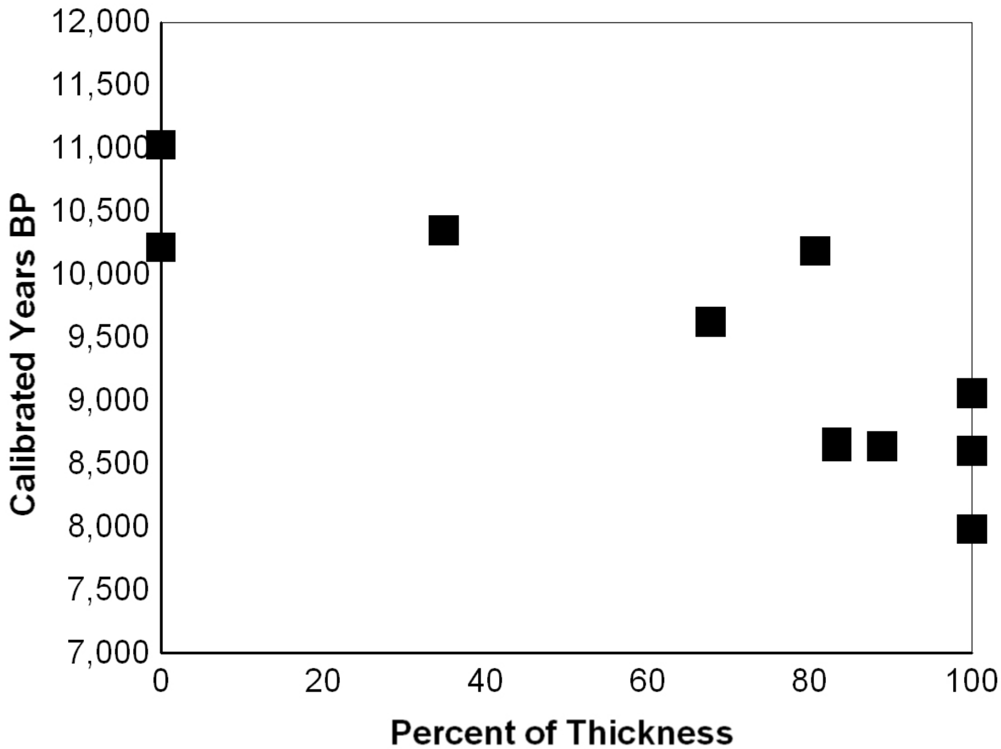


Figure 112: Plot of Calibrated Radiocarbon Dates relative to the Percent Thickness of the Central Builders member

The layout of the plot is patterned after that prepared by Leigh and Knox (1993) for the temporal envelope of the Roxana Silt, a late Pleistocene loess unit in the Upper Mississippi River valley. The age decreases up section in **Figure 112**, but the trend is not perfectly linear. Most of the nonlinearity is due to the early cultural dates from Central Builders (36NB117) and Cremards (36LU58). Although each of these contexts occurred at least 50 cm above the lower bounding surface for the member, their dates are only slightly younger than the basal Holocene dates. The two earliest dates for the upper bounding surface (100 percent thickness) are for the "Ab6" buried soil at Jacobs (36LU90) and Feature 29 at Mifflinville Bridge (36CO17). The calibrated mean for these two dates, 9000-8590 cal BP, is here considered to be the best estimate for the bounding surface at the top of the Central Builders member.

Discontinuity II occurred during the time interval between the 9000-8590 cal BP age of the Central Builders member upper boundary and the 7,150-5,850 cal BP age for the base of the Wyoming member. As noted in **Chapter 4**, there is a gap in the dates from cultural contexts during this interval. Whereas the geological discontinuity is here suggested to span at least two thousand years, no more than a thousand years elapsed between the dated cultural contexts.

The Wyoming member sharply overlies the Central Builders member at Discontinuity II in ten of the stratigraphic sections. A total of 34 radiocarbon dates from the Wyoming member can be placed by thickness as shown in **Figure 113**. The two dates at 0 percent thickness are from Gould Island and Harding Flats, while the basal dates for Falls Bridge and the Wyoming T-1 cutbank were both for contexts at least

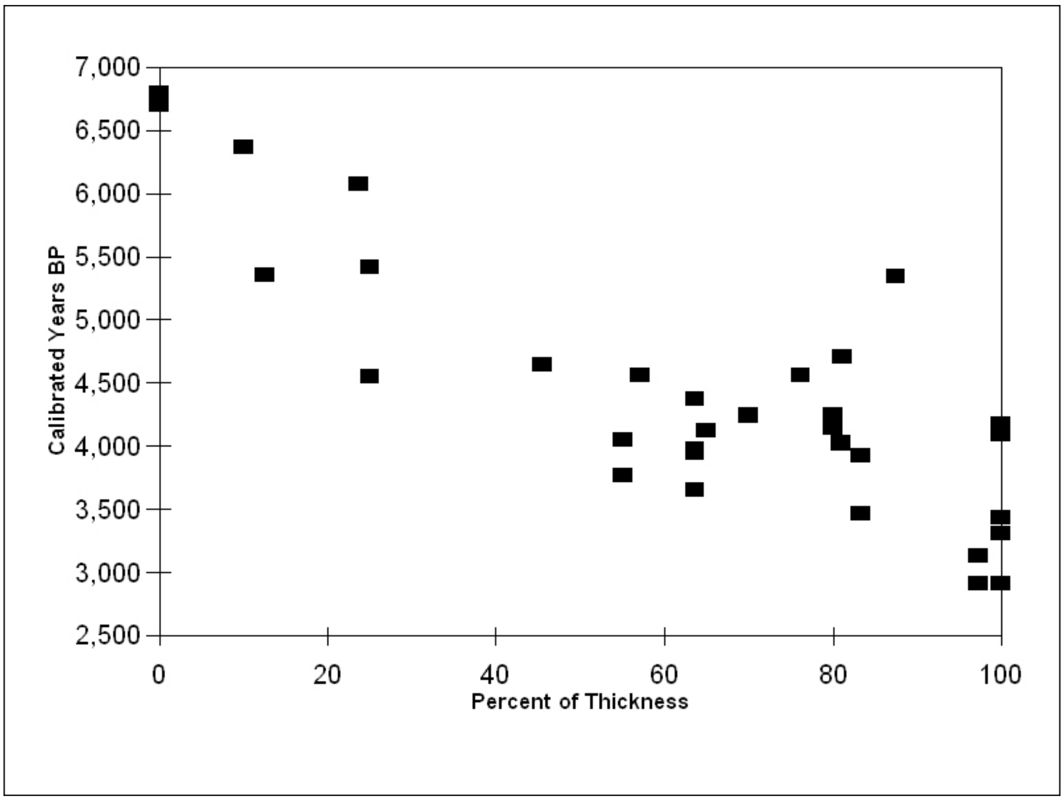


Figure 113: Plot of Calibrated Radiocarbon Dates relative to the Percent Thickness of the Wyoming member

30 cm above the contact with glacial outwash. Using only the two "0 percent" dates and averaging them with the OxCal R_Combine procedure, we narrow our estimate for the end of Discontinuity II from 7,150-5,850 cal BP to 6,790-6,660 cal BP.

Wyoming member deposition began by 6,660 cal BP and ceased by 4,230 cal BP. The remarkably consistent thickness and sediment texture of the Wyoming member strongly argues for "allogenic," valley-wide forcing. The earliest contexts at the upper bounding surface (100 percent thickness) are Features 48 and 58 at Gould Island. These are part of a cluster of Late Archaic features which date from 4,230-3,980 cal BP.

In 20 of the 23 stratigraphic sections in the present study, the upper bounding surface for the Wyoming member of the Wyoming Valley formation can be identified based on its weakly developed to moderately well developed soil. Although the age of the upper boundary has here been constrained using the Late Archaic pit features that intrude it, in many cases this former land surface was stable for several thousand years. The wide scatter of dates from 60 to 100 percent of the thickness of the Wyoming member is largely due to mixing of these upper sediments by anthropogenic and biogenic processes.

Discontinuity III occurred during the time interval between the 4,230-3,980 cal BP age of the Wyoming member upper boundary and the 2,750-2,100 cal BP age for the base of the Forty Fort member. The Forty Fort member is sparsely represented as a depositional unit, but where it occurs the cultural contexts of late prehistoric cultures are associated with terrace surfaces distinct from those at the top of the Wyoming member.

The gap in the radiocarbon charonology at Discontinuity III is less than 500 years, barely large enough to preclude overlap at one standard deviation.

Between the onset of Forty Fort member deposition and 400 cal BP, radiocarbon dates from cultural contexts in North Branch of the Susquehanna River alluvium form a continuous sequence. For many of these later prehistoric cultural contexts, their relative age can be most precisely determined using ceramics and other items of material culture. Discontinuity IV has been estimated to begin prior to AD 1162 using a dated context at the Forty Fort Airport which contained Late Woodland ceramics. Similarly, historical documents suggest that Discontinuity V began prior to AD 1800, and the discontinuity can be physically identified using contexts that contain items of Euroamerican culture.

In addition to the vertical contacts for Discontinuity V reported in **Table 16**, it also occurs as a lateral contact between T-1 and T-0 landforms as mapped in **Appendix 1**. The Nanticoke member attains thicknesses of over a meter on many floodplain islands, far greater than those reported in the selection of stratigraphic sections used to trace bounding discontinuities along the longitudinal valley axis. Natural levee deposits also typically occur riverward of the profiles in which the archaeological contexts were found. It is nearly always possible to identify both Discontinuity V and Discontinuity I in even the most cursory reconnaisance of alluvial deposits in the North Branch of the Susquehanna River valley. The identification of the remaining discontinuities and members of the Wyoming Valley formation hangs on the morphology of buried soils and presence of unique lithofacies as detailed above.

The subdivision of the North Branch alluvial deposits into four members separated by bounding discontinuities represents a level of detail greater than that currently required for quadrangle-scale maps in Pennsylvania. Perhaps, in the final analysis, a single Holocene alluvial unit may suffice for such purposes. The Wyoming Valley formation as described in this chapter could in fact be considered to be either lithostratigraphic or allostratigraphic. The more detailed subdivision does fulfill a demand from archaeologists interested in predicting the occurrence of buried prehistoric sites. As the following chapter will show, detailed allostratigraphy also points us toward regional responses to external forcing on time scales ranging from 10^2 to 10^5 yr. Such responses have been the focus of several comparative studies aimed at a systematic and theoretical understanding of alluvial deposits (Blum and Tornqvist, 2000; Knox, 1995; Maddy et al., 2001).

CHAPTER 6

EXPLANATION OF STRATIGRAPHIC DISCONTINUITIES IN TERMS OF REGIONAL ENVIRONMENTAL CHANGE

This dissertation has shown that the alluvial deposits of the North Branch of the Susquehanna River represent a mappable stratigraphic unit, the Wyoming Valley formation. The Wyoming Valley formation is an allostratigraphic unit which underlies the first terrace (T-1) as mapped in **Appendix 1** for the reaches from the Pennsylvania/New York state border downstream to the juncture of the North and West Branches of the Susquehanna River at Northumberland, Pennsylvania.

The Wyoming Valley formation is bounded by a basal contact with glacial till or outwash and by internal discontinuities between the four members which were defined in the preceding chapter. Age constraints were placed on these discontinuities using the chronology developed in **Chapter 4** with calibrated radiocarbon dates and the regional sequence of prehistoric cultures. The present chapter will conclude the dissertation by testing the hypothesis that the discontinuities observed in the alluvial stratigraphy were caused by changes in the regional climate or vegetation of the study area.

PREVIOUS DESCRIPTIONS AND EXPLANATORY MODELS

Previous studies of alluvial deposits in the Susquehanna River valley and elsewhere in the eastern United States have identified discontinuities similar to those which bound the Wyoming Valley formation. The basal contact with till or outwash has been traced by geologists interested in the Pleistocene deposits themselves (e.g. Braun, 1988b; 1994d; 1997; Crowl and Sevon, 1980; Sevon and Braun, 1997) as well as by archaeologists interested in finding the earliest prehistoric sites (Kirkland and Funk, 1979; Vento et al., 1999). Bedrock controls on the direction and magnitude of scour by meltwater sluiceways have been emphasized in Braun's recent mapping of both Pleistocene and Holocene valley sand and gravel deposits. Nonetheless, differential resistance to erosion cannot explain all of the features of either the bedrock valley or the channels which have been routed through it. The "water gaps" at Pittston and Rupert, in particular, were cut through quite resistant lithologies either by very powerful flows or by flows that reversed direction in response to tectonic tilting (Reif, 1993; Sevon, 1986).

To paraphrase Schumm (1977, p. 10), the North Branch of the Susquehanna River valley is a physical system with a history. History contributes the complexity in relating form to process. Mechanical factors of channel form and bed material size are primary controls, but channel pattern and sediment transport are also affected by the meanders which the river has carved during previous stages of its evolution. This inheritance from prior history was described for the North Branch of the Susquehanna River in particular by Leopold et al. (1964), one of the classic texts on fluvial geomorphology.

In addition to the bedrock meanders, which date back at least to the Mesozoic if not to the "Anthracite River" of the Upper Paleozoic, channel derangements during the advance and retreat of the Laurentide ice sheet have been proposed to account for several constricted, enlarged, or overdeepened reaches by Braun (1988a, 1994a, 1994c. 1997, 1999). Itter (1938) proposed that several tributary creeks in the Wyoming Valley follow channels inherited from "yazoo streams" which flowed at the margins of a tongue of glacial ice, a hypothesis which Braun (1997) disputed owing to physical constraints on the size of an ice tongue.

Peltier (1949) proposed that the majority of the alluvium underlying T-1 surfaces was deposited by storms whose tracks were determined by the continuing presence of the Laurentide ice sheet under a cold periglacial climate. Because several members of the Wyoming Valley formation have been found to directly overlie the basal contact with till or outwash, the present dissertation challenges Peltier's interpretation of what he referred to as the "Mankato" terrace. The deposits which underlie T-1 surfaces must be explained on the basis of processes or events known to occur in the present environment, or at any rate long after the retreat of the ice-sheet.

Stratigraphic investigations reported in the preceding chapter have identified five bounding unconformities, four of which have been traced for at least 200 km within the alluvial deposits of the North Branch of the Susquehanna River. A previous study in the Upper Susquehanna River valley (Scully and Arnold, 1981) identified discontinuities which appear to correlate with Discontinuities I and III in the present framework. A radiocarbon date of 9705±130 BP (uncalibrated) was obtained on wood at the contact between sandy lateral accretion deposits and gravelly channel lag deposits (Discontinuity I). Twenty additional radiocarbon dates from deposits at the two study sites were used to propose chronostratigraphic boundaries represented by buried soils.

Scully and Arnold (1981) found insufficient variation in the morphology of buried soils at their two study sites for the sort of time-independent correlations made in the present study. In their study of locations in the West Branch and in the Lower Susquehanna River valley downstream of Harrisburg, Engel et al. (1996) similarly failed to find alluvial soils that were strongly developed enough to distinguish the age of the deposits. Buried soils at the top of chronostratigraphic unit 3 in the Upper Susquehanna River study (Scully and Arnold, 1981) appear to represent Discontinuity III in the present framework. Unit 3 dates range from 2130±85 BP (uncalibrated) to 3240±110 BP (uncalibrated).

In the Delaware River valley, Ritter et al. (1973) demonstrated that overbank deposition of suspended sediment is a significant process which explains much of the geological record from postglacial times. Fourteen radiocarbon dates from cultural contexts at the Faucett archaeological site (36PI13) were used to infer rates of overbank accretion ranging from .08 to .02 cm yr^{-1}. The fine sandy to silty texture of the basal alluvium at Faucett suggests that it correlates with the Wyoming member of the Wyoming Valley formation as defined in the present dissertation. The basal date of 6190±135 BP (uncalibrated) falls within the range estimated for Discontinuity II in the present investigations (see **Table 11**).

The radiocarbon dates at Faucett were in perfect stratigraphic order, and the archaeological contexts were separated by fine-textured sediments that were nearly devoid of artifacts (Kinsey, 1972, p. 160-161). Ritter et al. therefore inferred that the overbank accretion was continuous without any significant episodes of scouring. Because many of the stratified archaeological sites in the North Branch of the Susquehanna River valley share the same sequence of occupations, it is unlikely that scour was very extensive in either valley between Discontinuity II and the more significant reworking that has occurred since the onset of Euroamerican settlement. The fact that rates of deposition appear to have been slower moving up the stratigraphic column was explained by Ritter et al. in terms of the greater energy requirement for floods to exceed the confines of the channel as the T-1 was built above the level of the active floodplain.

Kirkland and Funk (1979) developed a model of floodplain evolution in conjunction with archaeological excavations in the Susquehanna River valley upstream of the reach studied by Scully and Arnold (1981). Being much closer to the river headwaters, the channel was more dynamic. A relatively stable interval characterized by vertical accretion was nonetheless identified from 4000 BP (uncalibrated) until historic times. Kirkland (1993, p. 95) suggested a relationship between the regional loss of hemlock trees in the forest canopy and the incision which preceded the interval of vertical accretion. The same causal mechanism was previously proposed by Scully and Arnold (1981, p. 341) for the Upper Susquehanna River valley. Brakenridge et al. (1988) subsequently proposed the same mechanism for deposits of the Missiquoi River in Vermont which contained subfossil wood of *Tsuga canadensis*. All of these deposits are stratigraphically equivalent to the Wyoming member of the present framework. The Wyoming member sediments contain abundant conifer charcoal fragments that probably also represent hemlock trees which succumbed to the blight and then burned.

Deposits similar in age and sediment texture to the Central Builders member of the Wyoming Valley formation outcrop at the surface of terrace T-3 in the reaches of the Upper Susquehanna River valley mapped by Dineen (1993). Dineen's T-1 and T-2 terraces overlap in elevation and include deposits equivalent to the Wyoming and Forty Fort members of the present framework. Neither Kirkland nor Dineen found it possible to subdivide Holocene alluvial deposits based on their lithology, and neither had the background in soil science required to describe the morphology of buried soils.

In their "genetic stratigraphy" of Susquehanna River alluvium, Vento and Rollins (1989) described packages of sediment that are equivalent to all four members of the Wyoming Valley formation. Although "buried A" (Ab) and cambic (Bw) horizons were indicated for most of the stratigraphic columns, many more "paleosols" were shown than are possible given known rates and processes of deposition and soil development (Birkeland, 1999; Foss and Segovia, 1984). Sedimentation rates were also inappropriately related to climatic periods in the Blytt-Sernander chronology of European pollen assemblages. As noted by Ritter et al. for the Delaware River at the Faucett site, channel dimensions changed as T-1 surfaces accreted above the level of the active floodplain. This would have caused slower sedimentation rates at the top of the Wyoming member in particular, independent of any changes in regional climate or vegetation.

Both Scully and Arnold (1981, p. 338-348) and Vento and Rollins (1989) described lithofacies that are here considered to be representative of the Forty Fort and Nanticoke members of the Wyoming Valley formation. As noted by Scully and Arnold, coarser texture in these deposits is partly related to the preservation of natural levees and crevasse splays immediately adjacent to the active river channel. Vento and Rollins described the thin but very dark A horizons which are stacked between coarse sandy deposits in the Forty Fort member. They attributed this lithofacies to changes in forest composition and more severe flooding during the "Neo-Atlantic" period of the Blytt-Sernander chronology. The same stratigraphy in deposits equivalent in age to the Forty Fort member has been described at sites in the Delaware River valley by Stewart (1991) and Wall and Stewart (1996, p. 202-220).

Deposits which represent sediment eroded off of recently cleared forests or intensively farmed agricultural fields have been described for relatively few drainages of the northeastern United States. A threefold division of alluvial deposits into Pre-settlement, Agricultural (brown silt loam), and Very Recent (sand to gravel point bars) was developed by Jacobson and Coleman (1986) for small streams on the Piedmont in Maryland. The Agricultural age brown silt loam is laminated and typically contains artifacts such as bottles, cans, textiles, brick fragments, and hewn timbers. Virtually identical Agricultural age deposits were described by Costa (1975) along Western Run, a watershed of 155 km^2 north of Baltimore.

Coal is not local to the Maryland Piedmont, and the occurrence of coal clasts in alluvial deposits must postdate the first railroad construction in the 1840s (Jacobson and Coleman, 1986, p. 625). The lowermost coal clasts occur up to a meter above the buried soil which typically marks the upper bounding surface of Presettlement alluvium in the small Piedmont valleys. The Nanticoke member deposits in the North Branch of the Susquehanna River valley, on the other hand, often rest directly on coarse bedload gravel.

In the Scoharie Creek valley of eastern New York state, Lindner (1987) described up to two meters of Agricultural age alluvium overlying intact prehistoric archaeological contexts.

Among the earliest and most detailed studies of historic alluvium are those by Happ (1945) and Trimble (1974) in the Piedmont of the southeastern United States. Happ described up to a meter of reddish-brown alluvium overlying a pre-agricultural topsoil, and he also noted that he sometimes found even older buried soils. Trimble (1974) did not describe the alluvium in as much detail, but he did estimate the volumes removed as the Piedmont uplands were lowered an average of 18 cm under 18^{th} and 19^{th} century row-crop agriculture. Meade (1982) independently estimated the volume which has been deposited offshore and the balance which has been stored as alluvium by rivers which drain into the Atlantic Ocean. In the midwestern United States, both Bettis (1992, p. 125-126) and Mandel (1992, p. 69-70) have described up to two meters of historic alluvium which may bury prehistoric contexts too deeply to be detected using traditional archaeological methods.

The above summary of previous research demonstrates the regional and possibly continental significance of most of the discontinuities and many of the lithofacies and buried soils of the stratigraphic framework developed in this dissertation. The explanations offered by these previous researchers, as well as several causal mechanisms which have not previously been investigated, will be evaluated in the concluding sections on the basis of the data presented in the preceding chapters. For each of the observed discontinuities, there were changes in the regional climate or vegetation which appear to have caused them or played a contributing role. The regional changes for eastern North America and other areas bordering the Atlantic Ocean will now be reconstructed on the basis of proxy records. The proxy records examined include ice-rafted detritus in marine sediments, stable isotope ratios and other chemical proxies in the ice-cores, secular variations in the carbon exchange reservoir, pollen cores, lake levels, and lake sediment chemistry.

RAPID CHANGES DURING LATE PLEISTOCENE GLACIAL RETREAT

Late Pleistocene till and outwash deposits in the study area were described in **Chapter 3**, and **Chapter 4** discussed the apparent gap between the age of the latest meltwater deposition and the basal alluvium. Continuous records across the Pleistocene/Holocene boundary are available (Alley et al., 1993; Bond, 1995, Bond and Lotti, 1995; Peteet et al., 1990; Rittenour et al., 2000; Watts, 1979, 1983), and these records all exhibit abrupt changes which could explain the discontinuities in alluvial sequences.

In eastern North America, the retreat of the Laurentide ice sheet appears to have been episodic and punctuated by catastrophic meltwater events (Broecker, 1999; Broecker et al., 1989; Teller, 1990; Teller and Thorleifson, 1983). Several abrupt changes in global climate were triggered by these events, the Younger Dryas event being the most extreme example. The Younger Dryas occurred at approximately 13 ka cal BP when glacial Lake Aggasiz drained through the Mississippi River and then the St. Lawrence River. The meltwater discharged from the lake cooled the surface waters of the North Atlantic Ocean (Broecker, 1999).

The reason that the Younger Dryas event occurred not only on both sides of the Atlantic but worldwide is probably that the meltwater and rafted ice inputs "shut down" or curtailed the production of North Atlantic Deep Water which drives the ocean circulation. Ocean sediment cores contain detritus rafted by glacial ice which supports this model of the Younger Dryas as well as several previous and subsequent global climate changes (Bond, 1995; Bond and Lotti, 1995). In the study area, a global change to colder and drier climate would presumably result in less river discharge with the exception of spring snowmelt or ice-damming events of the sort documented from the 18th and early-19th centuries.

All of the ice cores taken so far from Greenland show the Younger Dryas event. The indicators include more negative values for the oxygen isotope ratio ($\delta^{18}O$), less negative values for the hydrogen isotope ratio (δD), more dust particles, lower electrical conductivity, and low accumulation rates (Alley et al., 1993; Bradley, 1999; Dansgaard et al., 1989; Taylor et al., 1993). Values for δD in the much longer ice-core record from Vostok on the East Antarctic ice plateau have been used to estimate the magnitude of the global temperature change (Jouzel et al., 1997; Petit et al., 1987). An increase in surface temperature of ~9°C from the last glacial maximum to the Holocene is inferred but the change occurred in a "two-step" pattern, with an intervening reversal when temperatures fell by ~3-4°C (Jouzel et al., 1992; Mayewski et al., 1996). Levels of methane (CH_4) also declined late in this cold episode, the southern hemisphere equivalent of the Younger Dryas event. Based on their analysis of oxygen isotope ratios in biogenic opal from Lindsley Pond in Connecticut, Shemesh and Peteet (1998) estimate that winter temperatures may have decreased as much as 12˚C in eastern North America during the Younger Dryas.

The distribution of carbon isotopes among the different parts of the carbon exchange reservoir provides another proxy record of the episodic advance and retreat of continental ice sheets during the late Pleistocene (Bard et al., 1990; Peng and Broecker, 1992; Stuiver et al., 1991; van Geel et al., 1999). Analyses of carbon isotope ratios for both benthic and planktonic foraminifera show that carbon sequestered in the late Pleistocene abyssal ocean bottom water became depleted in ^{14}C (Peng and Broecker, 1992; Shackleton et al., 1988). Such "reservoir changes" apparently reinforced the effects of increased ^{14}C production due to lower solar activity, magnetic field strength, or both (Mankinen and Champion, 1993; Sternberg, 1992). The result was over 3,000 years of divergence at the last glacial maximum (Bard et al., 1990; Stuiver et al., 1998). During deglaciation, carbon ventilated from bottom water to the atmosphere probably contributed to the jagged appearance of the calibration curve (Duplessy et al., 1992; Edwards et al., 1993). Subsequent Holocene secular variations were more directly coupled to magnetic field strength and solar activity (Damon and Jirikowic, 1992; Damon et al., 1978; Sternberg, 1992; Stuiver et al., 1991; Van Geel et al., 1998, 1999).

CIRCUM-ATLANTIC CLIMATE CHANGE DURING THE HOLOCENE EPOCH

Regional environmental change is emphasized here in explaining the discontinuities in the Wyoming Valley formation. Nonetheless, several mechanisms identified in recent studies do link the regional climate of eastern North America with other regions bordering the Atlantic Ocean and possibly with global climate as well. One such mechanism is the teleconnection known as the North Atlantic Oscillation (NAO). Positive or "high" NAO-index cooling episodes have been suggested to coincide with ice-rafting identified from detrital grains in North Atlantic Ocean sediment cores (Bond et al., 1997; Broecker et al., 1998).

Synoptic reanalyses of weather events which caused floods on the Susquehanna River between 1957 and 1996 **(Appendix 2**) all show considerable interaction of regional air masses with the currents and sea-surface temperatures of the Atlantic Ocean. There also appear to be linkages between the regional synoptic patterns and the NAO in that. very low NAO-index values mark the years 1865, 1936, and 1996 when devastating winter floods occurred. Low NAO-index years were shown to have greater snow accumulation in western Greenland (Appenzeller et al., 1998), and a weakened NAO has been associated with a stronger Pacific-North America (PNA) connection (Burroughs, 1992, p. 46-47; Wallace and Gutzler, 1981). While some models link both the PNA and the NAO with El Niño events in the eastern Pacific (Hoerling and Kumar, 2002; Lins et al., 1990; Rogers, 1984), the ENSO appears to affect Pennsylvania climate primarily in La Niña years, if at all (Forbes et al., 1999; Ropelewski and Halpert, 1986). Snowy winters and snowmelt floods occur in somewhat warmer years with weakened as opposed to strengthened zonal flow across the Atlantic Ocean.

At least as compelling as the linkages between oceanic and atmospheric circulation are those between mean annual temperature or monthly temperature indices and longer term changes in the sunspot cycle and geomagnetic field strength (Bradley, 1999, p. 461-467; Pfister, 1992). In particular, the very cold temperatures of the Little Ice Age clearly occurred during the "Maunder minimum" in geomagnetic field strength (Stuiver, 1965; Stuiver and Braziunas, 1989; van Geel et al., 1999, p. 334). Such episodes of global cooling can also be hypothesized to have occurred during earlier events when radiocarbon production increased abruptly, although there are other possible causes (Faure, 1986, p. 390-393; Stuiver et al., 1991). The abrupt cooling event at ca. 2.7 ka cal BP (850 BC) has been discussed above as a significant correlate of Discontinuity III in the Wyoming Valley formation. The calibration curve for a date obtained on a sample of bulk sediment from Block 3, Stratum 16 at the Harding Flats site (**Figure 114**) shows two spikes in ^{14}C content which Van Geel et al. (1999, p. 334) relate to reduced solar activity and a consequently weak magnetic field. Further evidence for climatic cooling beginning approximately three thousand years ago comes from peat deposits in northwestern Europe (Killian et al., 1995) and oxygen isotopic shifts in fish otoliths from Tennessee (Wurster and Patterson, 2001).

An abrupt cooling event at 8.2 ka (uncalibrated) has been identified in North Atlantic seafloor sediment cores (Bond et al., 1996, 1997; DeMenocal and Bond, 1997;

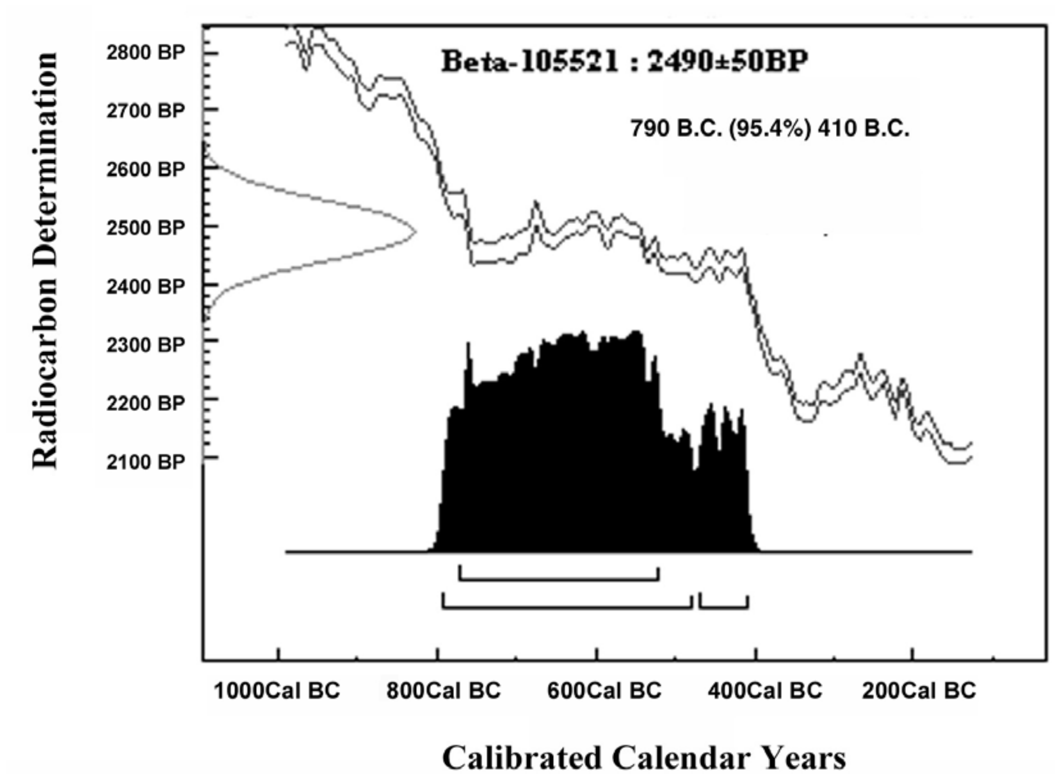


Figure 114: Calibration of the date of 2490±50 BP on a sample of bulk sediment from Block 3, Stratum 16 at the Harding Flats site (36WO55)

Marchitto et al., 1998) as well as the Greenland ice cores (Alley et al., 1997; Meese et al., 1994; O'Brien et al., 1995) and West Greenland lake records (Willemse and Tornqvist, 1999). An increase in the concentration of ice-rafted lithic grains, a greater frequency of hematite staining on grain surfaces, and a shift to cooler faunal assemblages is reported for two North Atlantic cores by Bond et al. (1996, 1997).

Another possible abrupt cooling in global climate has been proposed at 4 ka (Bond et al., 1997; Cullen et al., 2000) but this has yet to be as conclusively demonstrated in the proxy records. Drier climate throughout the Mediterranean and the Near East (Bar-Matthews et al., 1997; Frumkin, 1991, Geyh, 1994; Weiss et al., 1993) and increased dust in seafloor sediment cores may have been triggered by a perturbation in NADW production. This cooling event may also coincide with one of the three broad intervals of glacier expansion within the last 6,000 years (Denton and Karlen, 1973; Porter and Denton, 1967; Denton and Porter, 1970). A perturbation of NADW production has been implicated in the Little Ice Age Interval ca. A.D. 1700-1850 (Keigwin, 1996), although there is quite compelling evidence for solar forcing as well.

REGIONAL POLLEN RECORDS OF PAST VEGETATION AND CLIMATE

Changes in forest composition are important in explaining alluvial stratigraphy both because they are a proxy for regional climate change and because the vegetation on land surfaces controls the rate of runoff and supply of sediment to the river channel (Knighton, 1998; Langbein and Schumm, 1958; Williams and Reed, 1972). There are four pollen cores from locations in close proximity to the North Branch of the

Susquehanna River valley (Barnosky et al., 1988; Clark, 1999; Watts, 1979). Basal radiocarbon dates for three of the cores (**Table 19**) have calibration intercepts of 14.3 ka cal BP (Longswamp), 16.0 ka cal BP (Tannersville Bog), and 15.3 ka cal BP (Spring Lake). All of these fall in the "Bölling-Allerød" postglacial warm phase of the European chronology, immediately prior to the Younger Dryas global cooling (Goudie, 1992, p. 139). While separate "Bölling" and "Allerød" intervals of rapid warming were proposed in the Scandinavian pollen studies (Bjorck et al., 1996; Hafsten, 1970; Mercer, 1969), in many areas of the world these are combined into a single phase between the Younger Dryas and the "Oldest" Dryas.

Peak amounts of pine pollen occur at ca. 14.7 ka cal BP. Pine then declines at the expense of spruce during what appears to be the Younger Dryas, although this still needs to be precisely dated. Identification of pine pollen to species by Clark (1999) for a core from Ely Lake shows the late Pleistocene pine pollen to represent jack pine (*Pinus banksiana*) as opposed to white pine (*Pinus strobus*). Particularly rapid rates of vegetation change occurred during the late Pleistocene in eastern North America according to Jacobson et al. (1987).

In eastern North America, the very latest pollen spectra from the Pleistocene epoch record spruce parkland vegetation with patches of tundra indicated by abundant herb pollen (Gaudreau and Webb, 1985; Watts, 1979). This is the spruce (A) zone in the system of Deevey (1939, 1943, 1951), succeeded in turn by the pine (B) and oak (C) zones. The three zones can be correlated within radiocarbon error to the Preboreal (A),

Table 19: Inventory of Radiocarbon Dates from Pollen Cores in the Vicinity of the North Branch of the Susquehanna River

Site/Location	Lat	Long	Zone	Depth (m)	^{14}C yr BP	Lab No.	Material	Reference
Spring Lake	41.67	76.35	C (Oak)	7.85-7.95	9,280±100	WIS-1837	organic sediment	Barnosky et al., 1998
Spring Lake	41.67	76.35	B (Pine)	9.85-9.95	10,250±110	WIS-1838	organic sediment	Barnosky et al., 1988
Spring Lake	41.67	76.35	A (Spruce)	11.05-11.15	12,670±120	WIS-1839	organic sediment	Barnosky et al., 1988
Spring Lake	41.67	76.35	A (Spruce)	11.29-11.39	12,500±400	LDGO-1683	organic sediment	Barnosky et al., 1988
Spring Lake	41.67	76.35	Not reported	Not reported	12,080±100	SI-6926	organic sediment	Barnosky et al., 1988
Spring Lake	41.67	76.35	Not reported	Not reported	14,240±150	WIS-1935	mammoth rib	Barnosky et al., 1988
Spring Lake	41.67	76.35	Not reported	Not reported	15,910±160	WIS-1925	sediment from skull	Barnosky et al., 1988
Tannersville	41.03	75.27	C (Oak)	5.25-5.30	4,610±70	WIS-790	organic sediment	Watts. 1979
Tannersville	41.03	75.27	C (Oak)	8.10-8.15	8,390±85	WIS-784	organic sediment	Watts, 1979
Tannersville	41.03	75.27	B (Pine)	10.40-10.45	9,835±95	WIS-789	organic sediment	Watts, 1979
Tannersville	41.03	75.27	B (Pine)	11.40-11.45	10,860±100	WIS-791	organic sediment	Watts, 1979
Tannersville	41.03	75.27	T (Herb)	12.40-12.45	13,330±120	WIS-781	organic sediment	Watts, 1979

Site/Location	Lat	Long	Zone	Depth (m)	^{14}C yr BP	Lab No.	Material	Reference
Longswamp	40.48	75.67	B (Pine)	0.70-0.77	9,750±00	WIS-783	organic sediment	Watts, 1979
Longswamp	40.48	75.67	A (Spruce)	1.50-1.55	12,060±120	WIS-782	organic sediment	Watts, 1979
Longswamp	40.48	75.67	A (Spruce)	2.30-2.35	12,540±120	WIS-780	organic sediment	Watts, 1979
Longswamp	40.48	75.67	T (Herb)	2.52-2.60	12,200±110	WIS-805	organic sediment	Watts, 1979
Longswamp	40.48	75.67	T (Herb)	3.75-3.95	12,095±110	WIS-807	organic sediment	Watts, 1979
Longswamp	40.48	75.67	T (Herb)	11.05-11.15	12,400±170	QL-1081	organic sediment	Watts, 1979
Crider's Pond	39.97	77.55	B (Pine)	1.35-1.40	11,650±130	WIS-785	organic sediment	Watts, 1979
Crider's Pond	39.97	77.55	A (Spruce)	4.00-4.10	13,260±125	WIS-787	organic sediment	Watts, 1979
Crider's Pond	39.97	77.55	A (Spruce)	6.80-7.50	15,210±150	WIS-903	organic sediment	Watts, 1979
Panther Run	40.8	77.42	C (Oak)	1.00-1.10	6,400±75	WIS-936	organic sediment	Watts, 1979
Panther Run	40.8	77.42	A (Spruce)	1.30-1.40	12,610±140	QL-967	organic sediment	Watts, 1979

Boreal (B), and Atlantic (C) periods of the Blytt-Sernander pollen chronology for western Europe (Godwin, 1975, p. 455-472; Sernander, 1910). At this very general level of classification of the pollen proxy records, there do appear to be circum-Atlantic controls on the timing if not necessarily the direction or magnitude of Quaternary climate change.

The spruce zone vegetation in the Northeast may not have resembled any known from modern sites (Overpeck et al., 1992). Nonarboreal pollen is generally quite abundant in comparison to pollen from tree species at most sites prior to 12 ka cal BP, suggesting that open parkland environments succeeded tundra as the ice retreated. Reconstructing vegetation from pollen is complicated, however, by varying rates of production by the individual species and varying transport by wind and other vectors (Davis et al., 1973). Spruce (*Picea*) commonly represents up to 20% of the pollen rain in tundra environments near and north of the spruce limit and pine (*Pinus*) is even more abundant (Birks, 1973). At Tannersville Bog (Watts, 1979), the local vegetation is represented by 20% Cyperaceae (sedge) and lesser amounts of *Sali*x, Graminae, *Artemisia*, and *Rumex*/*Oryxia* and other herbs. Plant macrofossils of *Betula grandulosa*, *Dryas integrifolia*, *Emptetrum* cf. *nigrum*, *Salix* spp., and *Vaccinium uglinosum* var. *alpinum* from the Longswamp core indicate survival of many shrubs characteristic of tundra as late as 13 ka cal BP. High Cyperaceae percentages were found at Spring Lake from 11.4 m to the bottom of the core at 12.8 m (Barnosky et al., 1988).

Pollen cores from northeastern Pennsylvania have yet to be sampled or analyzed with the degree of precision apparently necessary to distinguish the abrupt Younger

Dryas cooling (Peteet, 1987; Peteet et al., 1990). One possible indicator is the abrupt increase in diversity in the pine zone at Crider's Pond (Watts, 1979, p. 441). This interval dated to 11,650±130 BP (uncalibrated), and the sediment was also full of small stones. Colluviation and slope instability occurred here at the very point when the landscape should have been becoming covered by closed canopy.

Holocene vegetation changes in northeastern Pennsylania are not yet as well dated as the alluvial deposits which have been investigated in the present dissertation. The few reliable dates will therefore be summarized here in uncalibrated radiocarbon years. There is one date of 9,750±100 BP (WIS-783) for the upper portion of the Longswamp core, which Watts subdivided into zones LS-3 and LS-4. These correspond to the B and C zones of Deevey (1939, 1943, 1951) with Pine (*Pinus*) and fir (*Abies*) dominant in LS-3 and oak (*Quercus*) in LS-4. At Spring Lake (Barnosky et al., 1988), the pine zone has been dated to 10,250±110 BP (WIS-1838) and the oak zone to 9,280±100 BP (WIS-1837). At the beginning of the oak zone, a gradient began to form between oak-rich deciduous forests to the south and more mixed coniferous or deciduous forests to the northeast. This gradient presently crosses the study area approximately at the boundary between the Appalachian Plateau and Ridge and Valley physiographic provinces (Gaudreau, 1988, p. 241).

The modern mixed deciduous forests in the Northeast feature tree species sometimes grouped together by palynologists as BAFT (*Betula*-*Acer*-*Fraxinus*-*Tsuga*). The "ecotone" or transition zone which crosses the study area is suggested to have become more pronounced between 8 ka and 6 ka (Gaudreau, 1988, p. 241), when a number of specific migrations of tree species are dated by pollen cores. The immigrations of both hemlock (*Tsuga*) and beech (*Fagus*) are bracketed by uncalibrated radiocarbon dates of 9,385±95 BP (WIS-789) and 8,390±85 BP (WIS-784) from the Tannersville Bog core (Watts, 1979). Hickory (*Carya*) immigrated around 7 ka cal BP, and chestnut (*Castanea*) a little before 6 ka (Watts, 1979, p. 447).

An abrupt decline of hemlock (*Tsuga*) relative to other pollen taxa occurred prior to the radiocarbon date of 4,610±70 BP (WIS-790) in the Tannersville Bog core. At Spring Lake, an interpolated age of 5,700 BP was proposed for the hemlock decline (Barnosky et al., 1988, p. 178). The decline has been conclusively connected to a specific insect pathogen (Bhiry and Filion, 1996; Davis, 1981; Filion and Quinty, 1993). Warmer climate may have facilitated the pathogen's spread and rate of reproduction. Although it may have occurred somewhat later than Discontinuity II based on the available radiocarbon dates, the regional deforestation is here suggested to explain much of the Wyoming member of the Wyoming Valley formation as well as many previously described alluvial deposits (Brakenridge et al., 1988; Kirkland, 1993; Scully and Arnold, 1981). The loss of the hemlock canopy on valley side slopes apparently increased the sediment yield considerably during this warm, wet period in regional climate.

Ely Lake, within the North Branch of the Susquehanna River drainage basin, has been cored in at least two separate palynological studies (Gajewski et al., 1987; Clark, 1999). The longer of the two cores extends prior to the hemlock decline (**Figure 115**), which Clark estimates to have occurred at 5,000 BP. The hemlock deline is followed in less than a thousand years by an increase in chestnut (*Castanea* sp.). An episode of

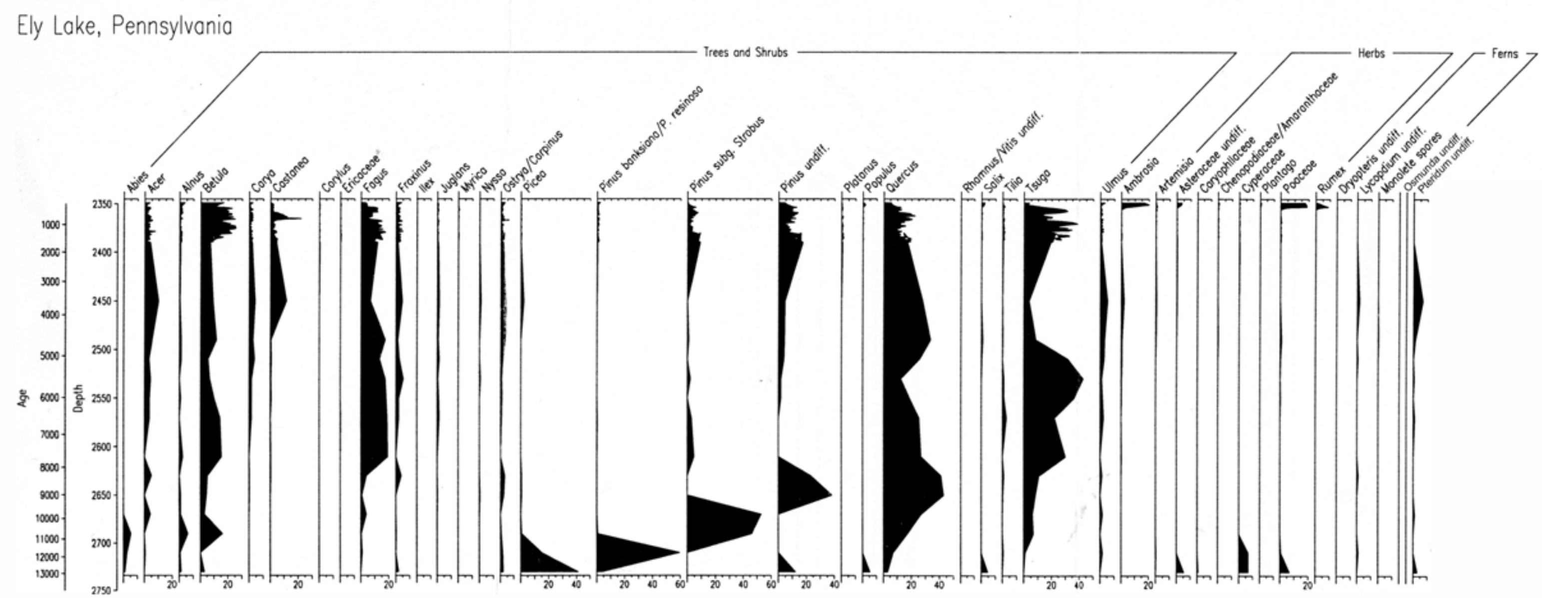


Figure 115: Pollen profile for a core from Ely Lake in the North Branch of the Susquehanna River drainage basin. Prepared by J. Clark (1999).

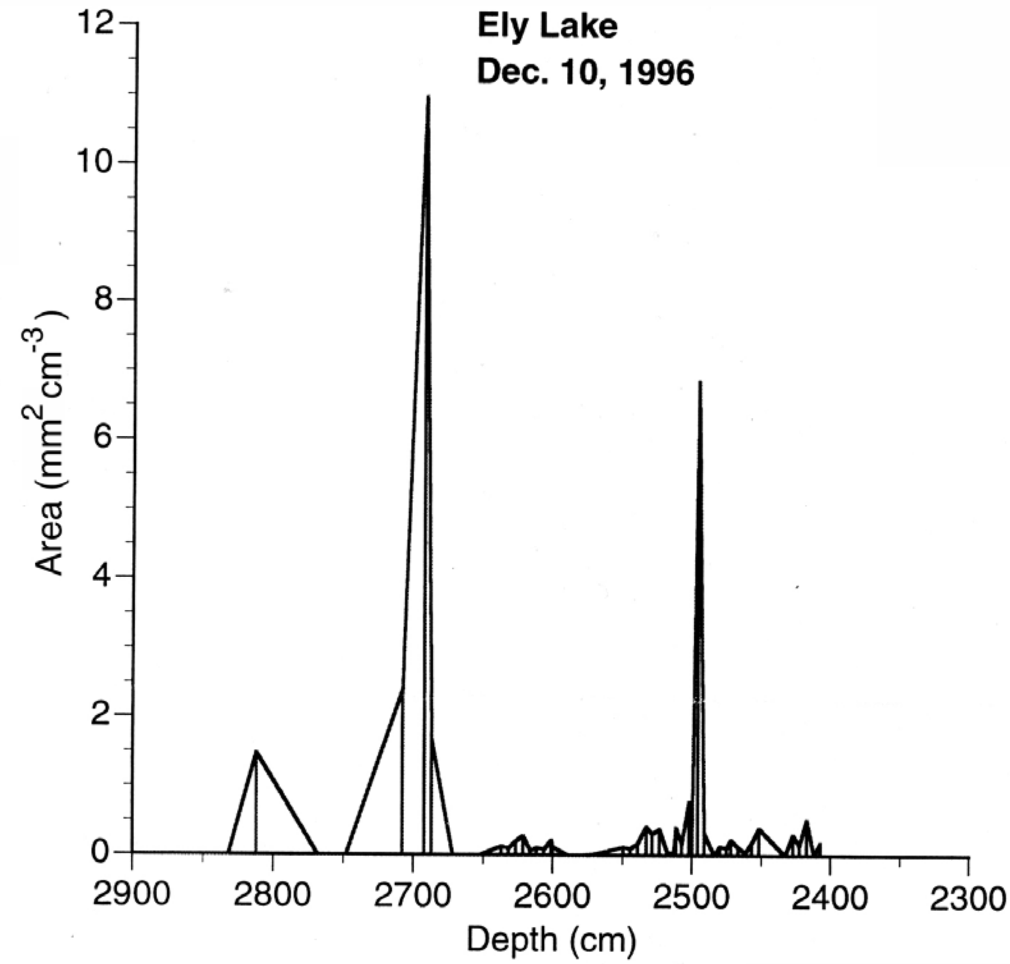


Figure 116: Charcoal abundance in the Ely Lake core as reported by Clark (1999)

increased charcoal accumulation was also identified at 5 ka (see **Figure 116**), as well as an earlier episode at 11 ka which probably represents the Younger Dryas event.

There is no convincing evidence for disturbance of deciduous forest vegetation in the Northeast by Native Americans prior to the introduction of *Zea mays* at ca. 1,000 BP. Paleoenvironmental indications for such disturbance have been reported by 6,000 BP, however, in the Southeast (Chapman and Shea, 1981; Delcourt et al., 1986). Both fire and girdling of trees may in fact have been practiced by the first humans to set foot in North America, to create and maintain forest clearings (Sauer, 1941, p. 160-161; Day, 1953).

Vento and Rollins (1989, p. 45-46) report high percentages of grass, vetch, and chenopodium (both pollen and seed) in Susquehanna River alluvial deposits less than 2,000 years old. The occurrence of ragweed (*Ambrosia*) and sorrel (*Rumex*) pollen in deposits dated ca.1,000-500 BP was further noted by Scully and Arnold (1981, p. 341-342), who attributed it to aboriginal clearing. The Global Pollen Data Base (NOAA, 2002) arbitrarily assigns the dramatic increase in ragweed at Longswamp, Tannersville Bog, and other Northeastern sites a date of 300 BP, since it is attributed to the initial Euroamerican settlement of the region. Increases in ragweed (*Ambrosia*), fern (*Dryopteris*), *Osmunda*, and *Rubiaceae* at Longswamp were suggested by Watts (1979) to date around 1,000 BP European-introduced plants such as plantain (*Plantago*) and bluegrass (*Poa*) appear somewhat later in the core. The main change from 3,000 to 300 years BP at Tannersville Bog appears to be a rise in hydrophytic taxa such as sedges (Cyperaceae), and *Sphagnum*. Gajewski et al. (1987) reported an increase in alder in the upper two zones for Ely Lake. This may have been caused by abrupt global cooling in the

Little Ice Age. Alder was suggested as a proxy for cooler climate in the late Pleistocene by Prentice et al. (1991, p. 2050). Gajewski et al. describe the change as occurring between 500 and 400 years ago, but their age control was obtained by counting the varves.

To summarize the diverse implications of the pollen cores for reconstructing past climate, there clearly was a warming trend during the Early Holocene which peaked locally with the oak zone of the pollen chronology. July temperatures were at least 2˚C warmer at 7 ka cal BP according to quantitative reconstructions based on climate-sensitive pollen taxa (Webb et al., 1993b, 1998). Intervals of drier climate do not appear to have coincided with this warming trend and may instead have been triggered by abrupt cooling episodes in the North Atlantic Ocean. There are definite signatures in both pollen and charcoal from a pollen core for the first of these episodes following late Pleistocene ice retreat, the Younger Dryas.

Climatic forcing is further indicated by the fact that regional vegetation changes occur at approximately the same time in eastern North America and in Europe. Deevey's zones A, B, and C for eastern North America are temporally equivalent to the PreBoreal, Boreal, and Atlantic periods of the European Blytt-Sernander chronology. The Blytt-Sernander terms are nonetheless placed in quotation marks in this dissertation, because the forest canopy itself was very different.

Deevey himself proposed a warm, dry climate lasting throughout the Early Holocene, from ca. 9-6 ka, which he referred to as the "Hypsithermal" Interval (Deevey and Flint, 1957). Watts, however, found no convincing evidence for a regional dry period in Pennsylvania (Watts, 1979). The climate may therefore have been at least as wet as the present at the time of the maximum Holocene warming. This generally supports the proposal by Wright (1976, p. 592-593) that the Hypsithermal be redefined from being "...a time stratigraphic unit with time-parallel terminations" to being "...a climatic episode with time-transgressive boundaries."

The occurrence of floods transporting suspended sediment within the period traditionally assigned to the Hypsithermal in the Northeast is thus fully in agreement with the paleoclimatic proxy data from pollen. The climate at 7 ka cal BP was at least as wet as at present, and both late winter to spring snowmelt and tropical storms may have occurred with approximately the same frequency. The soils formed on bounding surfaces in the stratigraphic framework, on the other hand, correlate most closely with abrupt cooling events in the regional climate. At least one such event probably occurred at ca. 8.2 ka (9.3 ka cal) BP during the "Boreal" period of the Blytt-Sernander chronology, the pine (B) zone of the Deevey chronology. The events became more frequent beginning in the "NeoBoreal" period, however, and the Little Ice Age event occurred recently enough that its effects on both the weather and river behavior have been described in detail.

LAKE SEDIMENT STUDIES

Several of the changes in regional climate identified above are corroborated by independent records obtained from lakes in eastern North America. Webb et al. (1993a) used sediment core transects to reconstruct changes in lake levels, finding that they decreased between 12,000 and 6,000 BP in lakes along the Atlantic Seaboard. The drop occurred progressively later at sites further north, and sedimentation rates in some interior lakes show an opposite trend.

Closer to the present study area, Dwyer et al. (1996) reported highstands in Lake Owasco at 10.5 and 6.9 ka with an intervening lowstand at 9 ka (uncalibrated). The Lake Owasco record appears to be out of phase with records from the midcontinent as well as the Atlantic Seaboard. Although Dwyer et al. attribute their Early Holocene lowstand to the global maximum in summer solar insolation, it could just as easily represent the recently discovered abrupt cooling event in the North Atlantic Ocean (Alley et al., 1997; Willemse and Tornqvist, 1999). That event occurred at 8.2 ka (uncalibrated), which calibrates to 9.3 ka cal BP.

In the midcontinent, maximum aridity occurs at 7 ka cal BP (Webb and Bryson, 1972; Yu et al., 1997), and warmer temperatures in the middle part of the Holocene epoch are also indicated by the formation of calcite in two long cores from Cayuga Lake (Mullins, 1998). The lake highstand reported by Dwyer et al.(1996), however, appears to indicate a wetter rather than drier Hyspithermal interval. Their explanation for this is a northeastward migration of the "Bermuda High," increasing the frequency of tropical cyclones. This is a similar mechanism to the latitudinal shift of the polar front proposed in some general models of Holocene climate change (e.g. Gunn, 1994). Because most of the precipitation actually falls as snow, neither lake nor river sedimentation in the Northeast is likely to be as directly triggered by tropical cyclones as these authors have suggested. As was observed in the synoptic charts for recent floods on the North Branch of the

Susquehanna River, however, severe weather events are definitely affected by the sea surface temperatures in the Atlantic Ocean.

Several studies have attempted to quantify changes in regional climate using stable isotope ratios from silicate or carbonate materials in lake sediments. A study by Shemesh and Peteet (1998) of biogenic opal from Linsley Pond in Connecticut suggested that winter temperatures dropped as much as 12°C during the Younger Dryas abrupt cooling event. Fritz et al. (1975) analyzed carbonate shell material from Lake Erie sediments, finding that the ^{18}O content increased by 4 to 5 per mil between the base of their core and deposits which were dated to ca. 8.5 ka cal BP. Assuming a linear relationship between lake water temperatures and those of the atmosphere, they infer that the mean annual temperature increased from 5-14°C. This is considerably higher than the increase of 2°C in July temperatures estimated by the COHMAP members (1988, p. 1048) based on Milankovitch forcing and pollen records. As noted by Fritz et al. (1975), their estimate may be in error due to the change from ostracod to gastropod valves up section and to the fluctuating water balance of the lake itself. It may also be that the cool paleotemperatures at the base of their core are more anomalous than the warm ones inferred to represent the Hyspithermal.

SYNOPTIC CAUSES OF GAGED FLOOD EVENTS

Several of the climatic forcing factors identified in the proxy records can also be identified as causes of gaged floods during the much shorter time frame of the NOAA synoptic reanalyses (Kalnay et al., 1996; NOAA, 1999). Maps of the height of the 850 mb pressure contour over North America and the adjacent Atlantic Ocean were prepared online and downloaded for each of twelve large flood events (see **Appendix 2**). All twelve of these events produced a discharge at the Wilkes-Barre gaging station which was greater than 2,860 m^3s^{-1}, the flood with a 1.5 year recurrence interval for 1913-1971. Other synoptic maps prepared in the analysis of specific events include the height of the 250 mb pressure contour, the specific humidity at 500 mb, and the specific humidity at 700 mb.

For most of the events, low pressure cells which produced the precipitation were centered over the drainage basin on the day preceding that of the maximum discharge at Wilkes-Barre. The maps were manually classified into synoptic types (Yarnal, 1993; Yarnal and Frakes, 1997), with eight of the twelve events resulting when more than one of these types occurred in sequence (see **Table 20**). Yarnal and Frakes (1997) identified sequences of synoptic types for periods of from one to four days preceding a larger sample of events occurring from 1978-1999 on tributaries as well as the trunk drainage. Although a sequential analysis was not performed in the present study, the results obtained do confirm the causal importance of several of these sequences.

The RC (Cyclonic Rain), CF (Cyclonic Front), and BH (Blocking High) synoptic types are associated with cyclones of midlatitude regions such as eastern North America (Yarnal, 1993). The sample of twelve events from the NOAA reanalyses (1958-1996) included two tropical cyclones, representing the final stage of tropical storms Agnes (1972) and Eloise (1975). Snowmelt was a causal factor in most of the other events. The events of March 10, 1964 and March 7, 1979, in particular, occurred following relatively

Table 20: Synoptic Causes of Large Floods on the North Branch of the Susquehanna River

Flood Event	Q at Wilkes-Barre (mm)	Monthly Precip (mm)	Monthly Temp (°C)	Annual Temp (°C)	NAO-Index[1]	SO-Index[2]	Synoptic Type	Causes
January 19, 1996	6,257	162.6	-4.39	9.06	-3.78	1.00	BH,CF	Frontal Rain, Snowmelt
March 24, 1994	4,190	96.5	1.80	9.78	-3.03	-1.40	RC,CF	Northeaster (Cyclone, Blocking High), Snowmelt
April 2, 1993	5,238	189.7	9.94	10.11	2.67	-1.60	RC	Extratropical Cyclone, Snowmelt
March 15, 1986	4,807	110.0	4.33	9.72	0.50	0.00	BH,EL	Cut off Low, Blocking High, Snowmelt
April 7, 1984	5,436	230.1	9.06	10.33	1.60	0.20	RC	Extratropical Cyclone, Snowmelt
April 15, 1983	3,907	242.8	7.72	9.83	3.42	-1.30	BH,CF	Northeaster (Cyclone, Blocking High)
March 7, 1979	5,436	38.6	4.83	9.61	4.89	-0.50	BH,CF	Snowmelt (January precip = 164 mm)
September 27, 1975	6,455	154.9	15.50	10.83	1.63	2.40	BH,CF	Tropical Storm Eloise
June 22, 1972	4,768	178.8	17.17	8.56	-0.96	-1.10	RC	Tropical Storm Agnes
March 10, 1964	5,323	89.9	2.72	9.83	-1.54	0.70	BH,CF	Northeaster (Cyclone, Blocking High)
April 7, 1958	4,813	91.2	9.44	8.44	-1.02	0.10	RC,EL	Cut off Low, Snowmelt
March 9-19, 1936	6,569				-3.89			Frontal Rain, Snowmelt
March 17, 1865	6,569				-1.24			Frontal Rain, Snowmelt

[1]NAO-Index values obtained online at http://www.cgd.ucar.edu/~jhurrell/nao.html

[2]SO-Index values obtained online at http://www.cpc.ncep.noaa.gov/data/indices/

modest frontal rains which melted snow that fell during much larger storms nearly two months prior to the flood. Strong negative values for the NAO-index of -2.86 (1964) and -4.89 (1979) demonstrate the effects of this mode of the NAO teleconnection on the hydrology of the study region. The very large snowmelt flood of January, 1996 also occurred in a low NAO-index winter, as did the floods of March, 1936 and March 1865. The winter NAO-index values in **Table 20** were calculated by Hurrell (1995, 2003) from the difference between normalized sea level pressures at Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland during December through March.

