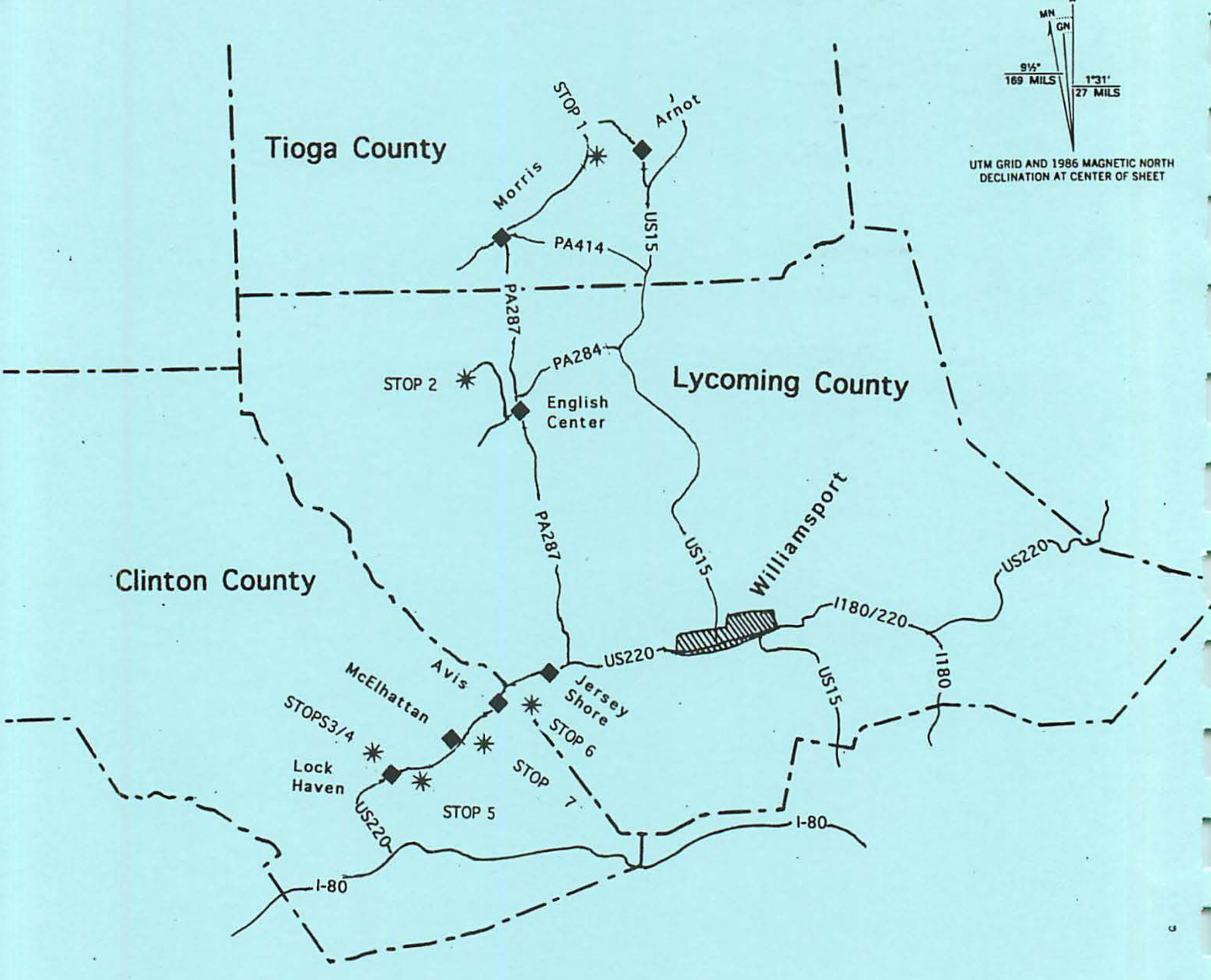
GUIDEBOOK

60TH ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

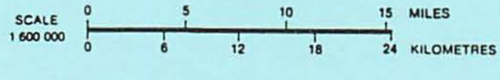
Applied Geology in the Lock Haven and Williamsport Region, Clinton, Lycoming, and Tioga Counties, Northcentral Pennsylvania

Host: Lock Haven University

October 5, 6, 7, 1995
Williamsport, PA



Sketch Map Showing Stop Locations
60th Field Conference of Pennsylvania
Geologists



Guidebook for the

60th ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

APPLIED GEOLOGY IN THE LOCK HAVEN AND WILLIAMSPORT REGION, CLINTON AND LYCOMING COUNTIES, NORTHCENTRAL PENNSYLVANIA

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Frontispiece. 1994 Field Conference of Pennsylvania Geologists group photograph at Marsh Creek State Park, Chester County, PA.

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INTRODUCTION

APPLIED GEOLOGY IN THE LOCK HAVEN AND WILLIAMSPORT REGION, CLINTON, LYCOMING, AND TIOGA COUNTIES, NORTHCENTRAL PENNSYLVANIA

JOHN H. WAY [1]

> Man is a singular creature. He has a set of gifts which make him unique among the animals: so that, unlike them, he is not a figure in the landscape—he is a shaper of the landscape. In body and in mind he is the explorer of nature, the ubiquitous animal, who did not find but has made his home in every continent.
>
> Jacob Bronowski, *The Ascent of Man*, 1973

The term applied geology is synonymous with the more popular term "environmental" geology. Specifically, it is the application of geologic information to solving conflicts, minimizing possible adverse environmental degradation, or maximizing possible advantageous conditions resulting from our use of the natural and modified environment (Keller, 1992, p. 1). Applied (environmental) geology texts commonly address topics such as natural processes that are considered hazards, Earth-materials that serve as resources, pollution and waste management, geologic factors impacting human health, land use, risk assessment, environmental-impact analysis, and environmental law. In the broadest sense, applied geology is that discipline within the Earth sciences that focuses upon the entire spectrum of interactions between human activity and the physical environment. As should be obvious, this subject area overlaps traditional boundaries of the "hard" natural sciences and requires synthesis with elements of areas sometimes referred to as "soft" sciences, including economics, social and political areas, ethics, and esthetics, to name just a few.

"Why applied geology as the focus of a Pennsylvania Field Conference?" you may ask. From our perspective, it is increasingly apparent that today's students and their parents are demanding accountability from institutions of higher education. No longer is the phrase "education for the sake of education" sufficient to justify the enormous costs and long-term debts accompanying a piece of paper labeled BS or BA held by a college or university graduate who is unemployed. With fond recollections of the way things used to be in those 'good ole days,' Earth scientists are finding it necessary to rethink their mission and recognize that, paraphrasing one of our colleagues— 'we have entered a post-romantic period where the image of the lone, ruggedly independent field geologist alone on the remote mountainside with his Brunton and hammer, surrounded by stunning scenery' has faded and been replaced by a slick, multi-disciplinary team of highly specialized men and women outfitted in Tyvec and respirators mucking through lagoons filled with all sorts of debris including rusted and crushed barrels containing who-knows-what possibly carcinogenic compounds, to sample fluids from a well drilled into the groundwater system which ultimately will be thoroughly tested and analyzed for hundreds of complex organic compounds whose concentrations will be determined in parts per billion.

The reality of these shifts in emphases within the geosciences has progressed at rates comparable to lithospheric-plate-translation movement; nonetheless, the recognition of the importance of environmental responsibilities is quietly, yet pervasively, invading the ivory towers of academe. Practically, administrators as well as faculty acknowledge that in order to 'populate classes' (to those non-academics among the group, that translates to us keeping our jobs), we must become more accountable to the clients we serve—our students. Increasingly, educators are called upon to redesign science curricula in order to provide students with both the fundamental scientific knowledge and basic skills as well as the intellectual flexibility to meet changing societal needs and shifting demands of the professions. Job responsibilities in the Earth sciences today require a clearer understanding of the complex interrelationships among components of the biosphere, the atmosphere, the hydrosphere, the shallowest levels of the Earth's crust, and human activities. In a recent address before educators

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gathered for an AGU Chapmen Conference in Washington, D.C., Gordon P. Eaton, Director of the U.S.G.S., stressed that our traditional curriculum "... is now in need of very serious critical review, with an eye toward today's and tomorrow's real professional opportunities." He urged "more broadly based studies that help our science majors meet the challenge of a changing emphasis toward multidisciplinary studies and work." Quoting Reds Wolman, of Johns Hopkins and the National Research Council, he stressed that "the health of our science is inextricably mixed up with the notion of whether or not it is perceived to be useful to society. Social and political issues are a paramount concern" (Eaton, 1994, p. 28).

By no means should this discourse be interpreted negatively. These are exciting and challenging times in the hallowed halls of academic institutions, especially for those of us in the Earth sciences. Remember, we all took chemistry, physics, biology, and math courses and we saw how these disciplines helped us understand the nature of geology. Today, we can proudly tell everyone the secret we too often held close to the chest—that geology is inherently interdisciplinary; it is relevant; and it is truly a science whose time has come. But, be careful, we can't let them know one our best kept secrets— Geology is fun too!

The academic institutions are not alone in responding to the winds of change; government as well as private industry are experiencing their own versions of this revolution. Looking back through the annals of the Earth sciences, many of the geologic surveys throughout the world came into being during that progressive era referred to by some historians as the Industrial Revolution. Nations began to seek information about their energy and mineral resources out of economic and strategic necessity. Experiencing growing populations and associated increasing demands for new products, the need for more resources was soon recognized. For example, the British Geologic Survey, formed in 1835, focused efforts on bedrock geologic mapping in order to facilitate coal exploration and production. Much of the work published by the Pennsylvania Geologic Survey, including the 1st, 2nd, and 3rd series reports, has been devoted to furthering our knowledge and understanding of the distribution of coal, petroleum, natural gas, and metallic and non-metallic mineral resources within our commonwealth.

The twentieth century has been sporadically filled with armed conflict, much of it with broad, multinational implications. These events have served to keep the spotlight focused on energy and metallic mineral resources, with particular emphasis on evaluating resource potential and remaining global reserves. As a result, mineral-resource exploration and research continued as the mainstays of the geosciences throughout the first two-thirds of this century. However, since the end of the "cold-war period" we have seen major shifts in national agendas around the world. Like the proverbial phoenix of Egyptian mythology which, after being consumed by fire, rose renewed from the ashes, a new, post-industrial society has evolved, characterized by a global economy based on growing interdependence of nations. The implications for the Earth sciences likewise have changed. Mineral-resource exploration and research continue to be an important focus, but these activities appear to be set within a new framework of thinking. A deep and genuine concern for the environment has become a growing force in this latter part of the twentieth century.

Earth Day, April 22, 1970, serves as one benchmark marking the advent of this new era of environmental awakening. Recognition that our planet cannot continue to sustain long-term, exponential population growth has generated fundamental concerns about the quality of the environment. The U.N. Conference on Environment and Development held in Rio de Janeiro, Brazil, June 1992, and referred to as the "Earth Summit" stands as another high watermark. National governments publicly acknowledged that environmental degradation is a global problem and that solutions require international cooperation. This meeting raised environmental awareness to new heights and produced unprecedented agreement that humans must work together to protect the environment.

Reaffirming the role of basic sciences in our understanding of the natural systems and processes of the Earth and in answer to a question being asked with increasing frequency—"How does geoscience fit into the realities of today?"—we submit the spotlighted subjects in this year's field conference. The 60th Annual Field Conference of Pennsylvania Geologists focuses upon the role the Earth Sciences play in solving some of society's problems including natural hazards, environmental degradation, and exploitation of natural resources. Participants will be "exposed" to real-life examples demonstrating the integrative nature of the geosciences combined with the interdisciplinary nature of the approaches to the solutions of several problems in the Lock Haven and Williamsport area throughout the two days of field stops.

FIELD STOP SYNOPSIS

We begin our survey of examples of applied geology by visiting two sites in the north-central Pennsylvania coal fields in order to address some of the problems associated with acidic surface and groundwater largely attributable to the extensive coal mining that has occurred throughout this region. Our first stop allows us to examine a field site testing an experimental procedure for treating acidic surface waters using limestone to buffer the low pH applying a uniquely simple, passive, flow-through design configuration. From there, we will visit an active strip-mine operation recovering low-sulfur coal. Using carbonates from the nearby Nippenose Valley in several innovative strategies, operators are not only able to reduce the acidity of the runoff from this site but also improve water quality derived from previous mining activity here.

The next leg focuses upon two projects in an urban setting that have generated considerable controversy among the population. In spite of the public challenges, technically complex, highly integrative solutions have been applied to each of the problems. We will examine several aspects of the flood-control measures designed to protect the city of Lock Haven, much of which is in the West Branch Susquehanna River floodplain and testifies to a long history of consequential flood events. The city also is home to a Superfund cleanup site and an adjacent active hazardous-waste remediation operation being carried out by the responsible party. We will take advantage of an overview of both projects and be able to contrast the technical aspects of the two different solution formulae being applied.

The last stop of the first day provides an opportunity to trudge upon surficial materials actively moving downslope along the flank of Bald Eagle Mountain. Such mass wastage would not be a problem were it not for a major four-lane cut into these materials. This is a typical setting for many highways in the Valley and Ridge province and we will not only examine the features formed by this process but also address the nature of the problem as it impacts highway design and construction.

The second day involves fundamentally only two stops: one illustrating the nature of the bedrock within the West Branch Susquehanna River/Bald Eagle Creek Valley; the other exposing multiple surficial units derived from several different geologic processes operating throughout the history of this valley.

Bedrock beneath this valley is complexly deformed. The Silurian/Devonian sequence comprises non-resistant carbonate and fine-grained clastic units that have been folded, faulted, and thickened by repetition of units. Outcrops and artificial cuts in this valley setting are sparse. Three quarries near Jersey Shore, two of which we will visit, expose deformed units and illustrate not only this structural complexity but also serve as local stratigraphic links for subsurface lithologic determinations in other parts of the valley.

Throughout its nearly 25-year history, the Clinton County Landfill site in McElhatten has provided a wealth of scientific data about the geology of this valley. However, as our last stop we visit this site not only to examine the surficial units exposed here, but we also wish to highlight the significant role both bedrock and surficial geology have played in the evolution of the landfill itself and examine its ongoing development within the framework of continually updated and increasingly more rigorous environmental requirements and regulations.

In addition and partly to satisfy the longings some might have for the more traditional approach, a pre-conference field trip is scheduled to the home of *Hynerpeton bassetti*, a new, recently unearthed Devonian tetrapod. Well-preserved fragments of *H. bassetti* have been recovered from the Duncannon Member of the Catskill Formation near Renovo, about 30 miles north of Lock Haven. Its presence here extends the known geographic range of early Devonian tetrapods into continental North America. Along with *H. bassetti*, fragments of a wide assortment of fish are locally abundant.

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The work of many individuals was necessary to put this field conference together, and these efforts are most graciously acknowledged. Contributions of authors and presenters are clearly noted at appropriate places and are much appreciated. Many presenters could not have contributed without the cooperation of their employers, and we wish to thank companies and agencies involved, including the Pennsylvania Department of Environmental Protection, Fisher Coal Co., the U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, Meiser & Earl, Inc., the Pennsylvania Geologic Survey, the Pennsylvania Department of Transportation, and the Clinton County Solid Waste Authority. A very special acknowledgment goes to Tom Earl of Meiser & Earl, Inc., State College, for undertaking the acrobatic flying necessary to provide both the black and white and color air photos for the guidebook and icebreaker. Thanks also go to Lock Haven University for allowing us to use their facilities for production of the guidebook. Finally, we wish to express our thanks to several of our students who have volunteered their time and energy—Paul Malmquist, Mike Matthews, Bret Ryan, and Josh Trevitz, and also to John Capwell, a former LHU student, who graciously agreed to help with registration.

GEOLOGIC SETTING OF NORTHCENTRAL PENNSYLVANIA

C. R. CARNEIN [1]

INTRODUCTION

More than 6000 meters (20,000 ft) of Paleozoic sedimentary rocks underlie Clinton, Lycoming, and Tioga counties. Units exposed range from the Upper Cambrian Gatesburg Formation through the Middle Pennsylvanian Pottsville and, possibly, Allegheny groups (see Cover 3 for a generalized stratigraphic column). These units will not be described here; detailed descriptions and data on engineering, environmental, and hydrogeologic characteristics can be found in Faill and Wells, 1977; Faill, Wells, and Sevon, 1977a and 1977b; Faill, 1979; Lloyd and Carswell, 1981; Taylor, 1977; and Wells and Bucek, 1980.

The area straddles the boundary separating the Appalachian Plateaus physiographic province to the north and the Ridge and Valley province to the south. Faill and Wells (1977) place the boundary along the hinge of the Short Mountain and Barbours synclines north of Williamsport. Asymmetrical folds, thrust, strike-slip, and normal faults, spaced cleavage, and evidence for simple shear fade out northward across the boundary.

PHYSIOGRAPHY AND STRUCTURAL GEOLOGY

The 1995 Field Conference will focus on localities in the West Branch Susquehanna River valley and the Appalachian Plateaus to the north. In Clinton and Lycoming counties, the West Branch Susquehanna River mostly occupies Bald Eagle Valley, the northernmost valley of the Ridge and Valley province. Ridge-and-Valley topography is controlled by differential erosion of folded sedimentary rocks, and, to a lesser extent, by faulting and localized fracture zones.

Bounding Bald Eagle valley on the south is Bald Eagle Mountain, a nearly continuous double ridge whose two parts are held up by resistant sandstone of the Bald Eagle and Tuscarora formations. The swale separating the two ridges is underlain by less resistant sandstone, siltstone, and shale of the Juniata Formation. Wind and water gaps cut the ridge at relatively regular intervals, and a few major water gaps join the valleys on either side of the double ridge (e.g., along US Route 220 at Mill Hall).

In Bald Eagle Mountain, the rocks generally dip steeply to the north-northwest and occupy the forelimb of the Nittany anticlinorium. This complex, asymmetrical, first-order fold plunges gently east-northeastward in Nittany Valley, south of Bald Eagle Valley and Lock Haven. To the east, the fold axis is offset southward, resulting in an *en echelon* pattern whose segments are doubly plunging under Nippenose and Mosquito valleys.

Gwinn (1964, 1970) ascribed the Nittany anticlinorium to ramping of a décollement, probably from Cambrian rocks upward and northwestward into Silurian rocks at depth. The Jersey Shore, Maranatha, and Antes faults, located in the vicinity of STOP 6 of this year's Field Conference, are interpreted as south-dipping splays bringing older Devonian rocks up over Upper Devonian strata (Fig. 1) (Faill and Wells, 1977).

The Nittany anticlinorium shows most of the characteristics of a large scale kink fold. Flexural slip is indicated by abundant bedding-plane striae, simple shear is shown by cleavage in shaly units, and the fold has flat limbs and a narrow hinge. Structural relief is estimated at 2700 meters relative to the hinge of the White Deer syncline, about 7 km to the southeast; and 4000 meters relative to the Short Mountain syncline, about 13 km to the north (Faill and Wells, 1977). However, both the Nittany anticlinorium and the White Deer syncline die out into east-dipping structural terraces and, finally, a north-dipping homocline, as one follows them eastward from Lycoming County. There, the northern boundary of the Ridge and Valley shifts southward.

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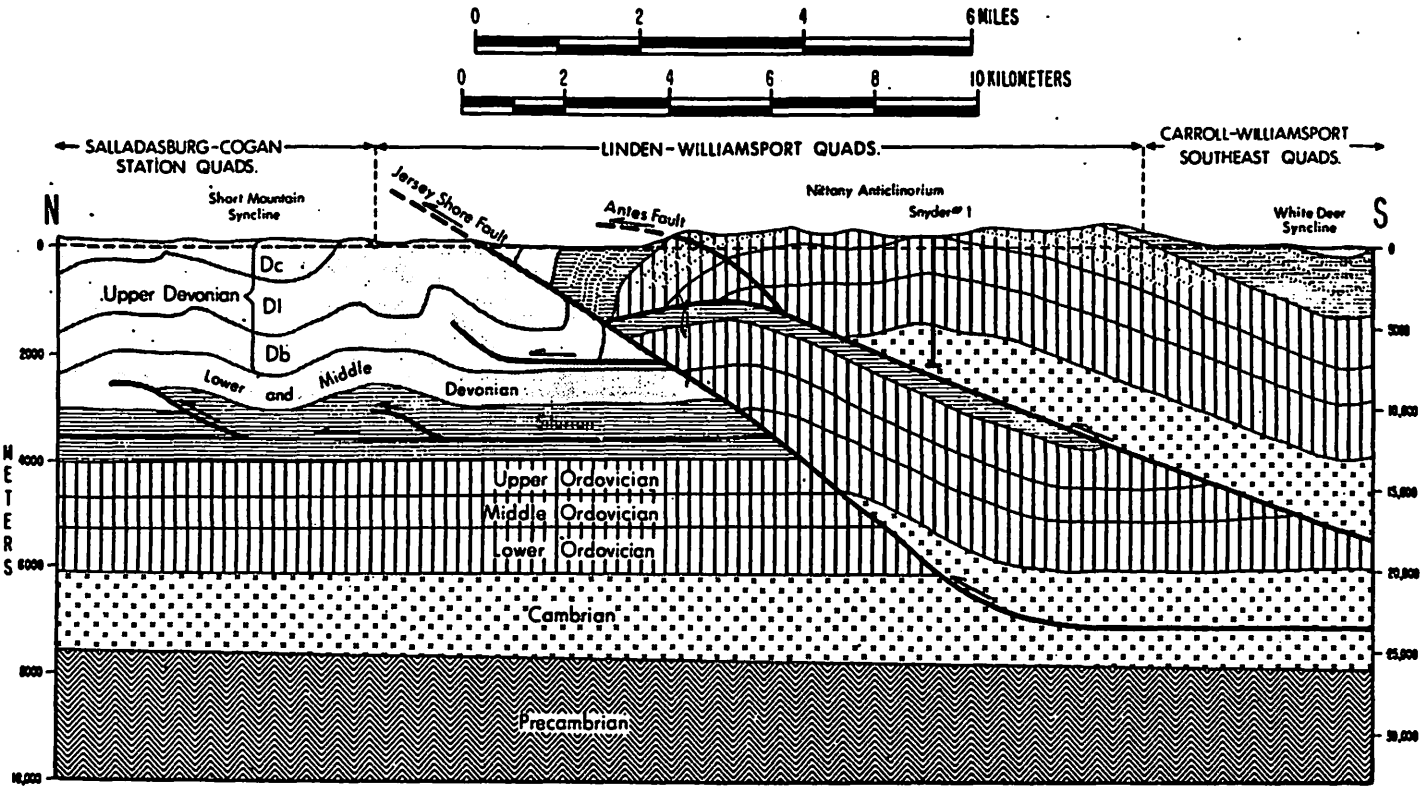

Figure 1. Generalized cross section by Faill and Wells (1977) showing their interpretation of structures underlying the northernmost Ridge and Valley near Williamsport. The Maranatha fault zone, seen at STOP 6, lies between the Antes and Jersey Shore faults.

Geology, physiography, and environmental problems of Nittany valley were highlights of the 1985 Field Conference of Pennsylvania Geologists (see, for example, Gold and Pohn, 1985 and Parizek and White, 1985). Bedrock exposures on Bald Eagle Mountain, near Lock Haven, were visited on both the 1983 and 1985 Field Conferences (see Nickelson and Cotter, 1983 and Cuffey and others, 1985a, b). Although those exposures (and some new ones related to construction of the Lock Haven dike and levee) are clearly visible from US Route 220, we will not visit them this year.

Bald Eagle valley occupies the Nittany anticlinorium's north limb. Numerous named second-order folds, with wavelengths of 1 to 5 km, occur here. Smaller folds and thrust faults, including the Jersey Shore, Maranatha and Antes faults, also occur on the north limb (Fig. 1), but these structures commonly are buried under alluvial and glacial sediments. Scattered outcrops, quarries, and drill-hole data along a line from Lock Haven through Jersey Shore, Williamsport, and the Montoursville area suggest the presence of thrust faulting and complex folding in Bald Eagle valley, analogous to the "disturbed zones" of Harris and Milici (1977). Considering the structural complexity shown along the Allegheny front to the southwest and south, into Maryland and West Virginia, this is not surprising. An example of this structural complexity will be seen at STOP 6, west of Jersey Shore, where the Maranatha fault offsets parts of the Devonian section (Fig. 1).

MINERAL RESOURCES

The area of this year's Field Conference has a long history of mineral-resource exploitation. Hematite in the Rose Hill Formation and the upper part of the Lock Haven Formation provided ore for several furnaces in Clinton and Lycoming counties in the mid-1800s. A few of these furnaces are preserved in the Williamsport and Lock Haven areas.

Quarries in the area have produced aggregate for road metal, macadam, concrete, and fill, and agricultural lime was burned from both the Ordovician carbonates of Nittany and Nippenose valleys and the Silurian-Devonian limestones in the valley of the West Branch Susquehanna River. Nearby, Ordovician carbonates are quarried for chemical-grade limestone and the manufacture of Portland cement. Numerous borrow pits expose the Reedsville, Mahantango, and other formations that are used to surface unpaved roads and driveways. Sand and gravel have been produced from alluvial deposits of the West Branch Susquehanna River Valley and nearby glacial outwash deposits.

An especially valuable resource that is not currently exploited is the Mercer clay. Both diaspore and flint clay were mined at several locations north and northwest of Lock Haven and formed the basis for a refractory brick industry. The deposits are lowermost Pennsylvanian underclays that underlie the Mercer Coal of the Mercer Formation (Pottsville Group) (Williams and Bragonier, 1985). A number of local shales have been used for manufacture of brick and terra cotta, and for the production of tripoli, which was formerly used as a paint filler.

Gas production began with a shallow well drilled into Upper Devonian (Chemung) rocks in northwestern Clinton County in 1864 (Ebright and Ingham, 1951). Until 1950, all production came from Upper Devonian rocks. 1950 marked the discovery of the Leidy gas field, also in northwestern Clinton County. Major production there came from Lower Devonian (Oriskany) rocks at depths of 5500 to 6500 feet. The field, located on the Leidy dome of the Wellsboro anticline, is now exhausted, but today serves as a major gas-storage area operated by CNG Transmission Corporation, at Tamarack. Up to 113 billion cubic feet of gas can be stored there for customers in northern New York. Additional storage fields are planned nearby for the future.

Compared to western Pennsylvania, the northcentral part of the state is not noted for its coal production. Coals that occur here belong to the Lower Pennsylvanian Pottsville and Allegheny groups. Many abandoned and partially reclaimed strip mines exist north of the Allegheny front, but active exploitation of the remaining relatively small bituminous coal reserves has almost ceased. An unfortunate by-product of both underground and strip mining in the Plateau consists of numerous tributaries, contaminated by acidic waters containing excessive amounts of aluminum, that continue to contaminate the West Branch Susquehanna River and other streams. On this Field Conference, we will visit two sites, one a commercial strip mine owned by the Fisher Coal Company and the other a water-treatment system operated by the Department of Environmental Protection, where innovative methods are used to prevent or remediate acid-mine drainage.

Ordovician carbonates of the Bellefonte through Coburn formations, in southern Clinton and Lycoming counties, account for 3 of the 11 second-order springs in Pennsylvania, as reported in Flippo (1974). Naturally acidic water from the mountain ridges surrounding Nittany and Nippenose valleys drains into a system of conduits following fractures in the carbonate rocks. Sinkholes are so common in Nippenose Valley that no surface drainage occurs in the center of the valley. Most of that valley's groundwater reaches the surface at Nippeno spring, reputed to be Pennsylvania's largest, with an average discharge of 26 to 52 million gallons per day (Flippo, 1974; Lloyd and Carswell, 1981). Similar large springs occur in Nittany Valley, where they supply water for private individuals, local water companies, fish hatcheries, and as the loci for small parks and recreation areas. Increasing development in rural areas not served by public sewage-treatment systems results in increasing levels of contaminants in the groundwater of the carbonate valleys. Numerous trash filled sinkholes also dot these valleys; the Soil Conservation Service has recently made education about sinkholes and sinkhole remediation a priority.

Other moderate to large supplies of groundwater are available in stratigraphic units exposed in the West Branch Susquehanna River Valley. Included are limestone of the Silurian/Devonian Keyser Formation, the Ridgeley Sandstone Member of the Devonian Old Port Formation, and other units where fracture systems locally give them greater than average permeability. Quaternary valley-fill deposits are a major potential source of future groundwater for the Williamsport area. High yield wells are concentrated at or near the confluence between major south-flowing, high-gradient streams and the West Branch Susquehanna River (Lloyd and Carswell, 1981). Additional data on groundwater resources of specific stratigraphic units in northcentral Pennsylvania can be found in Lloyd and Carswell, 1981.

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LIMESTONE DIVERSION WELLS—A LOW-MAINTENANCE, COST-EFFECTIVE METHOD FOR TREATING ACID-MINE DRAINAGE WITH LIMESTONE

JOSEPH H. SCHUECK [1]

INTRODUCTION

Coal production has been and remains significant to the Commonwealth's economy. Unfortunately, the production of acid-mine drainage (AMD) is a by-product of coal mining in many cases. AMD has degraded about 2500 miles of the state's streams. Mitigating the effects of this acidic runoff remains a challenge for researchers.

The mineral pyrite, FeS_2, is commonly associated with coal deposits and the surrounding strata. In undisturbed strata, the weathering of pyrite occurs relatively slowly. However, mining breaks up the host rock containing the pyrite, exposing this mineral to the elements and increasing the rate of physical, chemical, and biological weathering processes. Pyrite readily reacts in the presence of oxygen and water to form sulfuric acid and ferrous iron. As the pH of the water drops, naturally occurring iron bacteria become active. These bacteria further accelerate the rate of pyrite oxidation. As the pH of the mine drainage continues to drop, other metal ions, such as aluminum, copper, and cadmium, go into solution. Many of these metal ions are toxic to fish and macro-invertebrates, and, as a result, water quality in natural stream systems within coal mining regions is degraded.

AMD can be neutralized by using various alkali reagents. A 1971 cost comparison of five commonly used reagents was assembled by the Mine Drainage Research Section of the Pennsylvania State University. Table I is a cost comparison for treating a 250-gallon-per-minute discharge containing 800 parts per million of acidity.

TABLE I Cost comparison among potentially useable reagents in treating acid-mine discharge.

Reagent	Chemical Formula	Cost per day
limestone	$CaCO_3$	$7.26
quick lime	CaO	$17.09
hydrated lime	$Ca(OH)_2$	$23.22
caustic soda	NaOH	$262.63
soda ash	Na_2CO_3	$98.71

Although each reagent has its advantages, it is clear that limestone is the most economical. However, neutralization of AMD causes ferric hydroxide to precipitate. When limestone is used, the ferric hydroxide forms as a coating on the surface of the limestone fragments. This armor inhibits further contact with the acidic waters, rendering the limestone useless in the mitigation process. To take advantage of the economics of limestone, a treatment system which prevents the armoring of the limestone is needed. Diversion wells can provide such a mechanism.

LIMESTONE DIVERSION-WELL REMEDIATION TECHNOLOGY

Limestone diversion-well technology was developed in Sweden and brought to Pennsylvania by Dr. Dean Arnold, Assistant Leader, Fisheries, National Biological Service. The design of this system harnesses hydraulic power to churn the limestone aggregate in the well. A limestone diversion well can effectively neutralize mildly to moderately acidic waters with flow rates of up to 450 gallons per minute.

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Design Model

The diversion-well design is rather simple and comprises three fundamental parts: (1) the diversion well, (2) a water-impoundment structure, and (3) a pipeline connecting the impoundment with the diversion well. The diversion well may be as "low-tech" as a manhole section or septic tank filled with crushed limestone. Treated water exits this well and re-enters the natural, surface-drainage system. The impoundment structure, situated up-gradient (upstream) from the exit well, serves to pond the surface water in the stream. As a result, stream water behind the impoundment enters the treatment system at a unform flow rate. A pipe, fitted with a special nozzle on the downstream end and sized to handle the design flow, extends from the impoundment to the well.

Water moves through the pipe under pressure, a result of the hydraulic head developed as a result of the difference in elevation between the impoundment and the well. As the water enters the limestone-filled well, the force of the water flowing through the nozzle causes the limestone fragments in the well to churn. Rock fragments conurning action, exposing more fresh limestone surfaces which can then chemically react with the acidic water.

Many attempts to treat AMD with limestone in the past have met with limited success because of the armoring of the grains with metal-hydroxide precipitates. However, any precipitates which may form on the limestone aggregrate in the diversion-well treatment system are rapidly removed by the churning action. In addition, both physical abrasion and chemical dissolution of the limestone continually exposes fresh surfaces as the stone breaks into smaller fragments. As a result, surface area increases allowing more continuous neutralization reactions to occur.

In addition to being a mitigation system which provides for the effective use of relatively low-cost limestone as a neutralizing agent, the diversion wells require little maintenance. There are no moving parts associated with the wells. Except for debris occasionally plugging intake openings or the erosion of the metal or concrete components, the wells require no mechanical maintenance. The wells do require a weekly filling with limestone. As indicated above, the neutralization reactions consume most of the stone. The rest is flushed out of the well and into the receiving stream once the particle size is small enough. Further neutralization takes place downstream from the diversion well as an added benefit. The wells consume about a ton of limestone each week.

Limitations of Model

The main drawback with diversion wells is that only mildly or moderately acidic mine drainage can be completely neutralized. The contact time between the limestone and the AMD within the well is only one to two minutes. Hence, the amount of limestone dissolution which can take place is limited. Even with the minimal contact time, biweekly sampling of the existing wells indicates that it is reasonable to expect a decrease in net acidity of between 50 and 80 mg/l. Where the initial pH is about 4.5 and dissolved metal concentrations are low, a well discharge pH of greater than 7 is common. However, where the initial pH is closer to 3.5 and dissolved metal concentrations are in the 10's of mg/l range, then the well discharge pH may only increase to about 4.0 with little change in metal concentrations. This is in contrast to other reagents, such as caustic soda, where the amount of reagent added to the discharge can be controlled to obtain a specific target pH. However, the effectiveness of diversion wells to treat the low-pH, high-metal discharges may be improved by using two or more wells in series.

DIVERSION-WELL REMEDIATION IN BABBS CREEK WATERSHED

The first two diversion wells in the Babbs Creek watershed were constructed on Lick Run in 1990 in an attempt to restore an aquatic community to the area streams (Fig. 2). Babbs Creek had been polluted for 150 years as a result of past mining practices, and the wells treat water derived from an old, abandoned, underground-mine complex. A survey of fish and invertebrate communities was conducted in 1990 at several locations between the confluence of Lick Run and Babbs Creek, downstream to the village of Morris. Few invertebrate and no fish species were found during the survey. It is felt that dissolved aluminum levels were just high enough to be toxic to the aquatic life.

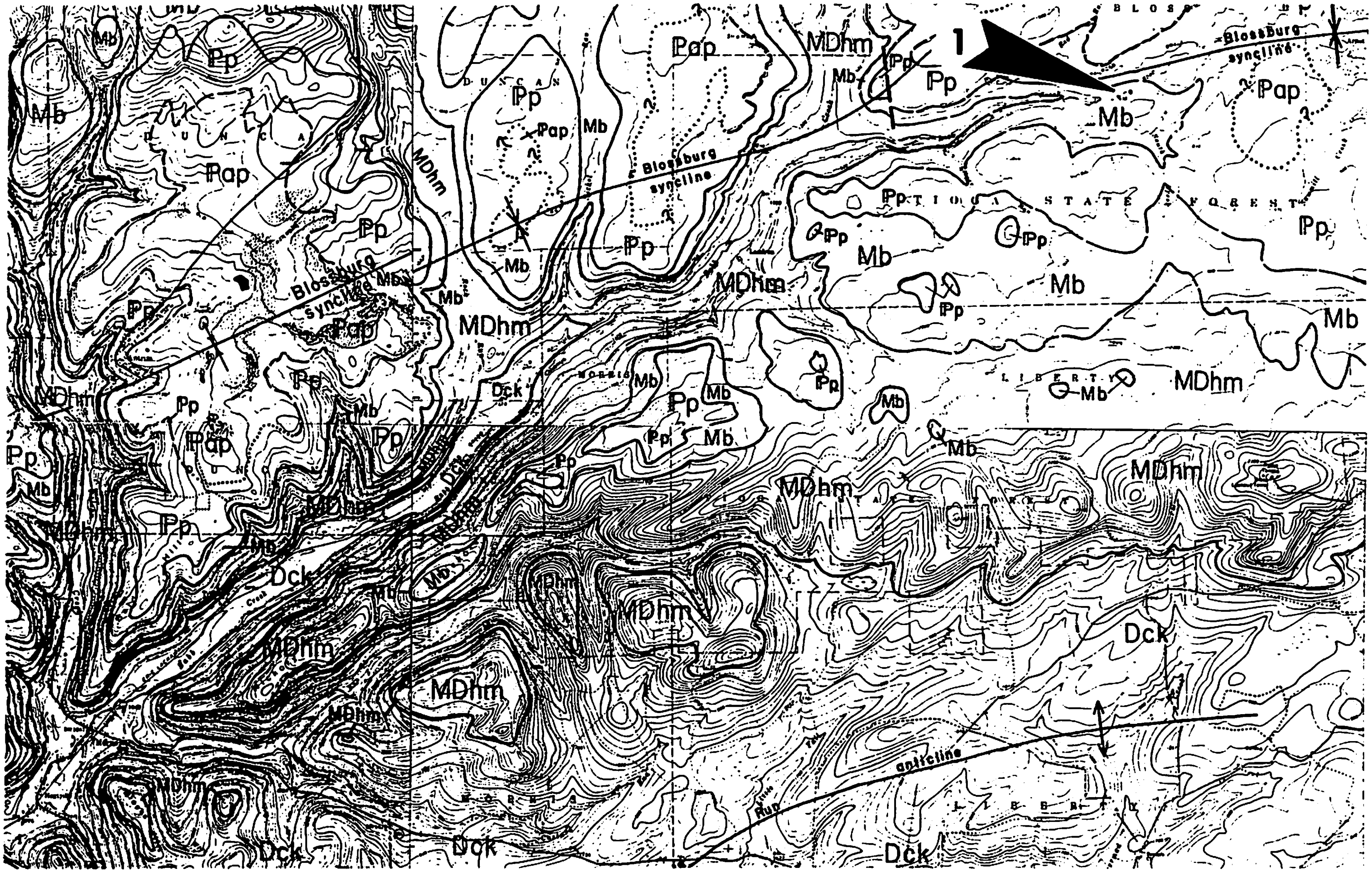

Figure 2. Preliminary bedrock geologic map illustrating a portion of the Babb Creek watershed within the Blossburg coal basin, southern Tioga County. The location of **STOP 1** on Lick Run, a tributary to Babb Creek, is indicated by the arrow. Morris lies at the confluence of Babb and Wilson Creeks in the lower left-hand corner. (Compilation of the NE corner of the Morris quad, SE corner of Antrim quad, S edge of Cheery Flats, and the N edge of Nauvoo quad; from Berg and Dodge, 1981, p. 395, 24, 112, 409.)

In 1994, four years after the wells were placed into operation, the aquatic survey was repeated. Fish were present at each of the locations surveyed and the number of invertebrate species found was much higher than in 1990. It is unclear where these fish have come from or whether they persist on a year-round basis; however, their mere presence in these historically fishless waters can be viewed with optimism.

In the summer of 1994, a third diversion well was installed on the Klondike underground mine discharge and in the fall of 1995, two additional wells are slated for construction. All three wells will treat Klondike-mine discharge. Construction of the additional wells will serve to further enhance the quality of Babbs Creek and perhaps allow for the restoration of an aquatic community in Lick Run as well. The wells are maintained by the Bureau of Forestry. Funding for the wells was provided for by the Babbs Creek Pollution Abatement Fund and the Department of Environmental Protection.

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Coal Geology and Remining, Little Pine Creek Coal Field, Northwestern Lycoming County

MICHAEL W. SMITH [1] AND CLIFFORD H. DODGE [2]

NOTE: For your safety, participants are not permitted within the active strip-mine pit. Moreover, PLEASE STAY BACK away from the edge of the low wall!

INTRODUCTION

At this stop, we visit an active strip mine in order to demonstrate improved methods of reclamation and pollution abatement of former surface- and underground-mine operations through remining and alkaline addition to treat acid mine drainage (AMD). At the same time we will review the coal geology of this portion of Lycoming County (the Little Pine Creek coal field), a region not normally associated with the occurrence or production of bituminous coal. (The geology of the Little Pine Creek coal field is summarized in this guidebook by Dodge, p. 27-36.) This site is the only active coal mine in the county (Surface Mining Permit nos. 41870101 and 41920101) and is operated by Fisher Mining Company, Inc., Williamsport, Pennsylvania.

LOCATION

The Fisher surface mine is located in the upland area between Buckeye Run, to the west, and English Run, to the east, on State Game Lands No. 75 in the English Center 7.5-minute quadrangle, Pine Creek Township, northwestern Lycoming County (Fig. 3). The operation is about 3 miles northwest of the village of English Center. The elevation of the mine ranges from about 1490 - 1650 feet.

SITE GEOLOGY

Up to four coals are present and being mined here. The B, C, and C' coals are the principal seams; the D coal is sporadic and mined incidentally. The E coal, once found near the old summit of this tract, was almost completely removed through strip mining by a former operator, Donald E. Fisher, during the 1950s and 1960s. The remainder of the E coal was removed a few years ago by Fisher Mining Company (J. A. Blaschak, 1995, oral communication). The other seams were also surface mined along the flanks of the hill by earlier operators. Fairly extensive underground mining occurred here in the past as well, primarily on the B seam and to a lesser extent on the C' coal. Currently, most of the coal mined in this operation is shipped to utility companies to generate electricity.

Structure

The Fisher strip mine is situated along the southern flank of the Little Pine Creek basin, just south of the axis and about 1 mile south-southwest of the deepest part of the structural depression (Fig. 3). The average strike and dip of the rocks at the site is N30°E, 170 feet/mile NW. However, there are many local variations in bedding attitude, particularly toward the central part of the mine operation—the area that comprises the "disturbed zone" of Koppe (1975). Local changes in structure are characterized by rolls, dip reversals, and marked deviations in strike.

Minor tectonic faulting also occurs locally, principally in the "disturbed zone." Vertical offset of beds (separation) generally ranges from 1 to 3 feet and seldom exceeds the thickness of the coal seams, the units in which faulting is most discernible (S. D. Blaschak, 1995, oral communication). The faults commonly persist downward through the entire exposure of highwall, but a few appear to die out with depth (S. D. Blaschak, 1995, oral communication). There is no evidence of significant

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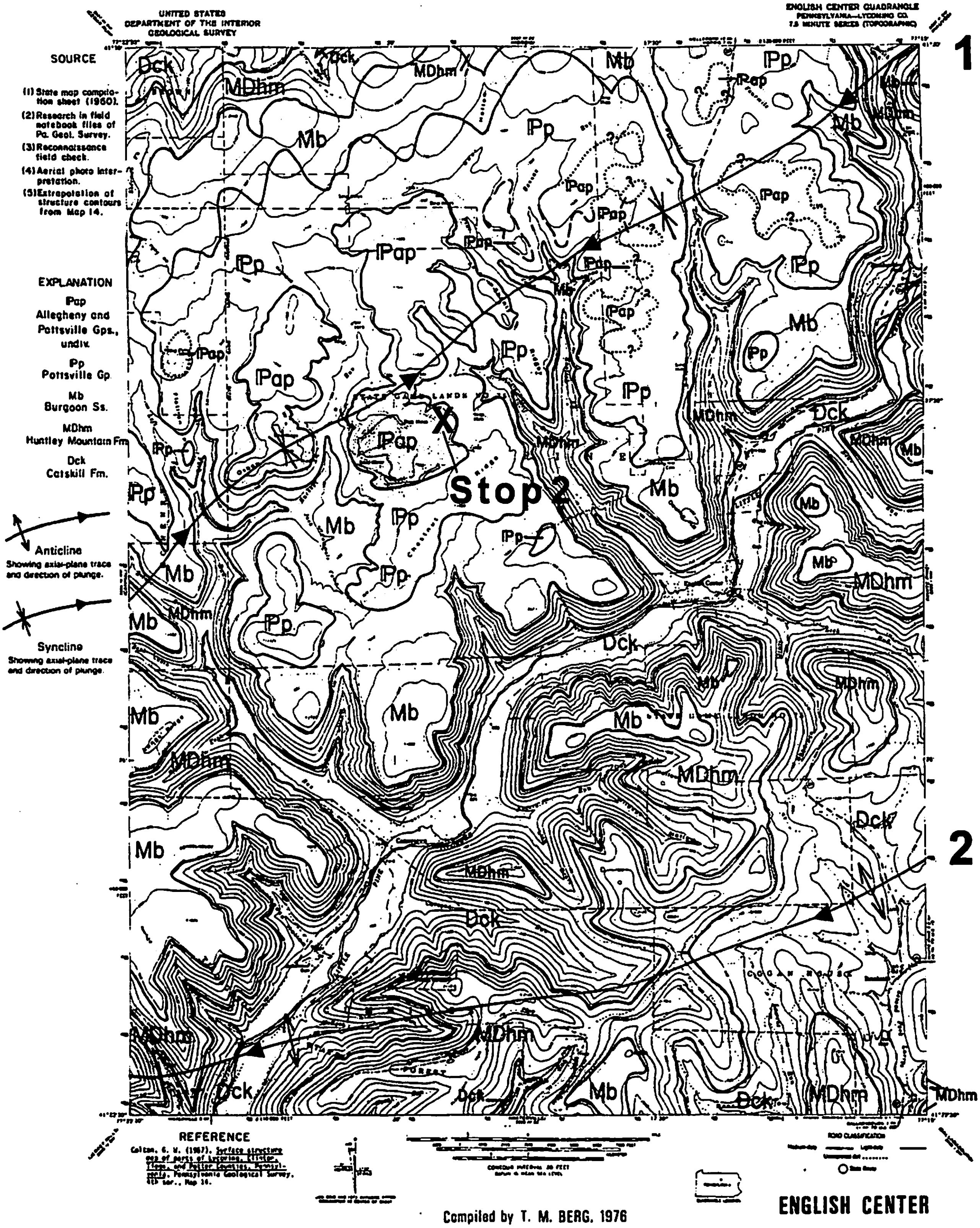


Figure 3. Preliminary bedrock geologic map of the English Center 7.5-minute quad, northwestern Lycoming Co., showing the location of STOP 2. 1 = axial-plain trace of Little Pine Creek basin (McIntyre syncline). 2 = axial-plain trace of Hyner anticline. Modified from Berg and Dodge (1981, p. 202)

rotation or contortion of beds nor of pronounced concaveupward curvature of fault planes, which collectively are diagnostic features of soft-sediment slumping. The coals thin within about 50 to 100 feet of either side of the faults but appear undeformed away from the faults themselves (S. D. Blaschak, 1995, oral communication).

To the south of this site, Dodge observed a normal fault at the top of a roll. Vertical displacement on that fault is 1.2 feet. The coal (C' seam) thins toward the fault from 2.4 to 1.6 feet and is undisturbed away from it. Measured attitudes of the observed fault plane are N63°W, 77°NE and N60°W, 61°NE.

Thinning of the coals appears to be related to depositional and not tectonic processes. This being the case, the thinner coals presumably would have been deposited as peat on paleotopographic highs (i.e., less accommodation space), which may in turn have controlled the occurrence and location of rolls and faults during subsequent deformation.

Highwall Section

At the time the strip-mine highwall was described (June 6-7, 1995), over 90 feet of vertical section was exposed. However, the entire stratigraphic sequence could not be examined at any one location. A columnar section of the exposed rocks is shown in Figure 4.

Lithologic Description

The highwall section is characterized by a preponderance of siltstone and sandstone. The overall trend in grain size is coarsening upward. Sandstones tend to increase in thickness and grain size toward the top of the section. (The shales adjacent to the D coal in Fig. 4 are not persistent and grade laterally to sandstone.) Maximum grain size is generally medium sand; some larger shale chips or clasts do occur in places. The most conspicuous sedimentary structures are in the thick sandstone at the top of the section and include trough crossbeds and lateral-accretion beds (epsilon cross-stratification).

Carbonate and calcareous units are absent. However, a few small, scattered siderite nodules and concretions occur locally in several beds, especially between the B and C coals. (Siderite concretions appear to be somewhat larger and more common farther to the west in the operation). Rootworked paleosols are found beneath the coals. Several other intervals are also rootworked, particularly in the lower half of the section. Fossil-plant compressions and debris are locally common, but there is no evidence of invertebrates or trace fossils.

Coal Characteristics

The B coal occurs at the base of the section and varies in thickness from 2.5 to 4 feet. It contains a thin, persistent carbonaceous-claystone parting toward the middle of the seam. Where sampled, the lower coal bench is 1.8-feet thick and very good in quality. It contains 14.1 percent ash, only 0.65 percent sulfur, and a heat value of 12,877 Btu/pound. The 0.75-foot upper bench is excellent quality coal, having 8.6 percent ash, 0.72 percent sulfur, and a heat value of 13,958 Btu/pound. Nearly all of the sulfur in the B coal is inherent organic sulfur.

The thickness of the C coal ranges from about 2 to 3 feet. The coal is bony in places and contains carbonaceous-claystone partings up to 0.5 foot thick. At the sampling site, the coal thickness, including parting, is 3.0 feet. Ash content of the 0.6-foot bottom bench is 11.4 percent; sulfur is 1.06 percent; and heat value is 12,908 Btu/pound. The next bench is a 0.5-foot-thick carbonaceous-claystone parting. The third bench, which is 1.3 feet thick, contains 17.0 percent ash and 0.76 percent sulfur; it has a heat value of 12,253 Btu/pound. The 0.6-foot-thick upper bench is bone coal and is not mined, having 46.2 percent ash, 1.09 percent sulfur, and a heat value of only 7,499 Btu/pound.