The EL (Extended or "Cut off" Low) synoptic type was identified on two maps where the pressure gradients were somewhat weaker than on the maps for the other ten events. In both the April 7, 1958 and the March 15, 1986 events, the relatively weak low pressure center which caused rain in the study region was subsidiary to a much larger system centered over Newfoundland and Greenland. The 1986 event drew in moist air from the northeast, much as occurred in the classic "Northeaster" events in the spring of 1964, 1983, and 1994.

The weather year 1982-1983 included one of the most severe El Niño events of the 20th century, characterized by pronounced warming of the surface waters of the eastern equatorial Pacific Ocean (Angell and Korshover, 1984, 1985; Ropelewski and Halpert, 1986). Many models of El Niño use the 1982/83 synoptic patterns as a "test case," particularly the downstream shift of the high pressure center over western Canada and the increased cyclonic activity on the West Coast and the southeastern United States (e.g. Hoerling and Kumar, 2002; Lins et al., 1990; Zebiak and Cane, 1987). The spring of

1983 was one of the wettest on record in northeastern Pennsylvania. A blocking high in the Atlantic Ocean off of the New England coast kept storm cells centered over the drainage basin. In spite of the large amount of rain that fell during the month of April, the flood of April 15, 1983 would be at most a 5-year flood using the frequency analysis for 1913-1971 (see **Figure 32**).

In their analysis of six strong El Niño events between 1895 and 1996, Forbes et al. (1999) found that northeastern Pennsylvania was warmer by ~0.6°C (1°F) and slightly wetter the following April, but was actually slightly colder than average in May. Forbes et al. ultimately conclude that ENSO has not had much effect on Pennsylvania weather within the period of instrumental record. The present analysis generally corroborates their conclusion, although both the 1983 and 1994 Northeasters did occur following El Niño events. This can be seen from the negative values in **Table 20** for the Southern Oscillation (SO) Index, which is calculated from the difference between mean sea level pressures at Tahiti and Darwin, Australia. A much stronger causal role for the NAO than ENSO is indicated in that three of the four largest floods were caused by low-NAO events, in which snow was melted by rain from extratropical cyclones.

DENDROCLIMATOLOGY

Tree-ring width measurements are probably the most promising paleoclimate proxy data to use in extending synoptic analyses back prior to the one or two centuries of instrumental measurements from weather stations in North America. The Hurrell (1995) index for the North Atlantic Oscillation has been calculated back to AD 1701, for example, using tree-ring widths from North America and Europe (Cook et al., 1998; Cullen et al., 2001; Mann, 2000). The longest period of consistently positive NAO-index values is for 1823-1828. A 20 year interval of negative values from 1864 to 1883 includes the meteorological events which caused the 1865 "St. Patrick's Day" flood on the North Branch of the Susquehanna River.

Ring widths of at least six species from forests in eastern North America have been found to be sensitive to the NAO or to other climatic parameters (Cook, 1991; Cook and Cole, 1991; Cook and Jacoby, 1983; Cook et al., 1992, 1998; Jacoby and D'Arrigo, 1989; Stahle, 1988, 1996; Stahle and Cleaveland, 1992; Stahle et al., 1988). Mean annual precipitation has been reconstructed for the southeastern United States back to AD 1000 using bald cypress (*Taxodium* sp.) ring-width measurements. For the northeastern United States, the most climatically sensitive species appear to be eastern hemlock (*Tsuga canadensis*) and white oak (*Quercus alba*), although other oak (*Quercus*), pine (*Pinus*), and spruce (*Picea*) species also show some sensitivity (Cook, 1991).

In addition to their ability to bridge the gap between instrumental measurements of modern weather events and other proxy records of past climate, tree-ring widths can be sensitive to regional hydrological changes which directly affect streamflow. For example, Cook and Jacoby (1983) found that streamflow in the Potomac River responded to persistent wet and dry periods that also determined the ring widths of eastern hemlock trees. The interval of below-median streamflow from 1850-1873, in particular, occurred after huge quantities of pack ice were destroyed in the Arctic. Cook and Jacoby (1983) hypothesize that both the growth of hemlock trees and river discharge may diminish following such abrupt cooling events in the North Atlantic Ocean. The Potomac River streamflow may not be synchronized with that of the North Branch of the Susquehanna River, however, where at least one large flood was associated with a low-NAO event during the 1850-1873 interval.

The response of hemlock to climate is not yet completely understood (Cook and Cole, 1991). There are also relatively few natural repositories of well-preserved hemlock trunks in eastern forests to use in building long chronologies. Hemlocks do grow well in boggy sites but are less stressed there so that the ring-widths show little response to regional climate change. The most sensitive living specimens are from drier, upland sites where soil moisture is derived from snowmelt. Hemlocks are rarely found in modern river floodplains, although they do appear to have grown in the North Branch of the Susquehanna River valley up until the first Euroamerican settlement.

A high resolution paleoclimate record for the Northeast based on hemlock tree-ring widths will probably be complete back to ca. 5 ka cal BP within the next five or ten years (Cook, 2002). It will be interesting to see how wet and dry periods evident in this reconstruction match those of other proxy records. Beyond 5 ka cal BP, dendroclimatological reconstruction will be seriously limited by the drastic hemlock decline which is observed in the pollen record.

VEGETATION, CLIMATE, AND ALLUVIAL LITHOFACIES

Changes in tree growth, pollen production, and other biological processes clearly were forced by changes in the regional climate of eastern North America. The rates of change in biological processes did not necessarily correspond, however, to the more abrupt changes which are characteristic of physical processes such as air mass circulation in the atmosphere or thermohaline circulation in the ocean. There are lags in the response of the proxy records as well as in the process of sediment transport itself. Because of these lags, bounding discontinuities in alluvial stratigraphy typically span several hundreds or even thousands of years, even when they were in fact caused by relatively abrupt changes in regional climate (Blum and Tornqvist, 2000; Knox, 1983).

Figure 117 is a model developed by Knox (1972) showing the response of vegetation to abrupt changes in precipitation. Drought that causes the devegetation of upland surfaces promotes erosion, but there is a significant lag between the start of a dry interval and the biological response. Sediment yield in river basins is a physical process, but its linkage with climatic forcing factors is mediated by the biological response of the vegetation.

The linkages between physical and biological processes shown in **Figure 117** are further apparent from the geographic variation in sediment yield described by Langbein and Schumm (1958). They compared sediment yields at both stream gaging stations and reservoirs with the annual effective precipitation, which is precipitation minus evapotranspiration. The greatest sediment yields occur in semiarid environments with

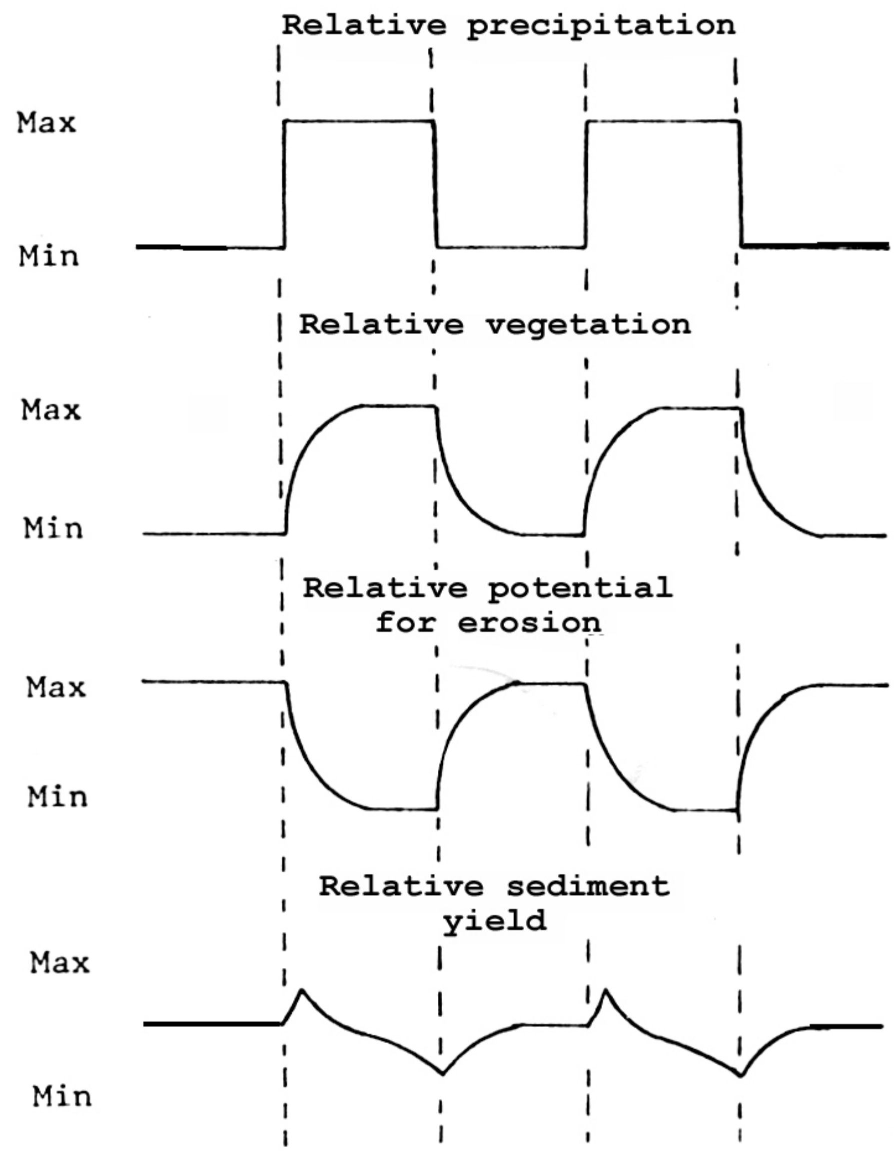


Figure 117: Model of biological and sedimentological responses to abrupt, "square wave" climate change (after Knox, 1972)

200-400 mm of effective precipitation (see **Figure 118**). Sediment yields are low in arid settings because relatively few events occur which transport sediment. Sediment yields also taper off at the other end of the Langbein-Schumm curve. Forest vegetation in humid settings protects the soil from erosion, so that runoff events transport less sediment per unit of discharge.

The effective precipitation in northeastern Pennsylvania is well over 500 mm, and it probably has remained so throughout the Holocene epoch in spite of the climate changes indicated by the proxy records. Sediment yields compiled by Williams and Reed (1972) are all less than 60 tons km^2 yr^{-1} (see **Figure 119**) but these are for small tributaries. Williams and Reed found that sediment yields are higher by up to 30 tons km^2 yr^{-1} for catchments that have been deforested for agriculture or suburban development. At Gunpowder Falls, Maryland on the lower Susquehanna River, the sediment yield under intensive agriculture during 1914-1943 was 344 tons km^2 yr^{-1} (Wolman, 1967). Sediment yield then declined to 86 tons km^2 yr^{-1} when much of the land reverted to forest after 1843.

The balance between sediment supply and discharge on the Susquehanna clearly has been affected by both logging and agricultural land use since the first Euroamerican settlement. Alluvial lithofacies in the Nanticoke member of the Wyoming Valley formation can be directly related to the regional pulses of sediment associated with these human activities. One example described in **Chapter 5** is the woody detritus found at the base of gullies upstream of Friedenshütten (km 396). Giddings Rig borings for the Wyoming Valley levee raising (Schuldenrein and Thieme, 1997) also encountered deeply

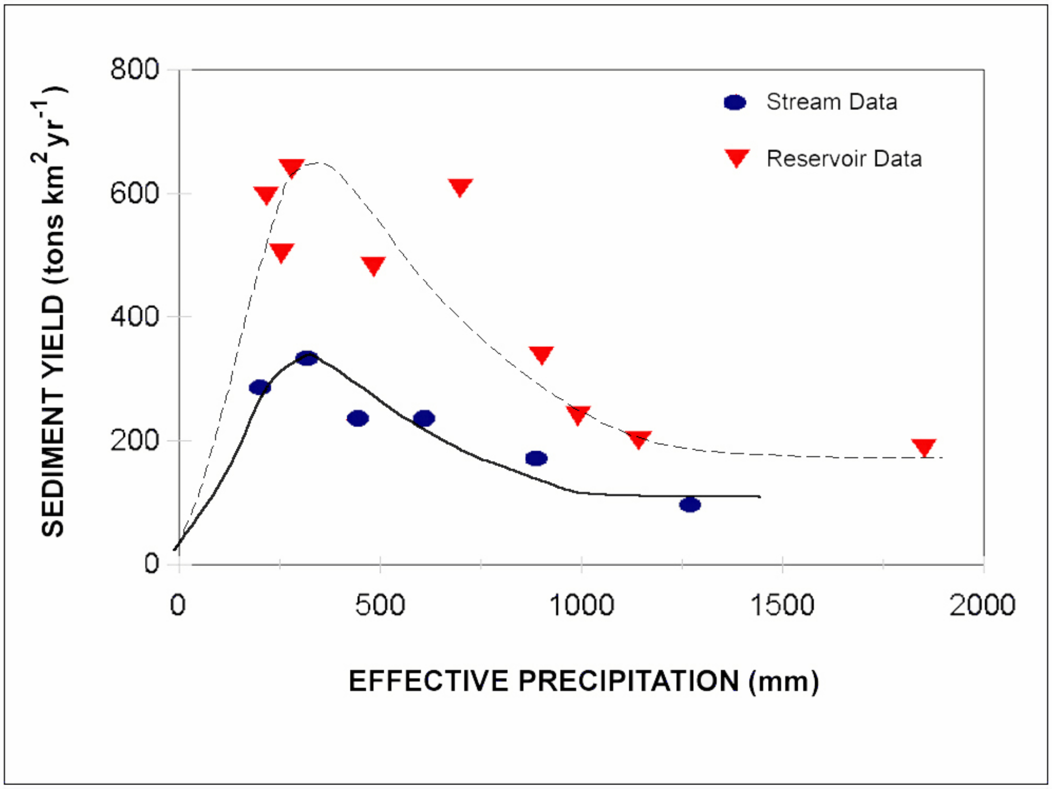


Figure 118: Curvilinear relationship between effective precipitation and sediment yield as reported by Langbein and Schumm (1958)

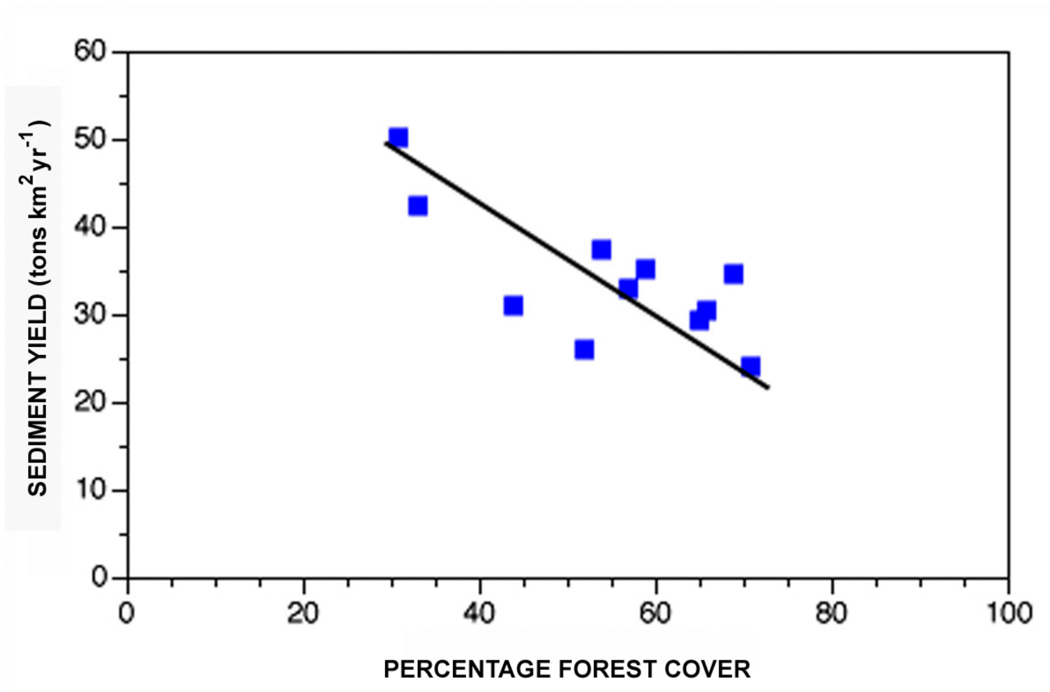


Figure 119: Relationship between forest cover and sediment yield for tributaries to the Susquehanna River (after Williams and Reed, 1972)

buried logs just downstream of Wilkes-Barre at the old Delaware and Hudson railroad trestle (km 297). These two woody log deposits are surely not unique. Historic maps and aerial photographs show that both terrace segments and floodplain islands have increased in size or changed their shape within the past two or three centuries. The basal lag that trapped the sand and silt in many of these deposits presumably consists of such woody material produced by historic logging.

Natural levees such as that described in the 8th Street Bridge Replacement Work Area are even more common alluvial features which contain specific lithofacies of the Nanticoke member. Most typical is the thinly laminated sand, composed of medium to coarse quartzose sand interbedded with fine particles of charred plant material. Both the thinly laminated sand and the sand beds which contain anthracite particles are coarse textured.

Happ (1945) previously remarked on the coarse texture of historic alluvium in his study of river deposits in South Carolina. "Agricultural age" deposits of the Maryland Piedmont were described by Jacobson and Coleman (1986) as "brown silt loam," texturally indistinguishable from their "Presettlement" deposits. Quite similarly, in the present investigations an overbank sand and silt lithofacies occurs in the Nanticoke member but is also very common in the Wyoming and Forty Fort members. It is more common to find well-preserved laminar bedding in historic deposits. As noted by Jacobson and Coleman, they also may contain temporally diagnostic artifacts such as bottles, cans, textiles, brick fragments, and hewn timbers.

Alluvial deposits which are of "Presettlement" age according to the framework of Jacobson and Coleman (1986) may also have anthropogenic causes or causes which involve disturbance of the natural vegetation. In the present framework, the stratic sand and charred organics lithofacies of the Forty Fort member clearly results from a sequence of events which supplied charred organic matter and allowed thin soils to form in relatively coarse sandy sediments.

The dark color of the thin A horizons exposed in the borrow pit at the Forty Fort Airport (see **Figure 64** and **Figure 78**) points to unique causes. One possibility is that these are in fact "middens" resulting from the disposal of wastes of some sort from the nearby village of the late prehistoric Clemson/Owasco culture. Dark-colored A horizons could also result from a successional stage dominated by grasses rather than deciduous forest. Mollic epipedons formed under grassland vegetation typically have dark, low chroma Munsell colors as well as a greater abundance of base cations (Birkeland, 1999, p. 36; Soil Survey Staff, 1997). The calcium increase in the 2Ab2 horizon of Section 5 in the borrow pit (**Table 15**) could indicate midden but would be compatible with other interpretations.

Causes for the Forty Fort member are discussed again below with reference to Discontinuity IV. Because the Forty Fort occurs intermittently, primarily in areas which were inhabited by Late Woodland villagers, the present causal model incorporates anthropogenic forcing. Other interpretations are possible, however. The description and identification of the members of the Wyoming Valley formation is based on their bounding discontinuities and should be independent of genesis. Furthermore, it should be possible to recognize each member and its lithofacies independent of any association with prehistoric or historic archaeological features or assemblages.

Massively bedded sand occurs in the Forty Fort, Wyoming, and Central Builders members, typically at the base of each unit. The bed at the base of the Wyoming member in the column at Falls Bridge (km 331) was designated as the 2C1 and 2C2 soil horizons (**Table 13** and **Figure 101**). Particle size analysis showed the bed to be only 64-70% sand, but over one percent of this was coarse sand. Stratigraphically equivalent beds are found in at least five other columns extending downstream at least as far as the Zehner site (km 252). These beds may all represent a single large flood event. More probably, however, they resulted from floods caused by similar meteorological events occurring over several decades or even several centuries during the middle part of the Holocene epoch. The synoptic analysis of modern floods suggests the most probable type of event to be one in which snow was melted by rain from extratropical cyclones during winters when the North Atlantic Oscillation was in its negative mode.

Other than the examples which have just been discussed, relatively few correlations can be made using lithic characteristics between the 23 columns in **Table 16**. Deposits may have been removed in a few cases by postdepositional scour. The variation along the downstream axis is so great, however, that an alternative hypothesis is here proposed. This is that considerable variation in stream power persisted even when the river was in flood. Each flood event consequently left deposits in patches which correspond to the spacing of regions of turbulent flow (Hey, 1976; Yalin, 1971, 1992).

The above hypothesis was suggested by the analysis of hydraulic channel characteristics in **Chapter 3** and appears to be supported by the stratigraphy described in **Chapter 5**. Because of the resulting variation in the distribution of alluvial lithofacies, the morphology of the buried soils was the most reliable basis for subdividing the Holocene alluvium. Allostratigraphic units were a natural choice because they can include a number of lithofacies and accomodate lateral and vertical changes in sediment texture within valley fills that are bounded by buried soils.

Patterned variations of sediment texture within an allostratigraphic unit can be particularly diagnostic for relating it to forcing factors in climate or vegetation change. For example, the deposits of the Wyoming member tend to fine upward from the coarse sand beds through finer-textured loam to one or more silt- and clay-rich buried soils. This sequence is typical of point bar depositional environments on the outside of bends in a meandering river channel (Allen, 1970; Leopold et al., 1960, p. 324-326). This channel pattern would be expected under a warm, wet climate with a mature deciduous forest canopy. A more thinly bedded unit such as the Forty Fort member implies a different set of environmental conditions as does the Central Builders member, in which silt and clay are sparse and tend to be draped over large, ripple-bedded bars.

In spite of the complexity in the response by rivers to external forcing, all of the discontinuities in the present stratigraphic framework do have causes that are truly "allogenic," or independent of the river's own workings. The following sections discuss the causes for each discontinuity. The dissertation then concludes with some general remarks about allostratigraphy and the extent to which the present investigations have confirmed the hypothesis of allogenic forcing for alluvial deposits in the North Branch of the Susquehanna River valley.

DISCONTINUITY I - THE PLEISTOCENE-HOLOCENE BOUNDARY

Discontinuity I is the basal unconformity of the Wyoming Valley formation, an interval of nondeposition of three to five thousand years between the last pulse of glacial meltwater and the onset of Holocene alluviation. Three radiocarbon dates from basal Holocene geological contexts have a combined 2-sigma range of 11,250-8,650 cal BP. Significant Holocene deposition probably began by 10,600 cal BP based on detailed analysis of the sections at which the thickness of Central Builders deposits can be estimated.

The last meltwater discharges into the North Branch of the Susquehanna River probably came down the Chemung River in the vicinity of Athens. A mastodon bone found in stratified sand along the Chemung near the New York state border (Coates et al., 1971) was dated to 13,320±200 BP (Y-2619), with a 2-sigma range of 16,658-14,873 cal BP. The gap or discontinuity between the age of the Chemung River mastodon bone and the base of the Central Builders member, Discontinuity I, represents at least three and perhaps as many as five thousand calendar years.

From a geomorphological perspective, each of the discontinuities in the present stratigraphic framework represents some change in channel form and the balance between stream power and sediment supply. **Figure 120** identifies hydraulic causes for Discontinuity I which are consistent with both paleoclimatic proxy data and the relatively

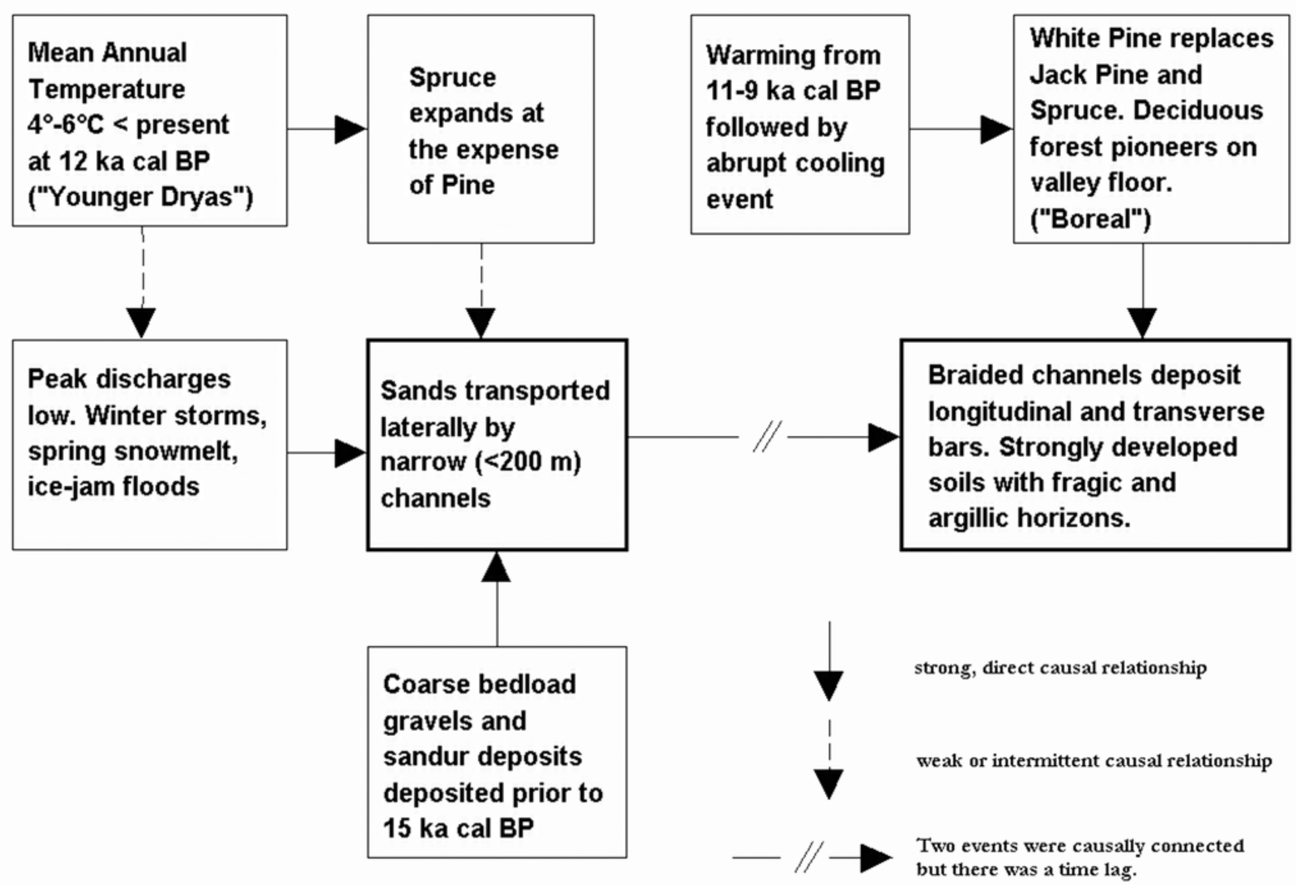


Figure 120: Causal Explanation of Discontinuity I and the Central Builders member of the Wyoming Valley formation

few exposures of the Central Builders member that have been investigated so far. Multiple channels were formed in the glacial deposits as coarse, poorly sorted sand was shifted laterally across the valley floor as well as downvalley to locations such as the Central Builders site.

Transport of coarse bedload has been found in both experimental and field studies to result in braided river channels (Ashmore, 1991; Church, 972; Rust, 1972; Schumm, 1977). As shown in my analysis of cross-sections in **Chapter 3**, however, braiding is not unique to "bedload" channels that have the planform and sedimentological characteristics specified in the Schumm model. Braiding persists in reaches of the present "mixed load" river, which transports silt and fine sand in suspension.

Because braiding is an active process which is not exclusively determined by the distribution of the relict gravels, it is important to investigate its association with the specific alluvial lithofacies in the stratigraphic record. Based upon the preservation of channel bars at the Central Builders site and elsewhere, the predominant pattern responsible for deposition of the Central Builders member of the Wyoming Valley formation is here considered to have been multi-thread, i.e. braided. This does not preclude the occurrence of floodplains and floodbasins to trap fine-textured sediment, however. These often occur in braided rivers at tributary mouths and downstream of channel bars (Brakenridge, 1988; Bridge, 1993b; Rumbsby et al., 2001). There are many good analogues for Central Builders member depositional environments in braided reaches of the modern North Branch of the Susquehanna River.

DISCONTINUITY II AND THE HEMLOCK DECLINE

The changes in regional climate and vegetation which explain Discontinuity II are presented in **Figure 121**. The discontinuity occurs immediately above the most strongly developed buried soil in the stratigraphic column, or at an unconformable contact with glacial deposits. A contact with glacial deposits was identified in the North Branch Lowland at site 36LU49 (Hayes et al., 1981) and 36LU105 (Weed and Wenstrom, 1992) and in the Wyoming Valley at the 8th Street Bridge Replacement Work Area and the Wyoming T-1 Cutbank (Schuldenrein and Thieme, 1997; Thieme and Schuldenrein, 1998). The basal contact at Upper Exeter is also presumed to represent Discontinuity II, although the section was not dated or excavated to river grade.

At Harding Flats (36WO55), Discontinuity II marks the point at which Tunkhannock Creek began to shift upstream to the northwest. The stratigraphic column in Trench A changed abruptly from a coarse gravel bed derived from the local Catskill formation sandstone and siltstone to the overbank sand and silt lithofacies most typical of the Wyoming member of the Wyoming Valley formation. The basal deposits at both Friedenshütten (36BR81) and Cass (36BR57) are here assigned to the Wyoming member as well, and Discontinuity II occurs at the base of these sections.

In twelve of the 23 sections described in Chapter 5, Discontinuity II is represented by a disconformity where the Wyoming member overlies the Central Builders member. Strongly developed buried soils with fragic or argillic horizons mark the top of the Central Builders member at the Central Builders site (36NB117), the Zehner site (36CO2), the Jacobs site (36LU90), the Skvarek site (36LU132), Scovell Island

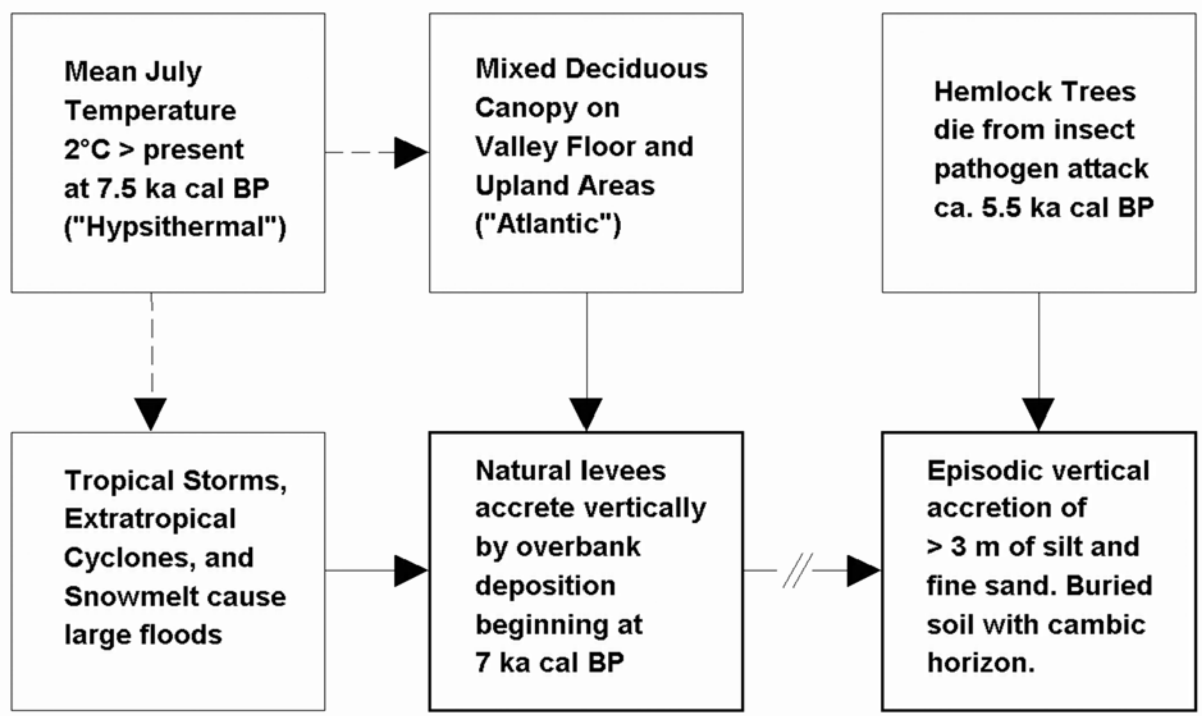


Figure 121: Causal Explanation of Discontinuity II and the Wyoming member of the Wyoming Valley formation

(36LU12), Falls Bridge (36WO56), Whites Ferry, and French Azilum (36BR134). Less soil development occurred in deposits of equivalent age at the Catawissa Bridge site (36CO2), the Mifflinville Bridge site (36CO17), the slackwater section at Wyoming, and the Cremards (36LU58) and Conrail (36LU169) sites. The most strongly developed buried soils typically occur either at the top of the channel sand lithofacies or in thin overbank deposits overlying the channel sand. Less soil development occurred in deposits of the slackwater silt and clay lithofacies.

Whereas the Central Builders member occurs in relatively isolated buried landforms with a patchy distribution on the valley floor, the Wyoming is nearly continuous over the 200 km longitudinal trace of Discontinuity II. This bolsters the argument for climatic forcing as opposed to more localized adjustments to Holocene conditions. The Discontinuity II events are inferred to be the result of the warm, wet climate during the "Atlantic" or oak (C) zone of the pollen chronology (see **Figure 121**).

Several alternative hypotheses to climatic forcing have been considered for Discontinuity II and for the other discontinuities in the allostratigraphic framework. The bedrock structure of the North Branch of the Susquehanna River valley was examined in **Chapter 3**, and it was shown that eustatic and tectonic controls fail to account for late Quaternary alluvial deposition. Vegetation change has been emphasized, but appears to have been too gradual to affect the river deposits with the exception of the Younger Dryas, the hemlock decline, and the most recent deforestation of the catchment by Euroamerican settlers.

Discontinuity II occurred during the time interval between the 9,000-8,590 cal BP age of the Central Builders member upper boundary and the 7,150-5,850 cal BP age for the base of the Wyoming member. Using only dates for sections of known stratigraphic thickness, the end of Discontinuity II is more precisely estimated at 6,790-6,660 cal BP. Based on this age estimate for the onset of Wyoming member deposition, point bars and alluvial ridges at locations such as the Wyoming T-1 cutbank and Harding Flats were already in place before the hemlock trees began to die. Prehistoric human impact is unlikely this early in the cultural sequence, although that has been inferred from botanical and geoarchaeological studies in the Little Tennessee River valley in the southeastern United States (Chapman and Shea, 1981; Delcourt et al., 1986).

Above Discontinuity II, floodplains at most of the stratified archaeological sites accreted to heights of 3-4 m above the present river grade by the time of the Terminal Archaic Period in the prehistoric cultural sequence. These deposits are here assigned to the Wyoming member of the Wyoming Valley formation. The thickness and fine sandy to silty texture of the Wyoming member probably are the result of the sediment supplied by enhanced erosion during the hemlock decline. Ecological studies by Foster and Zebryk (1993) have demonstrated that disturbance episodes in hemlock-dominated forests increase fire frequency and local sedimentation rates. Sand-sized particles of conifer charcoal are sufficiently abundant in the Wyoming member to be present in soil micromorphological thin-sections prepared in the present study.

The explanation for Discontinuity II and the overlying deposits provided by the present investigations is that several causal mechanisms were involved. Climate change produced the discontinuity where sandy beds overlie either a buried soil or glacial deposits. But without the enhanced sediment supply caused by the hemlock decline, the discontinuity would not be so well preserved and identifiable throughout the North Branch of the Susquehanna River valley.

DISCONTINUITY III AND LATE HOLOCENE COOLING EPISODES

Discontinuity III was relatively easy to trace in that it is essentially at the top of the T-1 landform of the North Branch of the Susquehanna River valley. This position within the stratigraphic architecture of the alluvial valley fills in fact shows that "internal" controls played a role in terminating the deposition of the Wyoming member. As shown by Ritter et al. (1973) in their analysis of the Faucett site (36PI13) in the Delaware River valley, T-1 surfaces in many reaches of the North Branch of the Susquehanna River valley had simply built up to an elevation where they no longer received sediment from annual flood events.

A downstream correlate of Discontinuity III occurs in the Chesapeake Bay statigraphic column (Cronin et al., 2000) where clastic sediment inputs increase abruptly during the late Holocene. Evidently the river was still transporting sediment but it was "bypassing" the reaches studied in the present investigation. In the terminology of marine sequence stratigraphy (Blum and Tornqvist, 2000; Miall, 1996; Wright and Marriott, 1993), the valley's "accomodation space" for alluvium had been been filled by the basal two members of the Wyoming Valley formation.

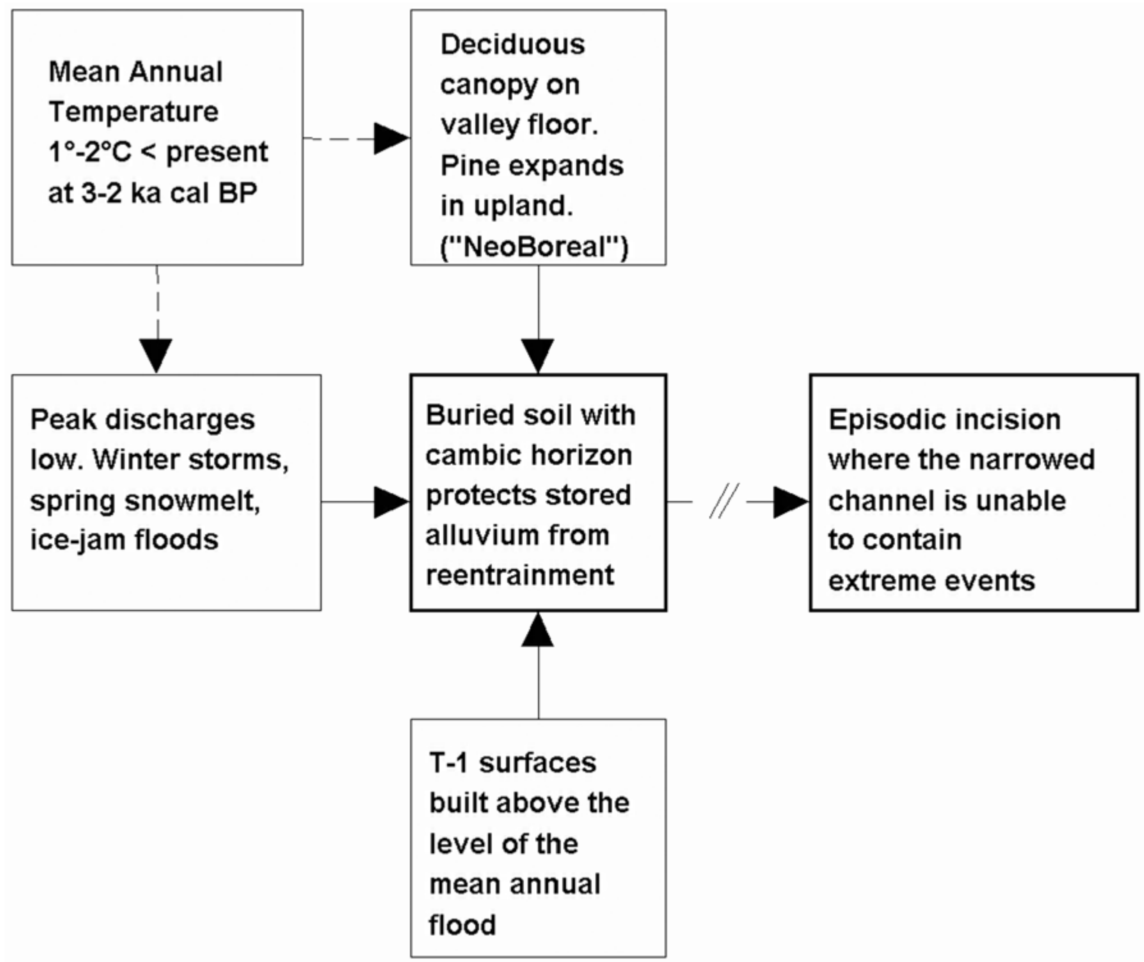


Figure 122: Causal Explanation of Discontinuity III and Late Holocene channel incision

Discontinuity III also marks the point in the valley evolution when channel cross-sections attained dimensions that resemble those of the modern river. As shown in **Chapter 3**, this means that much of the channel is entrenched and has relatively little room to meander or store sediment from year to year. Where it is not constrained by bedrock, it has been encroached on by banks of the T-1 that have accreted to heights of up to 8 m above the base of the channel. The T-1 banks are composed of material that has been made more resistant by soils that formed following Discontinuity III. Strongly developed buried soils also occur at the top of the Central Builders member, making this sediment more difficult to entrain than was the case in the wide, shallow cross-sections characteristic of the early part of the Holocene epoch.

Regional climate change may not have been needed to produce a discontinuity at the top of the T-1 landform. The specific timing of channel entrenchment and soil development on the abandoned floodplains does appear to be controlled, however, by some abrupt climate changes in the late Holocene. Abrupt cooling events at ca. 4.5 ka and 2.7 ka cal BP have been repeatedly identified in a variety of proxy records for global climate change (Bianchi and McCave, 1999; Bond et al., 1996, 1997; DeMenocal and Bond, 1997; DeMenocal et al., 2000; Magny, 1999; Marchitto et al., 1998; Meese et al., 1994; O'Brien et al., 1995; van Geel et al., 1998, 1999). The regional changes in river hydrology and alluvial landforms would have affected the distribution of plant and animal populations in the valley. They are also thought to have caused considerable subsistence stress among prehistoric cultural groups in the Northeastern forests (Fiedel, 2001; Snow, 1981).

Current reconstructions attribute the abrupt cooling events of the late Holocene to a plethora of climate mechanisms. Discharges of icebergs and meltwater into the North Atlantic have been emphasized in the present investigation and in other recent studies. Volcanic eruptions are also likely causes for abrupt cooling events, however (Bradley, 1988, 1999; Hammer, 1977; Hammer et al., 1980; Holden, 1992; Lamb, 1970; Zielinski et al., 1994, 1997). Documented historic examples include the 1992 eruption of Pinatubo in the Phillipines and the 1815 eruption of Tambora in Indonesia.

Particularly suspect as causes for cooling events which may coincide with Discontinuity III are the eruptions of Hekla on Iceland (Baillie, 1988; Grattan and Gilbertson, 1994; Holmes et al., 1999; Sigurdsson et al., 1993). The Hekla eruptions may have affected the climate as far away as the Tigris and Euphrates River valleys in the Near East (Cullen et al., 2000; Weiss et al., 1997). Possible results of these abrupt cooling events in the North Branch of the Susquehanna River valley include relatively low sediment supply and fewer floods of sufficient magnitude to overtop the T-1 surfaces. These changes might have occurred independently of the climate forcing, however, as part of the river's own internal workings.

DISCONTINUITY IV AS HUMAN IMPACT OR MEDIEVAL WARM PERIOD?

Discontinuity IV is the only one of the five discontinuities in the allostratigraphic framework which cannot be traced through most or all of the study area for this dissertation. The discontinuity occurs at the base of the Forty Fort member, identified in eleven of the 23 sections described in **Chapter 5**. Seven of these are archaeological sites in which the Forty Fort occurs in the upper 50 cm of the soil profile and contains late prehistoric cultural material. Lamellar sand and silt or stratic sand and charred organics are the most common lithofacies. The lower boundary at Discontinuity IV occurs where the Forty Fort overlies a buried soil which shows at least some development of structure or change in texture relative to the initial parent material.

The contribution of cultural refuse to the thin, dark A horizons of the Forty Fort member is tentatively indicated by laboratory results presented in **Table 15**. These same laboratory results also show, however, that extremely coarse sand lenses are present as well as massively bedded sand in beds up to a meter thick. In at least four of the sections described in **Chapter 5**, the coarse-textured Forty Fort beds occur above a deeply incised contact where large floods removed much of the soil at the top of the Wyoming member. These floods and their probable forcing by a brief, abrupt warming of the regional climate are therefore prominently featured in the causal model for Discontinuity IV presented in **Figure 123**.

There is strong evidence for abrupt climate change at Discontinuity IV in the high resolution pollen stratigraphy of Ely Lake (Gajewski et al., 1987). Jack pine (*Pinus banksiana*), beech (*Fagus*), and birch (*Betula*) decline at the expense of oak (*Quercus*) and chestnut (*Castanea*). This clearly suggests climatic warming during the interval traditionally assigned to the Medieval Warm Period (Barber, 1981; Bevan, 1993; Lamb, 1965, 1982), which is equivalent to the Neo-Atlantic period of the Blytt-Sernander pollen chronology (Sernander, 1910; Godwin, 1975, p. 455-472).

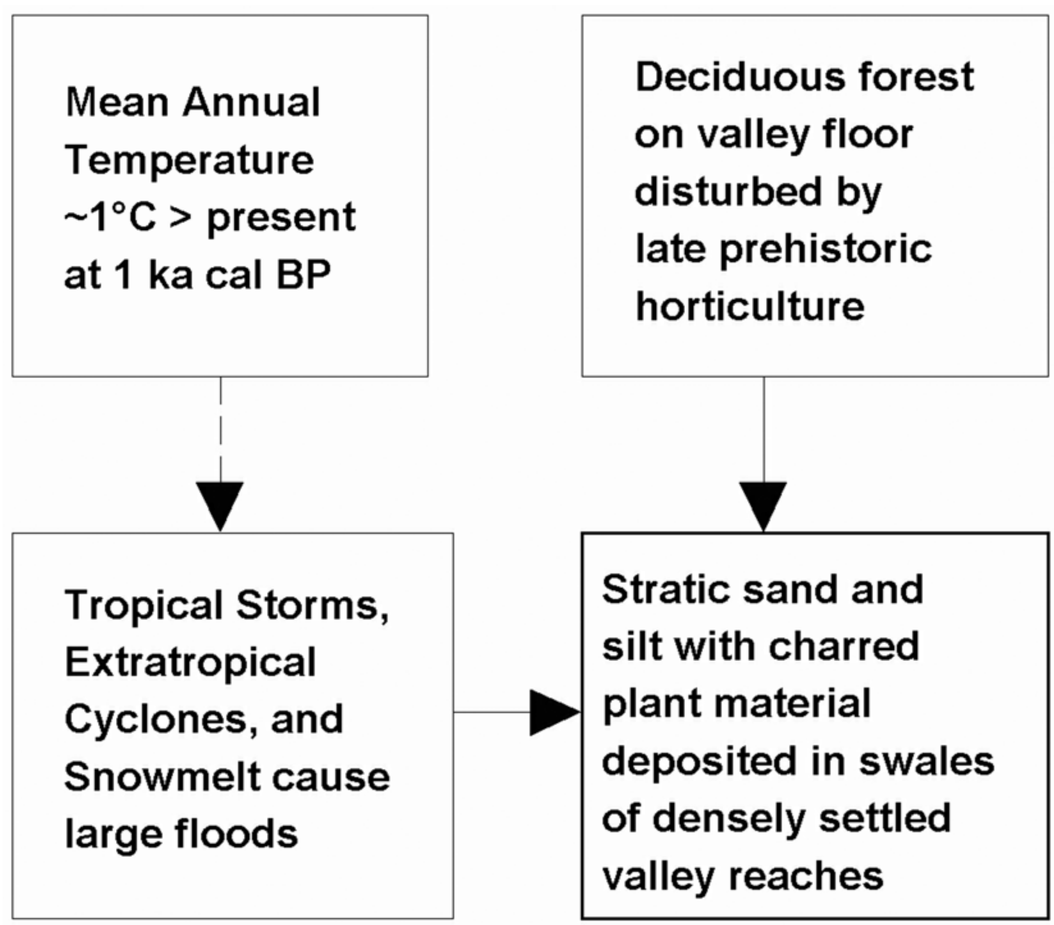


Figure 121: Causal Explanation of Discontinuity IV and the Forty Fort member of the Wyoming Valley formation

Pollen cores from Chesapeake Bay further suggest warmer and drier climate from AD 1000-1200 (Brush, 2001). Brush attributes charcoal and sediment influxes to natural forest fires, although other researchers on her team favor an anthropogenic cause (Cronon, 2001; Miller, 2001). The Medieval Warm Period appears to have been an episode of significant environmental change in the North Branch of the Susquehanna River valley, in spite of the fact that the suggested global forcing mechanisms have recently been called into question (Bradley, 1999, p. 447; Hughes and Diaz, 1994). The associated discontinuity in the alluvial stratigraphy is characterized by localized channel incision and increased additions of charred organic matter. The organic matter and other additions to the alluvial deposits may be related to intensive late prehistoric settlement in the river valley, and future geoarchaeological field and laboratory investigations should address this important paleoenvironmental problem.

EUROAMERICAN SETTLEMENT (DISCONTINUITY V)

Regional environmental changes in eastern North America following Euroamerican settlement were nearly as significant and considerably more abrupt than those which occurred at the Pleistocene/Holocene boundary. All of the pollen records show an abrupt increase in "disturbance" taxa such as ragweed (*Ambrosia*), sorrel (*Rumex*), plantain (*Plantago*), *Rubiaceae*, and Graminae (grasses). Deforestation caused an abrupt increase in sediment yield as well as an influx of woody detritus which was deposited at the base of many discrete alluvial features. Wolman (1967) has shown that sediment yields in the Susquehanna River under intensive agriculture were as high as those at semiarid gaging stations on the Langbein-Schumm curve (**Figure 118**).

Vegetation changes and erosive land use are specified as independent, primary causes for **Discontinuity V** in **Figure 124**. The causal model also suggests, however, that the regional climate may have been considerably colder during the first century or so of Euroamerican settlement. This is supported by regional pollen cores (Brush, 2001; Gajewski etal. 1987) and dendroclimatic reconstructions (Cook et al., 1998; Cullen et al., 2001; Mann, 2000) as well as by proxy records for global climate change such as ice cores from the Peruvian Andes (Thompson et al., 1987??; 1995) and marine sediments from the Atlantic Ocean (Keigwin, 1996).

Although cooler intervals were typically drier with fewer large floods, specific types of flooding during the end of the Little Ice Age have been recorded on the North Branch of the Susquehanna River because of their impact on the construction of the North Branch Canal (**Table 6**). In addition to the icejams of 1832 and 1864-65, there were several spring freshets and at least one late fall event. The recent Chesapeake Bay study (Cronin et al., 2000) also indicates periods of greater than average discharge and rainfall characterized by an abundance of foraminifera such as *Ammobaculites* which are toleratnt of lower salinity.

The most tangible causes of the deposition of the Nanticoke member are the anthracite mining activities in the Wyoming Valley and the modification of the river's course so that the coal could be transported along the North Branch Canal. Nanticoke member deposits have been identified in the present investigations where they were

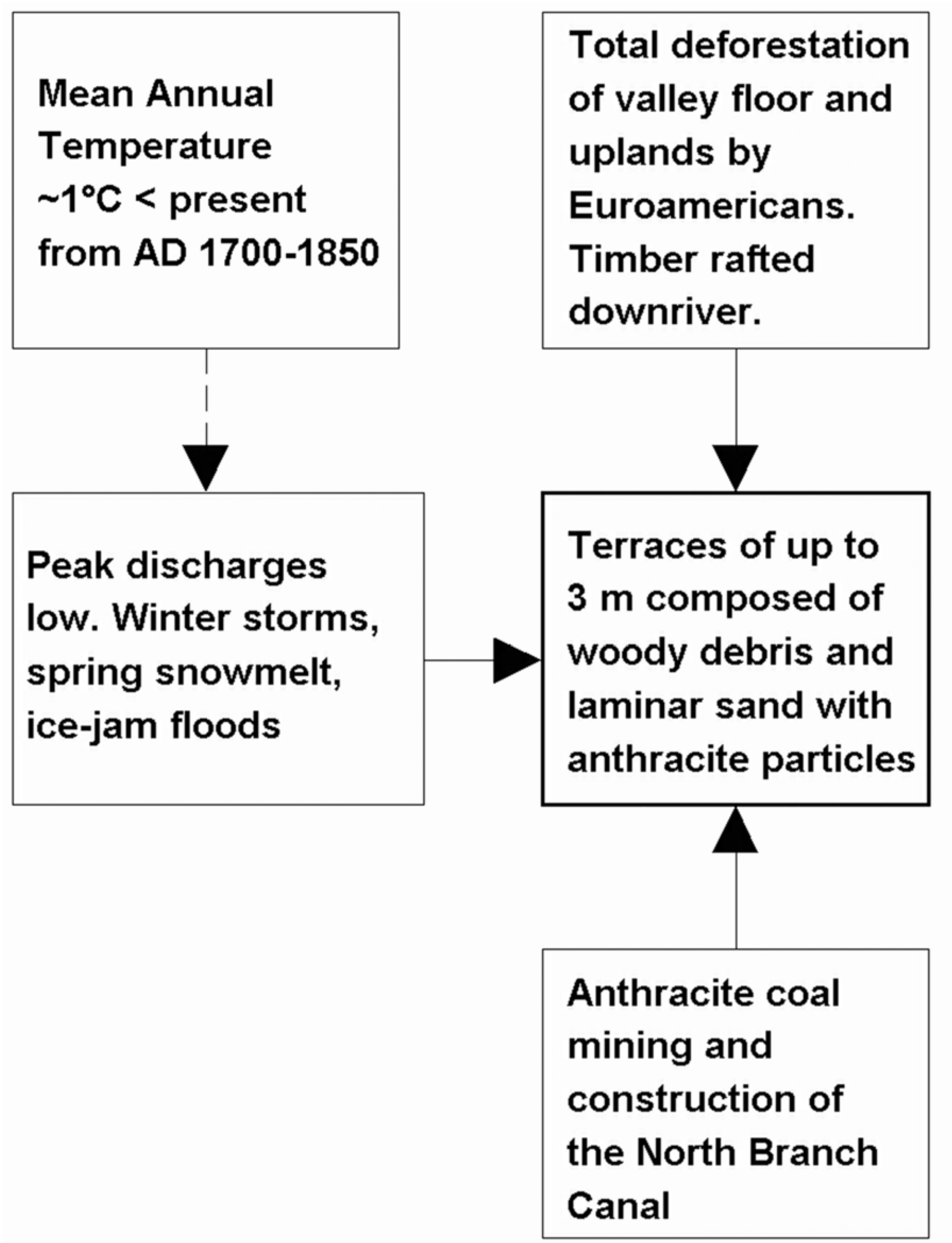


Figure 124: Causal Explanation of Discontinuity V and the Nanticoke member of the Wyoming Valley formation

found in contact with the other members of the Wyoming Valley formation. Many of the stratigraphic details have been left unexplored, however.

CONCLUSION: BOUNDING SURFACES AND ENVIRONMENTAL CHANGE

All five of the discontinuities in the Wyoming Valley formation were apparently caused by changes in the regional climate and vegetation of northeastern Pennsylvania which are indicated in independent proxy records. Bounding surfaces used to define allostratigraphic units should by definition represent allogenic, "external" forcing as opposed to random, "internal" adjustments of a depositional system. There may not always be a one-to-one correspondence between cause and effect, however. Several environmental changes acted simultaneously to produce Discontinuity II at the base of the Wyoming member, for example, as well as Discontinuity IV at the base of the Forty Fort member. Cause and effect can also vary considerably in both spatial and temporal scale, and most river deposits show some effects of the river's own internal workings.

The causes for bounding discontinuities will in many cases will include abrupt tectonic events or eustatic sea level fluctuations. Although uplift is occurring in the Appalachian mountains, there is no independent geological evidence for episodes during the Holocene epoch which could have formed terraces in river valleys (Gardner, 1989; Pazzaglia et al., 1998). Postglacial sea level rise has drowned the lower reaches of the Susquehanna River, forming the Chesapeake Bay (Colman and Mixon, 1988; Colman et al., 1990; Mixon, 1985; Poag, 1985). Sea level changes only affect the river base level as far upstream as Conewango Falls, however. At that point, a vertical drop of 30 m occurs where the river enters a bedrock gorge. As opposed to tectonic or eustatic forcing, proxy records indicate that regional changes in annual or seasonal temperature coincided with several of the discontinuities in the present stratigraphic framework. Abrupt cooling events at 9 ka, 4.5 ka, and 2.7 ka cal BP, in particular, are represented by "bounding surfaces" beneath which soils began forming.

Abrupt changes in vegetation also appear to have affected river discharge and sediment supply. The Younger Dryas, the hemlock decline, and the most recent deforestation of the catchment by Euroamerican settlers all appear to be significant causes of changing rates and patterns of alluvial deposition in the present study area within the forested Northeast. On the other hand, the gradual changes in the forest canopy associated with postglacial warming do not appear to have had much effect on the alluvial stratigraphy. The results of the present dissertation thus build on rather than contradict the conclusions drawn by Knox (1983) in his comparison of North Amerian alluvial chronologies.

The allostratigraphic approach of the present study has much to recommend it for three-dimensional mapping of river deposits. There are immediate benefits when applying the geology to archaeological studies, since it becomes possible to predict the age and lithofacies of deeply buried alluvium. The more conservative lithostratigraphic approach which has been taken heretofore would not have identified the buried soils and lithofacies associated with the prehistoric occupations.

Although the causative role of many of the regional environmental changes shown in **Figures 120-124** has been proposed by some previous researchers (Brakenridge et al., 1988; Kirkland and Funk, 1979; Ritter et al., 1973; Scully and Arnold, 1981; Vento and Rollins, 1989), the present study represents the first attempt to subdivide the Susquehanna River alluvial deposits into members which represent responses to specific allogenic forcing factors. The stratigraphy described for 23 profiles spanning over 200 km along the downstream river axis supports the hypothesis that regional discontinuities occur. The proxy records summarized in the present, concluding chapter support the hypothesis that these discontinuities represent responses to regional changes in climate, vegetation, and land use. Causal models for the relative importance of these forcing factors and their interactions have also been presented as explanations for each of the individual discontinuities.