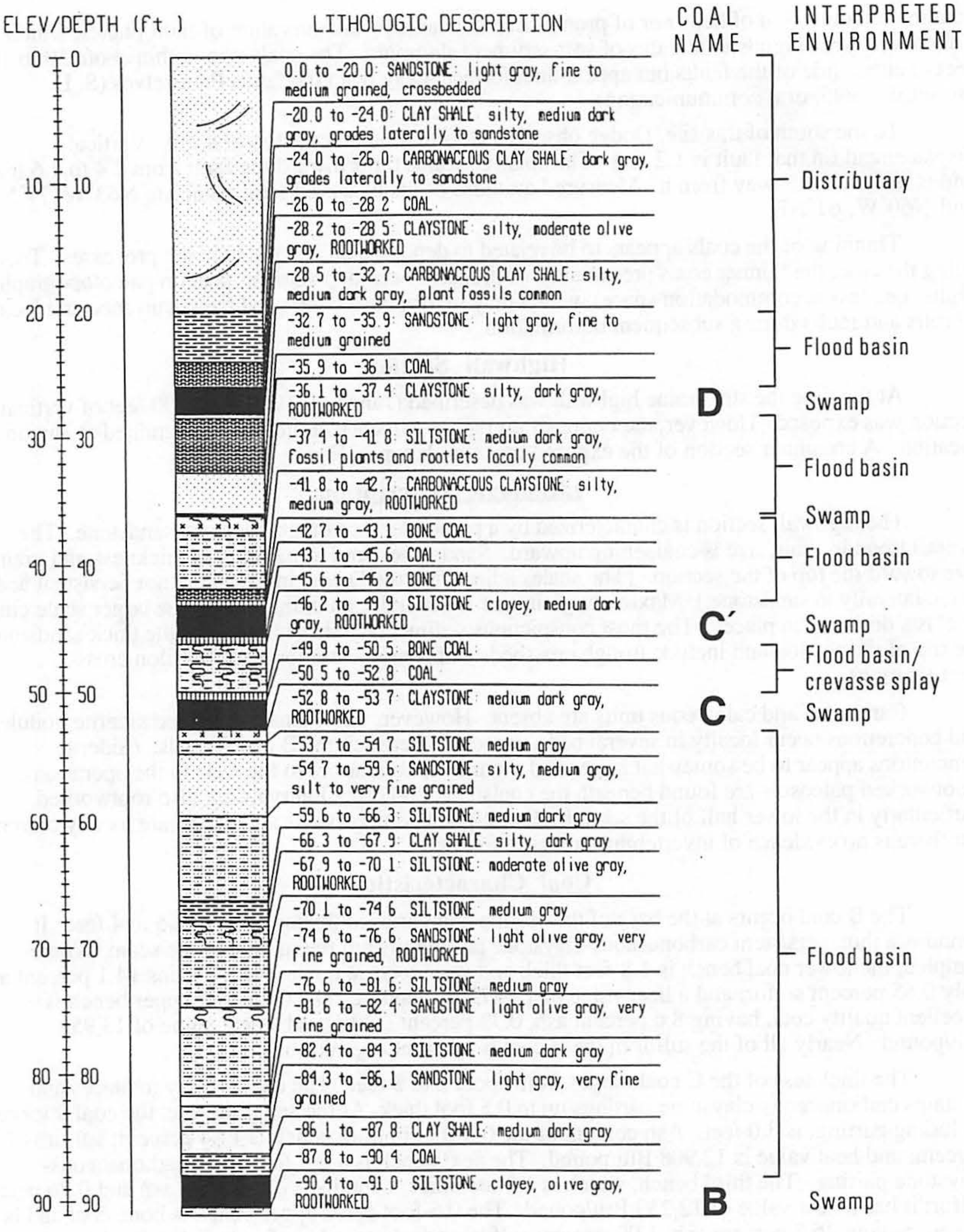


Figure 4. Columnar section of strip-mine highwall at STOP 2.

The thickness of the C' coal is generally 2.5 to 3.5 feet, but thins locally to around 1.5 feet. It is situated about 3 to 4 feet above the top of the C. The C' coal locally has benches of bone coal at its base and top. Partings within the main coal interval are thin and generally nonpersistent. The seam, where sampled, consists of two benches of coal separated by a thin parting. The 1.1-foot lower bench has the better quality. It contains 7.1 percent ash and 1.01 percent sulfur, and has a heat value of 13,998 Btu/pound. The ash content of the 1.3-foot upper bench is 14.6 percent, and the sulfur is 2.51 percent. Nearly 60 percent of the sulfur in the upper bench is pyritic. The sulfur content of the sample is considered atypically high for the bench (J. A. Blaschak, 1995, oral communication). The heat value of the upper bench is 12,630 Btu/pound.

The D coal ranges from 0 to 2.2 feet thick. Where the seam is mined, the upper 0.3 foot or so is shaly and is rejected. Elsewhere in the operation, the D thins and pinches out or develops a parting up to 0.7 foot thick. The sampled coal is 1.9 feet thick. It is excellent in quality at this location, having 8.6 percent ash, 0.54 percent sulfur, and a heat value of 12,005 Btu/pound.

Depositional Environments

The rocks exposed in the strip mine were deposited as sediments by meandering streams on an upper delta plain, the part of a subaerial delta above the area of significant marine or tidal influence. The mine section (Fig. 4) reflects changes in sedimentation associated with migrating fluvial distributary channels. The sequence represents a cyclic succession of very low energy (coal) and high-energy (siltstone and sandstone) environments that are characterized by peat-swamp, flood-basin, and fluvial channel-fill deposits.

The coals represent peat swamps that formed in relatively stable interfluvial areas. Clastic partings in the coals indicate rapid influxes of fine-grained sediments into the swamps during flooding events that temporarily inhibited or terminated peat formation. Bone-coal benches or partings reflect more restricted or gradual input of detrital material into the peat swamps. Partings tend to be thicker or more common in the higher seams, suggesting less isolation or stability of the swamps.

The siliciclastic sequence between the B and C coals was deposited in a flood basin. Termination of the coal swamp representing the B seam was brought on by the influx of claysized clastics, followed by much more abundant silts and sands. Sedimentation probably resulted from both overbank flooding and levee breaches. Variations in grain size are a function of flood strength and distance from the channel. Rootworked zones attest to reestablishment of vegetation on the floodplain, but unsuitable conditions precluded significant preservation of organic matter. The thick sandstone just below the C coal may represent a crevasse splay that was a precursor to channel abandonment and subsequent return to more stable interfluvial conditions.

The C and C' coals appear to be genetically related and part of the same coal swamp. The seams are separated by several feet of rootworked clayey siltstone, which represents crevassesplay deposits that terminated peat formation, but only until the levee break healed, and subsequently developed into soil (paleosol). (At some other places in the Little Pine Creek field, only a few inches of clastics come between the two coals.) The coal swamp reflourished, resulting in the C' coal.

Thereafter, the swamp was buried by a new influx of sediments into the flood basin. The cycle of flood-basin and peat-swamp deposits repeated itself, only on a smaller scale. The thin coal about 10 feet above the base of the C' seam indicates very limited peat formation prior to termination by coarser grained crevasse-splay deposits. The fine- to medium-grained sandstone overlying the coal heralded the approach of a major fluvial distributary.

The D coal and associated fine-grained clastics are lenticular and represent restricted peat-swamp and overbank deposits that were preserved in a narrow, protected interfluve.

The thick sandstone that caps the highwall section represents the lower part of a distributary meander belt. The deposit is fine to medium grained. Elsewhere in the coal field, it is locally coarser grained and may include some quartz granules to small pebbles. The sandstone contains few to locally common, carbonized and coalified plant material (channel-lag debris) up to 1 foot or more in length. Scattered shale chips, probably representing cutbank material, occur as well. Scouring was not observed at the base of the unit, but access to the sandstone was limited. The trough crossbeds probably resulted from sinuous dunes that migrated within the channels. Lateral-accretion (*point*-bar) surfaces are preserved in places and are useful indicators of meandering streams.

REMINING

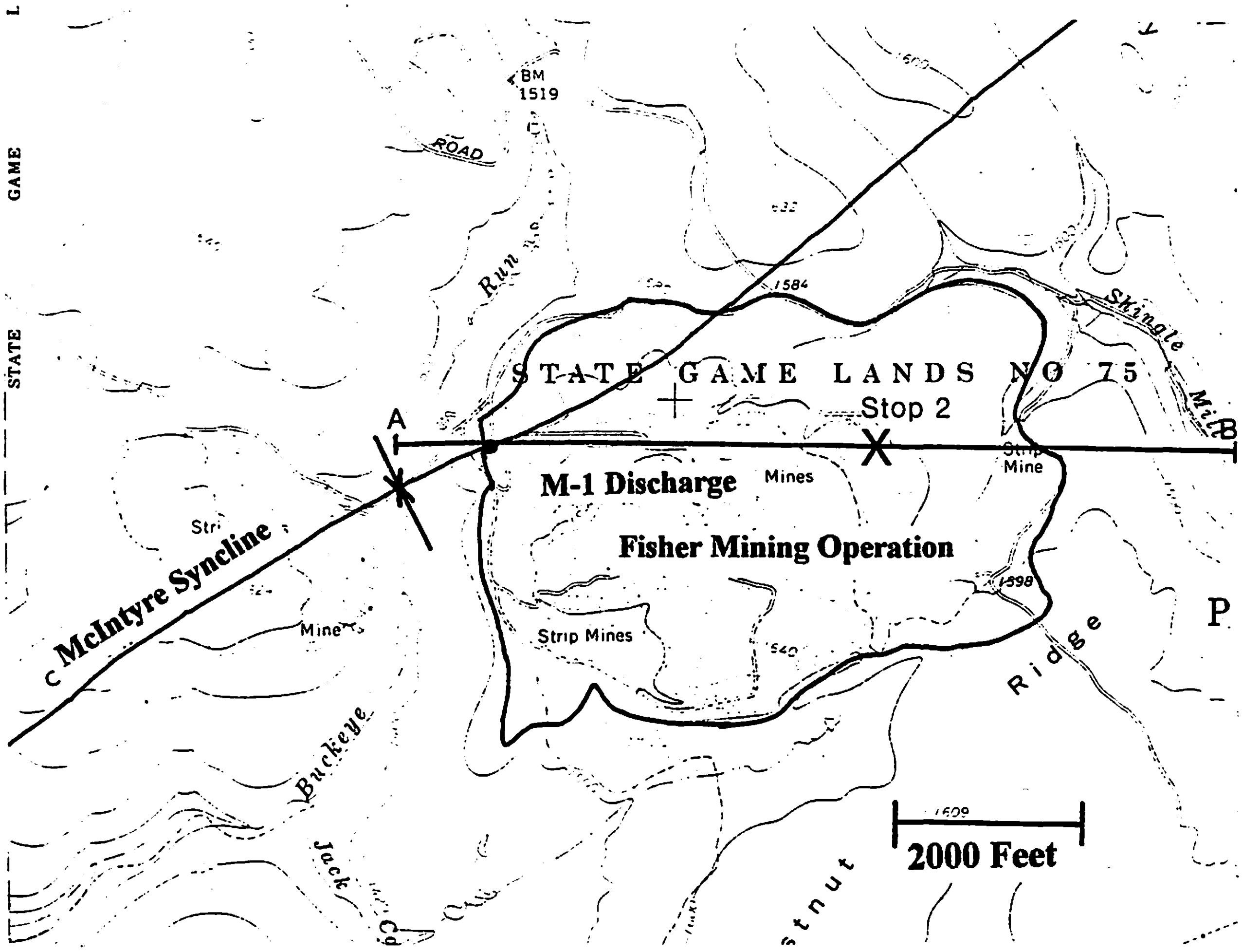
Remining is the practice of surface mining areas that were previously affected by surface or underground mining in order to extract remaining mineral resources. With the development of modern surface-mining equipment and techniques in the 1960s and 1970s, the mining of many areas of previously unrecoverable coal became possible. Very commonly, these areas had already been partially exploited by underground mining, leaving from 10 to 50 percent of the coal for roof support, or by shallow-cover surface mines, taking one or two "cuts" of coal near the outcrop. With little or no reclamation requirements, most of these older sites left Pennsylvania with a legacy of landscapes covered with unreclaimed spoil piles and discharges of acidic drainage into surface and subsurface systems. However, under subsequent regulations, a mine operator who reentered these areas to recover additional coal had to reclaim them to current standards. Although this has resulted in the reclamation of many thousands of acres of abandoned mine lands in Pennsylvania at no cost to taxpayers, the economics of treating preexisting discharges of AMD to comply with conventional effluent standards created no incentives to remining. This, in turn, increased the justification to mine virgin sites, which are frequently located in environmentally sensitive areas or previously unmined watersheds.

In 1984, Pennsylvania began to grant special permits for remining operations which limited the liability for treatment of preexisting discharges of AMD. The mine operator is required to reclaim abandoned mine lands and implement a pollution-abatement plan. In turn, his liability for treatment of preexisting discharges is generally limited to increases in the pollution load over and above that which existed prior to the remining operation. In short, the operator establishes the "baseline pollution load" by monitoring pollution discharge for a pre-remining period. The discharge is also monitored during and after remining. If the pollution load has not increased and the agreed upon reclamation has been accomplished, no further work is required. These permits are frequently referred to as "Subchapter F" permits, a term derived from the underlying provision in Pennsylvania's mining regulations.

Fisher Operation

One of the first mine sites in Pennsylvania to take advantage of this rule change was the Fisher Mining Company operation. The Fisher operation comprises four separate permitted sites which are run as a single mine. In aggregate, the operation covers 624 acres with 373 acres permitted for coal removal. Of this area, 82 acres of what was identified as the B coal was deep mined by D. E. Fisher (no relation to the current operator) beginning in 1932. That operation removed approximately 80 percent of the coal reserve (J. A. Blaschak, 1995, oral communication).

The Fisher deep mine was subsequently abandoned and eventually flooded. In 1969, a severe rainstorm resulted in the build up of a hydrostatic head sufficient to blow out the underground mine seal and generate a 70-foot-high water spout. The blowout occurred near the structural low point of the mine along the axis of the McIntyre syncline. It created a permanent source of AMD, referred to today as the M-1 discharge, near the entrance to the mine on the east (left) side of the haul road (Fig. 5). That initial slug of acid mine discharge flowed first to Buckeye Run, a tributary of Otter Run and then into Little Pine and Pine Creeks and resulted in a massive fish kill in Buckeye and Otter Runs and Little Pine Creek. A biological survey conducted in 1977 (Sheaffer, 1977) showed the continued absence of any fish population in the affected reaches of Buckeye and Otter Runs. Prior to remining, the M-1 discharge had a median flow rate of 52 gallons per minute. M-1 discharges occur only intermittently during active operations because the mine is being dewatered by pumping.



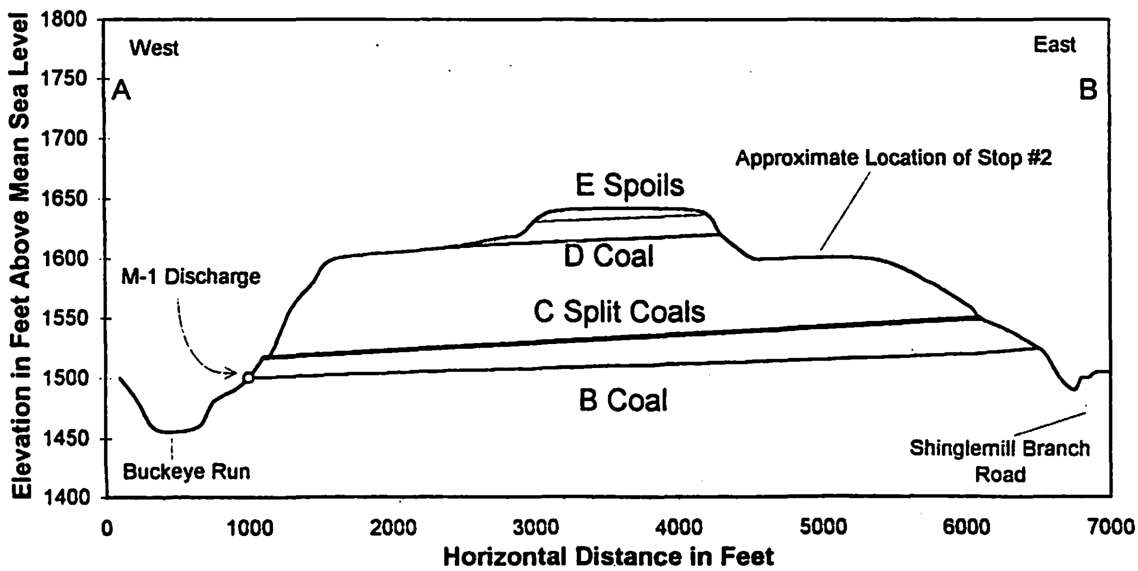


Figure 5. Map and generalized cross section showing the location of Fisher remining site and M-1 discharge.

At least nine other underground mines were also developed on the B and C' coals in the 1940s and early 1950s. Most were small country-bank drift mines. The most significant, and the only ones having continuous discharges of AMD, were the Frazier Mine (19 acres) and the Smith-Butler Mine (29 acres), respectively on the B and C' coals. Intermittent discharges of mine drainage are also produced by the B-coal Grasso Mine (~ 5 acres) and an unnamed mine on the C' coal.

In the 1950s and 1960s, D. E. Fisher also surface mined 250 acres of the E coal. This area was poorly reclaimed and regrading directed additional water into the underground mine via holes drilled into the pit floor to dewater the surface mine ultimately adding to the M-1 discharge. All of the E coal has been mined.

The Fisher Mining Company obtained a mining permit for a portion of this area in 1970. However, due to the presence of the M-I discharge and the liability to treat it to meet conventional standards, the major portion of this site could not be mined. With the implementation of Subchapter F in 1984, Fisher was able to permit the remaining portion of the operation. This operation involves remining the Fisher underground mine as well as the other underground mines on the B and C'. The C and C' coals and, where present, the D coal are also extracted. Although the E seam was mined earlier, Fisher's operation had to reaffect these areas in order to extract the lower coals and in so doing, the surface was reclaimed to current standards.

The Fisher site is mined as a multi-seam operation using five draglines, four loaders, four bulldozers, and five rock trucks. The C, C', and D seams are exposed in successive parallel cuts, each ~180 feet wide and up to 3800 feet long. The preceding cut is backfilled with overburden from the active pit being developed. The B seam is exposed in a series of shorter block cuts within the elongate pit, with overburden being placed on each prior block. In this manner, costly rehandling of overburden is minimized, allowing an operating stripping ratio (overburden:coal) of 27—unusually high for a bituminous surface mine. Topsoil is replaced on the graded backfill and replanted with grasses and trees.

ACID MINE DRAINAGE (AMD) AND ALKALINE ADDITION

Acid mine drainage is formed when pyrite and other iron-disulfide minerals present in coal and overburden are exposed to oxygen and water through mineral-extraction activities. The oxidation of pyrite releases dissolved iron, hydrogen ions (acidity), and sulfate (refer to Equation 1 below). Although this process occurs very slowly in undisturbed strata, it can be greatly accelerated by both surface and underground mining.

$$(1) \quad 2\,FeS_2 + 7\,O_2 + 2\,H_2O \rightarrow 2\,Fe^{+2} + 4\,SO_2^{+2} + 4\,H^+$$

The pyrite oxidation process is further accelerated by the iron-oxidizing bacterium *Thiobacillus ferrooxidans* which thrives in a low-pH environment and oxidizes ferrous iron (Fe^{+2}) to ferric iron (Fe^{+3}) (Kleinmann and others, 1981) (Equation 2). Under low-pH conditions, ferric iron remains in solution and can directly oxidize pyrite (Equation 3). Thus, once the AMD-formation process gets started, decreasing the pH of the mine environment, the AMD reaction is further accelerated by bacteria and the production of ferric iron, resulting in extremely acidic mine drainage.

$$(2) \quad 4\,Fe^{+2} + O_2 + 4\,H^+ \rightarrow 4\,Fe^{+3} + 2\,H_2O$$

$$(3) \quad FeS_2 + 14\,Fe^{+3} + 8\,H_2O \rightarrow 15\,Fe^{+2} + 2\,SO_2^{-2} + 16\,H^+$$

Acidity produced by acid mine drainage can be neutralized in the presence of sufficient carbonate minerals. This reaction is shown by Equation 4, for which it is assumed that CO_2 will be produced and will exsolve from solution. If the reaction product is HCO_3^-, twice as much carbonate will be required (Cravotta and others, 1990).

$$(4) \quad FeS_2 + 2\,CaCO_3 + 3.75\,O_2 + 1.5\,H_2O \rightarrow Fe(OH)_3 + 2\,SO_4^{-2} + 2\,Ca^{+2} + 2\,CO_2\,(g)$$

Where neutralization is occurring, the pH can remain at a level which prevents bacterial catalysis of iron oxidation and where ferric iron is relatively insoluble. Thus, the quality of drainage produced by a given mine is largely dependent not only on the presence or absence of pyritic sulfur, but also the availability of calcium carbonate or other neutralizing agents in the coal and overburden.

Acid-base accounting (Sobek and others, 1978) was developed to compare the amount of neutralizers present in mine spoil with the maximum potential acidity which could be produced. Although it is one of several commonly used techniques for predicting post-mining water quality from surface mining, it is the only technique which readily lends itself to quantitative analysis. The percent total sulfur content of the spoil is used to calculate the maximum potential acidity (MPA). Neutralization potential (NP) is determined by digesting a pulverized sample of overburden in HCl, and then by titrating to determine how much acid was consumed. Both the MPA and the NP are expressed in terms of tons of $CaCO_3$ equivalence per thousand tons of overburden (or parts per thousand).

A sample drill log illustrating overburden-analysis results from this site is included in Figure 6. This allows the relative comparison of the potential acidity versus the availability of potential neutralizers. Sulfur contents were generally low (< 0.5 %), except for a 3-foot carbonaceous shale overlying the D coal, which has sulfur contents up to 1.4 %; minor dark-shale intervals between the C and C' coals, which have sulfur contents of approximately 1 %; the B-coal underclay (0.5 %), and the coal units themselves. Although overburden sulfur contents are generally low, the entire thickness of overburden is essentially devoid of significant neutralizers. The only significant NP recorded, 47 tons per thousand, did not effervesce to HCl, possibly indicating a siderite source.

Because there are many factors which affect the ultimate chemistry of mine drainage, a direct comparison of MPA versus NP is not valid (Brady and others, 1994). In other words, overburden which has a NP to MPA ratio > 1 does not necessarily guarantee net alkaline drainage. Brady and others (1994) also noted, however, that the quantity of NP present in overburden provides the most reliable indicator of post-mining water quality and that sites having an overall NP of 15 tons per thousand or a net NP (NP-MPA) of 10 tons per thousand produced alkaline drainage. In essence, mine sites with overburden having significant carbonate content resulted in alkaline drainage. Without significant carbonate, acidic drainage was likely.

Many mining companies have attempted to simulate naturally alkaline overburden conditions by importing alkaline material from off-site and incorporating it into the backfill. Alkaline importation rates have ranged from very small (30 tons/acre) to very large, exceeding 1,000 tons/acre. These experiments have been a mixture of successes and failures. Brady and others (1990) examined eight alkaline addition sites in detail, only two of which successfully prevented the formation of acid mine drainage. The principal reason the other sites failed was that the lime addition rate was too low. Also, thorough mixing of the alkaline material into the backfill, rather than layered placement only on the pit floor or surface, appeared to be a key element in a successful alkaline-addition operation. Other studies of alkaline addition to prevent AMD formation can be found in Waddell (1980), Lusardi and Erickson (1985), and Rose and others (1995).

AMD Abatement Efforts

The Fisher Mining Company's pollution-abatement activities comprise two principal components: (1) daylighting of the Fisher deep mine and (2) the addition of imported limestone to the backfill. The term daylighting refers to the elimination of abandoned underground mines through remining. The remaining pillars of coal are extracted, and the area is backfilled. The success of this remining operation in improving water quality at M-I is very evident (Figs. 7 & 8). Pre-remining data show a median net acidity (acidity - alkalinity) exceeding 100 mg/l, compared to the current quality, which is alkaline. The downstream biological impact has been equally dramatic: Otter Run, where no fish were present in a 1977 electro-fishing survey (Arway, 1994), now supports a brooktrout population generally exceeding 1000 fish per hectare. Biological communities of aquatic macroinvertebrates have also substantially improved since 1977, presumably due to improved water quality.

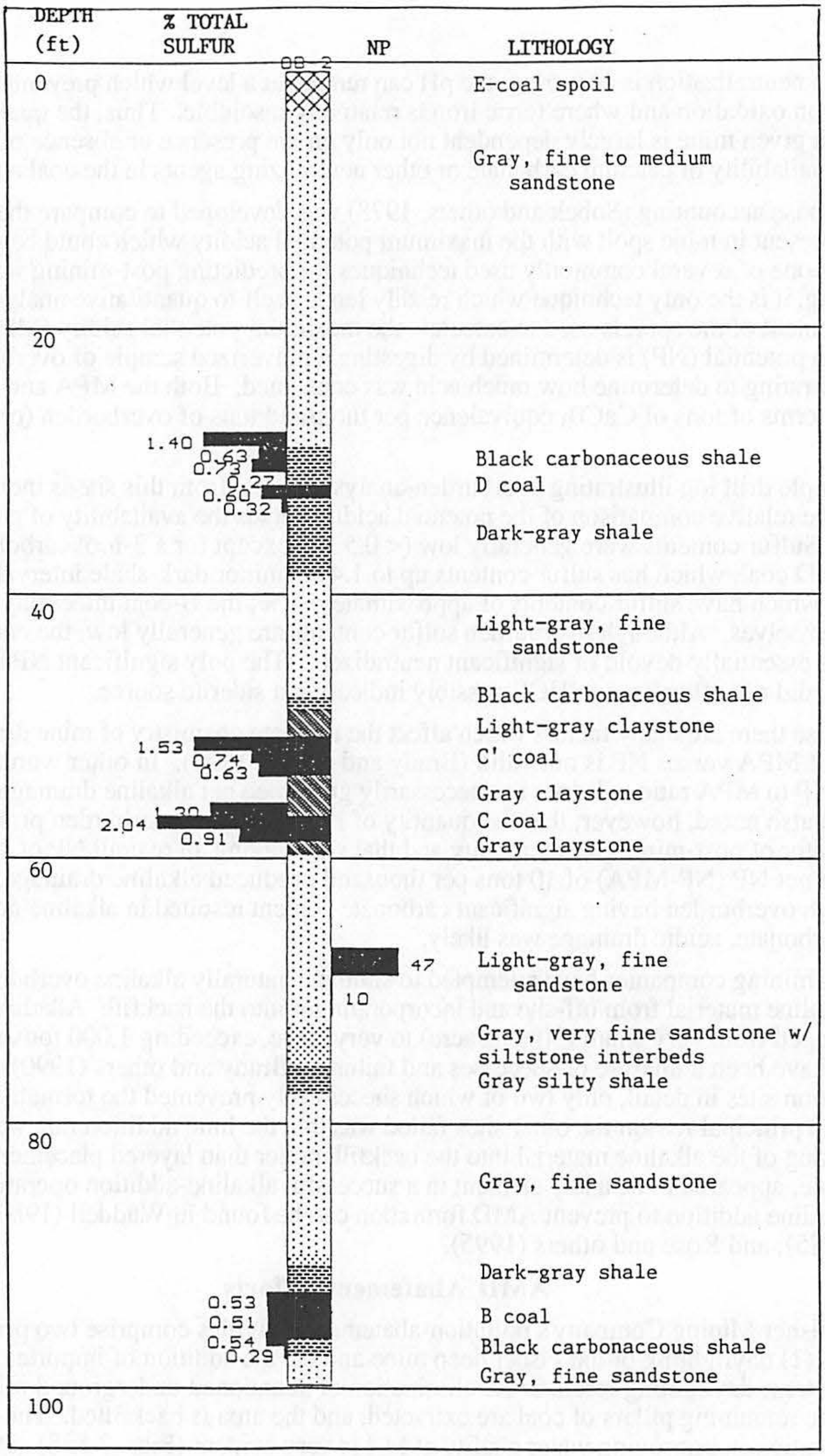


Figure 6. Typical overburden analysis from Fisher mine operation. Sulfur contents less than 0.25% and NP values less than 10 tons per thousand have been omitted for clarity. Drill hole 380 from Fisher Mining Company, Inc., Pennsylvania Department of Environmental Resources Surface Mining Permit 41920101.

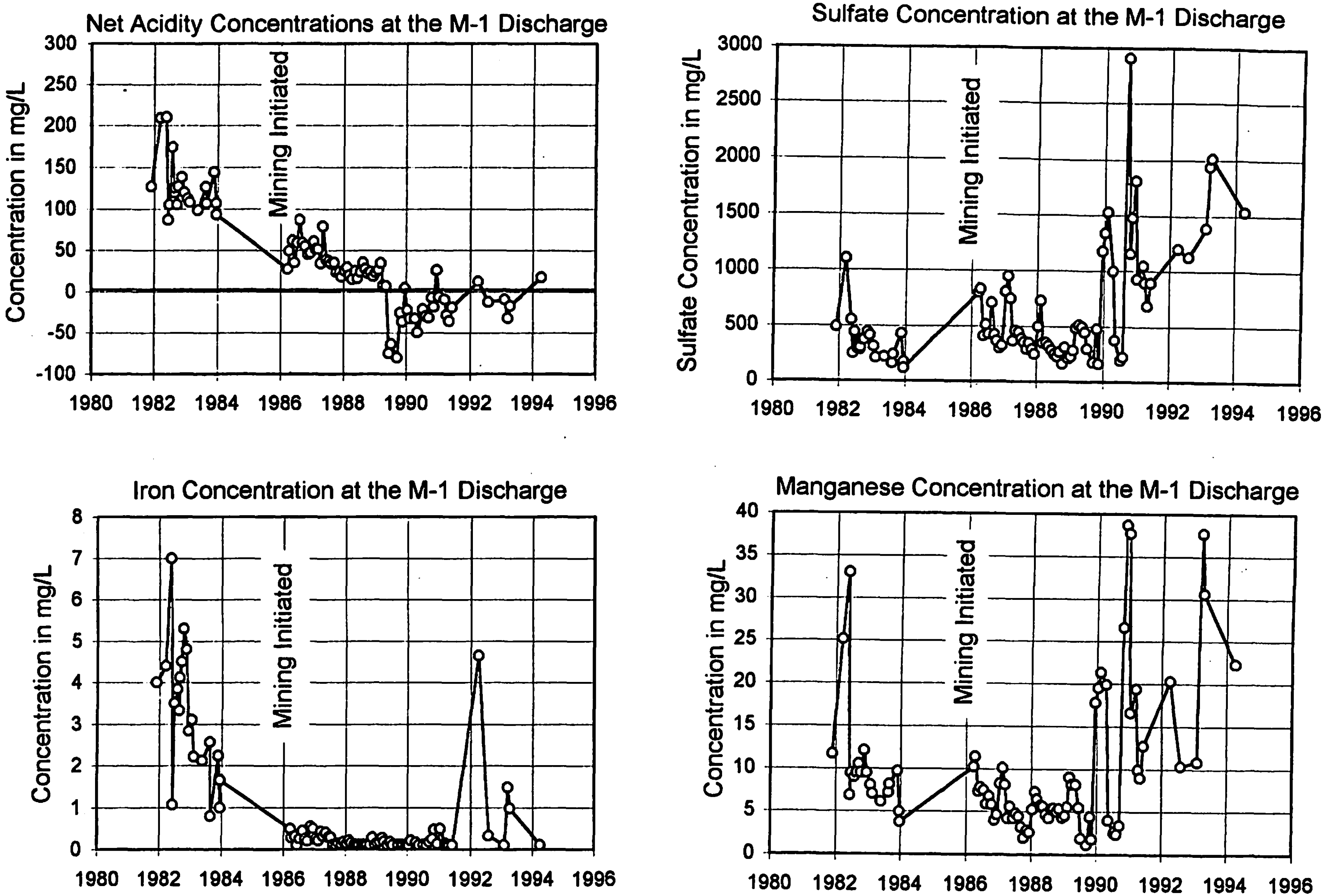
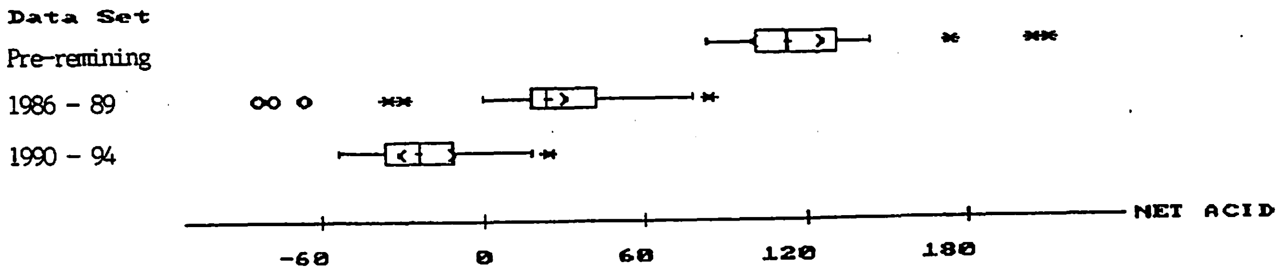
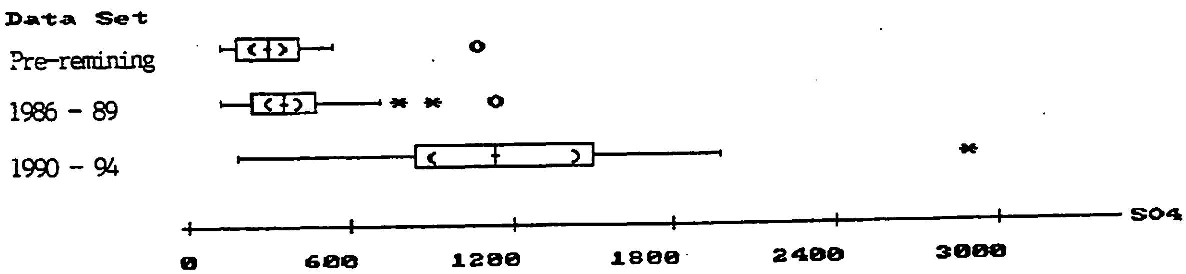
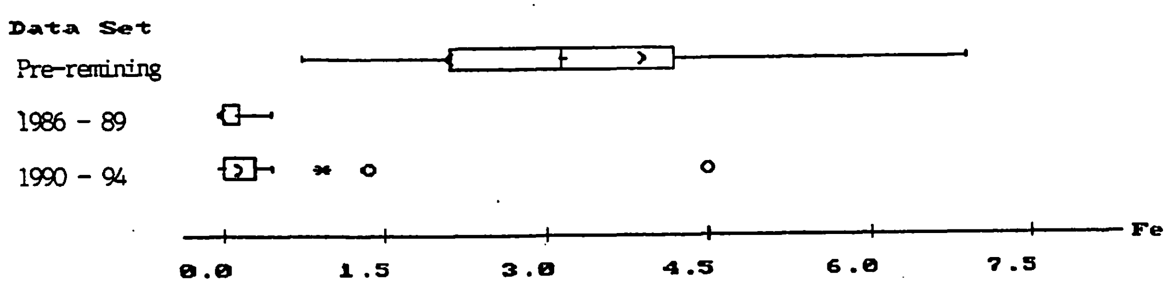


Figure 7. Changes in selected water-quality characteristics over time at the M-1 discharge.







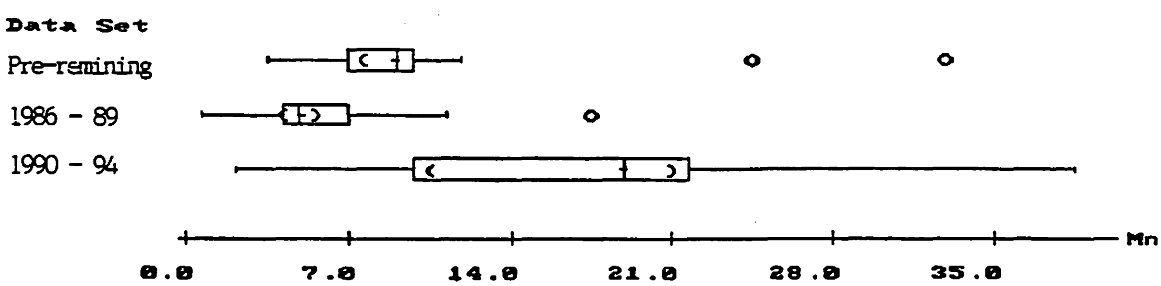


Figure 8. Boxplots showing changes in quality at M-1. The first data set represents water quality prior to remining. The second and third data sets represent early (1986-1989) and later (1990-1994) water quality following the initiation of daylighting and alkaline addition. The box section indicates data between the lower and upper quartiles. The horizontal line indicates the range of data. The short vertical line indicates the median and the parentheses (notches) represent 95% confidence intervals about the median value. Outliers are represented by an individually plotted "*" or "o."

On this site, Fisher Mining Company applies ~600 tons of waste lime per acre of disturbed area. The lime is a waste product imported from crushing operations at the Lycoming Silica Sand Company operation in southern Clinton County which quarries a sequence of Lower Ordovician carbonates. It has a NP value equivalent to 92% $CaCO_3$. The waste lime is applied three ways:

1) 100 tons/acre is applied to the pit floor;
2) 100 tons/acre is applied to the top of the regraded backfill, prior to replacement of topsoil;
3) 400 tons/acre is dispersed throughout the mine spoil.

Thorough mixing in the backfill is accomplished through a simple but innovative and practical technique. Drill holes which are charged with explosive for overburden blasting are "stemmed" with imported waste lime rather than drill cuttings. Because the waste limestone is a mixture of sizes ranging in size from +200 mesh to 0.25 inch, it packs very well and provides a dense cover, more effectively directing the force of the blast into the rock. Through blasting, the alkaline material is very effectively distributed into the mine spoil where it is then redistributed by a dragline as it removes and places the overburden, providing additional mixing. Besides alkaline addition, Fisher also segregates high-sulfur material and places it in layered pods within the backfill, well below the spoil surface and above the pit floor.

The decrease in acidity at M-1 is attributed to neutralization by alkaline material rather than a decrease in pyrite oxidation as evidenced by the concomitant increase in sulfate, a product of pyrite oxidation. Median sulfate concentrations increased from 305 mg/l to 1153 mg/l (refer to Table II). Iron, also a product of pyrite oxidation, decreased from a pre-remining median of 3.2 mg/l to 0.14 mg/l, presumably because of its low solubility under alkaline conditions. Median manganese concentrations, however, have increased from 9.4 mg/l to 19.4 mg/l. Manganese is a common constituent of acid mine drainage, although it is not derived from pyrite oxidation. When present, it is much less likely to precipitate than iron, unless under conditions of very high pH.

TABLE II M-l Discharge -- Median Water Quality

	Pre-Remining	1986-1989	1990-1994
Net Acidity	119.5 mg/l	27.7 mg/l	-18.8 mg/l
SO_4	305	362	1153
Fe	3.21	0.18	0.14
Mn	9.44	5.32	19.40

This remining operation poses an important question in terms of applicability to other remining sites: Is the observed water-quality improvement attributed to daylighting or alkaline addition? In theory, daylighting will improve water quality by removing the remaining coal, preventing pyrite oxidation. In actual practice, daylighting can both improve or worsen water quality. A nearby daylighting operation on Babb Creek, for example, resulted in increased acidities (Reed, 1980). Conversely, many daylighting operations elsewhere in Pennsylvania have resulted in water quality-improvements. The deciding factor appears to be the nature of the overburden above the coal. Areas with significant alkaline overburden which will be disturbed through remining are likely to realize water-quality improvements. Daylighting projects which will disturb high-sulfur overburden with little calcareous material may well produce even worse water quality than the original discharge. In this operation, the overburden is largely devoid of calcareous material; yet the chemistry of M-l clearly shows the presence and impact of alkaline material. We conclude, therefore, that the improved water quality has primarily resulted from the addition of imported alkaline material and that daylighting, by itself, would be unlikely to have achieved this effect.

Reduced groundwater recharge to the Fisher deep mine may also play a significant role in improving water quality from this site. The D. E. Fisher surface mine, which overlies the Fisher underground mine, directed additional water to the underground mine via holes drilled into the pit floor. Regrading and revegetating this area restored surface drainage and enhanced evapo-transpiration, reducing the availability of water to M-1. Hawkins (1995) examined 24 remining sites in Pennsylvania and noted that reduced pollution loading through reduced groundwater recharge was the most frequent reason for water-quality improvement.

The Fisher Mining company site was one of the first mining operations to successfully employ alkaline addition to abate AMD. Current industry practices in the application of imported alkaline material and in determining appropriate application rates are in part based on information obtained from this operation. As more is learned about remining and AMD-abatement methods, surface-mining companies will be even better able to prevent AMD from future operations and abate AMD from past mines.

ACKNOWLEDGMENTS

We wish to thank John A. Blaschak, President, and Steven D. Blaschak, Vice President, of Fisher Mining Company, Inc., for their outstanding cooperation and assistance and for permission to visit their surface-mine operation during this conference. The Blaschaks also provided historical data regarding prior mining operations and the M-1 discharge. Christine M. Dodge, Pennsylvania Geological Survey, generously helped prepare some of the illustrations on her own time using computer graphics. Robert Weiss, DEP, analyzed water-quality data and prepared associated graphics. Keith Brady, DEP, provided valuable comments and suggestions. Jonathan Bell, DEP student intern, prepared the overburden-analysis graph.

LITTLE PINE CREEK COAL FIELD, NORTHWESTERN LYCOMING COUNTY, PENNSYLVANIA

CLIFFORD H. DODGE

LOCATION

The Little Pine Creek coal field of northwestern Lycoming County is one of four small bituminous-coal regions comprising the North-Central coal fields (Fig. 9). The other three fields include the Barclay (southwestern Bradford County), the Blossburg-Antrim (southeastern Tioga County), and the Ralston (northeastern Lycoming County). The North-Central coal fields are confined to a series of small, detached structural basins or closed synclines.

The Little Pine Creek field is situated in upland areas mostly in the northern half of the English Center 7.5-minute quadrangle (Fig. 10). The field covers an area of approximately 20 mi^2, but only about a quarter of it is considered productive. The NE-SW trending Little Pine Creek coal field is named for the nearby stream to the south that runs roughly parallel to it. This region is also known as the English Center coal field.

PHYSIOGRAPHY

The Little Pine Creek coal field is in the Mountainous High Plateau Section of the Appalachian Plateaus Physiographic Province. This section is characterized by broad, rounded to flat uplands that are separated by very deep, angular valleys, which follow structural axes to varying degrees (Berg and others, 1989). Local relief near STOP 2 (this guidebook), for example, exceeds 800 feet (see Fig. 10).

The topographic form of the uplands in the area is chiefly the result of fluvial erosion with modification by periglacial mass wasting and deposition (see Berg and others, 1989). For example, the upland area about 1.5 miles north of STOP 2 is capped with up to 50 to 70 feet of colluvium. Although most of this material is derived locally from bedrock, some may represent pre-Late Wisconsinan colluviated glacial drift (W. D. Sevon, 1995, oral communication). The late Wisconsinan glacial border is only about 3 miles north of STOP 2 (Crowl and Sevon, 1980).

COAL GEOLOGY

Structure

The Little Pine Creek coal field lies within the Little Pine Creek coal basin, an inwardly doubly plunging or canoe-shaped segment of the McIntyre syncline (Fig. 10). The McIntyre syncline is one of a series of first-order folds found in northern Lycoming County and vicinity. The wavelength of the McIntyre syncline ranges from ~ 7 to 10 miles. Structural relief measured from the bottom of the Little Pine Creek basin to the top of the adjacent Slate Run anticline to the north, or Hyner anticline to the south, is about 1550 feet (Faill, in preparation).

Lithostratigraphy and Nomenclature

The coal measures of the Little Pine Creek basin are Early (?) and Middle Pennsylvanian in age and have a maximum thickness of about 200 feet (Fig. 11). The rocks have been mapped as the Pottsville Group [Formation] and the Allegheny and Pottsville Groups [Formations], undivided (Berg and Dodge, 1981, p. 202) (see Fig. 10). Dodge (this study) has refined the lithostratigraphy and subdivided the coal measures into the Pottsville and Allegheny Formations (Fig. 11). Dodge (1994, unpublished work) has also recognized that the coalbearing strata for much of this area immediately overlie rocks of the Upper Mississippian Mauch Chunk Formation and not the Lower Mississippian Burgoon Formation as was previously believed (see Berg and Dodge, 1981, p. 202). A regional Mississippian-Pennsylvanian disconformity is present at the base of the coal measures (Edmunds and others, 1979; Berg and others, 1983).

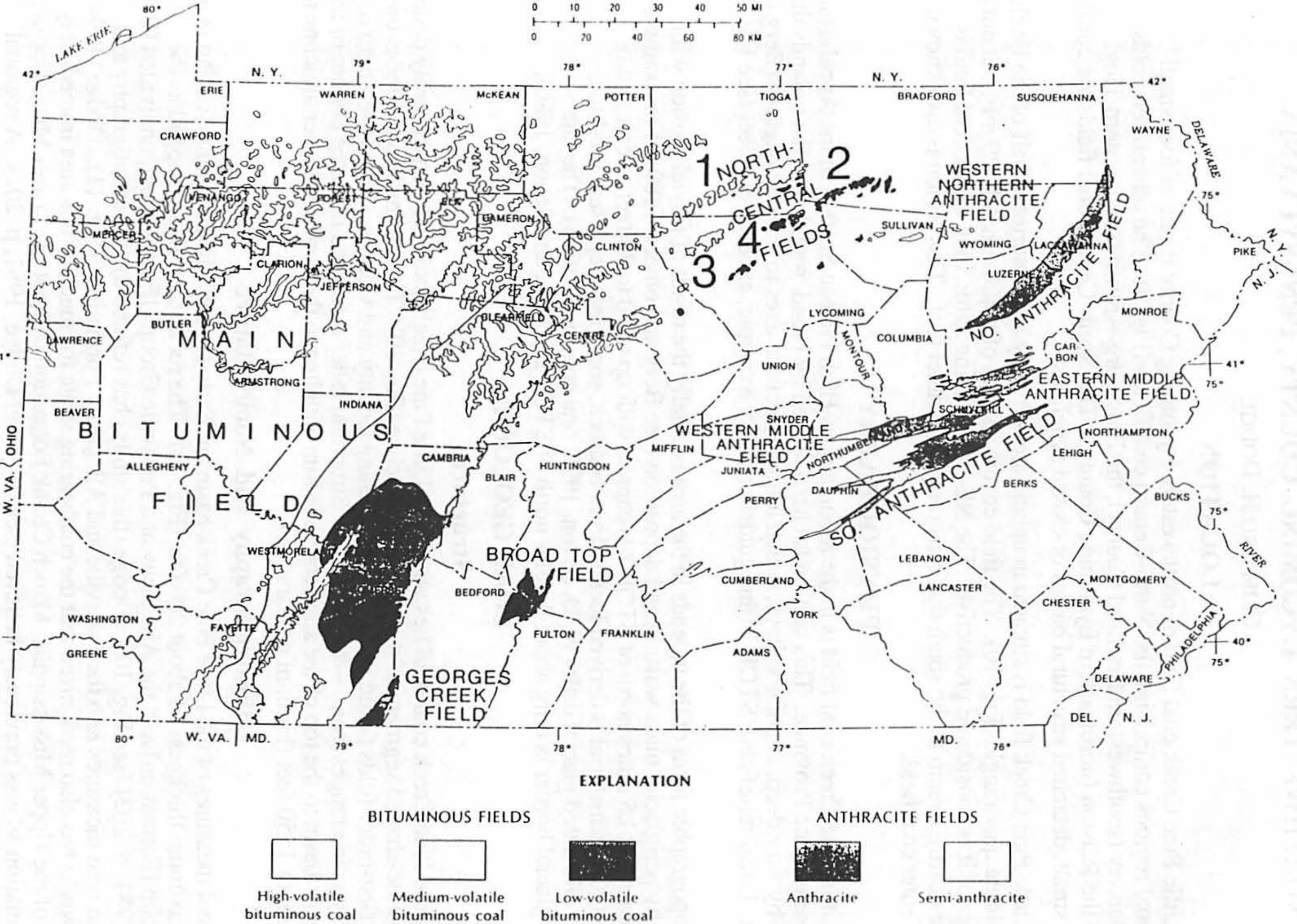


Figure 9. Map showing the distribution of Pennsylvania's coals. Bituminous coal fields comprising the Northcentral coal fields are as follows: 1—Blossburg-Antrim, 2—Barclay 3—Little Pine Creek (English Center), 4—Ralston. (Base map from Pennsylvania Geological Survey, 1992.)

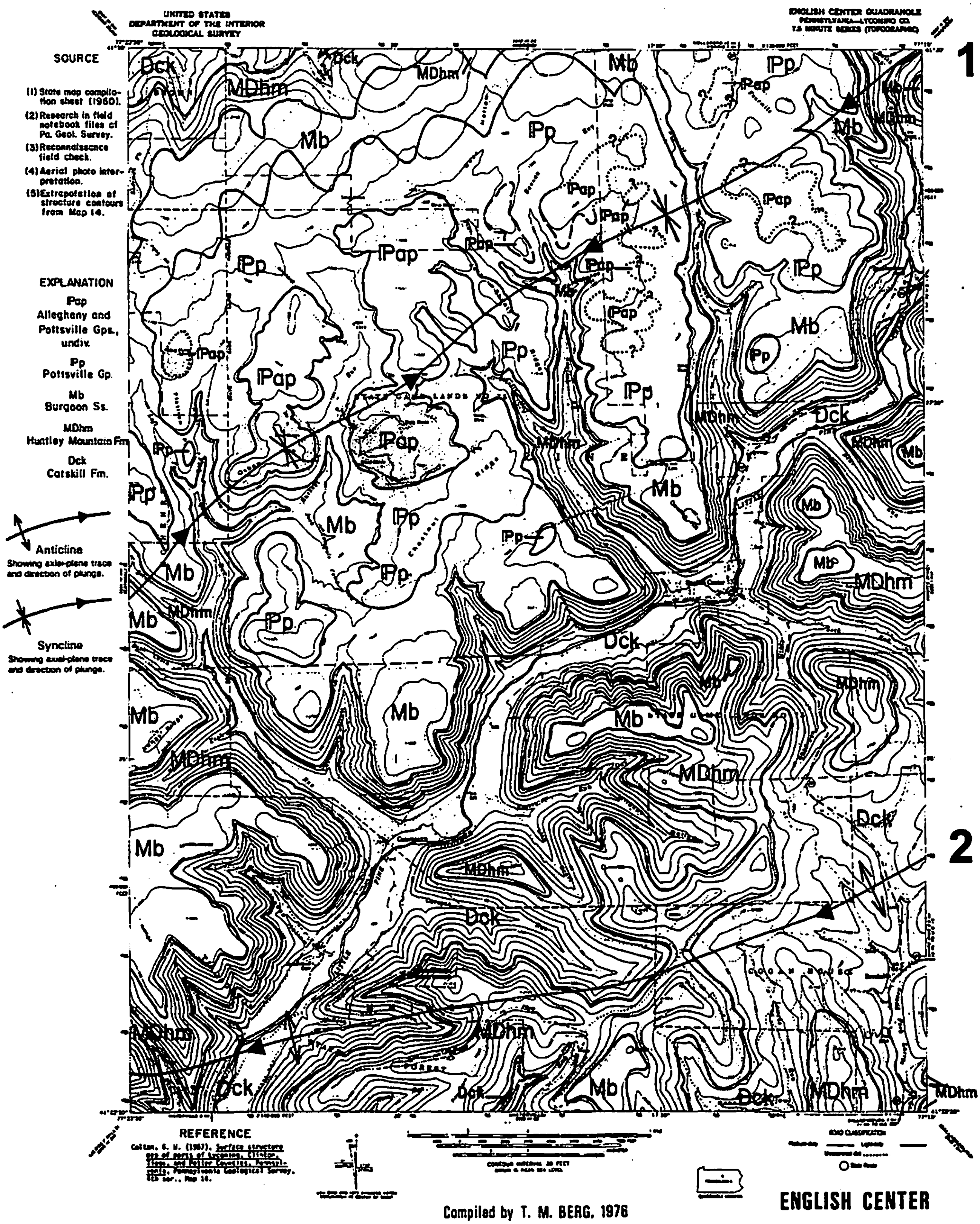


Figure 10. Preliminary bedrock geologic map of the English Center 7.5-minute quadrangle, northwestern Lycoming County. 1 = axial-plane trace of the Little Pine Creek basin (McIntyre syncline), 2 = axial-plane trace of the Hyner anticline. Modified from Berg and Dodge (1981, p. 202).

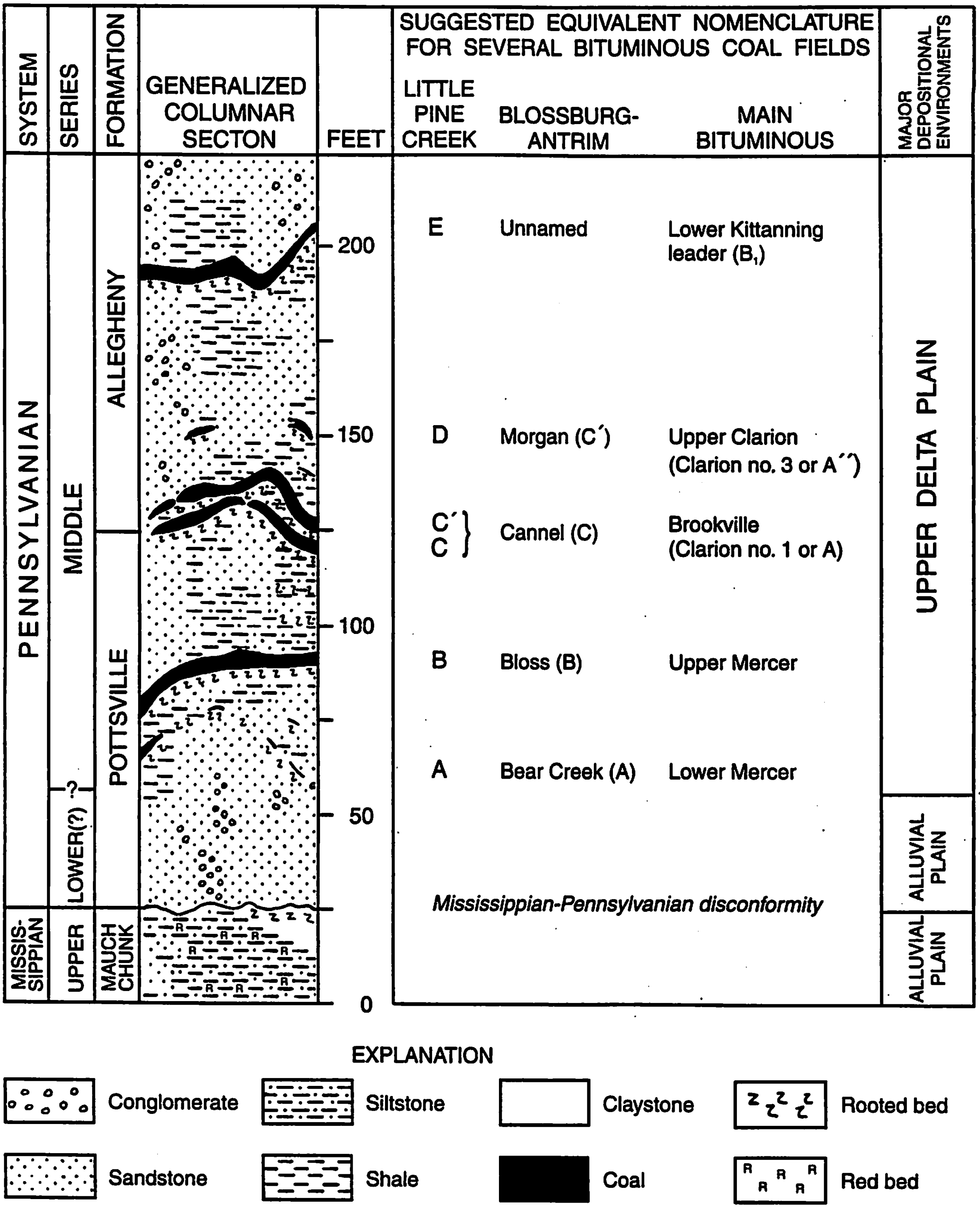


Figure 11. Stratigraphic column of coal measures and immediately subjacent rocks in the Little Pine Creek coal field, northwestern Lycoming County.

Information on the coal geology of the Little Pine Creek field is derived from Platt (1880) and Koppe (1975), and especially from numerous unpublished drill-hole records, core descriptions, and measured sections. Particularly noteworthy and helpful was the examination of continuous core from an exploratory diamond-drill hole that was drilled by Fisher Mining Company, Inc., in cooperation with the Pennsylvania Geological Survey in May 1994. The hole penetrated the entire coal-bearing sequence at the bore-hole site, a total of 155.5 feet, and also 24.5 feet of the underlying Mauch Chunk Formation. The core provided valuable information on the coal measures, particularly the basal portion beneath the lowest mineable coal (i.e., the B seam)—an interval rarely penetrated by drilling. The hole also supplied direct evidence of the occurrence of Mauch Chunk in the basin. The location of the drill-hole site (41°27'33"N / 77°21'17" W, NAD27) is ~1.3 miles west-northwest of STOP 2.

The Little Pine Creek coal measures consist of a heterolithic, coal-bearing, siliciclastic sequence of slabby, light-gray to light-olive-gray sandstone; slabby, medium-gray to mediumdark-gray and olive-gray siltstone; and chippy to platy, medium-dark-gray to dark-gray shale; and subordinate slabby to blocky, light-gray to light-olive-gray conglomeratic sandstone and quartzpebble conglomerate; hackly to rubbly, medium-dark-gray to dark-gray and olive-gray claystone and siltstone; and chippy to platy, dark-gray to grayish-black carbonaceous shale and claystone. There are no known carbonate or calcareous rocks. Several commercial coals are present. Seat earths (paleosols) occur beneath the coals and are rooted. Although plant fossils are preserved in many of the rock units, body fossils (invertebrates) and lebensspuren are unknown.

Sandstones are generally very fine to medium grained but become coarser in places, particularly toward the base and top of the section, where scattered beds and lenses of conglomeratic sandstone and conglomerate occur. Conglomeratic units contain quartz granules to small pebbles. Sandstones are commonly crossbedded and locally contain scattered, carbonized fossil-plant compressions, coal lenses, and shale chips. Conglomerates are crudely to locally crossbedded or massive. Sandstones and conglomerates exhibit basal scouring in places and commonly represent fluvial channel-fill deposits.

Six principal coal horizons have long been recognized in the basin and have traditionally been designated by successive letters, from oldest to youngest, as A, B, C, C', D, and E (Fig. 11). These local coal names (letters) were mostly derived from nomenclature applied first to the Ralston coal field of northeastern Lycoming County. Coal correlations between the Little Pine Creek and Ralston fields were first made in the late 1870s. (See Platt, 1880.) Other "local" names have been given to some of the Little Pine Creek coals, primarily through lithostratigraphic correlation with the Tioga County coals of the Blossburg-Antrim field (Blossburg syncline) to the north. Valid historical synonyms appear to include for the A, the Bear Creek coal of Tioga County, and for the B, the Bloss coal of Tioga County, the Big bed, and rarely used, the Pine Creek coal. However, past uncertainties in correlation, especially with coals above the B, have led to inconsistencies and confusion in the nomenclature. It is, therefore, probably best to continue using the well-established lettered nomenclature when studying or discussing the internal lithostratigraphy of the Little Pine Creek basin. Nevertheless, Pennsylvania coal geologists have long been interested in determining a unified regional lithostratigraphy for the Main Bituminous coal field of western Pennsylvania and other outlier fields, including the North Central coal fields (see discussion under Regional Lithostratigraphy).

There is little information on the A coal, but it appears to be mostly absent. It may represent more of a coal complex or extended interval rather than a discrete horizon. Its maximum reported thickness is generally less than 1 foot. Its underclay is apparently more persistent than the coal itself and commonly can be located by a line of springs found along its upper contact (S. D. Blaschak, oral communication, 1995). The A horizon is situated about 10 to 30 feet below the base of the B coal, whereas the base of the coal measures is only about 50 to 65 feet below the base of the B (see Fig. 11). The A coal has not been mined commercially.

The B coal has historically been the most important economic seam in the basin. It is widespread and laterally continuous. Its thickness varies from about 2 to 7 feet (but more typically is

2.5 to 5 feet). It is the best key bed for correlation and best datum for structure contouring. The B coal has been extensively deep mined and strip mined.

Owing to their proximity to each other, the C and C' coals are informally referred to as "split seam." The distance between the two coals (i.e., top of C to base of C') ranges from about 0.5 to 8 feet. The intervening strata are rootworked and typically consist of silty claystone to clayey siltstone and siltstone.

The C coal is approximately 0.5- to 3-feet thick but is reported by Koppe (1975) to be very locally absent due to non-deposition. In at least one small area, it is cut out and replaced by sandstone. The coal is impure and contains few to common bone-coal (i.e., coal having a high detrital content), carbonaceous-shale, or carbonaceous-claystone partings. The base of the coal is about 30 to 45 feet (commonly 30 to 35 feet) above the base of the B. The C bed has been strip mined in places.

The C' coal generally varies in thickness from 1.5 to 4 feet. It is rather persistent but missing in a few places as a result of erosion (i.e., cutouts) (Koppe, 1975). The coal has less impurities than the C and contains only a few bone-coal partings. Both underground and surface mining have occurred in this seam.

The D coal is highly lenticular and present only locally. Its thickness ranges from 0 to about 2.5 feet. The base of the D is approximately 60 to 65 feet above the base of the B. The D bed has been strip mined incidentally with other coals.

The E seam is the highest (youngest) coal preserved in the area. It is confined to several hilltops toward the deepest part of the basin. The coal appears to be persistent throughout its areal extent; no seam discontinuities have been observed. The E is usually slightly weathered, as the maximum cover over the coal is only about 30 to 35 feet. The thickness of the coal ranges from about 2 to 5 feet. The vertical distance from the base of the B to the base of the E varies from approximately 100 to 115 feet (generally 100 to 105 feet). The E coal has been surface mined in the past.

Regional Lithostratigraphy

The coal measures in Pennsylvania have traditionally been correlated and subdivided into mappable units using key beds. Age dating of the coal-bearing rocks by paleontology provides supporting information but generally still lacks the resolving power of physical stratigraphy for detailed correlations.

Concepts concerning the suitability of beds or units as markers have evolved over the years. It is now recognized that marine zones provide the best means of establishing detailed regional correlations. (Marine zones are relatively thin, persistent, widespread intervals that contain marine and/or brackish-water fossils and are not necessarily restricted by facies or lithology.) Sandstones have long been shown to have little or no value for correlation. Most limestones are discontinuous and indistinctive. Individual coal seams are not indefinitely continuous, and most change in physical and chemical character laterally, thus potentially complicating their identification. (See Dodge, 1983.)

As noted by Edmunds and others (1979, p. B25), "most coal names (such as Brookville, Lower Freeport, Sewickley, etc.) actually represent several areally limited individual coal lenses, or multiple-split coal complexes at about the same stratigraphic position within the coal-bearing sequence." Therefore, when coal-bed names are applied regionally, they imply similar relative stratigraphic position more than actual seam continuity.

In his discussion of the Little Pine Creek coal basin, Platt (1880) identified the coal-bearing strata between the A and E seams as comprising all of the lower productive measures (now called the Allegheny Formation). Platt's interpretation was based on his belief that the conglomeratic sandstones (his key beds) above and below his productive measures were equivalent to, respectively, the Mahoning sandstone and Pottsville sandstone of western Pennsylvania. (The Mahoning overlies the Upper Freeport (or E) coal of western Pennsylvania, and the Pottsville is situated below the Brookville (or A) coal of the same area.) However, he cautioned against equating the Lycoming County coal-bed lettering system with the same scheme (letters) used to designate seams of the lower productive measures in the Main Bituminous coal field.

Nevertheless, the Lycoming County names were soon considered stratigraphically equivalent to their western Pennsylvania counterparts. This was particularly true for the B coal, which was thought to be the same as the Lower Kittanning (or B) coal of the Main Bituminous field (e.g., see Sisler, 1926; Koppe, 1975). The rationale for this may have been the traditional notion that the Lower Kittanning is most everywhere the first (lowest) thick, persistent, commercial coal of the lower productive measures.

In 1976, Thomas M. Berg, former staff member of the Pennsylvania Geological Survey, undertook a rapid reconnaissance of selected areas of the North-Central fields in order to revise the geology of the region for the 1980 *Geologic Map of Pennsylvania* (Berg and others, 1980). Berg initially attempted to map the coal measures by subdividing them into the Pottsville and Allegheny Groups [Formations]. (That the coal measures belong to one or both of these units has never been disputed.) However, having limited time and little available stratigraphic information, he was unable to identify the contact or key bed (i.e., Brookville coal or its equivalent) marking the boundary between the two units.

Instead, Berg had to rely mostly on somewhat meager paleobotanical evidence, which he himself collected, to determine the gross relative ages of the rocks--either as "Pottsville" or "Allegheny." Consequently, he wisely concluded that his data would only support a subdivision of the coal-bearing strata into the Pottsville Group [Formation] (i.e., lower unit of well-constrained "Pottsville" age) and the Allegheny and Pottsville Groups [Formations], undivided (i.e., upper unit that may contain some rocks of"Allegheny" age) (see Fig. 10.) It is clear from his preliminary geologic maps that the key bed he intended to use everywhere to define the contact between the two mappable units was the lowest-most persistent commercial (commonly mined) coal. (Admittedly, the lower boundary of the Allegheny and Pottsville Groups [Formations], undivided, as shown on several maps, was only approximately located in places and often based on "educated guesswork.") The contact corresponds to the B coal in the Little Pine Creek field and to its correlative, the Bloss coal, in the Blossburg-Antrim field. Thus, according to Berg, these coals are in the Pottsville and considerably below the position of the Lower Kittanning seam. (See Berg and Dodge, 1981.) Gray and others (1960), however, did not equate the two coals. They considered the B as a lower Allegheny coal and the Bloss as a lower Pottsville seam, but their reasons for concluding this are unknown.

Perhaps the most important aspect of Berg's reconnaissance work was his discovery and recognition of poorly preserved marine invertebrate fossils, chonetid brachiopods, in the darkshale spoils of an abandoned strip mine near Blossburg on the presumed Seymour coal. Berg ([1976], unpublished field notes) suggested that the overburden may represent the Columbiana marine shale or marine zone, which overlies the Lower Kittanning coal throughout much of western Pennsylvania. This marine zone has proved to be the best key to understanding the regional lithostratigraphic relationships or tie-in between the Main Bituminous and North-central coal fields.

In May 1994, this author revisited the old strip mine where Berg made his find. I collected a larger suite of fairly poorly preserved marine and brackish-water invertebrate fossils, identifying *Chonetes* sp., *Dunbarella* sp., and *Lingula* sp. In June 1995, I also found similar invertebrates at the same stratigraphic position in an old deep-mine rock dump near Arnot. The fossils included *Lingula* sp. and nuculid bivalves.

Based largely on detailed information from long drill holes (some of the data were acquired during a recent exploratory core-drilling project by the Pennsylvania Survey), this author confirmed that the marine zone does, indeed, overlie the Seymour coal. The economically important Bloss seam is about 130 to 140 feet below the Seymour.

An ongoing regional study by this author strongly suggests that the marine zone is the Columbiana. The marine shale can certainly be no higher in the stratigraphic section. In their regional context, younger preserved units throughout much of Clearfield County and eastward are known to be nonmarine. (The Pottsville and Allegheny marine incursions came from the west or southwest.)

Recognized marine zones below the Columbiana farther to the west in Clearfield and Clinton Counties appear to be much thinner (i.e., transgressive events of shorter duration). Other considerations supporting identification as the Columbiana marine zone are beyond the scope of this discussion, but the results of this investigation will eventually be published elsewhere.

It is now believed that the Seymour coal is the Lower Kittanning. This being the case, the Bloss coal is equivalent to the Upper Mercer seam (based on stratigraphic interval), a coal in the upper Pottsville. This author has recently (1995) confirmed that the B coal of the Little Pine Creek field correlates with the Bloss seam; therefore, the B is also Upper Mercer. These interpretations are consistent with the earlier work of Berg (Berg and Dodge, 1981). Some suggested equivalent coal names for the Little Pine Creek, Blossburg-Antrim, and Main Bituminous coal fields are given in Figure 11.

In the Little Pine Creek basin, the C and C' coals are now considered equivalent to the Brookville coal. Accordingly, the base of the C coal marks the contact between the Pottsville and Allegheny Formations. In the basin, the Pottsville Formation ranges from about 95 to 105 feet thick. The maximum thickness of the Allegheny is about 105 feet.

The Little Pine Creek coal measures are not quite thick enough to preserve the Lower Kittanning (Seymour) seam or interval . The E coal is interpreted as corresponding to a leader coal of the Lower Kittanning.

Depositional Environments

The Little Pine Creek coal measures were deposited as sediments in alluvial-plain and upper-delta-plain environments (Edmunds and others, 1979, p. B22) (see Fig. 11). There is no known paleontological (i.e., marine or brackish-water fossils) or sedimentological evidence of a lower-delta-plain setting for any of the rocks. However, over 20 miles to the northeast, near Fall Brook, this author has recently (1994) observed rarely present restricted-marine brachiopods (i.e., *Lingula* sp.) above the Bloss coal, the equivalent of the B seam, in core from a Pennsylvania Geological Survey diamond-drill hole.

The rocks below the A coal or its horizon represent a depositional environment characterized by sandy and locally gravelly braided streams that crossed an alluvial plain. The overlying coal measures were deposited as sediments by meandering-stream systems on an upper delta plain.

COAL QUALITY

The Little Pine Creek coals are classified as medium-volatile bituminous rank, having between 69 and 78 weight percent fixed carbon (dry, ash-free basis). Limited information on the coal quality has been available since the pioneering work of the Second Geological Survey of Pennsylvania (1874-1889) (Platt, 1880). As a whole, the coals tend to be low to medium in sulfur (2 weight percent or less) and medium to high in ash (8 weight percent or more); heat values on an as-received basis range from about 11,500 to 13,500 Btu/pound. However, there is considerable variability in quality among the coals and within certain coals as indicated below:

- The coal quality of the A coal is unknown.
- The B coal has the best quality; it is low in sulfur (less than 1 percent) and medium in ash (8 to 15 percent). Sulfur content is generally less than 0.7 percent. It has long been recognized as a superior steam coal.
- The C coal is typically high in sulfur (greater than 2 percent) and high in ash (greater than 15 percent). Individual benches, however, may have much better coal quality locally.
- The C' coal is generally medium to high in sulfur (l percent or more) and medium to high in ash.
- The D coal is highly variable in quality.
- The quality of the E coal is poorly known. However, because the coal is normally slightly weathered and was mined considerably in the past, it is probably low to medium in sulfur and medium in ash. Several acres of E coal were mined a few years ago by Fisher Mining Company; the reported sulfur content was 0.95 percent and ash was 8 to 9 percent (J. A. Blaschak, 1995, oral communication).

MINING HISTORY

The occurrence of coal in the Little Pine Creek basin has been recognized since at least the time of the First Geological Survey of Pennsylvania (1836-1842, 1851-1858) (Rogers, 1858, p. 517-518). Sometime thereafter, coal was exploited on a limited basis for domestic use and blacksmithing. More widespread exploration and mining commenced around 1878. (See Platt, 1880.)

Coal production during the late nineteenth and early twentieth centuries was limited and confined mostly to the B coal. Mining at that time was probably hindered by inadequate means of transportation to markets. Early production data are unavailable, and mines were apparently too small to require state inspection. (Prior to 1933, all mine inspectors' reports and production figures for Lycoming County were for the Ralston coal field.)

Underground mining prevailed through the late 1940s. Strip mining began as early as 1948 and immediately dominated production. Prior to the mid-1960s, annual coal production for the basin seldom exceeded 50,000 tons and was often much less. Thereafter, coal production increased considerably. The Little Pine Creek coal field has accounted for the total county output since 1979. In 1994, coal production for Lycoming County totaled 245,816 tons, and all of it came from Fisher Mining Company's operation at STOP 2 (Pennsylvania Department of Environmental Resources, [1995]). Last year, Lycoming ranked 14 in coal production out of 22 bituminous coal-producing counties in the Commonwealth.

Before World War II, most coal from the North-Central fields was used as fuel by the railroad industry in locomotive steam engines. It is now consumed mostly for power generation.

ACKNOWLEDGMENTS

Fisher Mining Company, Inc., Williamsport, provided valuable assistance and geologic information that contributed greatly to this study. Boyer Kantz and Associates, Wellsboro, generously supplied many of the maps and drill-hole records pertaining to the Little Pine Creek coal field. Christine M. Dodge, of the Pennsylvania Geological Survey, kindly helped prepare two of the illustrations on her own time using computer graphics.

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SUSQUEHANNA RIVER BASIN
LOCK HAVEN FLOOD-PROTECTION PROJECT, WEST BRANCH SUSQUEHANNA RIVER AND BALD EAGLE CREEK, CLINTON COUNTY, PENNSYLVANIA

JOHN H. WAY [1] AND ROBERT YOWELL [2]

The authorized Lock Haven Flood Protection Project will protect the city of Lock Haven against the 200-year flood level, which is equal to the 1936 flood (the flood of record). The project consists of a series of levees, flood-walls, and closure structures, and additionally, various recreation facilities. Total project cost of the Lock Haven Local Flood Protection is estimated at $67,722,000. The project is tentatively scheduled for a construction start in October 1988 with completion by October 1992.

Preface, Department of the Army, Baltimore District Corps of Engineers, 1987

INTRODUCTION

Natural Hazards Overview

As geoscientists, we recognize, perhaps better than many, how all those natural processes we learned way back in physical geology operate and how they affect the Earth's surface. And, as we moved from the classroom into the real world, we were better able to see how those processes impact our environment and our society, often we experienced them first hand. One basic principal we were taught in environmental geology and that should have stuck with us is that natural processes usually only become a problem when people live close to a potential danger or modify those natural processes in such a way so as to increase the danger. Once these processes impact society, we classify them geologic hazards.

Volcanoes, earthquakes, tsunamis, mass movements, cyclonic storms, and floods all periodically cause loss of life and property, and when they do, they usually make the news. However, the people who report for the media are generally more interested in the impact of a particular event on people than in the scientific aspects of an event. As a result, the public rarely perceives the full significance of these phenomena and typically display a causal attitude toward any geologic hazard. This perspective derives in part from a lack of understanding of the physical relations that control the severity and frequency of hazardous processes. Our responsibility as scientists includes not only recognizing hazards and hazardous conditions, but also in being able to make predictions about the natural phenomena we investigate. Learning how to predict hazards so we can minimize human pain and suffering as well as property damage is for us an important endeavor and one that we should take seriously and responsibly.

Flooding as a Geologic Hazard

For hundreds of years, Americans have lived, worked, and played on floodplains. Advantages and enticements to do so are numerous. The abundance of fertile alluvial soils comprising the floodplains, virtually infinite surface water and groundwater supplies, ease of waste disposal, proximity to various modes of transportation facilitating commerce and communication account for many of these. In Pennsylvania, flatlands contiguous to rivers were originally dotted sparsely with farms. As these lands evolved over time, they became well-defined corridors marked by urban concentrations and the infrastructure that accompanies development of these population centers. This type of growth invites disaster, yet flooding has become an accepted part of life for many residents living adjacent to rivers and streams throughout our commonwealth. Most of these floodplain residents have refused to recognize the natural floodway of the river for what it is—part of the natural river system.

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Two factors appear to contribute to this mindset among these individuals. First, families with long histories of battling the rising and falling waters see their efforts as perpetuating a tradition of survival against the elements. "This is our home. We have been flooded before. We'll rebuild, and when the waters rise once more, we'll stand and fight again." Second, our government also has a tradition—that of providing financial reimbursement, almost as a reward, to these individuals. Thus, this pattern continues to be perpetuated. But as growth continues, it's not just the private farms and individual homes and businesses that suffer losses. Urban areas are getting larger and more sophisticated. Flooding looms as potentially an insurmountable problem to burden a tax-wary populace.

Historically, society's response to flooding has been to control the water by constructing dams, modifying the stream by building levees, or even, in some cases, rebuilding the entire stream to more efficiently remove the water from the land. Every new project has the effect of luring more people to the floodplain in the false hope that the flood hazard is no longer significant. However, history shows us that we have yet to build a dam or channel capable of controlling the heaviest rainwaters, and when the water finally exceeds the capacity of the structure, flooding will likely be extensive and the results potentially deadly.

SETTING THE STAGE FOR FLOOD PROTECTION

This report and field stop documents one such effort to reduce the flood hazard for an urban center—the Lock Haven Local Flood-Protection Project. This was a technically complex, multi-million-dollar project involving an interdisciplinary effort of professionals including contributions from geologists, biologists, chemists, archaeologists, engineers, mathematicians, economists, historians, planners, social scientists, and politicians (apologies to those in professions that have also contributed to this project but have not been specifically included herein). The intent of including this project in this year's Field Conference is to focus upon the nature of such projects today—expensive, complex, and requiring the coordination of a long list of professionals. It is not our intent to debate the pros and cons of undertaking the flood-protection project; for Lock Haven, it is now a moot point. However, it is important to consider the wisdom of addressing the geological hazard of flooding with flood-prevention engineering structures as a long-term solution to this environmental problem by putting the Lock Haven project into perspective.

This flood-protection project is the most recent in a series of several structures designed and built by the Baltimore District of the US Army Corps of Engineers aimed at reducing flood damage in the West Branch Susquehanna River basin and along the Susquehanna River south of Sunbury. This particular "local" project combines earthen levees, concrete flood walls, and closure structures into a continuous "wall" of protection which is designed to hold back the floodwaters from either the West Branch Susquehanna River (WBSR) or Bald Eagle Creek (BEC) and keep them from entering the city of Lock Haven, Clinton County, Pennsylvania. What follows is a brief summary of information principally derived from a thick stack of documentation required for this complex, multi-phase construction project that began in 1988 and was recently completed and dedicated in September 1994.

Lock Haven's Hydrologic Setting

The Susquehanna River and its tributary system drain nearly half the state of Pennsylvania (54,300 km^2; 20,965 mi^2) and about one quarter of upper New York state (Shank, 1988, p. 5). Two major branches, the West Branch and the main stem, sometimes referred to as the North Branch, comprise the upper portion of the basin. From the confluence of these two branches just south of Northumberland, Northumberland County, the Susquehanna River flows south and southeast into Maryland where it enters the Cheasapeake Bay at Havre de Grace.

The West Branch portion of the Susquehanna River system (Fig. 12), smaller of the two, has a drainage area of 18,100 km^2 (6,990 mi^2) (U.S. Corps of Engineers, undated #1). Its headwaters drain uplands of the Appalachian Plateaus in Indiana, Clearfield, and Cambria County, west-central Pennsylvania. From McGees Mills in southwest Clearfield Country, the river meanders to the

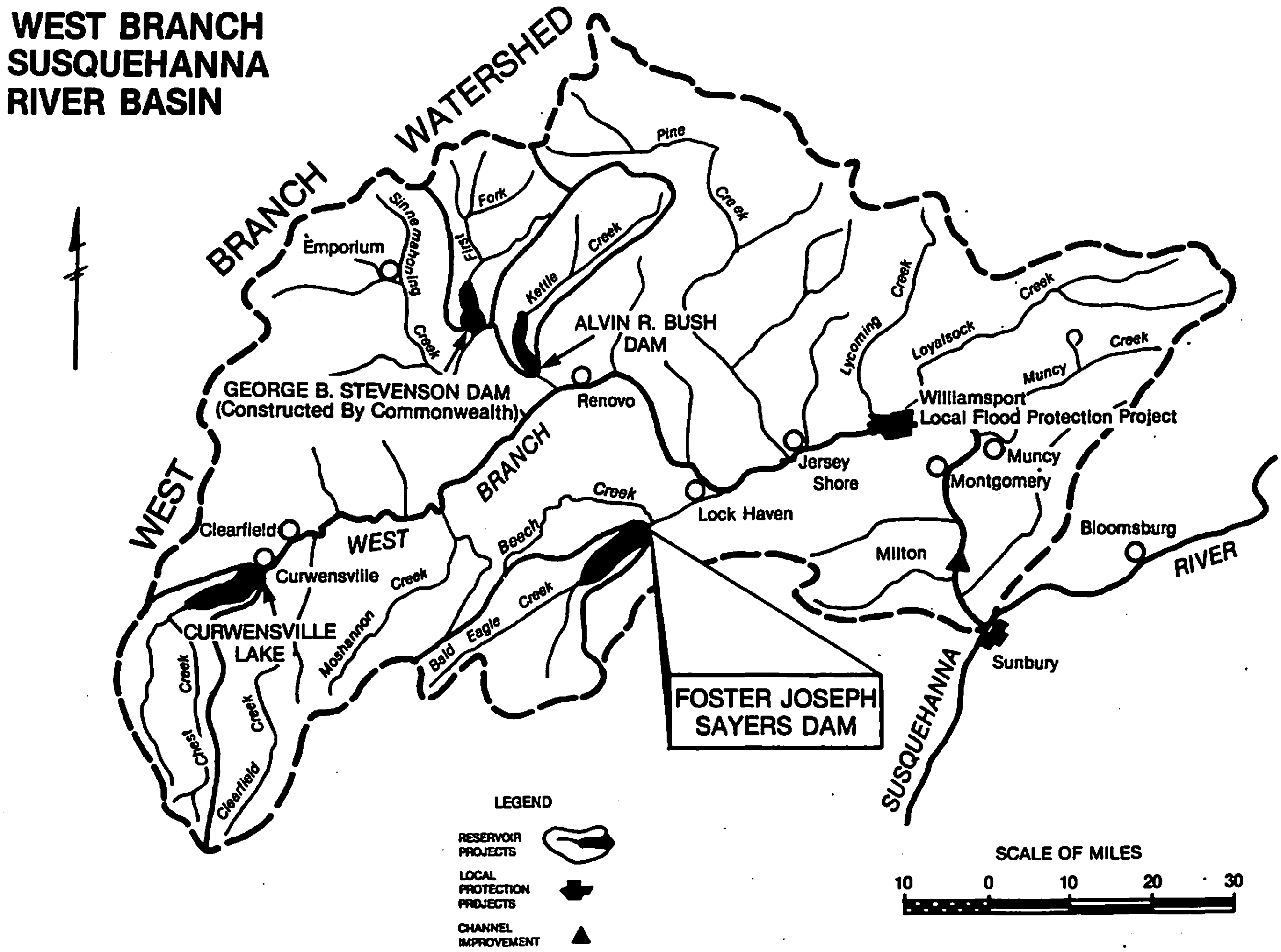

Figure 12. West Branch Susquehanna River basin, located in northcentral Pennsylvania, has a drainage area of 18,100 km^2 (6,990 mi ^{2}). The West Branch flows more than 400 km (240 mi) from its source in Cambria County to Sunbury where it joins the (North Branch) Susquehanna River. Above Lock Haven, its principal tributaries include the Chest, Clearfield, Moshannon, Sinnemahoning, Kettle, and Bald Eagle Creeks. Further east and south, Pine, Lycoming, Loyalsock, and Muncy Creeks contribute to the flow. Foster Joseph Sayers Dam is the only flood control structure on Bald Eagle Creek upstream from Lock Haven.

northwest through Clearfield and on into Centre County. At Keating, in western Clinton County, it is joined by Sinnemahoning Creek, a major tributary that drains significant areas in Cameron, Elk, and Potter Counties to the northwest. About 5 km (3 mi) east of Renovo, the West Branch turns and flows southeast, through the Allegheny Front, and out into the first valley of the Ridge and Valley province (moving from the NW to the SE), near Lock Haven.

Here, the West Branch portion flowing down from the Plateaus joins Bald Eagle Creek just east of the city of Lock Haven. Bald Eagle Creek, with a drainage area of about 2,000 km^2 (770 mi ^{2}) flows along the base of the Allegheny Front, and, for the most part, follows the structural grain of the folded Appalachians, from the southwest corner of Centre County northeast to just east of Lock Haven, a distance of more than 30 km (50 mi).

Lock Haven's Historic Setting

Lock Haven, the largest city and county seat of rural Clinton County, is situated immediately upstream from the confluence of the WBSR and BEC. Much of the city of Lock Haven lies within the combined floodplain of these two water bodies. It is important to recognize that much of the city's history has revolved around the rivers and their associated resources. Throughout most of the 1800s, this area rode the crest of the lumbering tide, and, along with Williamsport, become recognized as the "lumbering capitol of the world." Also, in the middle part of that century, Lock Haven was a principle center on the upper portion of the Pennsylvania canal system, the West Branch Division.

With the passing of the heyday of the canals, the city became a major railroad hub, and succeeded, through growth in agriculture and small-scale industry, in surviving economic downturns and actually thrived. Still later, the chemical and metals companies moved in and helped underwrite the area's economic base. This trend continued into the 1970s and it has only been relatively recently that the area has sustained downturns in its regional economic health.

Flooding History of the Region

The WBSR and the BEC have a long history of flooding and the Lock Haven region, located just upstream from the confluence of these two water bodies, is in constant peril of devasting floods from either or a combination of both. The highest flood levels result when the WBSR reaches its maximum stage preventing BEC from entering the river. In addition, water from WBSR can move up BEC as well during flood stage.

Flooding in this region results from storms or storm-snowmelt combinations. Since 1878, there have been 17 flood events that have affected the city of Lock Haven (US Corps of Engineers, 1980, p. D-13). Four of these storms have had significant impact to the city and the surrounding region (see Table III). These are summarized below:

• June 1889—an intense storm , producing as much as 20 cm (8 in) of rainfall, was centered over West Branch and Juniata River basins. This rainfall amounted to approximately 11 cm (4.5 in) over the average precipitation for June (US Corps of Engineers, 1987b, p. H-4). (Type I storm—see Table IV below.)

• March 1936—heavy rainfall, between 13 and 15 cm (5 & 6 in) fell on the upland areas throughout the region . As a result, on March 12, the WBSR crested 3 cm (0.1 ft) above flood stage and then receeded. On March 16-18, additional precipitation, combined heavy runoff with a significant snow melt. The WBSR to rose again, this time to 3.4 m (11.3 ft) above flood stage, and flood levels continued for approximately 64 hours. This flood is considered the "flood of record" for the purposes of flood analysis for Lock Haven and is predicted to have a recurrence interval of one every 170 years (US Corps of Engineers, 1980, p. D-12). (Type I-Type III storms.)

TABLE III Major Floods Impacting the West Branch Susquehanna River at Lock Haven. Estimated Flood Crest Elevations Above Bankfull Stage from 1847 through 1979 (US Corps of Engineers, 1987b, Table H-6)

DATE OF CREST	MAXIMUM CREST READING
June 1, 1889	29.8 feet
March 18, 1936	32.3 feet
June 23, 1972	31.3 feet
September 26, 1975	22.9 feet

• June 1972—Tropical Storm Agnes moved up the east coast, merged with a non-tropical low pressure system, and after following a considerably erratic path, centered over the central Pennsylvania region for more than 30 hours. During that time, up to 20 cm (8 in) of precipitation fell on the Lock Haven area (13.5 cm, 5.3 in, were measured in Renovo falling in a 24 hour period) (US Corps of Engineers, 1987b, p. H-4). Prior to this event, the ground was saturated from previous precipitation and water tables were high throughout the basin. Flood levels were maintained for about 48 hours. (Up to 48 cm, 18 in, fell throughout the Susquehanna River basin). (Type II - Type III storm.)

• September 1975—Tropical Storm Eloise produced 12 cm (4.6 in) in watershed above Lock Haven. The ground was saturated as a result of earlier precipitation events; the tropical low followed this period with additional heavy rainfall. In the Lock Haven area, 17 cm (6.5 in) fell over a four-day period, with maximum 24-hour total of 9 cm (3.7 in) (US Corps of Engineers, 1987b, p. H-4). Low-lying areas remained flooded for approximately 25 hours (US Corps of Engineers, 1987b, p. H-6). (Type II - Type III storm.)

TABLE IV Storm characteristics that may produce flooding in the Susquehanna River Basin (modified from US Corps of Engineers, 1987b, p. H-3).

STORM TYPE	STORM DESCRIPTION
Type I storm	High rainfall-producing, non-tropical; usually slow moving; originate in Gulf of Mexico and move from SE to NE; resupplied w/ moisture from Atlantic Ocean as a result of a Bermuda high-pressure area; also in place is a high-pressure area NE of PA, and a weak low-pressure trough east of the Appalachian Mts. Referred to as Gulf storms
Type II storm	Tropical storm; generated in low latitude Atlantic Ocean, Caribbean Ocean, Gulf of Mexico, (rarely in Pacific Ocean); season—June to October; ground conditions usually allow for infiltration (moderate to high) and runoff (moderate to low) even if rainfall amounts are high; result—significant flooding unlikely unless ground is saturated and rainfall is sustained (e.g., several storms following one another)
Type III storm	Moderate rainfall amounts; flooding results from antecedent conditions—i.e., saturated or frozen ground, frozen river; result— rapid runoff; warm temperatures can accelerate snowmelt, produce additional runoff, and make for more severe flooding.

Over the past 100 years, the water has risen to the heights of 3 m (10 ft) above flood stage on two occassions and to 1.5 m (5 ft) above flood stage eight times. Based on past records, the projected recurrence of flooding at Lock Haven will be every 6 years (US Corps of Engineers, 1987b, p. H-6).

Flood Control within the West Branch Susquehanna River Basin

The US Corps of Engineers have constructed four dams, a local flood-protection project at Williamsport and South Williamsport, and carried out a channel-clearing project at Milton under a flood-control plan developed for the West Branch basin and authorized by the Flood Control Act of 1964 (Public Law 780, 83rd Congress, 2nd session) (Fig. 12). This plan was implemented to reduce flooding in the West Branch basin and on the Susquehanna River below Sunbury and comprises the following elements (US Corps of Engineers, undated #2):

• The George B. Stevenson Dam on First Fork Sinnemahoning Creek, Clinton County, was completed in 1956 by the Commonwealth of Pennsylvania.

• The Alvin R. Bush Dam on Kettle Creek, Clinton County, was completed in 1962 by the US Corps of Engineers.

TABLE V Estimated flood crest elevations for the West Branch Susquehanna River above bankfull stage between 1848 and 1979. Measured at National Weather Service gage at the Jay Street Bridge, Lock Haven (U.S. Corps of Engineers, 1980, Table D-6, p. D-11).

Date of Crest	Stage[1] m	Stage[1] ft	Estimated Elevation[2] m	Estimated Elevation[2] ft	Discharge cms	Discharge cfts
1847	7.71	25.3	170.8	560.5	not determined	
1865	7.53	24.7	170.7	559.9	not determined	
February 7, 1878	6.71	22.0	169.8	557.2	2,770	98,000
June 1, 1889	9.08	29.8	172.2	565.0	5,430	192,000
May 1894	8.05	26.4	171.2	561.6	3,990	141,000
March 1, 1902	7.22	23.7	170.4	558.9	3,200	113,000
March 4, 1904	7.38	24.2	170.5	559.4	3,310	117,000
March 14, 1907	7.47	24.5	170.6	559.7	3,400	120,000
February 21, 1918	8.17	26.8	171.3	562.0	4,130	146,000
March 4, 1923	7.65	25.1	170.8	560.3	3,570	126,000
March 18, 1936[3]	9.85	32.3	173.0	567.5	6,740	238,000
April 1, 1940	6.61	21.7	169.7	556.9	2,690	95,000
December 31, 1942	7.07	23.2	170.2	558.4	3,060	108,000
May 28, 1946	8.20	26.9	171.3	562.1	4,160	147,000
November 26, 1950	8.41	27.6	171.5	562.8	4,440	157,000
January 26, 1961	6.43	21.1	169.6	556.3	2,550	90,000
March 10, 1964	7.96	26.1	171.1	561.3	3,900	138,000
June 23, 1972	9.54	31.3	172.7	566.5	5,380	190,000
September 26, 1975	6.98	22.9	172.7	558.1	2,590	91,500

[1] Flood stage = 6.4 m (21 ft)
[2] Gage Datum = 163.12 m (535.18 ft), msl
[3] Flood of record

• The Curwensville Dam on the West Branch at Curwensville, Clearfield County, was completed in 1965 by the US Corps of Engineers.

• The Foster Joseph Sayers Dam on Bald Eagle Creek, Clinton County, was completed in 1969 by the US Corps of Engineers.

• The Williamsport Flood Protection Project, Lycoming County, was completed in 1955 by the US Corps of Engineers and includes approximately 24 km (15 mi) of earthen dikes and levees along Lycoming Creek and the West Branch.

• A channel-improvement project in Milton was completed by the US Corps of Engineers.

From the dates listed above, it is obvious that the flood-protection projects upstream from Lock Haven came on-line after the 1936 flood but before the 1972 flood. If the Stevenson, Bush, and Curensville dams have been in operation in March 1936, it is estimated that the peak discharge at the Jay Street Bridge in Lock Haven would have been reduced more than 22%. (US Corps of Engineers, 1980, p. D-12). Additionally, had these dams not been available in 1972, the Agnes event would have been the "flood of record," produced an uncontrolled peak discharge at the Jay Street Bridge more than 26% higher than it did, and crested approximately 0.8 m (2.5 ft) higher than the observed peak stage of 9.5 m (31.3 ft) (US Corps of Engineers, 1980, p. D-13).

Flood-Protection-Project Rationale

Both the March 1936 flood and the June 1972 flood played major roles in the city's decision to affirm the undertaking of the flood-protection project. Neither of these floods and the circumstances responsible for them, major tropical storms or melting snow and rainfall, can be considered as highly unusual for this area. Over the years, several attempts at initiating a flood-protection projects met with varying degrees of success: (US Corps of Engineers, 1980, p. A-1):

- Section 5 of the Flood Control Act of 1936 authorized construction of a flood-protection project at Lock Haven. The authorization expired on June 3, 1951 because necessary local cooperation was never provided.

- A report by the Baltimore District titled "Susquehanna River, New York, Pennsylvania, Maryland" (May 6, 1938), House Document 308, 69th Congress, 1st Session, discussed a wall and levee system for Lock Haven, but its construction was not recommended. A subsequent revision of that report titled "Preliminary Examination and Survey of [the] Susquehanna River and [its] tributaries for flood control" (December 18, 1940), however, recommended construction of a wall and levee system for Lock Haven.

- A Baltimore District review of the report (House Document 308) (April 14, 1942), House Document 702, 77th Congress, 2nd Session "Susquehanna River and [its] tributaries, New York, Pennsylvania, Maryland" did not recommend authorization of flood protection project for Lock Haven because of economic considerations.

- The Susquehanna River Basin Study (June 1970) Coordinating Committee explored several alternatives for Lock Haven including both upstream reservoirs and a wall-and-levee system and ultimately recommended a local flood-protection project for Lock Haven.

- In House Document 94-577 (August 5 1976) "Lock Haven, Clinton County, PA" Congress recommended a wall-levee project for the city.

- Senate and House Public Works committees (July and October 1972 respectively) authorized a review of previous studies of Susquehanna River Basin with an emphasis on flood control. This study's results—the only other economically justified flood protection on the West Branch Susquehanna River is the raising of the existing flood-protection projects at Williamsport and South Williamsport

- The Phase I study "Advanced Engineering and Design" was authorized by the 1976 Water Resource Development Act, Section 101(a) Public Law 94-587 (October 22, 1976) and Lock Haven's Flood Protection Project was finally authorized by Section 401 (a) of the 1986 Water Resources Development Act. (Authorized Phase II -- General Design Memorandum)

Recognizing that nearly 43% of the area of Lock Haven lies within the 100-year floodplain, and, of this, almost half is in the floodplain and half is in the floodplain fringe the US Corps of Enigineers estimated that a recurrence of the 1936 flood would result in $104,000,000 in damages (using 1979 dollar values) to the city and that $84,500,000 (cf. approximate actual costs of $50,700,000 in 1972 dollars) in damages would result from an Agnes-type event (US Corps of Engineers, 1980, p. A-12). A major portion of this flood-prone area is industrial (38.5%) and the residential portion is a close second (31.8%). There are a great many residential structures in the floodplain and it was estimated that approximately one third of the city's residents live in flood-prone areas of the city (US Corps of Engineers, 1980, p. A-12).

In order to achieve a significant level of "protection" from the threat of flooding to Lock Haven and its surroundings, the city began a long and expensive process that culminated with the structures marginal to the West Branch Susquehanna River and Bald Eagle Creek that we see today. Flood protection was championed as the vehicle necessary to provide for a significant reduction in damages to the socio-economic sectors of the region that would no doubt occur in the future and for the long-term economic values beneficial to the region as a whole by generating land that was "flood-proof" and therefore attractive to new business interests.

LOCK HAVEN'S FLOOD-PROTECTION PROJECT

Throughout the planning, design, and construction phases, the Lock Haven Flood-Protection Project evolved. As a result, the completed project turned out to be significantly different from that initially proposed. These changes occurred in response to a number of factors including public input, technical and engineering modifications, interpretations with respect to compliance with various environmental protection statues and other existing laws and regulations under which the project fell, and variations in the soil and geologic conditions encountered during construction.

At STOP 3 we will examine several aspects of this newly constructed flood-protection project. What follows are summary outlines of some of the aspects of this plan. The project not only involved the construction of the various structures designed to hold back floodwaters—the "line of protection" for the city, it also required the relocation and modification to the existing infrastructure, the completion of new recreational facilities, and beautification and enhancement of areas structures themselves as well as surrounding areas. In addition, a considerable effort was devoted to investigating the cultural resources of the area in order to determine the potential impact to these resources. Architectural resources in the community were evaluated and inventoried, historical archeaological investigations were performed, and archaeological studies were undertaken at several sites.

Summary of Structures and Improvements

Lock Haven's flood-protection plan requires the construction of earthen and rock-filled levees marginal to both the WBSR and BEC (Fig. 13). Similar structures were built in 1955 around portions of Williamsport and, as a result, that city escaped the 1972 flood with only minor damage (Shank, 1988, p. 75). A combination of floodwalls and dikes, completed back in 1948, rim the Susquehanna River at Sunbury, and it too managed to come through the Agnes event relatively unscathed.

Locally called the "dike/levee," the Lock Haven project comprises the "structures and improvements" listed below (refer to Table VI for details of each structure):

- Levees
- Floodwalls and retaining walls
- Closure structures
- Drainage structures
- Sanitary pumping station

Summary of Induced Flooding

One result of the construction of the earthen levees and floodwalls is that flood levels will increase upstream on both the WBSR and BEC; this phenomenon is referred to as induced flooding. For the region upstream on the WBSR , the topography of this region limits the extent of the floodplain and reduces the areas where relatively flat, easily developed land exists. Growth and development of this region is likely to be slow, modest at best, and involve single-family housing. However, substantial growth and development will likely continue upstream in the floodplain of Bald Eagle Creek. Economic and political pressures will be brought to bear to fill in or modify the floodway with buildings and accompanying parking lots. In addition to destroying valuable agricultural land, these modifications will no doubt induce further upstream flooding, the extent of which is unpredictable and depends on numerous, unquantifiable variables.

In response to a Congessional directive accompanying the project's authorization, a mitigation plan addressing the induced flooding was developed for properties upstream on the WBSR. Essentially, the mitigation plan called for the acquisition of more than 100 properties, standard flowage easements on more than 100 others, utility floodproofing, and structure-raising of 8 properties. All of these required negotiations with the owners at considerable expense to the project.