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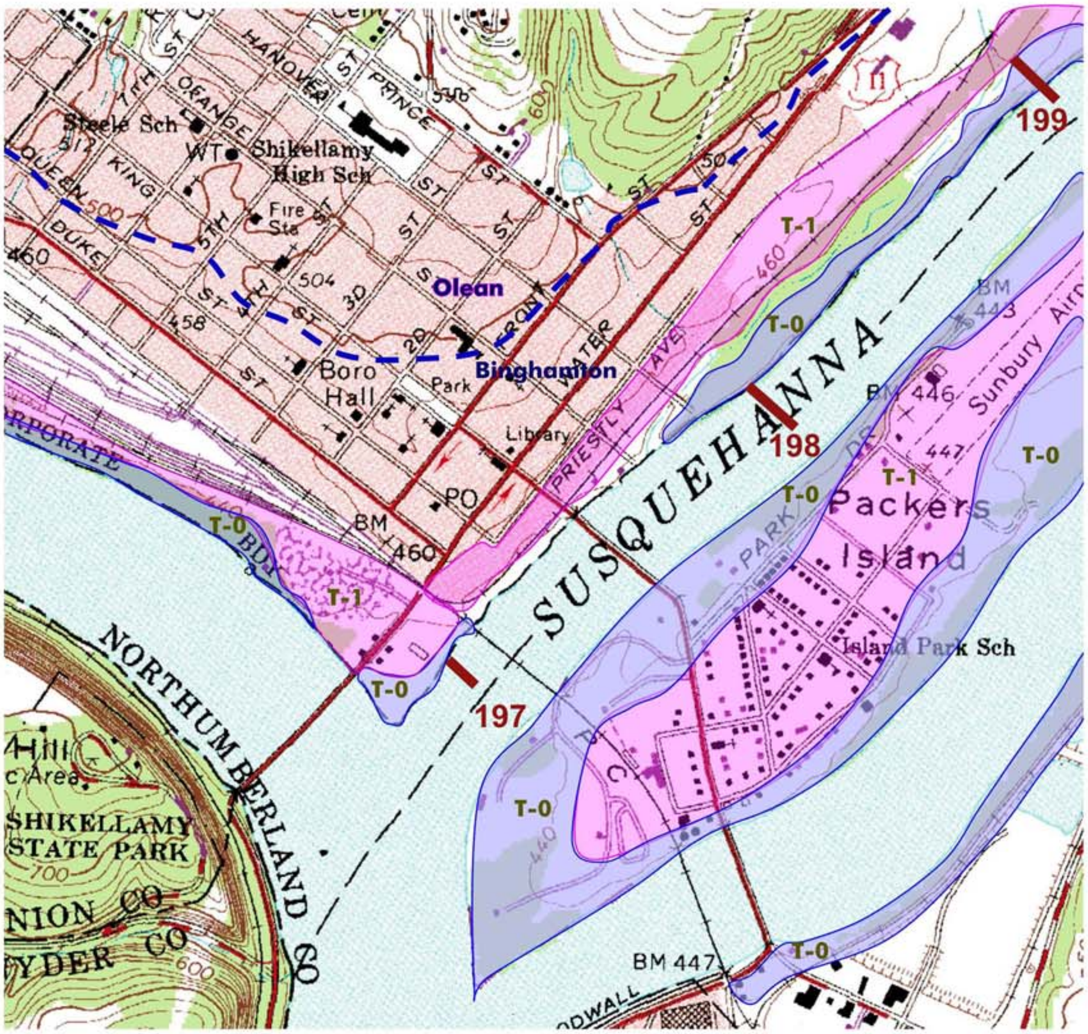
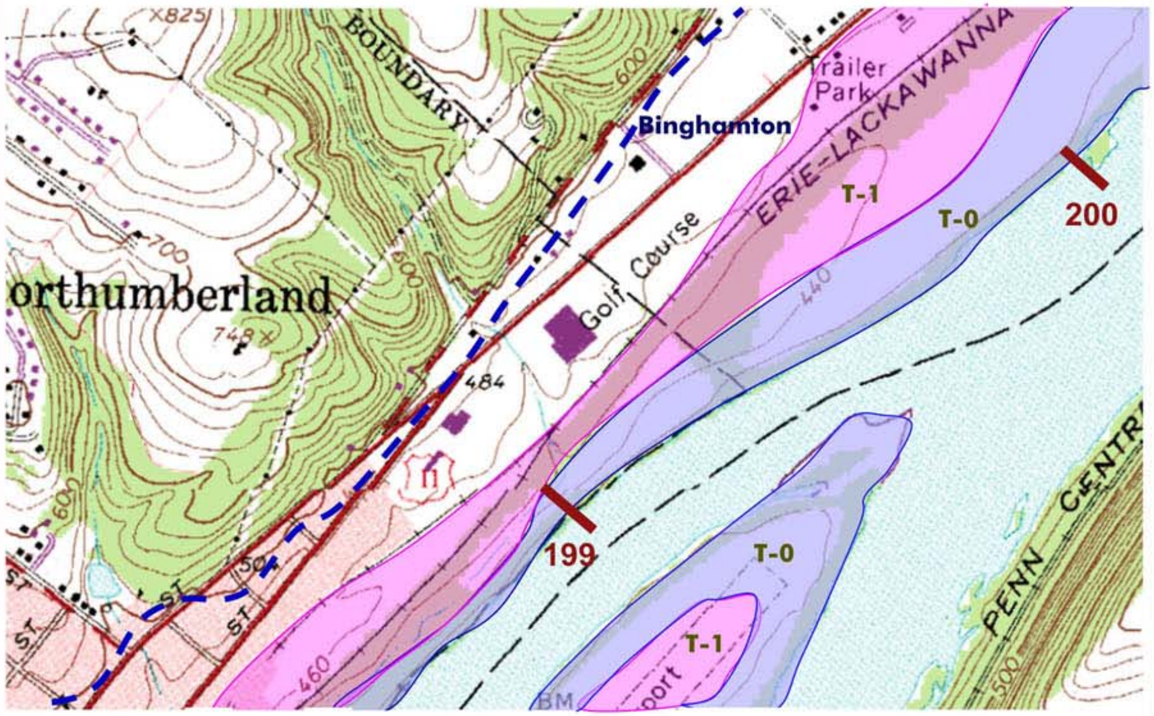
APPENDIX 1

TOPOGRAPHIC QUADRANGLE MAPS

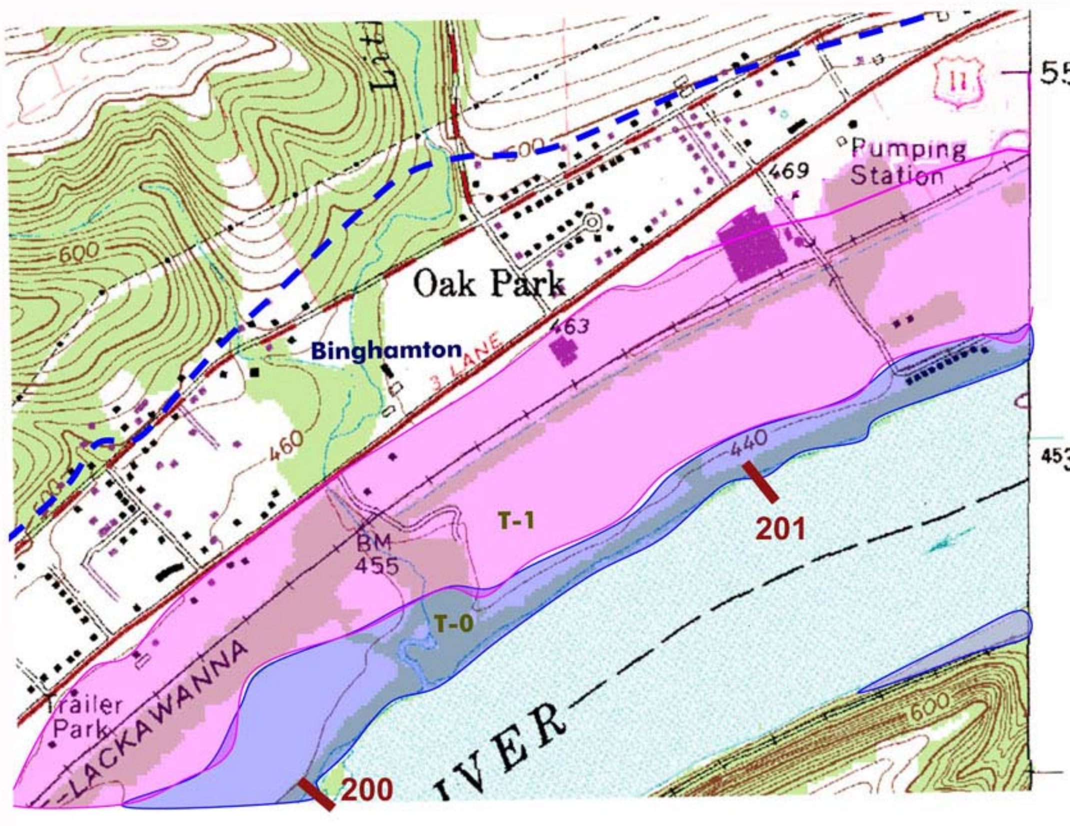
Each of the following maps shows the terrace (T-1) and the active floodplain (T-0). The maps span the reaches from Northumberland (km 197) upstream to Sayre (km 452), a total of 245 kilometers. The deposits beneath the T-0 and T-1 surfaces together comprise the Wyoming Valley formation as detailed in **Chapter 5**.



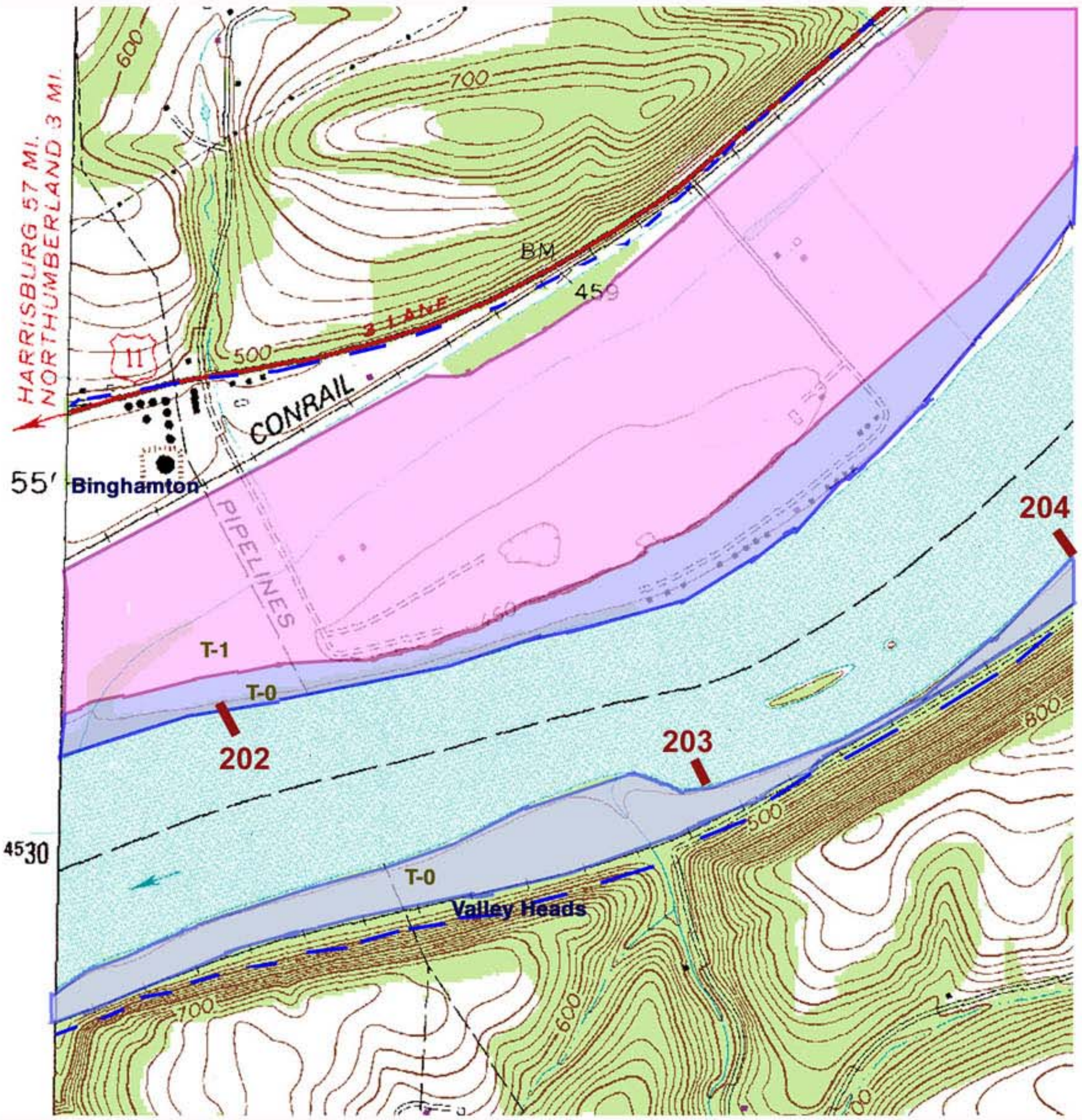
Appendix 1-1: Northumberland quad, kilometers 197-200



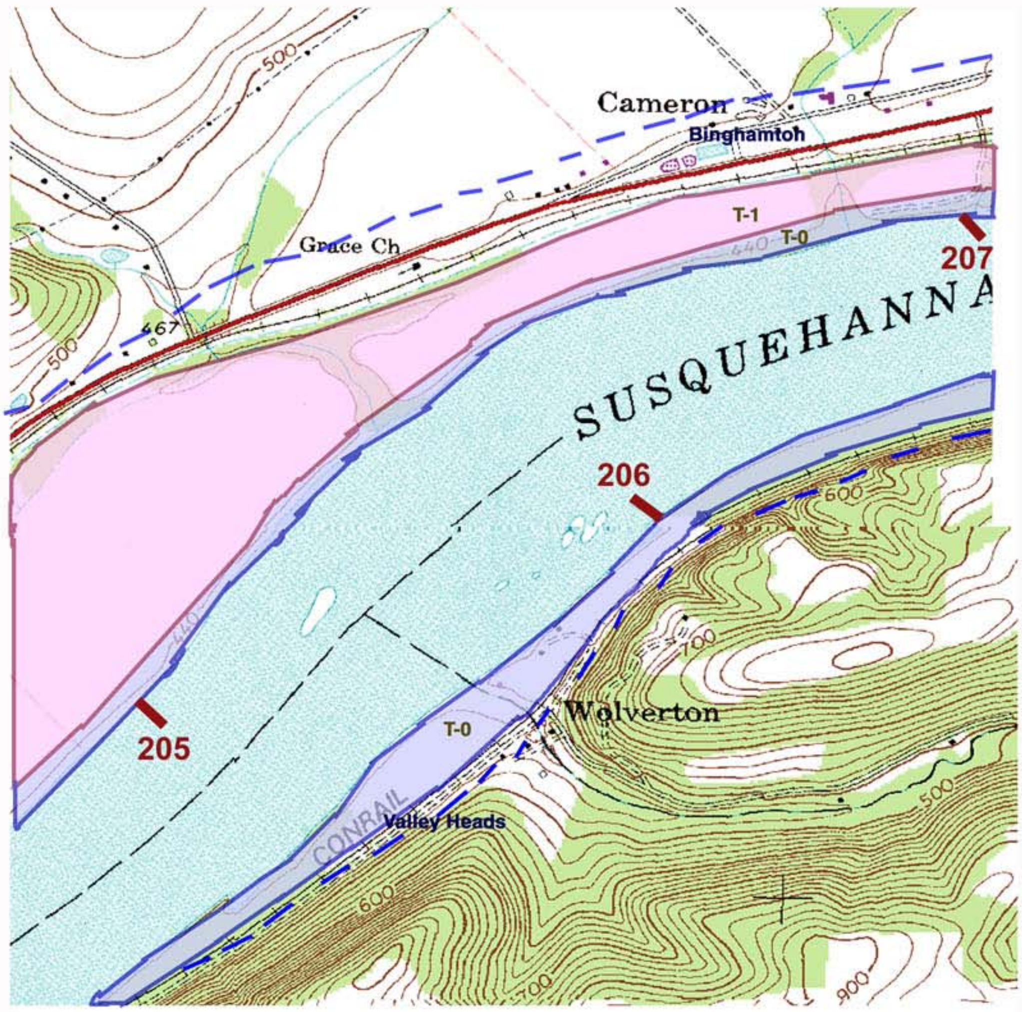
Appendix 1-2: Northumberland quad, kilometers 198-200



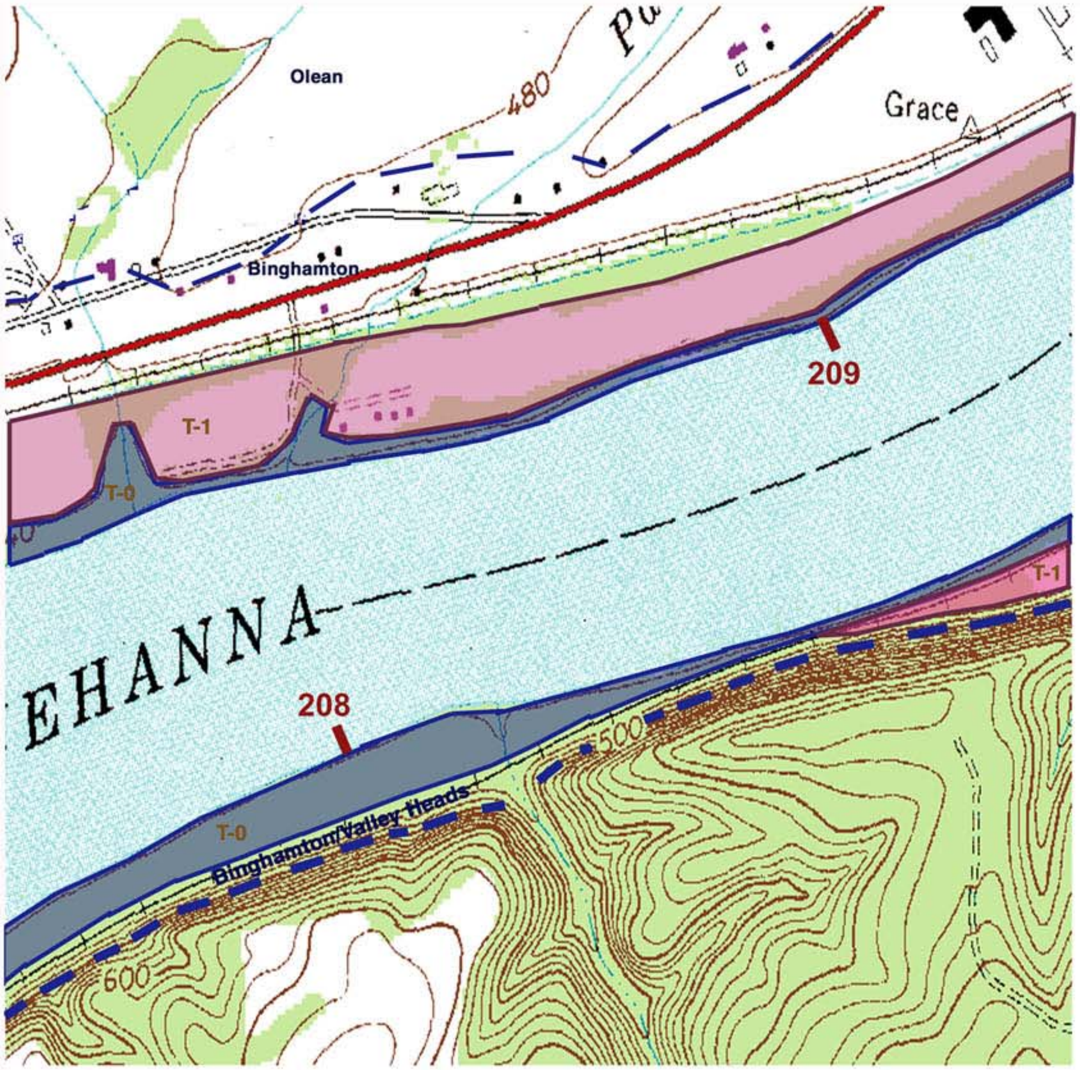
Appendix 1-3: Northumberland quad, kilometers 200-202



Appendix 1-4: Riverside quad, kilometers 202-204



Appendix 1-5: Riverside quad, kilometers 204-207



Appendix 1-6: Riverside quad, kilometers 207-210

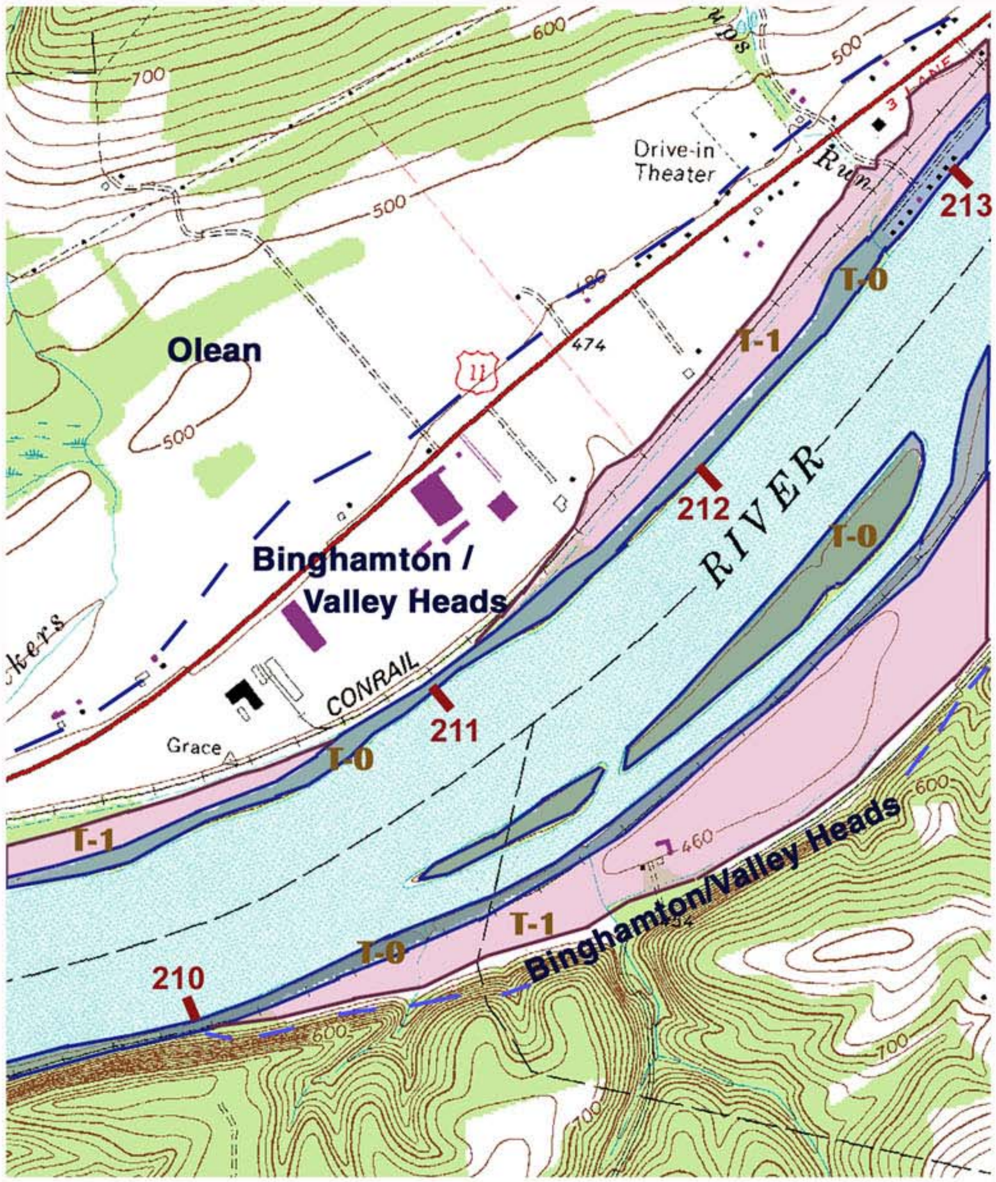
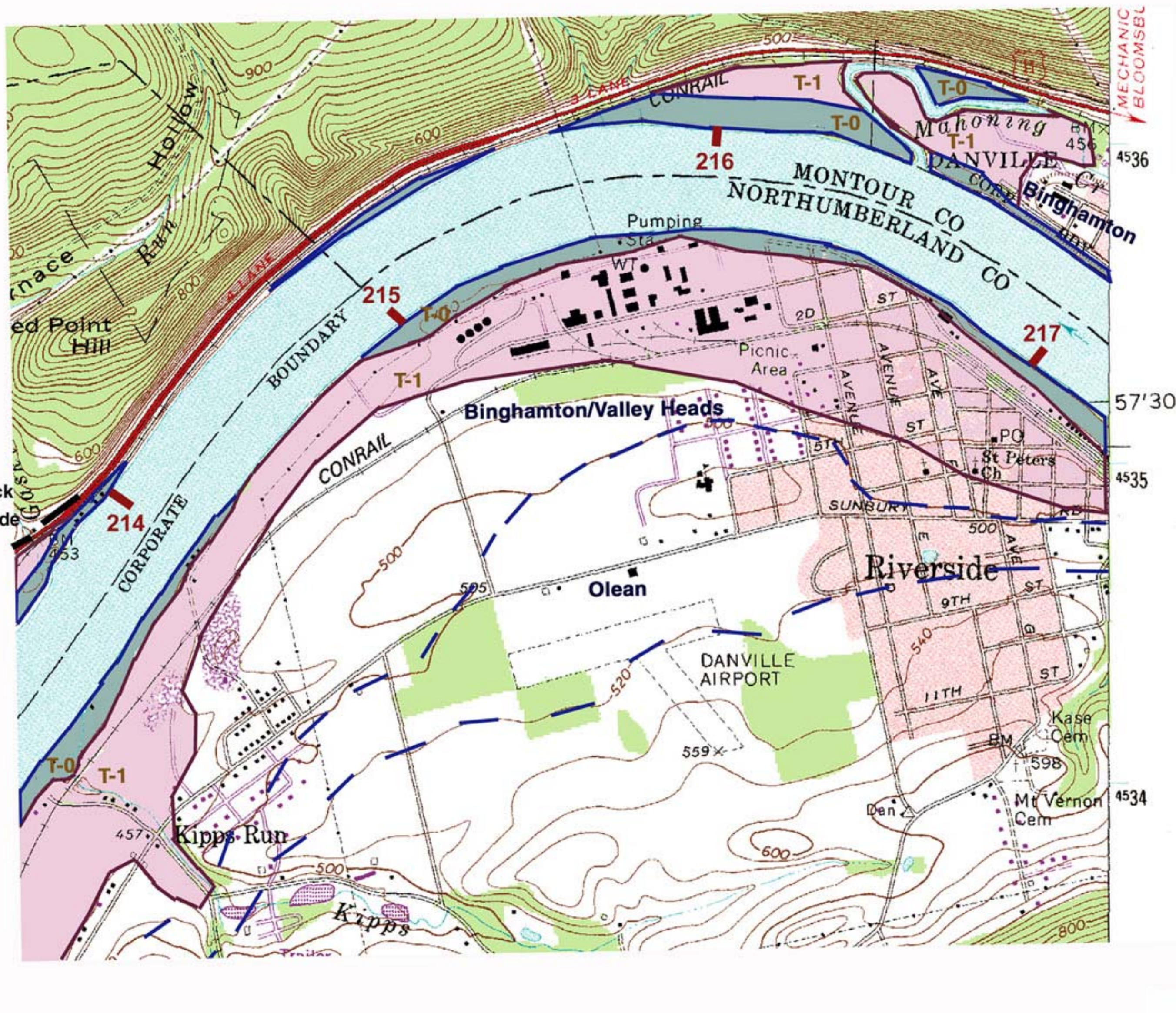
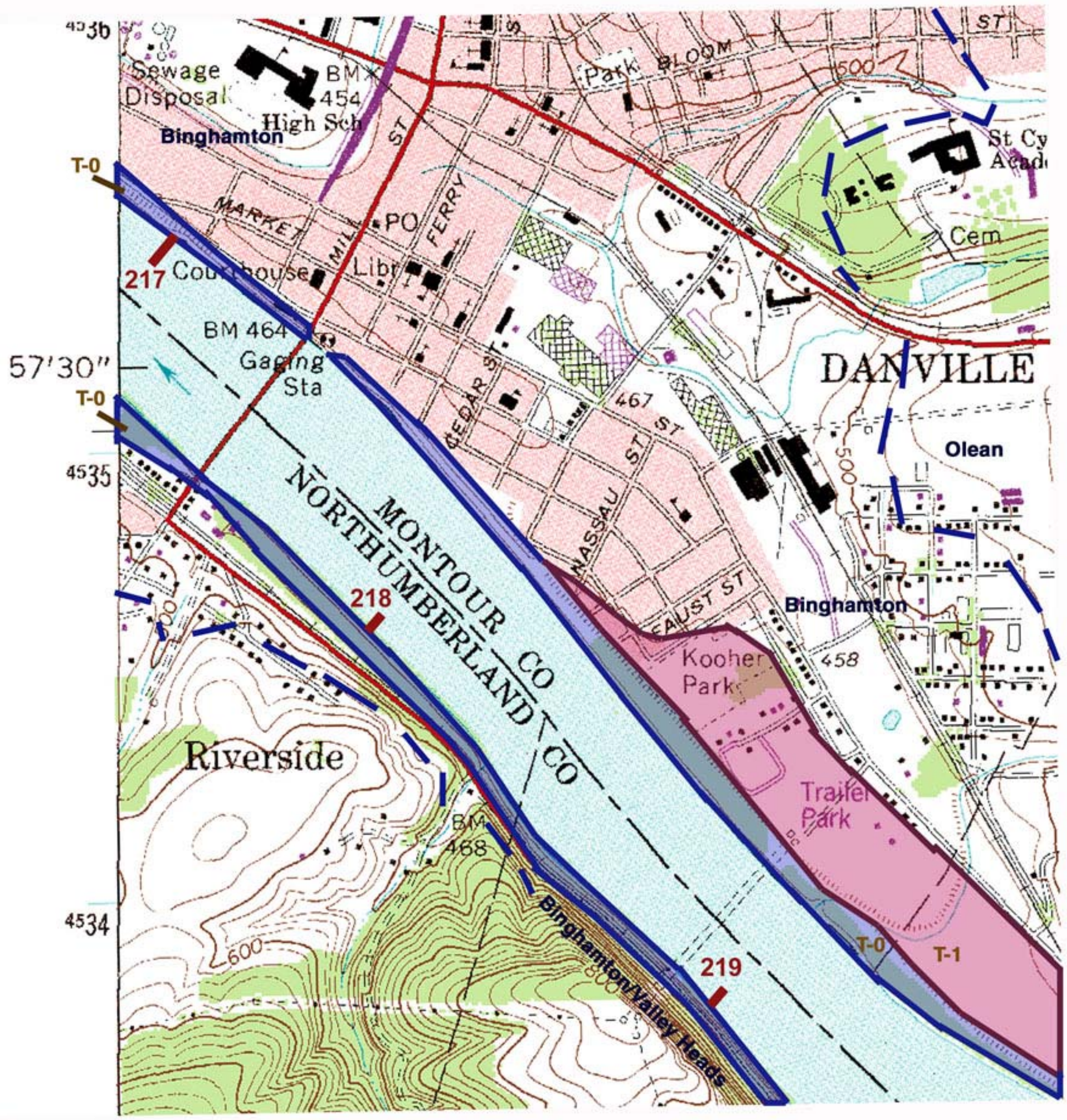


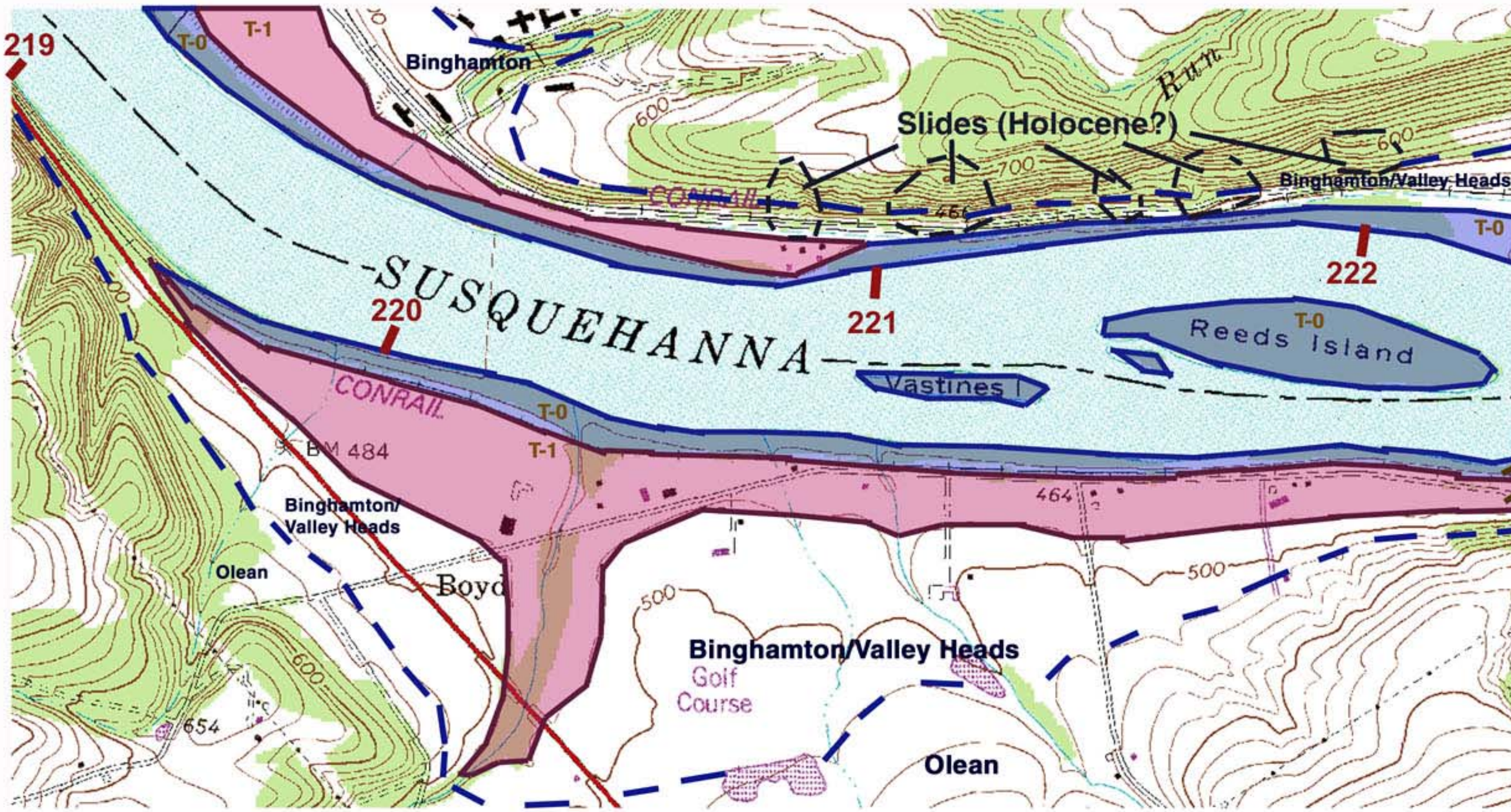
Figure 1-7: Riverside quad, kilometers 210-213



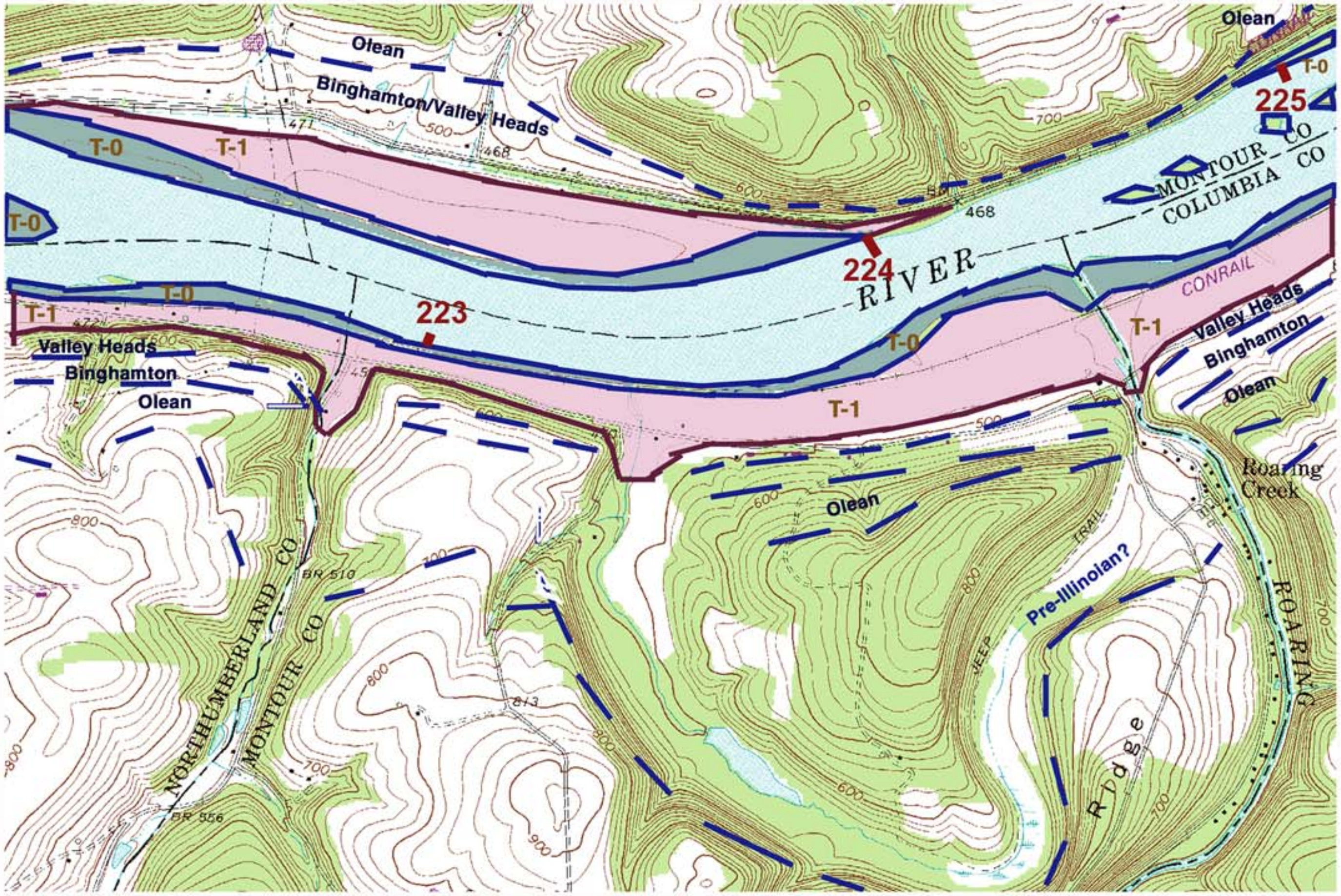
Appendix 1-8: Riverside quad, kilometers 213-217



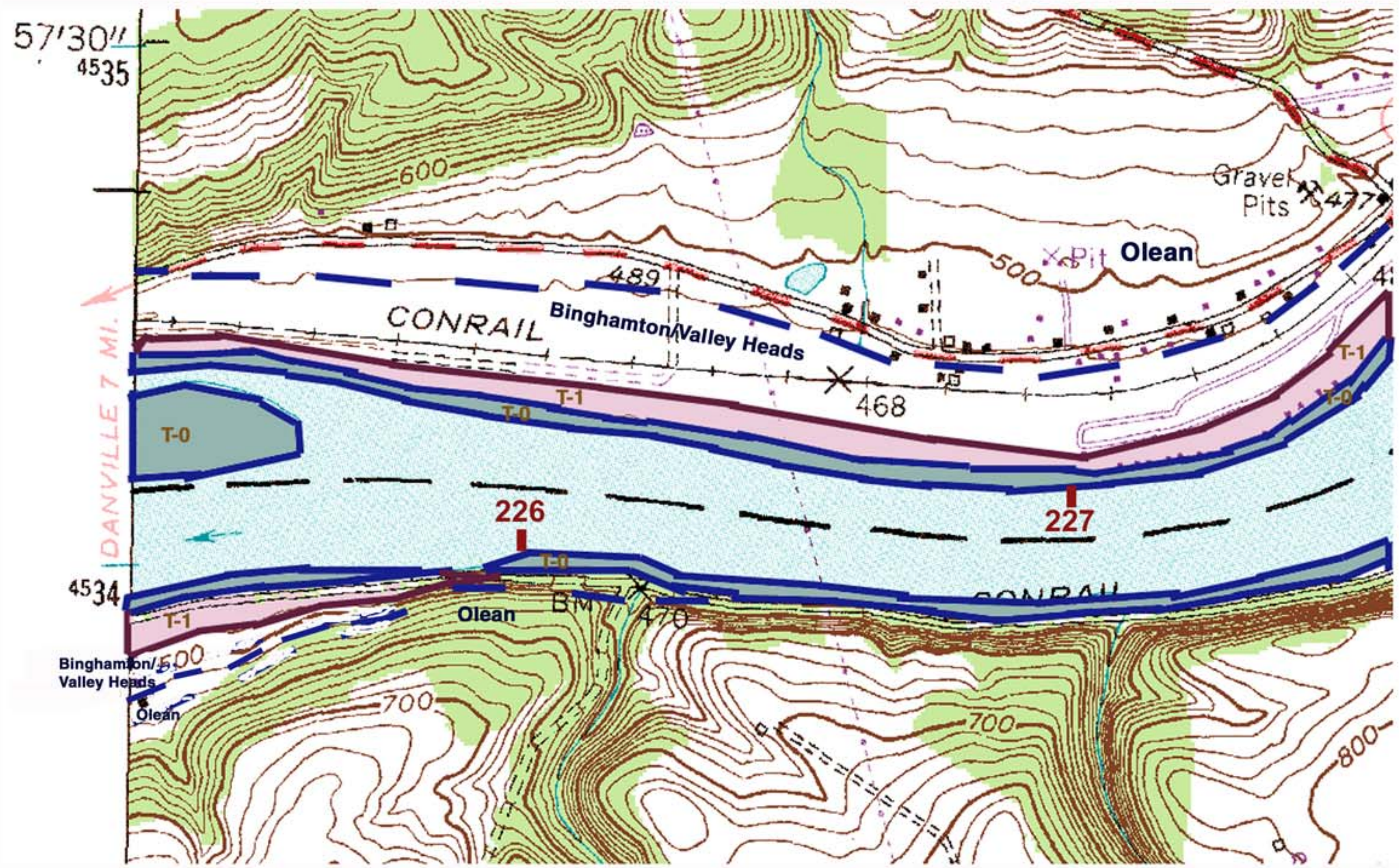
Appendix 1-9: Danville quad, kilometers 217-219



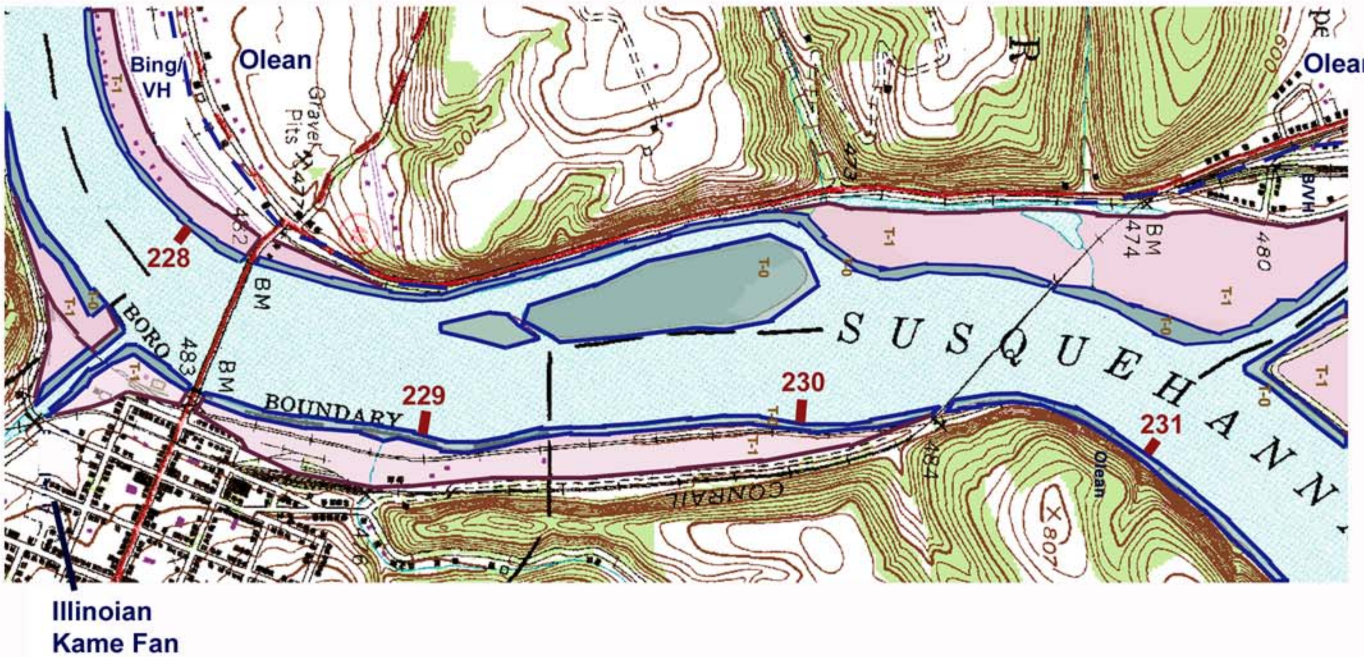
Appendix 1-10: Danville quad, kilometers 210-222



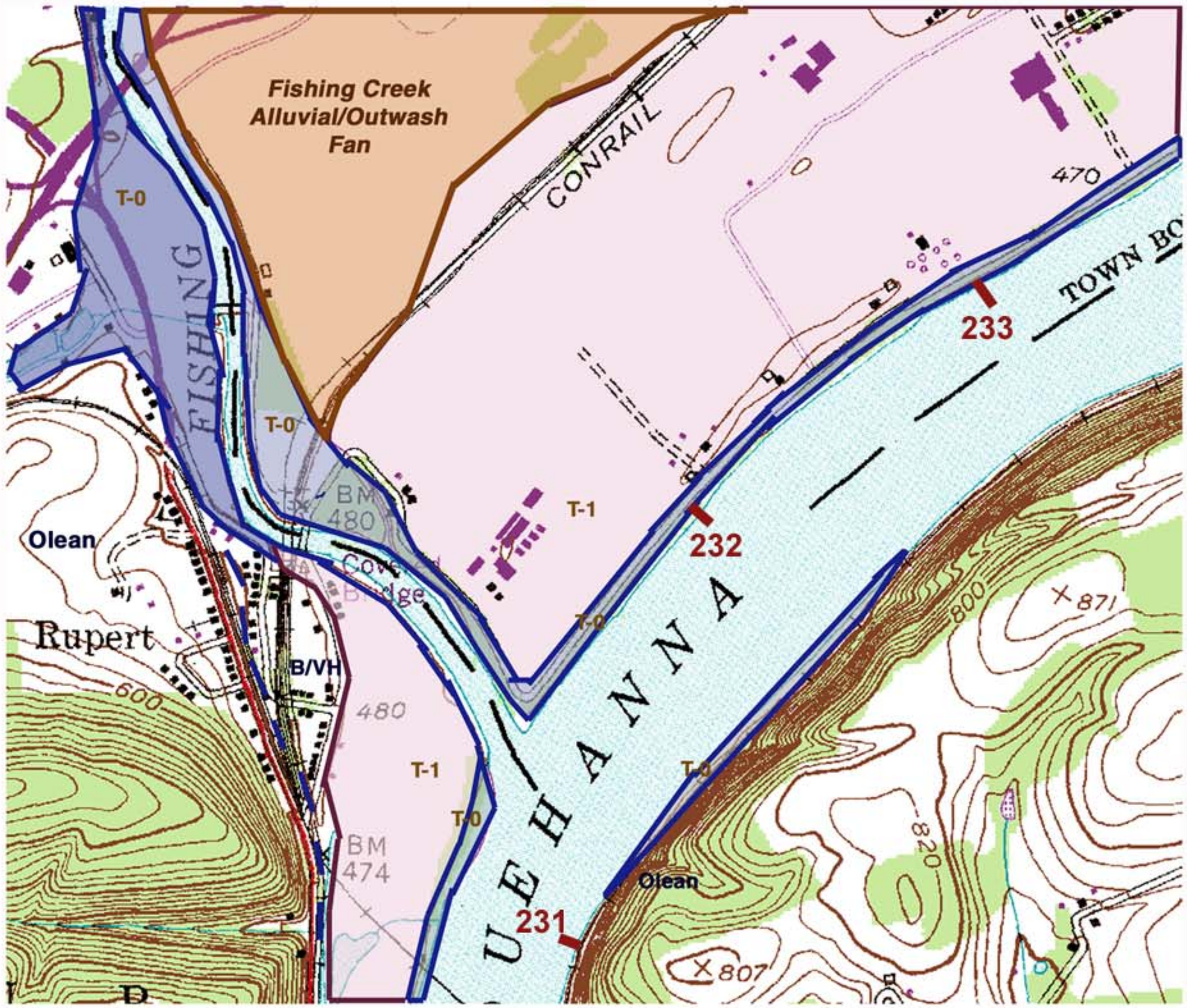
Appendix 1-11: Danville quad, kilometers 222-225



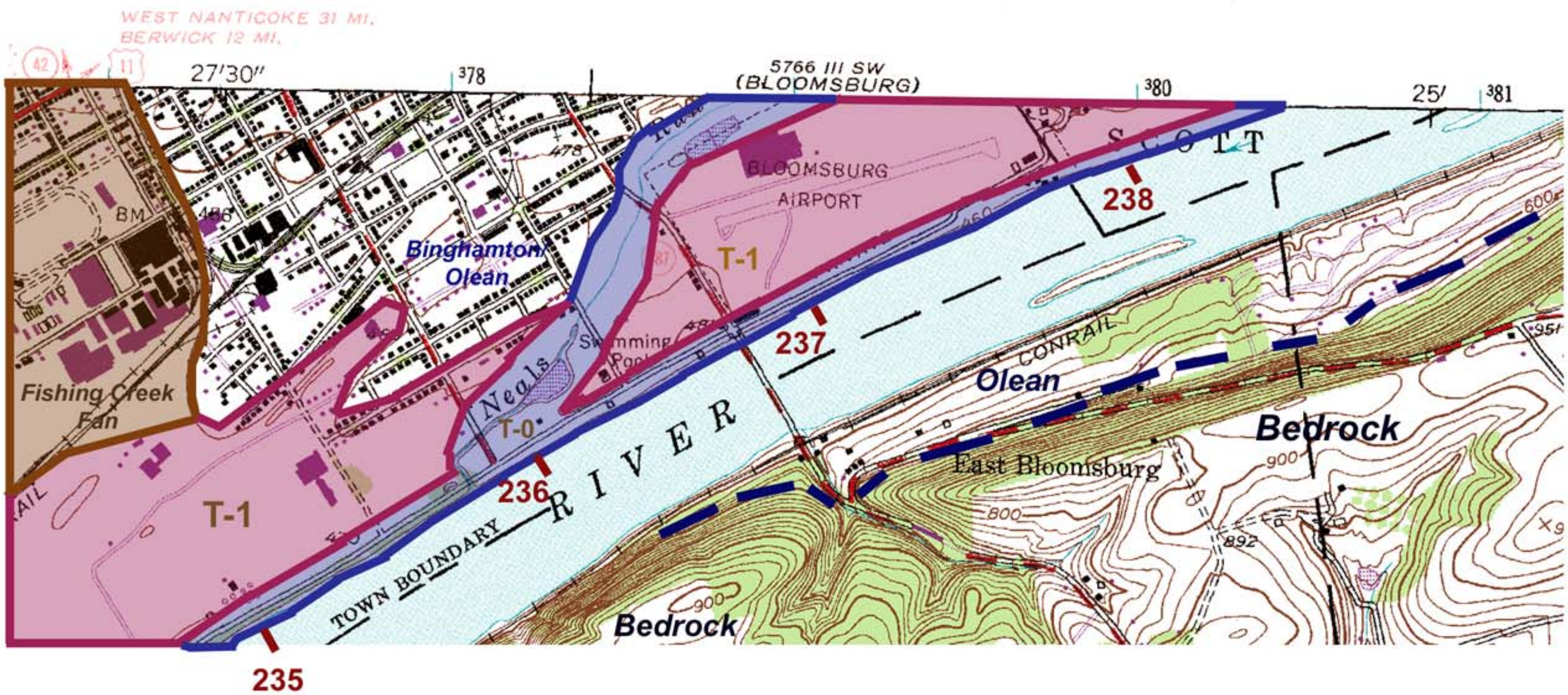
Appendix 1-12: Catawissa quad, kilometers 225-228



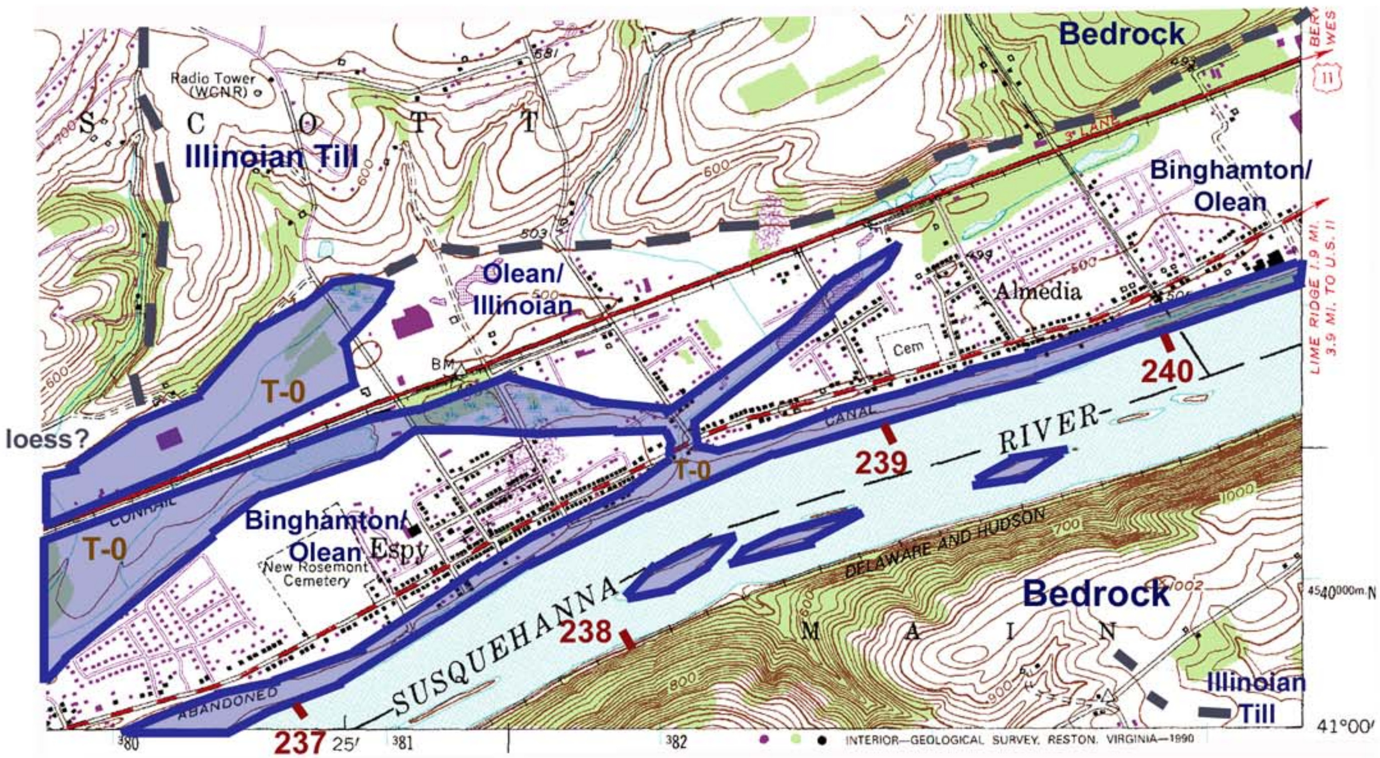
Appendix 1-13: Catawissa quad, kilometers 228-231



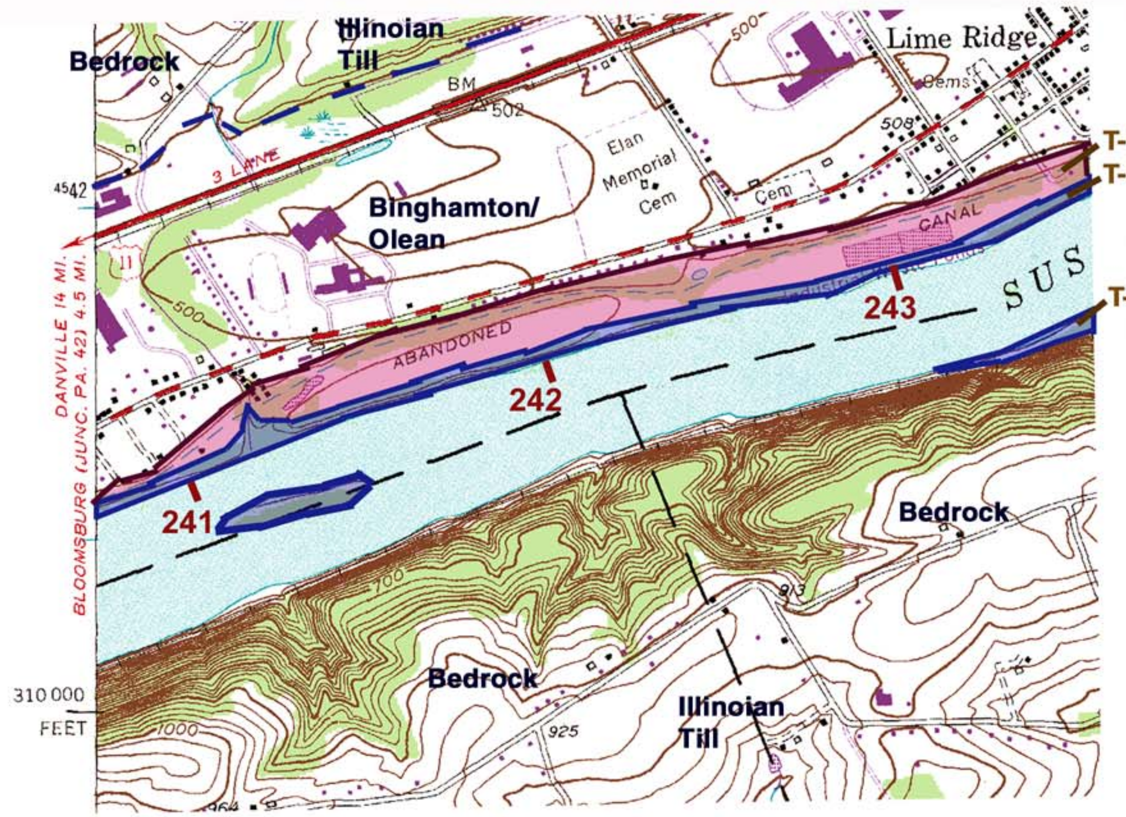
Appendix 1-14: Bloomsburg quad, kilometers 231-233



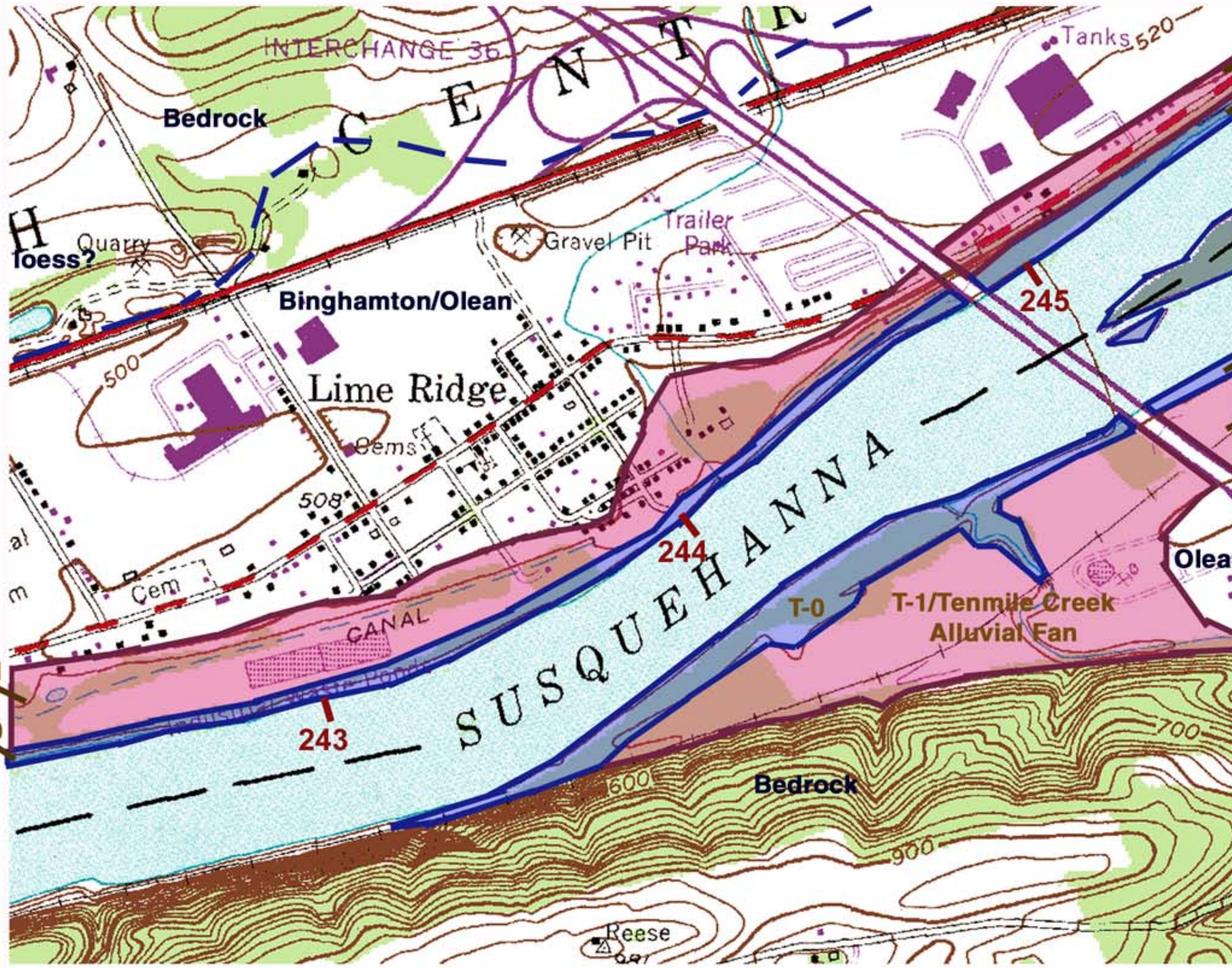
Appendix 1-15: Bloomsburg quad, kilometers 233-236