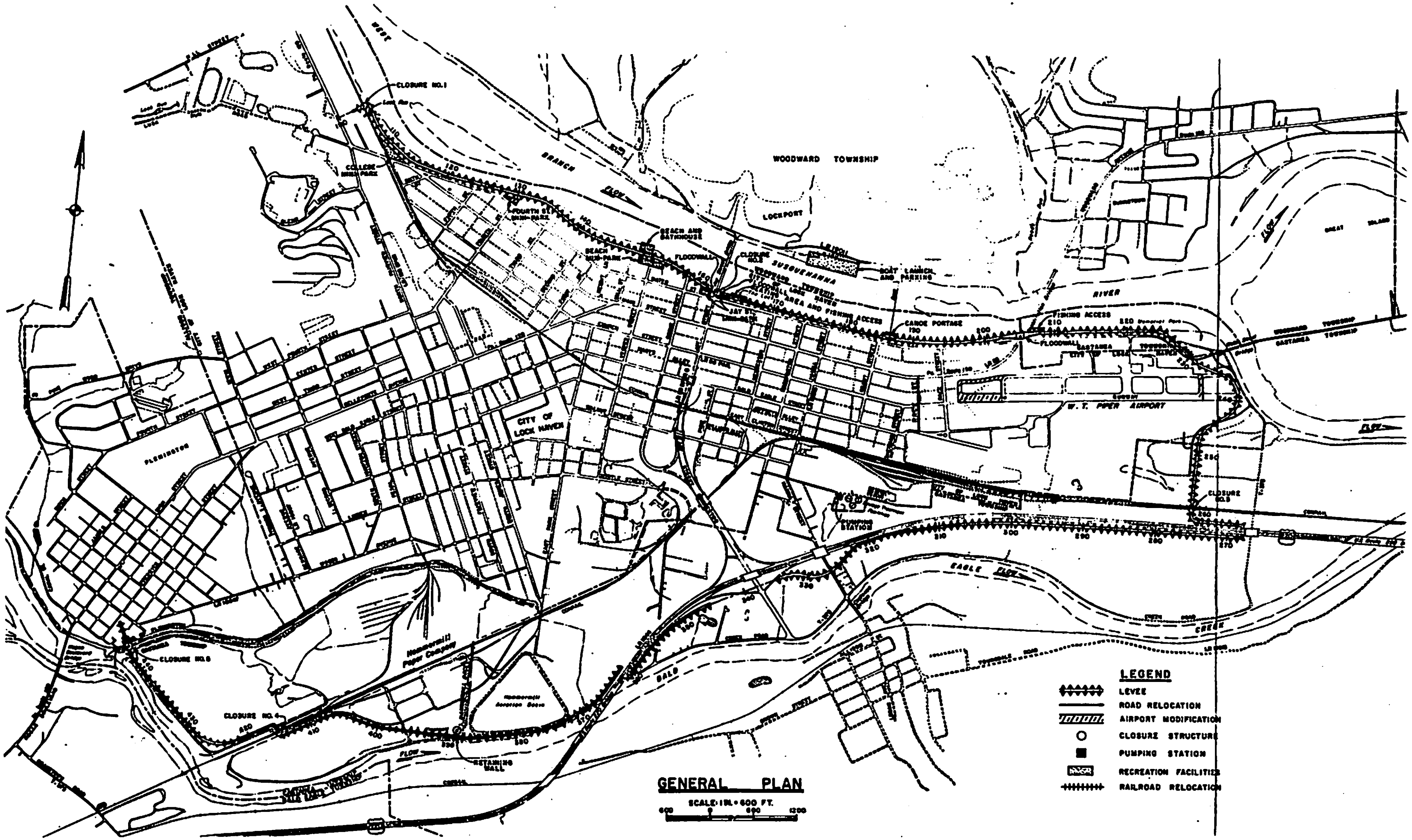

Figure 13. General plan for Lock Haven's Flood Protection Project comprising principally earthen and rock-filled levees marginal to both the West Branch Susquehanna River on the south shore and the Bald Eagle Creek running along the north shore.

TABLE VI Summary of structures and improvements required as part of the flood-protection project for Lock Haven (US Corps of Engineers, 1987a, p. 4-1).

STRUCTURES	EXPLANATION
Levees (Fig 14a.)	Approximately 11,160 m (36,600 ft). Two types of sections—(a) standard, homogeneous, earth-fill for those sections that do not encroach into the WBSR or BEC; (b) zoned earth and rockfill for reaches that do encroach into a water body. Levees typically 3-m (10-ft) wide at the top with 1: 2.5 (vertical to horizontal) slopes on earth-fill side slopes; 1: 2 slopes for rockfill side slopes .
Floodwalls and Retaining wall (Fig 14b.)	conventional, inverted T-type reinforced concrete structures founded on undisturbed soil or rock . Used at three locations—(a) Jay Street Bridge, (b) Constitution Bridge, (c) Hammermill Race
Closure Structures (Fig 14c.)	Five structures of three types—(a) fabricated structural steel miter-gate railroad closure structures (#1, #3, #4), (b) aluminum stoplog street closure structure (#2), (c) gated, twin-celled reinforced concrete box culvert (#5).
Drainage structures	Thirty-five gravity-type drainage structures to pass drainage through the line of protection. Three for sanitary effluent, 33 for storm water. Each includes a control manhole on the riverside crown with a manually-operated sluice gate for positive means of closure; a majority will include an automatic flap gate
Sanitary pumping station	Pumping station required to pump sanitary sewage from sanitary treatment plant over the line of protection into BEC during flood stage. Pumping station will eliminate ponding of both treated and untreated sewage inside the line of protection

The presence of the Lock Haven flood-protection project, however, should have no significant adverse impact to communities downstream. Computer modeling of flood events indicated that increased velocities should be expected downstream of the point of constriction. However, these velocities were shown to dissipate a short distance downstream in the direction of Great Island. At this point the flow is no longer confined, and only the upper end of the island would be susceptible to project effects during bankfull conditions (US Corps of Engineers, 1987a, p. EA-8).

Summary of Relocations and Modifications

Construction of the flood-protection project required the relocation or modification of the following facilities (refer to Table VII for details of each facility):

- roads
- Grand Street Dam
- railroads
- USGS Gaging Station
- airport facilities
- utilities

Summary of Recreation Facilities

A number of recreational facilities were designed in order to give the project broader public appeal as well as to provide for facilities that were lost as a result of construction. Listed below are some of these features (refer to Table VIII for details of each facility).

- College mini-park
- Swimming Beach mini-park
- canoe portage
- boat launch area
- Fourth Street mini-park
- Jay Street mini-park
- Constitution Bridge fishing area
- trail system

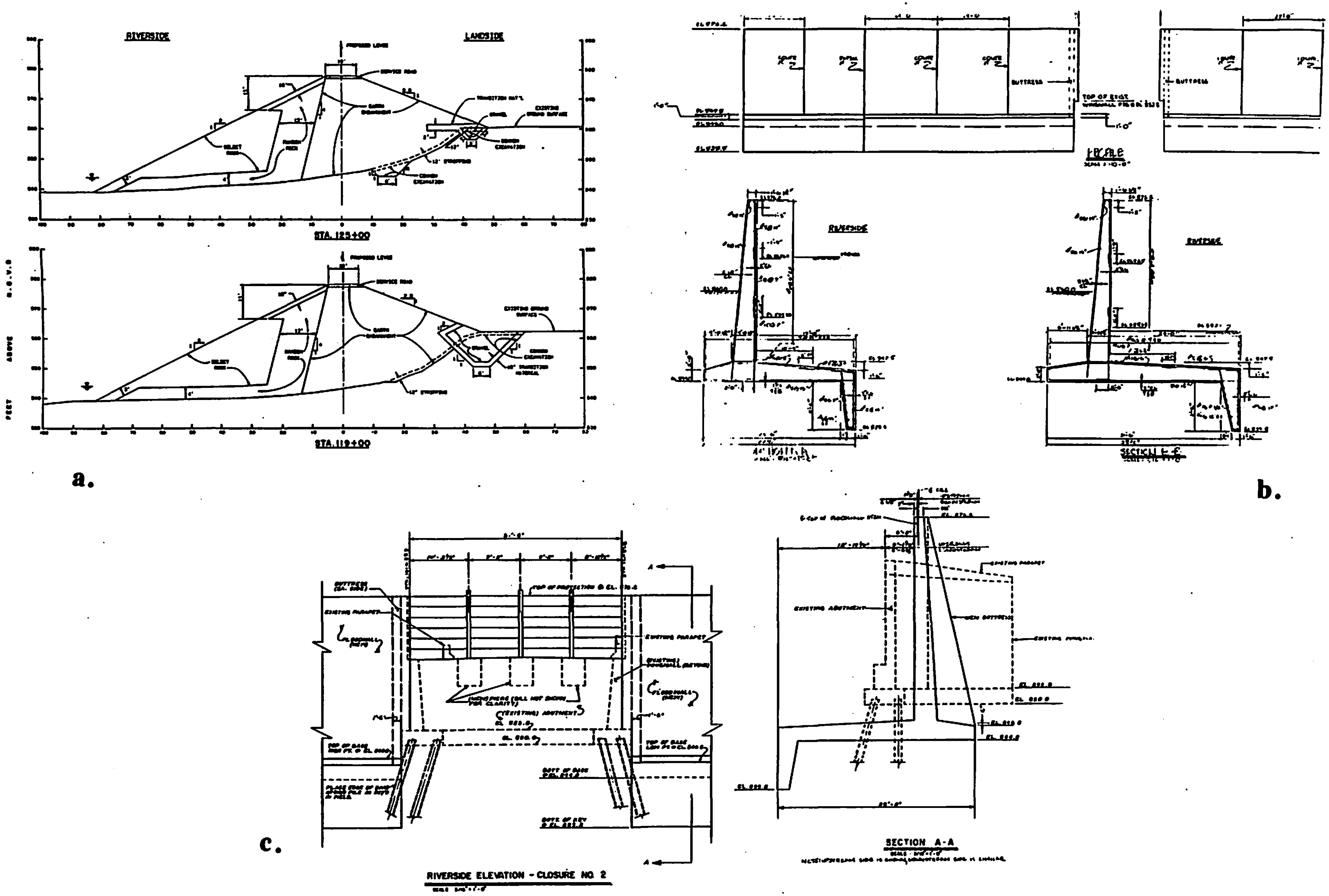

Figure 14. a. Typical levee section. b. Profile, Jay Street floodwall. c. Jay Street closure structure—riverside elevation and profile.

A considerable effort was devoted to the addition of these facilites that would serve to physically integrate the project into the community in terms of appearance and recreational use. Measures were developed to compensate for community-wide affects that impacted public resources.

TABLE VII Summary of relocations and modifications required as part of the flood-protection project for Lock Haven (US Corps of Engineers, 1987a, p. 6-1).

FACILITIES	EXPLANATION
roads	Portions of several roads were involved. All designs were in accordance with American Association of State Highway and Transportation Officials standards
railroads	Construction of three closure structures require track relocations of both Conrail and Hammermill Paper Co.
airport facilities	Eastern portion of the runway eliminated and western extension completed; taxiways relocated; clear zones and transition zones relocated. Result—runway length was extended. All designs were in accordance with Federal Aviation Adminisration requirements. Numerous other modifications and improvements were made
Grand Street Dam	Modifications to low-level recreation dam required
USGS Gaging Station	Relocation stream gaging station 475 m (1550 ft) downstream
utilities	relocation, modification, or termination of water, gas, sanitary sewer, power, telephone, and cable TV lines

TABLE VIII Summary of recreational facilities constructed as part of the flood-protection project for Lock Haven (US Corps of Engineers, 1987a, p. 7-1).

FACILITIES	EXPLANATION
College mini-park	Small parking and picnic area with tables and trash receptacles; ramp access to the levee crest; landscaping
Fourth Street mini-park	Small picnic area with tables and trash receptacles; ramp access to the levee crest; landscaping
Swimming Beach mini-park	paved parking lot, turn-around, and picnic tables on city side; beach and bathhouse (built into riverside slope)
Jay Street mini-park	pedestrian walks and ramps, small picnic area, plaza area, fishing platform, large-seating area (concrete bleachers); eight historic light standards relocated across street from levee; picnic area surrounds memorial monuments
canoe portage	ramps extending from levee crest to riverside berm
Constitution Bridge fishing area	upstream and downstream ramps extending from levee crest to riverside berm; fishing platform overlaid by gravel for level footing
boat launch area	parking for cars and boats with trailers; concrete boat-launch ramp, comfort station, picnic facilities, access ramp to river
trail system	trail extends from College mini-park to Memorial Park; paved levee crest, several access ramps, timber curbs, lighting

MISCELLANY

Borrow Areas

Locations were identified throughout the local area to excavate earth and rock for construction of the levee (refer to Table IX below).

TABLE IX Summary of borrow areas and commercial sources of rock.

FACILITIES	EXPLANATION
NW flank of Bald Eagle Mountain	Silurian Upper Mifflintown Formation—thin-bedded, finely-crystalline gray limestones and limy mudstones.
Dunnstown	Brallier Formation—thin- to medium-bedded, dark-gray siltstones and mudstones
Flemington	Regolith and weathered rock of the Devonian Mahantango Formation including the Tully Member
Commercial sources: Lycoming Silica Sand Co.'s Salona facility, south slope, Bald Eagle Mt. & others	Middle Ordovician carbonates

Toxic and Hazardous Waste Sites

Considerable effort and coodination among state and federal agencies has gone into the design of the plan to avoid known sides of toxic and hazardous waste contamination. At the eastern (airport) end of the project area, the levee has been realligned to avoid a known site. In addition, along the southern side of the project area, coordination with the Environmental Protection Agency (EPA) resulted in measures taken to insure that the levee project will be "engineeringly compatible" with the EPA remedial measures being taken at the Drake Chemical Company Superfund site (US Corps of Engineers, 1987a, p. EA-11).

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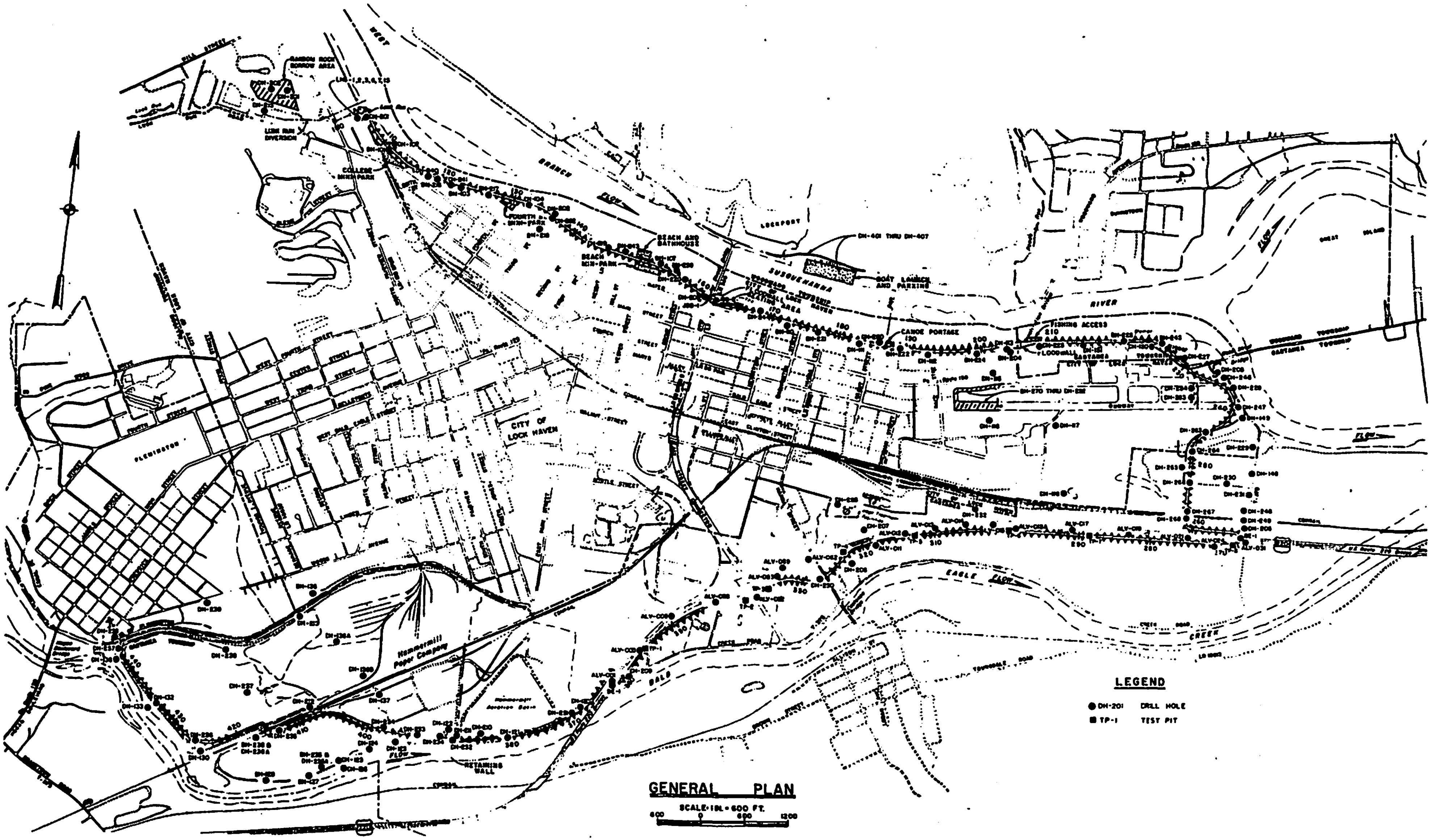

Figure 14d. General plan for Lock Haven's Flood Protection Project (US Corps of Engineers, 1987c).. The locations of drill holes are indicated with prefix DH.

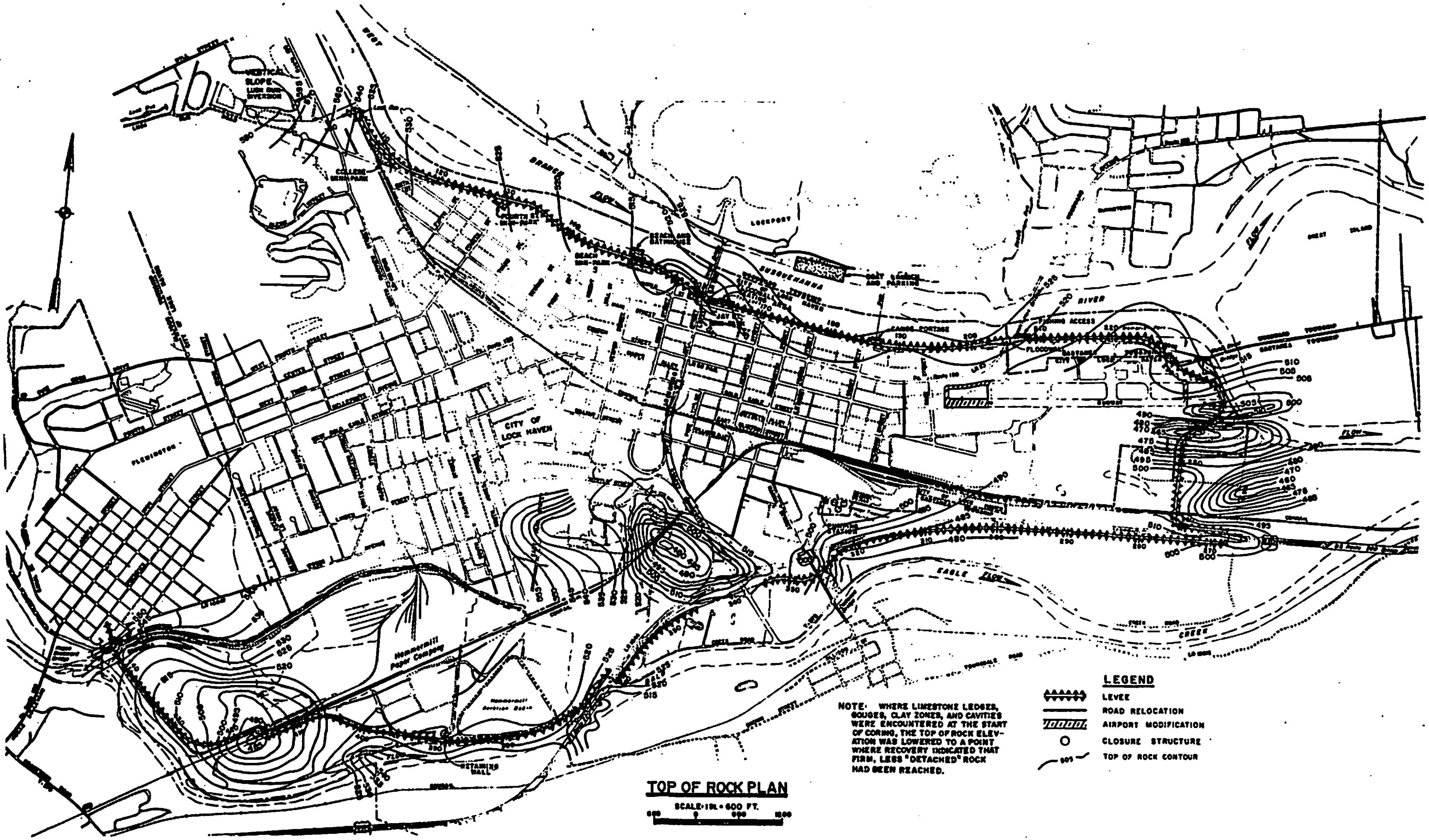

Figure 14e. Top of Rock Plan for Lock Haven's Flood Protection Project (US Corps of Engineers, 1987c)..

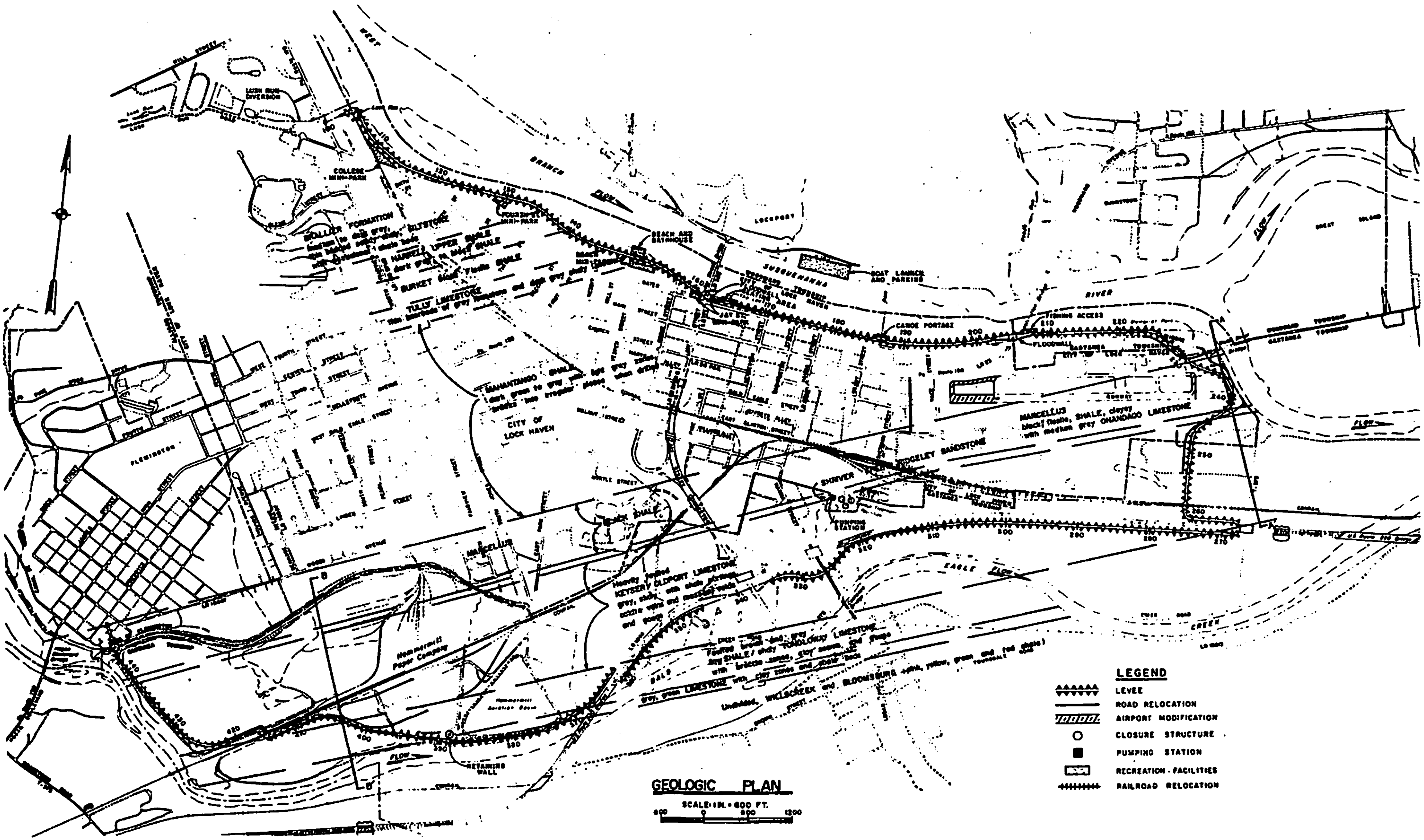

Figure 14f. Geologic Plan for Lock Haven's Flood Protection Project (US Corps of Engineers, 1987c).

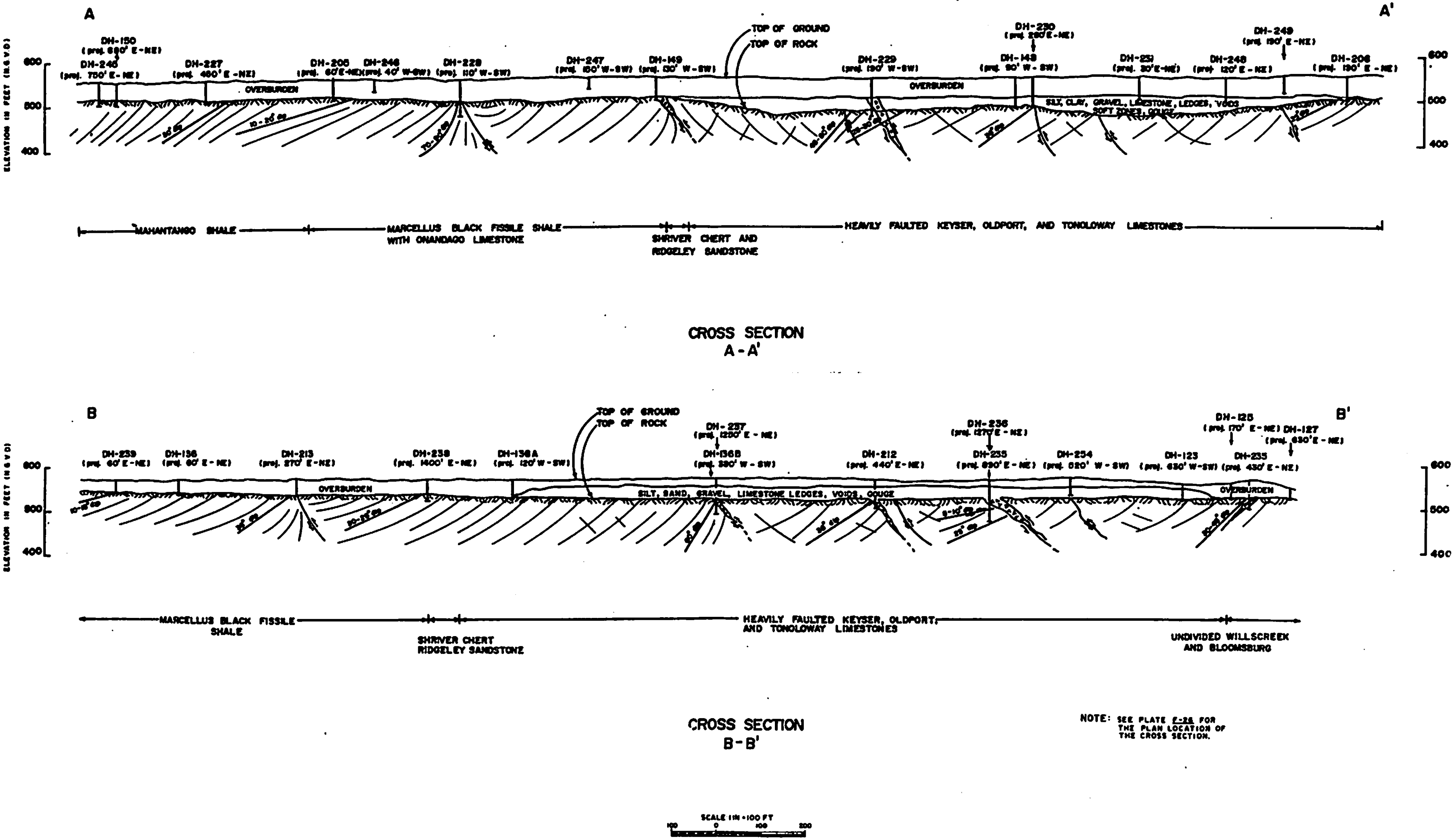

Figure 14g. Geologic Cross Sections for Lock Haven's Flood Protection Project (US Corps of Engineers, 1987c).

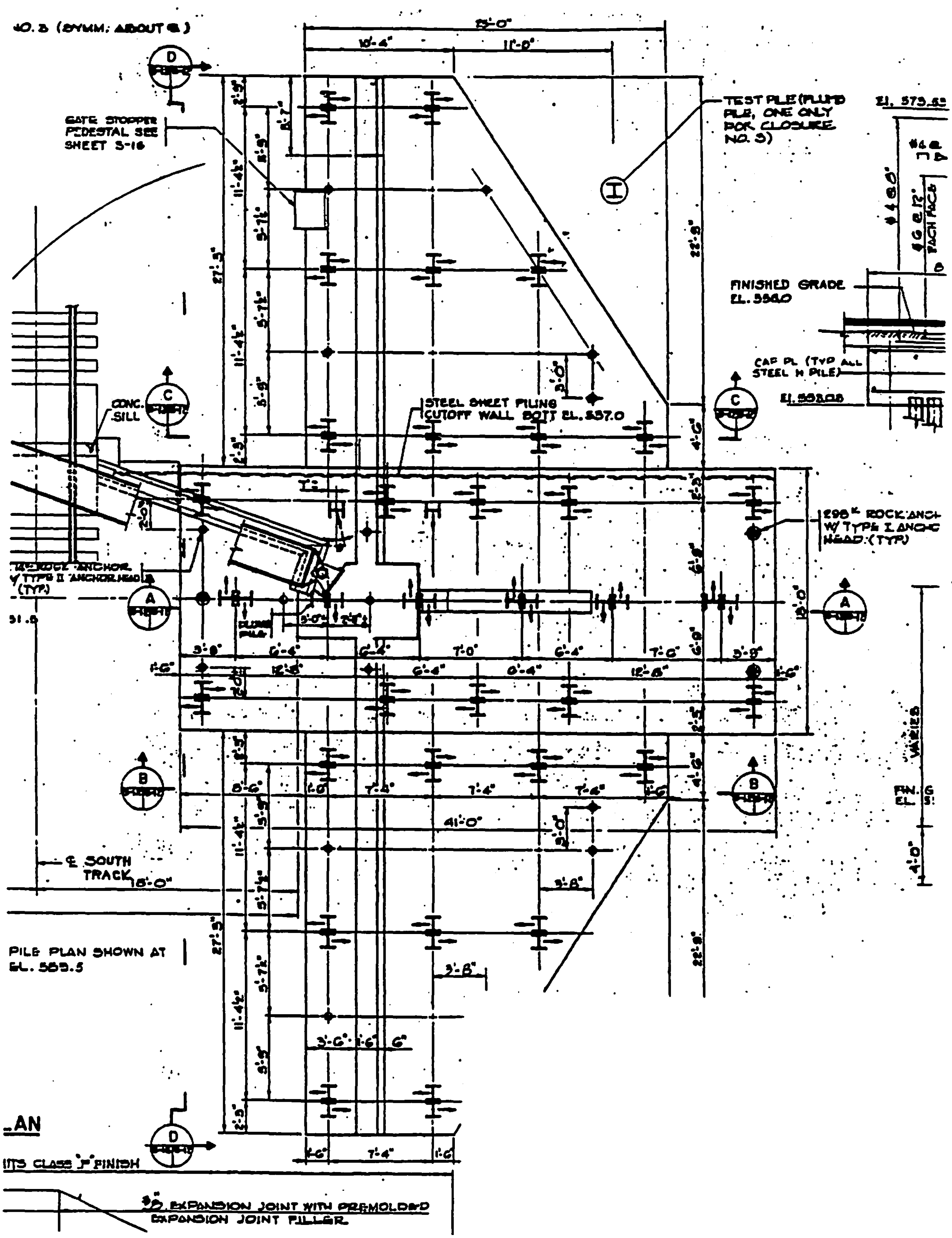

Figure 14h. Unit IIB Closure Structure 3 Foundation Plan. Original plan based on Top of Rock (Figure 14e) being approximately 50 feet beneath the surface. Actual conditions encountered required modifications because "top of rock" was in the range of 80 to 110 feet. Rock anchors were driven to between 105 and 135 feet. (T. Swanson, US Corps of Engineers, personal communication).

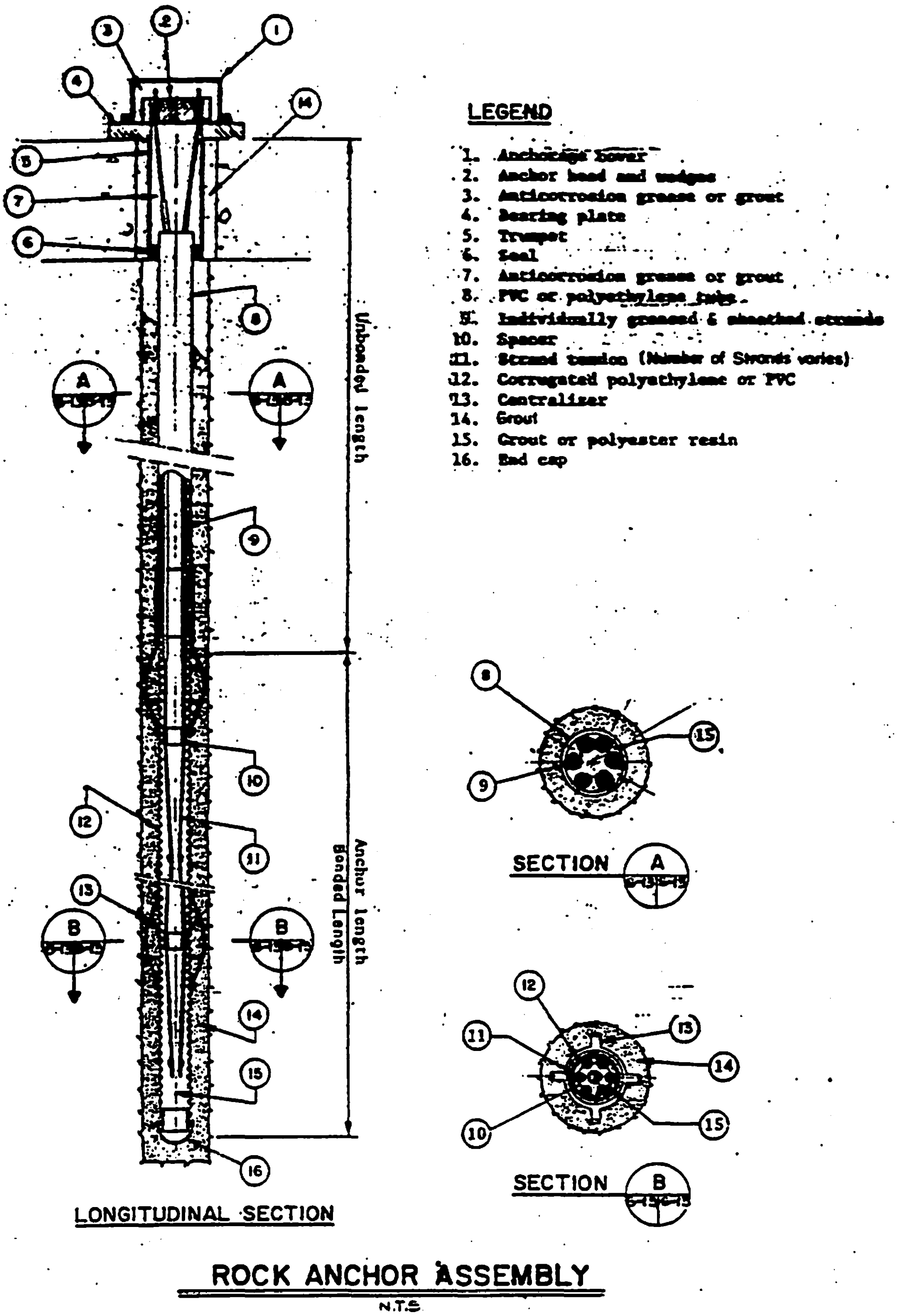

Figure 14i. Rock anchor details for railroad closure strutures, approximately 25 feet into sound rock (T, Swanson, US Corps of Engineers, personal communication).

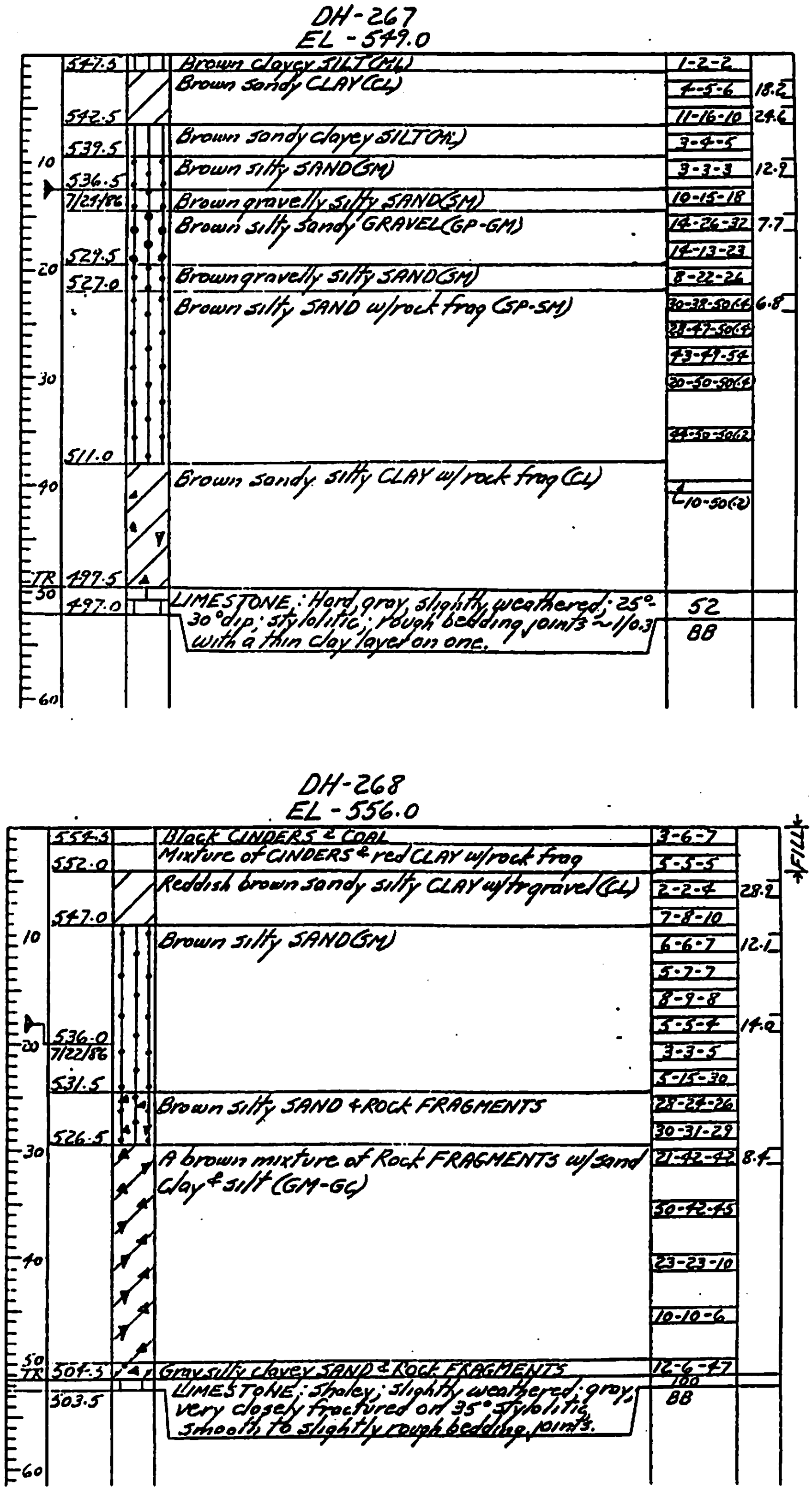

Figure 14j. Unit IIB Lock Haven Levee Boring Log DH-267 and DH-268 at Closure Structure 3. Top of rock approximately 50 feet (T. Swanson, US Corps of Engineers, personal communication).

THE DRAKE CHEMICAL SUPERFUND SITE
LOCK HAVEN, CLINTON COUNTY, PENNSYLVANIA

C. R. CARNEIN [1]

ABSTRACT

The Drake Chemical Superfund site was used for the manufacture of chemicals relating to the dye, pharmaceuticals, herbicide, and other industries in the 1950s through the early 1980s. In the process, more than 60 organic and inorganic chemicals, some of which are potentially hazardous to human health, were released into the sediments, surface water, and groundwater at the site. Remediation of contaminated soils and sludges will begin soon, with installation of a rotary kiln incinerator now in progress. Groundwater remediation is in the planning stages.

INTRODUCTION

The Drake Chemical Superfund site is STOP 4 of the 60th Annual Field Conference of Pennsylvania Geologists. This article summarizes the history, geology, and status of the site and is based on reports, newsletters, and other documents that are a part of the public record relating to the site. Much of this information was gathered by geologists and engineers for contractors involved in various studies carried out over the last 15 years, including Ebasco Services, Inc., NUS Corp., Gannett Fleming, Inc., Environmental Science and Engineering, Inc., Chemical Waste Management, Inc., Environmental Research and Technology, Inc., and the U.S. Army Corps of Engineers. Although these documents generally agree on major issues relating to the history and geology of the site, they are plagued by minor inconsistencies. Detailed information is available at several repositories, including the Stevenson Library at Lock Haven University, the Ross Library in Lock Haven, and the Lock Haven City Hall.

LOCATION AND GENERAL GEOLOGY

The Drake Chemical Superfund site is located in the City of Lock Haven and in Castanea Township, Clinton County, Pennsylvania (Fig. 15). The site occupies an area of about 8 acres on the floodplain separating Bald Eagle Creek (less than one-half mile to the south and southeast) and the West Branch of the Susquehanna River (about three-quarters of a mile to the north). Prior to recent remediation activities, topography reflected disturbance of the floodplain by industrial occupants.

The valley of the West Branch of the Susquehanna River results from differential erosion of sedimentary rock units dipping gently to steeply northwest. Studies by the U.S. Army Corps of Engineers and others indicate that, at the Drake site, the interface between floodplain deposits and bedrock varies between depths of about 35 and 110 feet. Bedrock consists mainly of fractured black shale identified by the U.S. Army Corps of Engineers as belonging to the Middle Devonian Marcellus Formation (NUS, 1988) (see Fig. 16).

Alluvial deposits underlie the whole site. In general, these consist of clay and sandy clay and silt to an average depth of 15 feet (NUS, 1988). The clay occurs as nearly pure lenses distributed throughout the sandy clay host. In most parts of the site, alluvial deposits are disturbed, containing sludge, construction debris, and other man-made materials to depths as great as 20 feet or more (Fig. 17). Below 15 feet, sand and gravel stream-channel deposits overlie medium to coarse sand mixed with sandstone cobbles believed to have been derived from Bald Eagle Mountain to the south. "Quartz and feldspar gravel" were identified in a buried alluvial channel under the site (USEPA, 1988). Because feldspar is rare or absent in nearby bedrock, this suggests a glaciofluvial origin for a part of the sequence.

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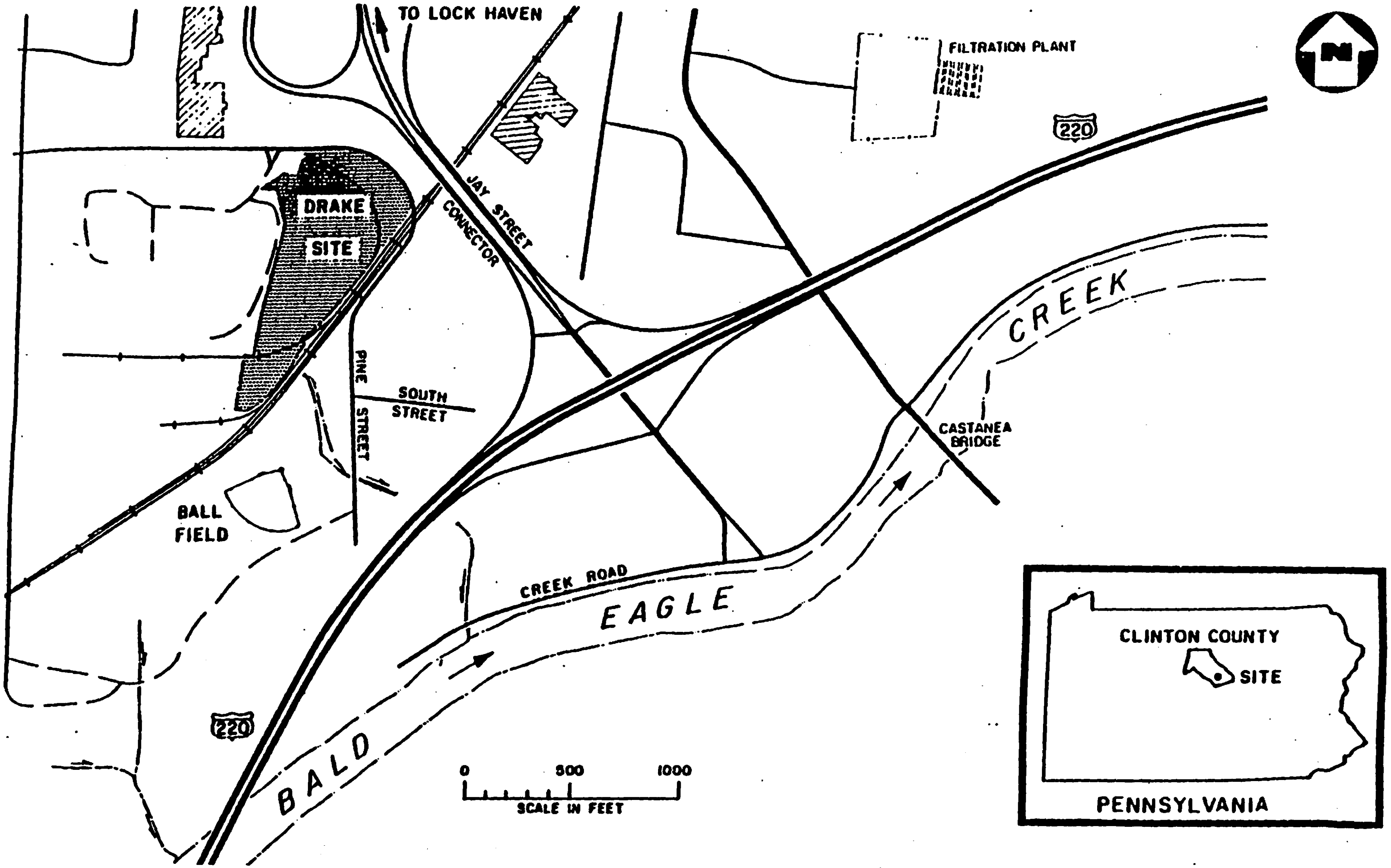

Figure 15. Location map, Drake Chemical Superfund site Lock Haven, Pennsylvania. (NUS, 1988)

The local water table occurs at an average elevation of 545 to 555 feet (NUS, 1985). A groundwater "high" occurs in the southern part of the site, resulting in water movement toward the north, east, and south before heading generally southward toward Bald Eagle Creek. Regional groundwater flow is toward the confluence of Bald Eagle Creek and the West Branch of the Susquehanna River. Elevation of the bedrock surface has an important effect on groundwater flow in the area, but the "buried channel" mentioned above is not thought to influence flow paths.

HISTORICAL BACKGROUND

The earliest industrial user of the Drake Chemical site was the Kilsdonk Chemical Corporation, which commenced operations about 1947 (Petechuk, 1992). They produced dye intermediates, which are compounds from which dyes are manufactured. Chemicals used included analine, toluene, xylene, and benzene. Kilsdonk was one of two U.S. manufacturers of beta-naphthylamine (BNA), a known carcinogen used in dye and rubber manufacture. BNA production was banned by the Commonwealth in 1961; after 1975, the U.S. prohibited its import or manufacture. In 1963, workers from the University of Pittsburgh's Graduate School of Public Health reported 78 cases of bladder cancer in area hospitals, including 11 cases among former workers at the Drake site and the adjacent American Color and Chemical site (Petechuk, 1992). Bladder cancer and kidney problems commonly are associated with BNA exposure.

Drake Chemicals, Inc., purchased Kilsdonk Chemical Corp. in the early 1960s and took over operation of the Lock Haven facility. By the mid-1960's, storage tanks, buildings, and waste-water storage lagoons covered most of the site (Fig. 18). Drake's business was similar to Kilsdonk's, involving manufacture of chemicals for the dye, pharmaceuticals, cosmetics, herbicide, and pesticide industries. Between 1967 and 1982, Drake received several citations for violations of the Pennsylvania Clean Streams Law, the Solid Waste Management Act, and the Occupational Safety and Health Act (Petechuk, 1992). In April, 1979, they signed a consent order with the Pennsylvania Department of Environmental Resources (PADER), agreeing to follow specific waste-handling procedures. However, Drake never complied with the consent order.

The U.S. Environmental Protection Agency (USEPA) made their initial inspection of the site in 1980. In 1981, workers from the National Institute of Occupational Health and Safety (NIOSH) visited the site to evaluate worker reports of health problems. Very soon thereafter, in August, 1981, Drake Chemicals, Inc., filed for bankruptcy. In January, 1982, PADER issued a cleanup order, based on violations of the 1979 consent order (USEPA, 1991). In response, Drake Chemicals ceased operations at the site.

Clean-up of the site began in February, 1982, when USEPA began an emergency action under the Superfund program (described in Box 1) (NUS, 1988). Their first priority was removal of the contents of storage tanks and chemical drums and fencing of the site. At one point, the clean-up effort triggered an oleum-tank explosion that released a cloud of sulfuric-acid-laced gas over the city. A bomb-disposal unit was called in to remove some chemicals (Petechuk, 1992). During this operation, clean-up crews discovered a leachate stream crossing Castanea Park and emptying into Bald Eagle Creek.

In 1983, the American Color and Chemical Corporation closed its plant on the property immediately to the west of the Drake site. In September, the Drake site was added to the National Priority List, making it eligible for long term investigation and remediation under the Superfund program. USEPA made clean-up of the surface leachate stream its first priority, resulting in preparation of a Remedial Investigation and Feasibility Study (RI/FS) for this first phase of the clean-up by NUS Corp. in July and August, 1984. A Record of Decision (ROD) detailing the remediation plan was issued in September, 1984. The leachate lagoon feeding the stream received a covering of soil and clay, some contaminated material was placed in a synthetic-lined and covered onsite landfill, and a French drain and sewer pipe were installed to drain the site to Bald Eagle Creek (see Fig. 19). USEPA and the U.S. Army Corps of Engineers completed the Phase I remediation in early 1987.

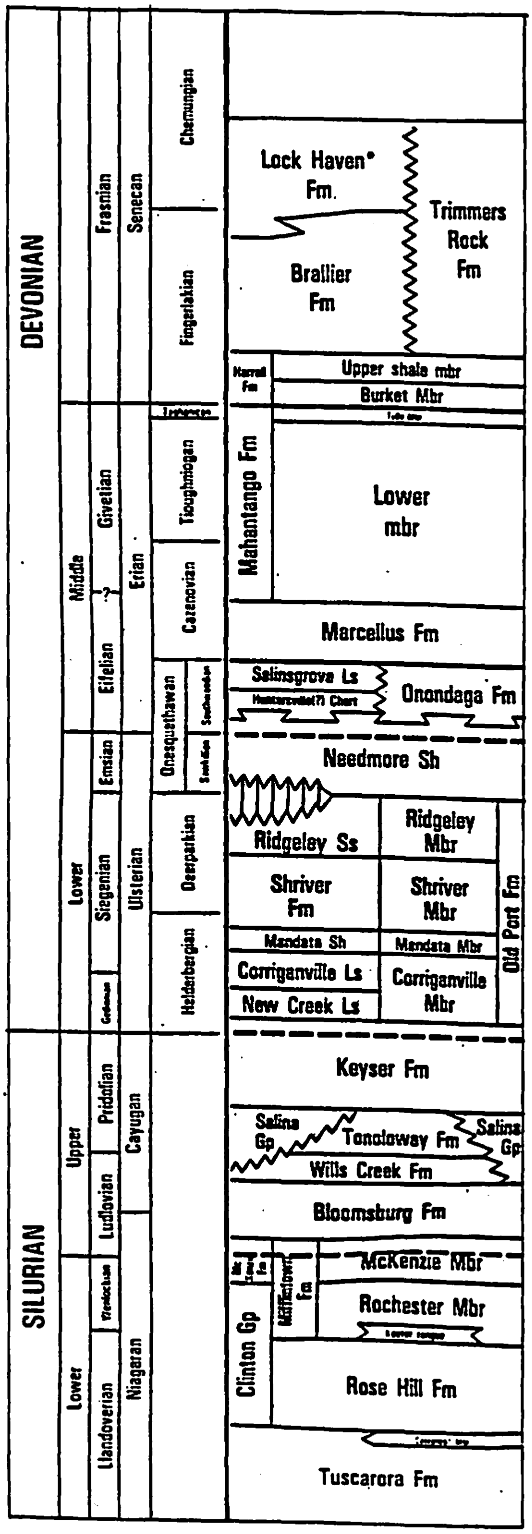

Figure 16. Partial stratigraphic column for the Lock Haven area. (Berg and others, 1983)

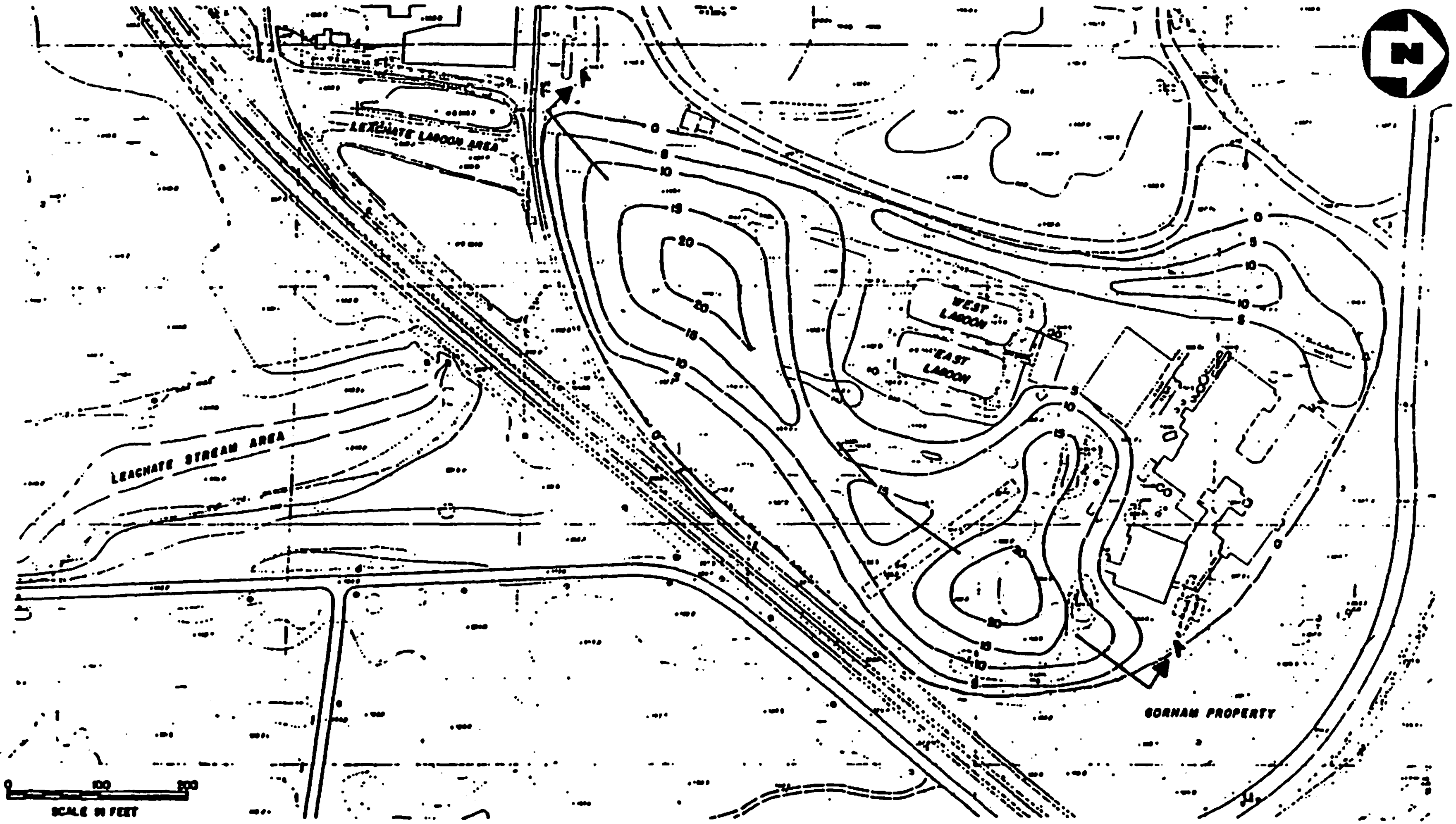

Figure 17. Approximate waste depths for the Drake Chemical Superfund site. Contour interval is 5 feet. (NUS, 1986)

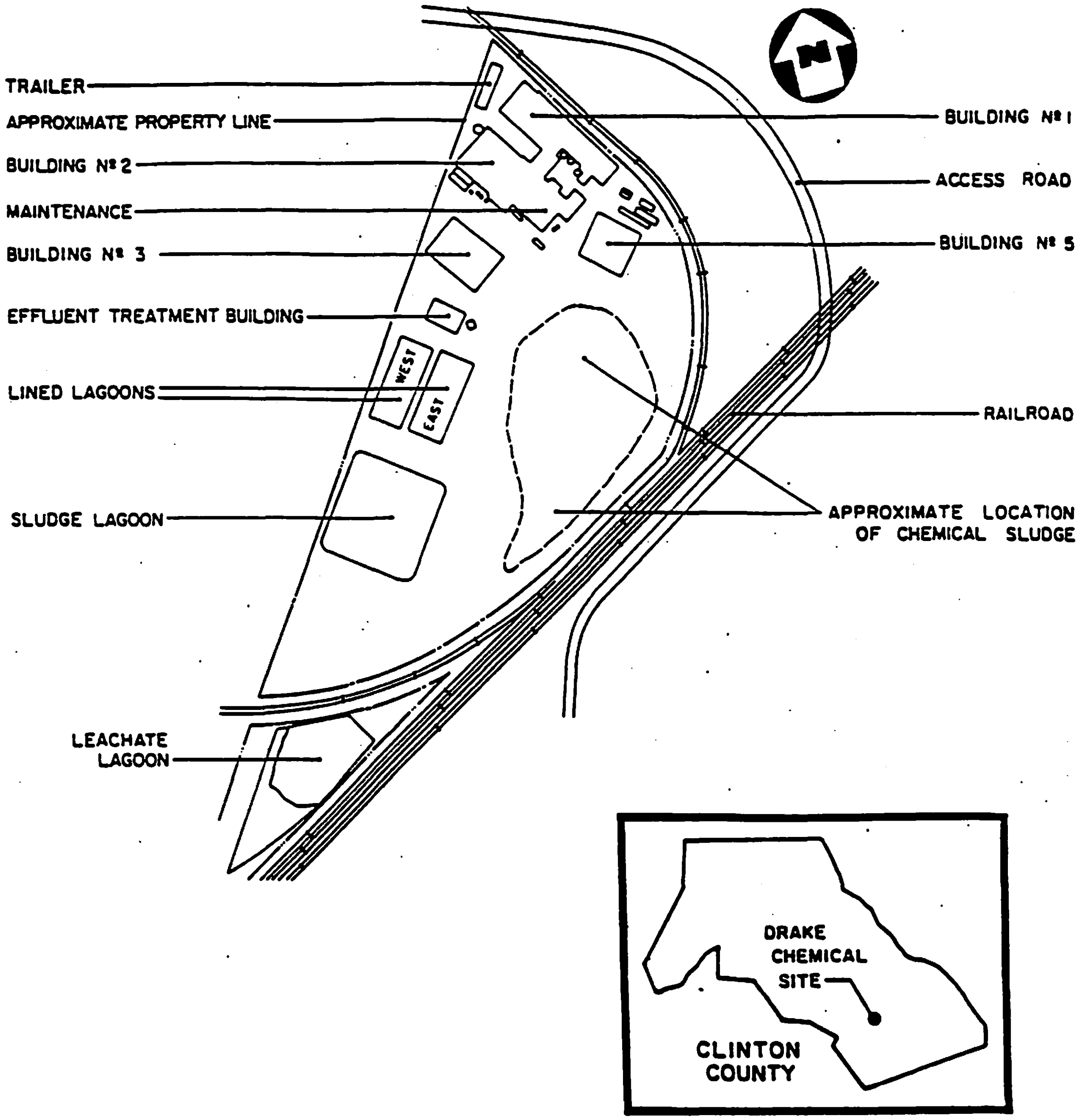

Figure 18. Site plan, Drake Chemical Superfund site prior to Phase II remediation. (U.S. Environmental Protection Agency, 1988)

Box 1.—How Does Superfund Operate?

The Superfund system is complex. Sites are identified and enter an inventory because they may require a cleanup. At this point, or at any time, a site may receive a *Removal Action* because of emergency conditions that require fast action or because the site could get a lot worse before a remedial cleanup could be implemented. (Most of SARA's requirements for remedial cleanups do not apply to removal actions, even though removal actions can cost several million dollars and resemble a cleanup.) In the pre-remedial process, sites receive a *Preliminary Assessment* (PA); some then go forward to a *Site Inspection* (SI), with some of those sites scored by the *Hazard Ranking System* (HRS). If the score is high enough, the site is placed on the *National Priorities List* (NPL) and becomes eligible for a remedial cleanup paid for by the government, if necessary, or by responsible parties identified as having contributed to creating the uncontrolled toxic waste site. Under current procedures, only about 10 percent of sites which enter the system are likely to be placed on the NPL. Some States have their own lists of sites which require cleanup; these often contain sites not on the NPL.

NPL sites receive a *Remedial Investigation and Feasibility Study* (RIFS) to define contamination and environmental problems and to evaluate cleanup alternatives. The public is given an opportunity to comment on the RIFS and EPA's preferred cleanup alternative. Then, EPA issues a *Record of Decision* (ROD) which says what remedy the government has chosen and the reasons for doing so; the decision may be that no cleanup is necessary. A ROD may only deal with part of a site's cleanup and several RODs may be necessary for a site. The ROD also contains a summary of EPA's responses to public comments. EPA chooses the cleanup goals and technology in the ROD. In actual fact a number of actions involving different technologies are likely to be chosen for any but the simplest sites. The ROD is like a contract in which the government makes a commitment to actions which will render the site safe. If responsible parties agree to clean up the site, they sign a negotiated consent decree with the government; this stipulates the exact details of how the responsible parties will proceed. If the cleanup uses Superfund money, the State must agree to pay 10 percent of the cleanup cost.

In the post-ROD process, the site receives a *Remedial Design* (RD) study to provide details on how the chosen remedy will be engineered and constructed. The whole process ends with the *Remedial Action* (RA), the actual implementation of the selected remedy. Many cleanups include long-term monitoring to determine whether the cleanup is effective and if more cleanup is necessary. A ROD may be reopened and amended because of new information discovered or difficulties encountered during the design and remedial action. When a cleanup is deemed complete and effective, the site can be delisted by EPA from the NPL.

(U.S. Congress, Office of Technology Assessment, 1988)

In 1985, workers from the University of Pittsburgh's Graduate School of Public Health returned to the region to conduct a comprehensive bladder-cancer screening program focusing on former employees of the Drake and Kilsdonk companies. Eventually, 80 percent of eligible former workers were tested. The study was completed in May, 1991, but extensions have been granted to allow the study to continue, because carcinogenic effects of BNA are thought to appear 2 or 3 decades after initial exposure (Petechuk, 1992). Of about 400 former workers, at least a dozen either have bladder cancer, have died of it, or have suspected precursors of the disease. School of Health workers expect to see a 20- to 30-fold increase of bladder cancer in their cohort, compared with already high Clinton County rates (Petechuk, 1992).

In April, 1985, NUS Corporation published its Phase II RI. A feasilbility study was published in August, and a Record of Decision was signed in May, 1986, detailing plans to demolish and remove contaminated structures at the Drake site. This mission was completed in 1988.

In the meantime, a Phase III RI/FS appeared in September, 1986, proposing methods for dealing with sludge, soil, and contaminated groundwater. The preferred solution consisted of groundwater extraction to lower the water table, combined with placement of a RCRA-type protective cap over the whole site. This generated public opposition, resulting in a new proposal to develop a RCRA-type capped onsite landfill (USEPA, 1991). In September, 1986, PADER proposed excavation of contaminated materials with disposal at an offsite landfill. However, no acceptable hazardous waste landfill could be found in Pennsylvania with room to accommodate all of the Drake site wastes. Thanks to passage of the Superfund Amendments and Reauthorization Act (SARA) in October, 1986, neither of these proposals proved workable.

SARA directed USEPA to choose permanent treatment methods over containment wherever possible. As a result, a new Phase III RI/FS was begun for the site in January, 1987. After public discussion of various options, USEPA issued its Phase III ROD in September, 1988. The site was divided into two "operable units" (A and B), to be treated in separate phases. Operable Unit A consists of soils and sludges; Operable Unit B consists of groundwater. According to the decision, soils and sludges would be treated in a mobile, high temperature incinerator, and groundwater would be extracted via onsite wells and undergo biological treatment. Design of the incinerator began in 1989, and, in 1990, treatability studies were conducted at a USEPA research facility in Arkansas, using samples collected at the Drake site.

Several changes have been made in the 1988 ROD. Biological treatment of groundwater was abandoned in favor of use of granulated activated carbon adsorption. Extraction wells for water treatment probably will be drilled in Zone II (see Fig. 19) in order not to interfere with remediation of soils and sludges. The fate of groundwater-treatment residuals has not been decided (USEPA, 1995c) and will require preparation of a separate new ROD for Operable Unit B.

Currently, activity centers around moving water and sewer lines that cross the site, construction of the incinerator itself, and installation of air-monitoring stations at several locations in Lock Haven and the Castanea area. USEPA hopes to have completed a trial burn at the site by January, 1996, with full scale operation of the incinerator to follow sometime in the spring. Treatment of soil and sludge should take less than two years. Groundwater treatment may begin sometime during the incineration process. Estimates of the time span for this part of the remediation vary from about 20 years to more than 50 years.

SITE CHARACTERIZATION

Geography and Land Use

The Drake site occupies 8 acres in the alluvial valley of Bald Eagle Creek and the West Branch of the Susquehanna River. This valley lies near the boundary between the Appalachian Mountain section of the Ridge and Valley province and the Mountainous High Plateau section of the Appalachian Plateaus province. Regionally, elevations range from about 530 feet to more than 2000 feet, but the site itself ranges between 555 and 565 feet above mean sea level. The site is in a relatively densely populated area, with residences to the north and west, a shopping center to the northwest, and the town of Castanea to the southeast. A property used until 1983 by the American Color and Chemical Co. (AC&C) lies immediately west of the Drake site. AC&C is now in the late stages of a Resource Conservation and Recovery Act (RCRA) remediation of that site. The International Paper Company occupies a large piece of property to the south and southwest of the Drake site.

Climate

Precipitation averages about 40 inches per year, with more rain- and snowfall on the ridges and plateau than on the valley floor. Bald Eagle Mountain, to the south of the valley, and the Appalachian Plateaus to the north constrain regional prevailing westerly winds. Stagnant air commonly accumulates in the valley and is a cause of concern among opponents of soil incineration at the Drake site.

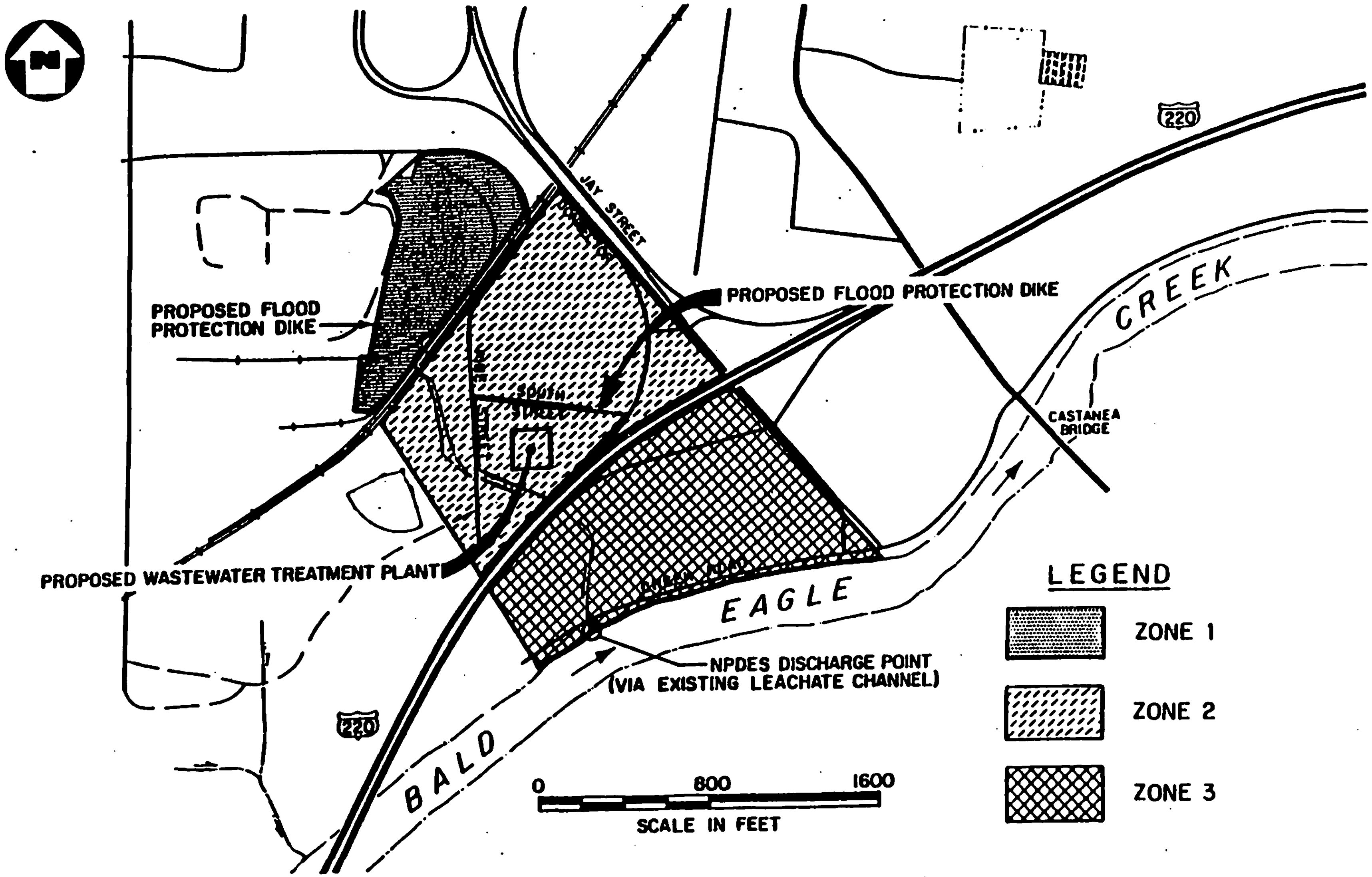

Figure 19. Groundwater remediation zones, showing location of leachate channel. Proposed flood protection dike has been eliminated as a result of recently completed U.S. Army Corps of Engineers flood protection system. (U.S. Environmental Protection Agency, 1988)

Bedrock Geology

Regional bedrock geology consists of folded and faulted Ordovician through Devonian sedimentary rocks. Shale and limestone predominate in the valley of the West Branch Susquehanna River, and clastic rocks are an important component of the surrounding high areas. The Bald Eagle through Bloomsburg formations (Fig. 16) are well exposed on Bald Eagle Mountain south of the valley, while excellent exposures of the Tully Limestone through the Catskill Formation occur to the north. Most of these units strike about N60E and dip gently to steeply to the northwest, toward the axis of the Little Plum syncline. Although few exposures occur in the valley itself, the geologic map of the Lock Haven quadrangle (Taylor, 1977) and drill-hole data suggest that the Drake site is underlain by Upper Silurian to Middle Devonian carbonate rocks and shale (Keyser through Marcellus formations).

Where bedrock was encountered in test borings and observation wells at the Drake site, it consisted of dark colored shale identified as belonging to the Marcellus Formation and limestone identified as Keyser and Old Port formations (USEPA, 1988). Abundant fractures, some with secondary calcite veinlets, probably result from a combination of stress release during valley cutting and deformation during the Alleghenian disturbance. Nearby, rocks are dominated by shear fractures oriented obliquely to the Alleghenian principal stress and by fractures that are perpendicular to local bedding and either parallel or perpendicular to the strike.

Surficial Geology

The Drake site is underlain by floodplain sediments. Elevation of the interface separating alluvial deposits and bedrock varies widely and exerts a major influence on groundwater flow. This surface generally slopes steeply to the north and east from the southern part of the AC&C property, where it is relatively shallow. A buried channel, approximately parallel to Bald Eagle Creek, extends across the southeastern part of the site (NUS, 1985).

Near the surface, clayey to sandy silt dominates the floodplain deposits. Clay content varies both vertically and laterally, and clay lenses have been identified in some borings. These materials coarsen downward into sand and gravel, followed by sandstone cobbles in a sandy matrix. Depth to bedrock averages about 40 feet except to the southeast, where the east-west "channel," containing brown, fine grained, well sorted sand with silt and gravel dispersed throughout, extends to a depth of up to 110 feet (NUS, 1988). This material is reported to contain "quartz and feldspar gravels" and may be glaciofluvial in origin.

Site soils are mostly profoundly disturbed. Fine sand, silt, and clay are intimately mixed with sludge, bricks, wood, and other man-made debris. Numerous soil borings and wells show contaminated sludge and fill ranging from 1 to 22 feet below the surface (Fig. 17) (NUS, 1986).

Groundwater

Regional groundwater flow is eastward or northeastward toward the junction of Bald Eagle Creek and the West Branch Susquehanna River. Groundwater from the Drake site flows predominantly southeastward toward Bald Eagle Creek. Long term average water levels for the site and adjacent areas are shown in Figure 20 (Gannett Fleming, 1992). Note that the Drake Superfund site comprises Zone I on this figure. Zones II and III are not part of the site but are underlain by contaminated groundwater and were affected by contaminated surface drainage. Their boundaries are based on man-made and physical boundaries and on levels of contamination (Fig. 19). Zone III is bounded to the southeast by Bald Eagle Creek.. The unconfined aquifer of the floodplain deposits normally discharges into the river system. Average regional flow velocities of 3.5 to 60 feet per year are estimated for the consolidated and unconsolidated materials in the area of the Drake site.

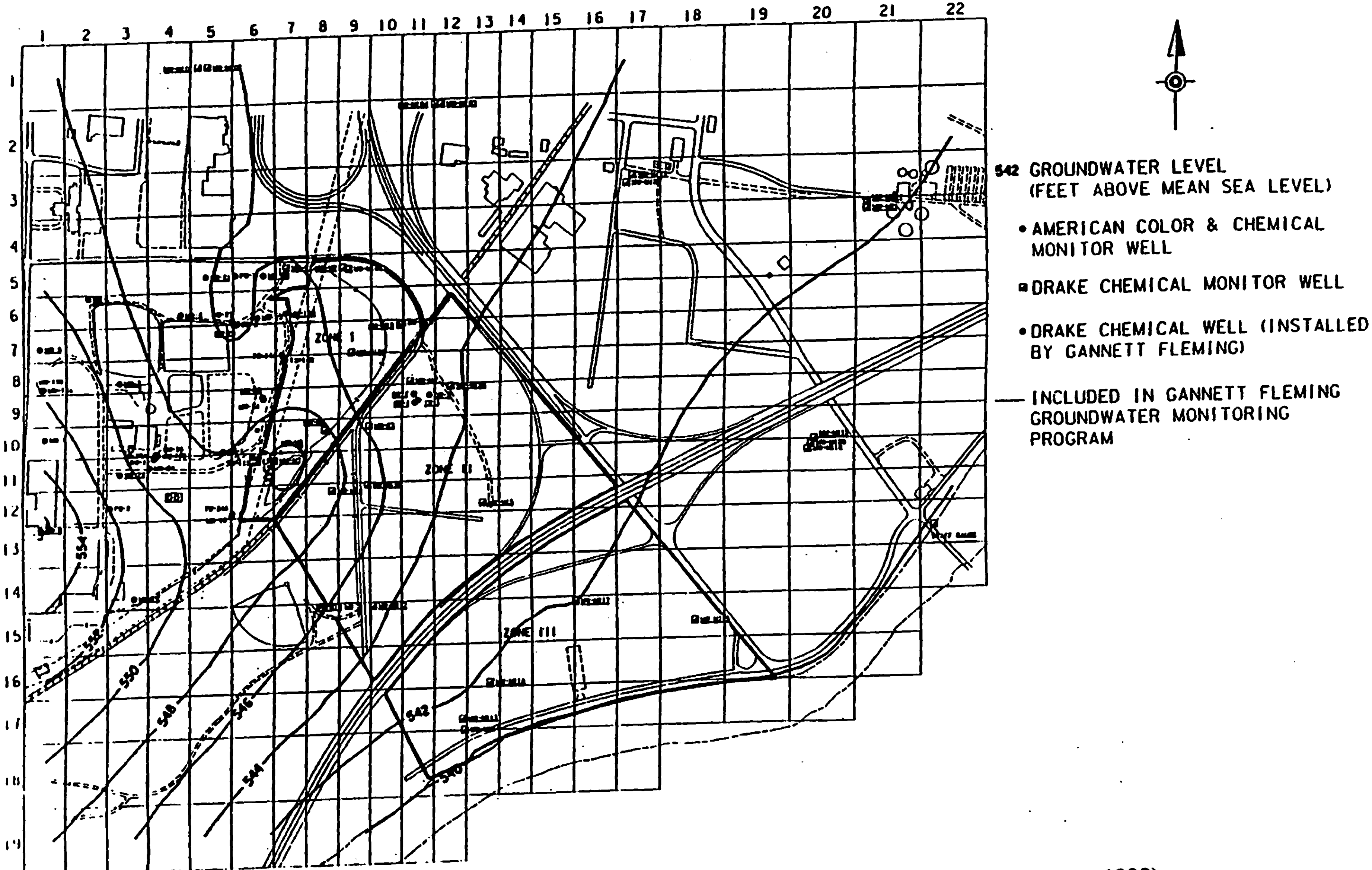

Figure 20. Long term average water levels, Drake site. Contour interval: 2 feet. (Gannett Fleming, 1992)

NUS Corp. installed 26 monitoring wells and 6 multi-level sampler wells during the Remedial Investigation completed in 1985 (Figs. 21 & 22). Reported hydraulic conductivities ranged from 1.4×10^{-5} cm/sec in silty sand to 8.4×10^{-3} cm/sec in sand and gravel deposits of the floodplain. However, large vertical and lateral variations in conductivity result from the heterogeneous character of the aquifer sediments. Intermediate values of hydraulic conductivity in the underlying fractured shale probably relate to the degree, depth, and orientation of the fractures (NUS, 1985).

In 1992, Gannet Fleming, Inc., reported the results of aquifer pump testing and groundwater-flow modeling required for the design of a groundwater-extraction system. They drilled, installed, and developed a test well and three new monitoring wells (labeled OW-1, 2, and 3 and TW-1 in Fig. 23), in addition to wells previously emplaced. Potentiometric contours drawn from data collected for that study confirm eastward to southeastward flow from Zone I toward Zones II and III and Bald Eagle Creek. Specific capacity, hydraulic conductivity, and transmissivity of the alluvial aquifer were determined by means of *in situ* hydraulic conductivity testing, a step-drawdown test, a 72-hour constant rate pump test, and a recovery test. Figure 23 and Tables X, XI, and XII show results of some of these tests. These data allowed groundwater modeling that will be used in planning the groundwater-treatment system for the site (Gannett Fleming, 1992).

SCOPE OF THE CONTAMINATION

Dozens of test pits, borings, and monitoring wells have been sampled since detailed studies of the Drake site began in the early 1980s. Site-related contaminants are found throughout the study area, including the Gorham property to the northeast and Zones II and III, southeast of the site proper. Table XIII gives representative lists of a few of the large number of organic and inorganic contaminants that occur in soils, alluvial sediments, surface water, and groundwater on or near the site. Contaminantion is so widely distributed that NUS, Inc., recommended, in their Phase III RI, that it be considered to be homogeneous, with respect to choosing appropriate treatment methods (NUS, 1988). As a result, an estimated 252,000 cubic yards of soils and sludges will require treatment, based on an average water-table depth of 12.5 feet. Soils below the water table cannot conveniently be treated by incineration.

NATURE OF CONTAMINANTS

Inorganic Contaminants

Contaminants at the Drake site consist of both inorganic and organic compounds (Table XIII). Inorganic compounds are mostly metals. NUS, Inc. (1988) established background concentrations of total and dissolved metals in groundwater by direct observation and literature search (Table XIV). Comparisons of site data with background data show higher than background concentrations of dissolved barium, beryllium, cadmium, cobalt, nickel, vanadium, and zinc in groundwater samples from Zone I. Values in Zones II and III are close enough to those for uncontaminated regional groundwaters so that they cannot be attributed to site-related activities (NUS, 1988).

Similar studies of inorganic contaminants in soils and sludges reveal that a number of metals exceed common ranges for soils (Table XV). Although other inorganics, including chromium, cyanide, mercury, nickel, and selenium, occur in site soils, they are not unambiguously related to industrial activity at that location.

Organic Contaminants

Surface water on the Drake site occurs in lagoons that were used during both chemical manufacture and earlier site-remediation activities. As expected, this water is contaminated by inorganics, base/neutral acid extractables, and fenac, all of which were made or used on site. The presence of fenac in numerous samples collected downstream of the site, in Bald Eagle Creek and the West Branch Susquehanna River, is thought to support the conclusion that contaminants have migrated into offsite surface waters (NUS, 1988). Fenac concentrations in downstream samples average 6 times higher than those in samples from above the site.

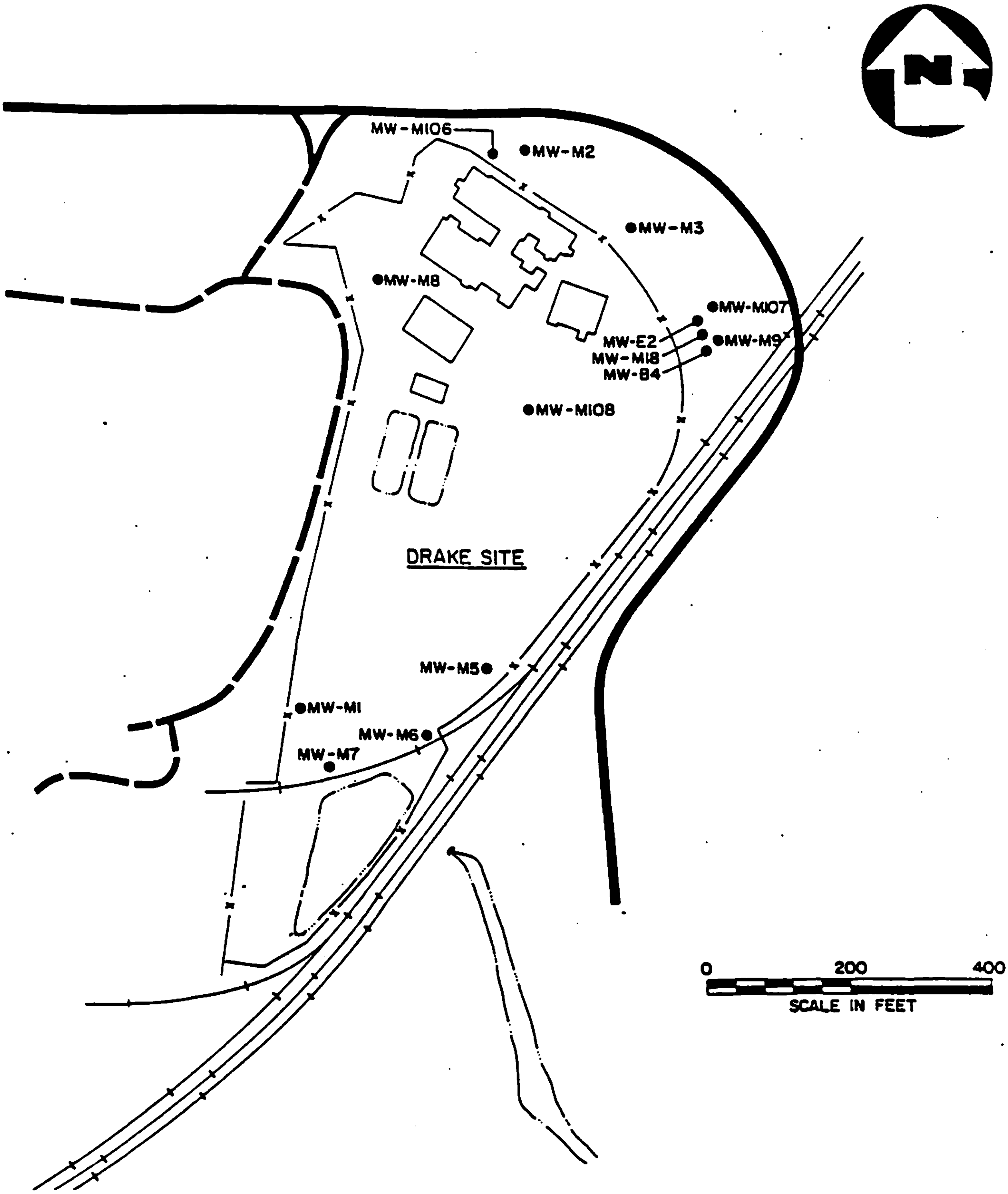

Figure 21. Onsite groundwater sampling locations, Drake Chemical Superfund site. (U.S. Environmental Protection Agency, 1988)

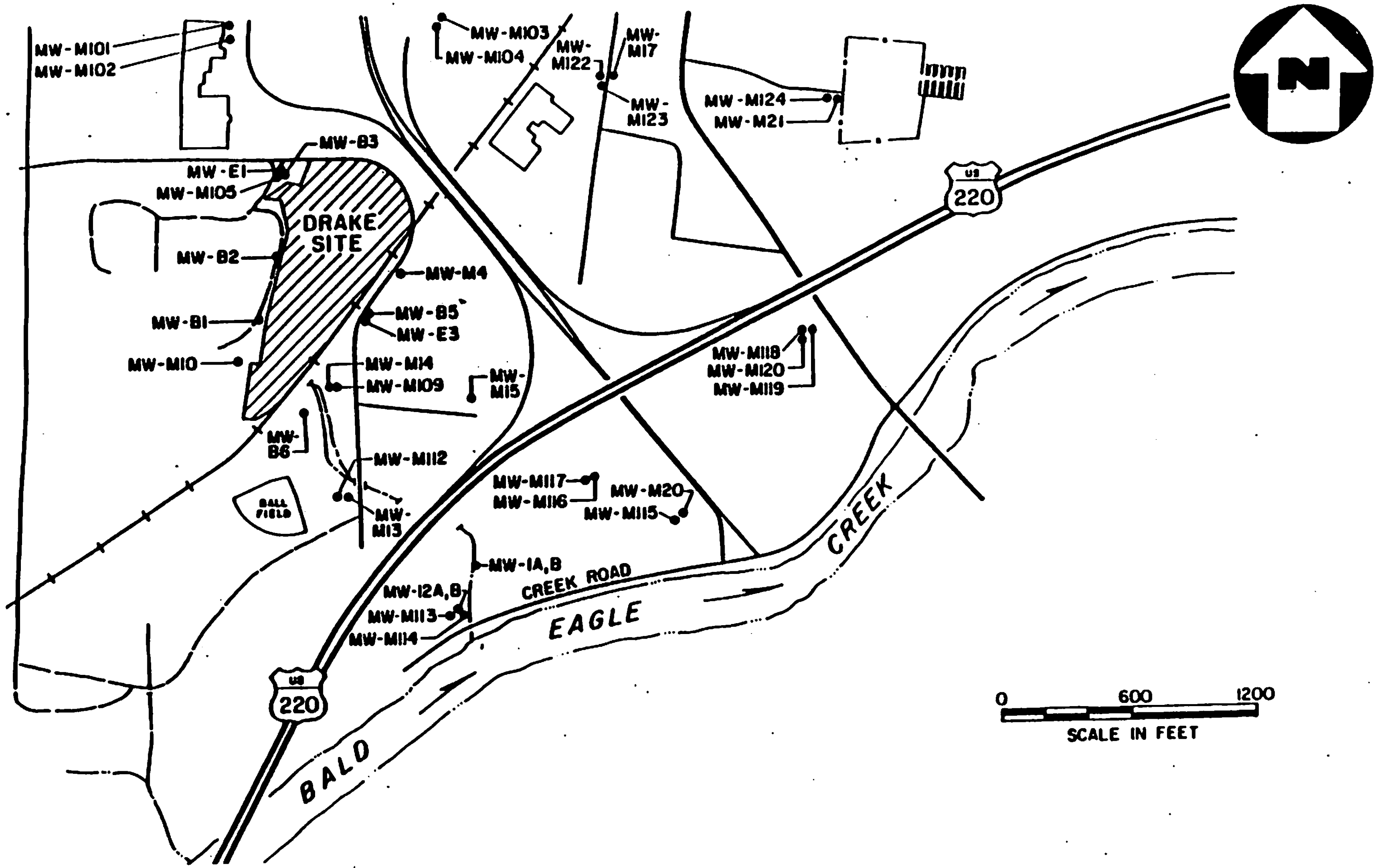

Figure 22. Offsite groundwater sampling locations, Drake Chemical Superfund site. (U.S. Environmental Protection Agency, 1988)

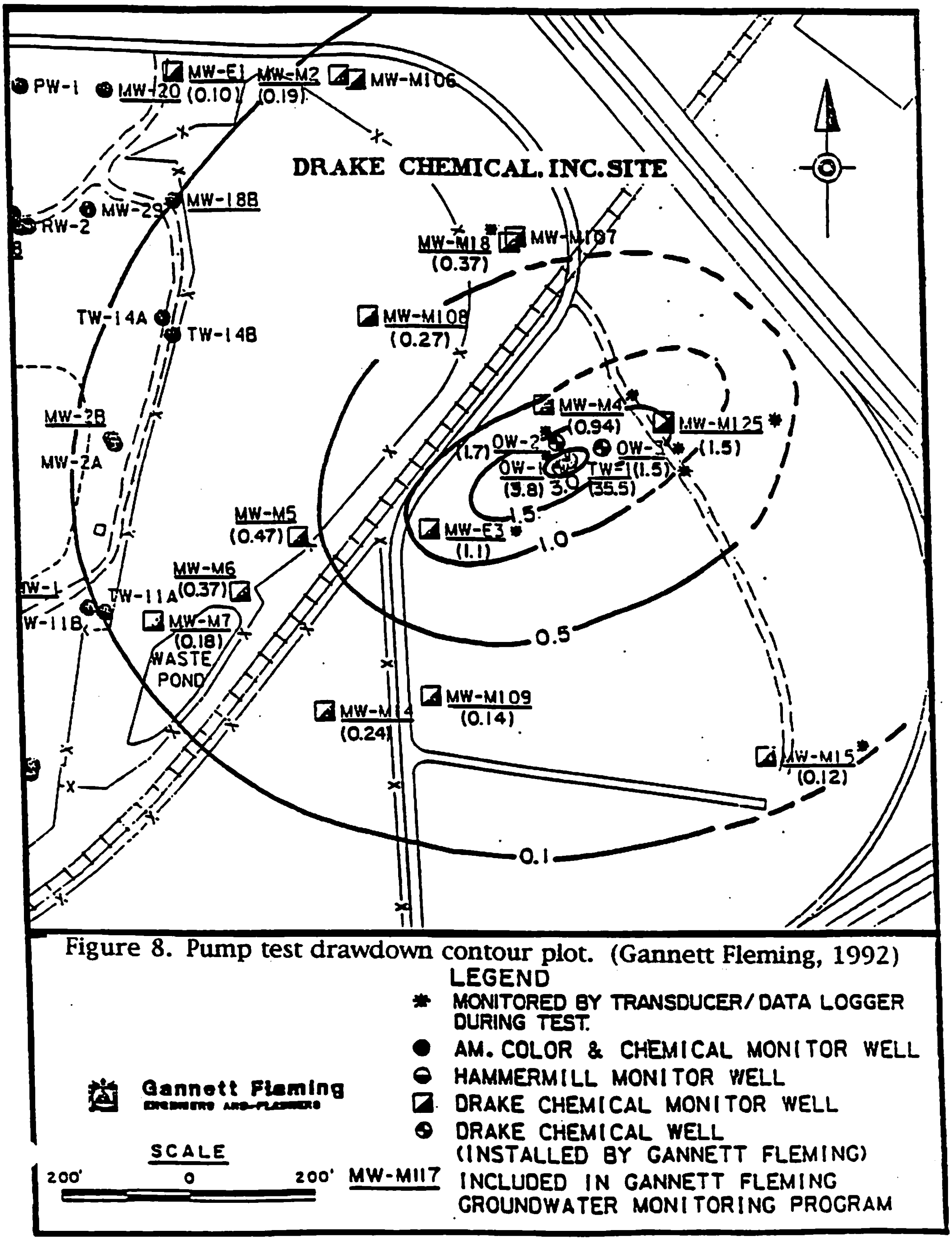

Figure 8. Pump test drawdown contour plot. (Gannett Fleming, 1992)

Figure 23. Pump test drawdown contour plot. (Gannett Fleming, 1992)

TABLE X. Summary of step-testing results for the Drake Chemical site (Gannett Fleming, 1992)

			Drawdown After 60 Minutes (ft)			
Test Step Number	Pumping Rate (gpm)	Specific Capacity (gpm/ft)	Test Well TW-1	Observation Wells		
				OW-1	OW-2	OW-3
1	29	1.29	22.616	2.851	1.093	0.774
2	34	1.19	28.661	3.344	1.535	0.988
3	40	1.05	37.957	3.970	1.696	1.190
4	45.5	0.89	51.041	4.513	1.777	1.385

TABLE XI. Summary of slug-testing results for the Drake Chemical site (Gannett Fleming, 1992)

		Hydraulic Conductivity (ft/min)		Hydraulic Conductivity (ft/day)	
Well ID	Trial	Falling Head Test	Rising Head Test	Falling Head Test	Rising Head Test
TW-1	1	4.30×10^{-3}	2.25×10^{-3}	6	3
	2	3.25×10^{-3}	2.31×10^{-3}	5	3
	3	3.98×10^{-3}	3.99×10^{-3}	6	6
OW-1	1	7.31×10^{-3}	7.74×10^{-3}	11	11
	2	6.83×10^{-3}	8.43×10^{-3}	10	12
OW-2	1	9.47×10^{-3}	1.27×10^{-2}	14	18
	2	5.83×10^{-3}	1.43×10^{-2}	8	21
	3	1.02×10^{-2}	1.50×10^{-2}	15	22
OW-3	1	2.82×10^{-2}	3.57×10^{-2}	11	51
	2	2.58×10^{-2}	3.51×10^{-2}	37	51
	3	3.11×10^{-2}	2.86×10^{-2}	45	41

TABLE XI. Summary of pump-testing results for the Drake Chemical site (Gannett Fleming, 1992)

Method Used			Theis[1]			Dupuit			Bouwer-Rice[2]		
Well #	Distance to Pumping Well (ft)	Drawdown ΔS (ft)	Hydraulic Conductivity K (ft min^{-1})	Hydraulic Conductivity K (ft day^{-1})	Transmissivity T (ft^2 min^{-1})	Hydraulic Conductivity K (ft min^{-1})	Hydraulic Conductivity K (ft day^{-1})	Transmissivity T (ft^2 min^{-1})	Hydraulic Conductivity K (ft min^{-1})	Hydraulic Conductivity K (ft day^{-1})	Transmissivity T (ft^2 min^{-1})
TW-1	0	35.5	(1.55×10^{-3})	(2)	(0.13)	-	-	-	3.35×10^{-3}	5	1.75
OW-1	15	3.8	1.77×10^{-2} (1.10×10^{-2})	25 (16)	1.48 (0.92)	1.21×10^{-2}	17	0.951	7.58×10^{-3}	11	1.56
OW-2	30	1.7	2.57×10^{-2} (2.13×10^{-2})	37 (31)	2.15 (1.78)	1.27×10^{-2}	18	0.999	1.12×10^{-2}	16	1.58
OW-3	60	1.5	2.83×10^{-2} (2.54×10^{-2})	41 (37)	2.38 (2.14)	-	-	-	3.07×10^{-2}	44	2.31
MW-E1	888	0.10	3.95×10^{-2}	57	1.11	-	-	-	1.7×10^{-3}	2	0.03
MW-E3	254	1.13	5.51×10^{-2}	79	4.64	1.21×10^{-2}	17	0.951	-	-	-
MW-M2	710	0.19	1.86×10^{-1}	268	5.16	-	-	-	-	-	-
MW-M4	98	0.94	1.99×10^{-1}	287	3.36	1.27×10^{-2}	18	0.999	-	-	-
MW-M5	455	0.47	5.12×10^{-3}	7	0.44	-	-	-	-	-	-
MW-M6	575	0.37	2.30×10^{-2}	33	0.60	-	-	-	-	-	-
MW-M14	575	0.24	1.13×10^{-1}	163	2.51	-	-	-	-	-	-
MW-M15	570	0.12	3.55×10^{-1}	511	7.85	-	-	-	-	-	-
MW-M18	360	0.37	1.99×10^{-1}	287	4.98	-	-	-	-	-	-
MW-M109	450	0.14	8.04×10^{-1}	1160	17.54	-	-	-	6.5×10^{-3}	9	0.6
MW-M125	162	1.5	4.93×10^{-2}	71	4.18	-	-	-	3.8×10^{-4}	1	0.03

[1] Values of hydraulic conductivity and transmissivity were determined using the Theis method, except values in parentheses which were determined using Theis (recovery) method.

[2] Values of hydraulic conductivity (K) and transmissivity (T) listed for OW-1, OW-2, OW-3, and TW-1 are an average of multiple falling and rising head tests performed at each well. Valu listed for MW-M125, MW-M109, and MW-E1 were obtained from Halliburton NUS Corp. (1988).