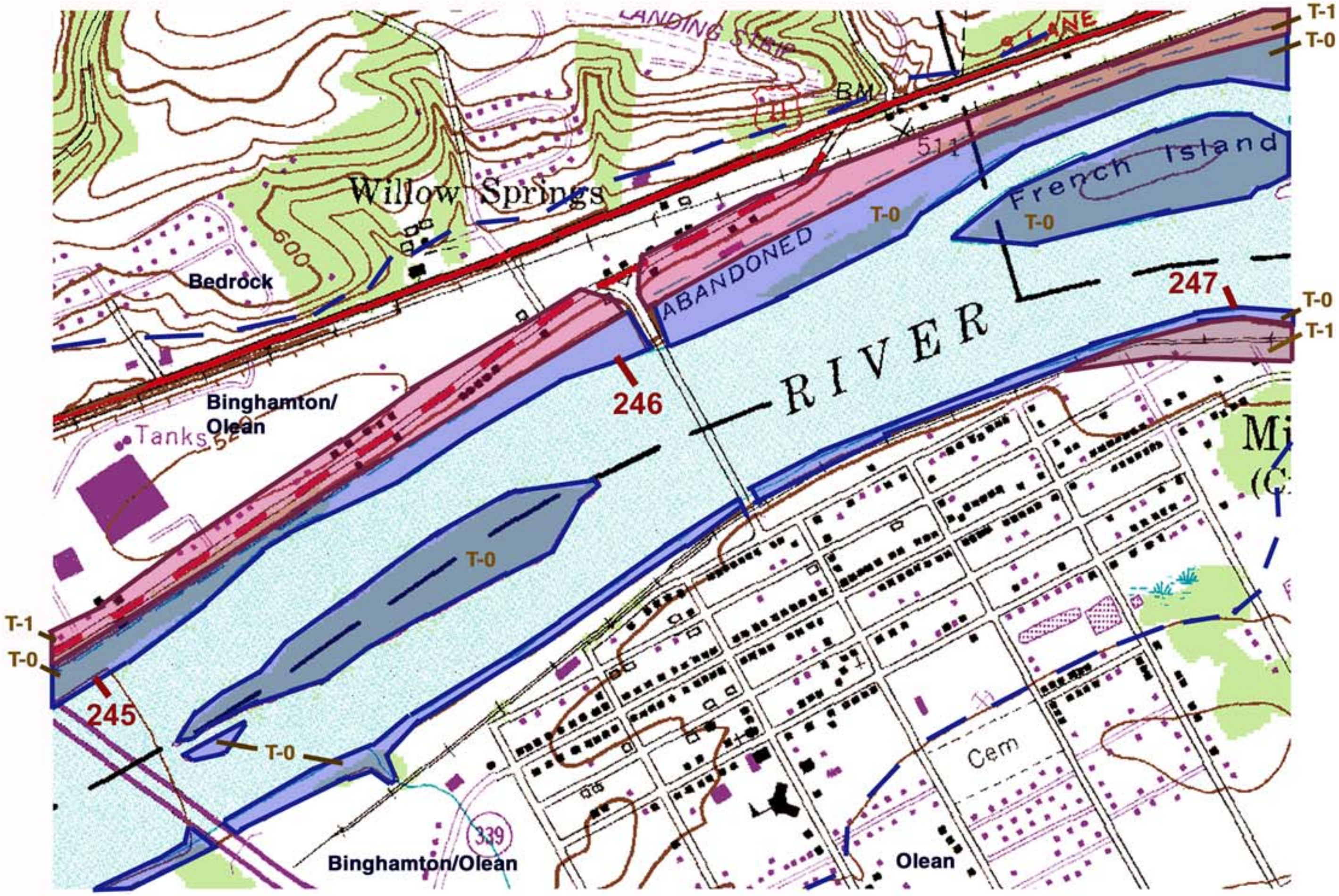
Appendix 1-16: Bloomsburg quad, kilometers 237-240



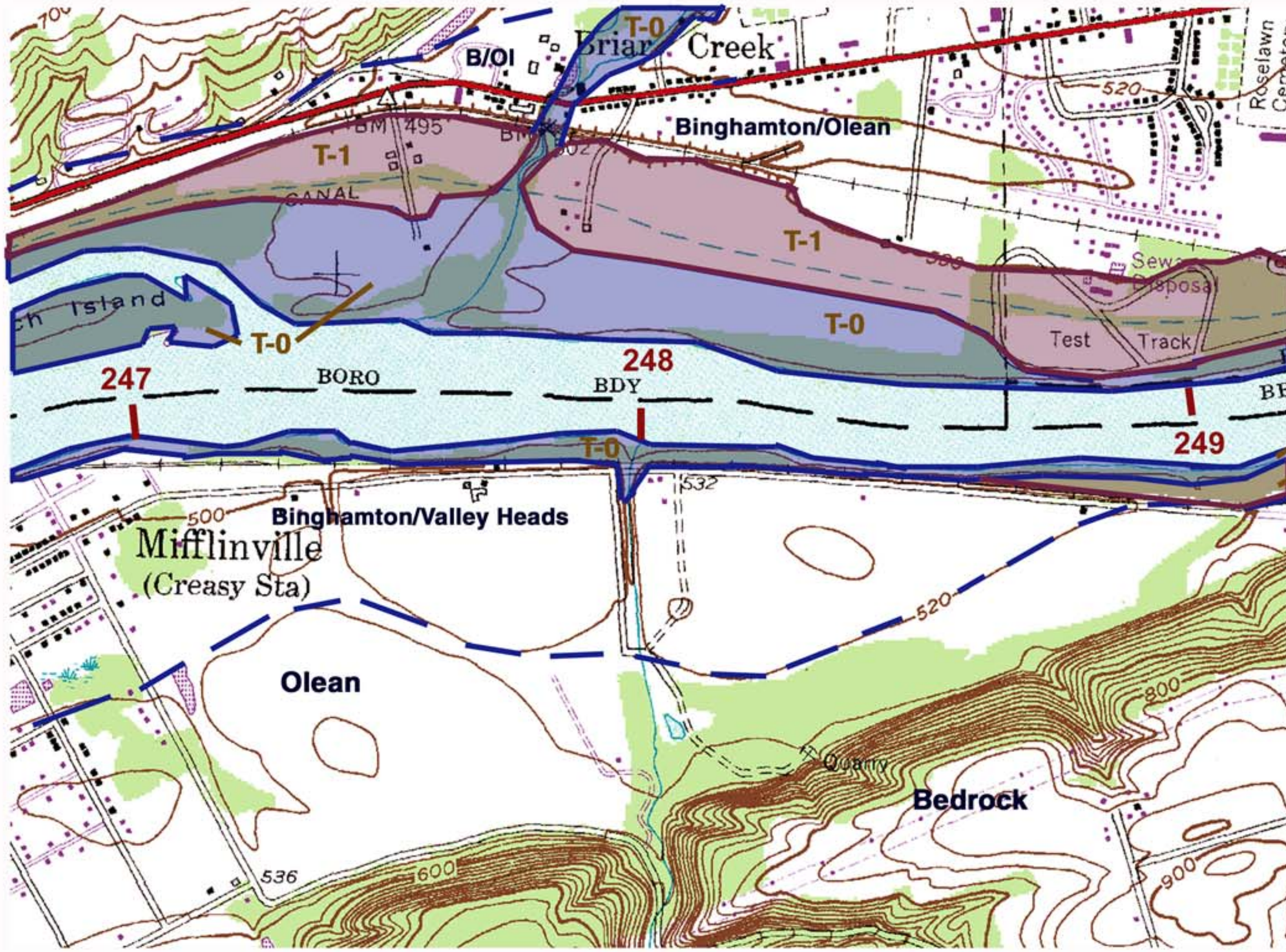
Appendix 1-17: Mifflinville quad, kilometers 241-243



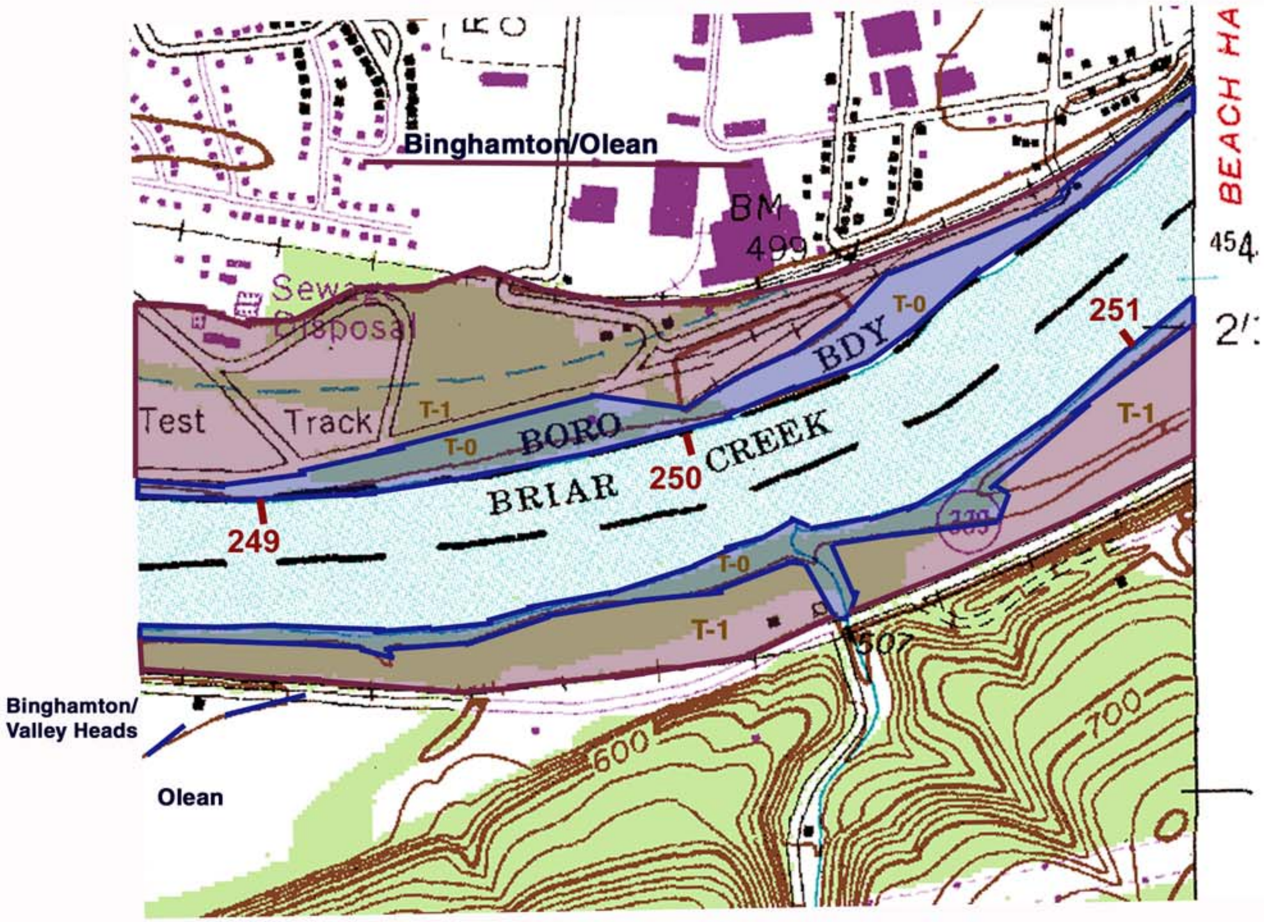
Appendix 1-18: Mifflinville quad, kilometers 243-246



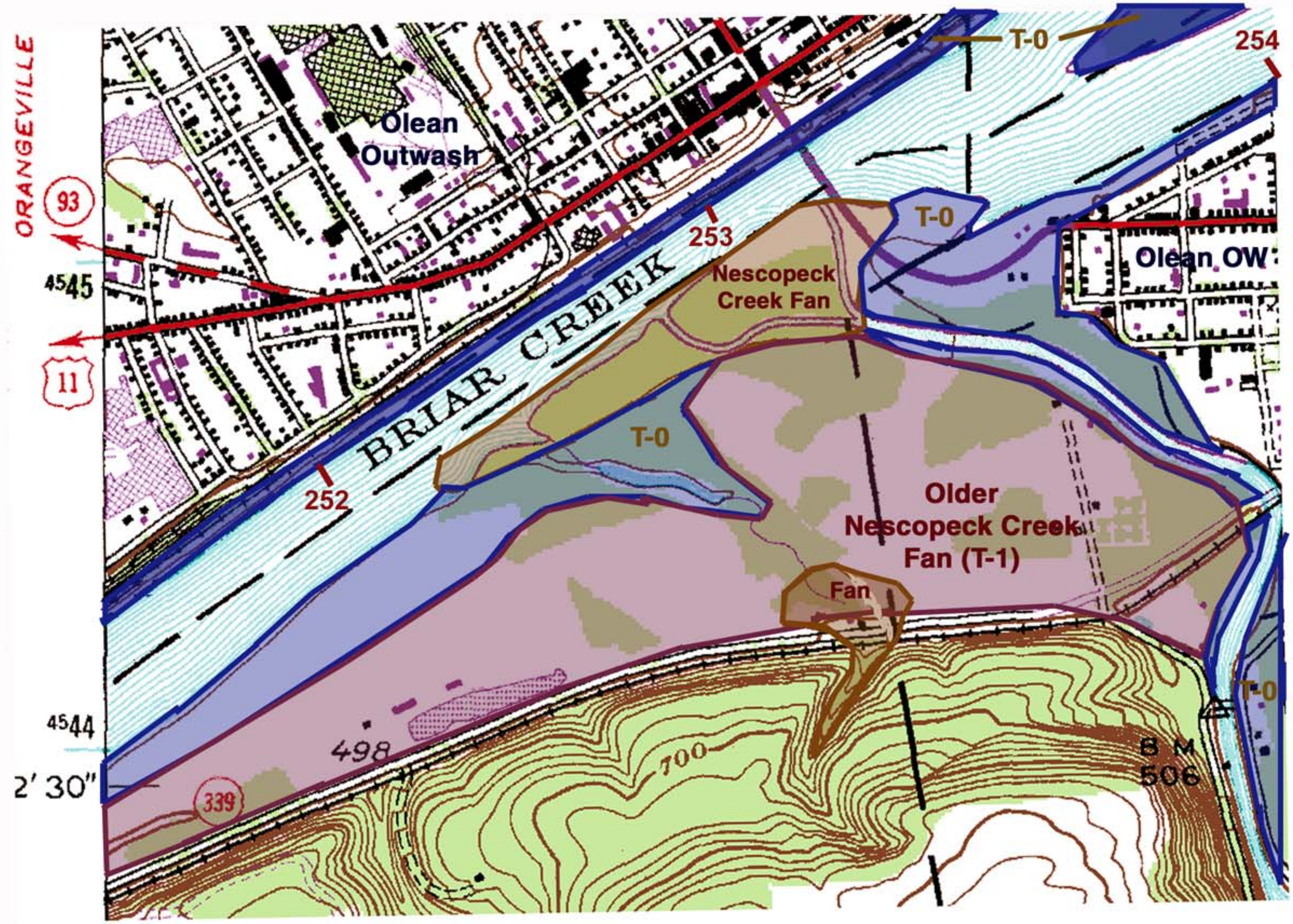
Appendix 1-19: Mifflinville quad, kilometers 245-247



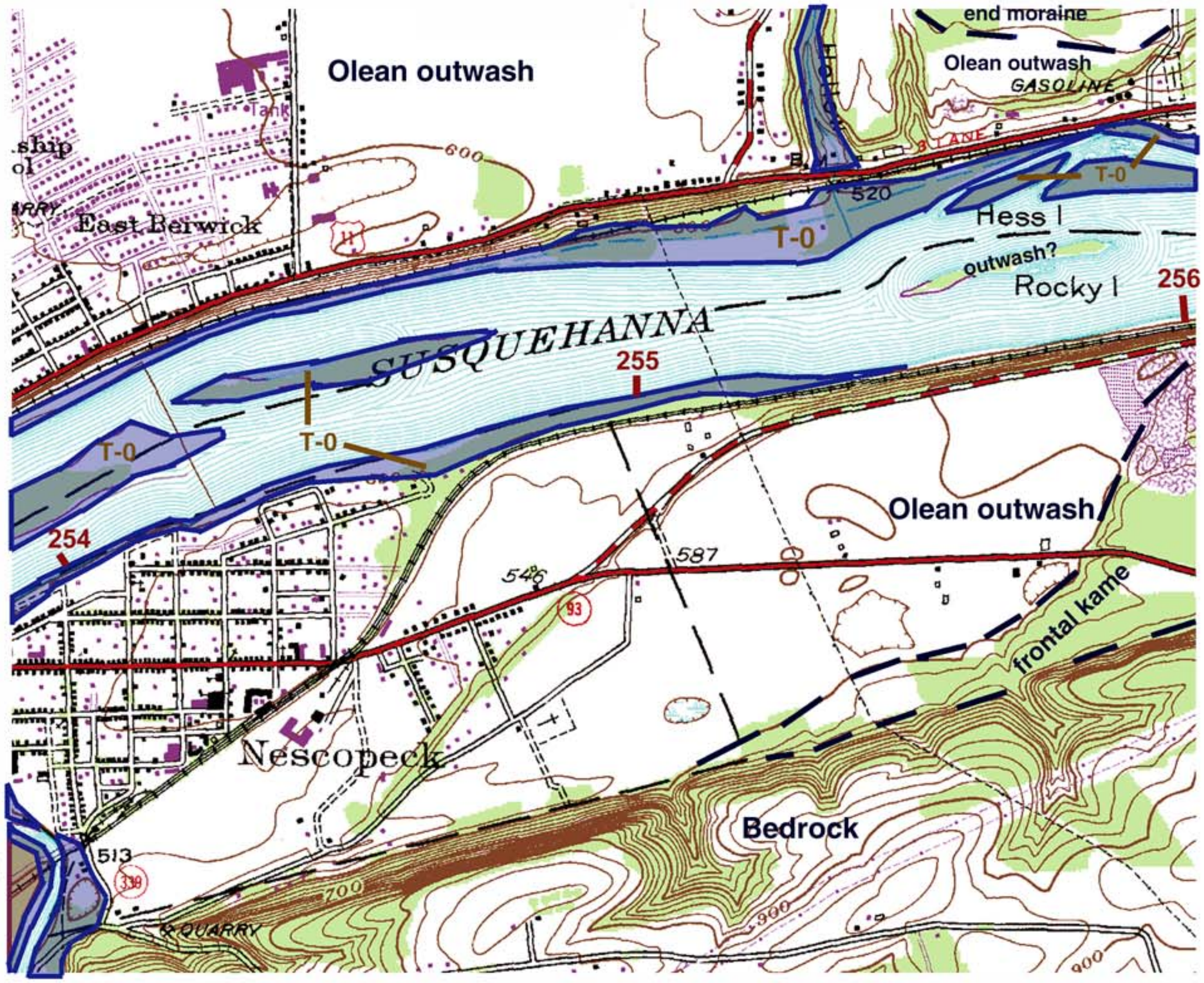
Appendix 1-20: Mifflinville quad, kilometers 247-249



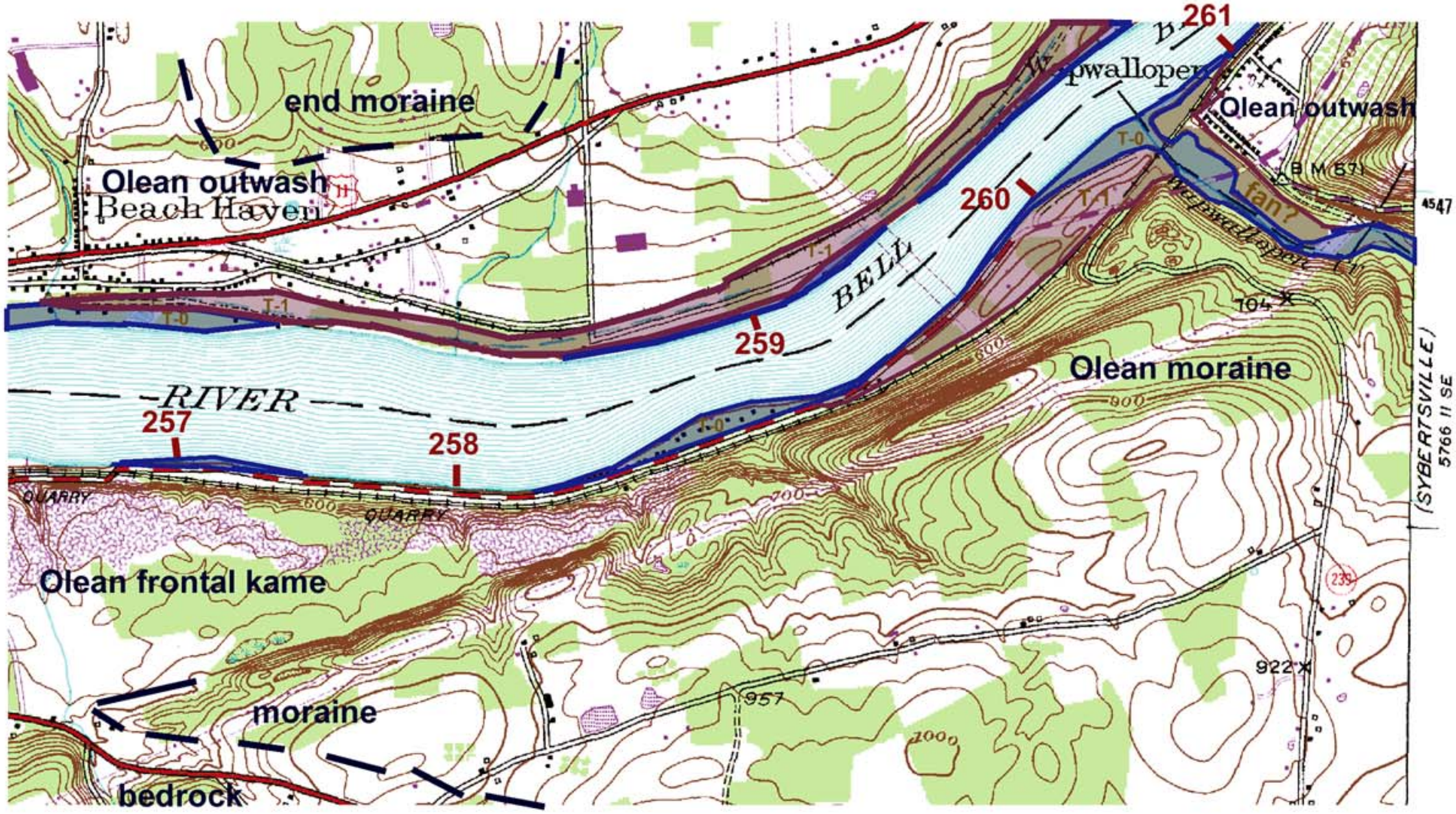
Appendix 1-21: Mifflinville quad, kilometers 248-251



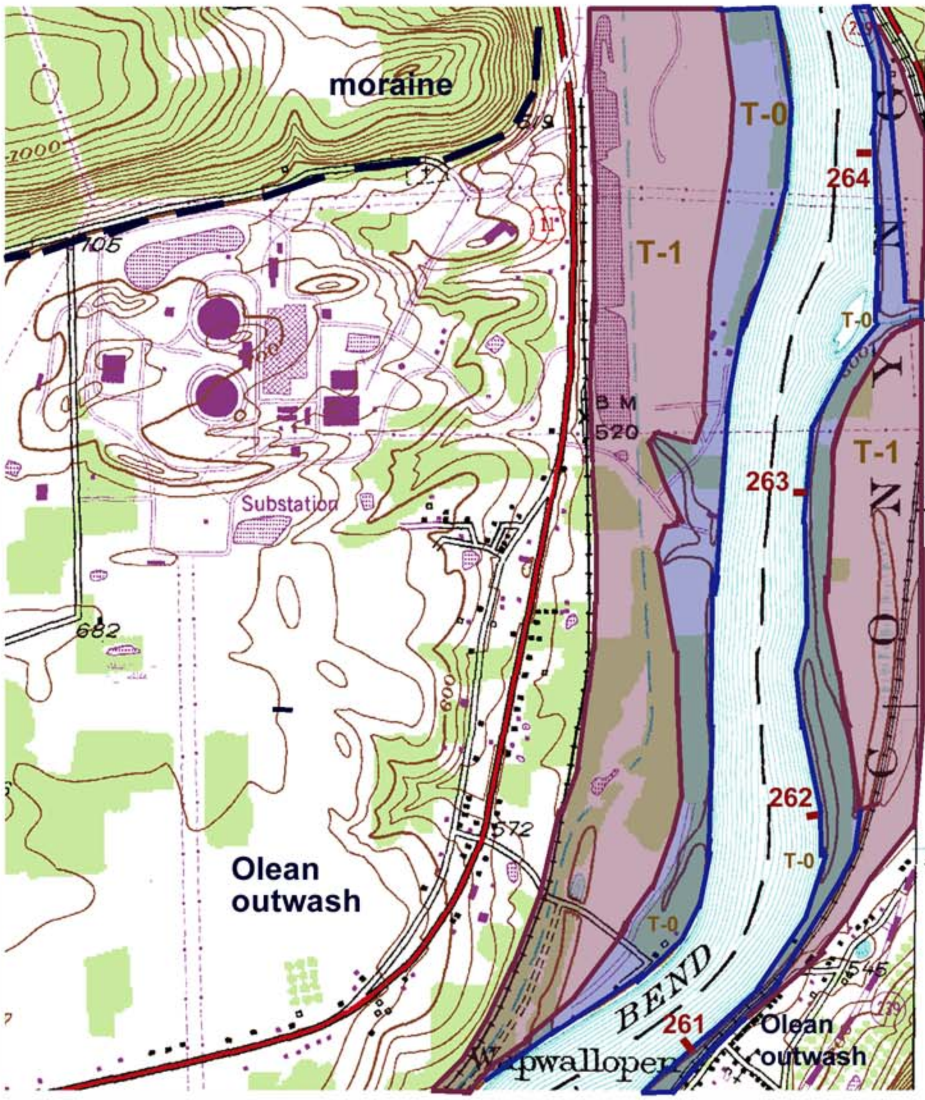
Appendix 1-22: kilometers 252-254



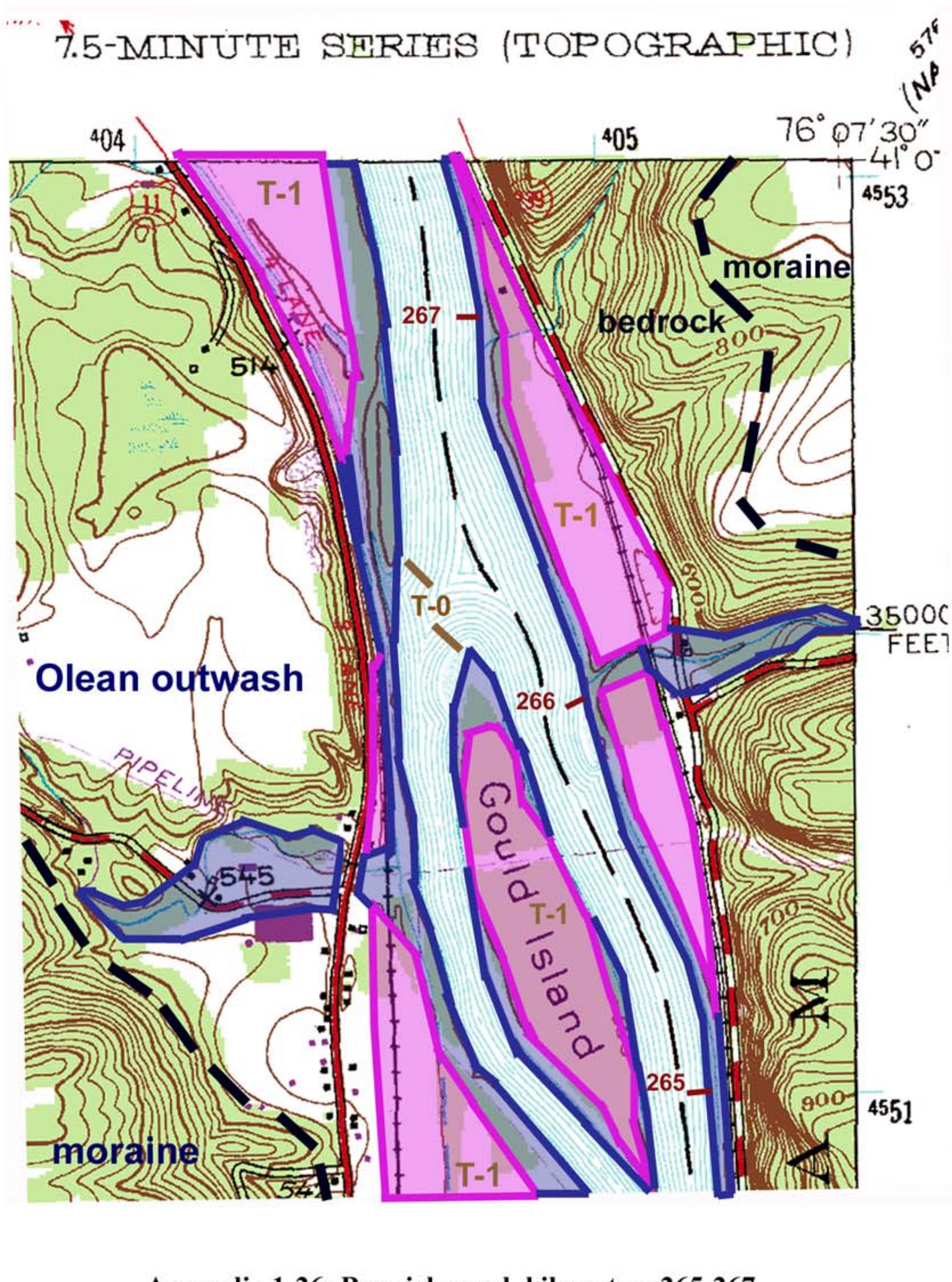
Appendix 1-23: Berwick quad, kilometers 254-255



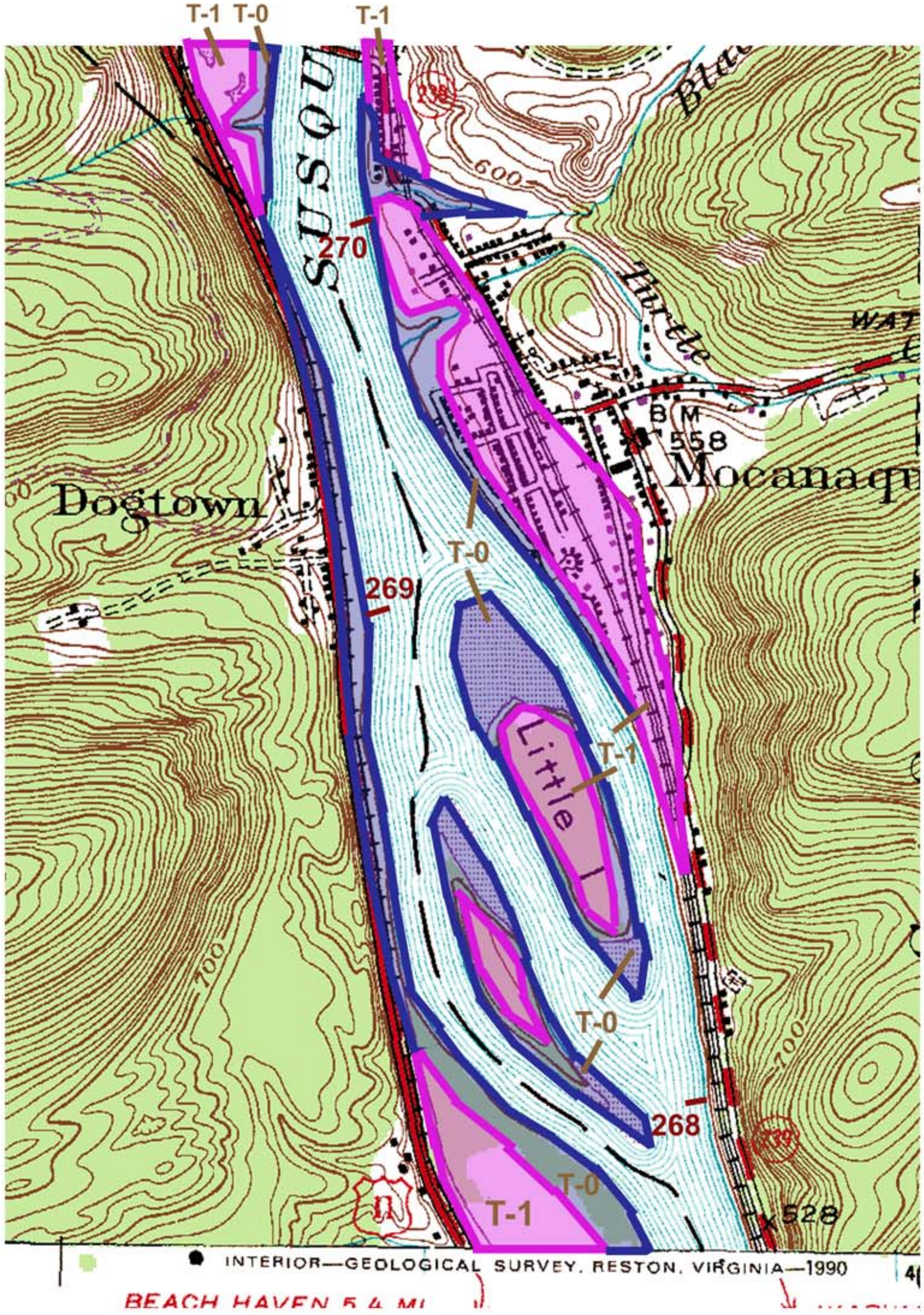
Appendix 1-24: Berwick quad, kilometers 256-261



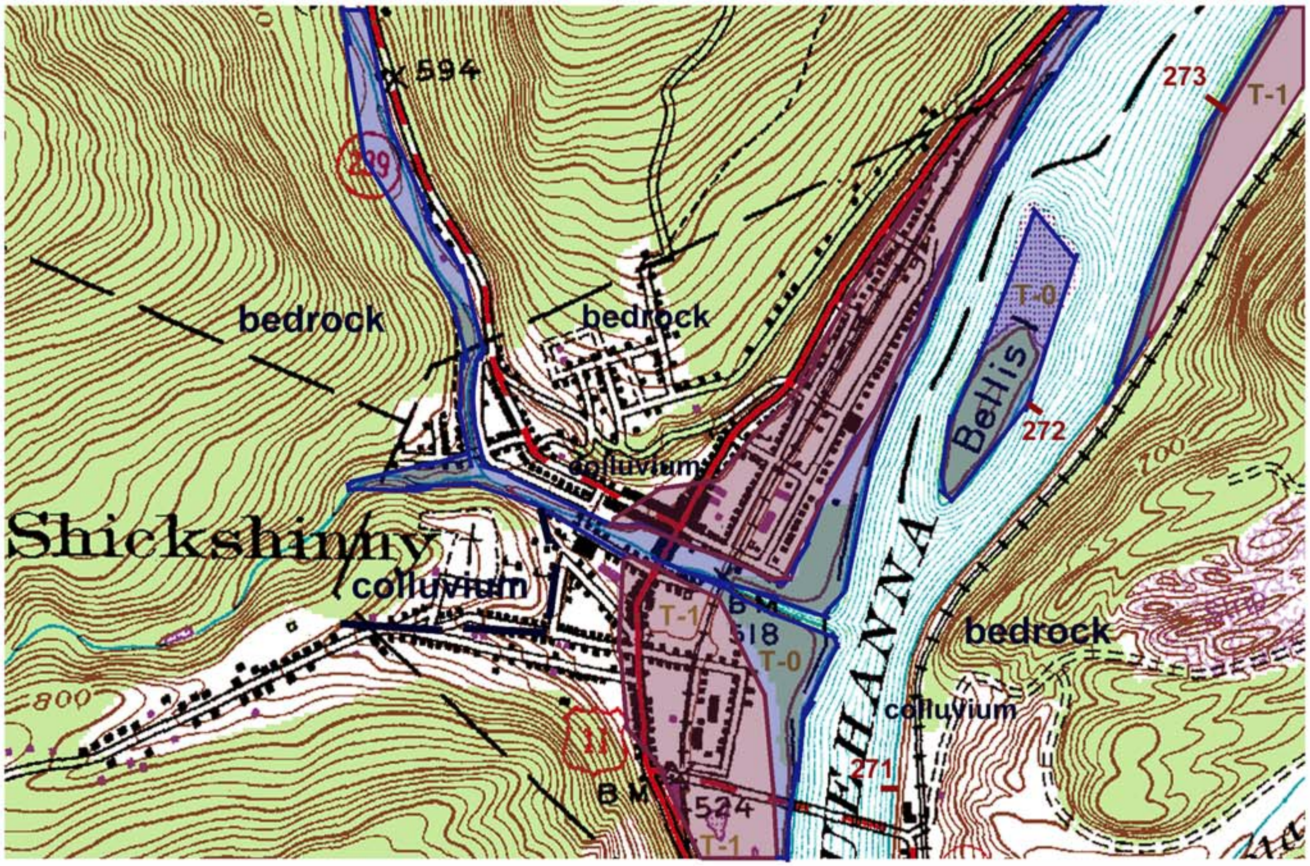
Appendix 1-25: Berwick quad, kilometers 261-265



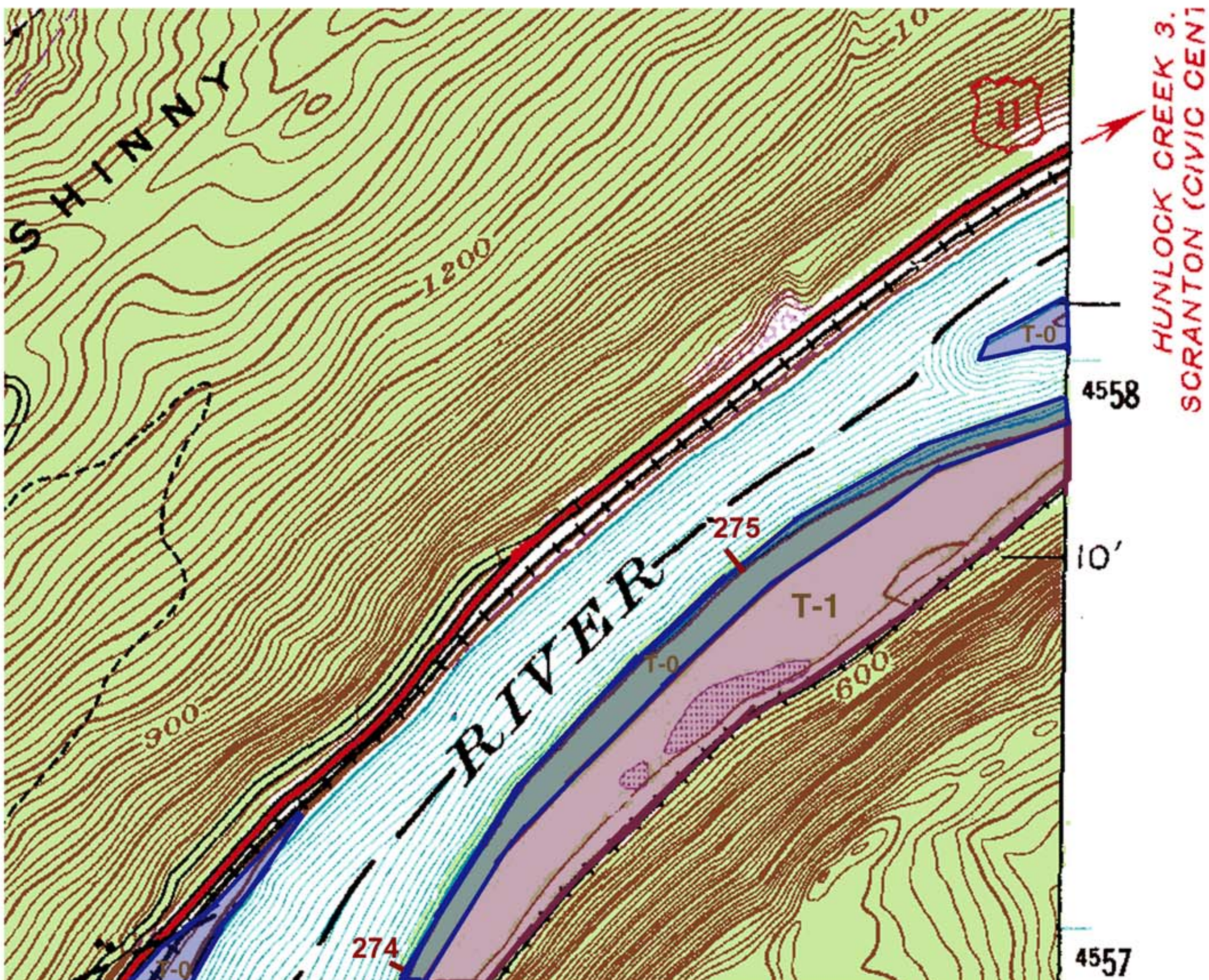
Appendix 1-26: Berwick quad, kilometers 265-267



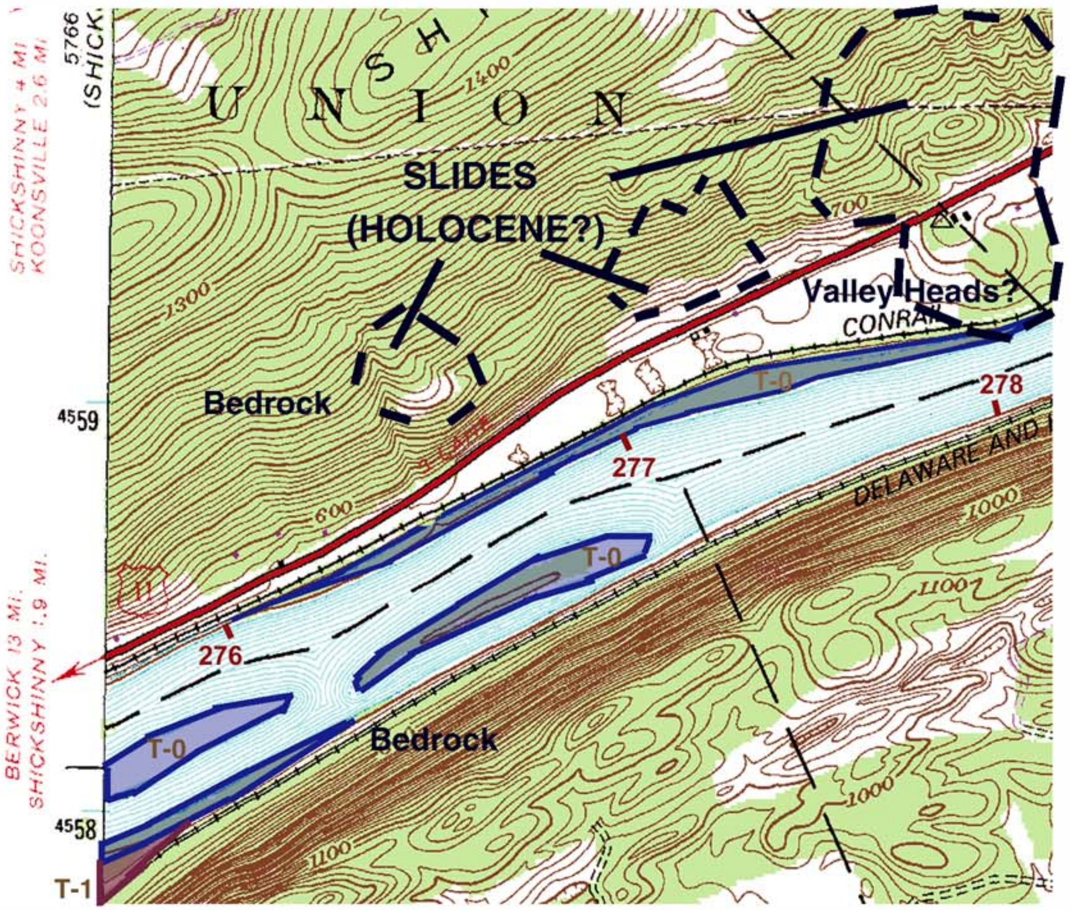
Appendix 1-27: Shickshinny quad, kilometers 267-271



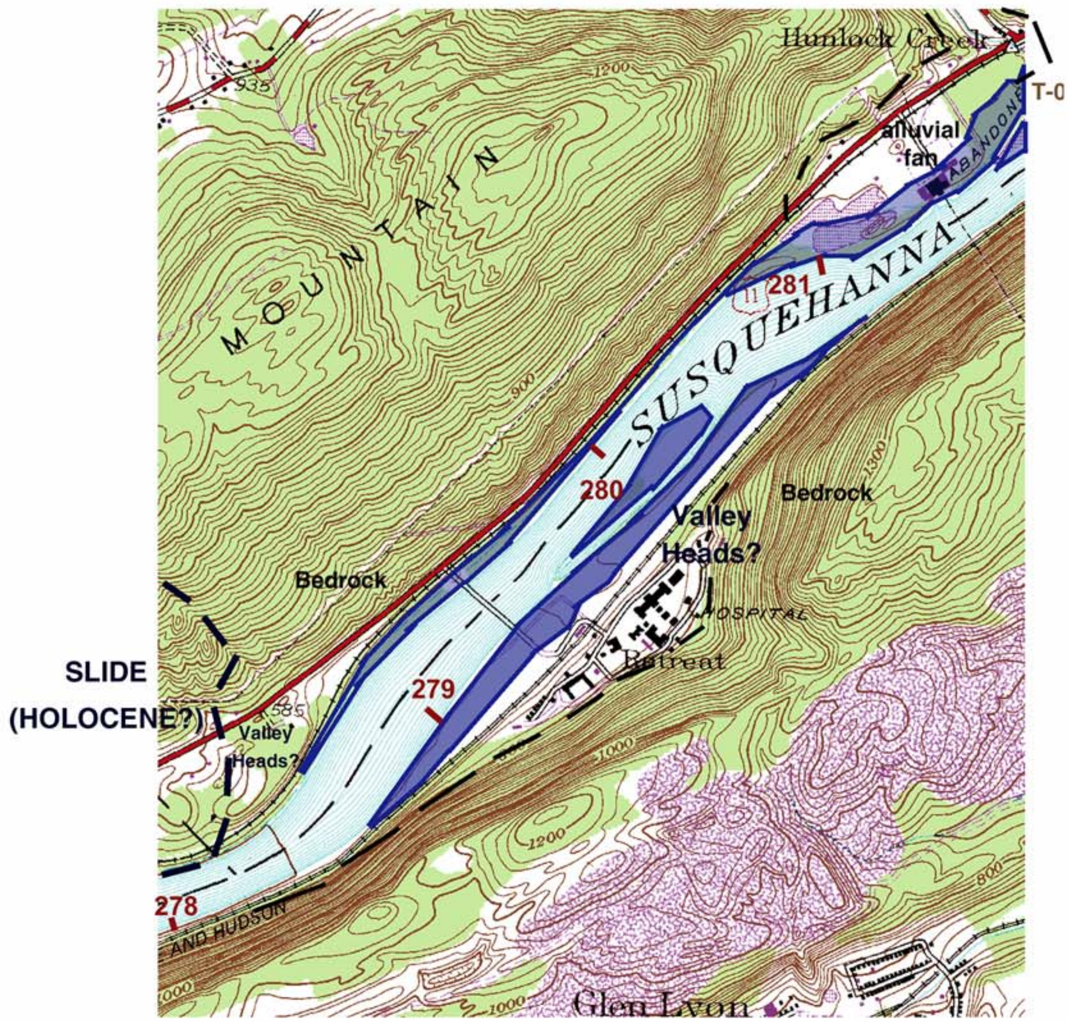
Appendix 1-28: Shickshinny quad, kilometers 270-272



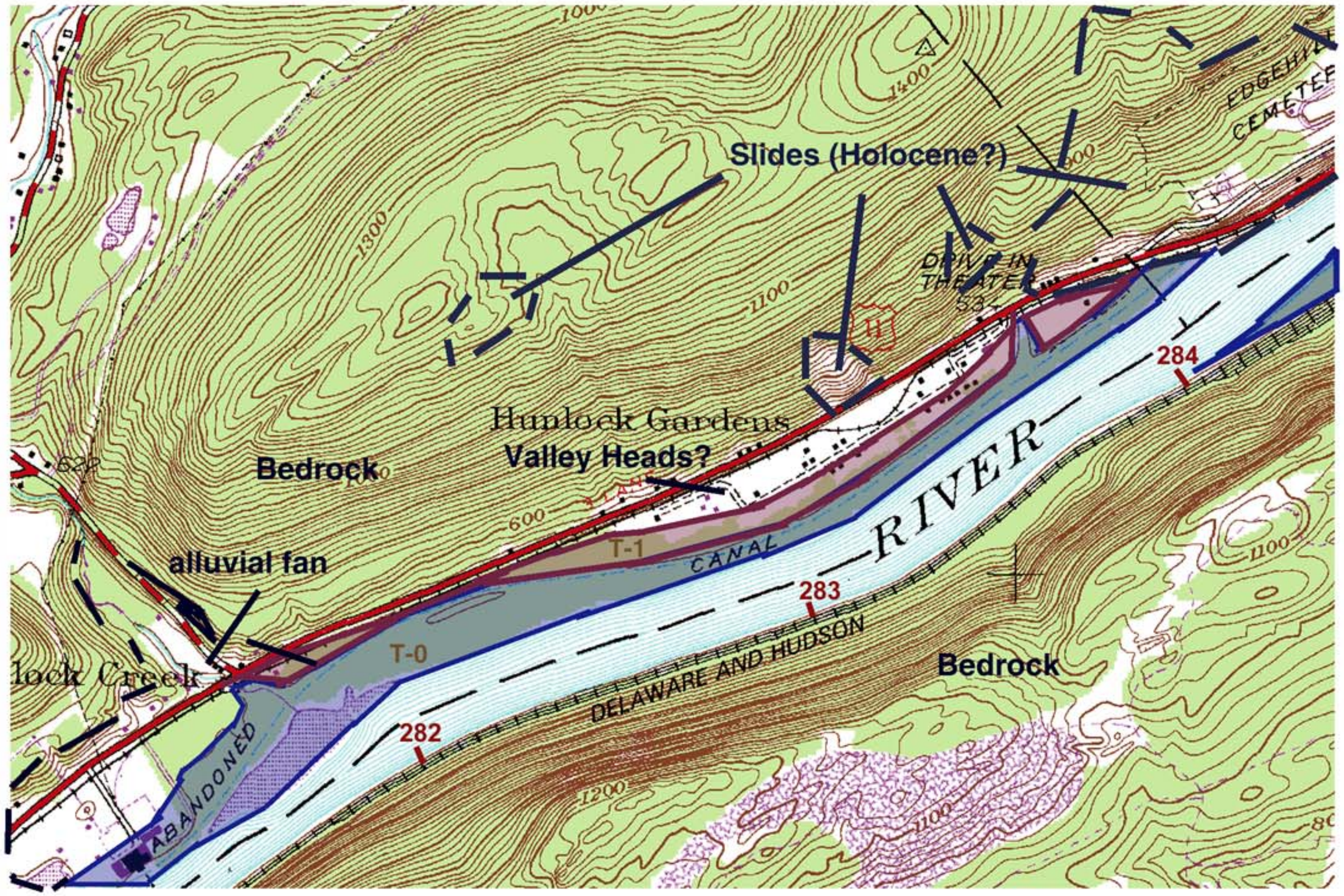
Appendix 1-29: Shickshinny quad, kilometers 274-276



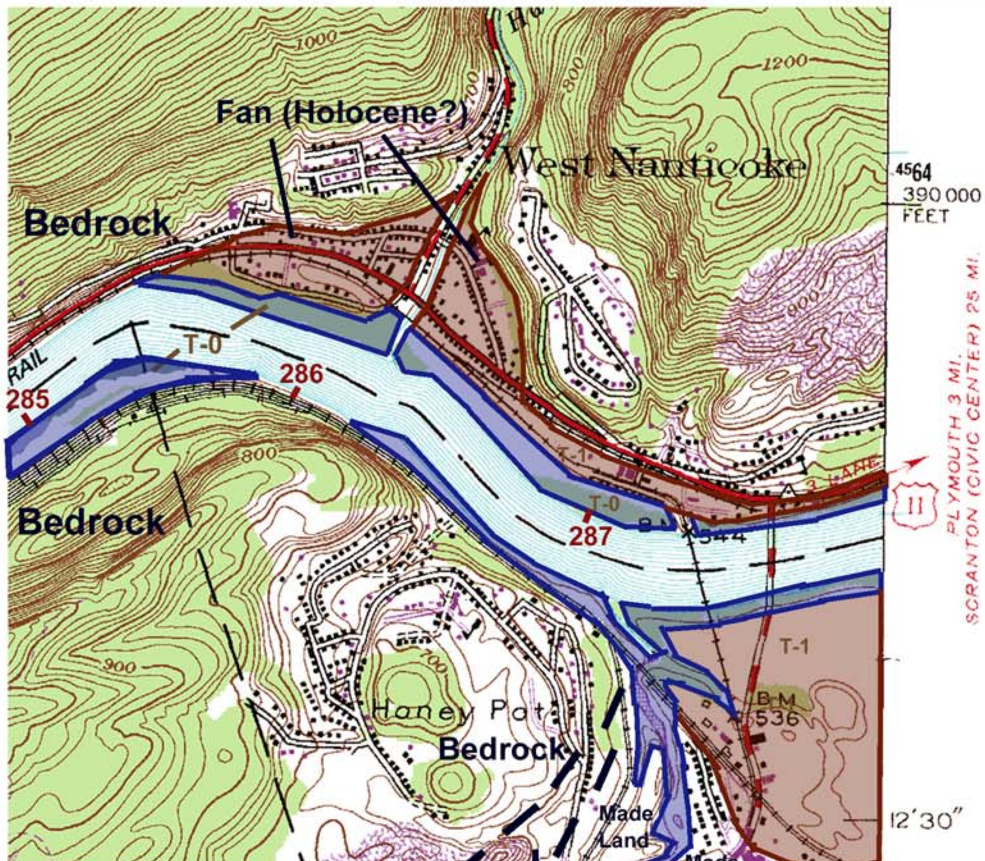
Appendix 1-30: Nanticoke quad, kilometers 276-278



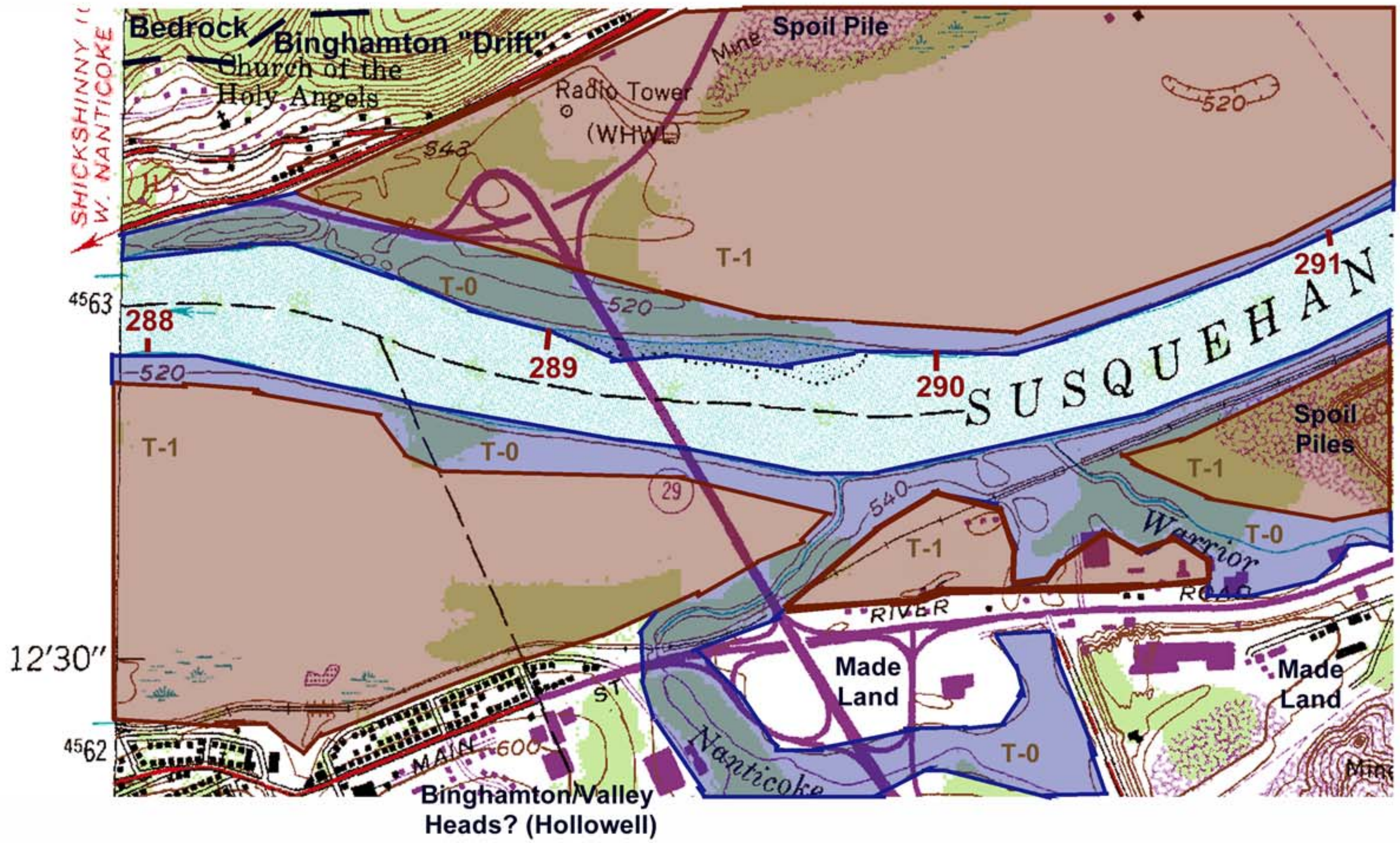
Appendix 1-31: Nanticoke quad, kilometers 278-282