TABLE XIII. Prominent site-related contaminant classes and compounds, Drake Chemical site (NUS, 1988)

Media Affected	Class	Example Compounds
Offsite Surface Water	Herbicides	Fenac
	Base/Neutral Acid Extractables	
Sediments	Herbicides	Fenac
	Base/Neutral Acid Extractables	Phenol
		4-Methylphenol
	Volatiles	Chlorobenzene
	Metals	Chromium
Onsite Soils	Herbicides	Fenac
	Base/Neutral Acid Extractables	Benzo(a)anthracene
		Napthalene
		Phenol
		2,4-Dinitrophenol
		1,4-Dichlorobenzene
	Volatiles	Chlorobenzene
		Xylene
		Ethylbenzene
		1,2-Dichloroethane
Groundwater	Herbicides	Fenac
	Base/Neutral Acid Extractables	Phenol
		2,4-Dinitrophenol
		1,4-Dichlorobenzene
	Volatiles	Chlorobenzene
		1,2-Dichloroethane
	Metals	Cadmium
		Chromium

TABLE XIV. Summary of background concentrations of metals in groundwater, Drake Chemical site (NUS, 1988)

Compound	Dissolved Concentration (µg/l)	Total Concentration (µg/l)
Aluminum	78.0(1)	8,220.0(1)
Antimony	---	---
Arsenic (Total)	---	46.1(1)
Barium	64.0(1)	1,540.0(1)*
Beryllium	---	7.2(1)
Cadmium	---	11.3(1)*
Calcium	68,400.0(1)	76,400.0(1)*
Chromium	---	153.0(1)*
Cobalt	---	111.0(1)*
Copper	---	161.0(1)*
Iron	721.0(1)**	224,000.0**
Lead	6.5(1)	87.0(3)*
Magnesium	13,100.0(1)	29,500.0(1)
Manganese	1,440.0(1)**	35,300.0(3)*
Mercury	---	0.4(1)
Nickel	19.1(1)	222.0(1)
Potassium	8,330.0(1)	15,400.0(1)
Selenium	---	---
Silver	---	---
Sodium	42,200.0(3)	40,400.0(3)
Thallium	---	---
Vanadium	---	124.0(1)
Zinc	49.1(1)	564.0(1)

(1) From monitoring well M101
(2) From monitoring well M9
(3) From monitoring well M102
* Exceeds DWS - Primary MCLs.

** Exceeds DWS - Secondary MCL

TABLE XV. Metals in soils and sludges exceeding common ranges for soils, Drake Chemical site (all units in mg/kg) (NUS, 1988)

Metal	Observed Range	Common Range for Soils(1)
Cadmium	1.1 - 283	0.01 - 0.07
Cobalt	2.1 - 104	1 - 40
Copper	4.2 - 17,200	2 - 100
Lead	3.3 - 1,170	2 - 200
Silver	3.8	0.01 - 5(2)

(1) Lindsay, 1979.
(2) Single observation is probably a spurious detection.

TABLE XVI. Select contaminant leaching characteristics, Drake Chemical site (NUS, 1988)

Compound	Estimated (1) Mass Presently Available for Leaching	Percent of Currently Available Mass Potentially Leached to Groundwater (2)			
		Year 1	Year 10	Year 30	Year 100
1,2-dichloroethane	8.28 kg	29.7	97.1	99.9	~100
chlorobenzene	113.6 kg	9.7	64.3	95.4	99.9
fenac	327.2 kg	4.4	40	74	98.8

(1) Based on summary statistics
(2) Assumes 95% of mass leaches in the theoretical chemical specific leach period.

As expected, sediment samples taken from lagoons on the site are highly contaminated by various volatile organic compounds, fenac, and base/neutral acid extractable compounds. In addition, sediments of Bald Eagle Creek, the West Branch Susquehanna River, and the confluence of the two streams contain the site-specific compounds chlorobenzene, 4-methylphenol, 1,2-dichlorobenzene, dimethyl-phenol, and fenac. Additional reported occurrences of fenac and chlorobenzene in upstream sediment samples suggest that these compounds have migrated upstream during regional flooding events (NUS, 1988).

NUS reported analyses of dozens of samples from test pits and borings distributed on a 100-x100-x12.5-foot grid. Samples were collected at 3 levels at each location. A number of compounds occur throughout the volume of this 3-dimensional sample grid covering Zone I and parts of the adjacent Gorham property. These include varying concentrations of chlorobenzene, dichlorobenzenes, phenol, chlorinated phenolics, nitrophenols, benzene, toluene, xylenes, ethylbenzene, and polynuclear aromatic hydrocarbons. Chlorobenzene was detected in about 75 percent, fenac in 71 percent, and 1,2-dichloroethane in 90 percent of the samples.

Groundwater analyses for Zones I, II, and III demonstrate contamination by site-related compounds. In Zone I, benzene, trichloroethene, chlorobenzene, ethylbenzene, toluene, 1,2-dichloroethane, 1,2-dichlorobenzene, 1,3-dichlorobenzene, and 1,4-dichlorobenzene were detected in varying amounts. Contamination of Zones II and III with fewer compounds at lower concentrations suggests migration of a contaminant plume southeastward toward Bald Eagle Creek. In addition, Zone I and II groundwater is contaminated by significant amounts of fenac and beta-naphthylamine. Beta-naphthylamine was not detected in Zone III (NUS, 1988).

CONTAMINANT MIGRATION

Groundwater currently provides the main pathway for contaminant migration from sludges and soils in the vadose zone. Leaching of contaminants occurs as approximately 16 inches of the annual ambient 42.5 inches of precipitation infiltrates to the water table (NUS, 1988).

Each of the many inorganic and organic chemicals at the site responds differently with respect to leaching behavior. NUS (1988) presented data (Tables XVI-XVIII) showing how retardation factors and partition coefficients for some site-related contaminants could affect their travel times from the site to Bald Eagle Creek at "typical" (60-foot-per-year) groundwater velocities. Data from monitoring wells show that fenac, because of its high concentration on the site, shows up at a given groundwater concentration before some much more mobile compounds. Analyses of surface-water samples suggest that some groundwater contaminants have already completed the 2000-foot journey from Zone I to Bald Eagle Creek.

PROPOSED TREATMENT SCENARIOS

Although no site-related contaminants currently exceed MCLs in offsite surface waters, a major reason for the site cleanup is to prevent such contamination in the future. Contaminated sludges, soils, and groundwater on the Drake site and Gorham property represent a public health risk, not only to those directly exposed to the site, but also to those who swim, boat, or fish in affected surface waters in the future. Aquatic flora and fauna in those waters may also eventually suffer from exposure to contaminants migrating offsite.

Carcinogenic risks are associated with beta-naphthylamine, 1,2-dichloroethane, vinyl chloride, and arsenic (USEPA, 1988). Other compounds, including fenac, phenolics, volatile organics, and several metals, occur in concentrations that exceed relevant regulatory standards.

TABLE XVII. Typical retardation (Rd) factors, Drake Chemical site (NUS, 1988)

Compound	Kd(1)	Rd
1,2-dichloroethane	0.3	2.7
chlorobenzene	1.6	9.1
fenac	4.0	22.7
cadmium	6.3(2)	36
chromium	37(2)	211

(1) Assumes 1% organic carbon content.
(2) For the more mobile species Cr VI, (Baes et al., 1983 and Looney et al., 1987) Cr III is the predominantly expected species.

TABLE XVIII. Contaminant velocities and travel times, Drake Chemical site (NUS, 1988)

Compound	Average Vcontaminant	Expected Average Travel Time
1,2-dichloroethene	22 feet/year	91 years
chlorobenzene	6.6 feet/year	303 years
fenac	2.6 feet/year	770 years
chromium	0.3 feet/year	7,033 years

Velocities and travel times are for the center of a plume. Lead and trail (first view, last view) travel times will be earlier and later, respectively.

During the Phase III FS, many technologies were evaluated for treatment of soils, sludges, and groundwater at the Drake site. In addition, a "no-action alternative" was considered, as required by law. Screening of the technologies was based on the Phase III RI and on Applicable or Relevant and Appropriate Requirements (ARARs). Loosely defined as requirements of state or federal environmental laws, ARARs relate to site-specific contaminants, natural or man-made site characteristics, and implementation of specific treatment methods (USEPA, 1988). Both single and combination treatment methods were evaluated, and emerging and proven technologies were considered in developing remedial action alternatives (RAAs).

Table XIX describes methods considered for treatment of contaminated soils and sludges, and Table XX summarizes the preliminary assessment carried out for each. USEPA assessed each method with respect to the following criteria:

(1) compatibility with site conditions;
(2) ability to achieve treatment goals;
(3) ease of implementation;
(4) developmental status;
(5) reliability;
(6) effectiveness in protecting public health during and after treatment (USEPA, 1995a).

Twenty-one single- and dual-technology options were considered, 16 of which were eliminated from further consideration for the reasons summarized below:

- RCRA Closure with Capping: Not a viable option because of the site's location in a floodplain, and lack of permanent protection.
- On-Site Landfill: See RCRA Closure, above.
- Off-Site Disposal at RCRA Landfill: No landfill is available that could accept the amount of waste that would be excavated from the Drake site.
- Constructing Slurry Walls: Not a feasible option because of bedrock conditions at the site.
- B.E.S.T.: Not viable because method offers only partial remediation and requires the use of potentially toxic compound additives.
- Pozzolanic Solidification: Not viable because method offers only partial remediation. Method works best with heavy metals; contamination at Drake is mostly organic compounds.
- Low Temperature Pyrolysis: An undeveloped and technically inappropriate option based on presence of metals and on soil types at Drake.
- Rotary Kiln Incineration and Pozzolanic Solidification: Because contamination is nearly uniform throughout the site, USEPA determined that a single-technology method would be most appropriate.

The same logic applies to other rejection of other dual-technology options:

- Rotary Kiln Incineration and Soil Washing;
- Rotary Kiln Incineration and B.E.S.T.;
- Infrared Incineration and Soil Washing;
- Infrared Incineration and B.E.S.T.;
- Infrared Incineration and Pozzolanic Solidification;
- In-Situ Vitrification and Pozzolanic Solidification;
- In-Situ Vitrification and Soil Washing;
- In-Situ Vitrification and B.E.S.T.

Five remaining methods were evaluated, as described below (USEPA, 1995b):

(1) No Action with Monitoring: Sludges, soils, and sediments would be left in their current state. USEPA rejected the "no action with monitoring" alternative because it does not eliminate or reduce site contamination.

TABLE XIX. Clean-up technologies considered for remediation of the Drake Chemical site (U.S. Environmental Protection Agency, 1995a)

Thermal Energy Methods

Rotary Kiln Incinerator - Contaminated soil is burned at high temperatures in a mobile unit with air pollution controls and an exhaust stack.

Plasma Arc Pyrolysis - Gas and electricity create a flame that burns waste and breaks it down into very small pieces. These recombine into gases that are scrubbed to remove any acids.

Infrared Incineration - Waste is placed on a conveyor belt and exposed to intense energy. The waste burns to create new gases and solids.

Extraction Methods

Basic Extraction Sludge Treatment (B.E.S.T.) - B.E.S.T. uses ammonia-derived compounds mixed with waste sludge to remove contaminants. Using varying temperatures, the contaminants are separated from other materials in the sludge.

Supercritical Fluid -This method uses liquified gas as a cleaning solution to separate contaminants from liquids and solids.

Vacuum Extraction - A vacuum pump and wells are installed at the site. Volatile organics, a very common type of contaminant, are pulled from the ground and released into the atmosphere or captured in a collection unit.

Soil Washing - Liquid is circulated through soil to extract contaminants. The liquid is then collected and removed for treatment.

Biodegradation Methods

Landfarming - The contaminated area is tilled and special nutrient-rich fertilizers are added. Bacteria or fungi feed on the contamination and nutrients.

In-Situ Biodegradation - Microbes are injected into the soil on site through wells. The microbes will eventually degrade the contaminants.

Solidification Methods

Pozzolanic Systems - Cement is mixed into the soil where it captures the contaminants. When the cement dries, the contaminants are sealed inside.

Thermoplastic - Waste is mixed into a heated, liquified, plastic material and then cooled into a solid and placed in containers. The waste remains suspended in the thermoplastic.

Organic Polymer - Waste is mixed with a chemical compound to create a spongy mass that traps the contaminants. The spongy mass is heated and cooled to make a solid. The solid is then placed in storage containers. The remaining liquids are treated and disposed.

Glassification - Solids are heated and captured in melted glass and then cooled. The glass is then disposed in an approved landfill.

In-Situ Vitrification - This method is like glassification but occurs in the ground. Electrodes and graphite are used to melt the soil and contaminants. The contaminants become part of the melted mass, which cools into a rocklike material. A hood is placed over the entire area to prevent gases from escaping into the air.

TABLE XX. Technology assessment for remediation of soils and sludges, Drake Chemical site (U.S. Environmental Protection Agency, 1995a)

Technology	Compatibility with Site Conditions	Waste Treatment Capability	Implementability	Status*	Reliability and Public Health and Environmental Protection
Rotary Kiln Incineration	Potential	Acceptable	Possible	C	Gases and ash must be treated and controlled
Plasma Arc Pyrolysis	Not ready for commercialization	Acceptable	Possible	E	Slag and acidic gases must be treated
Infrared Incineration	Not ready for commercialization	Acceptable	Possible	C	May release inorganics if already present in soil
B.E.S.T.	Potential	Efficiency dependent on types and amounts of contaminants	Possible	C	Contaminants must be treated after removal; residues from additives
Supercritical Fluid	No commercialization record	Little data regarding inorganics and heavy metals	Possible	E	Contaminants must be treated after removal; residues from additives
Vacuum Extraction	Questionable for level of BNa in soil	Not appropriate for inorganics	Possible	E	Contaminants must be treated after removal; residues from additives
Soil Washing	Not realistic: BNa levels are too low	Soil permeability, salt content, contaminants, and pH must be competely identified	Possible	E	Contaminants must be treated after removal; residues from additives
Landfarming	Not realistic: Human health problems would be accentuated	No known microorganism can take care of all organics at site; not good with site's inorganics	Possible	C	Worker exposure; contaminants moving to groundwater or other areas
In-Situ Biodegradation	Clean-up levels for BNa will not be reached	No known microorganism can take care of all organics at site; not good with site's inorganics	Possible	C	Worker exposure; precise controls are not feasible
Pozzolanic Systems	Potential	Organics interfere with setting of cement	Possible	C	Dust, noise, and chemicals released during mixing; leaching
Thermoplastic	Potential	Organic contaminants may cause deterioration of thermoplastic	Effects of application to contaminated soil are unknown	D	Air emissions; fire hazards; release of organics, oils, and odors
Organic Polymer	Potential	Not good when heavy metals and oxidizers are present	Effects of application to contaminated soil are unknown	E	Fumes; release of contaminants because glues disintegrate
Glassification	Potential	Acceptable	Possible	E	Fumes and small particles are difficult to remove from gases
In-Situ Vitrification	Explosion potential if metals or drums are left in contaminated area	Acceptable	Possible	D	Stability/leach resistence unknown; dioxin potential; gases and vapors must be treated; lateral gas movement

* The developmental status of the technology is defined as follows: C = Commercial; E = Emerging; D = Demonstrated

(2) Infrared Incineration: The mobile, high temperature incinerator proposed in this alternative uses electrically powered silicon carbide rods to burn contaminants. The components of this clean-up process (including post-incineration activities) are similar to those in the rotary kiln incineration process described below. USEPA rejected infrared incineration because the process, though technically proven, would take longer and cost more than rotary kiln incineration.

(3) In-Situ Vitrification: Soils, sludges, and sediments are electrically melted and transformed into a stable, glass-like solid. After using this process, USEPA would replace soil and replant the site. The method was rejected because it is not yet a fully developed technology, and it is not suited for large scale operations such as that proposed at the Drake site.

(4) In-Situ Soil Washing: Treated water from the on-site waste water-treatment plant is sprayed on the ground and allowed to "percolate" through the contaminated soils. This water is then removed from the soils through extrations wells and treated on site. USEPA rejected this method because the process would not sufficiently reduce levels of some major contaminants, including beta-naphthylamene and chlorinated compounds, and would produce liquid wastes needing further treatment.

(5) Rotary Kiln Incineration: Soils, sludges, and sediments are excavated and treated in a temporary, mobile, high temperature incinerator. After the treatment process is completed , the incinerator is dismantled and treated soils are vegetated. After landscaping , the site is available for unlimited access and unrestricted use. USEPA selected this method, rather than any of the alternatives, because it is the most effective technology available to effect permanent destruction of organic contaminants in the sludges, soils, and sediments at the site. It is a proven technology that has been used successfully at other sites.

CURRENT STATUS

Remediation of Soils and Sludges

The incinerator now being installed at the Drake site will consist of two burners (a rotary kiln and a secondary combustion chamber) whose operating temperatures will be 1400°F and 1800°F (Fig. 24). After thermal destruction of organic compounds, gases will pass through a quencher, which will reduce their temperature to about 400°F. This step reduces the probability that dioxins will form and prevents damage to the baghouse. Dioxins are a group of chemicals that typically form during thermal breakdown of chlorinated compounds, organic materials (such as hospital wastes), and trace metals during and after incineration (Johnson, 1995). They are associated with a variety of human-health effects, including reduced glucose tolerance and other metabolic disorders, decreased sperm counts in males, endometriosis in females, changes in cellular biochemistry and (or) physiology, and reduced ability to withstand immunological challenge (USEPA, 1994). Dioxins are a major issue for opponents of incineration at the site.

Stack gases will be monitored continuously for the presence of certain combustion products. If compounds produced by incomplete combustion appear, corrective measures will be taken. Residue remaining after thermal treatment of the approximately 252,000 cubic yards of soil and sludge will be returned to the site, eventually to be covered and vegetated. Selected remediation goals are given in Table XXI. If work progresses according to the current plan, remediation of soils and sludges should be complete by 1997.

Groundwater Remediation

Data derived from pump tests (Tables X to XII) were used by Gannet Fleming to model groundwater flowlines for various well-placement configurations designed to capture contaminated groundwater from Zones I and II (Gannet Fleming, 1992). The design of extraction-well and water-treatment systems for the site has not yet occurred. However, extraction wells and water-treatment

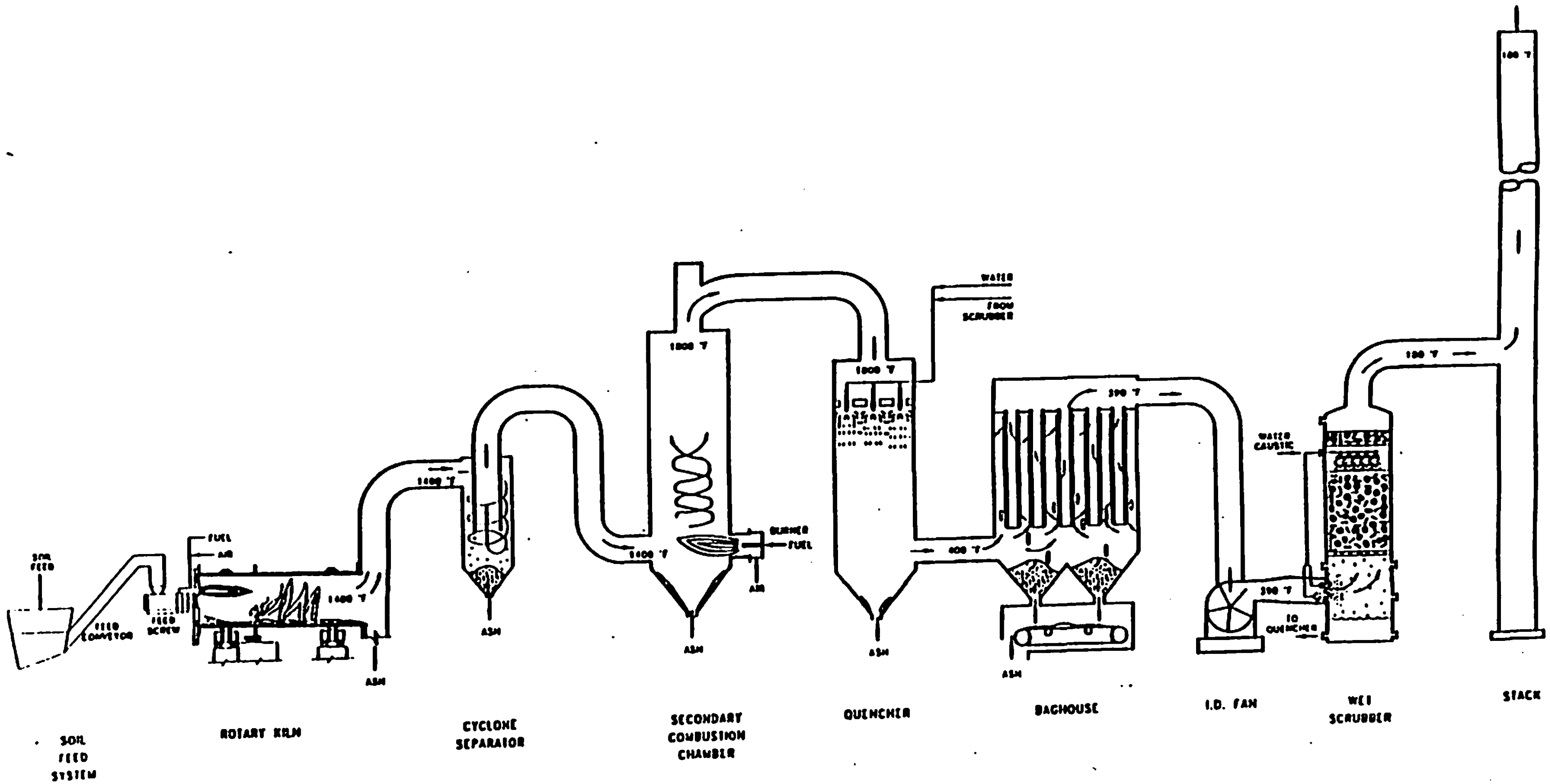

Figure 24. Mobile incineration/air-pollution-control system Drake Chemical site. (U.S. Environmental Protection Agency, 1994)

facilities most likely will be located in Zone II, in order to avoid interfering with the soil and sludge remediation (USEPA, 1995c). The treatment system will use granular activated carbon adsorption to remove contaminants. The ESD establishes concentration levels for benzene, 1,2-dichloroethane, and beta-naphthylamine. Remediation goals for selected compounds are shown in Table XXII. When these concentrations are reached, treatment activities will cease, and groundwater monitoring will continue in Zones II and III, as detailed in the ESD (USEPA, 1995c).

TABLE XXI. Soil/sludge remediation goals for site-related contaminants, Drake Chemical site (Ebasco, 1988)

Compound	Remediation Goal µg/kg	Estimated Resultant Pore Water Concentration (µg/l)
benzene	3.25	5.0
chlorobenzene	1,512.0	945.0
1,2-dichloroethane	1.5	5.0
tetrachloroethene	25.12	6.9
β-naphthylamine	0.09	0.07
Fenac	9,800.0	2,450
cadmium	63.0	10
cyanide	220.0	220.0

TABLE XXII. Groundwater remediation goals for select site-related contaminants, Drake Chemical site (Ebasco, 1988)

Compound	Remediation Goal µg/l	Basis
benzene	5.0	MCL
chlorobenzene	945	Reference Dose
1,2-dichloroethane	5.0	MCL
tetrachloroethene	6.9	10^{-5} Cancer Risk
β-naphthylamine	0.07	10^{-5} Cancer Risk
Fenac	2,450.0	Reference Dose
cadmium	10.0	MCL
cyanide	220	Health Advisory (child, long-term)

CONCLUSIONS

The Drake Chemical Superfund site illustrates some of the problems inherent in remediation of areas in which a complex mixture of contaminants affects several media. Such sites require the cooperative efforts of geologists, chemists, biologists, physicists, and engineers, all of whom must be able to communicate with each other and with the public. The site also illustrates problems resulting from delay in proceeding with remediation efforts, once a method is chosen. As recently as August 7, 1995, nearly 7 years after release of the Phase III ROD, the City Council of Lock Haven requested that USEPA reopen the ROD to allow consideration, or reconsideration, of technologies other than incineration. Opposition to incineration developed slowly but recently has become a potent political issue in the community. Although the remediation probably will proceed as planned, and although USEPA and its contractors have tried to maintain effective communications with the public, many in the community are now convinced that incineration poses a greater threat to their health and safety than does the site in its current state.

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THE AMERICAN COLOR & CHEMICAL CORPORATION SITE LOCK HAVEN, PENNSYLVANIA

PRIMO MARCHESI [1]

INTRODUCTION

The American Color & Chemical Corporation (AC&C) site is located west of and adjacent to the Drake Chemical Superfund site, in Lock Haven, Pennsylvania. Although the site will not be visited during the 60th Annual Field Conference of Pennsylvania Geologists, its setting, history, and environmental problems are related to those of the Drake site (STOP 4). The property has been used for clay sewer pipe and chemical manufacturing activities by a variety of companies. The first commercial operation within the limits of the property was the Lock Haven Clay Works, which manufactured terra-cotta sewer pipe. On-site operations may have included excavation of clay soils, resulting in the present discontinuous nature of this unit. This operation lasted from 1888 to about 1900, after which the site stood idle for 15 years.

From 1915 to 1956, the site was owned and operated by two companies, which manufactured various chemicals and dyes. Two distinct operations were present at the site, separated by what was reported to be a swamp, until about 1939, when a fire destroyed all of Plant No. 2 and most of Plant No. 1. The Plant No. 1 area was then rebuilt.

Through the next several decades, facility operations included the manufacture and distribution of dyes, auxiliary chemicals, and intermediate chemicals primarily for use in the color processing of textiles, fibers, paper products, and plastics. Facility processes included distillation and reuse of chemicals such as 1,2-dichlorobenzene and nitrobenzene. During recycle and recovery of the various process chemicals, still bottoms were collected for off-site disposal. There are no records of direct discharge of spent process chemicals from the operations. Chemical manufacturing processes and operations conducted at the site included:

- manufacture of color dyes, auxiliary chemicals, intermediates, and dye-process related chemicals;
- storage, handling, and recycling of process chemicals;
- generation of wastewater treatment sludge in surface impoundments;
- treatment and subsequent discharge of process wastewaters.

All commercial operations were discontinued as of June, 1982. Plant production facilities were demolished, and most of the operations areas are now graded and revegetated. Wastewater management surface impoundments are either closed (impoundments 1A, 3, and 4, Fig. 25) or are in the process of being closed (impoundments 1B, 2, and 5) in accordance with a Pennsylvania Department of Environmental Protection (PADEP) closure plan, which was approved on April 24, 1990. The plan specifies on-site treatment of impoundment sludges, treatment and monitoring of vapors and liquid effluent, and on-site placement of materials that meet specified constituent concentration criteria. Following such operations, a low permeability clay cap will be constructed atop the limits of the impoundments, and the entire facility will be graded and revegetated as necessary.

In 1993, a voluntary groundwater extraction and treatment program was initiated at the AC&C facility. The project entails recovery of groundwater from two on-site wells: RW-1 (with a recovery rate of about 10 to 15 gallons per minute) and RW-2 (at approximately 30 to 35 gallons per minute). The wells are screened in the alluvial sand and gravel aquifer that underlies most of the site. Well-pump operation is anticipated to coincide with sludge treatment for the surface impoundment closure program, i.e., 8 hours per day, 5 days per week during non-freezing weather (April through October). Treatment of the recovered groundwater includes metals removal (via equalization, aeration, pH adjustment, flocculation/precipitation, and clarification) and organics removal (via activated carbon

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[1] American Color & Chemical Corporation, Lock Haven, PA

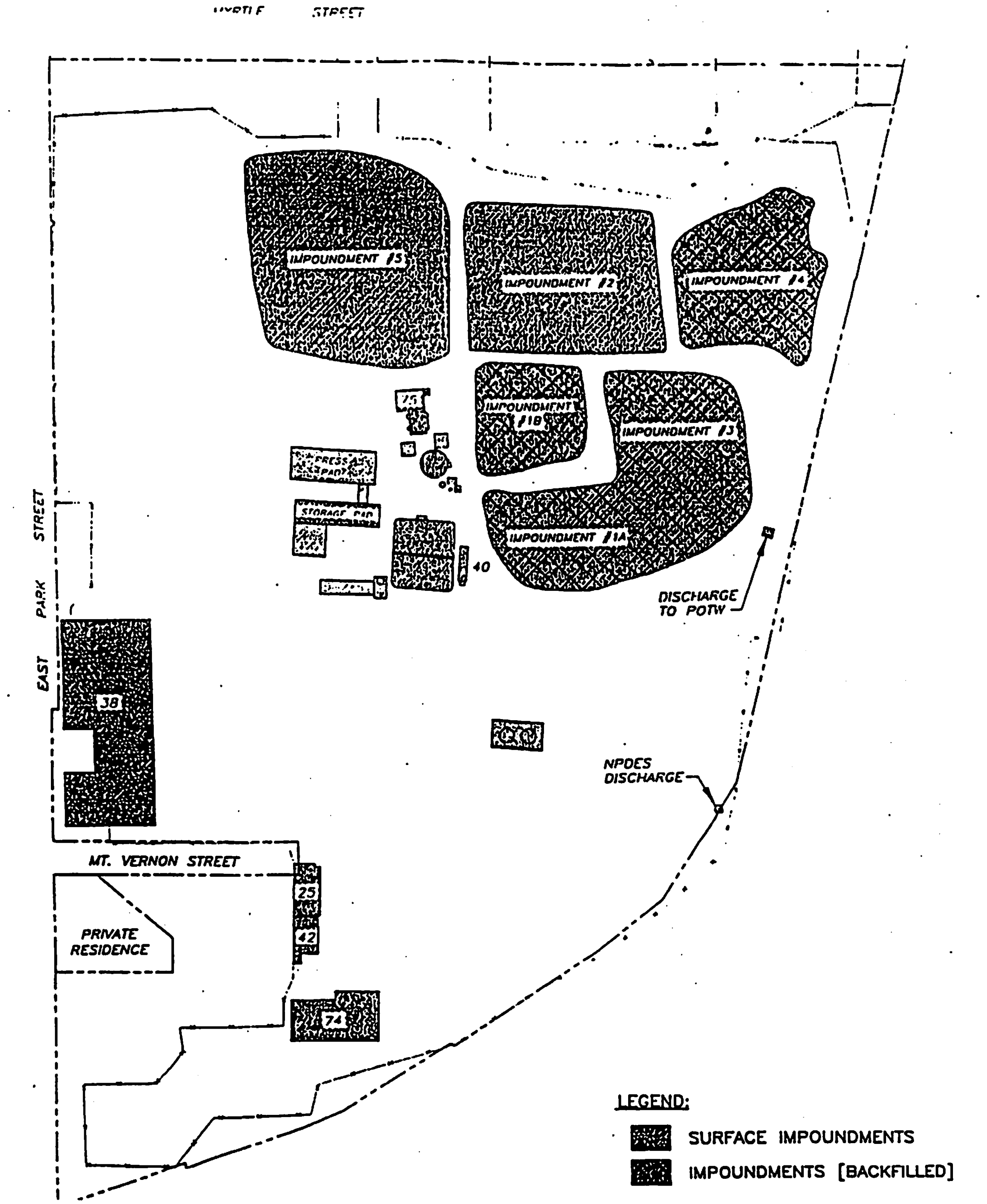

Figure 25. Site layout, American Color and Chemical site, Lock Haven, Pennsylvania

adsorption). Treated water is either recycled as process water makeup (for the sludge treatment system) or discharged to the Lock Haven publicly owned treatment works (POTW). Vapor emissions from the aeration tank are controlled by the vapor-phase activated carbon unit. System operation is monitored via on-line data logging of flow rates, well and tank water levels, and aeration tank pH. System startup operations began on July 8, 1993.

CURRENT UNDERSTANDING OF SITE CONDITIONS

Environmental Setting

The AC&C site is located within the Appalachian Mountain section of the Ridge and Valley physiographic province. Regional elevation ranges from 530 to 2,107 feet above mean sea level; site elevation ranges from 554 to 570 feet. The site is situated on an alluvial floodplain, bounded on the south by Bald Eagle Creek and by the West Branch Susquehanna River to the north. The facility is within the 100-year floodplain of these rivers, and has been flooded on 19 occasions between 1897 and 1975. Flow direction of both rivers is easterly, and their confluence is 1.6 miles due east of the site.

Geologic Setting

Bedrock Geology

Much of the information in this section resulted from studies done by contractors retained by AC&C and is detailed in the AC&C RCRA Facility Investigation, dated September 15, 1993. The local stratigraphic sequence consists of alluvial sediments overlying Devonian shale and limestone, which are underlain by Silurian and Ordovician limestone. Bedrock depth ranges from 15 feet, in the southwest corner of the site, to 44 feet in the northeast. The bedrock surface slopes generally to the east.

The site is located approximately 5 miles southeast of the axis of the Snow Shoe syncline. The rocks of the southeast limb of the syncline have an average strike of N60°E and a dip of 20° to 50° northwest. Several regional joint systems are reported to be prominent. One of the most pronounced is a northwest-southeast trending set oriented approximately perpendicular to the regional structural trend. No major faults are known to occur in the immediate Lock Haven area.

Surficial Geology

The unconsolidated materials at the AC&C facility are indicative of an alluvial depositional setting, with a typical "fining upward" sequence of sediments. The near-surface clayey to sandy silt sequence extends to depths of 5 to 18 feet. It is laterally discontinuous and is interlayered with occasional sandy lenses. With increasing depth, fine, near surface sediments grade into a sand and gravel layer with sandstone fragments that varies from 1 to 27 feet thick. Drilling indicates that this unit is absent in the southwestern portion of the AC&C property. Based on three samples, the average grain-size distribution is 51% gravel, 38% sand, and 11% silt and clay. Sediments are overlain by fill materials ranging in thickness from less than 1 foot to 20 feet. Fill includes brown shaley material, black fly ash, and cinders.

Regional Hydrogeology

Regional groundwater flow conditions are reported to be primarily controlled by the presence of the eastward flowing West Branch Susquehanna River and Bald Eagle Creek. The regional shallow aquifer, consisting of alluvial deposits underlain by fractured shale bedrock, appears to be hydraulically connected with these two rivers. Water-level elevations measured in selected AC&C and Drake monitoring wells indicate that the regional groundwater flow direction is dominantly east-southeast.

Site Hydrogeology

The site hydrogeology is locally affected by bedrock conditions and vertical and horizontal inhomogeneity within the unconsolidated materials (i.e., changes of relative percentages of silts, sands, and clays). An increase in clay content relative to sand occurs primarily in the central portion of the AC&C site, forming a discontinuous, confining to semiconfining aquitard. The presence of this low permeability unit leads to the designation of 3 hydrogeologic regimes at the AC&C site:

- an upper, unconfined aquifer predominantly within the fill and clayey silt materials;
- a lower, partially confined to semiconfined alluvial sand and gravel aquifer;
- an underlying fractured shale and limestone bedrock unit.

Fill and Clayey Silt Aquifer: This aquifer is restricted to portions of the facility where the fill is underlain by the low permeability clayey silt and fine sand unit at elevations within the saturated interval. Saturated fill is present in the central portion of the site, where the water-table surface is between 4 and 5 feet below the surface. However, this unit is absent in the northern and southern areas of the site. The vertical seepage velocity through the clayey silt zone to the underlying sand and gravel aquifer is calculated to be 8.4×10^{-7} foot per second, or 0.073 foot per day. This slow leakage occurs primarily in the central part of the site, where the clayey silt and fine sand unit is present. Where this unit is absent, as in the northern part of the site, downward infiltration of groundwater directly recharges the underlying sand and gravel unit.

Alluvial Sand and Gravel Aquifer: Extensive hydrogeologic investigation of this unit within the boundaries of the AC&C site reveals the following characteristics:

- The fill aquifer is not directly connected to the sand and gravel aquifer in areas where the clayey silt acts as an upper confining to semiconfining layer.
- The upper portion of the underlying fractured bedrock is hydraulically connected to the sand and gravel aquifer.
- Boundary conditions were observed in the southwestern portion of the site, where the sand and gravel pinch out against bedrock. The irregular bedrock configuration results in a groundwater divide, with flow either to the east-northeast or to the east-southeast, within the limits of the AC&C site.
- The average horizontal hydraulic gradient is 0.009 foot per foot in the central and northern parts of the site, and 0.02 ft/ft in the southern part of the site.
- Average hydraulic conductivity, determined from 2 pumping tests, is 0.045 cm/sec.
- Average transmissivity is calculated to be 27,115 gallons per day per foot in the northeastern portion of the facility and 5,328 gal/day/ft in the central portion.
- Storativity values obtained are typical of semiconfined to confined conditions.

Bedrock Aquifer: The previous understanding of site bedrock conditions was limited due to the paucity of bedrock information. However, based on pumping tests, shallow bedrock (approximately 40 to 50 feet deep) was determined to be highly interconnected to the sand and gravel aquifer, and low positive vertical hydraulic gradients exist between these 2 aquifers. In addition, the upper bedrock aquifer appears to be mostly unconfined to semiconfined where overlain by silty clay, and the configuration of the bedrock surface controls the flow pattern within the sand and gravel aquifer.

CLOSURE OF IMPOUNDMENTS

Background and Regulatory Status

An on-site sludge processing system was developed by AC&C during the mid-1980s, in order to allow treatment of impoundment sludges, in lieu of stabilization and off-site disposal. The process was designed to remove volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) from the impoundment sludge via conditioning and reacting the sludge with water and hydrochloric acid (HCl), followed by filter-press dewatering. Filter-press filtrate and gases released during the process were to be treated by liquid and vapor-phase granular activated carbon (GAC), prior to discharge. Treated filter cake was to be placed within the impoundment excavations.

AC&C conducted bench and pilot scale testing during 1987 and 1988 to develop approximate mix ratios of sludge to water and HCl. This testing also led to the conceptual design of the treatment system, which was contained in the Closure Plan Supplement submitted to PADEP in October, 1988.

PADEP informally discussed their conditions for approval with AC&C during 1989 and early 1990. As a result, AC&C proceeded with the detailed design and initial construction of the treatment plant.

Additional pilot-scale testing by Remcor in 1989 evaluated the addition of air sparging to enhance VOC removal. This testing also led to the development of the final detailed design, process requirements, and equipment specifications.

PADEP issued formal conditional approval to AC&C in a letter dated April 23, 1990. Key regulatory conditions of the PADEP approval letter regarding operation of the sludge treatment facility are summarized as follows:

- Specific treatment standards for the filter cake must be met prior to on-site placement.
- Two-day ambient air monitoring must occur at each impoundment location at the initiation of full scale sludge removal operations.
- Continual ambient air monitoring must occur at or near the perimeter fence line.
- Continual monitoring of the vapor-phase GAC system exhaust must occur, with a limit of one pound per hour of organic compound emissions.
- Vapor-phase carbon-system inlet and outlet testing is required.
- Treatment of filtrate prior to discharge, in accordance with publicly owned treatment works (POTW) limits, is required.
- Spent GAC must be accounted for.
- Pennsylvania Professional Engineer (P.E.) certification is required for each major phase of the closure.

The HCl/Carbon Soil-Washing System

Figures 26 and 27 show the HCl/Carbon soil-washing system used to treat sludges at the AC&C site. The process begins with fluidization and conditioning of the excavated soils. Material then passes through a screen, which removes rocks and other coarse debris. The fluidized waste contains 10 to 20 weight percent solids. This conditioned material is pumped into the reactor vessel, where it is mixed with hydrochloric acid. The resulting reaction causes VOCs and some SVOCs to volatilize. The gas mixture is directed into an activated carbon adsorber, which removes VOCs and SVOCs. The organics that are water soluble are solubilized by the slightly acidic liquid. This liquid phase, which includes the treated soils, is then directed into a dewatering unit, typically a high pressure recessed plate filter press. The resulting filter cake is about 35 weight percent solids. The filtrate from this dewatering step is directed into a metals reduction tank and a clarifier, where any precipitates and solids are allowed to settle. After passing through a sand filter, it is then directed to a liquid-phase treatment system, typically using activated carbon adsorption, where the remaining organics are removed. Treated water can then be recycled as process water or discharged.

Performance of the soil washing process is measured by comparing contaminant levels in the treated soils (filter cake) with values established by PADEP. If the treated soil is non-hazardous, it is redeposited on-site or taken elsewhere to be used as backfill. If the treated soil requires additional treatment, it may be reprocessed, treated with a different technology, or transported off-site for disposal.

Method for Treatment of Contaminated Materials with Superheated Steam Thermal Desorption and Recycle

AC&C has invented a new technology for the remediation of contaminated soil by removing volatilizable organic pollutants with superheated steam maintained in a closed, circulating loop. The process works where the volatilizable organic content of the soil exceeds the allowable maximal but is less than about 5 weight percent of the soil. Figure 28 depicts the methodology.

Contaminated soils are introduced into an enclosed treatment zone, a sealed rotating drum which is maintained at an elevated temperature that promotes volatilization of organic pollutants. Appropriate soil temperatures are 300°F to 700°F. A stream of treatment gas passes through the treatment zone in contact with contaminated soil. The treatment gas consists of superheated steam and volatilized organics which have been removed from the soil.

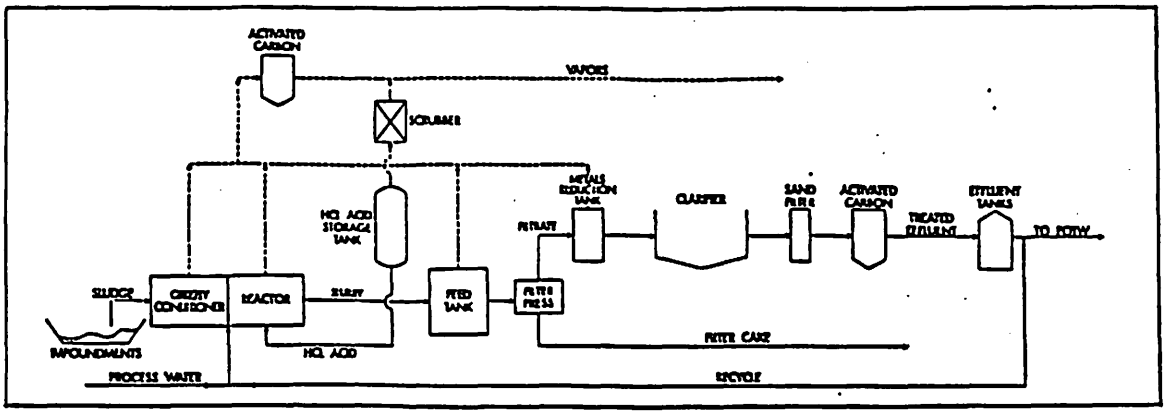

Figure 26. Simplified flow chart of the HCl/Carbon soil-washing process.

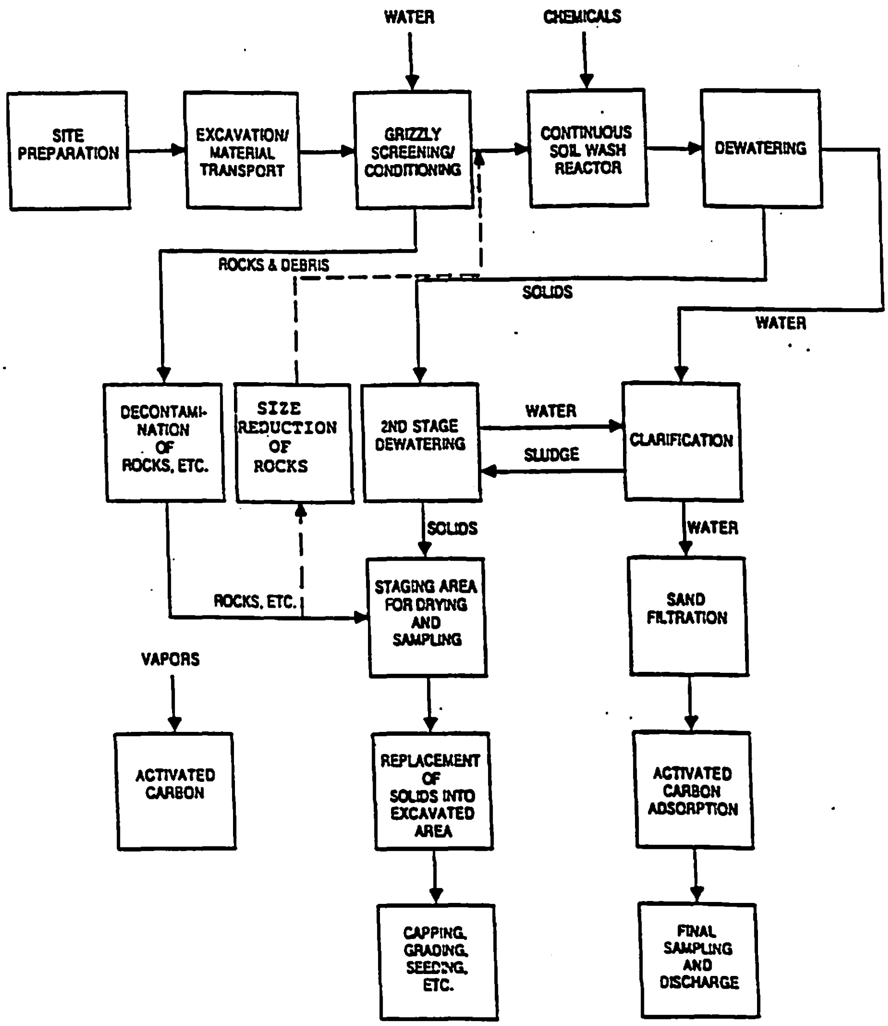

Figure 27. Flow chart of the *ex-situ* soil-washing treatment system.

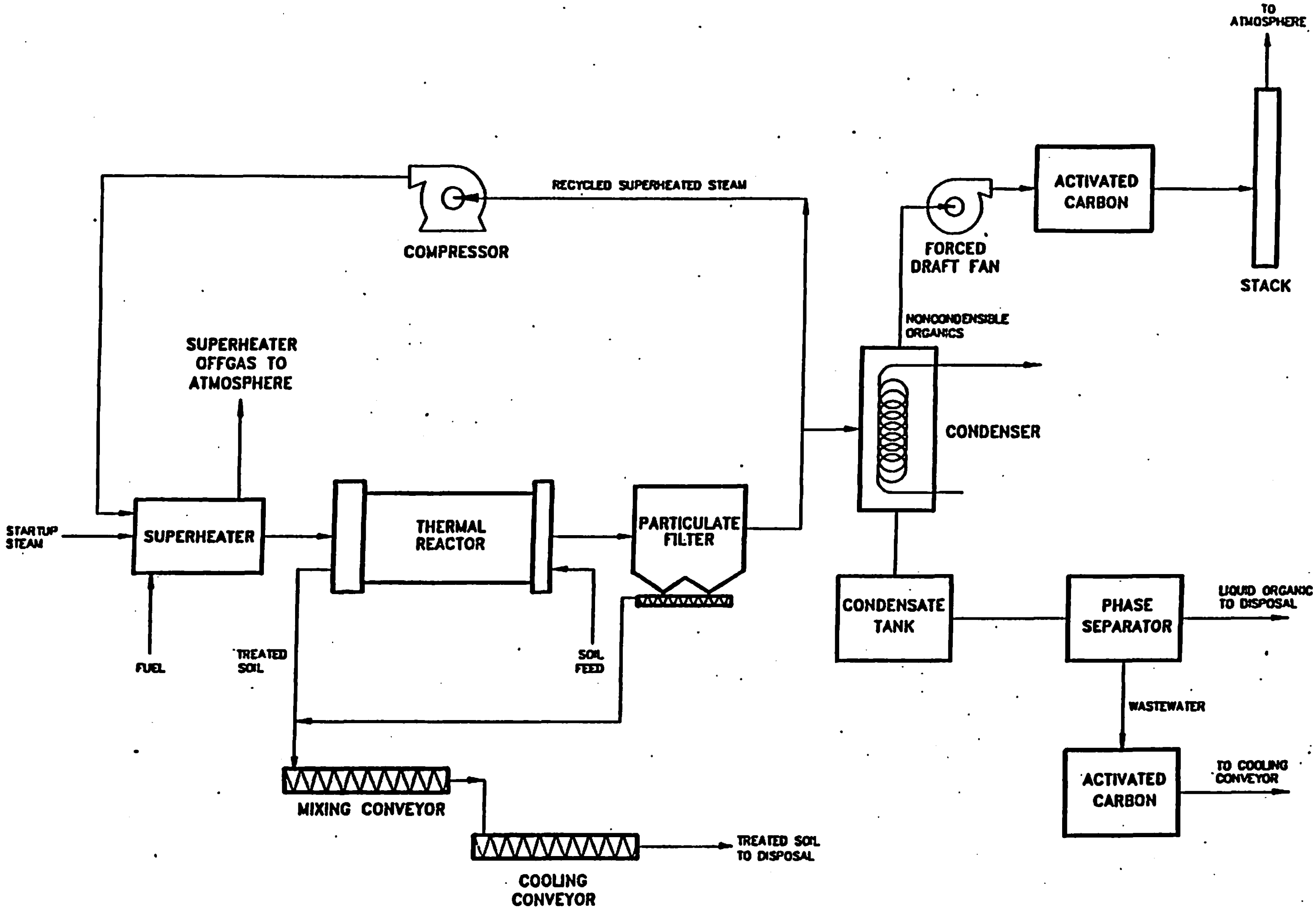

Figure 28. STDAR-10 thermal desorption system.

The treatment gas is withdrawn from the treatment zone at an exit pressure and an exit temperature to maintain the steam in a superheated state. A portion of the exit gas, consisting of superheated steam and volatilized organic pollutants, is separated from recirculating treatment gas and is cooled to condense the superheated steam and most of the vaporized organic pollutants. The major portion of the treatment gas is repressurized, reheated, and returned to the treatment zone as treatment gas. Non-condensed organic pollutants are recovered as a gas stream; the condensed organics are recovered as a liquid stream; and the condensed steam is recovered as water. The hot decontaminated soil is recovered from the treatment zone through appropriate seals and is recycled to the environment. Water recovered from this process may be used to cool and moisten the decontaminated soil.

SLOPE STABILITY PROBLEMS AND CORRECTIONS FOR THE LOCK HAVEN BYPASS (US ROUTE 220), CLINTON COUNTY, PENNSYLVANIA

G. M. UHL [1], A. A. ADLER [2], AND R. H. HERLOCHER [3]

INTRODUCTION

During the design and construction of the Lock Haven Bypass (a portion of US Route 220 in the vicinity of Lock Haven) complex soil conditions and water systems were encountered which resulted in a series of costly cut-slope failures and extensive drainage designs. Unsuspected glacial deposits, thick colluvium, and large periglacial slides provided an extremely unfavorable engineering setting in which to construct a highway. The combination of these factors plus an abundant water supply and cut slopes designed on a 1.5 horizontal to 1 vertical led to extensive slope failures.

PROJECT AREA SETTING

The project is located south and east of Lock Haven in the Ridge and Valley Physiographic Province. It is situated in a mountain flank location between Bald Eagle Mountain to the southeast and the adjacent floodplain of the West Branch Susquehanna River to the northwest (Fig. 29).