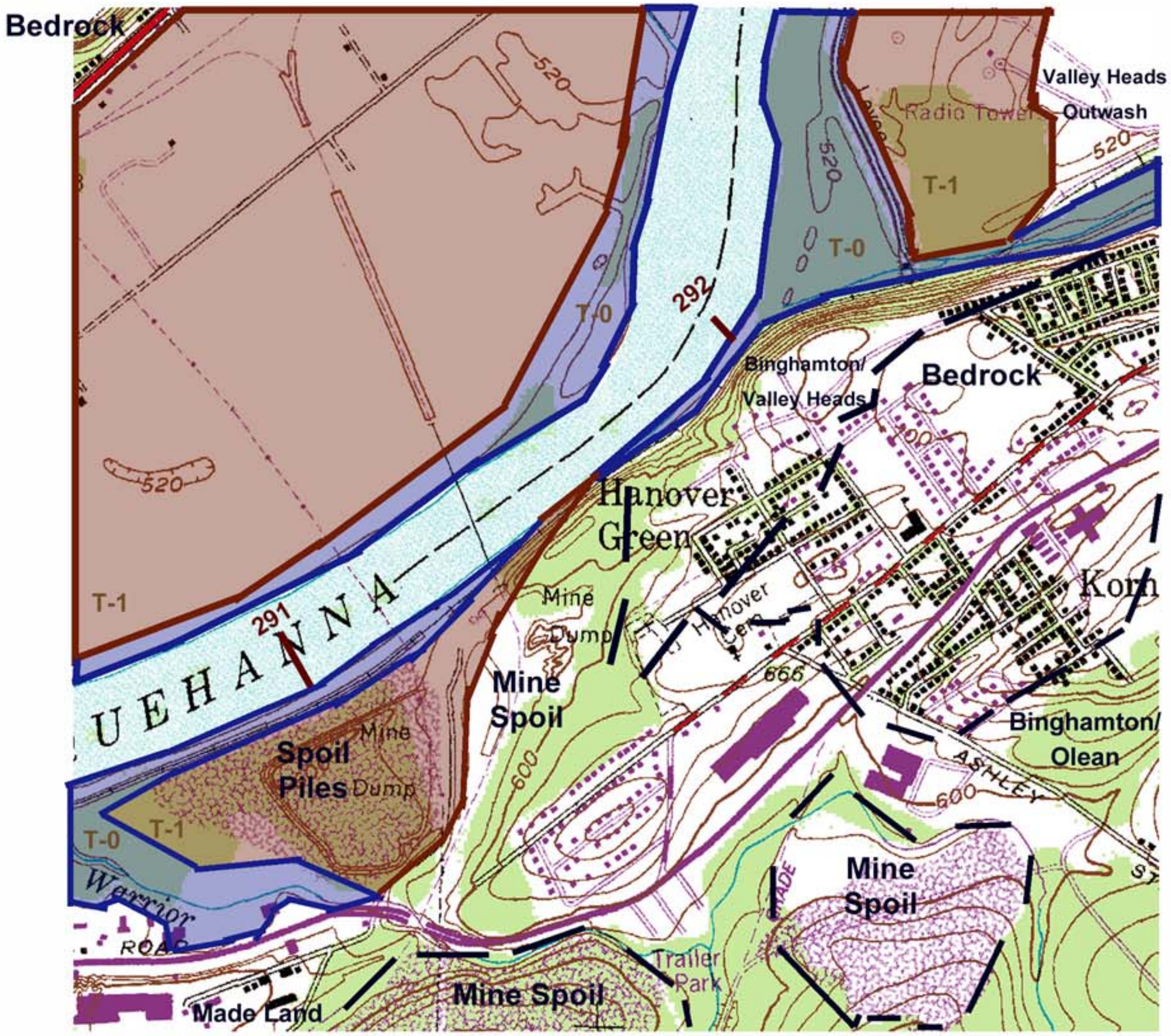
Appendix 1-32: Nanticoke quad, kilometers 281-285



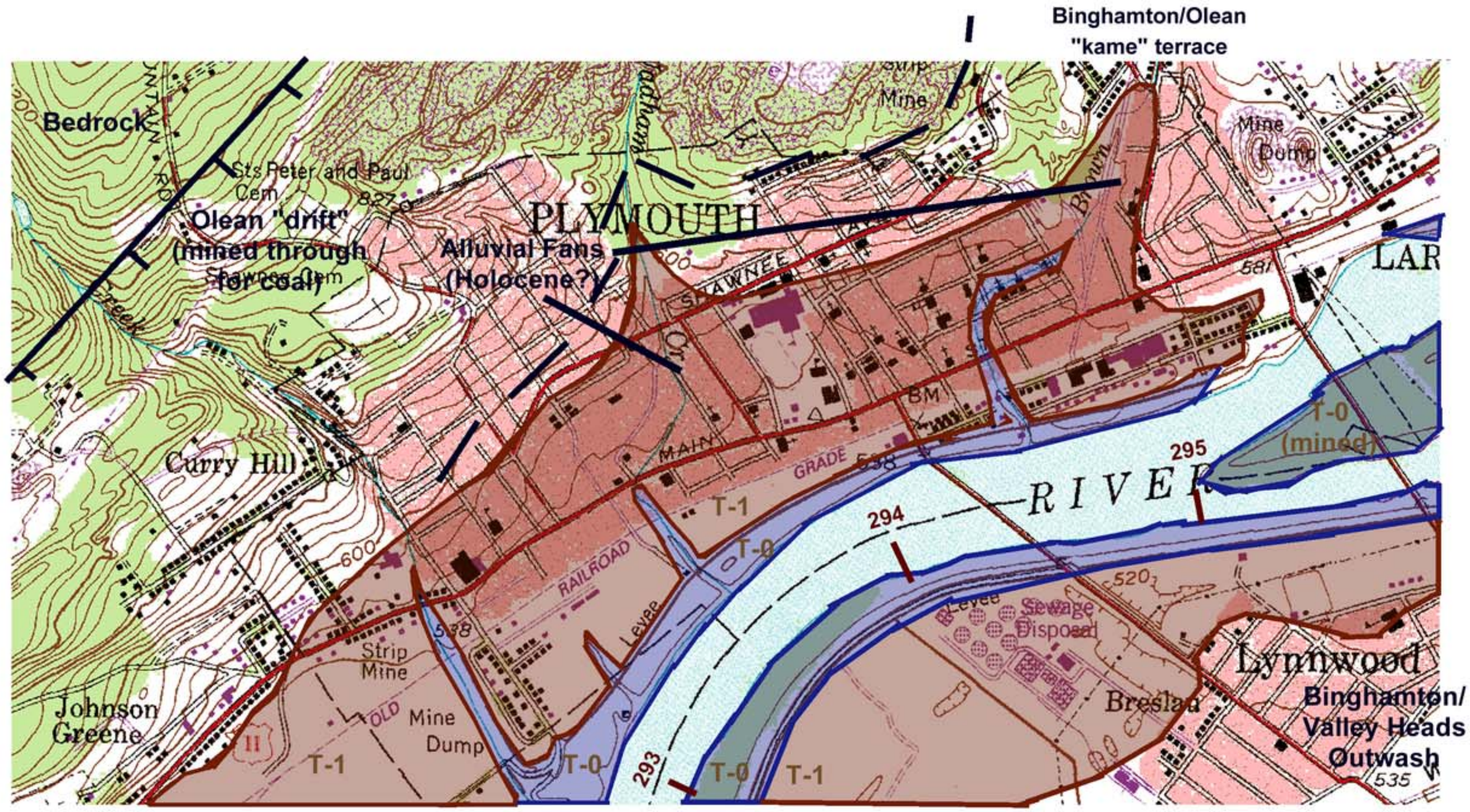
Appendix 1-33: Nanticoke quad, kilometers 285-288



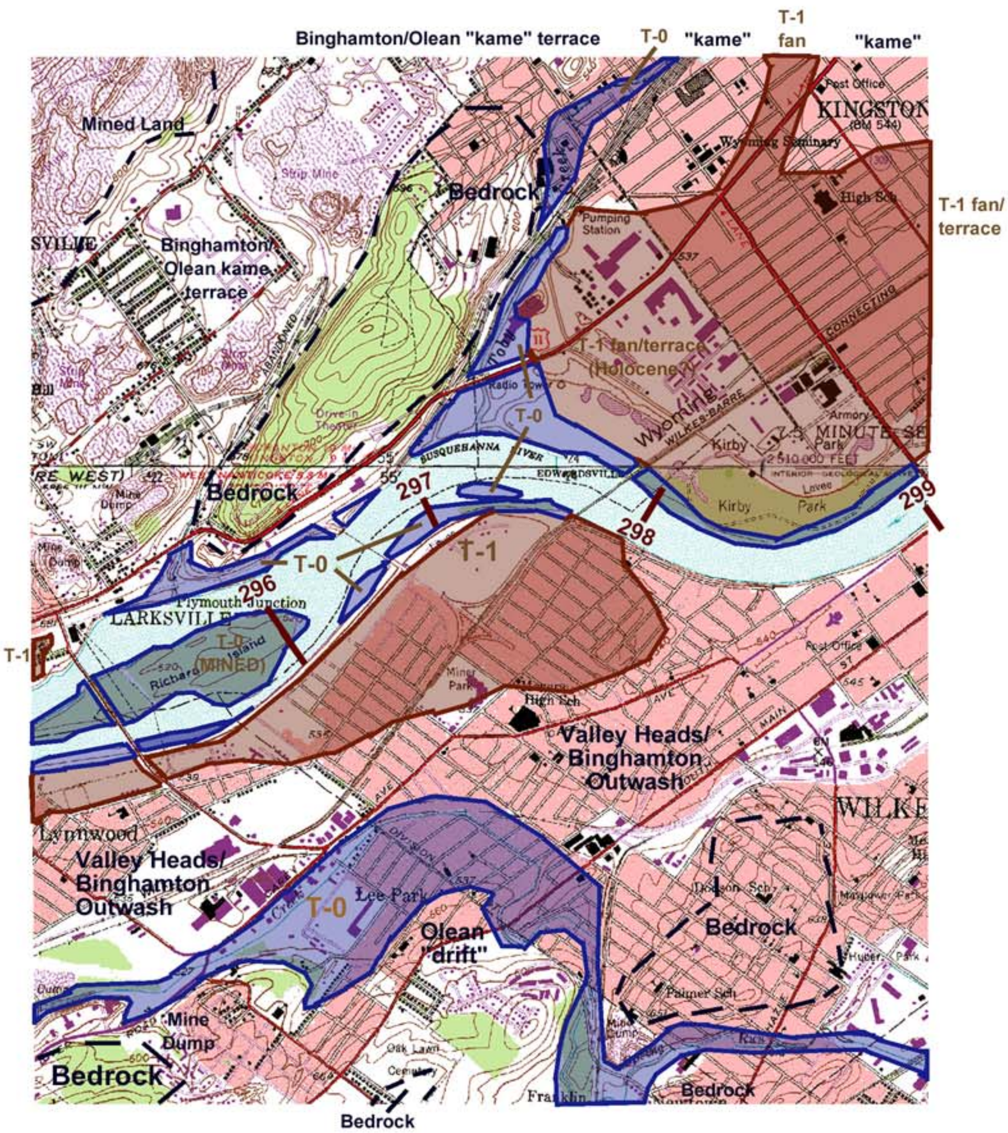
Appendix 1-34: Wilkes-Barre West quad, kilometers 288-291



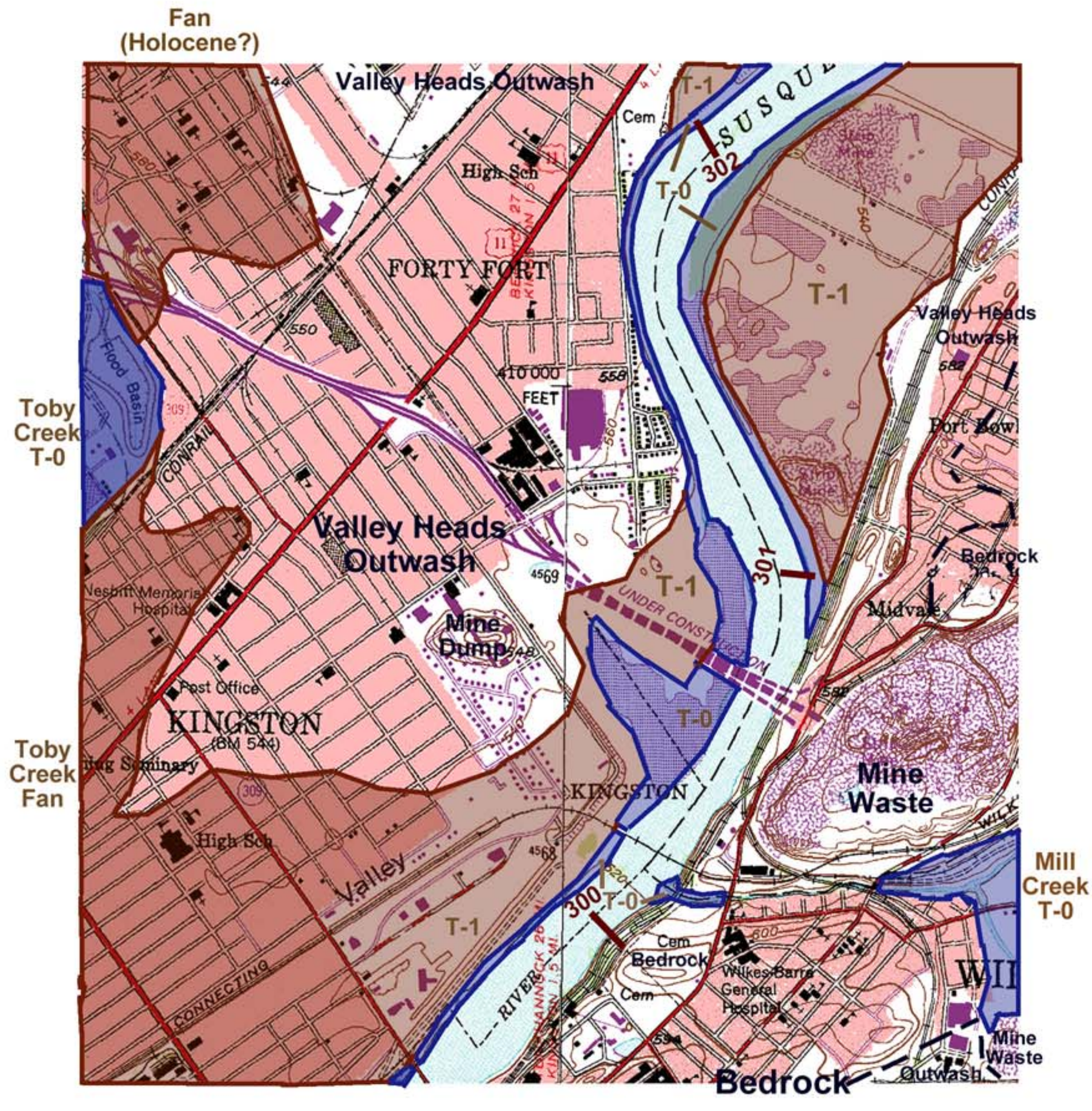
Appendix 1-35: Wilkes-Barre West quad, kilometers 291-293



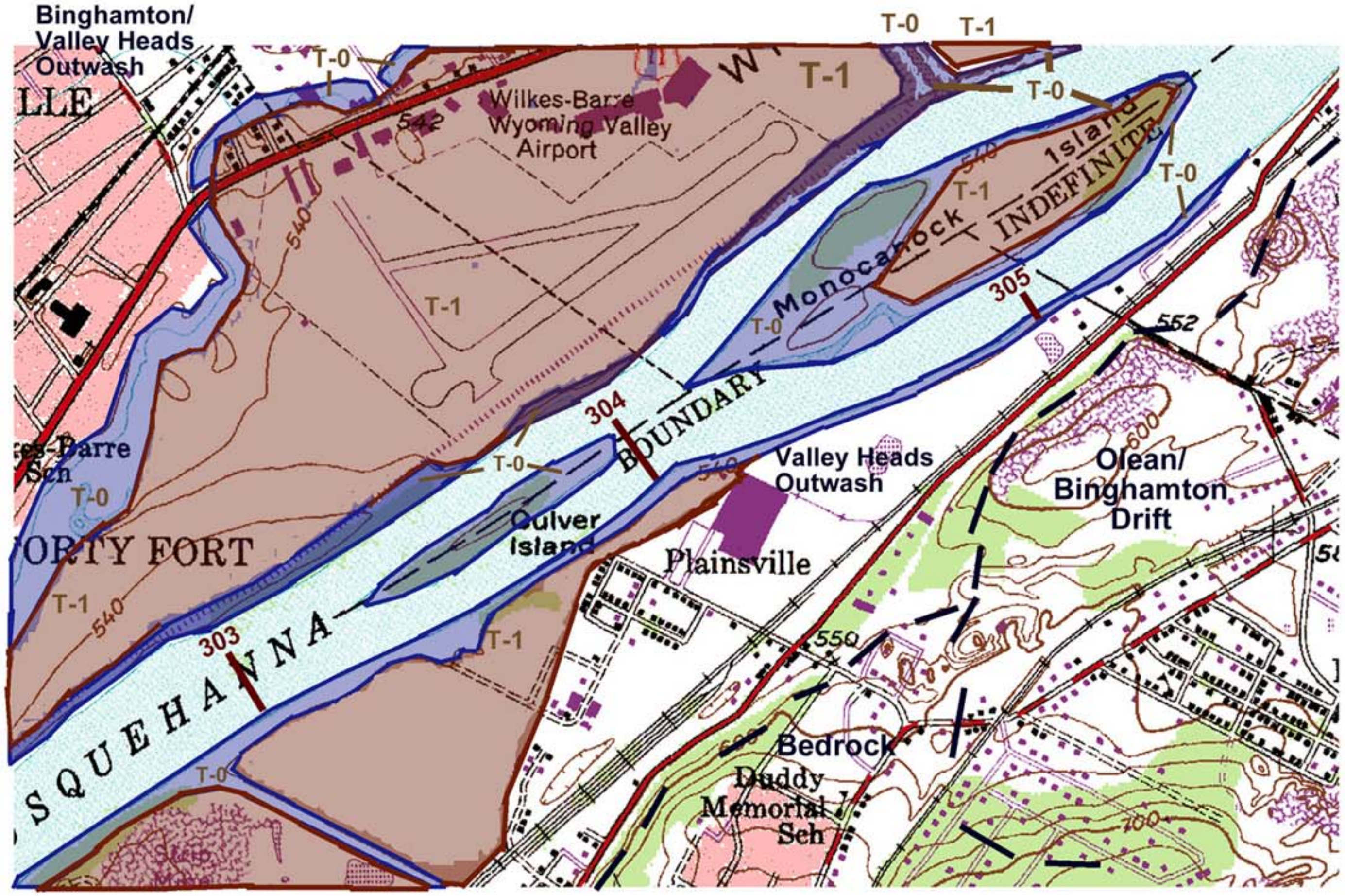
Appendix 1-36: Wilkes-Barre West quad, kilometers 293-296



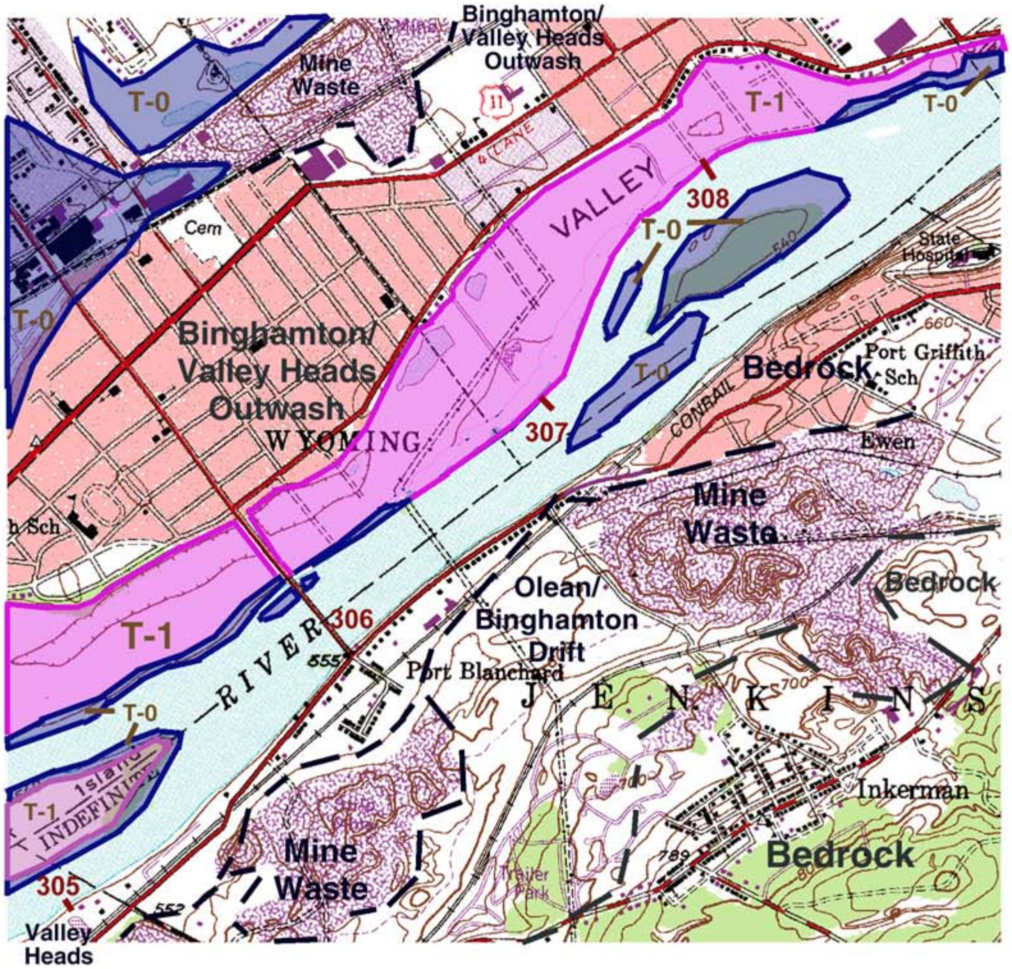
Appendix 1-37: Wilkes-Barre West/Kingston quads, kilometers 295-299



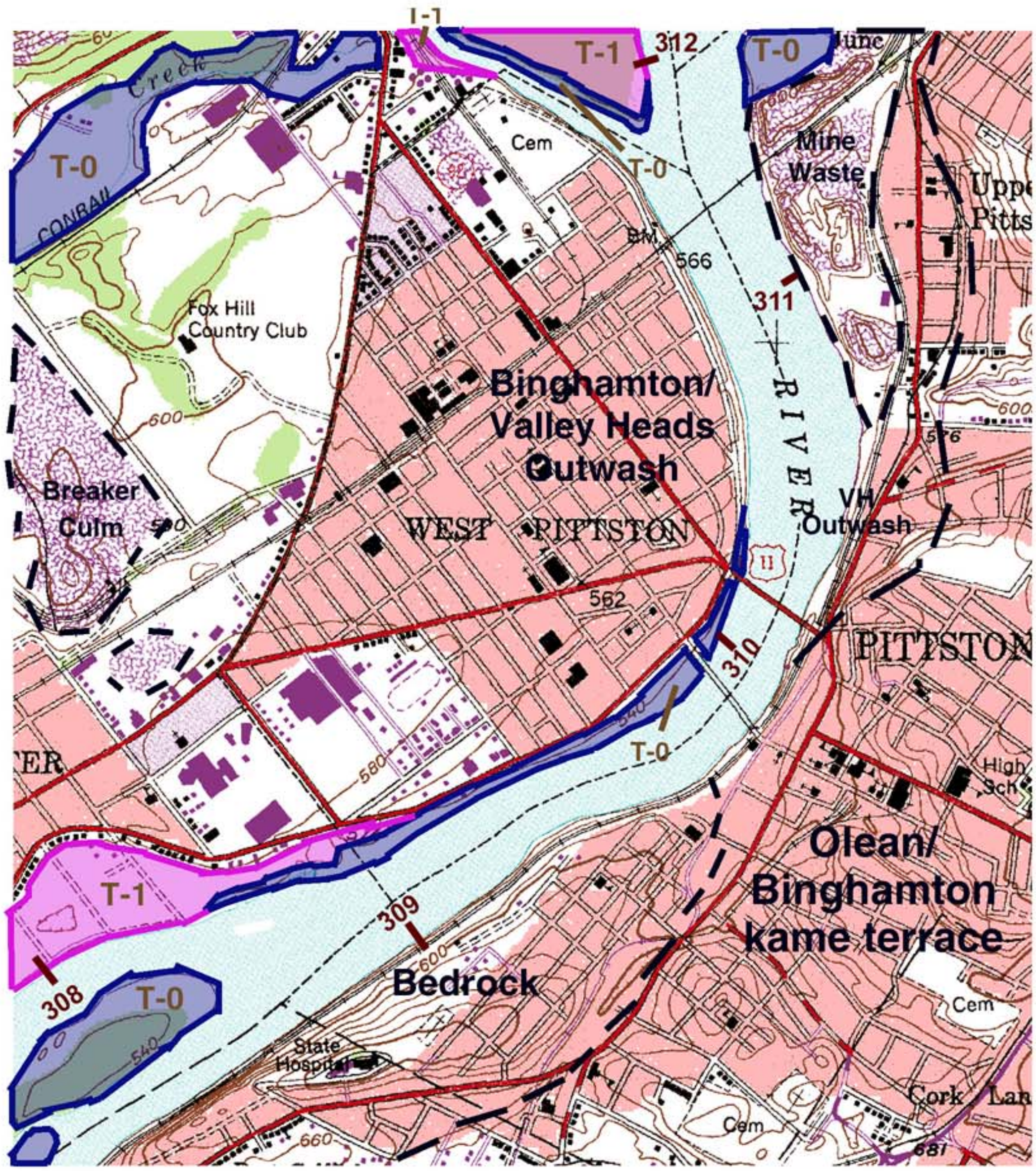
Appendix 1-38: Kingston/Pittston quads, kilometers 299-302



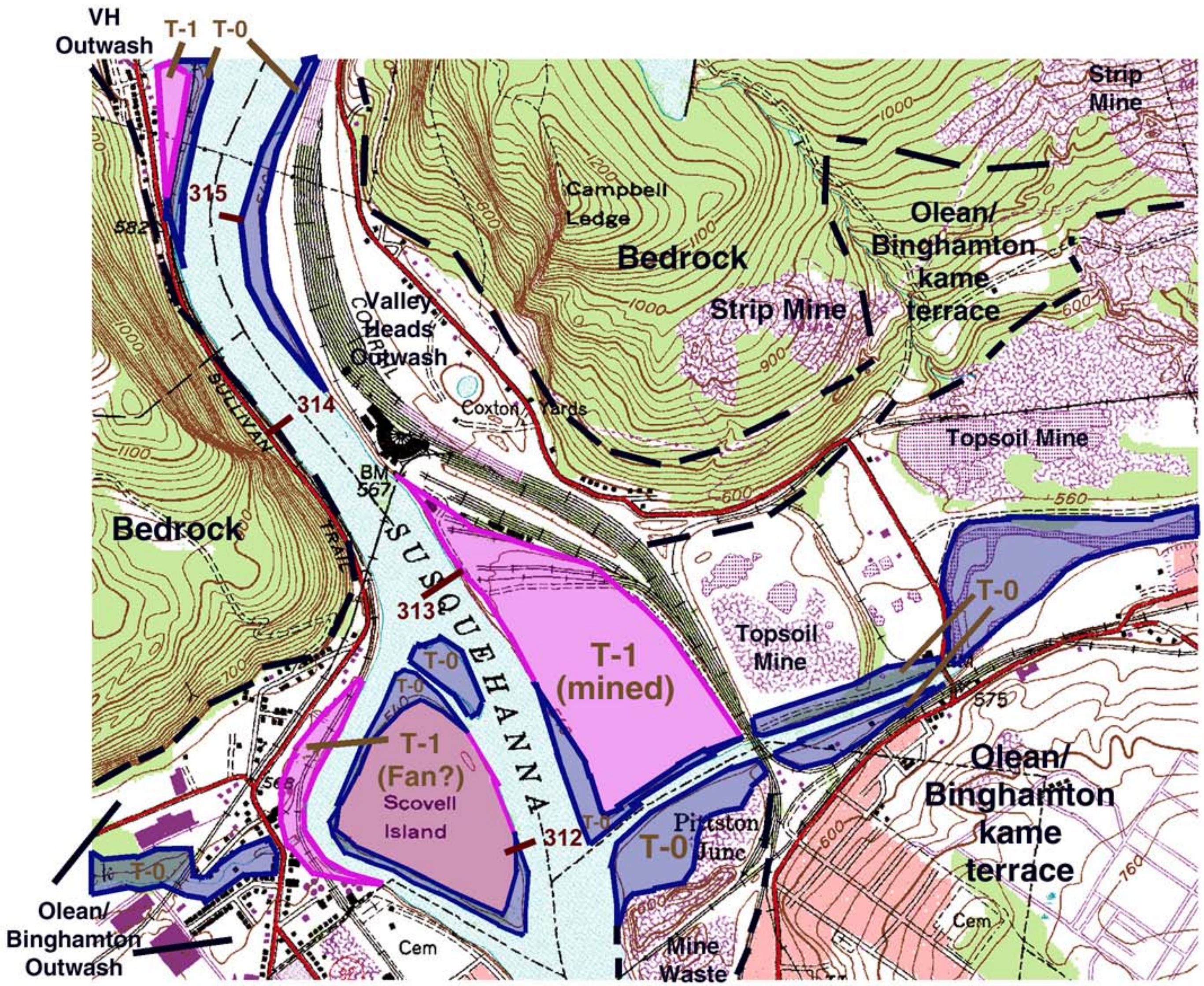
Appendix 1-39: Pittston quad, kilometers 302-306



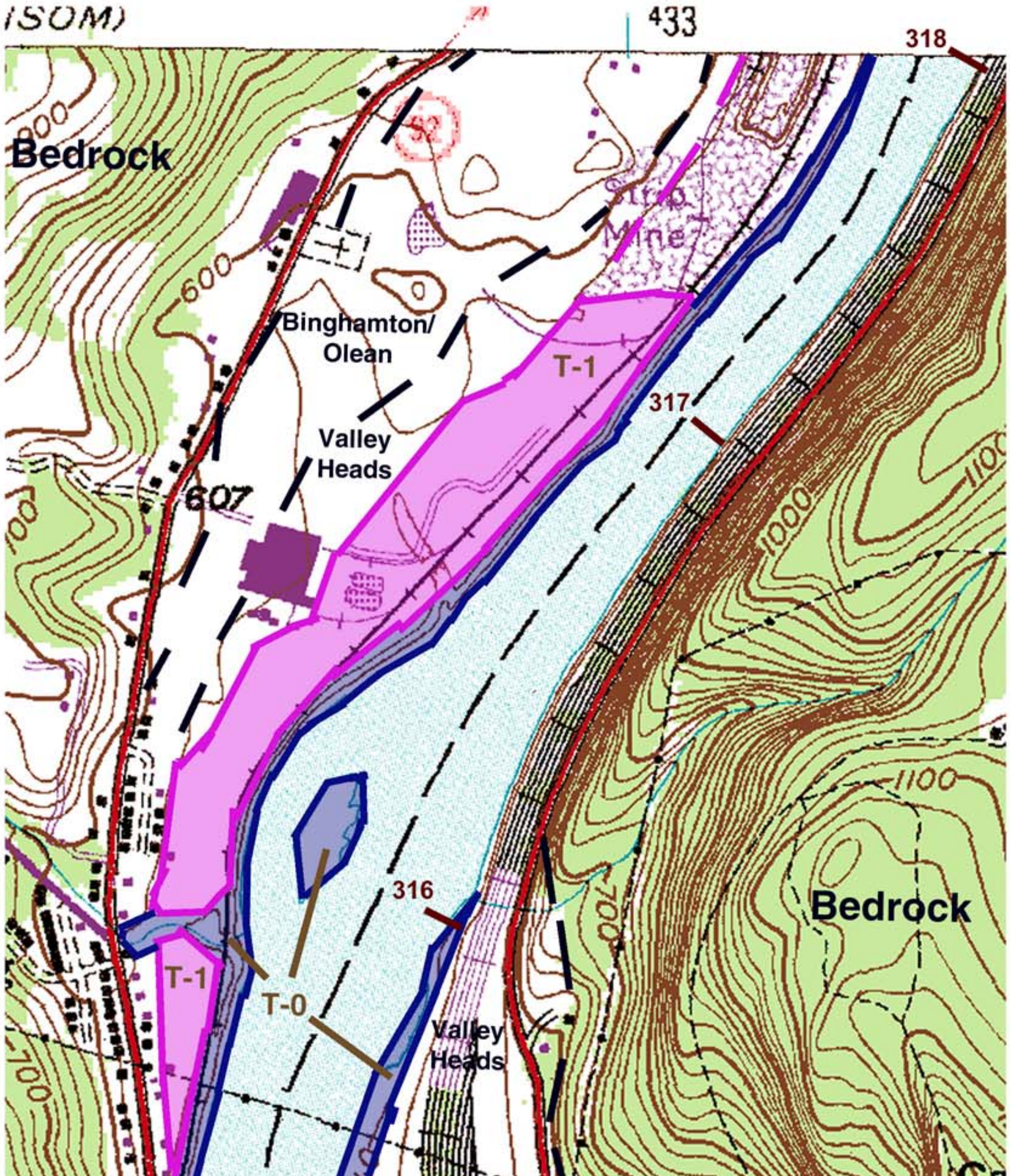
Appendix 1-40: Pittston quad, kilometers 305-308

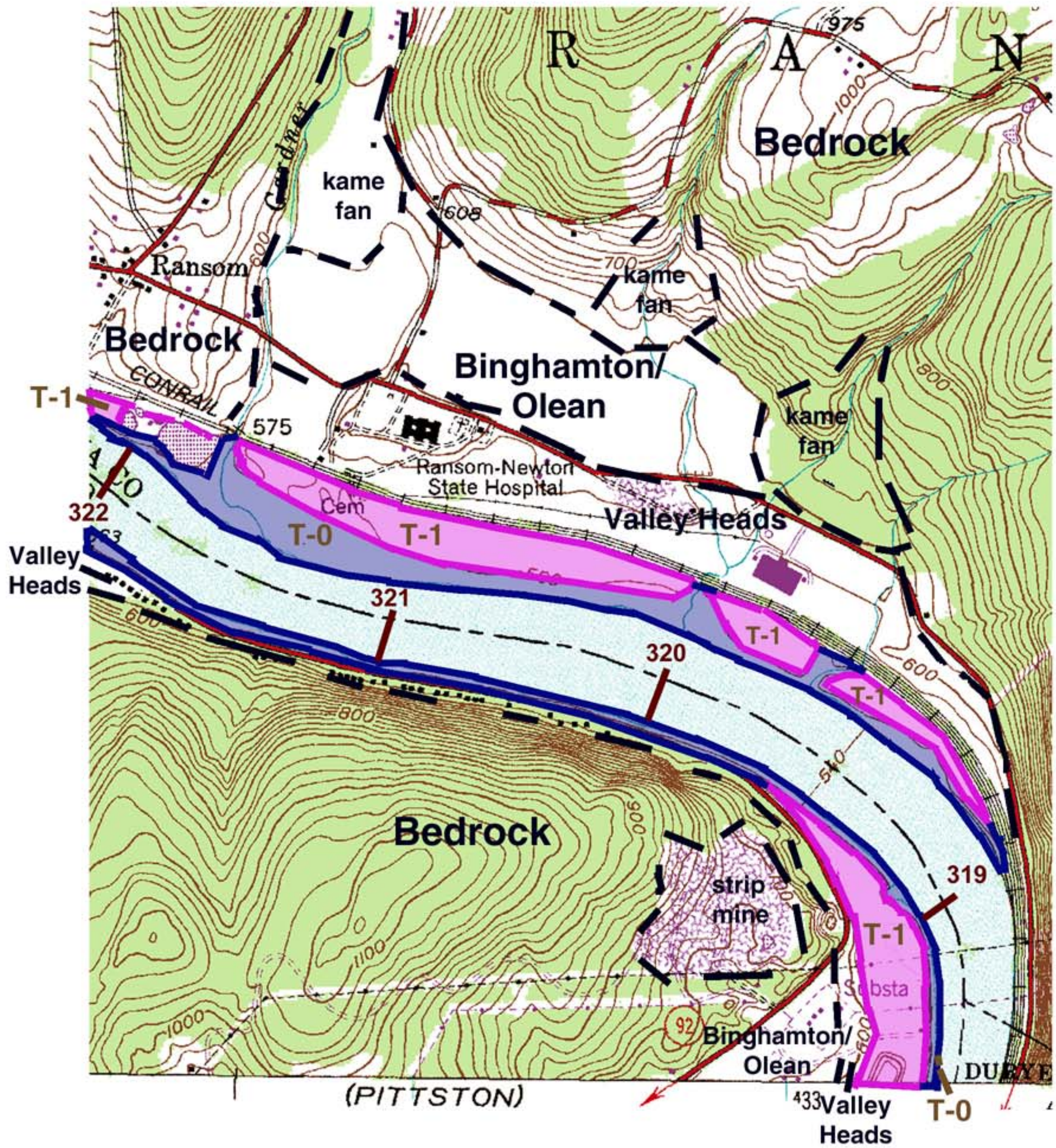


Appendix 1-41: Pittston quad, kilometers 308-312

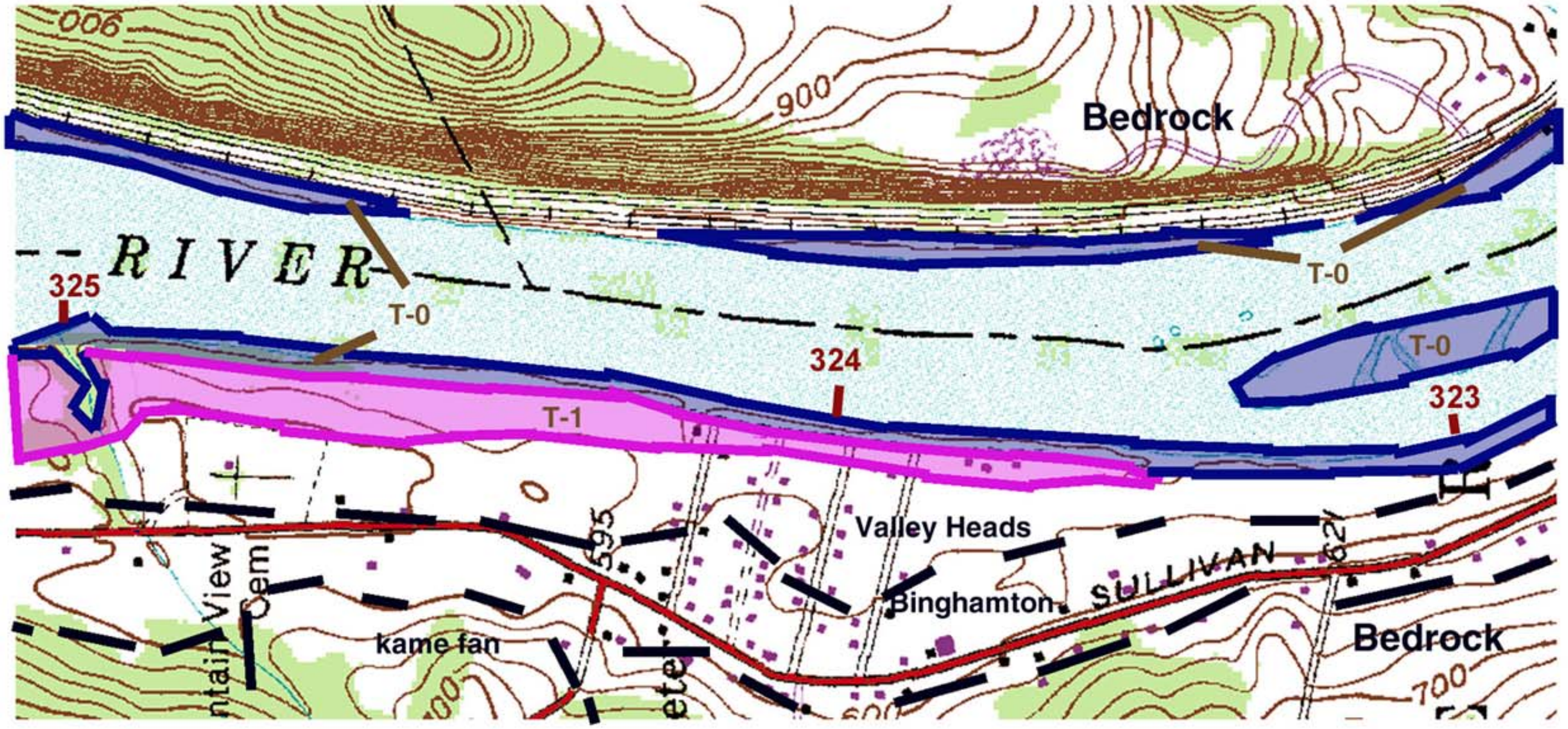


Appendix 1-42: Pittston quad, kilometers 312-315

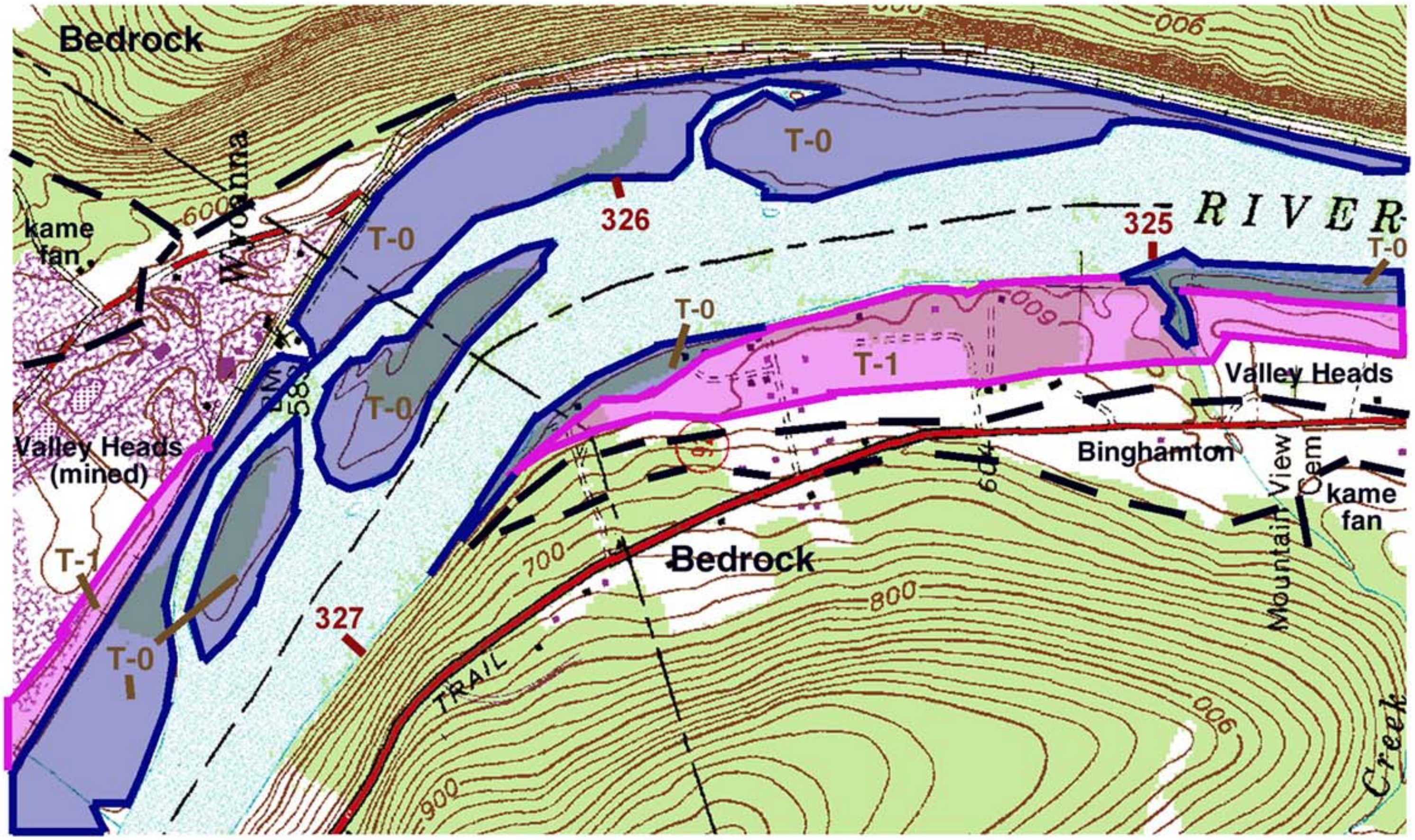

ISOM)
433
318
Bedrock
Strip
Mine
Binghamton/
Olean
T-1
317
Valley
Heads
607
316
Bedrock
T-1
T-0
Valley
Heads
Ca



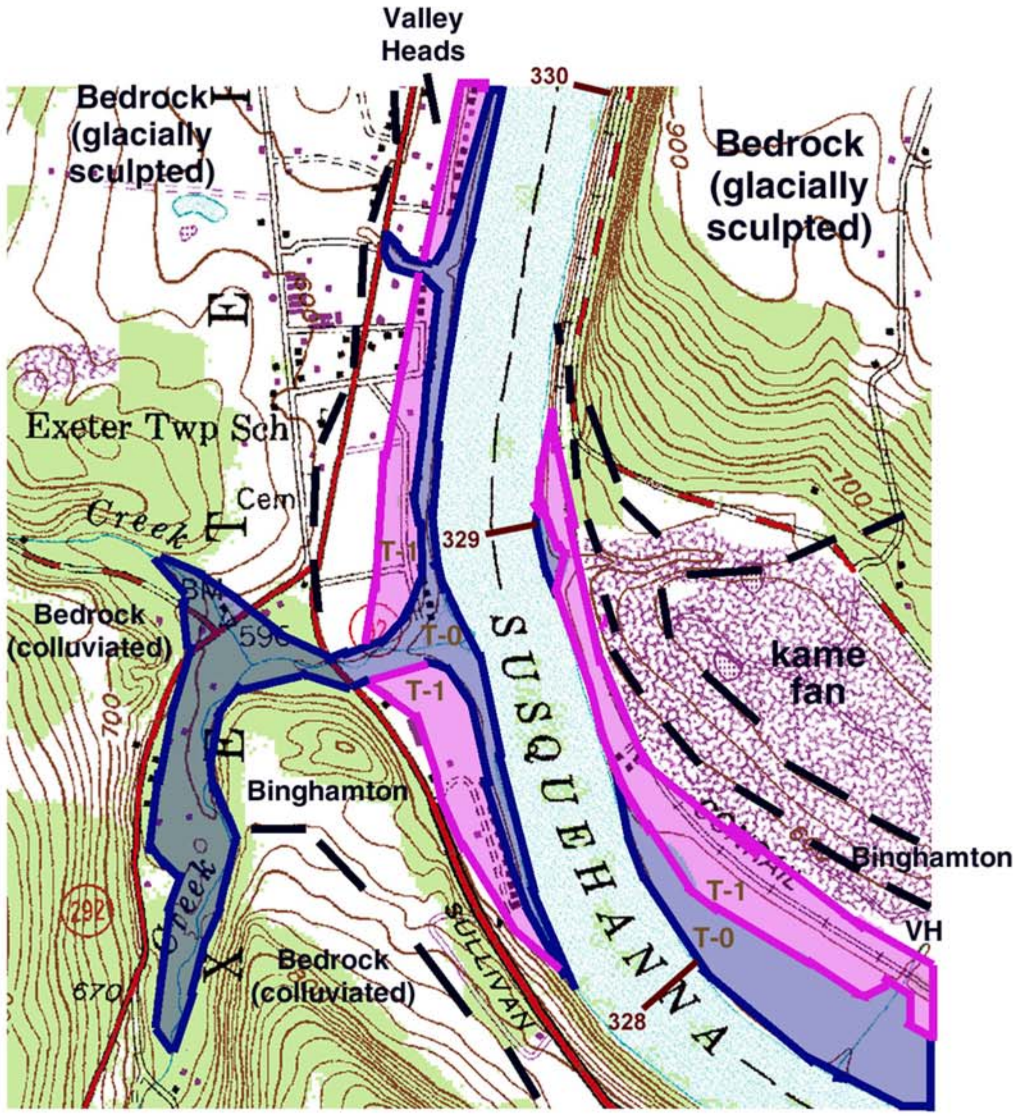
Appendix 1-44: Ransom quad, kilometers 318-322



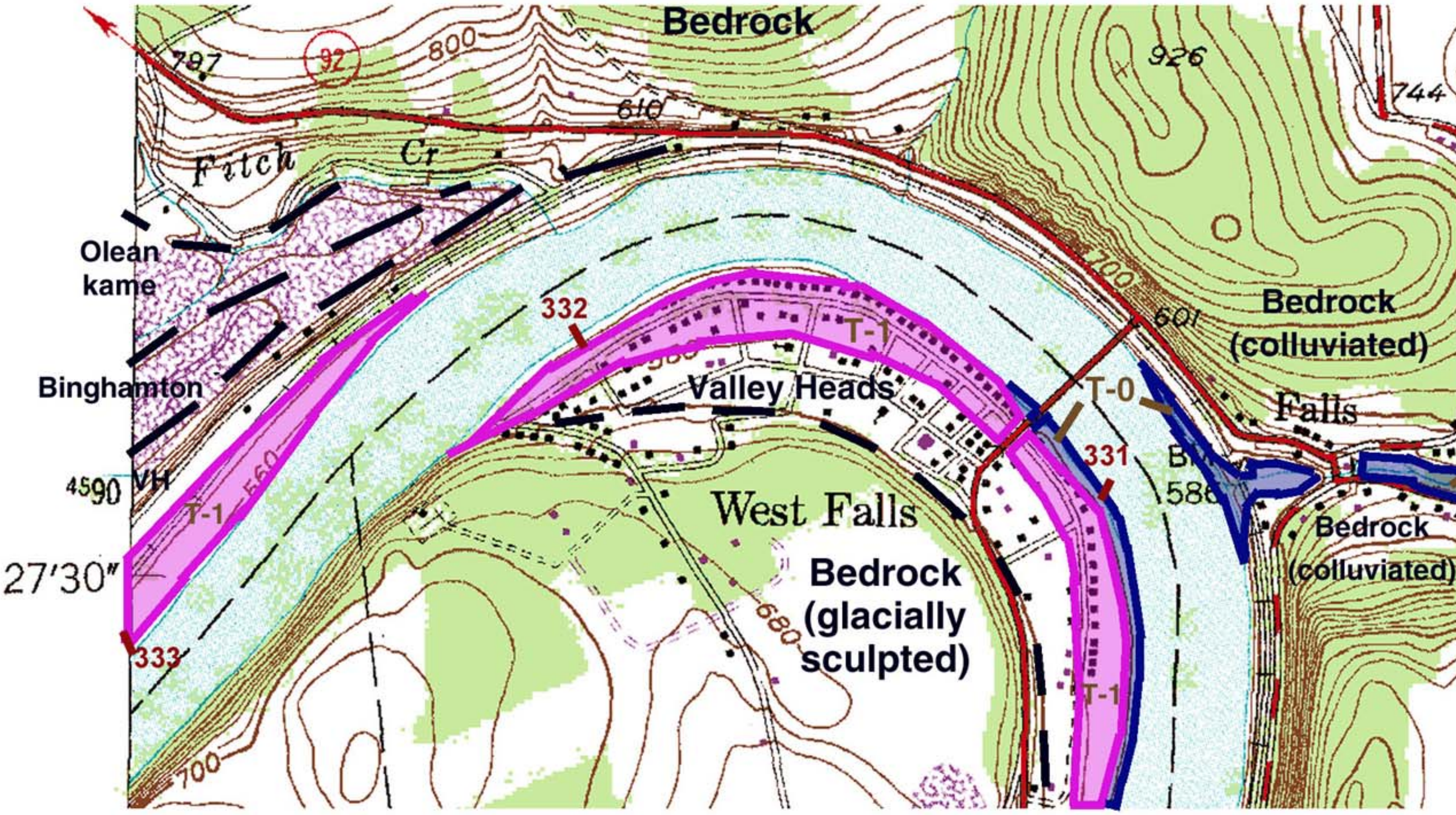
Appendix 1-45: Ransom quad, kilometers 323-325



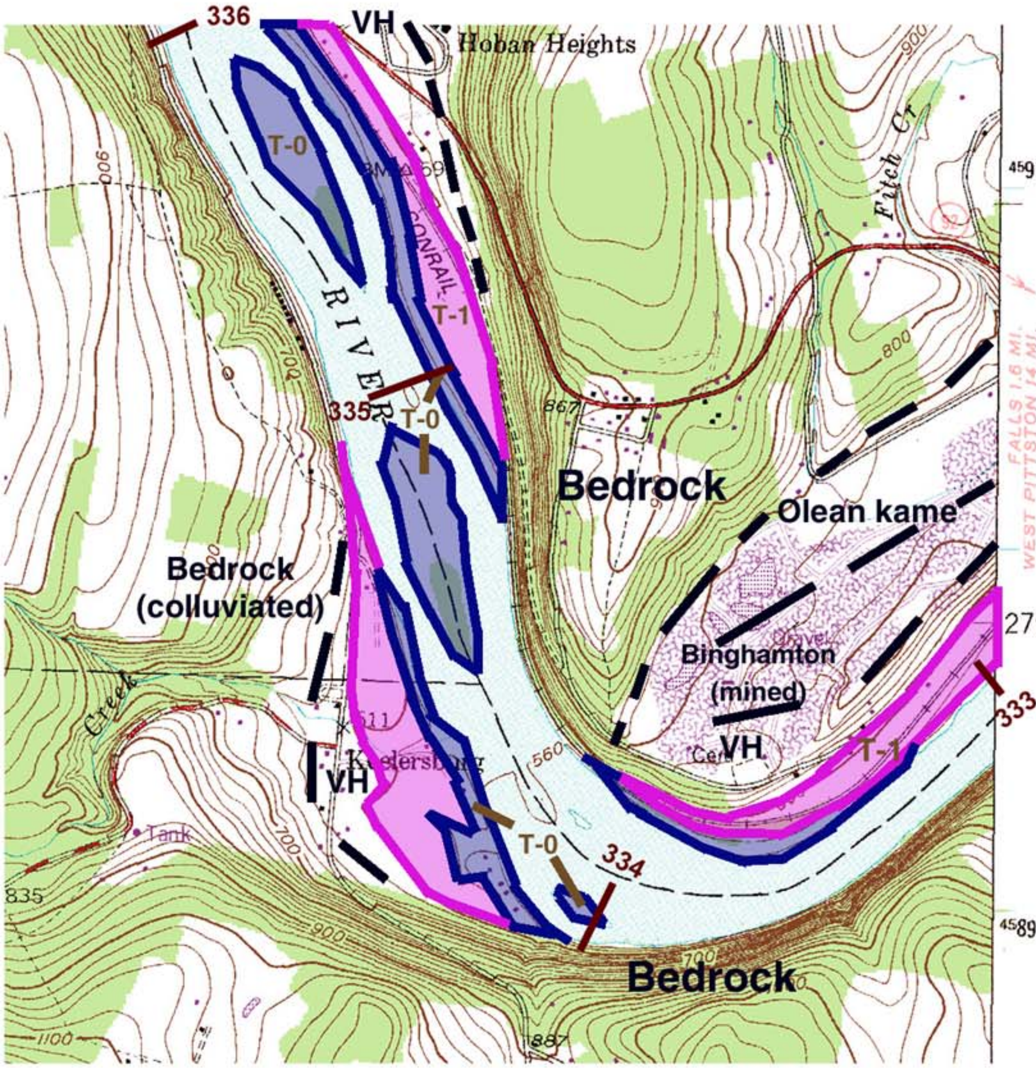
Appendix 1-46: Ransom quad, kilometers 325-327

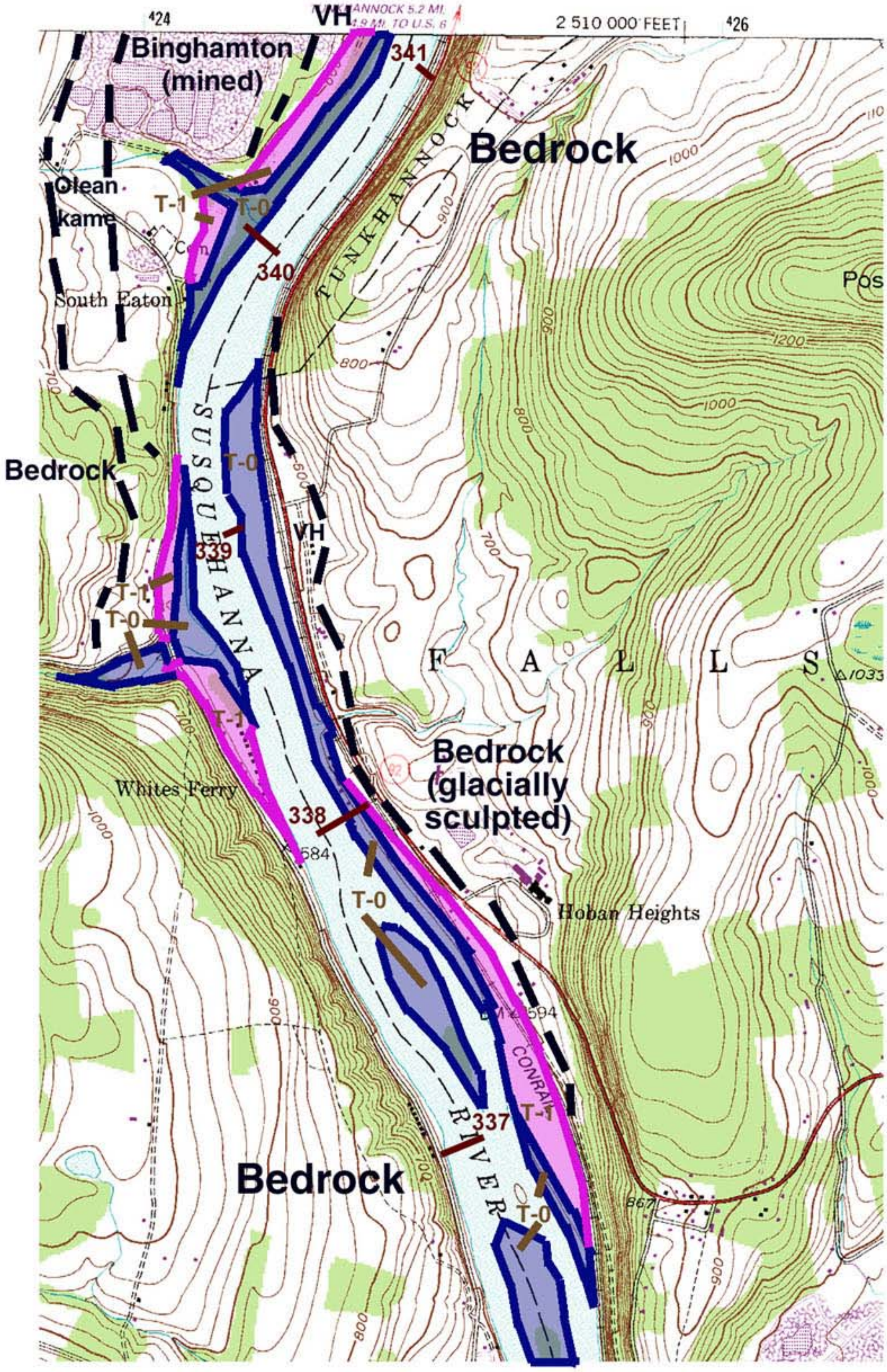


Appendix 1-47: Ransom quad, kilometers 328-330

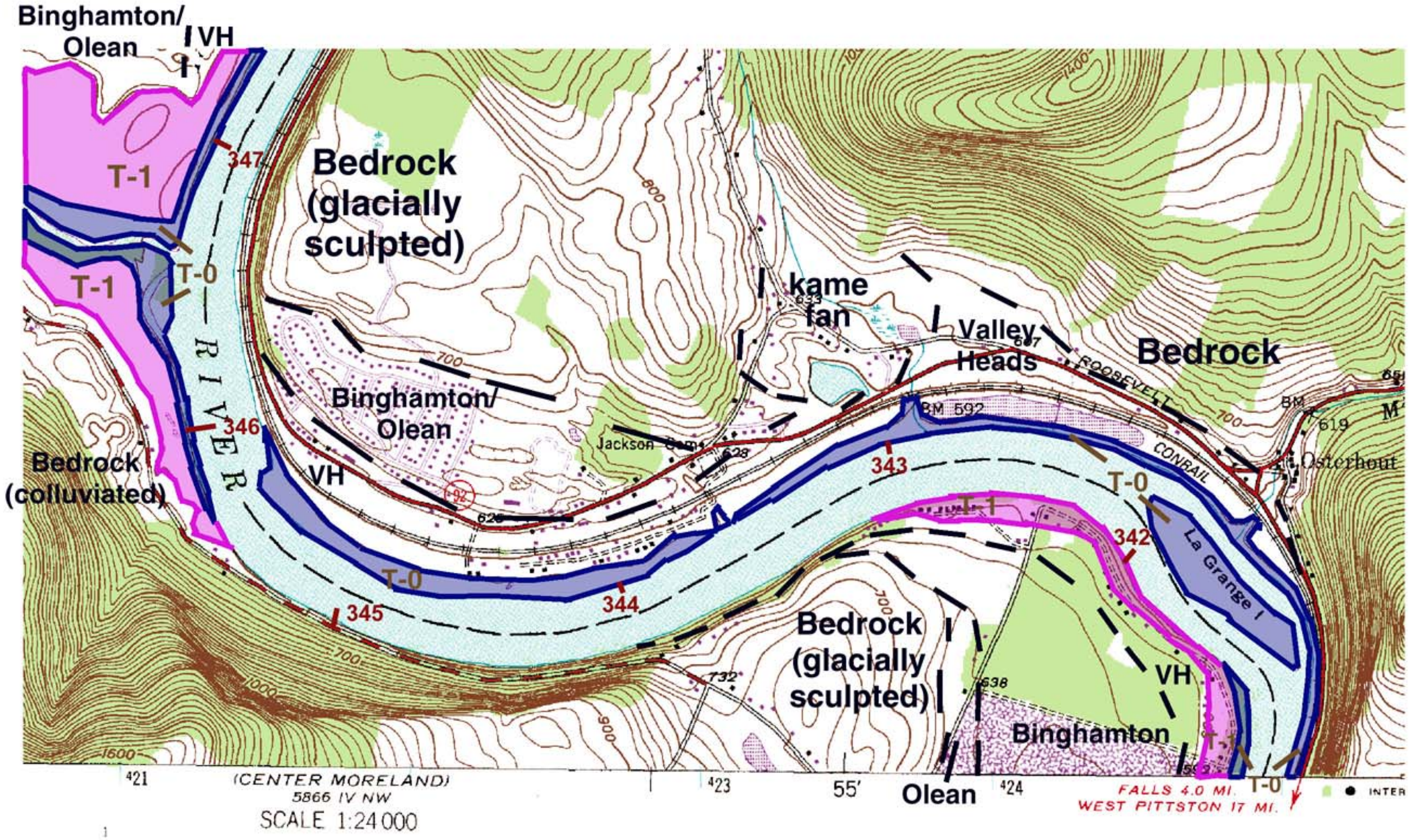


Appendix 1-48: Ransom quad, kilometers 330-333

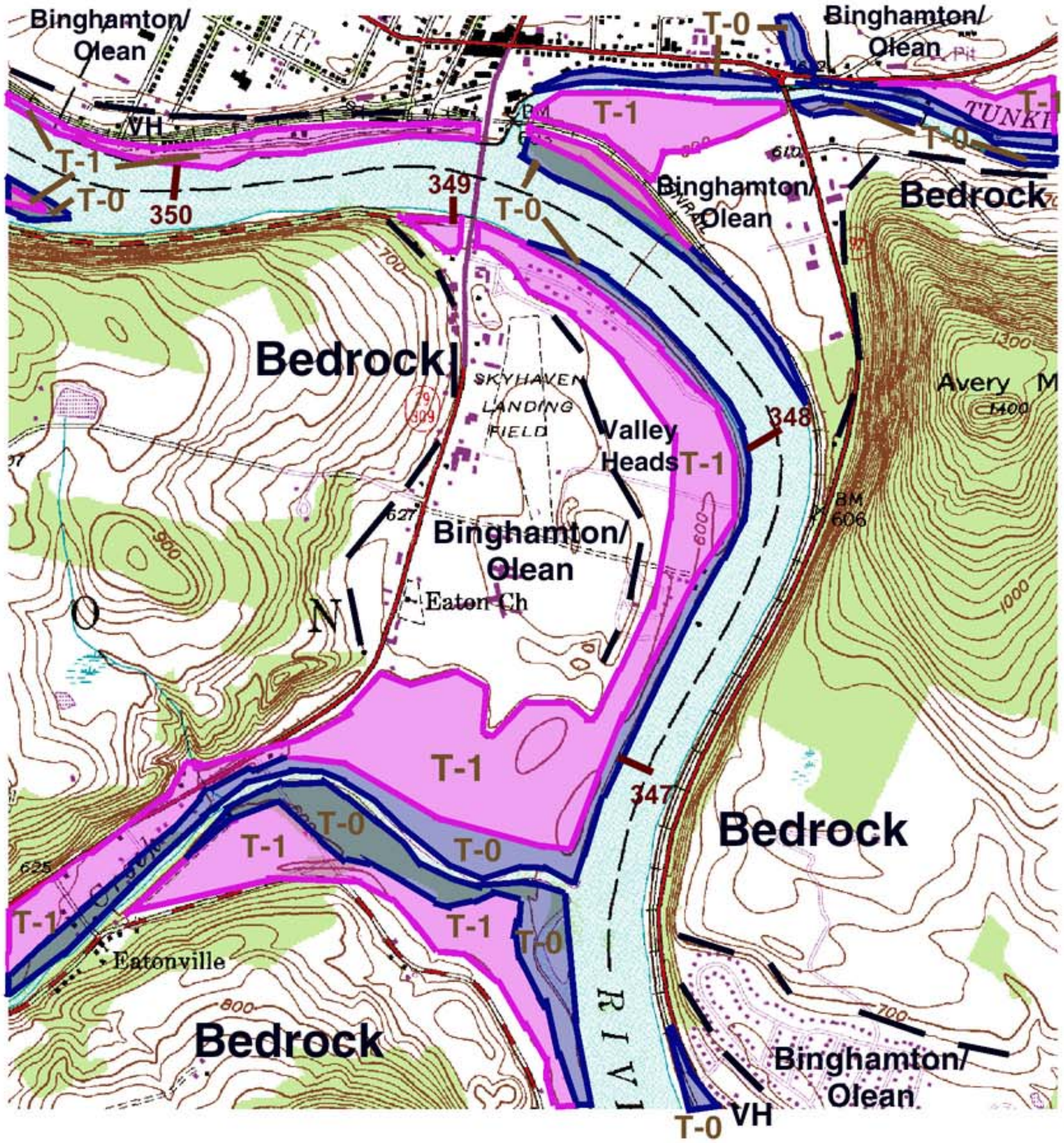

336
VH
Hoban Heights
T-0
CONRAIL
T-1
RIVER
335
T-0
Fitch Cr
Bedrock
Olean kame
Bedrock
(colluviated)
Binghamton
(mined)
VH
T-1
333
27'30
Creek
VH
T-0
334
Tank
Bedrock
WEST PITTSTON 14 MI.
FALLS 1.6 MI.



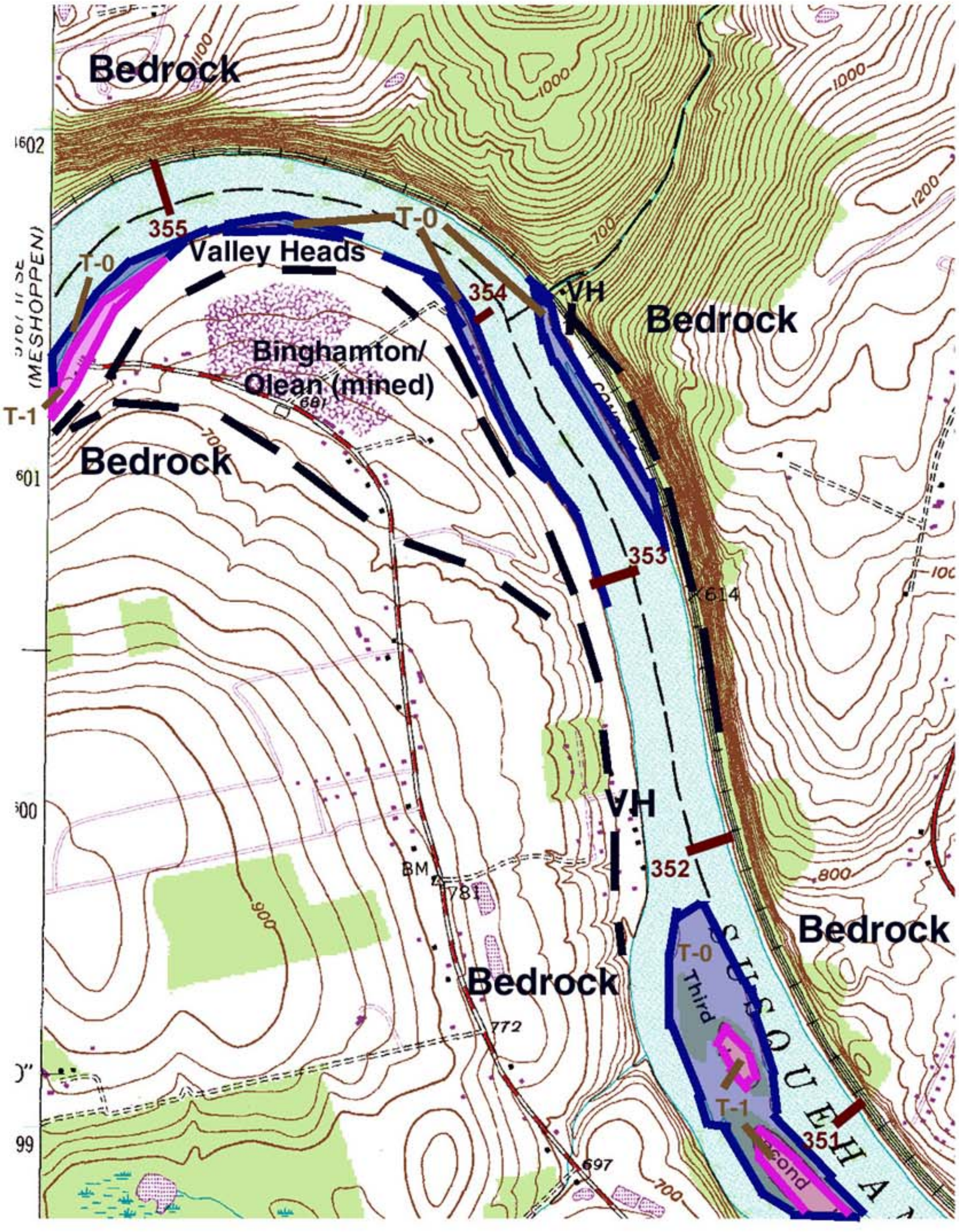
424
VH
TUNKHANNOCK 5.2 MI.
1.9 MI. TO U.S. 6
2 510 000 FEET
426
Binghamton
(mined)
341
Bedrock
Olean
kame
T-1
T-0
340
South Eaton
TUNKHANNOCK
Pos
SUSQUEHANNA
Bedrock
T-0
VH
339
T-1
T-0
FALLS
1033
T-1
Bedrock
(glacially
sculpted)
Whites Ferry
338
584
T-0
Hoban Heights
594
CONRAIL
T-1
337
RIVER
Bedrock
T-0
867



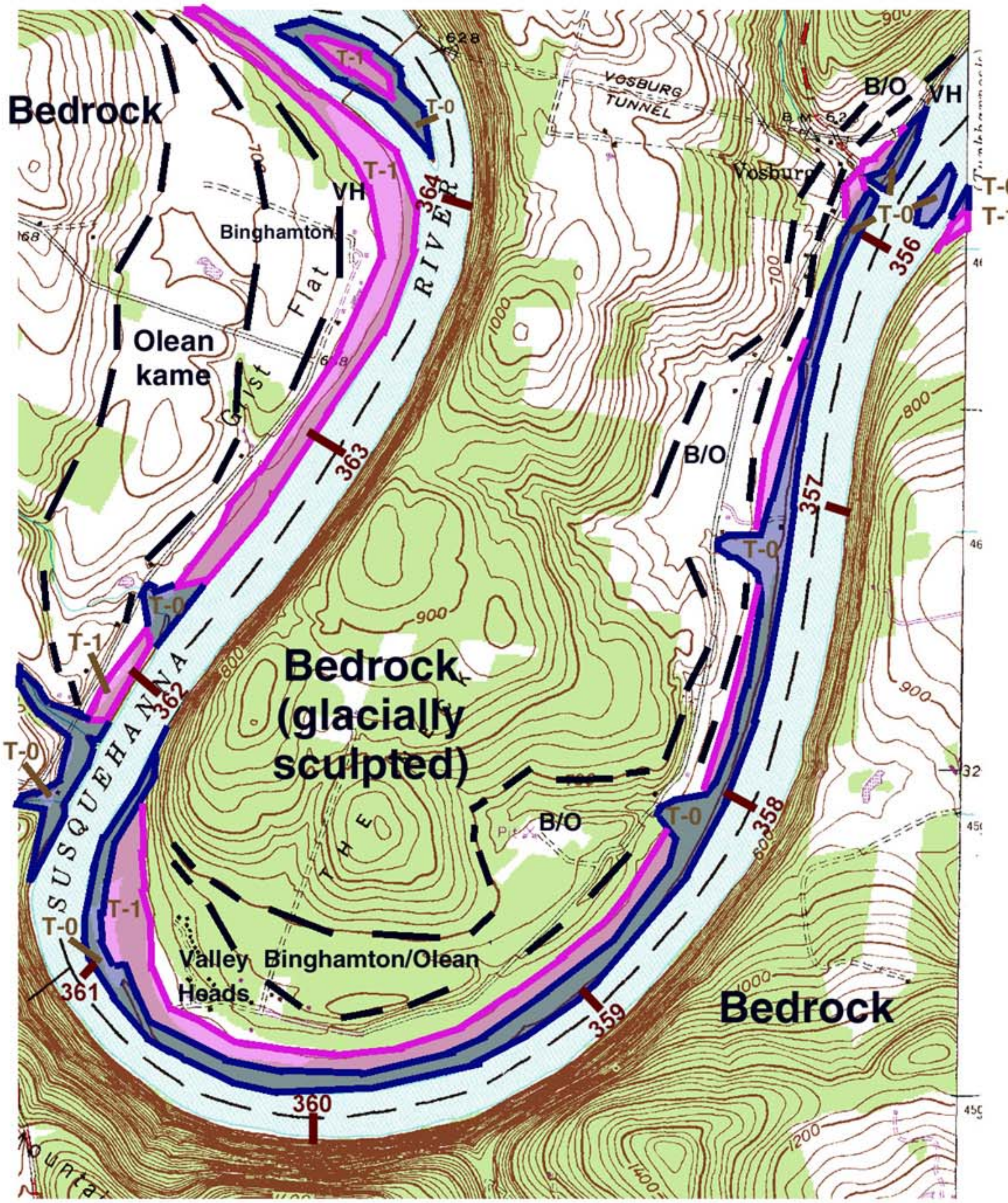
Appendix 1-51: Tunkhannock quad, kilometers 341-347



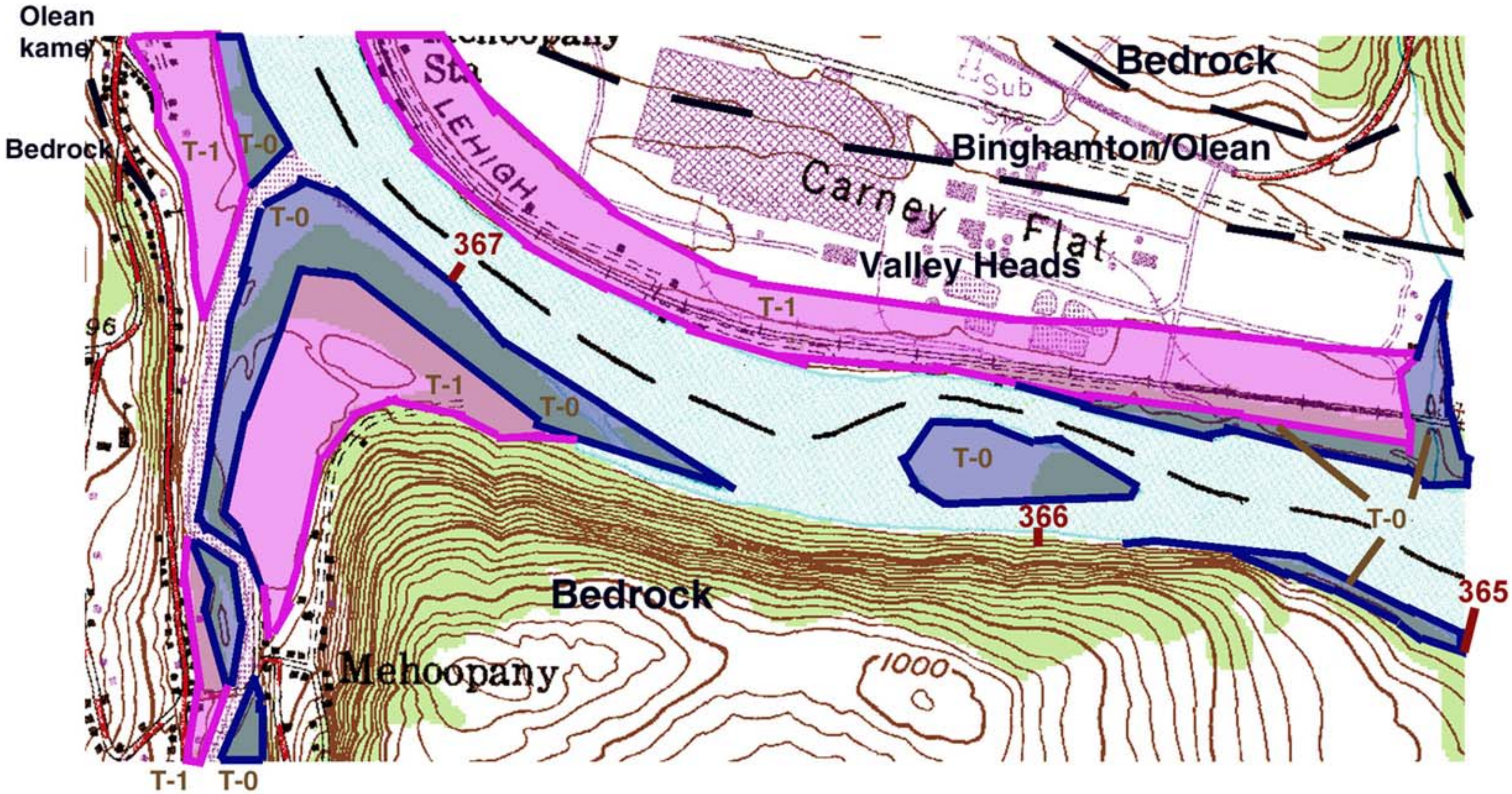
Appendix 1-52: Tunkhannock quad, kilometers 347-350



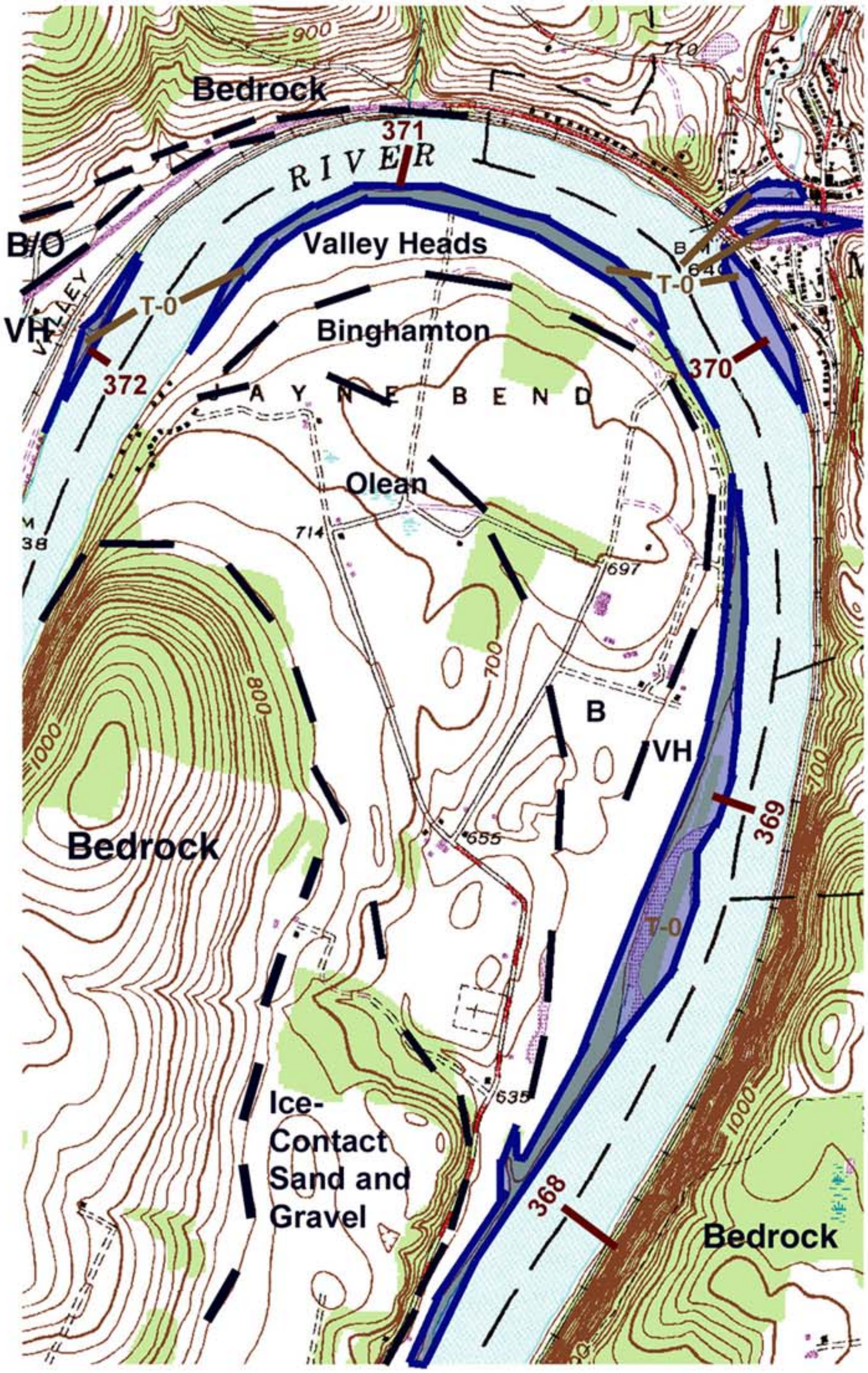
Appendix 1-53: Tunkhannock quad, kilometers 351-355



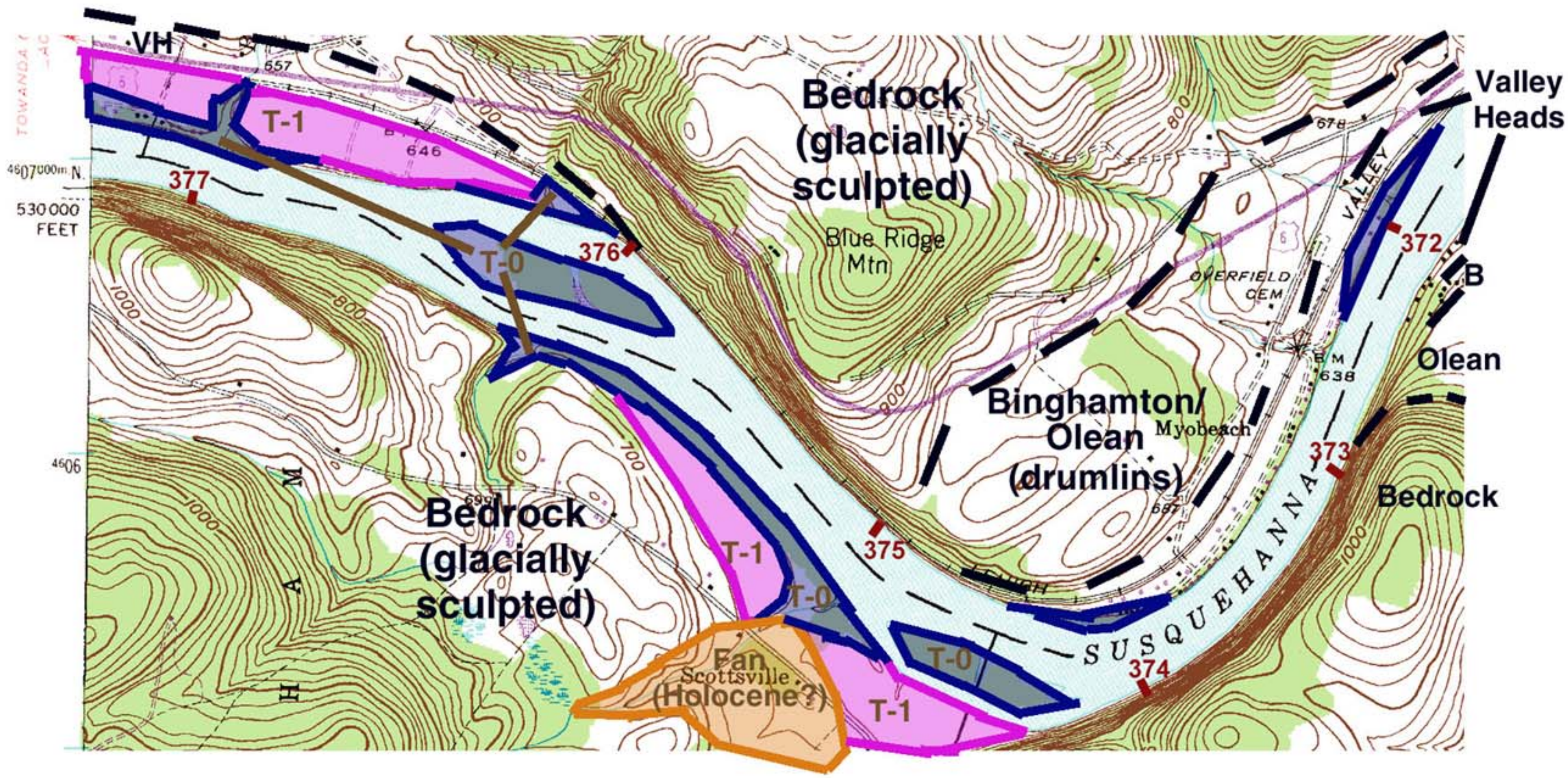
Appendix 1-54: Meshoppen quad, kilometers 356-365



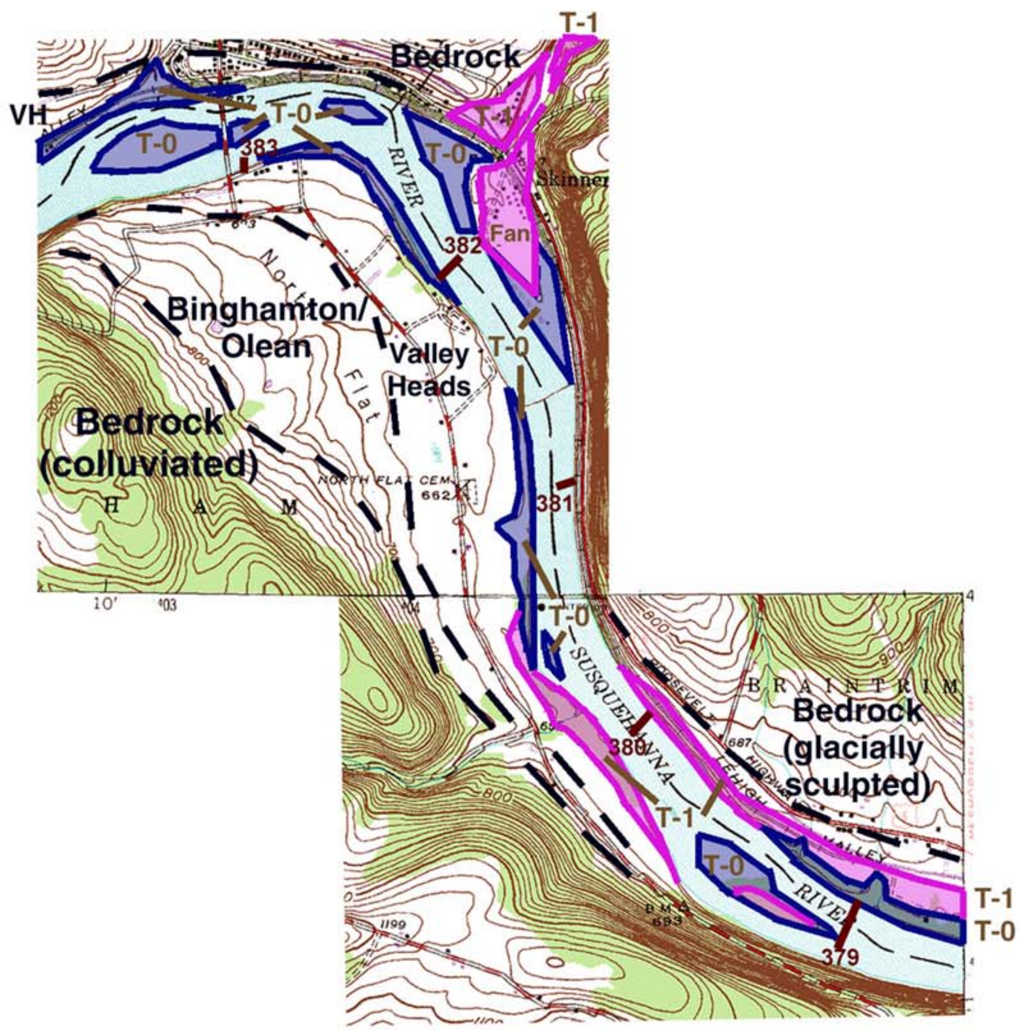
Appendix 1-55: Meshoppen quad, kilometers 365-367



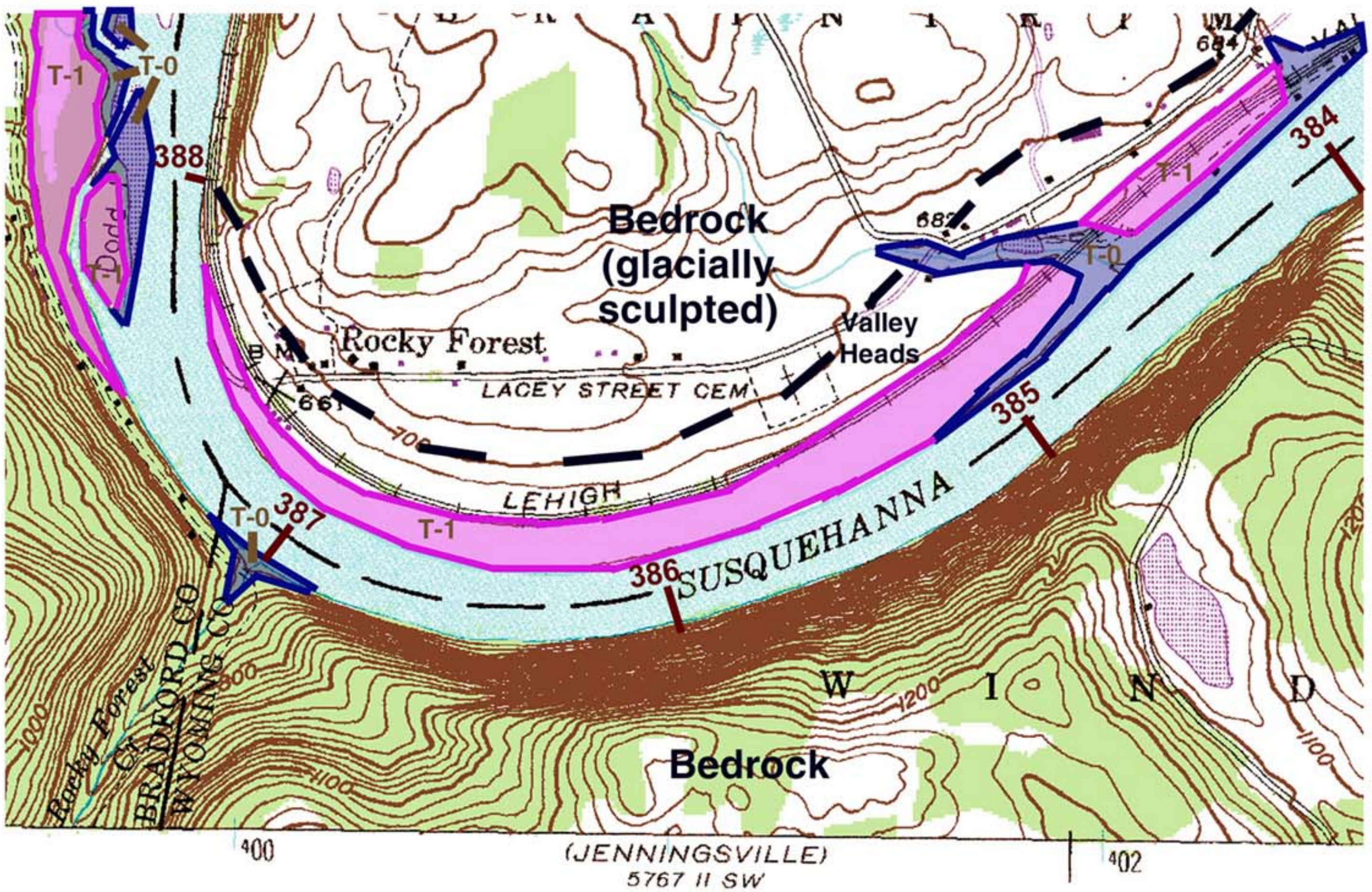
Appendix 1-56: Meshoppen quad, kilometers 368-372



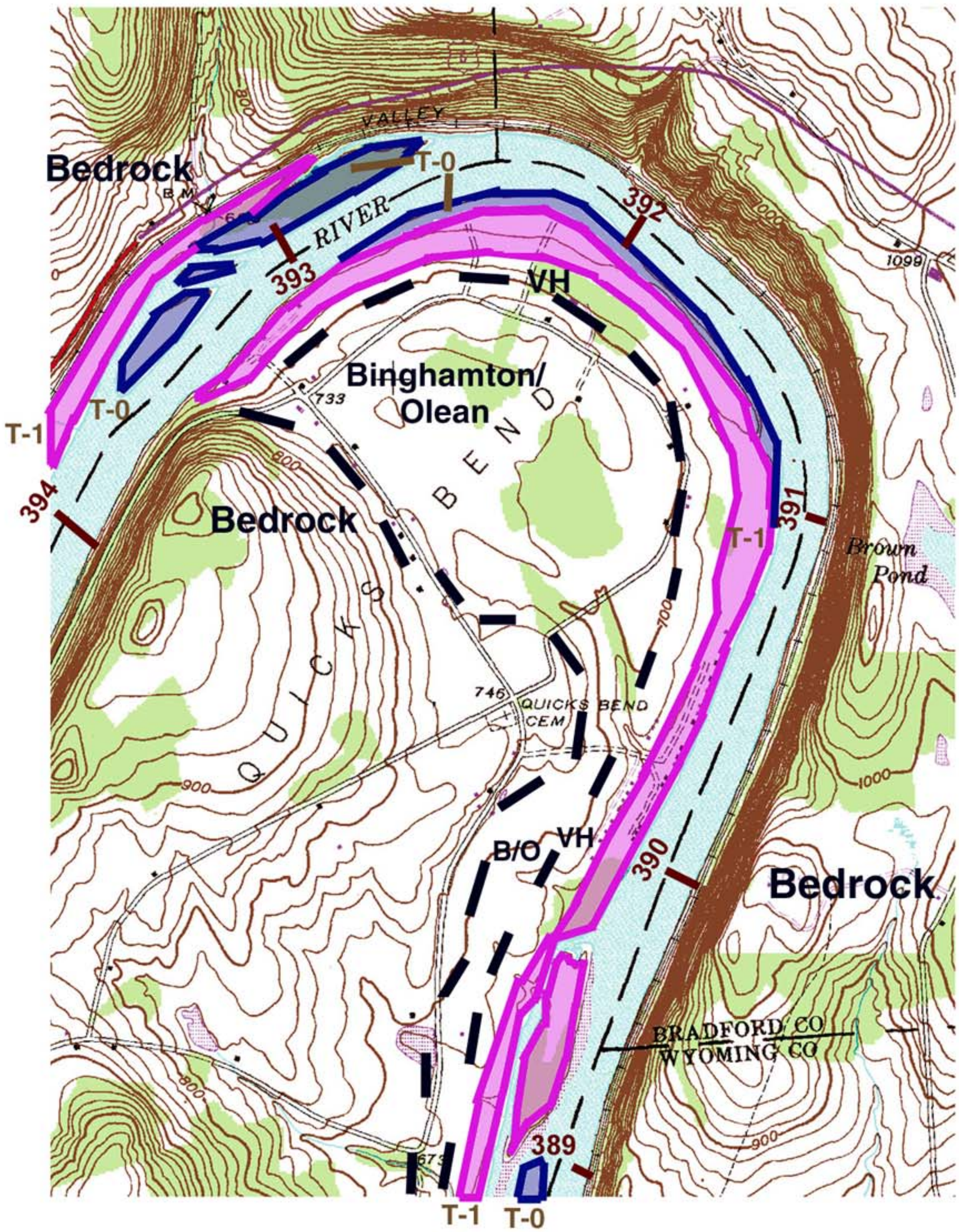
Appendix 1-57: Meshoppen quad, kilometers 372-378



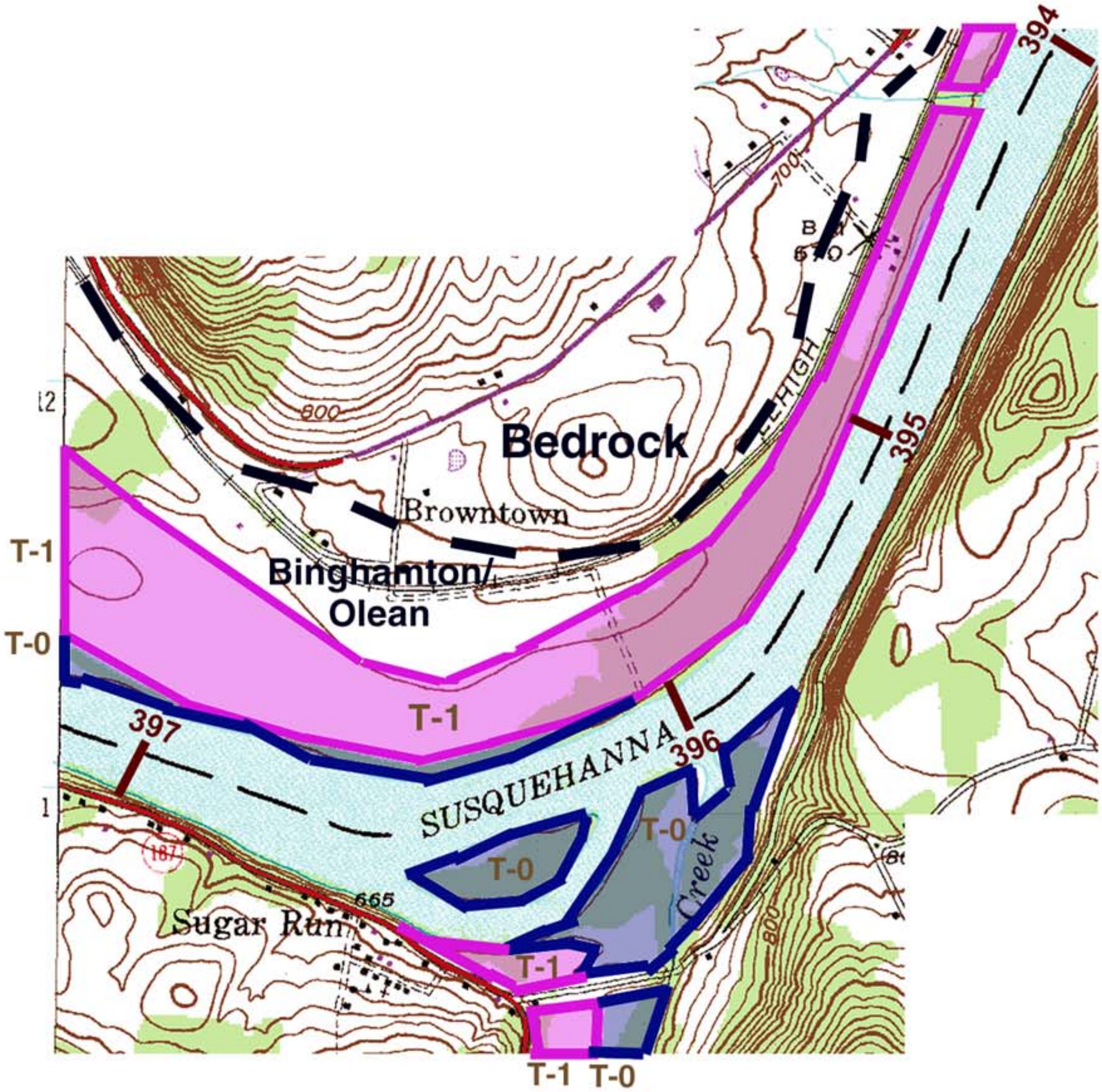
Appendix 1-58: Jenningsville/Laceyville quad, kilometers 379-384



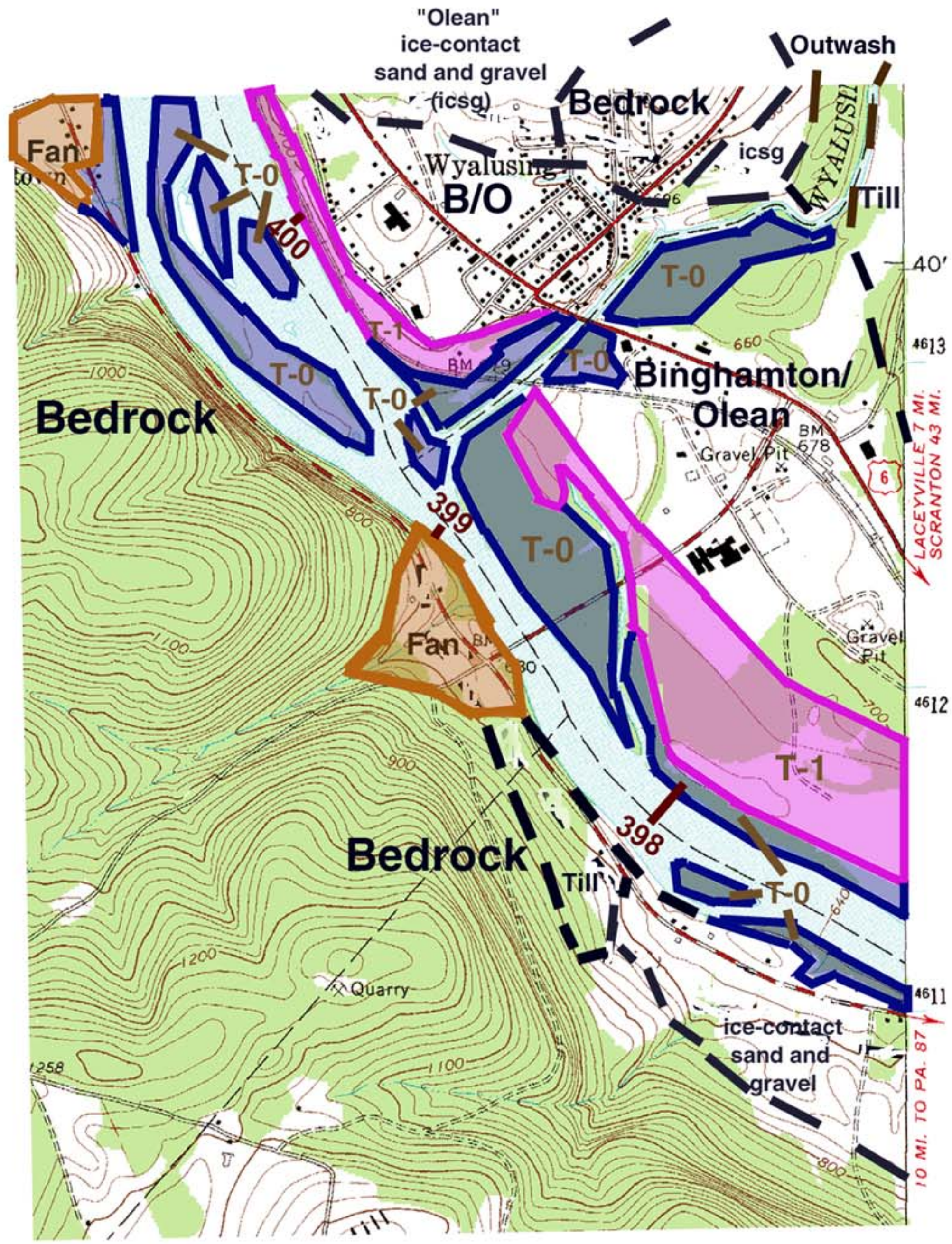
Appendix 1-59: Laceyville quad, kilometers 384-388



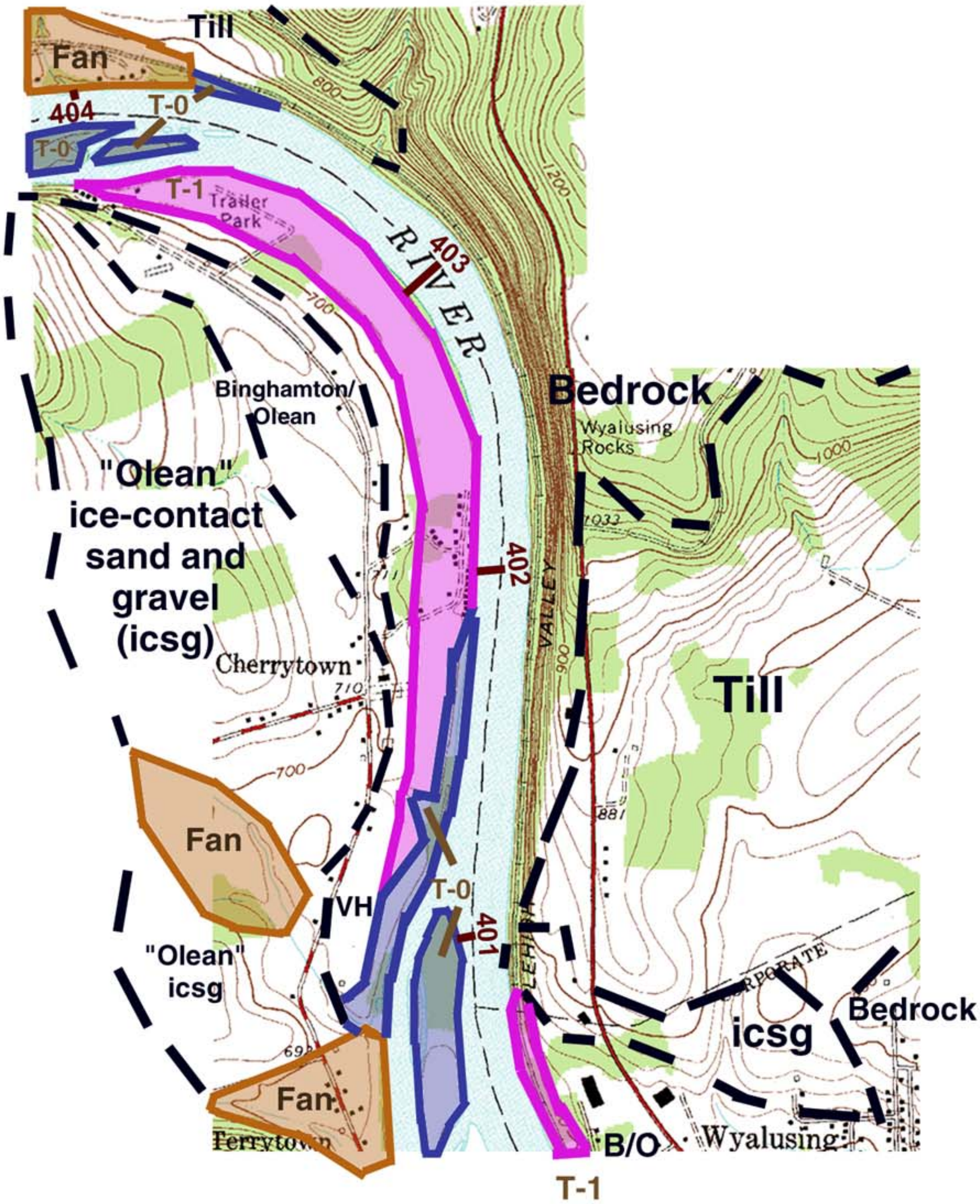
Appendix 1-60: Laceyville quad, kilometers 389-394



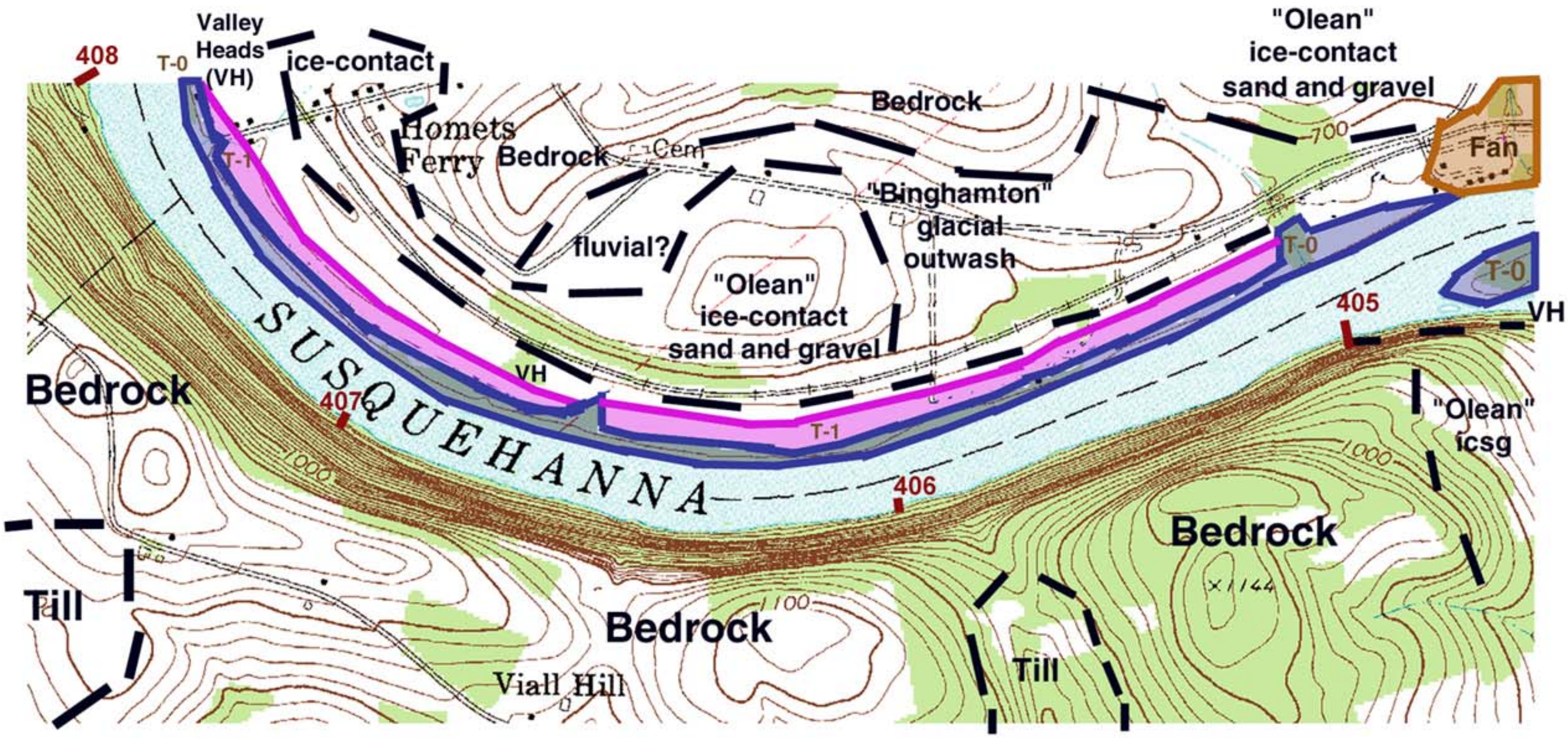
Appendix 1-61: Laceyville quad, kilometers 394-397



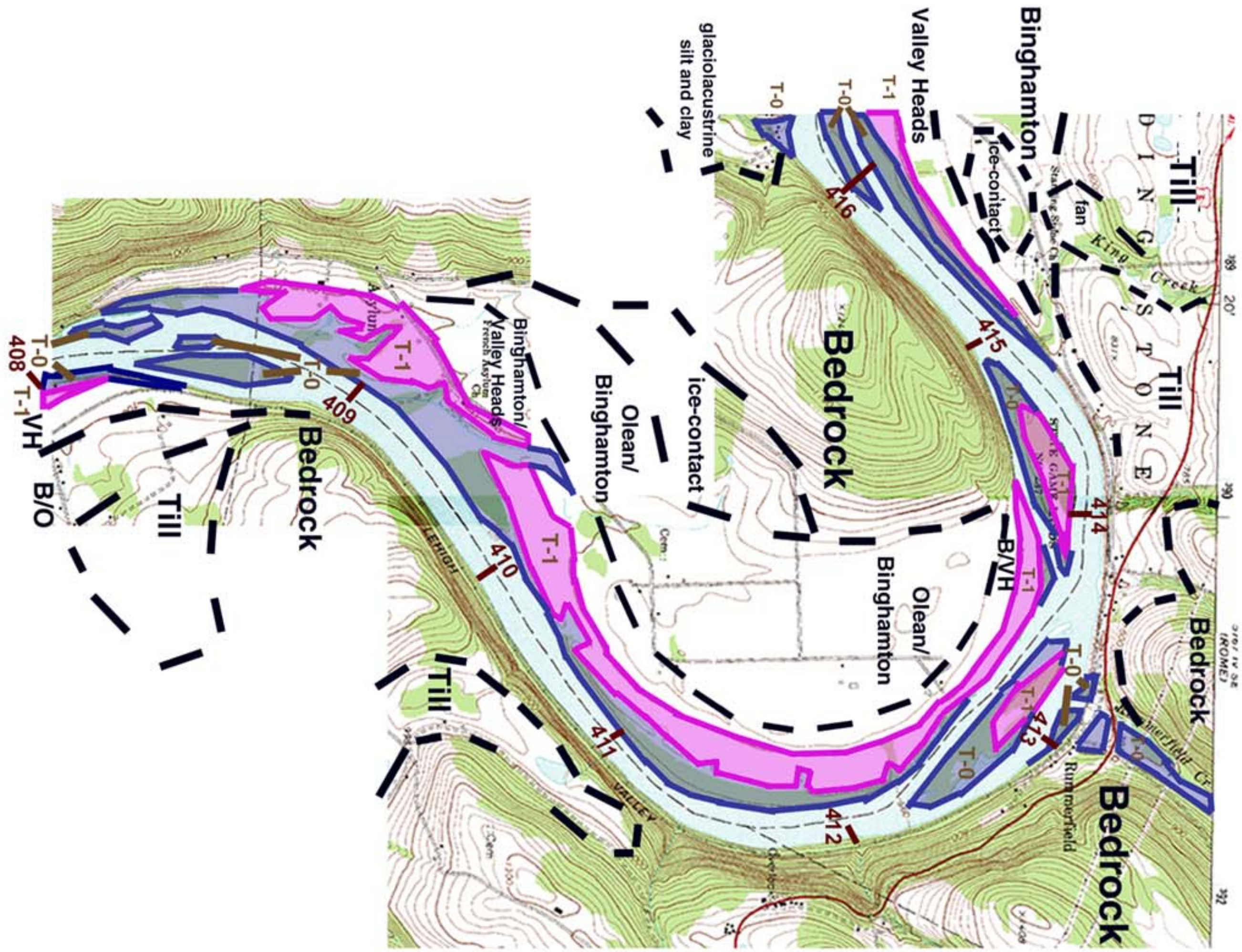
Appendix 1-62: Wyalusing quad, kilometers 398-400



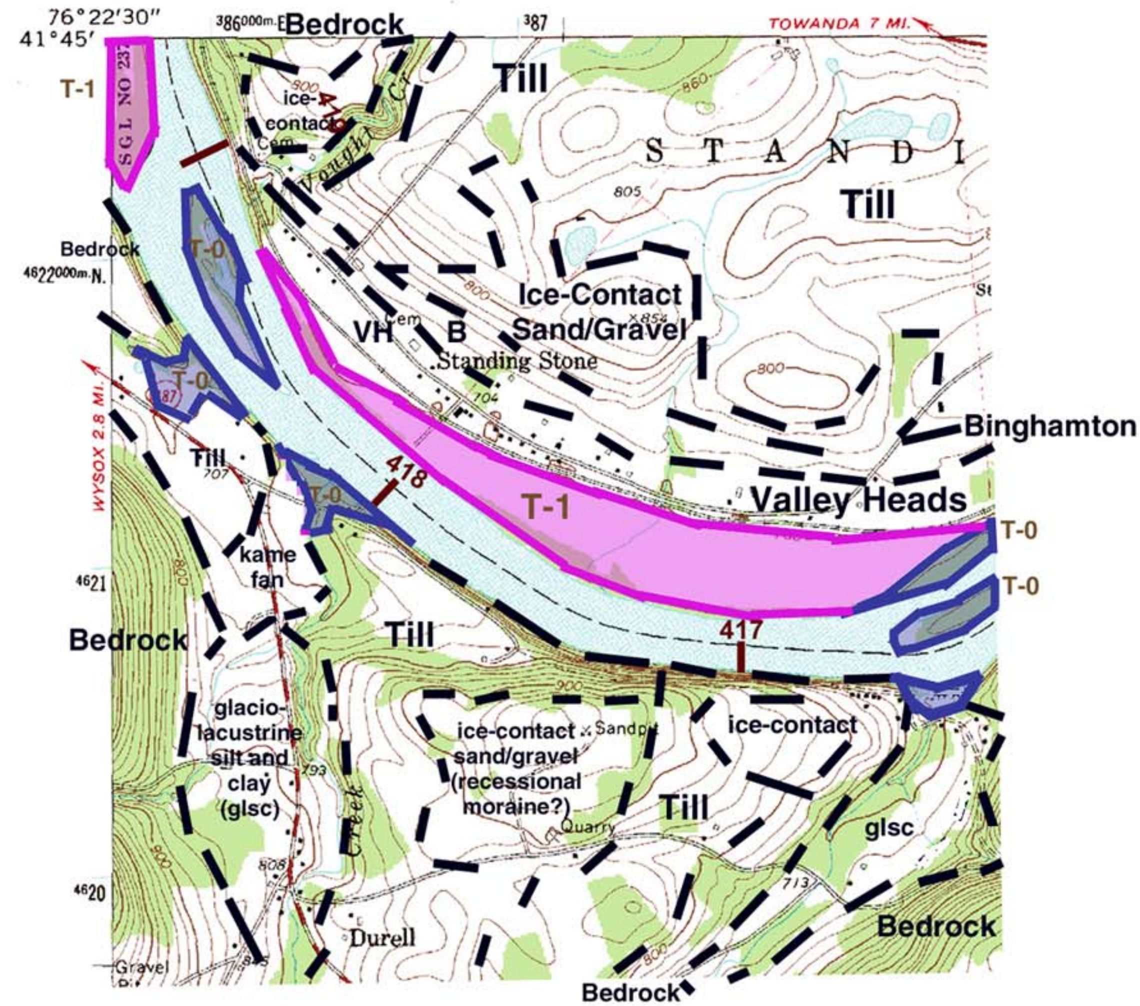
Appendix 1-63: Wyalusing quad, kilometers 401-404