According to the State Geologic Map (Berg and others, 1980) the project is located well beyond the western limit of glacial drift. However, till and stratified drift were found at the base of several cut sections. The glacial material is overlain by at least two different ages of colluvial material. The underlying bedrock in all three cut sections includes the McKenzie-Bloomsburg-Wills Creek sequence (Fig. 30). In this area the Wills Creek shale is known for its highly weathered (clayey) soil-rock transition zone.

In addition to the engineering complications resulting from the diverse materials found in the cut sections, two very large periglacial slides [boulder fields] occur right of centerline on the mountain flank (Fig. 31). These ancient slides have probably moved down the mountainside under the influence of severe climatic conditions associated with the last stage of glaciation. The 60° orientation of the large block field suggests that the original slide area may have been structurally controlled by an underlying fault "rock shatter" zone or several fracture zones. (It has been shown in other areas that small faults and fracture zones frequently make an angle of about 60° with the ridge crests.) The middle portion of the slide scar also seems to nearly coincide with the Rose Hill-Tuscarora contact. This is a very hazardous zone on the mountainside. The natural upwelling of the water table from the clayey Rose Hill barrier frequently intersects the surface and creates unstable soil conditions. Many smaller-scale slides and flows have been found throughout Bald Eagle Mountain in this particular zone.

The entire drainage system of Bald Eagle Mountain discharges water downslope toward Bald Eagle Valley and the project area. Figure 32 (Parizek, 1970) illustrates in a general way the overall groundwater conditions along many mountainsides in the Ridge and Valley Province of central Pennsylvania. Very permeable materials high on the mountainside allow a high degree of rainwater infiltration to be incorporated into the subsurface drainage systems. Block fields and stony-rubbly areas on the mountain top act as collectors which funnel water into the various systems. Features such as stone stripes and weathered (gravely) bedrock transmit water rapidly downslope to a cut section or embankment. Other systems transmit water more slowly, or act as deflectors to water percolating through the colluvium from the ground surface further down the mountainside.

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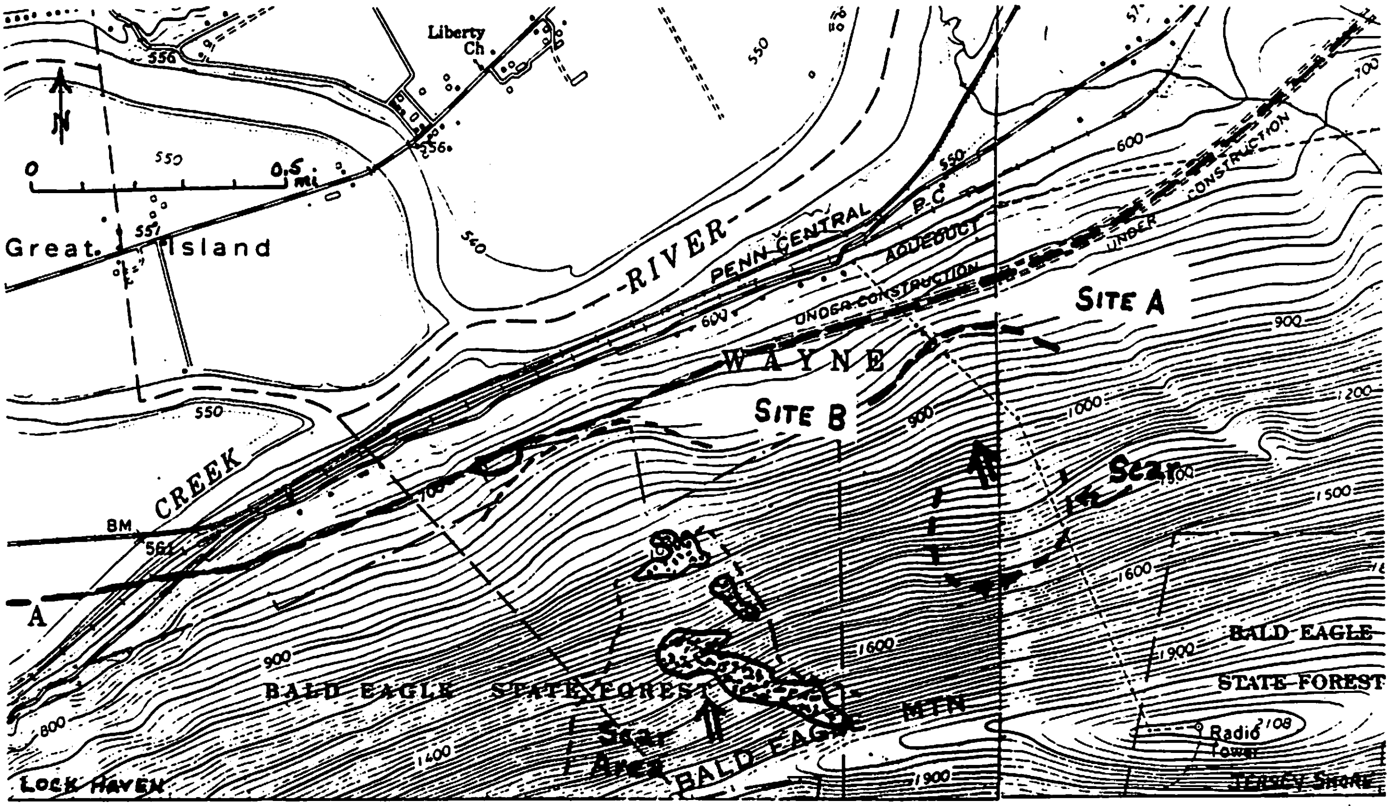

Figure 29. Topographic setting of sites A and B of the US Route 220 project area in the vicinity of Lock Haven. STOP 4 will focus attention on site B.

Most of the individual systems seen in Figure 32 are shown schematically in more detail on Figure 33. Figure 33 represents a partial view of an idealized cut section in which all of these water systems are illustrated in a colluvial-bedrock setting. Obviously, all of these systems are not necessarily found in any one cut section. However, most of these systems were seen at various points along Site A on the Lock Haven Bypass. Slight permeability differences become important in transmitting water through colluvial deposits. A greater concentration of boulders or sandy material within a colluvial zone will permit groundwater to flow more rapidly within that zone. As a result this will yield a larger volume of water and corresponding seepage problems at its point of intersection on the cut face. Figure 34 (Parizek, 1976) illustrates the underlying geology and a different perspective of three general groupings of groundwater systems. The upwelling of the water table at the Rose Hill-Tuscarora contact with its corresponding unstable zone can also be seen on this figure.

SITE EXAMPLES OF SLOPE STABILITY CONDITIONS

Three construction sites are used to illustrate some of the failures and conditions involved in the design and construction of the Lock Haven Bypass.

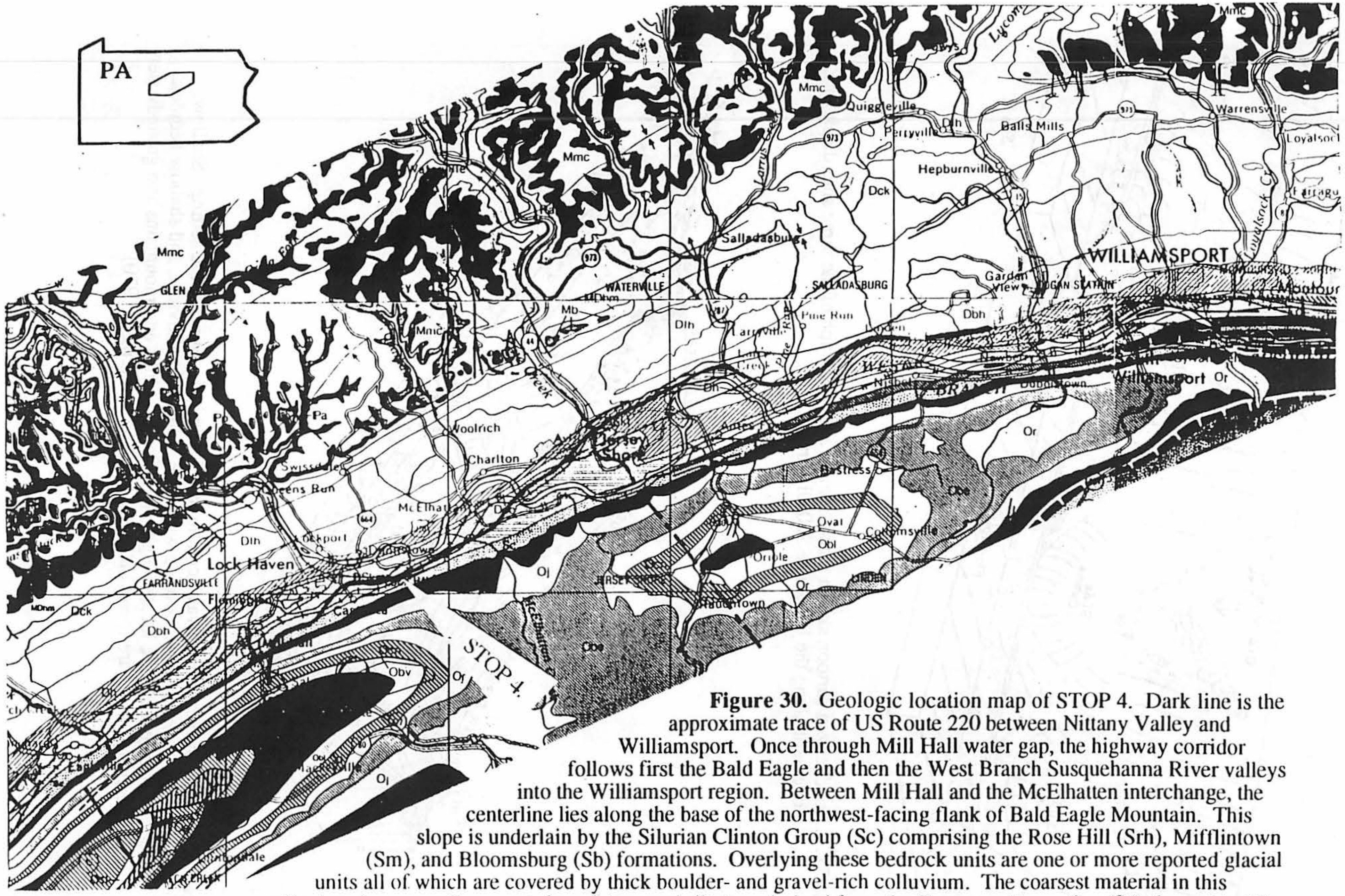

Figure 30. Geologic location map of STOP 4. Dark line is the approximate trace of US Route 220 between Nittany Valley and Williamsport. Once through Mill Hall water gap, the highway corridor follows first the Bald Eagle and then the West Branch Susquehanna River valleys into the Williamsport region. Between Mill Hall and the McElhatten interchange, the centerline lies along the base of the northwest-facing flank of Bald Eagle Mountain. This slope is underlain by the Silurian Clinton Group (Sc) comprising the Rose Hill (Srh), Mifflintown (Sm), and Bloomsburg (Sb) formations. Overlying these bedrock units are one or more reported glacial units all of which are covered by thick boulder- and gravel-rich colluvium. The coarsest material in this colluvium is very well cemented sandstone and siltstone derived from the Tuscarora Formation (St), the unit holding up the ridge crest along the entire length of Bald Eagle Mountain.

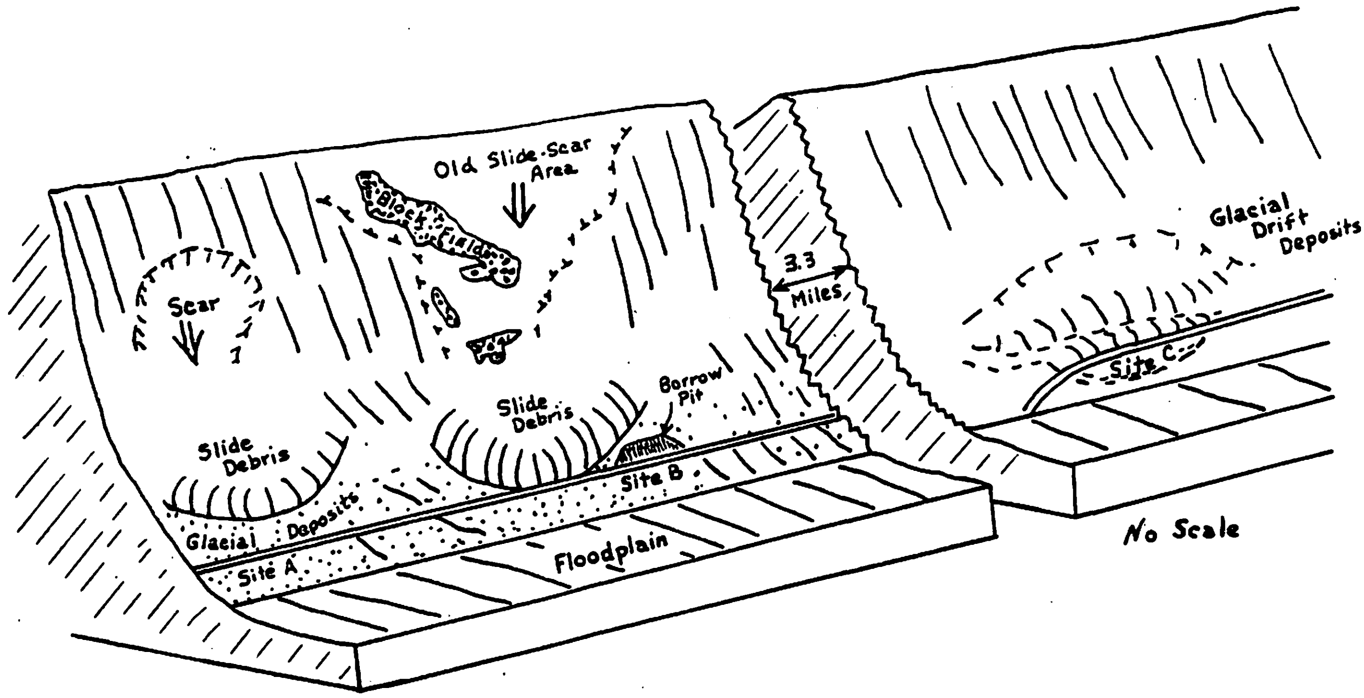

Figure 31. An idealized cartoon sketch made from an air photograph of the three sites displaying movement along the US Route 220 allignment.

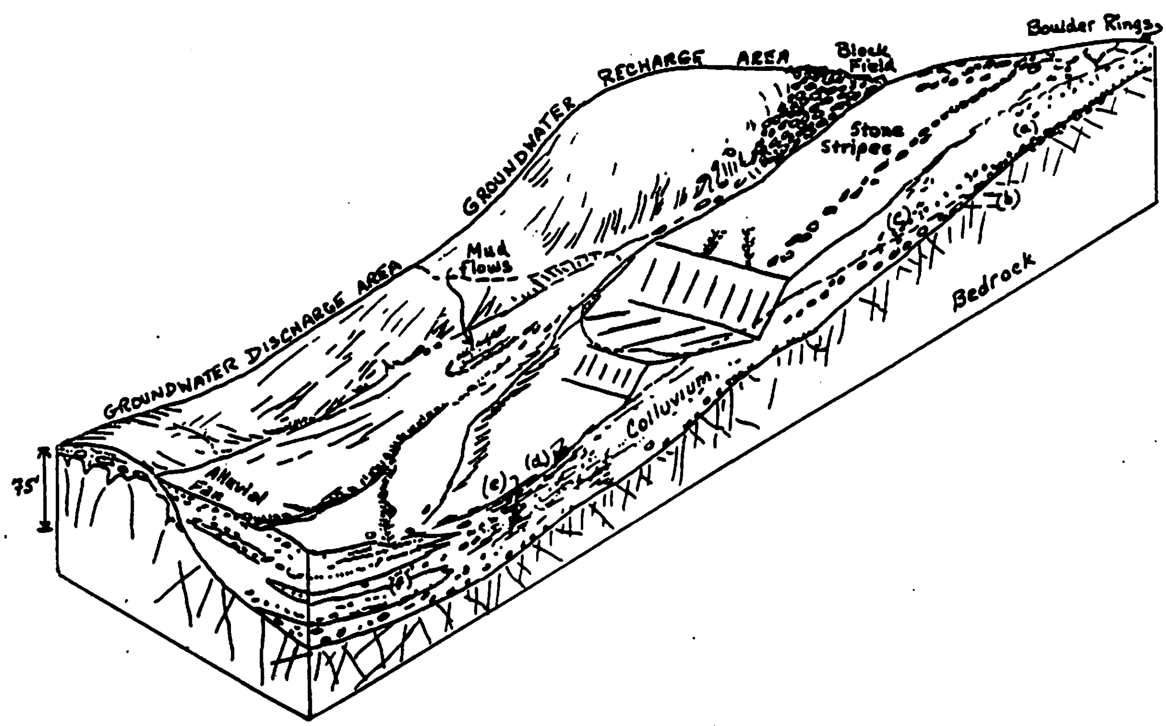

Figure 32. Geomorphic-groundwater conditions of a typical mountainside setting. Shallow, blanket-like aquifers develop within the colluvium, alluvium, and shallow bedrock. Recharge areas are located high on the flanks of hills and mountains and groundwater discharge areas are lower on these slopes (after Parizek, 1970).

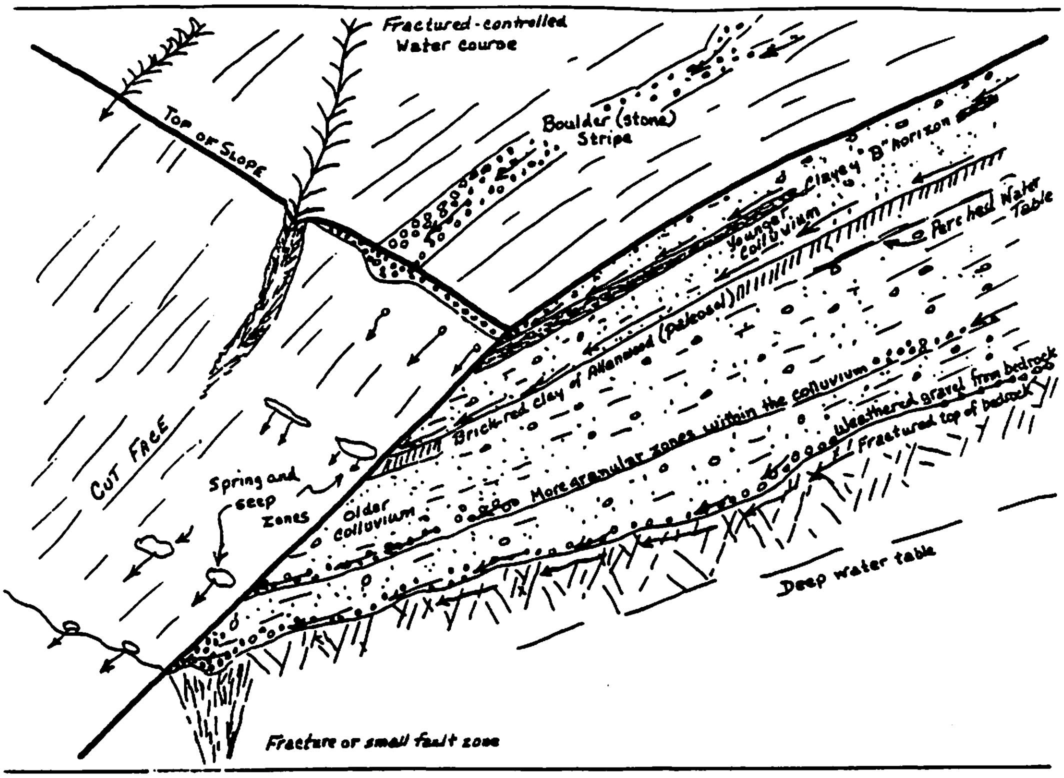

Figure 33. A cartoon sketch illustrating an idealized surface and subsurface water system. This is basically an expanded view of groundwater conditions illustrated in the previous figure. Note: all of these systems do not necessarily occur in any one setting (after Parizek, 1976).

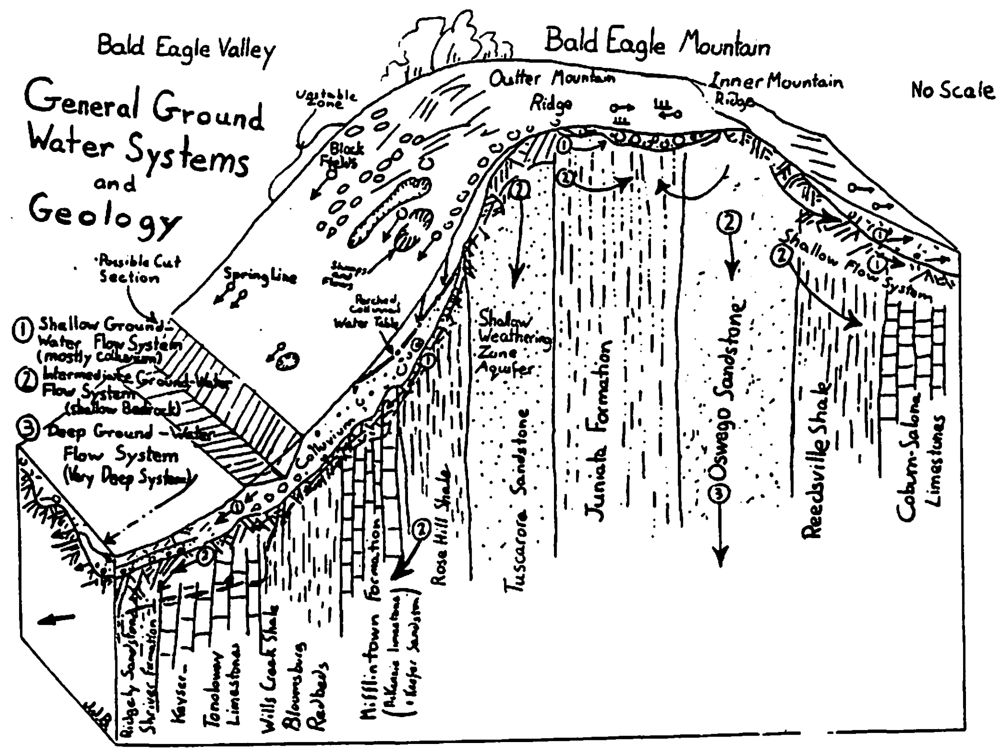

Figure 34. General groundwater systems and the geology controlling them (after Parizek, 1976).

Site A (S.R. 220, Segment 0230) is located in the northeastern portion of the Bypass. This 2500-foot cut section was in various stages of failure for a distance of approximately 1600 feet before the excavation had even been completed. The 50-foot-high cut section is underlain at its base by a shaley unit which is exposed periodically along the swale. Glacial material overlies the bedrock and a thick sequence of colluvium overlies the glacial deposit (Figure 35). Large quantities of water are discharging from the excavated cut face. The complexity of the entire water situation was further compounded by the occurrence of the unexpected glacial deposits and their own water systems. The various types of slope failures ranged from small mudflows and seep-sloughage to very large slump and earthflow masses. All stages of development of each type of failure could be seen. Many of the larger failures would block and disrupt (or pond) some of the more freely discharging areas which would further aggravate that particular failing segment.

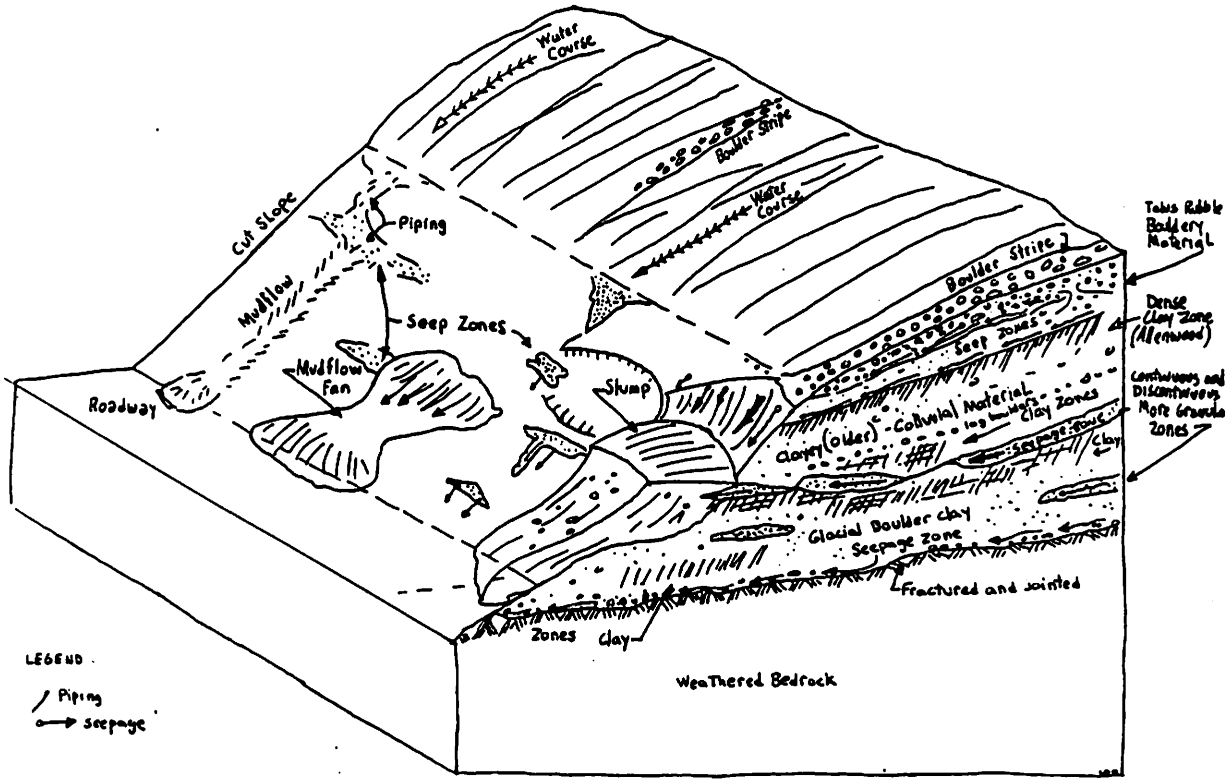

Figure 35. Idealized cut-slope conditions illustrating the setting of Site A (after Parizek, 1970).

Site B (S.R. 220, Segment 0220) consists of a 35- to 45-foot cut section which extends for about 4000 feet (Fig. 36). After corrective measures were taken along the entire length of the cut, approximately 1100 feet are still failing. The corrective measures that were taken involved installing drainage and flattening the slope. The conditions in this cut are very similar to Site A except that the toe of a large periglacial slide is within 50 to 100 feet of the top of slope. In addition, the Wills Creek shale in this section has a very highly weathered clay at the soil-rock transition zone.

Site C (S.R. 220, Segment 0140) - A large portion of this 4500-foot cut encounters glacial till and glacial fluvial deposits (Fig. 37). The glacial material is overlain with colluvium and no bedrock is exposed in the swale. After extensive studies, the slopes were redesigned with various drainage measures and slope flattening. At present, none of this slope is failing.

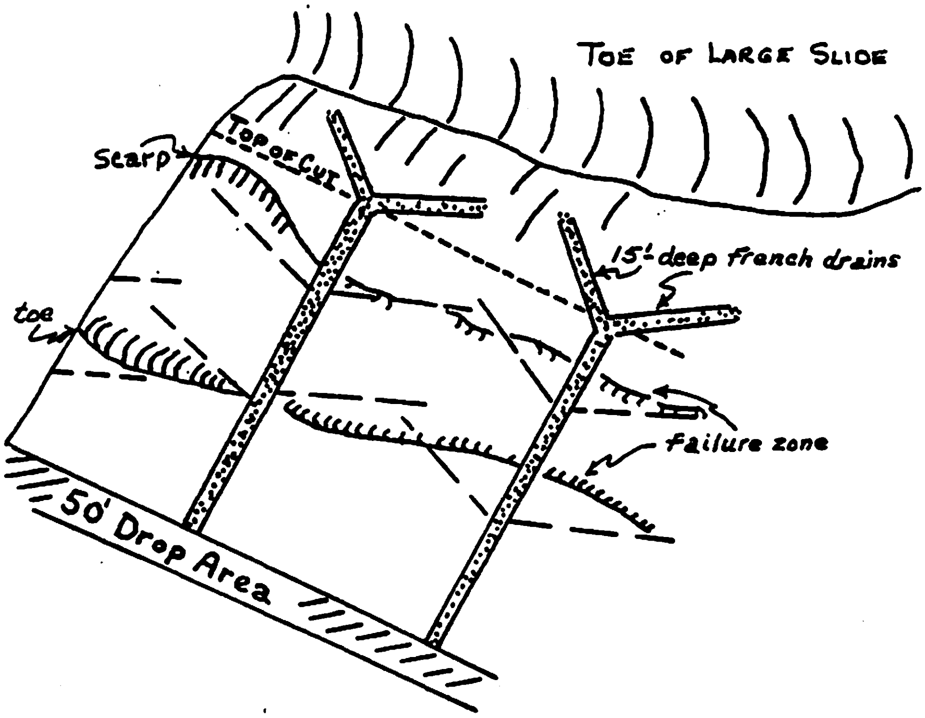

Figure 36. Idealized slope conditions at Site B.

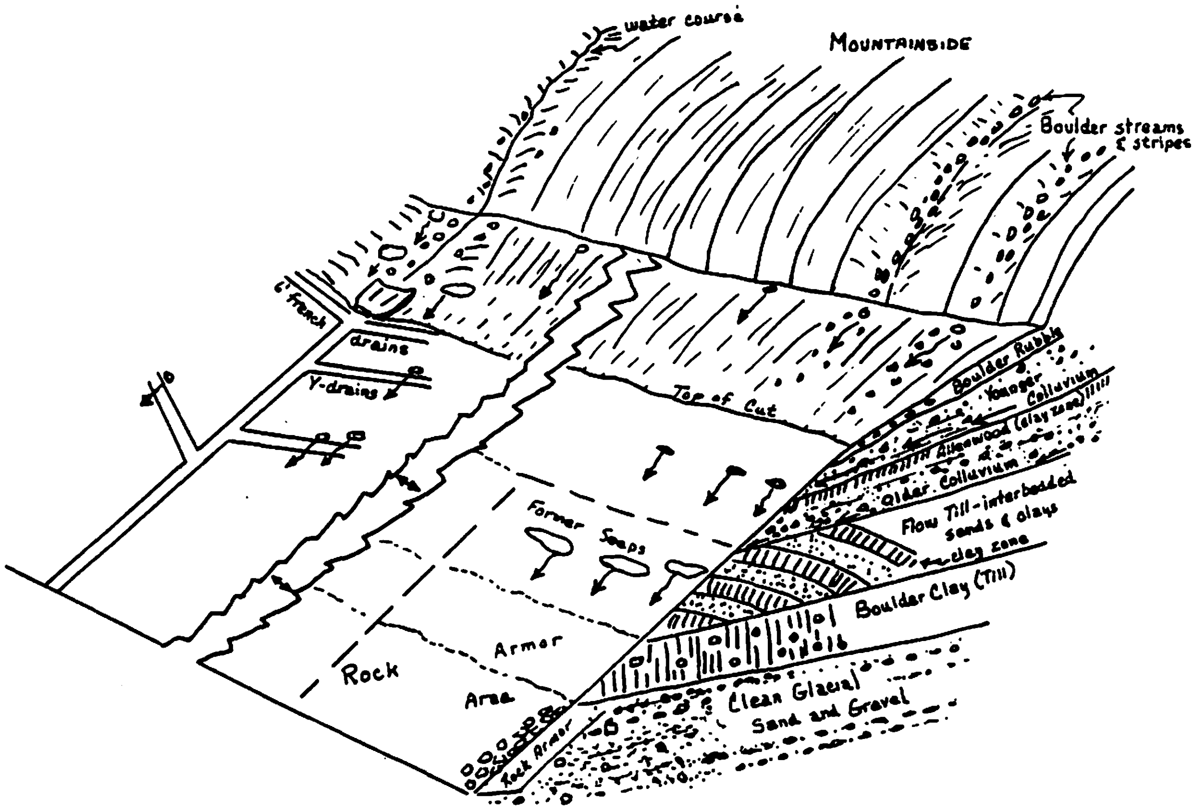

Figure 37. Idealized slope conditions at Site C.

REFERENCES CITED

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Site Development Issues Related to the Geologic and Hydrogeologic Investigation of the Clinton County Solid Waste Authority Site Wayne Township Landfill, Clinton County

ROBERT M. HERSHEY, P.G.[1] AND ROGER W. POLLOK[1]

INTRODUCTION

The Clinton County Solid Waste Authority (CCSWA) landfill in Wayne Township, Clinton County, McElhattan, Pennsylvania was issued a Municipal Permit No. 100955 by the Pennsylvania Department of Environmental Resources (PADER) on August 20, 1973 for 52 hectares (127.5 acres). The present permitted area is shown on Figure 38 (Jersey Shore 7.5-minute USGS quadrangle). The site is located approximately 8 km (5 mi) east of Lock Haven and 6 km (4 mi) west of Jersey Shore. It lies within a large meander of the West Branch Susquehanna River at the base of the north slope of Bald Eagle Mountain and north of the water gap cut by McElhattan Creek.

Approximately 19 hectares (46 acres) of the site west of US Route 220 was used for solid-waste disposal and operated as a natural renovation site from the Fall 1973 to November 1991. This portion of the site relies on suitable soil beneath the waste to naturally attenuate the leachate emanating from the waste. Trenches up to 9 m (30 ft) wide, 90 m (300 ft) long, and 5 m (16 ft) deep were excavated into the unconsolidated material for waste disposal. The 1973 permit included 18 hectares (44 acres) east of US Route 220 which was not used for waste disposal under the original permit. Under the Municipal Waste Management Regulations enacted on April 9, 1988, all municipal waste landfills must either receive a permit or have submitted a complete application complying with the new regulations by April 9, 1990, or cease operation.

The CCSWA submitted a permit application modification on April 20, 1989 and was issued a permit for 88 hectares (218 acres) on December 27, 1990. In addition to the natural-renovation area and surrounding support area, the re-permitting application documents also included the utilization of an additional 36.1 hectares (89.3 acres) of Authority-owned land surrounding the proposed 13-hectare (33-acre), double-lined disposal area for the development of support facilities. Leachate storage ponds, a leachate pre-treatment plant, sedimentation basins, access roads, an equipment-maintenance shop, a recyclable-materials-processing center, and soil stockpiles are all required by the CCSWA to operate the lined-disposal area and the Clinton County recycling program.

The now partially developed 13-hectare (33-acre), double-lined landfill east of US Route 220 is permitted for municipal- and residual-waste disposal on a double-composite liner system. The liner system includes: a clay subbase; two 100-ml, high-density polyethylene (HDPE) liners; a geosynthetic clay layer; geonet detection and collections zones; and a protective cover-stone layer. The lined disposal area will encompass 10 cells or fields within the 13-hectares (33 acres) and is expected to be operational through the year 2011. The Authority is permitted to receive up to 550 tons per day and currently receives an average of 350 tons per day. The total site capacity is estimated to be 2.3 million tons of solid waste. The leachate is collected and pre-treated at the on-site treatment plant. The treated effluent is then discharged to the Pine Creek Sewage Treatment Plant.

****

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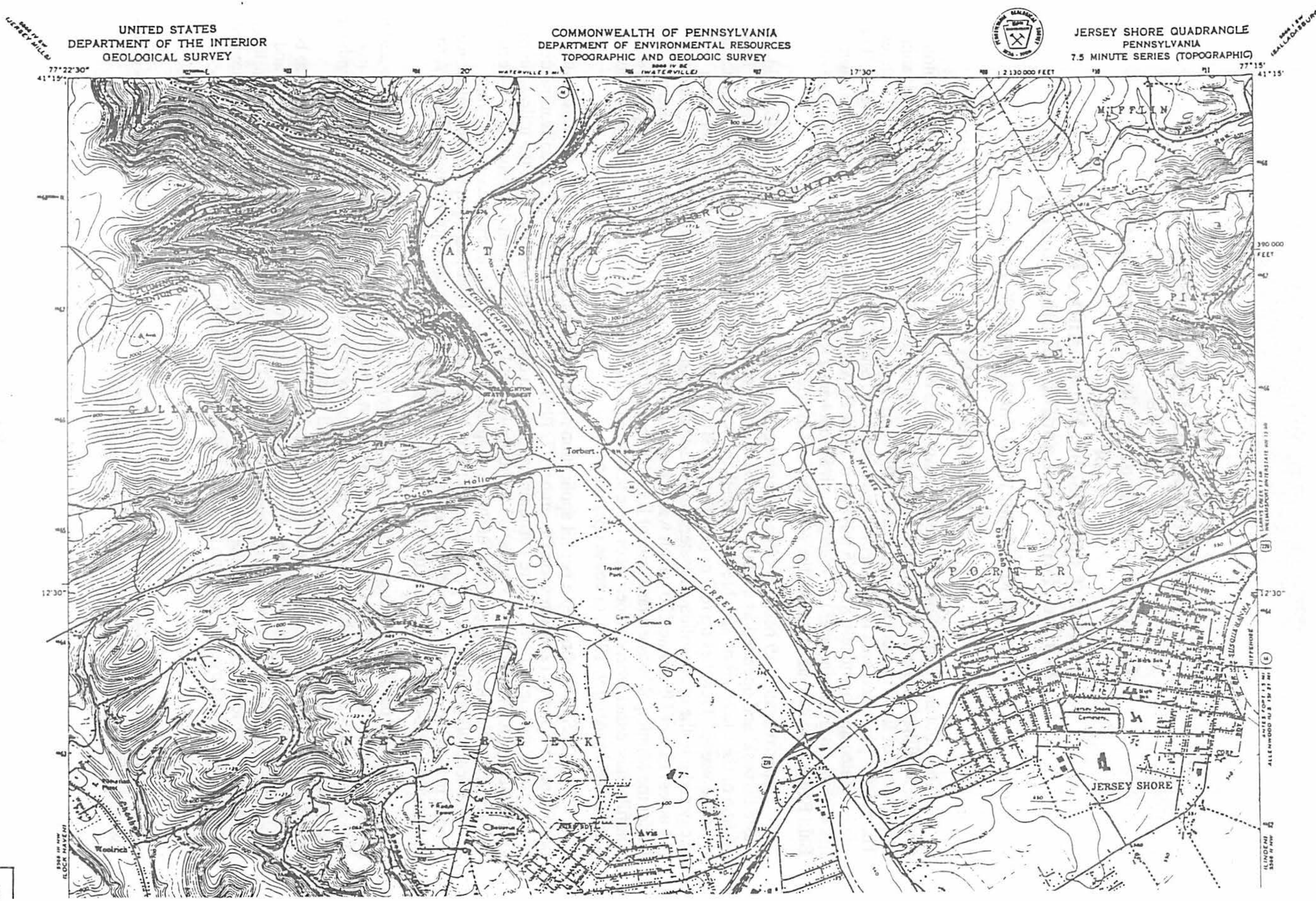

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES
TOPOGRAPHIC AND GEOLOGIC SURVEY
JERSEY SHORE QUADRANGLE
PENNSYLVANIA
7.5 MINUTE SERIES (TOPOGRAPHIC)
77°22'30"
41°15'
20'
17'30"
77°15'
41°15'
390 000 FEET
12'30"
12'30"
MIFFLIN
SHORT MOUNTAIN
WATSON
GALLAGHER
PINE
CREEK
Torbert
Dutch Hollow
PORTER
PINE CREEK
JERSEY SHORE
Avis
Woolrich
SUSQUEHANNA

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1963. Field checked 1965

Polyconic projection. 1927 North American datum
10,000-foot grid based on Pennsylvania coordinate system, north zone
1000-meter Universal Transverse Mercator grid ticks, zone 18, shown in blue

To place on the predicted North American Datum 1983, move the projection lines 5 meters south and 26 meters west as shown by dashed corner ticks

There may be private inholdings within the boundaries of the National or State reservations shown on this map

UTM GRID AND 1986 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 KILOMETER

CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

PENNSYLVANIA
QUADRANGLE LOCATION

Revisions shown in purple compiled in cooperation with Commonwealth of Pennsylvania agencies from aerial photographs taken 1983 and other sources. This information not field checked. Map edited 1986

ROAD CLASSIFICATION

Heavy-duty	———	Light-duty	———
Medium-duty	———	Unimproved dirt	....
U S Route		State Route	

JERSEY SHORE, PA.
41077-B3-TF-024

1965
PHOTOREVISED 1986
DMA 5906 III NE–SERIES V831

SITE INVESTIGATION

In order to complete the soils, geologic, and hydrogeologic portions of the PADER Landfill Permit Application, an extensive geotechnical investigation was performed beginning in the Spring 1985 by *Meiser & Earl, Inc.* (M&E). This site investigation was designed to address the regulatory issues involved in permitting a municipal waste landfill, but, in addition, we needed to understand those geologic and hydrogeologic issues that could impact the design, the groundwater monitoring, and the ultimate construction of the site.

Forty-six wells were constructed to provide both geologic definition and water-level measurements, and 17 additional holes were drilled for stratigraphic definition. The original site had 5 monitoring wells (MW-1 through MW-5). The newly permitted site, in addition to using Well MW-5, has 7 newly constructed monitoring wells (M6 through M10, M12, and M14). PennDOT drilled 17 borings for the US Route 220 bridge north of the lined area (P-series holes), and the logs from these holes were also used for geologic definition at the site.

Forty-eight test pits were excavated, logged, and sampled to depths of up to 10 m (32 ft) below ground level to help define the unconsolidated deposits. The location of these wells, holes, and test pits are indicated on Figures 39 and 40, the geologic data maps for the western and eastern portions of the site, respectively; the geologic cross sections are shown on Figure 41. The geologic summary of Wells 1 to 24 and A-1 to A-6 is shown in Tables 23 and 24, respectively.

BEDROCK STRATIGRAPHY

Rocks underlying the unconsolidated materials at the site range in age from Upper Silurian to Lower Devonian and include the Tonoloway, Keyser, Old Port, Onondaga, Marcellus, and Mahantango Formations. The only bedrock outcrops at the site are exposures of the Ridgeley and Shriver Formations along the northeast edge of the cemetery just off the northern edge of the site (see Fig. 40). A nearly complete stratigraphic section is exposed approximately 6 km (3.5 mi) to the north along the east side of Pine Creek between Jersey Shore and Avis (includes STOP 6 quarries). The following descriptions are based on rock exposures at the CCSWA site, the Jersey Shore outcrops, and Faill and others (1977) and are summarized in Figure 42.

Tonoloway Formation

The Tonoloway is a 120-m- (400-ft-) thick unit of light gray, fine-grained, thin-bedded limestone with occasional thin beds of siltstone and limy shale. The lower contact with the Wills Creek Formation is gradational and contains more numerous yellow and light-green shales and siliceous siltstones. The upper contact with the Keyser Formation is sharp where thin-bedding gives way to more massive bedding. Also, vugs containing calcite and strontianite crystals occur near the top of the Tonoloway at the Jersey Shore quarry. A striking visual petrographic feature of these thin-bedded limestones is the fine, light- and dark-gray laminations within the thin beds, and carbonaceous and micaceous partings between many beds. Fossils are generally sparse, but, when present, tend to be small. The most common macrofossils are ostracods which typically occur as single valves concave downward on bedding planes.

Keyser Formation

The Keyser in this area is 30 m (100 ft) thick (Faill, 1977) and consists of thin to medium-bedded, dark-gray limestones. The lower part of the unit is thicker bedded and contains a nodular (stromatolitic?) bed near the base. The character of these lower beds, along with several fossil-rich beds, provide the basis for distinguishing it from the underlying Tonoloway. The upper part of the unit tends to be thinner bedded and many are strongly laminated. Hand samples from this part can be easily confused with those from the Tonoloway. Corals, stromatoporoids, and bryozoans are common macrofossils in the Keyser; crinoid ossicles are concentrated in fossil hash zones.

Old Port Formation

The Old Port Formation includes those rock units lying between the Keyser and Onondaga Formations. Four lithostratigraphic units, all members of the Old Port Formation, were observed in the quarries west of Jersey Shore. They are listed below in ascending order.

Corriganville Member - The basal Corriganville Member is a 9-m- (30-ft-) thick, fossiliferous, sparingly cherty (scattered black nodules), medium-dark gray, fine to medium-grained, thin- to thick-bedded limestone, with some laminated dolomites (Faill and others, 1977). In hand samples, this member is difficult to distinguish from the underlying Keyser Fm. The presence of chert nodules in this unit are diagnostic.

Mandata Member - The Mandata is a 15-m- (50-ft-) thick, dark-gray to gray-green, fissile shale with dark-gray limestone nodules and laminae near the base; it is carbonaceous in some horizons. It contains a higher proportion of clay minerals compared with other shale units in the study area and consequently has a more "soapy" texture. It weathers to a light-gray-brown color. The upper and lower contacts are sharp.

Shriver Member - At the Pine Creek exposure, the Shriver consists of a lower unit (15 m, 50 ft) of thin-bedded, dark-gray to black shale and shaley limestone, and an upper unit (24 m, 80 ft) of massive, dark-blue-gray, coarse to medium-crystalline, very hard limestone with large (up to 5-cm, 2-in diameter) brachiopod fossils. The upper unit contains black chert beds and nodules and shows only a 10% insoluble residue upon dissolution in HCl. The top 6 m (20 ft) of the section are missing at the Pine Creek exposure, so it is unknown if there are any of the typical tan siliceous siltstones (observed 32 km, 20 mi to the southwest) in this upper unit here. It does not appear that the lower limy unit could weather to this siltstone lithology.

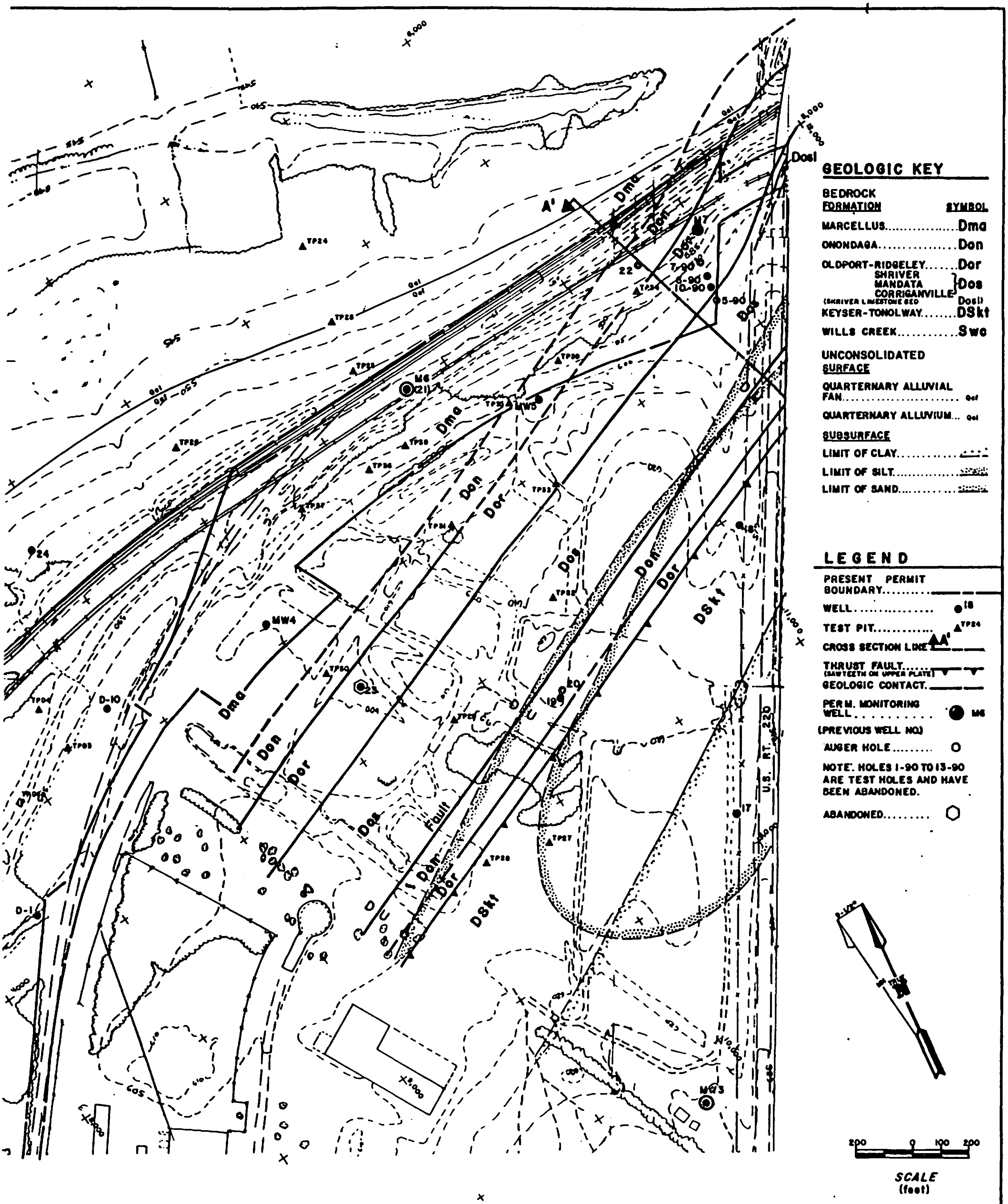
At the CCSWA's landfill site, the Shriver was exposed in the stormwater-drain excavation east of the lined area and in outcrops near the cemetery. Here, it displays the more typical character as dark-gray, tan-weathering, calcareous-cemented, siliceous siltstone with chert beds and thin limestone beds. It contains what appears to be a 6- to 10-m (20- to 30- ft) thick interbed of pure, bluish-gray, coarse- to medium-crystalline limestone with a few brachiopods and chert nodules. However, the very gentle dip on this bed relative to the dip of the surrounding siltstone beds suggests that it could be a structurally-emplaced block of Corriganville limestone. On the geologic data maps and cross-sections we have interpreted it as an interbed in the Shriver Member.