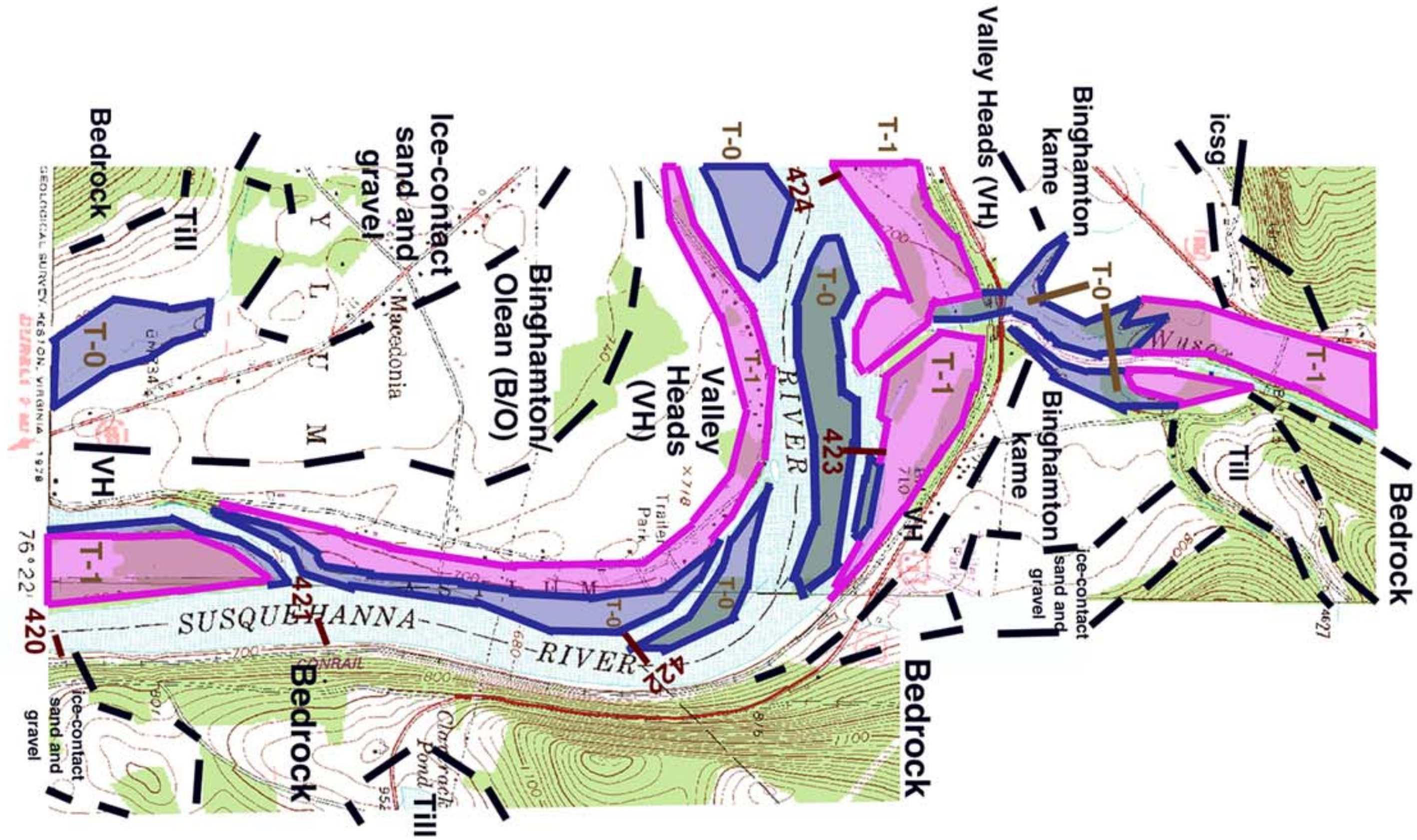
408
T-0
Valley
Heads
(VH)
ice-contact
Hornets
Ferry
Bedrock
Cem
Bedrock
"Olean"
ice-contact
sand and gravel
Fan
T-1
"Binghamton"
glacial
outwash
fluvial?
"Olean"
ice-contact
sand and gravel
T-0
T-0
405
VH
SUSQUEHANNA
VH
Bedrock
407
T-1
"Olean"
icsg
1000
406
1000
Bedrock
Till
1100
Bedrock
Till
Viall Hill



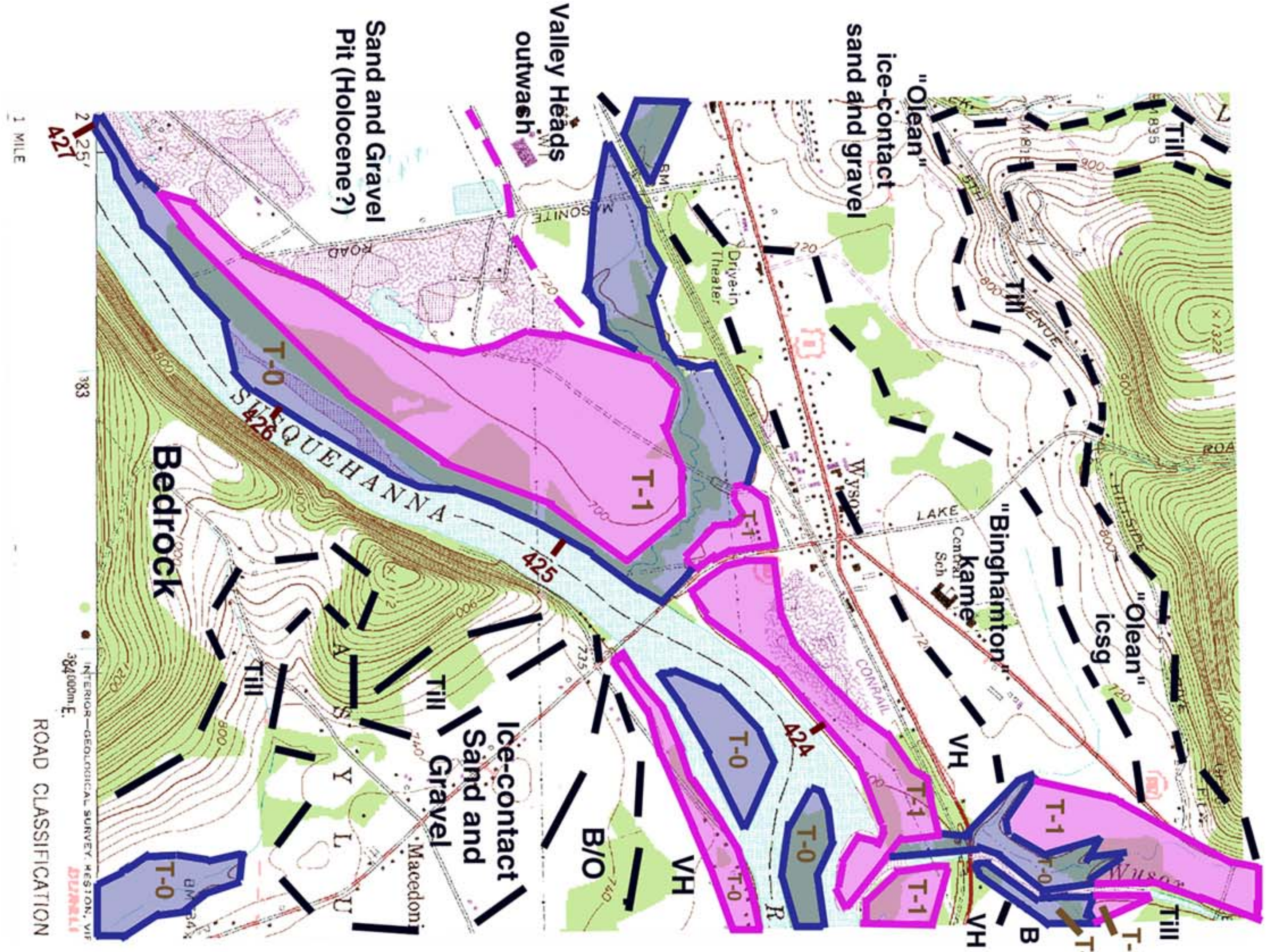
Appendix 1-65:Wyalusing quad, kilometers 408-416



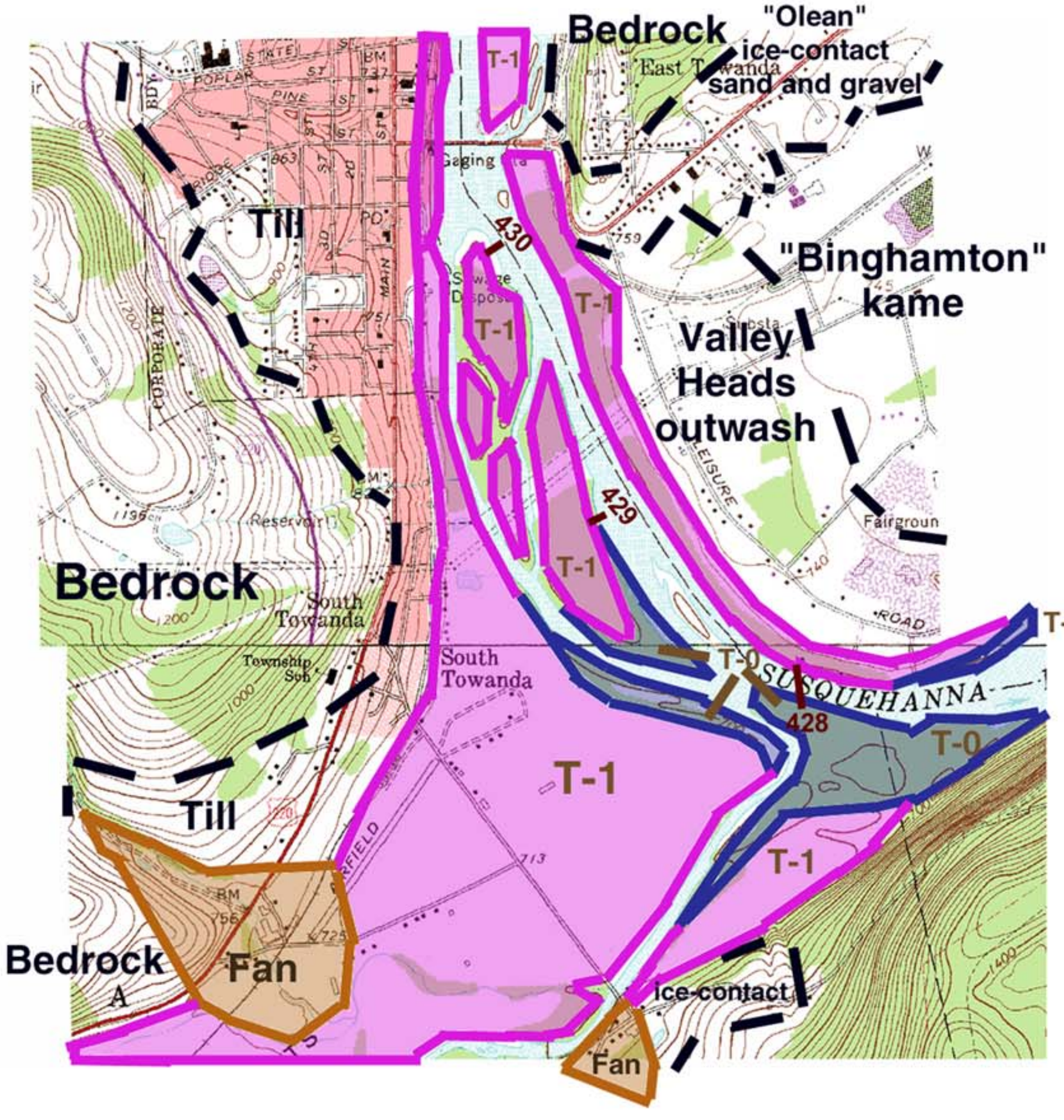
Appendix 1-66: Wyalusing quad, kilometers 47-49



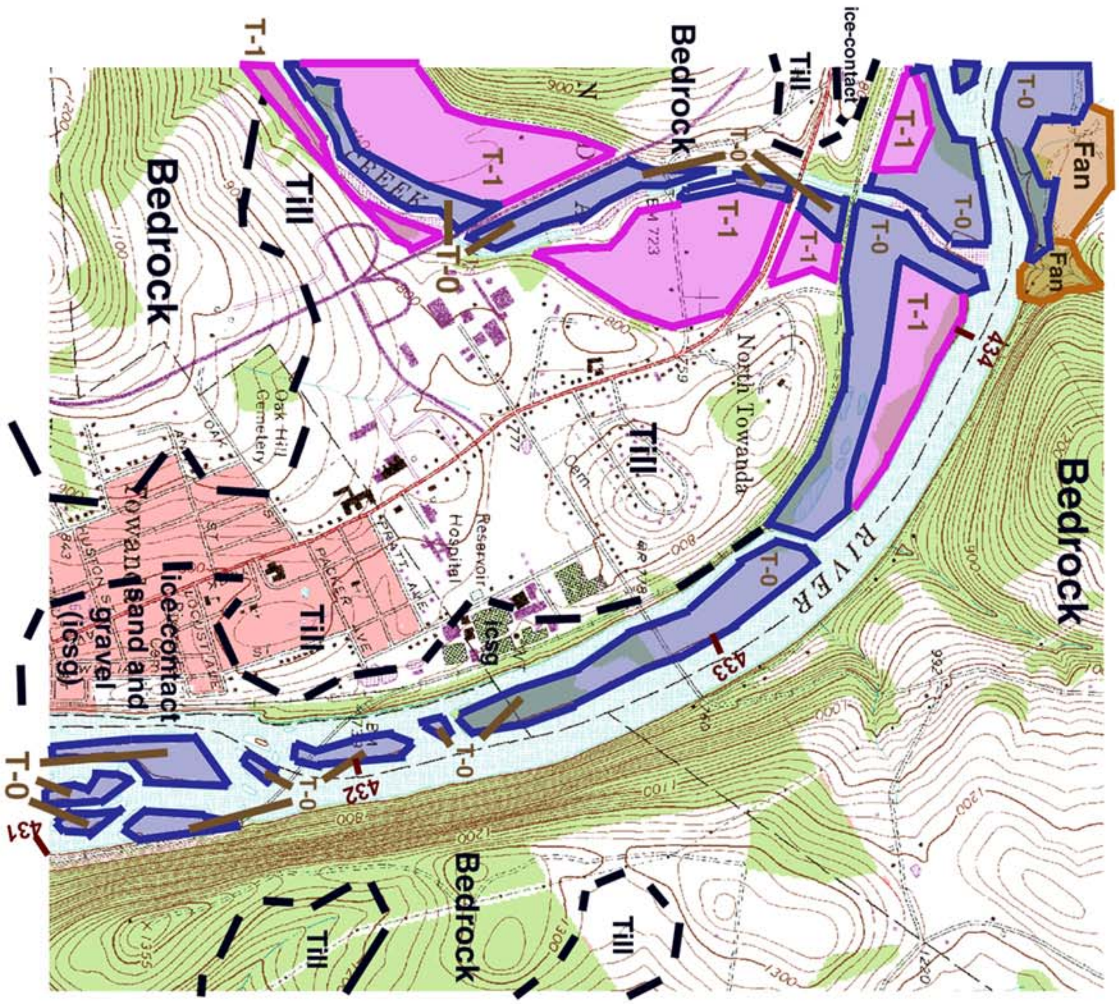
Appendix 1-67: Towanda quad, kilometers 420-424



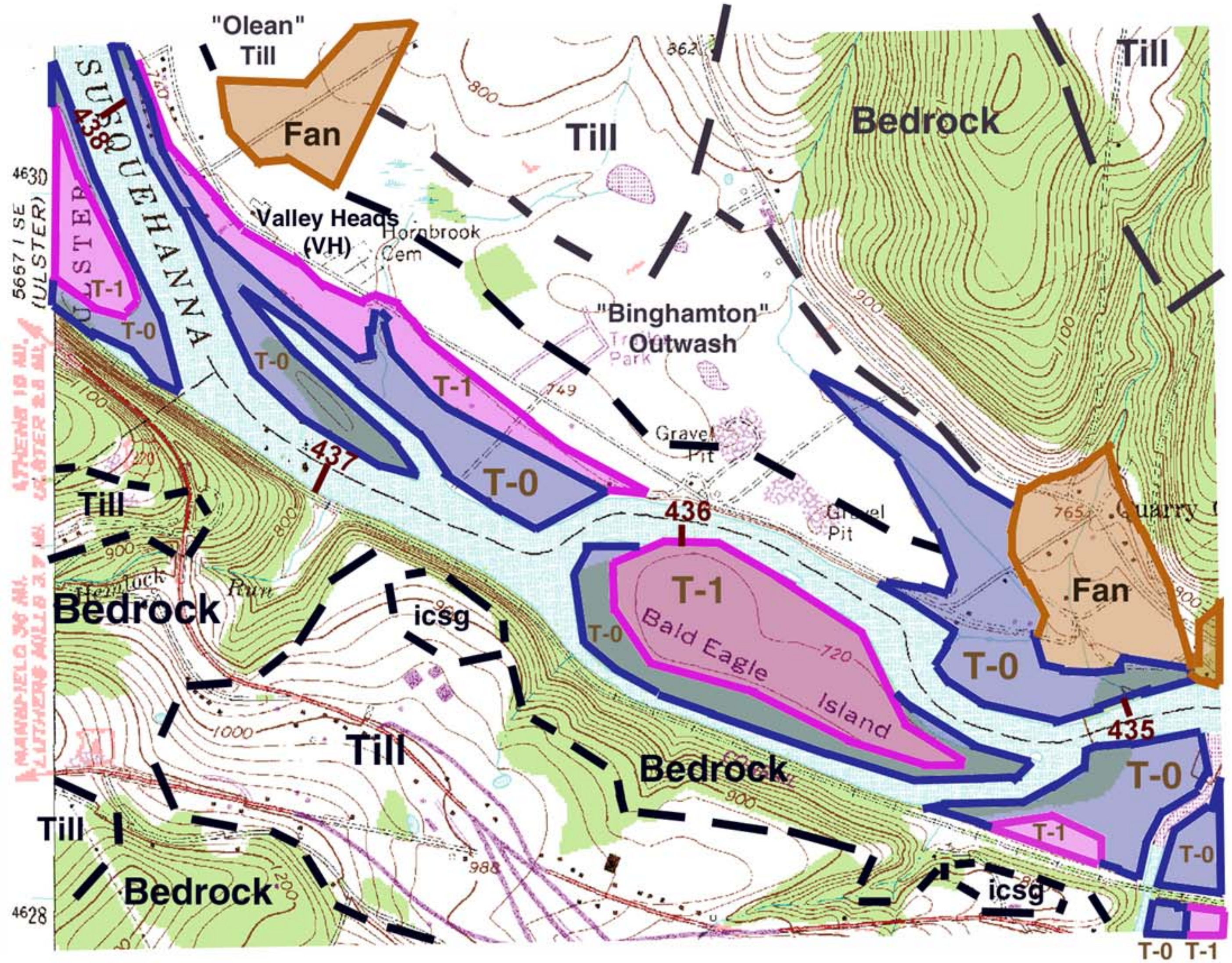
Appendix 1-68: Towanda quad, kilometers 424-427



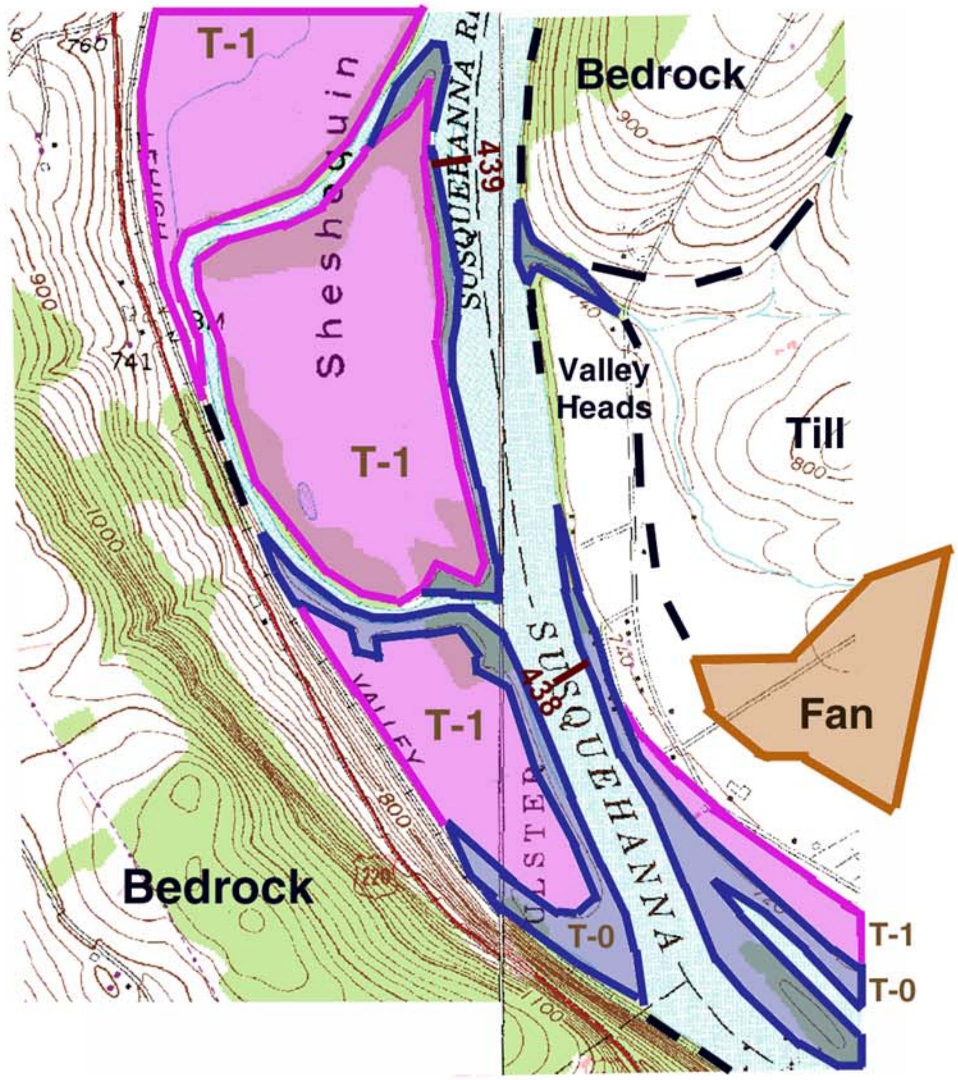
Appendix 1-69: Towanda quad, kilometers 428-431



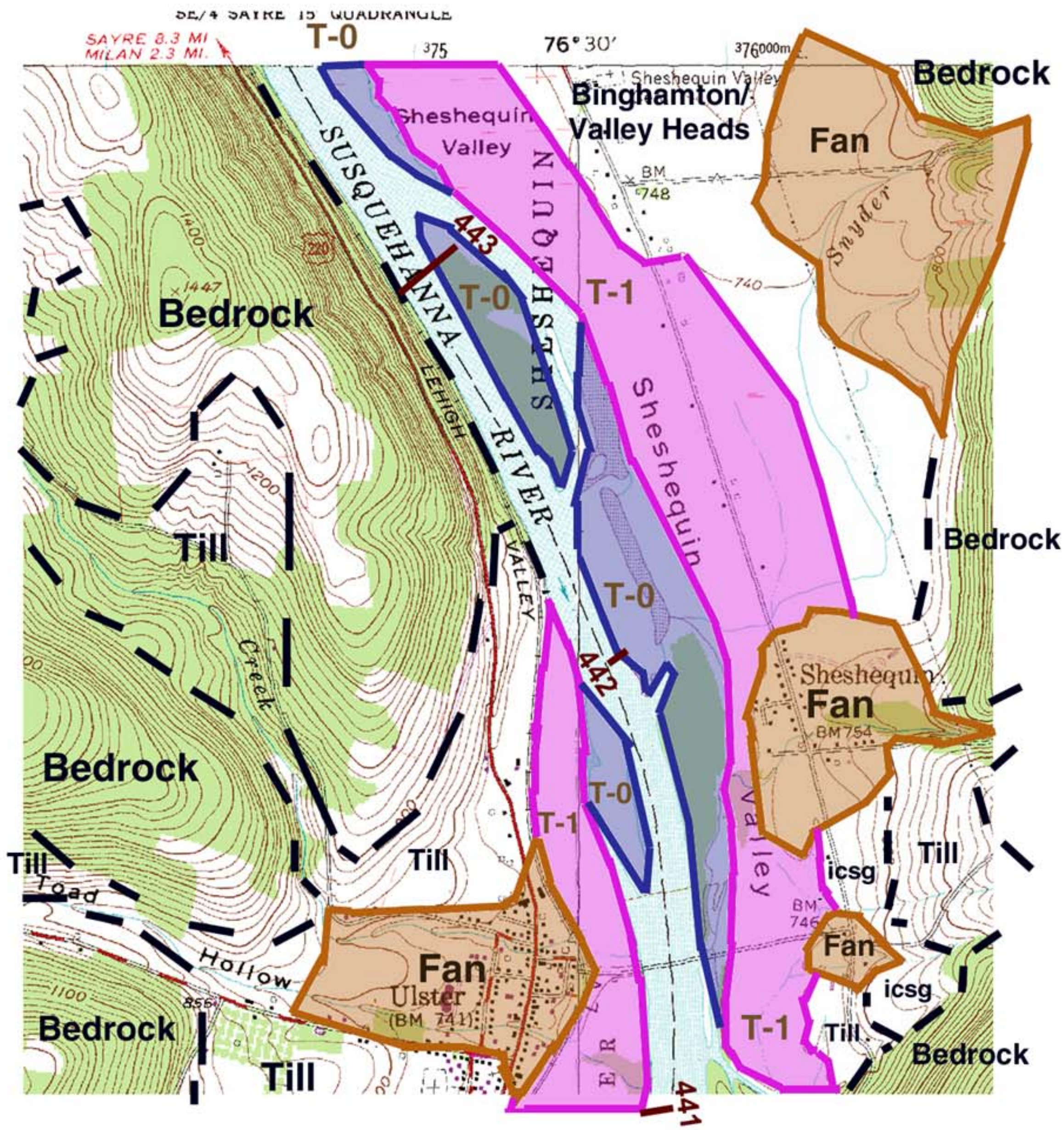
Appendix 1-70: Towanda quad, kilometers 432-434



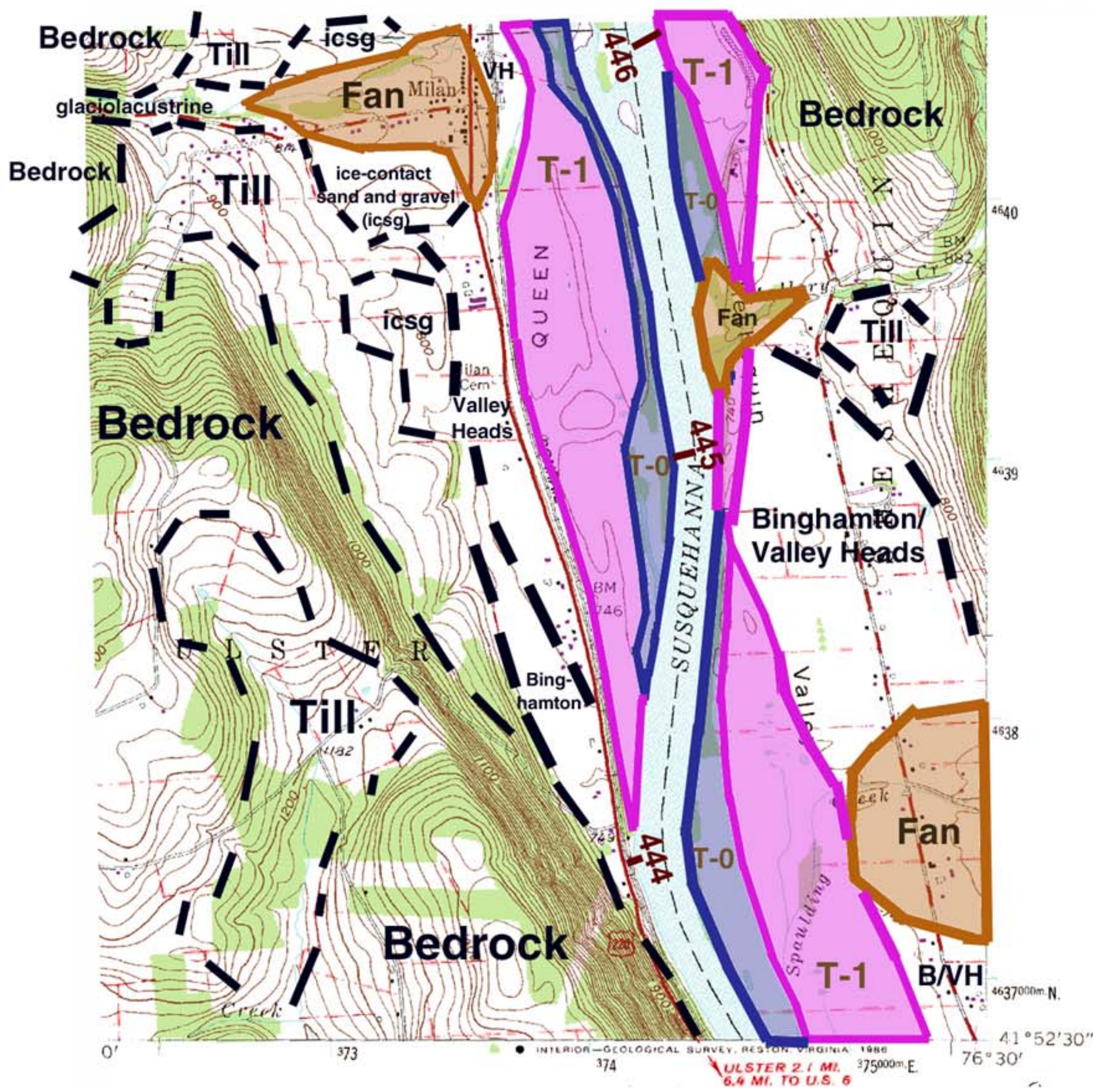
Appendix 1-71: Towanda quad, kilometers 435-438



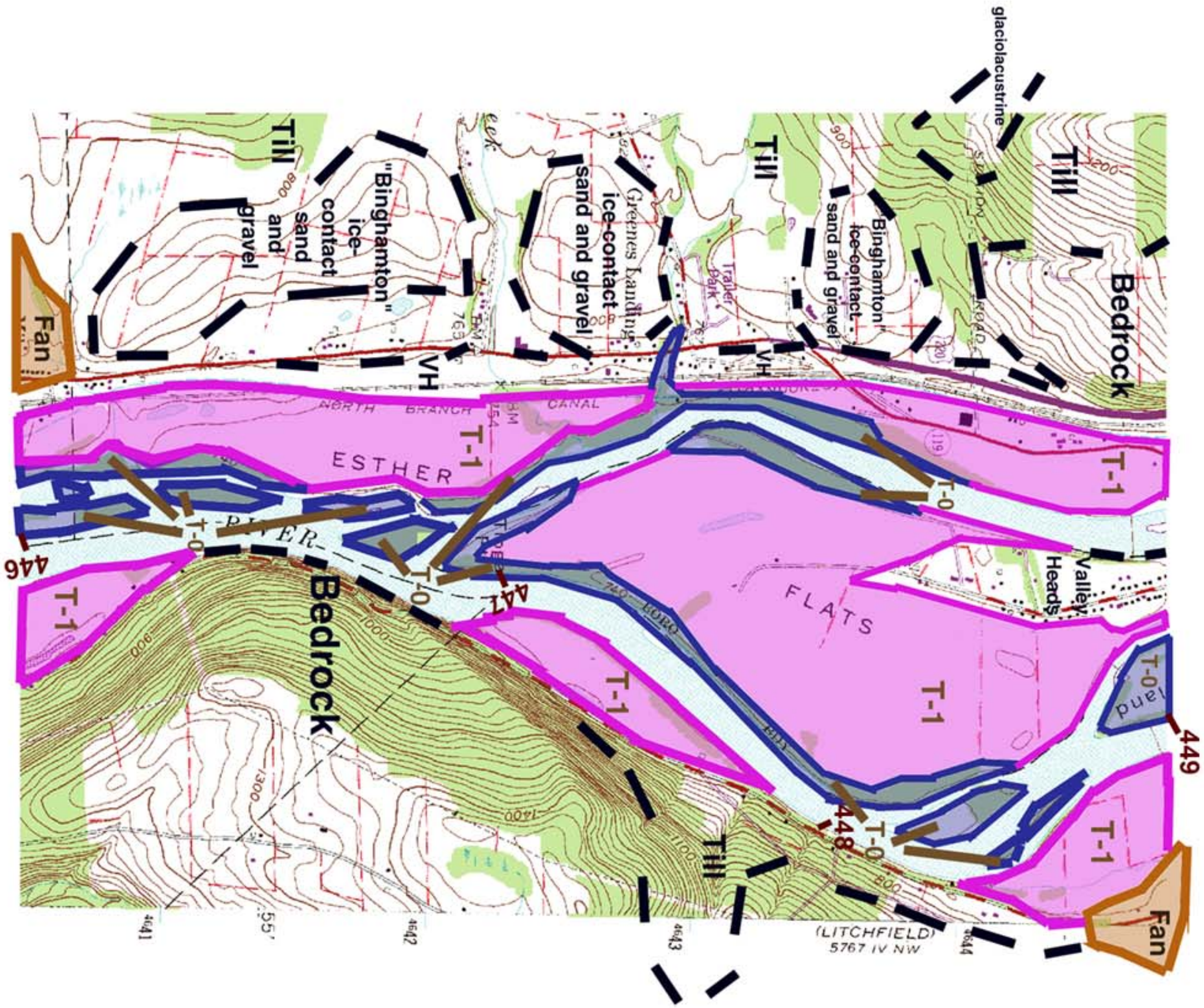
Appendix 1-72: Towanda/Ulster quads, kilometers 437-430



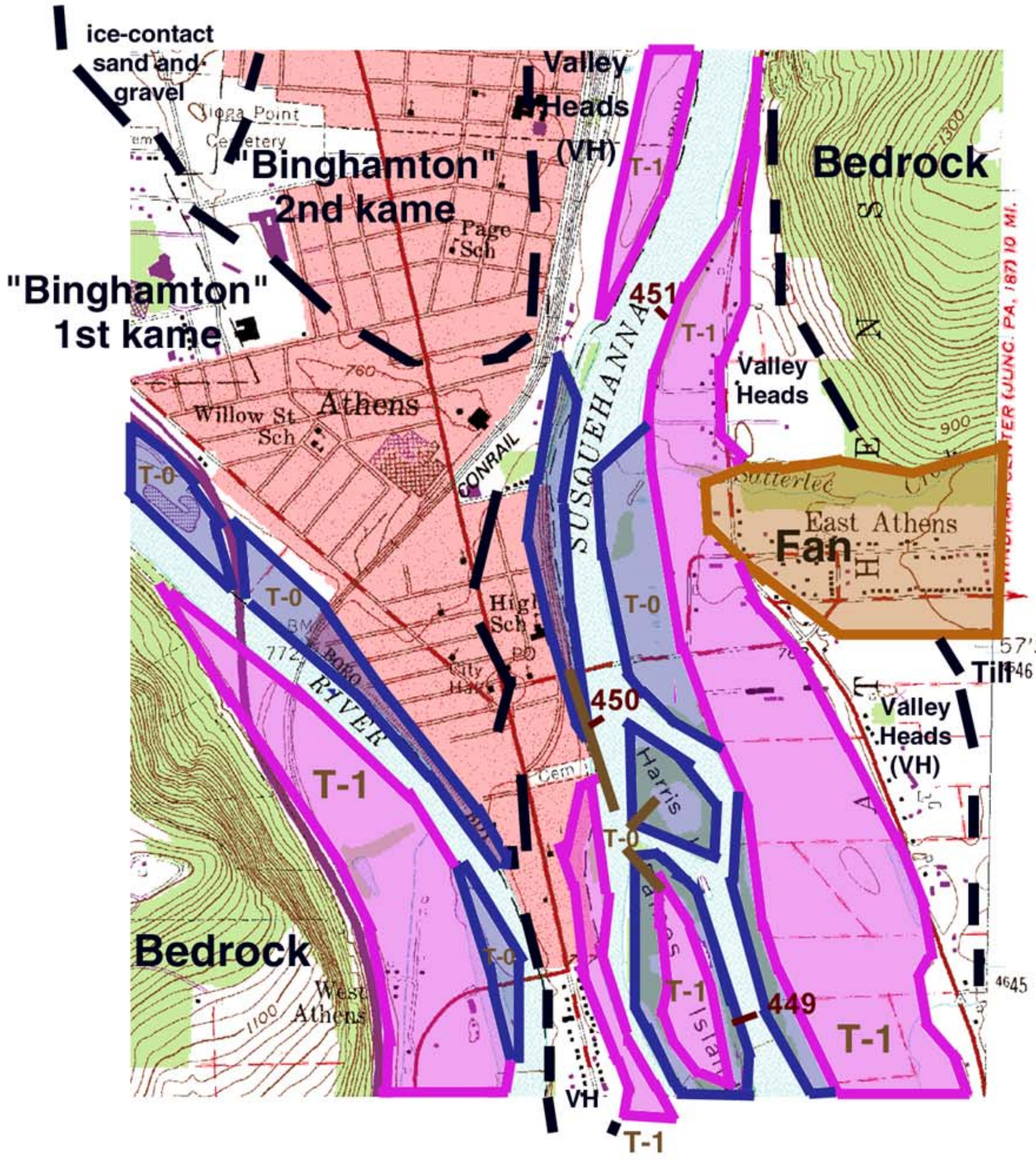
Appendix 1-73: Towanda/Ulster quads, kilometers 441-444



Appendix 1-74: Sayre quad, kilometers 444-446



Appendix 1-75: Sayre quad, kilometers 446-449



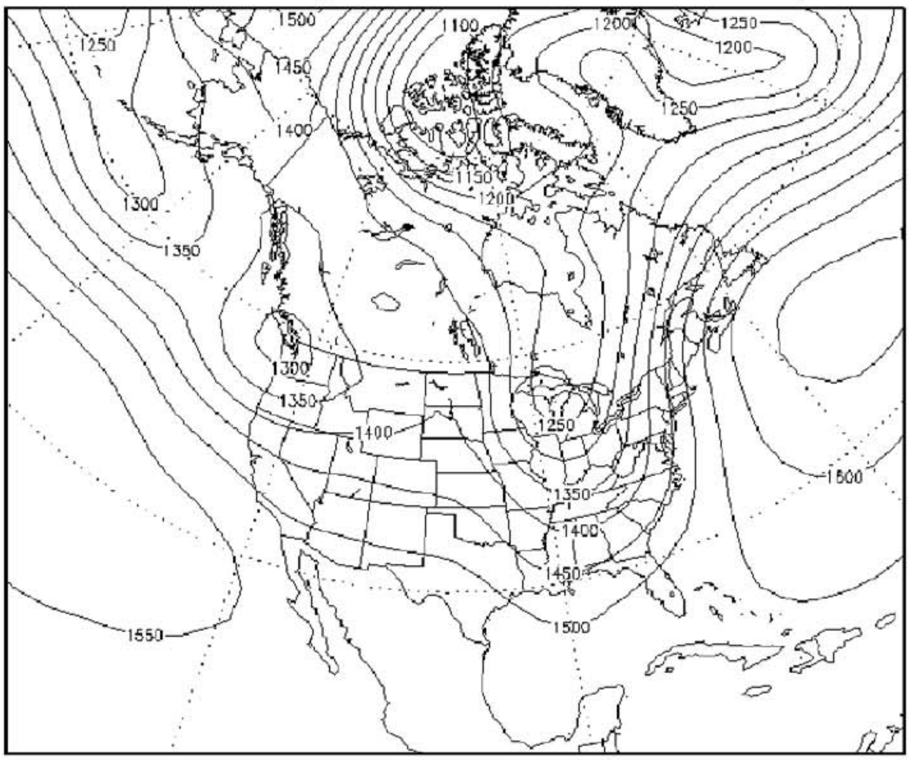
Appendix 1-76: Sayre quad, kilometers 449-452

APPENDIX 2

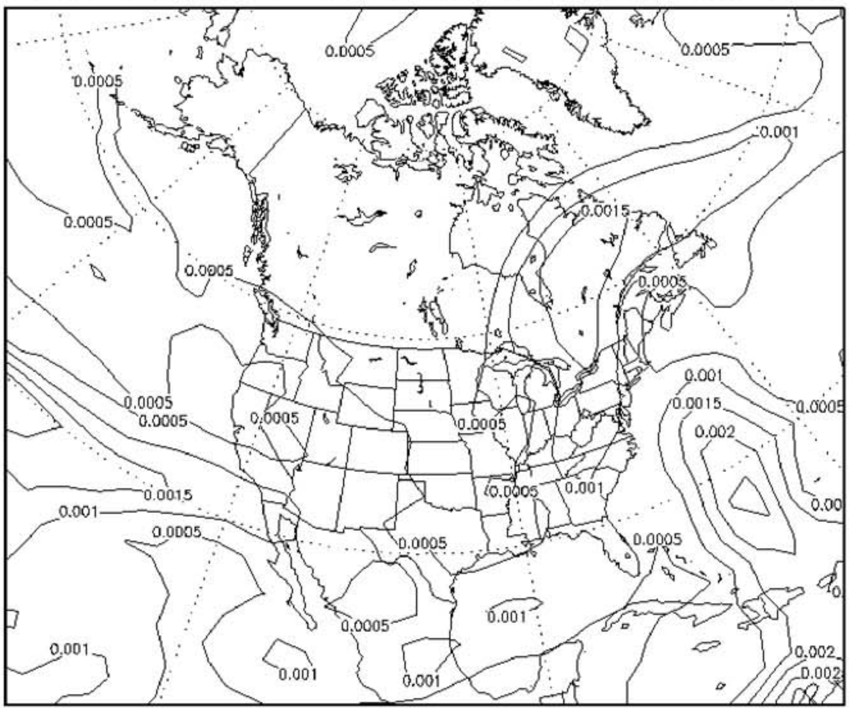
SYNOPTIC METEOROLOGICAL REANALYSES

The following synoptic meteorological maps were downloaded from NOAA (1999). Maps of the height of the 850 mb pressure contour are shown for each of twelve large flood events. All twelve of these events produced a discharge at the Wilkes-Barre gaging station which was greater than 2,860 m^3s^{-1}, the flood with a 1.5 year recurrence interval for 1913-1971. Other synoptic maps prepared in the analysis of specific events include the height of the 250 mb pressure contour, the specific humidity at 500 mb, and the specific humidity at 700 mb.

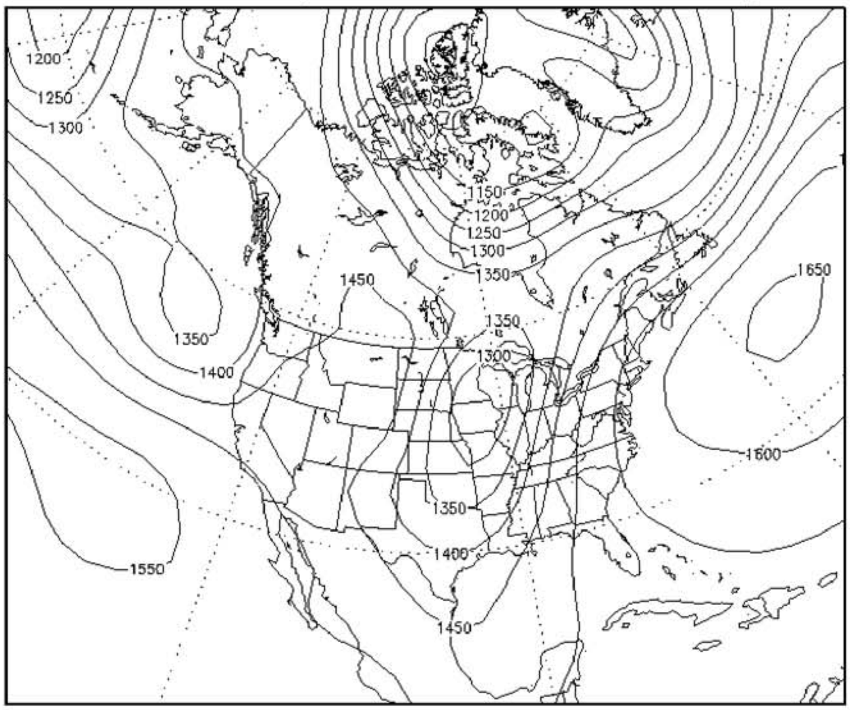
Height of the 850 mb pressure contour on January 19, 1996



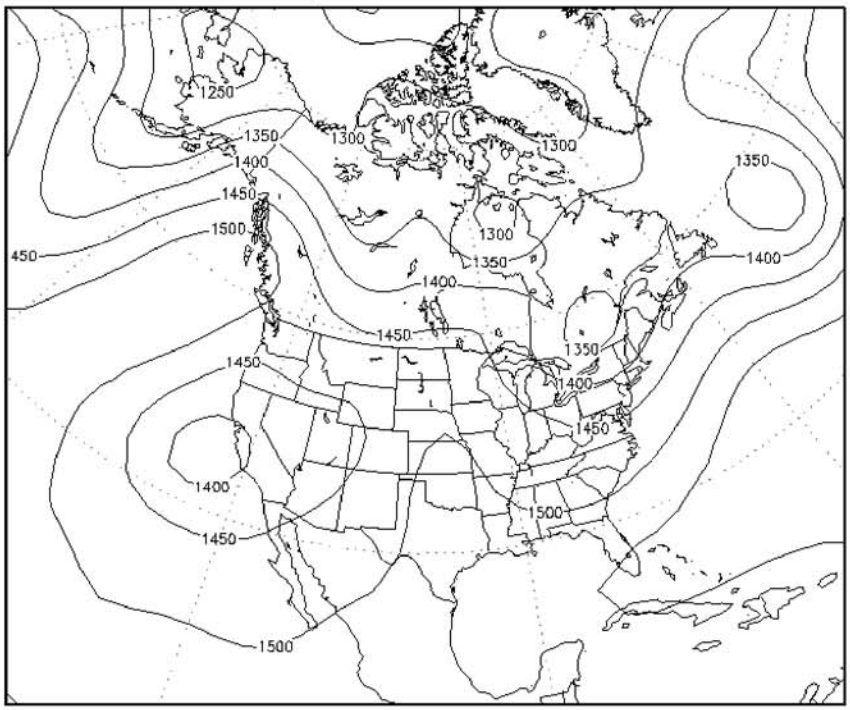
Specific Humidity at 500 mb on January 19, 1996



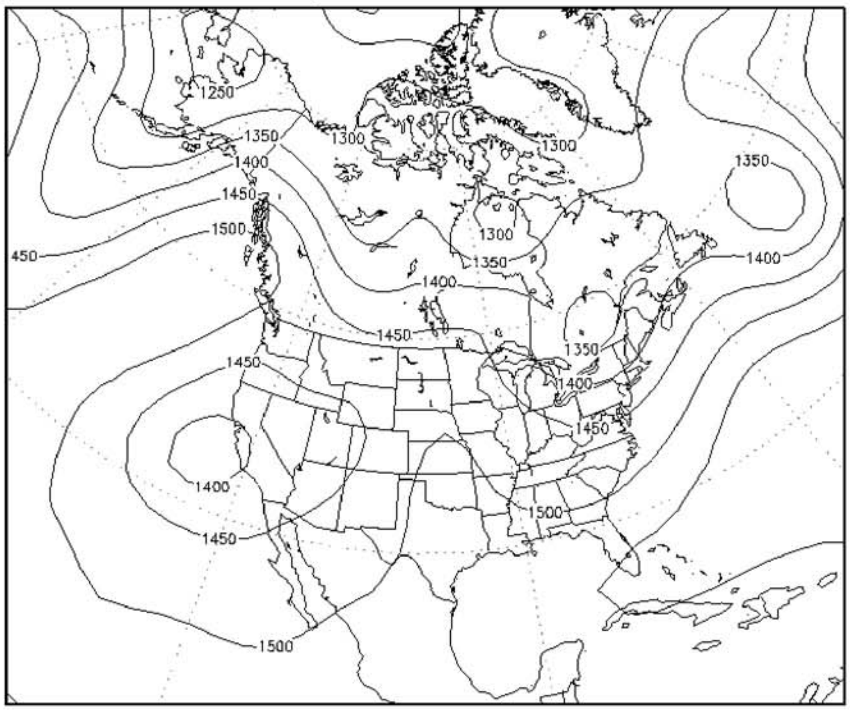
Height of the 850 mb pressure contour on January 18, 1996



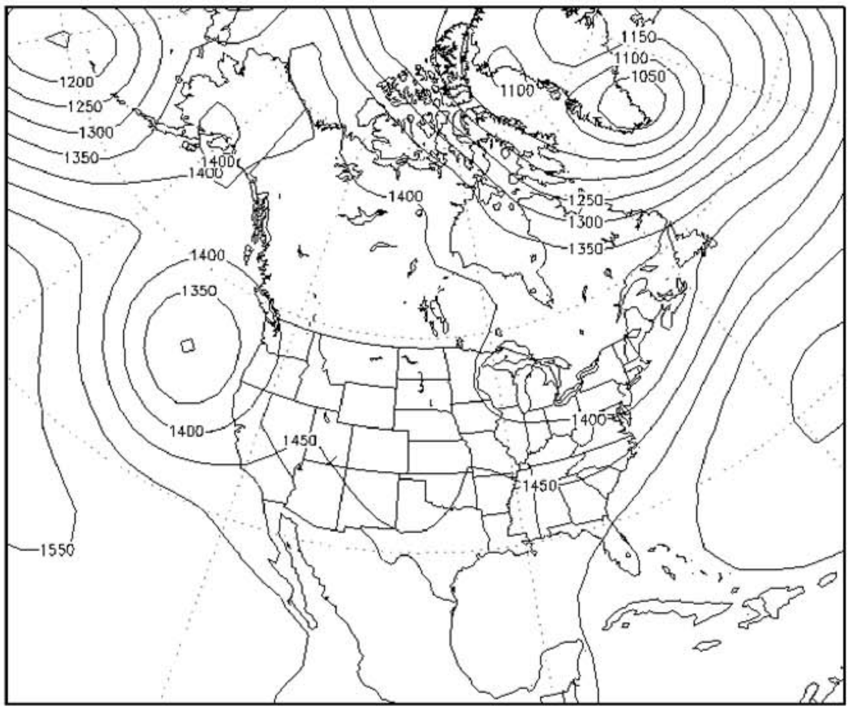
Height of the 850 mb pressure contour on March 25, 1994



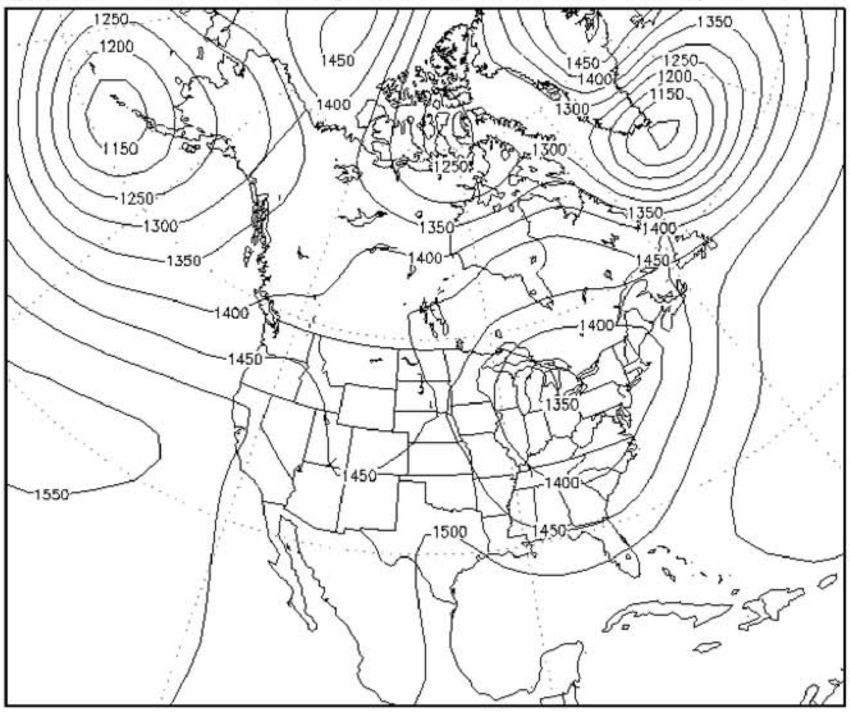
Height of the 850 mb pressure contour on March 25, 1994



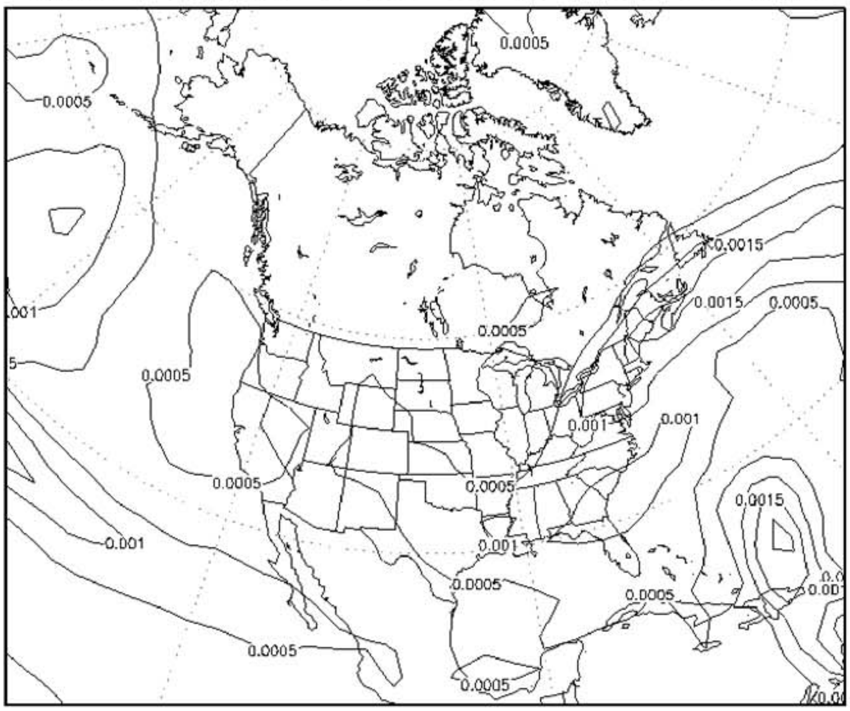
Height of the 850 mb pressure contour on March 15, 1986



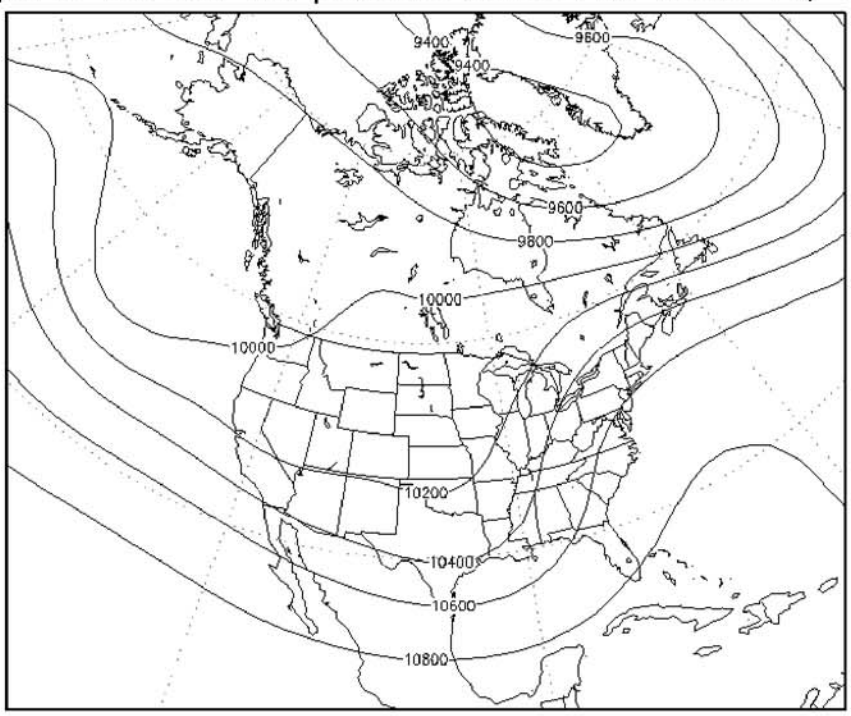
Height of the 850 mb pressure contour on April 2, 1993



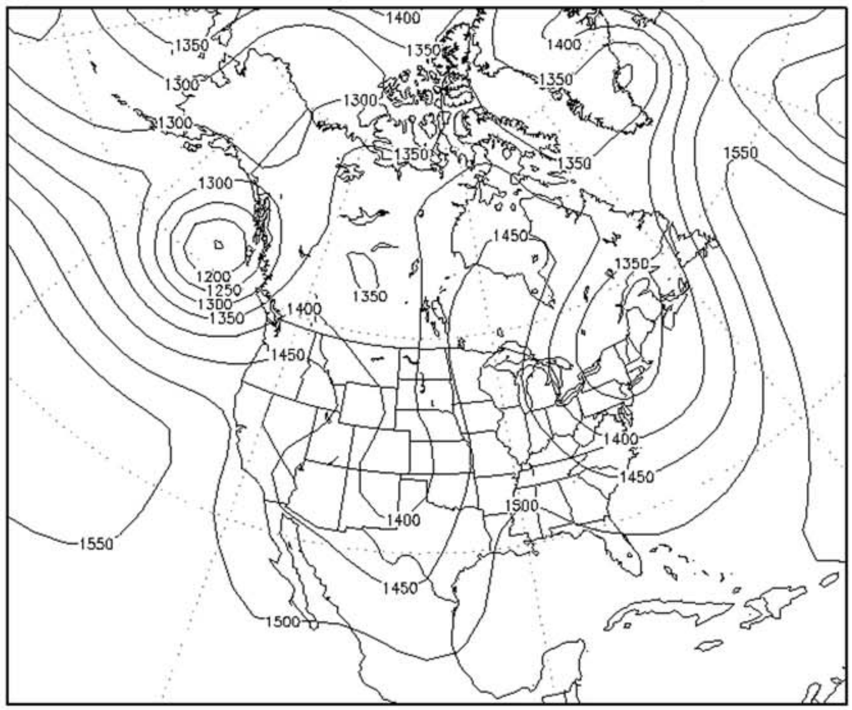
Specific Humidity at 500 mb on March 15, 1986



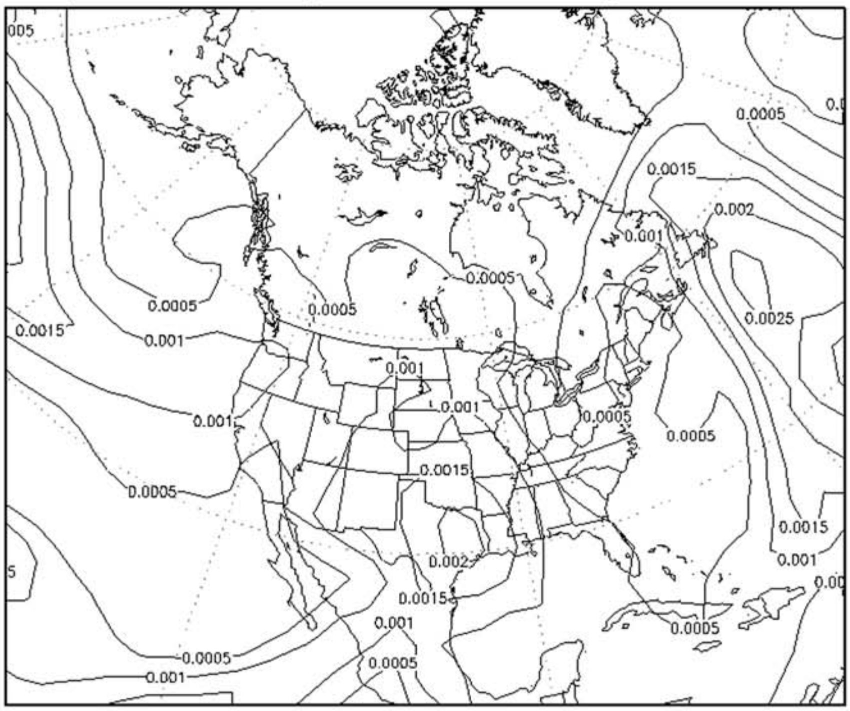
Height of the 250 mb pressure contour on March 14, 1986



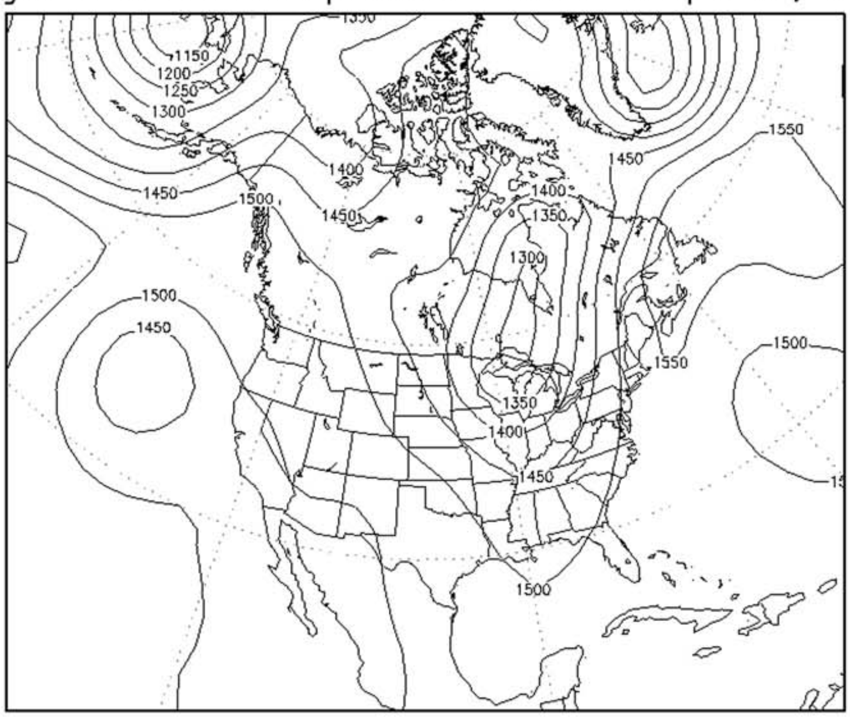
Height of the 850 mb pressure contour on April 7, 1984



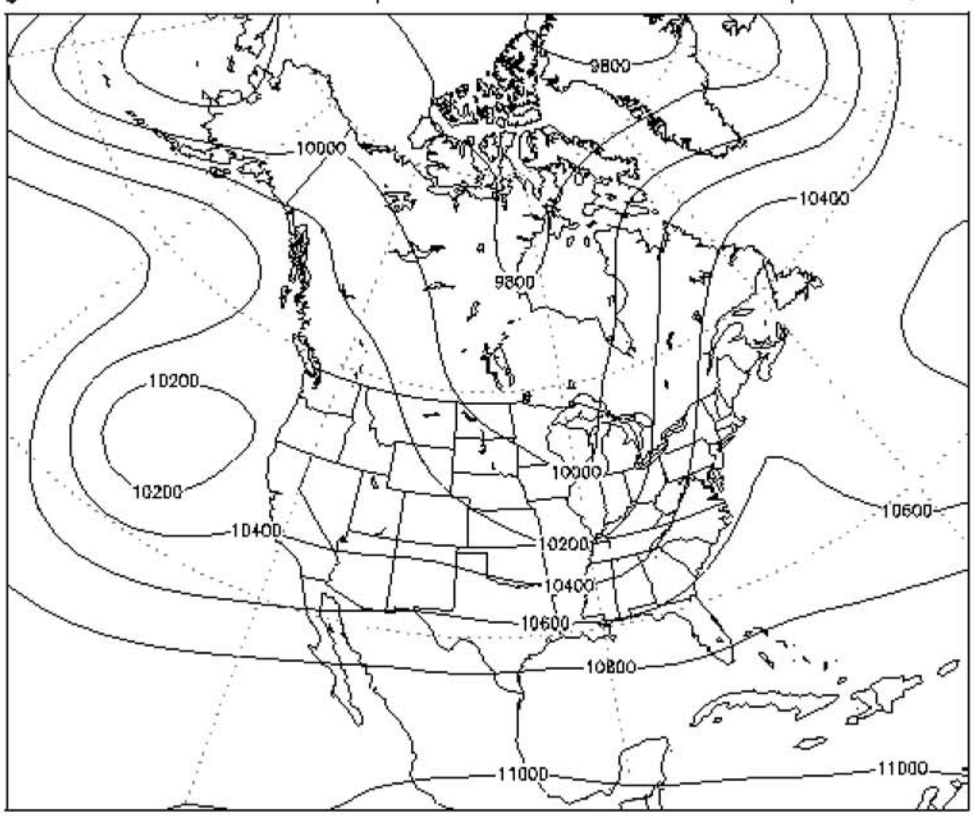
Specific Humidity at 500 mb on April 7, 1984



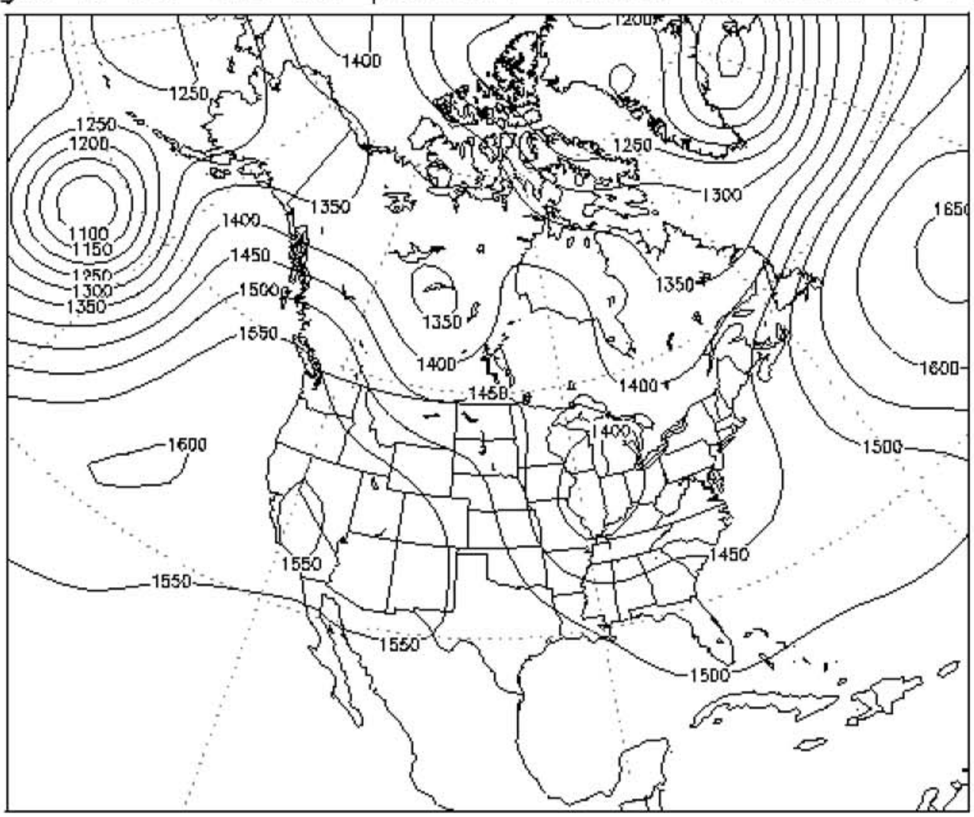
Height of the 850 mb pressure contour on April 15, 1983



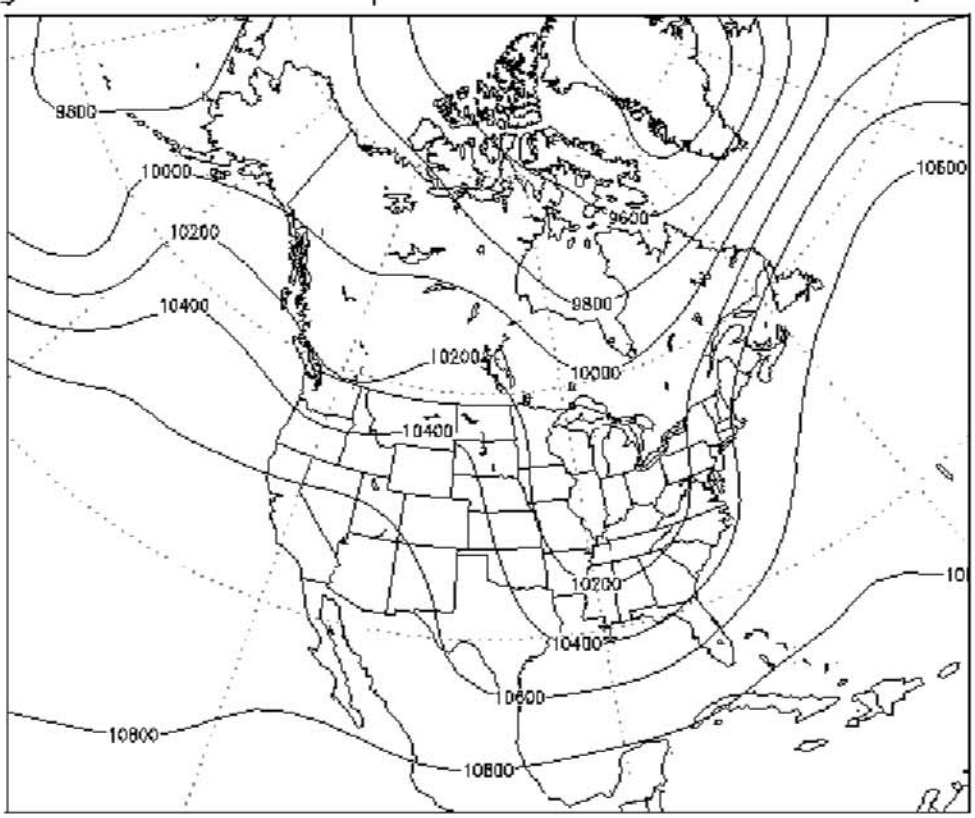
Height of the 250 mb pressure contour on April 15, 1983



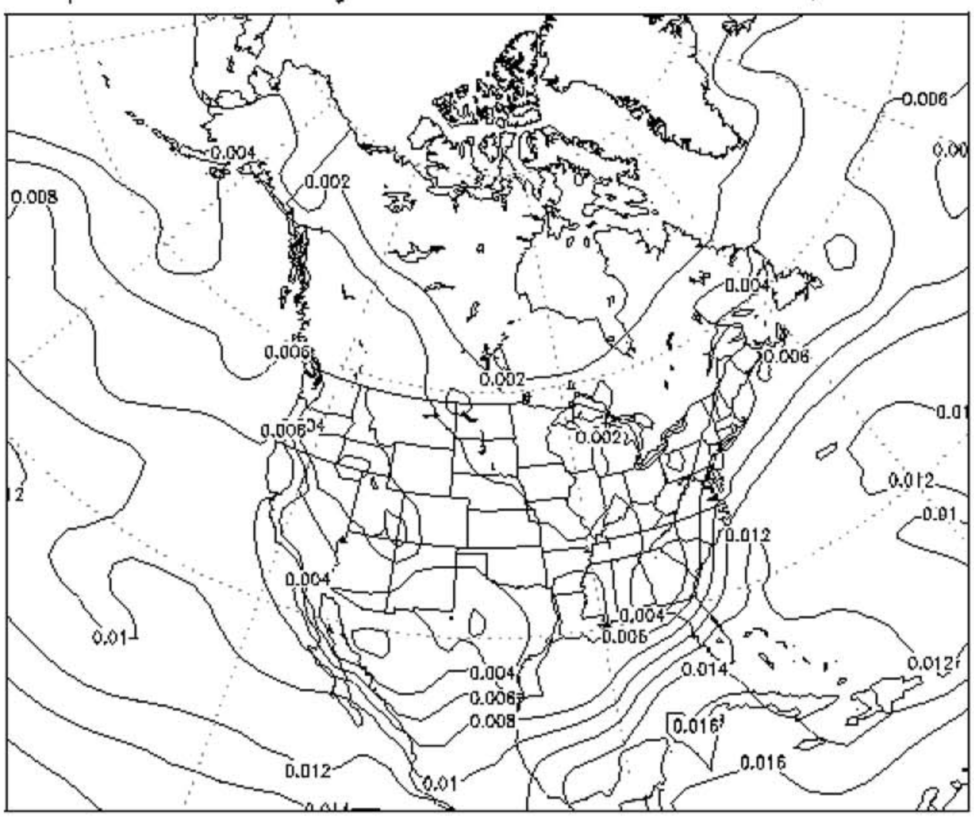
Height of the 850 mb pressure contour on March 7, 1979



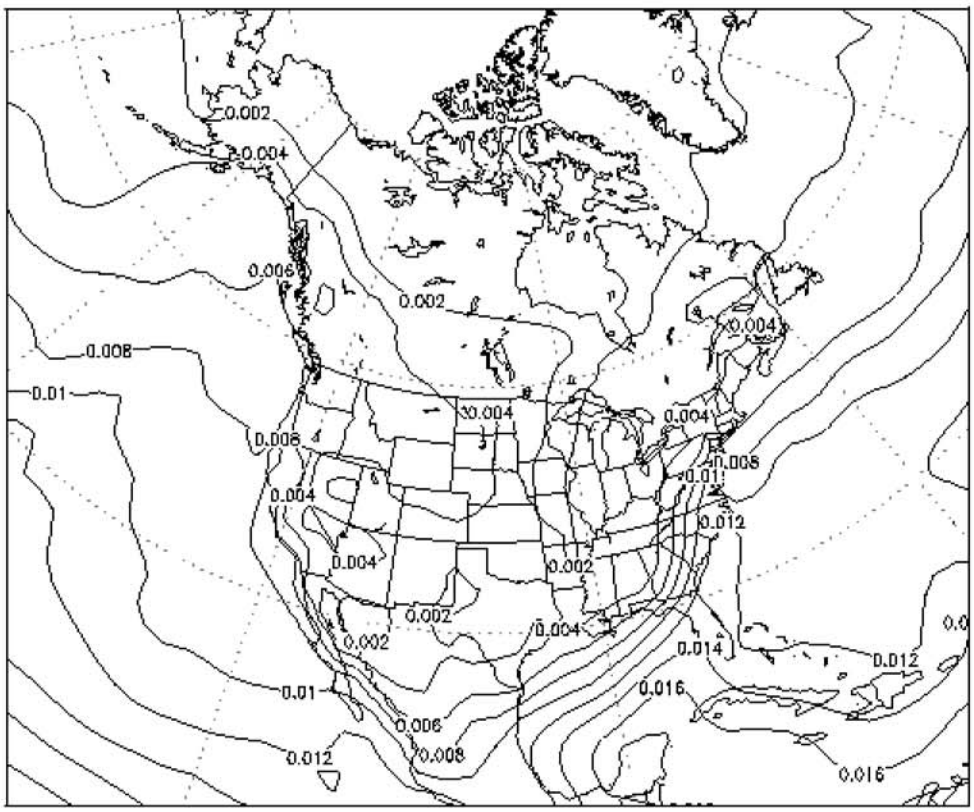
Height of the 250 mb pressure contour on March 7, 1979



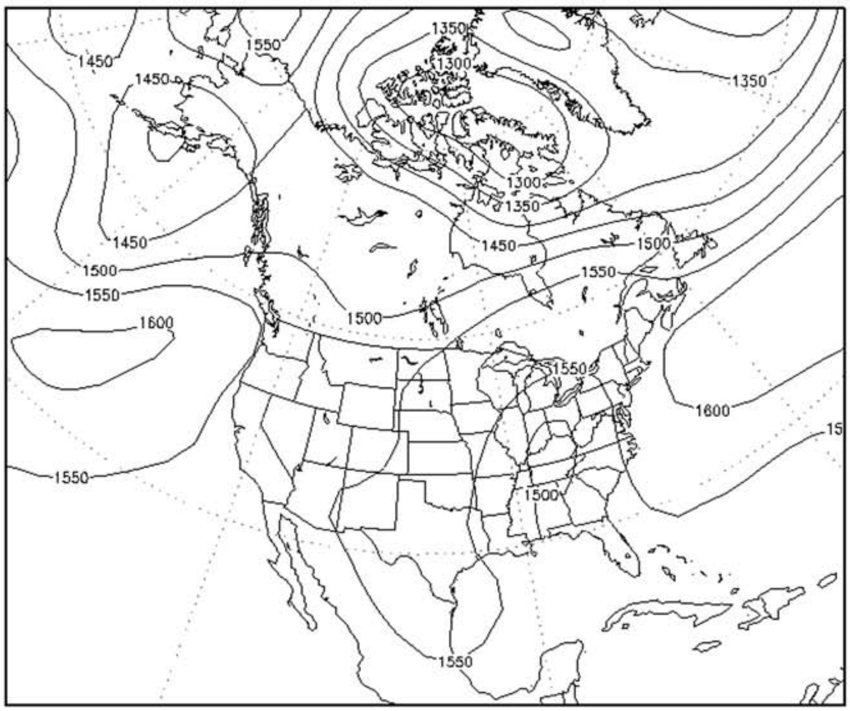
Specific Humidity at 500 mb on March 7, 1979



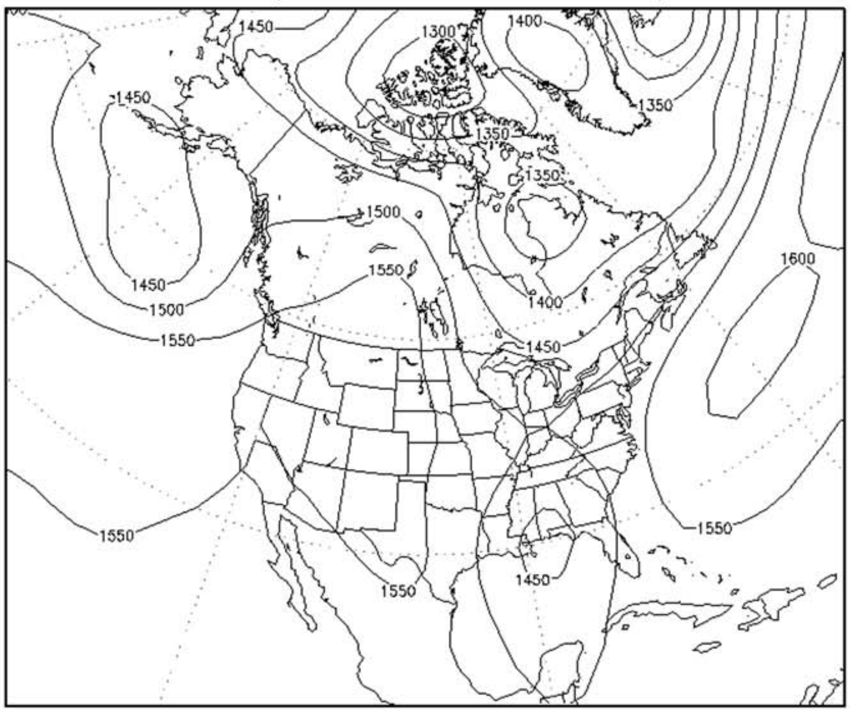
Specific Humidity at 500 mb on March 6, 1979



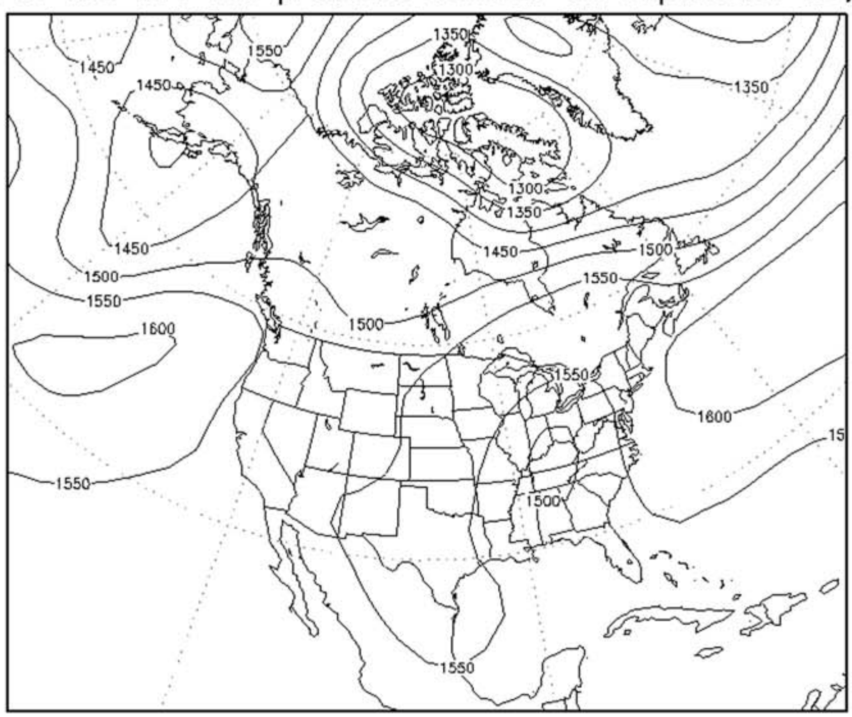
Height of the 850 mb pressure contour on September 25, 1975



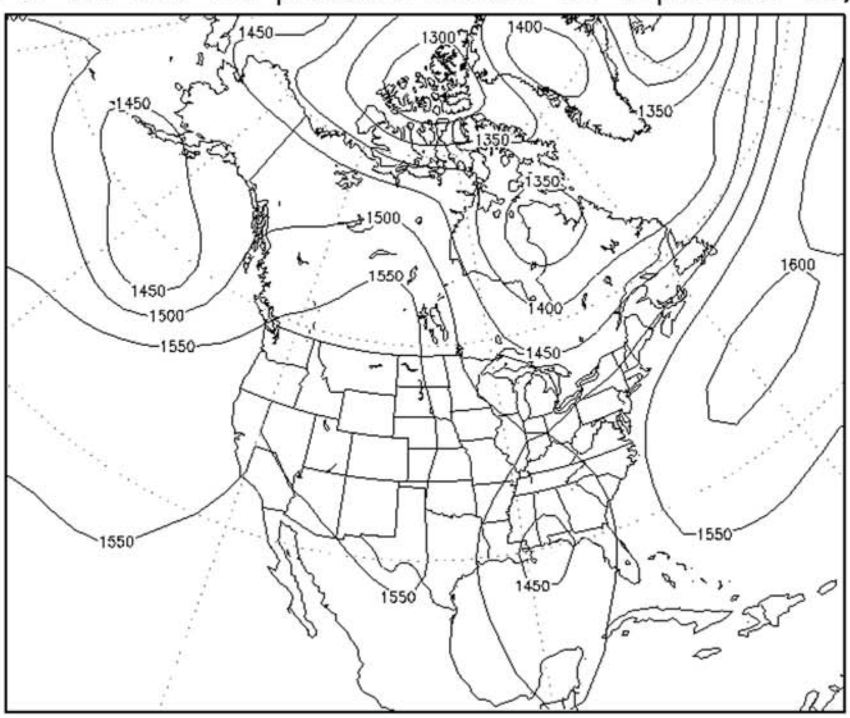
Height of the 850 mb pressure contour on September 23, 1975



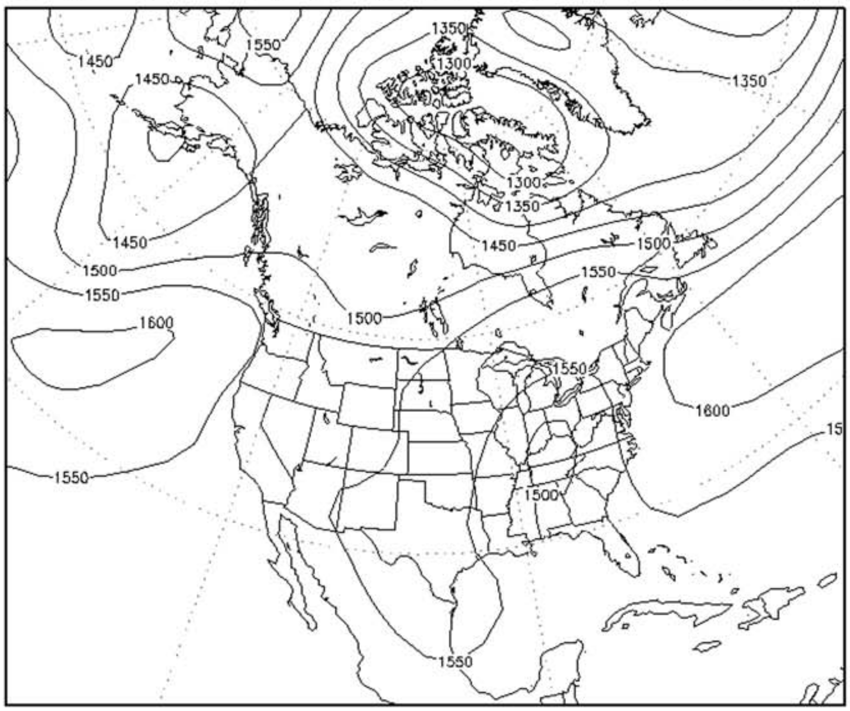
Height of the 850 mb pressure contour on September 25, 1975



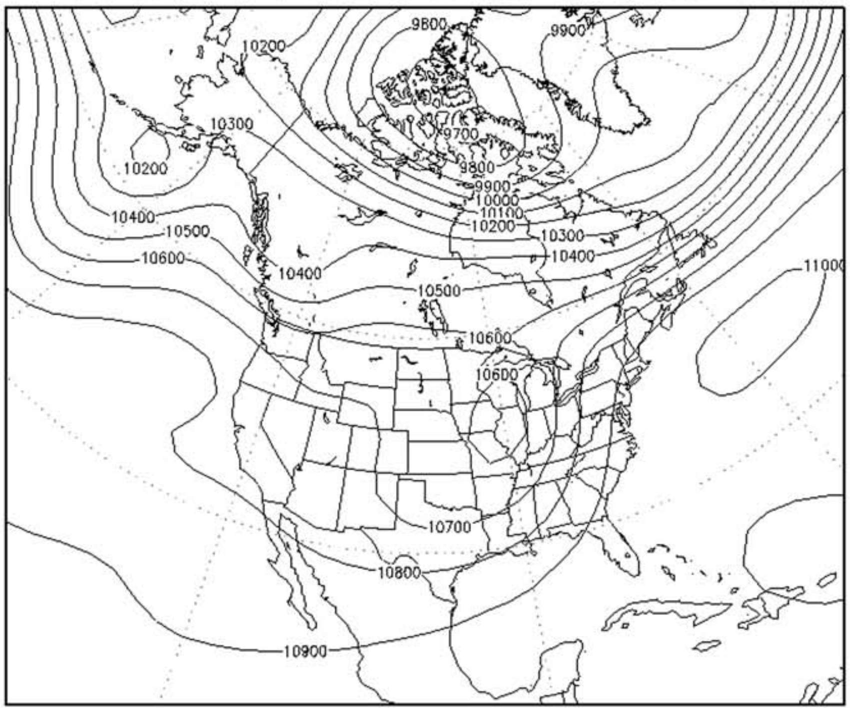
Height of the 850 mb pressure contour on September 23, 1975



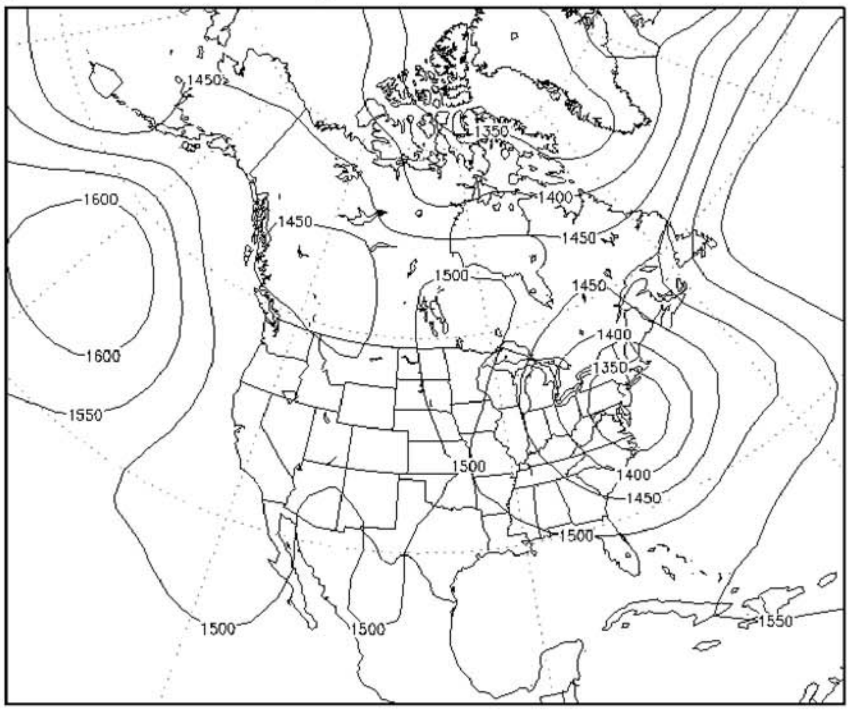
Height of the 850 mb pressure contour on September 25, 1975



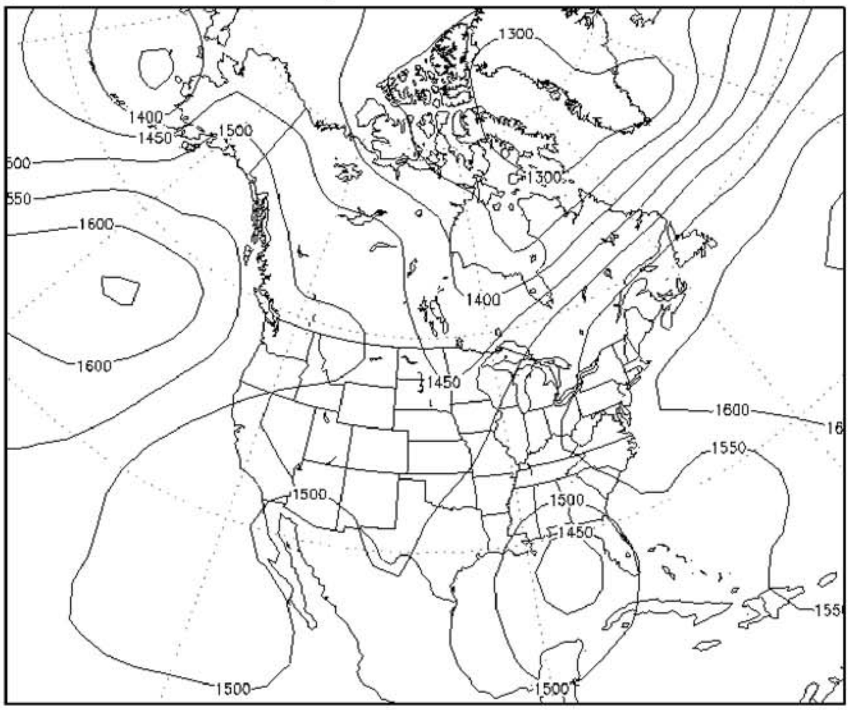
Height of the 250 mb pressure contour on September 25, 1975



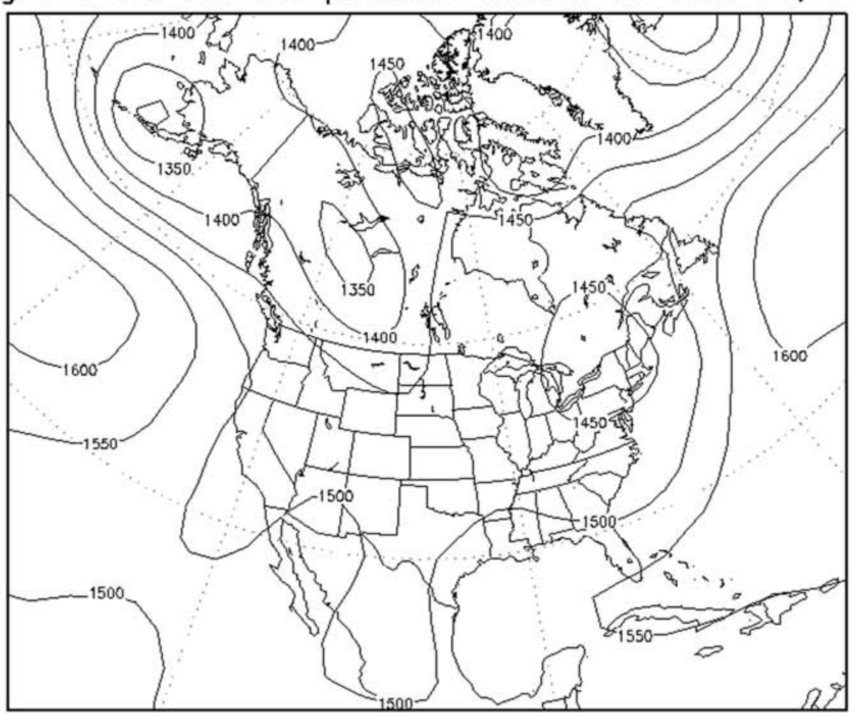
Height of the 850 mb pressure contour on June 22, 1972



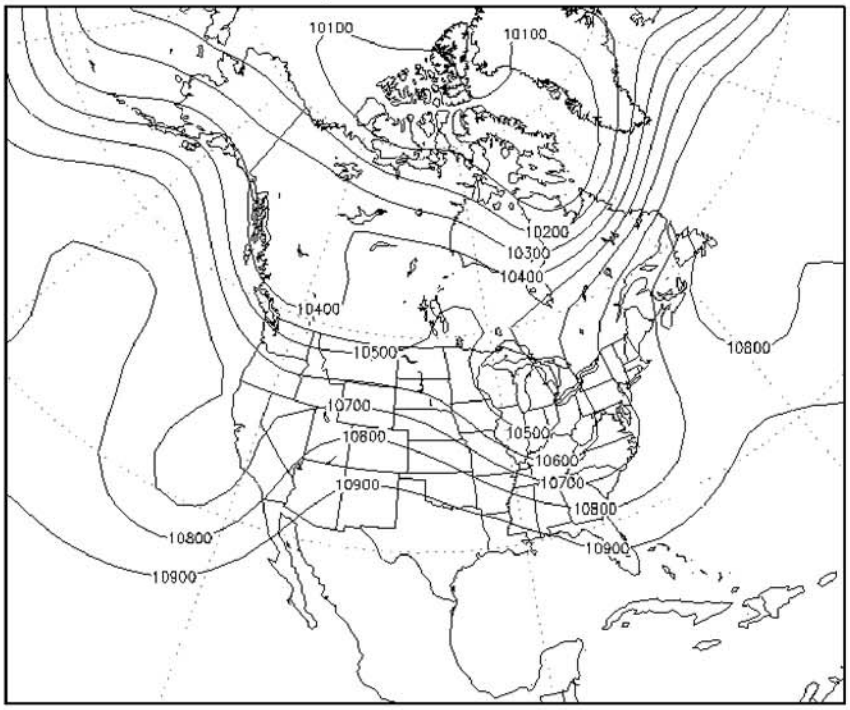
Height of the 850 mb pressure contour on June 19, 1972



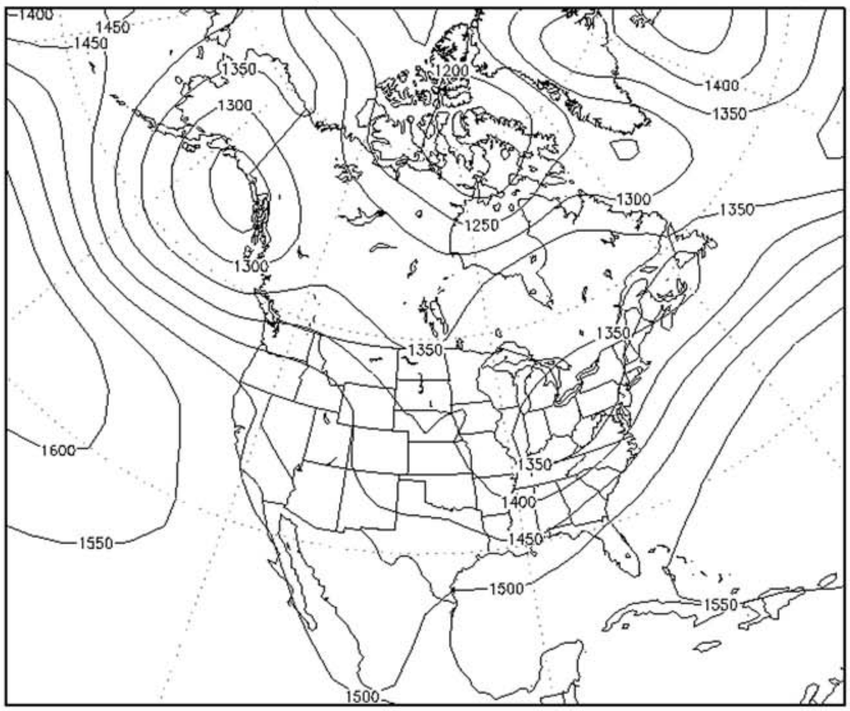
Height of the 850 mb pressure contour on June 26, 1972



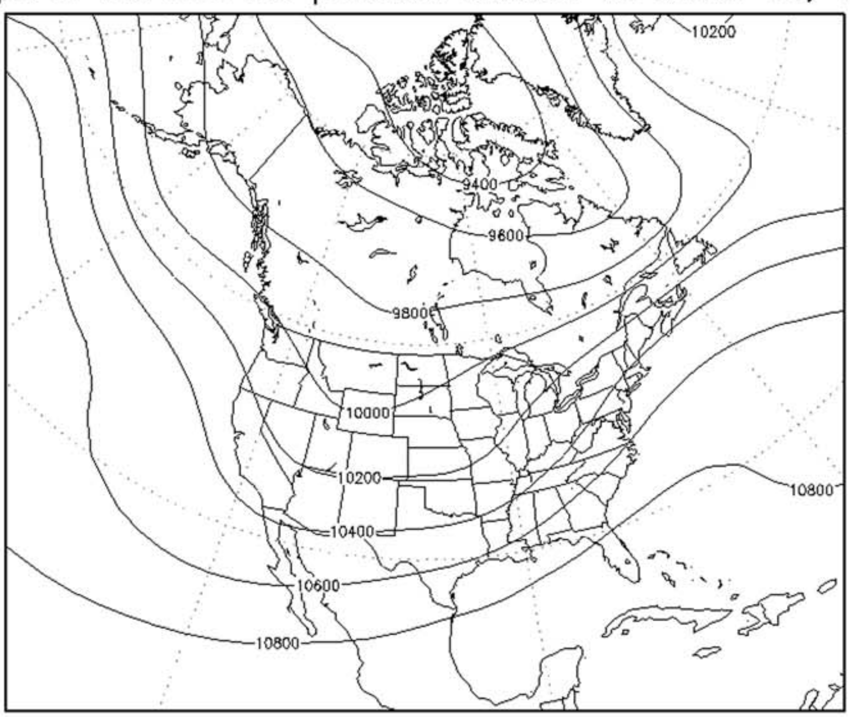
Height of the 250 mb pressure contour on June 22, 1972



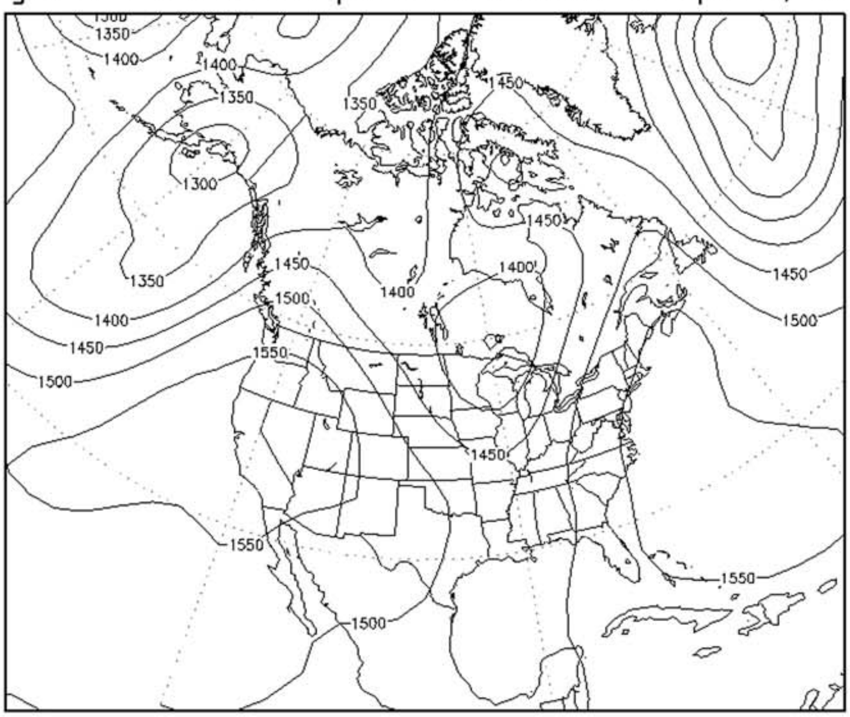
Height of the 850 mb pressure contour on March 10, 1964



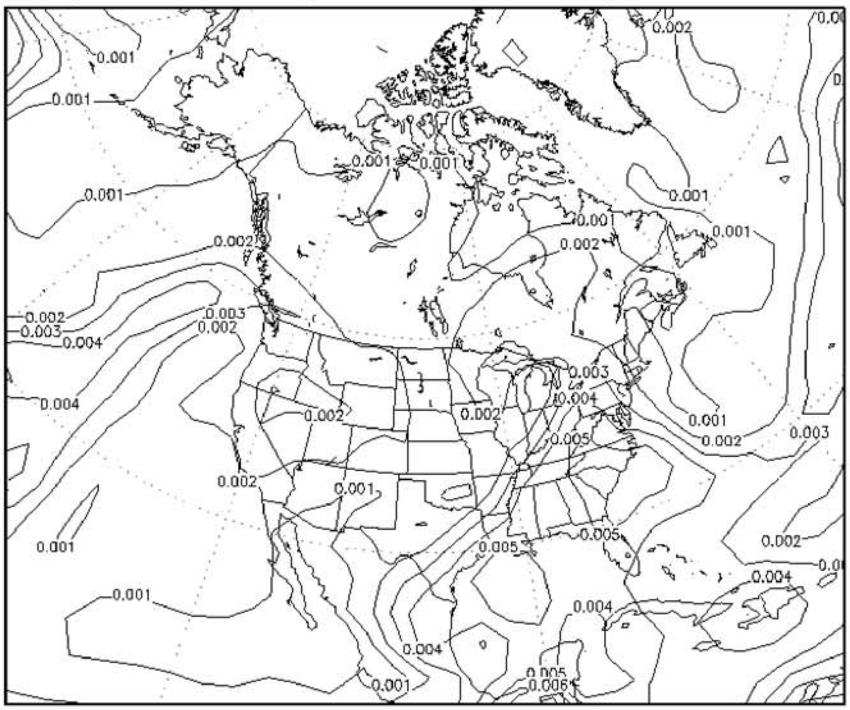
Height of the 250 mb pressure contour on March 10, 1964



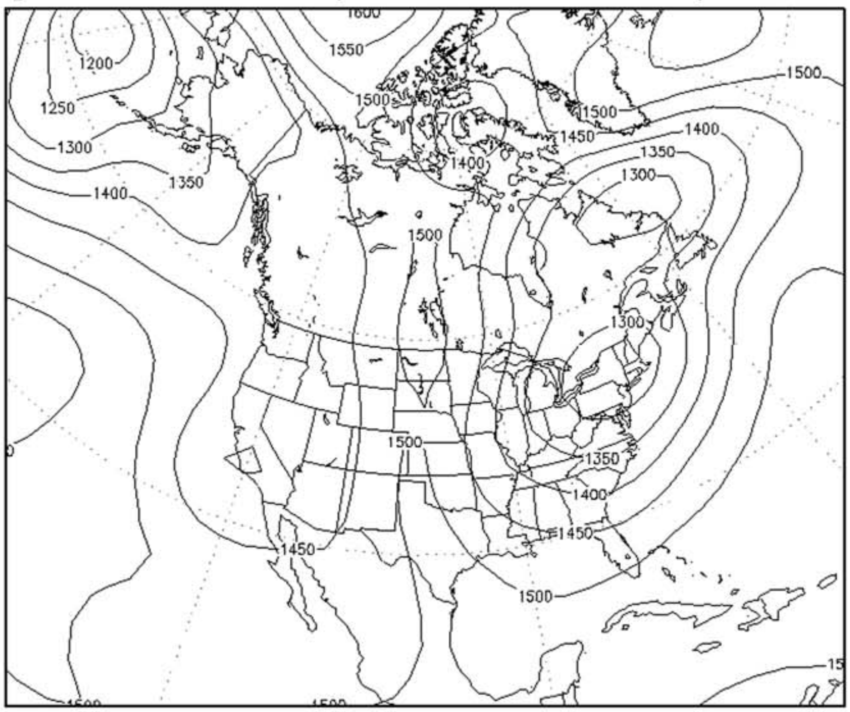
Height of the 850 mb pressure contour on April 3, 1960



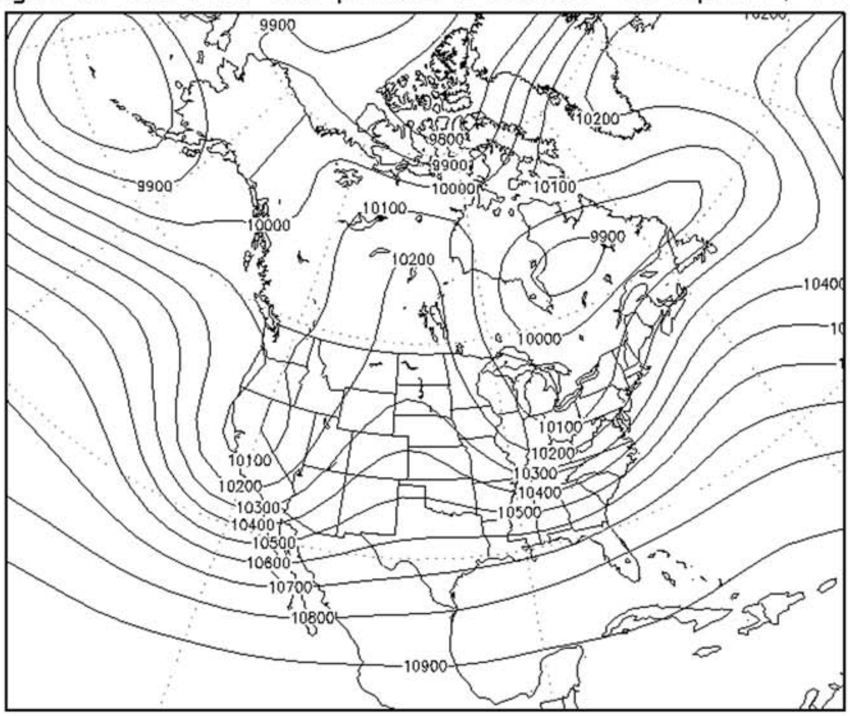
Specific Humidity at 700 mb on April 3, 1960



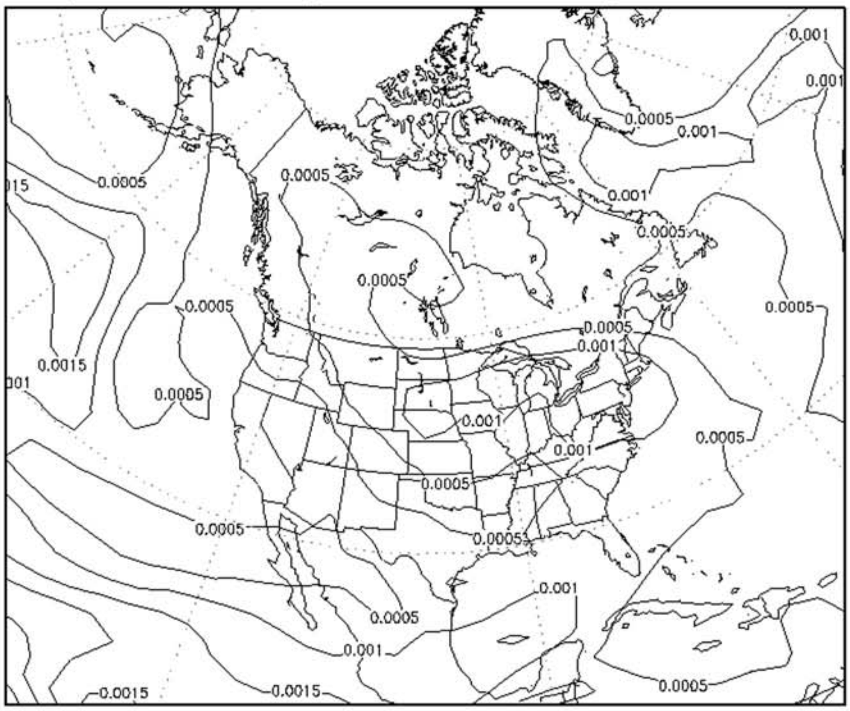
Height of the 850 mb pressure contour on April 7, 1958



Height of the 250 mb pressure contour on April 7, 1958



Specific Humidity at 500 mb on April 6, 1958



APPENDIX 3

MAGNETIC SUSCEPTIBILITY OF SOILS AND SEDIMENTS

The following table reports measurements of magnetic susceptibility (P) for a total of 54 samples of rock, soil, or sediment. Magnetic susceptibility is the ratio of the intensity of magnetization induced in a substance to the intensity of the magnetizing field to which it is subjected (Dalan and Banerjee, 1998, p. 6; Gale and Hoare, 1991, p. 202; Mullins, 1977, p. 224). The column labeled "Moment" represents the magnetic moment of the entire volume packed into a glass vial and placed under the bridge, while the "Moment/Gm" column represents the magnetic moment per unit mass. The susceptibility ("Susc/Gm") was calculated using a regression equation based on the magnetic field calibration of this bridge (Garrison, 2001). Values range from less than 10-400 x 10^{-7} m^3/kg or from 1-55 x 10^{-5} SI as reported in the final two columns.

Forty-two of the samples measured in the UGa susceptibility bridge were Holocene alluvium from sections described above. The remaining ten samples include five samples of local bedrock (LOCK, CAT1, CAT2, Llew, BM), three samples of Pleistocene deposits from north central Pennsylvania (FOP-1, FOP-4, and FOP-4b), a sample from the sandy Pleistocene channel fill in Little Roaring Creek (RC), and a sample of very recent floodplain silt (MOD).

Preliminary hypotheses based on results obtained in the United Kingdom and the midwestern United States proved incorrect in almost every case. While "redbed" rocks such as the Bloomburg formation (BM) are rich in iron oxides, for example, the sample analyzed for this study has the lowest magnetic susceptibility (3.65 x 10^{-5} SI) of the rock sample measurements. The lack of a simple match with parent mineralogy was paralleled by a poor match between magnetic susceptibility and either age or depth below surface for the samples of Holocene alluvium. Recent floodplain silt (MOD) collected just downstream of the mouth of Tunkhannock Creek has higher susceptibility (7.91 x 10^{-5} SI) than any of the rock samples and most of the samples from buried soils.

Samples from fragic (4Btx) and argillic (5Bt) buried soils in the Wyoming T-1 cutbank are surprisingly low in magnetic susceptibility (<5 x 10^{-5} SI) whereas values range from 5-10 x 10^{-5} SI for samples from AB or BC horizons of cumulic soils at Conrail, Scovell Island, Jacobs, Upper Exeter, and Cass. These cumulic soils show much less alteration of color or structure from their presumed parent materials but also do not have the light gray, leached zones and visible "gleying" of the much older Wyoming T-1 buried soils. Gleying is prolonged saturation of soil material as indicated by hydromorphic features (Birkeland, 1999, p. 134-137). Retardation of the fermentation process which generates most ferrimagnetic domains as well as destruction of ferrimagnets by gleying have previously been reported by Dalan and Banerjee (1998, p. 28), Dearing et al. (1985, p. 251-253), and Oldfield et al. (1979, p. 216).

Values from B horizons such as the Wyoming T-1 examples, which are perching soil solutions, are nonetheless significantly higher than those obtained for samples which are "endosaturated" by waters at river grade or below. Values less than 2 x 10^{-5} SI, essentially "background" for the UGa susceptibility bridge, were measured for samples at the base of boring B2 at Friedenshuetten, at the base of the organic silt facies in boring B-2 at Wyoming, and at the base of the late Pleistocene sandy channel fill in boring B-1 at the Little Roaring Creek cutoff. Further insight into the magnetic mineralogy of "episaturated" as opposed to "endosaturated" soils and sediments can be obtained with more sophisticated instrumental methods (Banerjee et al., 1981; Dalan and Banerjee, 1998; Jackson et al., 1988).

The relatively high susceptibility (8.6×10^{-5} SI) measured for a sample of the Bw/Bt1 horizon at the 8th Street Bridge Replacement contrasts with the stratigraphically equivalent Wyoming T-1 examples. An even higher susceptibility (20.6×10^{-5} SI) characterizes the lamellar C at slightly greater depth in the same trench but ~50 m further from the river. Relatively high magnetic susceptibility values greater than 5×10^{-5} SI were also measured for two samples of apparently unweathered and relatively coarse sand, the 7C horizon at Conrail and the sand immediately above gravel at Cass. These values probably indicate an abundance of detrital magnetite (Friedman and Sanders, 1978, p. 35-39; Gale and Hoare, 1991, p. 204; Mullins, 1977; Schwertmann and Taylor, 1989). The detrital magnetite probably originates in igneous or metamorphic rocks transported into the valley as outwash, although some is also present in the local sedimentary lithologies.

The highest measured magnetic susceptibility, 54.6×10^{-5} SI, represents the argillic horizon from a soil formed on pre-Illinoian till. The sample (FOP-4) was collected during a field trip with the Northeast Friends of the Pleistocene from a backhoe trench excavated into the Buffalo Valley fan deposits. Two other samples collected during the same field trip have much lower susceptibilities, possibly indicating Holocene as opposed to

Pleistocene weathering profiles. Further sampling must be conducted, but it appears that magnetic susceptibility may be useful in identifying true paleosols dating to the late Pleistocene, particularly those formed in upper landscape positions where gleying has not occurred.

Magnetic susceptibility was measured in four entire sediment columns of between seven and ten samples each. Two of these, from the Jacobs and Cass sites, contain cumulic soil profiles in which magnetic susceptibility increases slightly either at the top or bottom of individual soils. The other two are slackwater or swale fill deposits in which susceptibility decreases irregularly down the column to a basal value indistinguishable from background (<2 x 10^{-5} SI). These preliminary results indicate that slight magnetic susceptibility peaks may mark stratigraphic discontinuities, as found by previous studies at cave and rockshelter sites.

Appendix 3: Magnetic Susceptibility Measurements for Samples of Rock and Sediment North Central Pennsylvania

Sample Description	ID	Wt	Moment	Moment/ Gm	Susc/ Gm	Susc 10E-7 m3/kg	SI
Lockhaven formation	LOCK	24.51	494	20.2	4.53E-03	45.3	5.69E-05
Catskill formation at Grist Flat	CAT1	12.81	363	28.3	6.17E-03	61.7	7.75E-05
Catskill formation at Tunkhannock	CAT2	13.22	185	14.0	3.30E-03	33.0	4.14E-05
Llewellyn formation	LLEW	13.74	172	12.5	3.00E-03	30.0	3.77E-05
Bloomsburg Formation	BM	17.77	214	12.0	2.91E-03	29.1	3.65E-05
NE FOP 1999 Fieldtrip Stop 1	FOP-1	14.04	142	10.1	2.52E-03	25.2	3.17E-05
NE FOP 1999 Fieldtrip Stop 4	FOP-4	16.7	3589	214.9	4.35E-02	435.0	5.46E-04
NE FOP 1999 Fieldtrip Stop 4b	FOP-4b	15.78	296	18.8	4.25E-03	42.5	5.34E-05
Little Roaring Creek B1	RC	17.76	15	0.8	6.69E-04	6.7	8.40E-06
NBranch below Tunkhannock Cr	MOD	14.25	413	29.0	6.30E-03	63.0	7.91E-05
8th Street Bridge Bw/Bt1	8-Bw1	29.07	922	31.7	6.84E-03	68.4	8.60E-05
8th Street Bridge C	8-C	17.57	1397	79.5	1.64E-02	164.0	2.06E-04
Conrail (36LU169) 2AB	169-2AB	16.82	827	49.2	1.03E-02	103.0	1.30E-04
Conrail (36LU169) 5C	169-5C	17.58	285	16.2	3.74E-03	37.4	4.70E-05
Conrail (36LU169) 7C	169-7C	17.17	411	23.9	5.29E-03	52.9	6.64E-05
Wyoming T-1 4Btx	4Btx	16.70	175	10.5	2.60E-03	26.0	3.26E-05
Wyoming T-1 5Bg	5Bg	18.10	232	12.8	3.06E-03	30.6	3.85E-05
Wyoming T-1 5Bt	5Bt	16.73	261	15.6	3.62E-03	36.2	4.55E-05
Scovell Island (36LU12) 2Bw	S-2Bw	17.63	507	28.8	6.25E-03	62.5	7.85E-05
Jacobs (36LU90) Site 3AB	J3AB	14.98	345	23.0	5.11E-03	51.1	6.41E-05
Jacobs (36LU90) Site 3B1	J3B1	14.37	314	21.9	4.87E-03	48.7	6.12E-05
Jacobs (36LU90) Site 3B2	J3B2	16.64	372	22.4	4.97E-03	49.7	6.24E-05
Jacobs (36LU90) Site 3B3	J3B3	17.04	406	23.8	5.27E-03	52.7	6.61E-05
Jacobs (36LU90) Site 4C1	J4C1	17.03	340	20.0	4.49E-03	44.9	5.64E-05

Appendix 3: Magnetic Susceptibility Measurements for Samples of Rock and Sediment North Central Pennsylvania

Sample Description	ID	Wt	Moment	Moment/ Gm	Susc/ Gm	Susc 10E-7 m3/kg	SI
Jacobs (36LU90) Site 4C2	J4C2	19.67	297	15.1	3.52E-03	35.2	4.42E-05
Jacobs (36LU90) Site 4C3	J4C3	19.83	248	12.5	3.00E-03	30.0	3.77E-05
Jacobs (36LU90) Site 5AB1	J5AB1	17.99	268	14.9	3.48E-03	34.8	4.37E-05
Jacobs (36LU90) Site 5AB2	J5AB2	17.83	238	13.3	3.17E-03	31.7	3.98E-05
Jacbos (36LU90) Site 5C	J5C	20.49	243	11.9	2.87E-03	28.7	3.61E-05
Upper Exeter BC 50 cm	EX50	15.18	767	50.5	1.06E-02	106.0	1.33E-04
Upper Exeter 2BC 90 cm	EX90	14.49	106	7.3	1.96E-03	19.6	2.47E-05
Cass (36BR57) CB1 90 cm	WY90	20.58	387	18.8	4.26E-03	42.6	5.35E-05
Cass (36BR57) CB1 130 cm	WY130	18.88	412	21.8	4.86E-03	48.6	6.11E-05
Cass (36BR57) CB1 160 cm	WY160	17.24	343	19.9	4.48E-03	44.8	5.63E-05
Cass (36BR57) CB1 190 cm	WY190	19.01	500	26.3	5.76E-03	57.6	7.24E-05
Cass (36BR57) CB1 210 cm	WY210	18.84	292	15.5	3.60E-03	36.0	4.52E-05
Cass (36BR57) CB1 270 cm	WY270	19.85	630	31.7	6.85E-03	68.5	8.60E-05
Cass (36BR57) CB2 gravel	WYgrav	19.92	386	19.4	4.38E-03	43.8	5.50E-05
Friedenshuetten B2 AB 30 cm	FH30	14.47	176	12.2	2.93E-03	29.3	3.68E-05
Friedenshuetten B2 Bw 60 cm	FH60	15.16	128	8.4	2.19E-03	21.9	2.75E-05
Friedenshuetten B2 BC 90 cm	FH90	15.39	145	9.4	2.38E-03	23.8	2.99E-05
Friedenshuetten B2 C1 140 cm	FH140	16.02	129	8.1	2.11E-03	21.1	2.65E-05
Friedenshuetten B2 C2 190 cm	FH190	11.94	105	8.8	2.26E-03	22.6	2.84E-05
Friedenshuetten B2 C2 260 cm	FH260	14.12	100	7.1	1.92E-03	19.2	2.41E-05
Friedenshuetten B2 C2 290 cm	FH290	16.41	38	2.3	9.63E-04	9.63	1.21E-05
Wyoming Slackwater B1 60 cm	B1 60	16.03	215	13.4	3.18E-03	31.8	4.00E-05
Wyoming Slackwater B1 80 cm	B1 80	15.24	68	4.5	1.39E-03	13.9	1.75E-05
Wyoming Slackwater B2 70 cm	B2 70	12.44	67	5.4	1.58E-03	15.8	1.98E-05
Wyoming Slackwater B2 100 cm	B2 100	12.56	50	4.0	1.30E-03	13.0	1.63E-05
Wyoming Slackwater B2 130 cm	B2 130	11.35	37	3.3	1.15E-03	11.5	1.45E-05
Wyoming Slackwater B2 200 cm	B2 200	11.85	75	6.3	1.77E-03	17.7	2.22E-05
Wyoming Slackwater B2 260 cm	B2 260	13.91	82	5.9	1.68E-03	16.8	2.11E-05

Appendix 3: Magnetic Susceptibility Measurements for Samples of Rock and Sediment North Central Pennsylvania

Sample Description	ID	Wt	Moment	Moment/ Gm	Susc/ Gm	Susc 10E-7 m3/kg	SI
Wyoming Slackwater B2 270 cm	B2 270	11.72	58	4.9	1.49E-03	14.9	1.87E-05
Wyoming Slackwater B2 300 cm	B2 300	12.84	18	1.4	7.80E-04	7.8	9.80E-06