Ridgeley Member - The Ridgeley is a 30-m- (100-ft-) thick, hard, calcite-cemented (siliceous cement in some horizons), white to light-gray, coarse- to medium-grained sandstone. It contains large brachiopods which are abundant in some horizons. The lower contact is probably gradational over 5 m (15 ft) (Faill, 1977) and the upper contact is reported to be sharp. North of the railroad bridge at the Pine Creek exposure, however, the bottom half of this unit is massive sandstone, and the upper half is sandstone interbedded with tan to yellow siltstone and chert. This silty sequence is very similar to typical Shriver Member. The contact between the Ridgeley and Onondaga was observed at this location as gray shale chips in tan silt.

Onondaga Formation

The Onondaga observed at the abandoned quarry on the east side of Pine Creek is a 15-m (50-ft) sequence of dark-gray to black, thin-bedded, shaly limestone and limy shales with small white brachiopods and occasional pyrite nodules. Faill and others (1977) described it as dark-gray, fissile, non-calcareous shales in the lower 5 meters (17 ft), with pyrite, brachiopods, and calcite partings and medium-gray, shaly, medium-bedded limestones and thin-bedded shales in the upper unit. Isolated coarser bioclastic (brachiopod-rich) beds occur within the upper unit. An ~4.5-meter (15-ft-) thick zone with thin, interbedded meta-bentonite beds crosses the Onondaga-Marcellus boundary in this area. These beds comprise the Tioga bentonite zone (J. H. Way, personal communication, 1988) and serve as an important stratigraphic marker horizon. The individual beds, which range in thickness from a few millimeters to 0.5 meters, occur as dark brown or gray, mealy-textured clay or claystone.


8,000
7,000
535
540
550
555
560
580
REVISED FEB. 1984
REVISED APRIL 1984
REVISED OCT 1989



MEISER & EARL, INC. / Hydrogeologists 1512 W. COLLEGE AVE. STATE COLLEGE, PA 16801	CLINTON COUNTY SOLID WASTE AUTHORITY McELHATTAN, PENNSYLVANIA	GEOLOGIC DATA
CUMMINGS & SMITH, INC. *Consulting Engineers* BRANDON, FL • UPPER MONTCLAIR, NJ HERSHEY, PA	WAYNE TOWNSHIP LANDFILL APPLICATION FOR PERMIT MODIFICATION	CRM (DRAWN) — RMH (CHECK) — APPROVALS — FEBRUARY 1989 (DATE) D (SIZE) – 8611 (PROJECT) – 6 (SUBJ) – 12 (NUMBER) — A (REV.) — 12 of 30 (SHEET)

Table XXIII Geologic Summary of Air-Rotary Wells 1 to 24

Well Number	Surface Elevation	Bottom of Fan Gravel	Bottom of Clay	Bottom of Silt	Bottom of Sand	Bottom of Basal Gravels	Top of Bedrock	Total Depth	Bedrock Lithology	Final Blown Yield (gpm)	Conductivity Micromhos/cm
1	631.1	17	37	67	--	69	69	116	gray limestone	20	230 @ 116'
2	632.8	9	22	38	42	43	43	47	gray limestone	1	80 @ 47'
3	621.1	12	43	58	81	137	137	172	dark gray limestone	50	187 @ 172'
4	611.2	23	54	72	110	144	146	182	gray limestone	15	185 @ 182'
5	604.9	12	44	64	82+	--	--	82	--	0	--
6	575.5	--	10.5	30	140.5	153	153	176	gray limestone	300	--
7	625.6	11	48	58	59.5	100.5	100.5	142	tan limestone	4	255 @ 142'
8	612.5	28	58	79	81+	--	--	81	--	1	--
9	614.4	15	62	82	98	--	98	135	gray limestone	30	190 @ 135'
10	627.3	21	37	48	--	115	115	153	gray limestone	60	130 @ 133', 160 @ 146'
11	627.6	16	35	44	--	80+	--	80	--	0	--
12	610.0	17	26	29.5	--	82.5	83.5	122	gray limestone	20	232 @ 102'
13	612.0	13	35	39	60	--	60	90	gray limestone	15	235 @ 90'
14	602.8	26	27	34	--	--	66	80.5	gray limestone	5	130 @ 80.5'
15	595.5	34	--	--	--	42	42	122	black shale, cherty siltstone	50	200 @ 87' 60 @ 122'
16	589.9	32	--	--	--	47	47	55	black shale	dry	--
17	620.8	15	22	30	36	61	87	127	tan limestone	100	220 @ 127'
18	612.7	27	--	47	70	72	72	76	gray limestone	<1	--
19	609.1	28	--	60	61	--	62	63	gray shale	dry	--
20	609.2	22	--	63	--	--	63	126	gray shale, sandstone & chert	10	260 @ 101' 100 @ 126'
21	575.1	25	--	--	--	--	48	77	gray shale	6	--
22	577.4	18	--	--	--	--	37	80	black shale	50	190 @ 80'
23	603.8	18	--	--	--	31	31	50	tan sandstone	0	--
24	558.5	87	--	--	--	31	31	47	gray shale	0	--

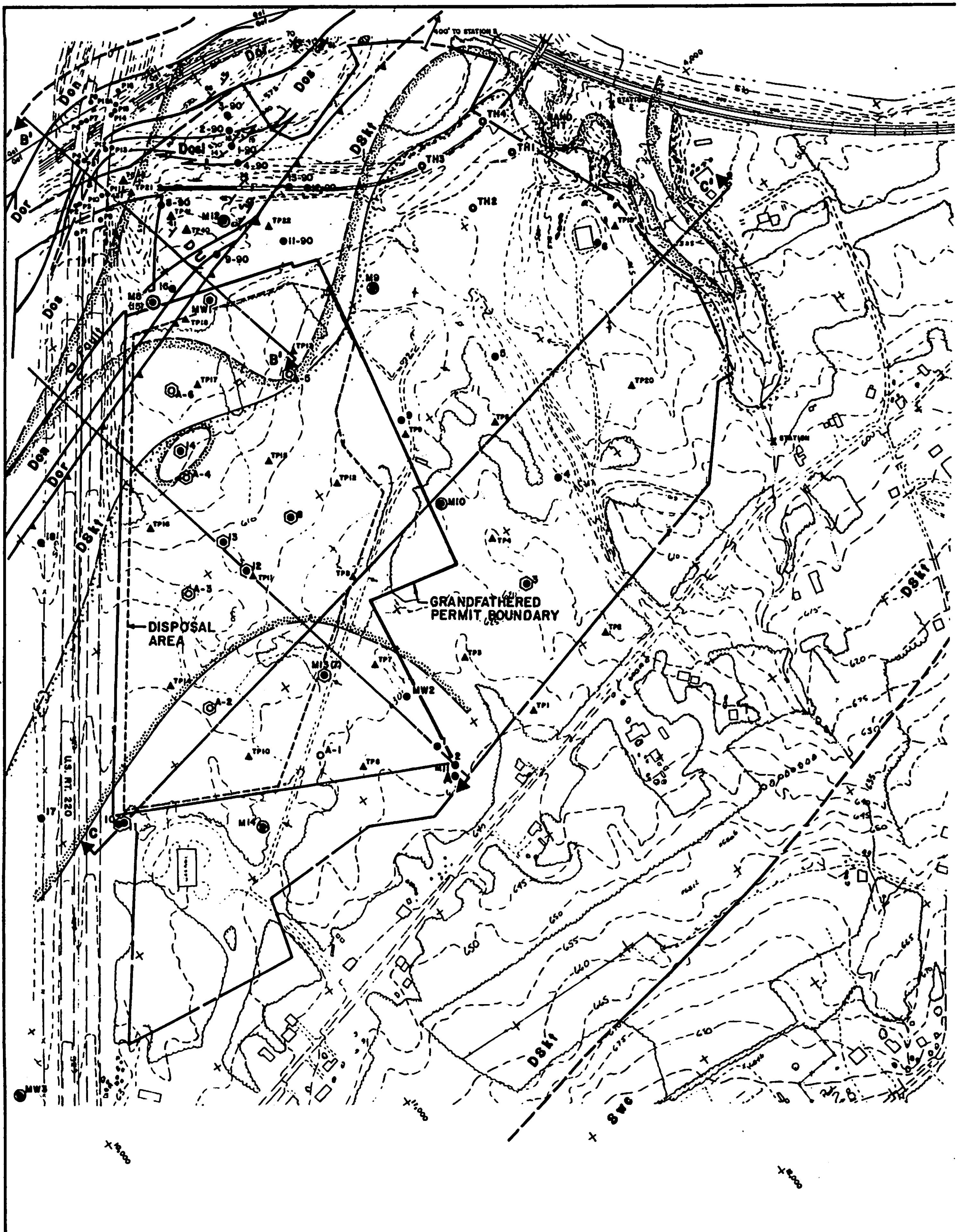
NOTE: All measurements in feet unless otherwise noted.

Table XXIV Geologic Summary of Auger Wells A-1 to A-6

Well Number	Surface Elevation	Bottom of Fan Gravel	Bottom of Clay	Bottom of Silt	Bottom of Sand	Bottom of Basal Gravels	Top of Bedrock	Total Depth	Bedrock Lithology	Comments
A-1	629.5	25	35	56	not present	*	*	65	*	Till below silt.
A-2	623.5	12.5	45	56.5	not present	*	*	61.5	*	Till below silt.
A-3	615.6	20.5	26	32	54	not present	*	61.5	*	Colluvium (?) below sand.
A-4	605.6	25.5	28	33	41	not present	63	82	limestone	Residual soil below sand, rock cored 64.7' to 82'.
A-5	608.6	39	not present	not present	73	not present	*	83.5	*	Colluvium below sand.
A-6	596.7	24	not present	not present	37	*	*	42.9	*	Till below sand.

NOTE: Surface elevation reported in feet. All other values reported in feet below ground surface.

* Well not drilled deep enough to encounter this material.



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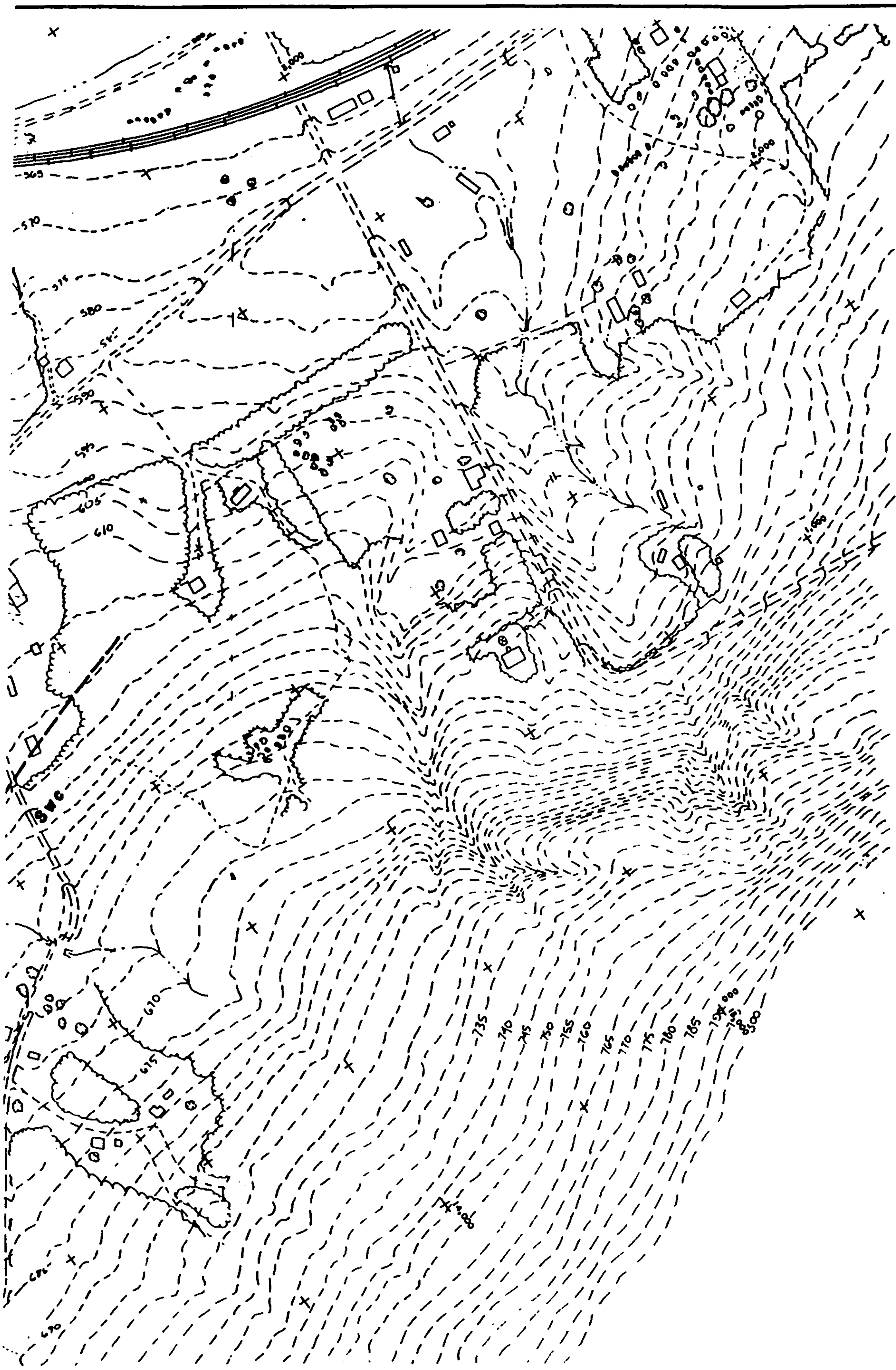
REVISED APRIL 1991
REVISED OCT. 1989



GEOLOGIC KEY

BEDROCK FORMATION — **SYMBOL**

- MARCELLUS.............Dma
- ONONDAGA..............Don
- OLDPORT-RIDGELEY.......Dor
- SHRIVER / MANDATA / CORRIGANVILLE ... Dos
- (SHRIVER LIMESTONE BED.........Dosl)
- KEYSER-TONOLWAY........DSkt
- WILLS CREEK...........Swc

UNCONSOLIDATED SURFACE

- QUARTERNARY ALLUVIAL FAN.......Qaf
- QUARTERNARY ALLUVIUM...Qal

SUBSURFACE

- LIMIT OF CLAY............
- LIMIT OF SILT............
- LIMIT OF SAND............

LEGEND

- PRESENT PERMIT BOUNDARY..........
- WELL.................. 18
- TEST PIT............. TP24
- CROSS SECTION LINE. A
- THRUST FAULT (SAWTEETH ON UPPER PLATE)
- GEOLOGIC CONTACT.
- TEST HOLE (ABANDONED).......... TH1
- AUGER HOLE.......... A-3
- PERM. MONITORING WELL (PREVIOUS WELL NO.) M12
- SURFACE WATER SAMPLING POINT..... STATION 1
- BEDROCK OUTCROP...

NOTE: HOLES 1-90 TO 13-90 AND P1 TO P16 ARE TEST HOLES AND HAVE BEEN ABANDONED.

- ABANDONED..........

200 0 100 200

SCALE (feet)

MEISER & EARL, INC. / Hydrogeologists 1512 W. COLLEGE AVE. STATE COLLEGE, PA 16801	CLINTON COUNTY SOLID WASTE AUTHORITY McELHATTAN, PENNSYLVANIA	GEOLOGIC DATA				
CUMMINGS & SMITH, INC. *Consulting Engineers* BRANDON, FL • UPPER MONTCLAIR, NJ HERSHEY, PA	WAYNE TOWNSHIP LANDFILL APPLICATION FOR PERMIT MODIFICATION	CRM (DRAWN)	RMH (CHECK)	APPROVALS		FEBRUARY 1989 (DATE)
		D (SIZE)	888 (PROJECT)	6 (SUBJ)	13 (NUMBER)	A (REV.) — 13 of 30 (SHEET)

Marcellus Formation

The Marcellus was not observed in outcrop but is described by Faill and others (1977) as a homogeneous, carbonaceous, black, fissile to massive shale with lenses and very thin beds of soft clay (Tioga bentonite). It is not calcareous except for widely-spread calcareous (siderite) concretions.

Mahantango Formation (Lower Shale Member)

The Mahantango was observed in backhoe pit TP D4 in the very western portion of the site (Fig. 39). This unit is described by Faill and others (1977) as a 210-m- (700-ft-) thick, dark greenish-gray shale with light-olive gray and light-gray to medium-gray horizons. Small concretions occur locally. Iron-stained weathered surfaces are common. Calcareous horizons become more common near the top of this member. The upper portion of this unit, the Tully Member, is not exposed in this area.

GEOLOGIC STRUCTURE

The structural interpretation shown in cross-sections A-A' and B-B', Figure 41, is the result of the "best fit" of four structural and stratigraphic elements: 1) a graphic construction to determine the maximum dip on the Keyser and Tonoloway Formations; 2) a graphic construction to determine dip of beds and stratigraphic relationships in the Penn DOT drill logs; 3) constraints of the drill data, especially near Wells 15, 18, and 20, and 4) comparison with known faulting in the same stratigraphic units about 6 km (3.5 mi) to the northeast. This approach was used because (a) there are very limited bedrock outcrops on or near the site, (b) no information on bed attitudes is included in the Penn DOT drill logs, and (c) most of the on-site wells were drilled using the air-rotary method.

The contact between the Wills Creek Formation and the Tonoloway Formation is mapped as the last appearance of sinkholes south of the site (down section). Measuring from this point perpendicular to regional strike (assumed to be parallel to the north edge of Bald Eagle Mountain above the site) across the site to the first appearance of non-limestone lithologies gives an outcrop width for the Keyser/Tonoloway Formations of roughly 885 m (2900 ft). Using this value and a combined thickness of 174 m (570 ft) for the Keyser and Tonoloway units to produce a graphic construction at 1:1 (no vertical exaggeration), shows that a maximum dip of 11 degrees to the north is required to just fit both formations into that space. This is the angle that was used for the Keyser/Tonoloway. A vertical exaggeration of 2.5 produces a dip angle of 28 degrees on cross-section A-A' and B-B'. We believe, however, because of structural complexity observed in the Keyser/Tonoloway section in the Pine Creek exposures, at Sayers Dam described by Gough (1977), at Curtin Gap in Bald Eagle Mountain (Milesburg), and elsewhere, that these beds do not dip uniformly at 11 degrees, but rather are more highly folded and faulted. The only bed attitudes that we have for the Keyser/Tonoloway strata at the site came from 5 m (17 ft) of Tonoloway Limestone core from Test Well A-4. Dip angles in the core ranging from 45 degrees to near vertical and beds in some horizons showing small folds (amplitudes of several cm) support the hypothesis that the carbonate units underlying this site have been folded and faulted and display similar structural complexity noted elsewhere within the West Branch Susquehanna River-Bald Eagle River valley.

Although we did not have access to the rock samples from the Penn DOT borings for the US Route 220 bridge piers at the northern edge of the site (plotted on Fig. 40), the fact that the bedrock was core-drilled gives us greater confidence in the logs. A topographic-structural cross-section was prepared from these data along line B-B' and compared with drill data from Wells 15, 20, M12, and 18. We interpret this section as a normal stratigraphic sequence of Shriver through Onondaga dipping to the north at roughly 45 to 70 degrees, the limestone being the coarsely-crystalline bed within the Shriver Member and the sandy shales (P6-P8) being the silty horizons of the Upper Ridgeley. Exposures of the Shriver and Ridgeley Members in the stormwater-drain excavation showed 30 to 60 degree dips to the north and extensive, low-angle (to bedding) shearing with bedding plane faults. Structural thickening resulting from this movement may account for the unusually wide Shriver outcrop in this area. This type of faulting coupled with the fact that the dips on the Shriver beds are very gentle, relative to those of the siltstone, could suggest alternatively that this limestone might be a block of the Corriganville Member thrust into place between two blocks of siltstone.

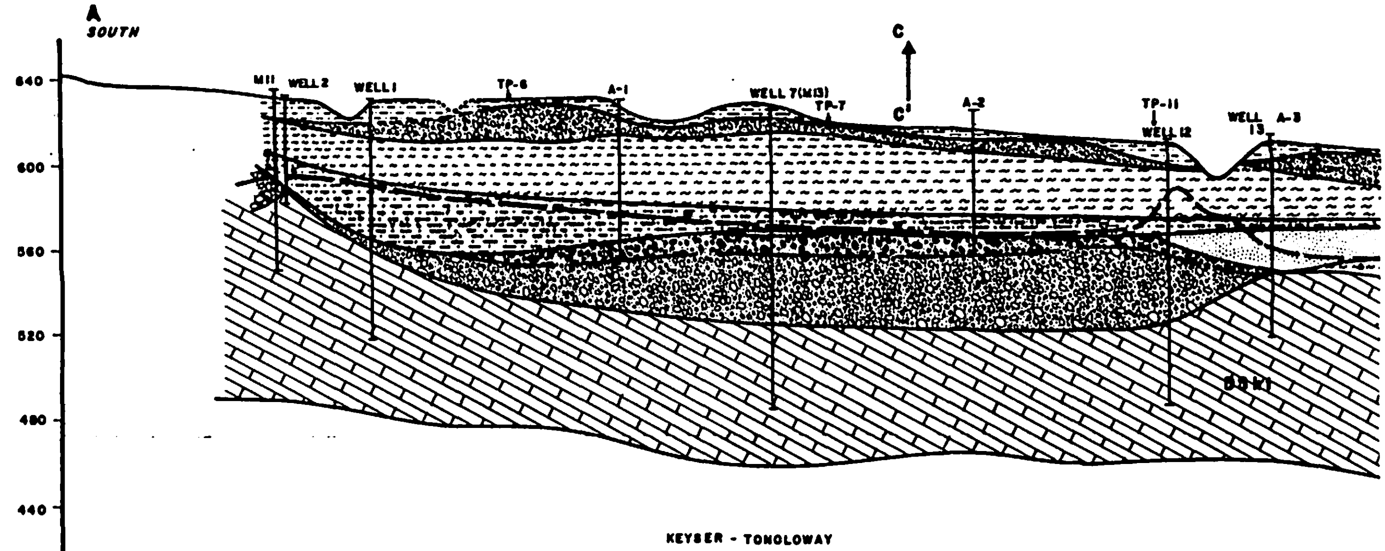
The fact that the Shriver, only 120 m (400 ft) east of the trench in an outcrop near the cemetery, is overturned at 50 degrees to the south, indicates the structural complexity of this area. Placing Wells 15 and 20 into the section at the same scale, we were constrained in having the Onondaga above the Ridgeley and dipping to the north with the Onondaga in contact with the Shriver. This requires the presence of a fault between the Onondaga and the Shriver. We believe this fault was encountered in Drill Hole M12 at 63 feet. Because of the shearing parallel to bedding observed in the Shriver outcrops, we oriented the fault plane parallel to Shriver bedding observed near Well M12. In the northern quarry at the cement plant, along Pine Creek 6 km (3.5 mi) to the northeast of the site, a high-angle fault like this exists with gently dipping Onondaga thrust against overturned Shriver limestone and Ridgeley sandstone. Well 18 shows gray, fine-grained limestone, unlike the Shriver siltstone which should be in this stratigraphic position. We steepened the dip of the Ridgeley to put it in touch with the unconsolidated materials, related it to our observed groundwater trough, and put a thrust fault between it and the Keyser/Tonoloway. The dip on the fault plane was constructed at 45 degrees (shown as 67 degrees on the cross-section because of vertical exaggeration) to account for the occurrence of Tonoloway in Test Well 18. This falls within the range of 20 to 50 degrees given by Faill and others (1977) for thrust faults in this area and geologic setting. The determination that the limestone in Well 18 was not Shriver was based on a small amount of sample with fair to poor return. An alternative interpretation would be that we have a normal sequence across the site from the northernmost fault to the south and that the Ridgeley extends, at a lower dip angle, from Well 15 up to the residual zone near Well 14. Weighing in favor of this fault, however, is the existence of the gently southward-dipping Keyser/Tonoloway beds thrust over Onondaga at the southern quarry at the cement plant.

UNCONSOLIDATED MATERIALS

Based on its topographic configuration (see Fig. 38), the unconsolidated material blanketing the southern portion of the West Branch Susquehanna River valley that includes the landfill site was initially interpreted as simply an alluvial fan deposit. However, based on drilling data, a much more complex picture emerged. This unconsolidated cover comprises a stratified sequence (in ascending order) of residuum/colluvium, gravel, till, sand, silt, clay, fan gravel and silt loam (Refer to Fig. 43 for the relative sequence of these unconsolidated materials). The US Department of Agricultural soils classifications in Figure 43 are based on more than 50 samples analyzed for particle-size using the ASTM Method D 422. The total sequence ranges from less than 3 m (10 ft) in the very western portion of the site at Test Pit TP D4 to more than 50 m (150 ft) at Well 6 in the very eastern portion of the site. In the western half of the site interbedded gravels, sand and silt (alluvium) replace the sand, silt, and clay part of the sequence over more than half the area.

Residuum/Colluvium

Within the area of the site mapped as Keyser/Tonoloway, we observed (in four test wells) 3 to 10 m (10 - 30 ft) of yellow to yellow-brown silty clay to silty clay loam containing iron oxide (goethite), chert fragments, and relic bedding which we judge to be residual soils developed on the limestones. Thomas Gardner, former geosciences professor at The Pennsylvania State University (1994, personal communication), suggested that some of the residuum may be glacial till moved from a nearby source possibly along strike. In three auger holes (A-3, A-4, and A-5), 1 to 3 m (4 - 10 ft) of yellow to yellow-brown silt loam to silty clay loam with fragments of sandstone, limestone, and black shale lie above the residuum. We believe this is colluvium which moved south from the area near the eastern fault (Fig. 40). Because it is not possible to differentiate residuum and colluvium except in split-spoon samples (auger drilling), we have combined them as a unit for the purposes of presentation in graphic form. The occurrence of these yellow-brown residual/colluvial materials seems to be on the north side of the eastern fault (Fig. 40) and may continue as far west as Well 17. The detailed log for Well 17 shows an 8-m- (26-ft-) thick zone of yellow-brown silt loam and cherty gravel on top of bedrock from 19 to 27 m (61 - 87 ft) below ground.



CROSS S

LEGEND

- WELL
- WATER TABLE
- FAULT (THRUST)
- FILL
- GRAVEL
- RIVER SILT
- CLAY
- CHERT
- LIMESTONE
- SANDSTONE/SAND
- SHALE
- TILL/ALLUVIAL FAN
- RESIDUUM/COLLUVIUM
- GLACIAL LAKE SILT
- ALLUVIUM (Qal)
- SILTSTONE

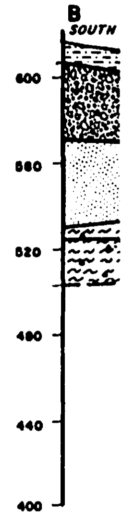
GEOLOGIC KEY

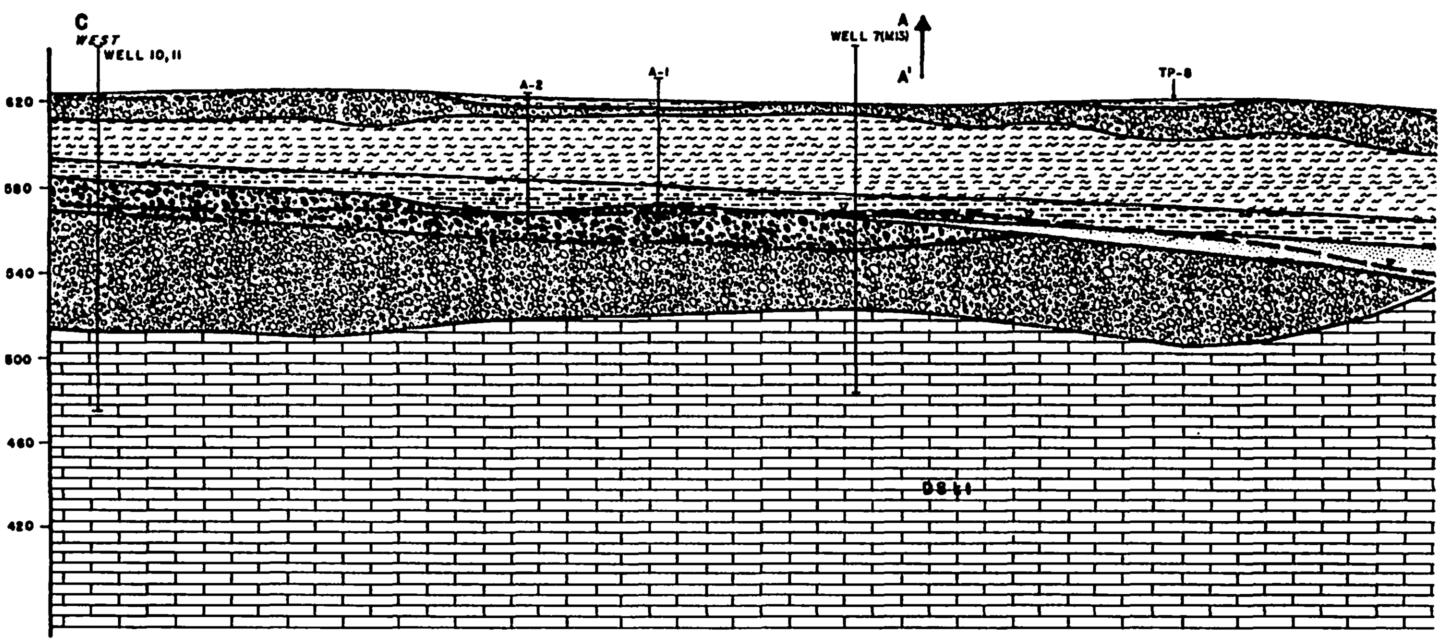
FORMATION	SYMBOL
MARCELLUS	Dmc
ONONDAGA	Don
OLDPORT - RIDGELEY	Dor
SHRIVER, MANDATA, CORRIGANVILLE	Dos
(SHRIVER LIMESTONE BED	Dosl)
KEYSER - TONOLWAY	DSkt

SCALE:

VERTICAL - 1" = 40'

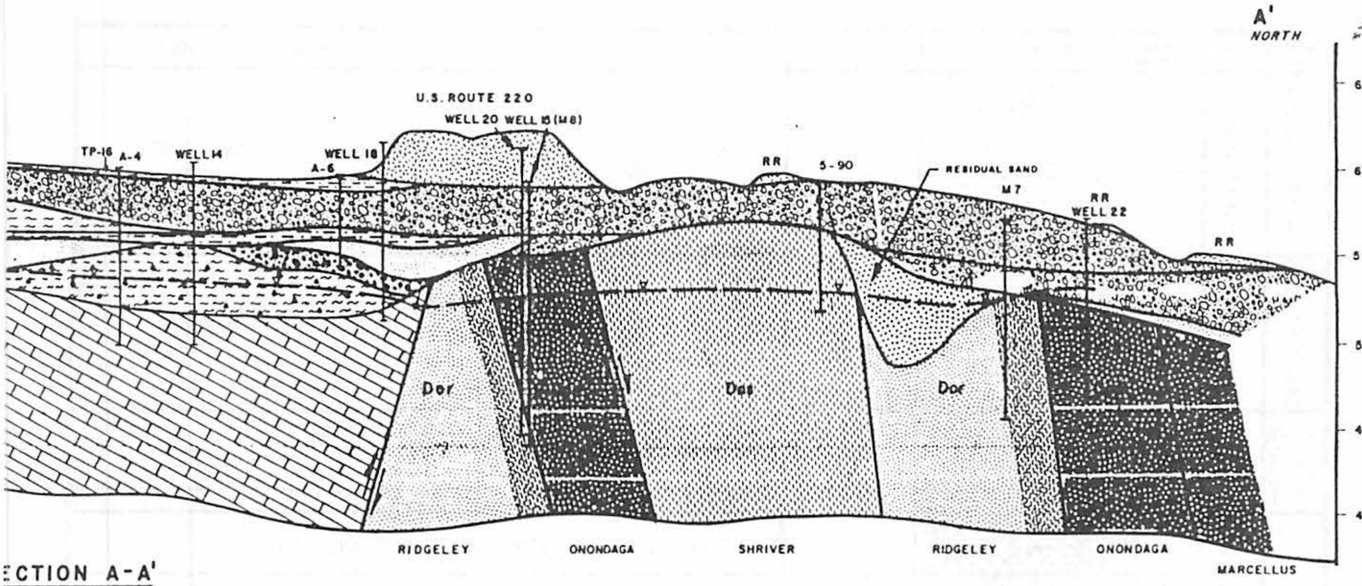
HORIZONTAL - 1" = 100'



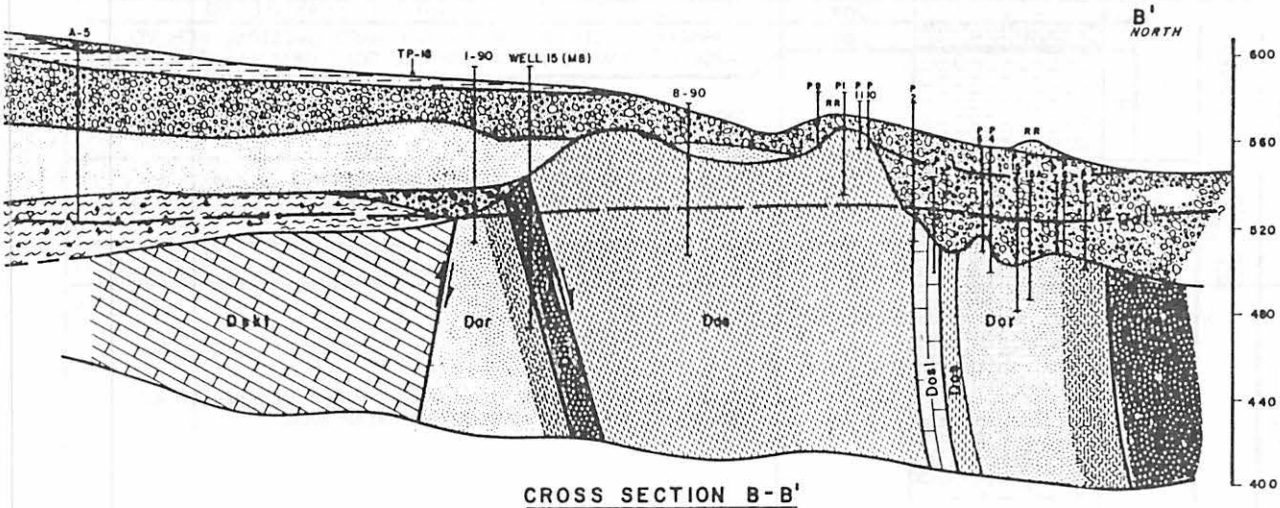


CROSS SECTION C-C'

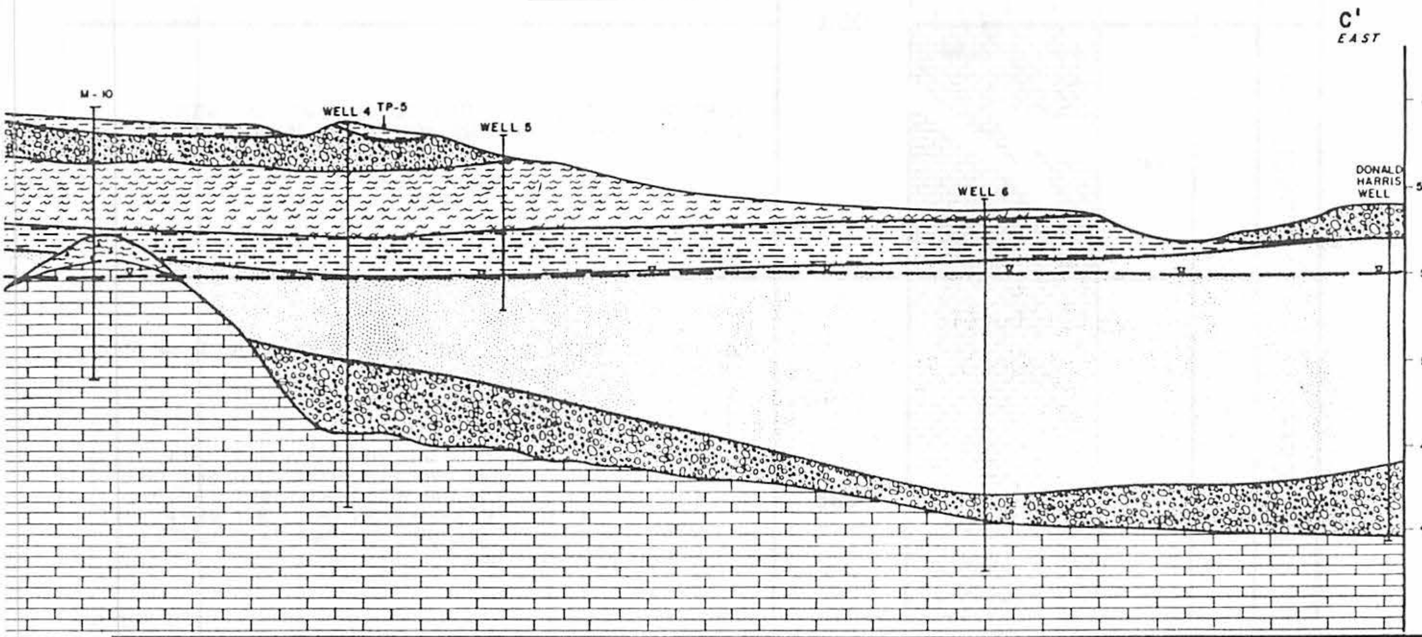
REVISED MARCH 1984
REVISED APRIL 1991
REVISED OCT 1989



ECTION A-A'



CROSS SECTION B-B'



MEISER & EARL, INC. / Hydrogeologists 1512 W. COLLEGE AVE STATE COLLEGE, PA 16801	CLINTON COUNTY SOLID WASTE AUTHORITY McELHATTAN, PENNSYLVANIA	GEOLOGIC CROSS SECTIONS
CUMMINGS & SMITH, INC. *Consulting Engineers* BRANDON, FL • UPPER MONTCLAIR, NJ HERSHEY, PA	WAYNE TOWNSHIP LANDFILL APPLICATION FOR PERMIT MODIFICATION	

DRAWN	CHECK	APPROVALS	DATE
CRM	RMH		FEBRUARY 1989

SIZE	PROJECT	SUBJ	NUMBER	REV	SHEET
D -	6811 -	6 -	14	A	14 of 30

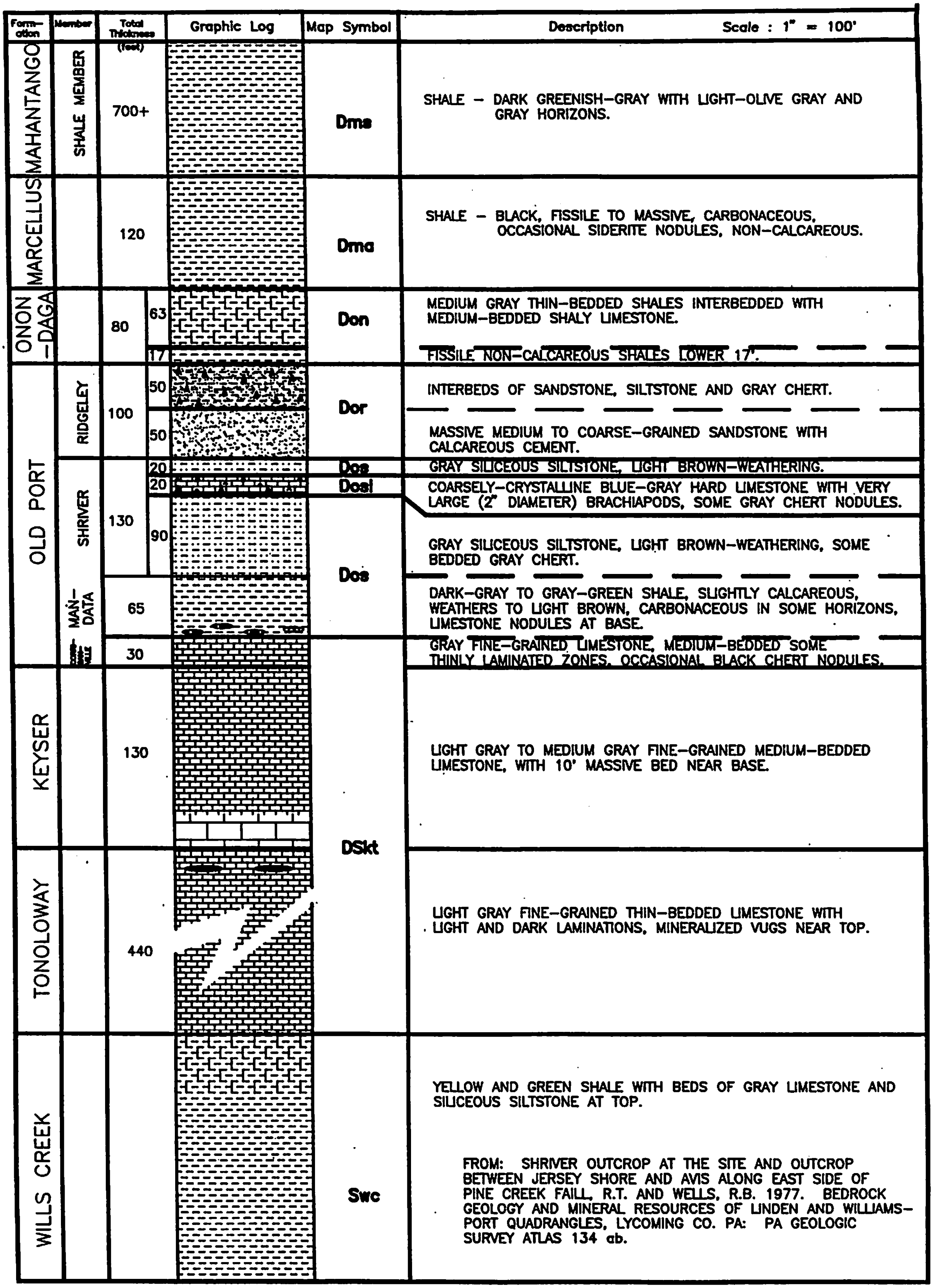
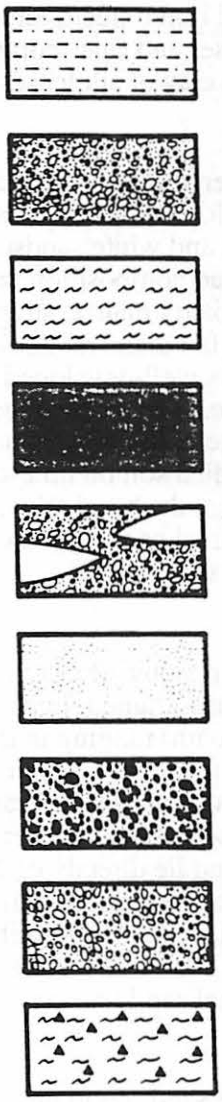


Figure 42. Bedrock Stratigraphic Column



REPORT NAME	RANGE IN THICKNESS (feet)	GRAPHIC LOG	USDA SOILS CLASSIFICATION	COARSE FRAGMENT (Percent)
LOESS SILT	2 - 12		LOAM	2 - 30
FAN GRAVEL	1 - 28		LOAM TO SANDY CLAY LOAM TO SANDY LOAM	20 - 90
GLACIAL LAKE CLAY	2 - 37		SILTY CLAY LOAM* TO SILTY CLAY	<1
GLACIAL LAKE SILT	4 - 30		SILT LOAM	<1
ALLUVIUM	1 - 28		LOAMY SAND TO SANDY LOAM	5 - 80
GLACIAL SAND	2 - 110		SANDY LOAM* TO SILT LOAM	<2
TILL/ALLUVIAL FAN	5 - 9		SILT LOAM TO CLAY LOAM	30 - 70
BASAL GRAVEL	1 - 69		SANDY LOAM	50 - 70
RESIDUUM/ COLLUVIUM	10 - 30		SILT LOAM TO LOAM/SILT LOAM TO SILTY CLAY LOAM	5 - 30

* = DOMINANT TEXTURE

Figure 43. Stratigraphic Sequence of Unconsolidated Materials

Five of the seven wells drilled into shale show a residual, dark-brown, silty-clay loam soil developed to a thickness of 2 to 5 m (8 - 15 ft) on the eastern half of the site, but intermittently only to a depth of 0.3 to 1 m (1 - 3 ft) on the western half of the site. There are no outcrops of the residual/ colluvial materials.

Basal Gravel

In nine of the sixteen air rotary holes drilled on the western half of the site, well-sorted gravel, ranging in thickness from 0.3 to 21 m (1 - 69 ft), covers the bedrock surface. Red and white to light-brown sandstones are the most common constituents of this gravel with lesser amounts of chert, gray-green siltstone, gray and black shale, and iron oxide/hydroxide (goethite) fragments. The fragments are well-rounded, often stratified in coarser and finer horizons, and relatively free of sand and silt, although they may contain small discrete clay or silt lenses.

Till/Colluvial Fan

Three of the auger holes encountered poorly-sorted gravel and cobbles in orange-brown to yellow-brown to dark-brown clay loam, loam, and silty clay loam matrix. The composition of the coarse fragments is a variable mix of red and white sandstone, gray and white chert, gray and light-green siltstone, and gray shale. The varied composition and unsorted fabric, with non-contiguous angular and subrounded fragments in a loamy matrix, suggest this material is till. During the excavation of Field 2, till with 2.5-m- (8-ft-) diameter boulders was encountered beneath the glacial sand. One of these boulders which shows well-developed striations has been recovered and is located near the entrance to the lined-disposal site. The till overlies alluvial gravels and is at least 3 m (9 ft) thick where it occurs on the southern edge of the eastern half of the site. In auger hole A-6 a small pocket of "till" is believed to overlie residual soil on limestone and is at least 2 m (5 ft) thick. Because we can only differentiate this material from the basal alluvial gravels by inspection of split-spoon samples, we are unable to determine its areal or vertical extent on the eastern half of the site. It appears to be absent from the western half of the site.

Glacial Sand

Above the till, basal gravels, and residuum/colluvium in 16 wells and four test holes lies a moderately well- to poorly-sorted, medium-grained, light-brown to brown sand (laboratory analyses show the texture is dominantly a sandy loam) ranging in thickness from 0.6 to 34 m (2 - 110 ft). The samples collected for grain-size analysis from the sand pit, Well 6, and TH2 are summarized in Table 25. These analyses, along with the other sieve analyses, indicate that the percentage of sand decreases and the silt increases going to the west, so the glacial sand is generally a sandy loam to silt loam beneath the landfill site. Only in Well 13 does the sand lie directly on limestone bedrock. The sand is thickest in the east and pinches out at the western edge of the eastern half of the site. There is an anomalously high 4-m (12-ft) mound in the sand horizon at Well A-3. The "limit of occurrence" of the sand body is shown on the Geologic Data Maps, Figures 39 and 40. Note the area of no-sand deposition on the residuum at Well 14. A surface exposure of the glacial sand unit occurs in the sand pit shown on Figure 40.

Alluvium

In the stratigraphic position of the sand found on the eastern half of the site there occurs on the western half of the site an interbedded sequence of well-sorted gravels, sands, and silts ranging in thickness from 0.3 to 9 m (1 - 28 ft). This unit was observed in seven backhoe test pits and is mapped at the surface as Quaternary alluvium (Faill, personal communication, 1988) from the northern edge of the western half of the site to the River (Fig. 39). The matrix of this material, according to laboratory analyses, is a sandy loam to loamy sand.

Since we did not see the glacial sand and alluvium units together in any test pits, we are uncertain of the stratigraphic (temporal) relationship between them, despite the fact that we have shown the alluvium on cross-section A-A' (Fig. 41) to be older than the glacial sand and silt. We are also uncertain of the stratigraphic relationship between the alluvium and the basal alluvial gravel on the eastern half of the site.

Table XXV Glacial Sand Analyses

Sample Location	Zone Sampled (Feet)	Coarse Fragment (Percent)	Sand (Percent)	Silt (Percent)	Clay (Percent)	USDA Soil Classification	Permeability cm/sec (Laboratory)
Sand Pit	Highwall Composite	0	89	6.6	4.4	sand	-
Well 6	60-140	0.3	72.7	21.3	5.7	sandy loam to loamy sand	-
TH 2	32-65	0.2	72.8	16.6	10.4	sandy loam	1.8×10^{-5}

Glacial Lake Silt

Above the sand (or above the till and gravel where the sand is absent) in 23 wells and four test holes over the entire site lies a fairly well-sorted, light-brown silt (laboratory analyses show the texture is dominantly a silt loam) ranging in thickness from 1.2 to 9 m (4 - 30 ft). In Well 14, the silt is lying on a residual soil. There are occasional thin lenses of plastic, pink and gray clay and fine sand laminae within this unit. The sand-silt contact surface is slightly undulating with a very gentle dip to the east. This surface rises slightly in the direction of Well 6 and is also turned up abruptly at Well 2. This silt horizon appears to be draped over a mound in the sand at Well A-3.

The silt-limit boundary (Figs. 2 and 3) shows that the silt underlies nearly the entire eastern half of the site and roughly the southern one-third of the western half of the site. The silt may be seen interbedded with very fine sand in an outcrop at the top of the sand pit, 122 m (400 ft) north of Well 6.

Glacial Lake Clay

The silt is overlain in all test wells and test holes, where it occurs on the eastern half of the site, by a reddish-brown clay (laboratory analyses show the texture is dominantly a silty clay loam) which ranges in thickness from 0.6 to 11 m (2 - 37 ft). This clay is very thinly laminated with occasional, orange, iron-oxide partings and very rarely contains pebbles or cobbles. In Wells 4, 5, 7, 9, 12 and A-2 there is a transition zone below the clay that is 1.5 to 5 m (5 - 15 ft) thick, where the clay becomes progressively more silty downward before giving way to nearly pure silt. The clay-silt surface is also broadly undulating with a gentle dip to the east, a gentle rise near Well 6, and an abrupt rise near Well 2. This surface is the most nearly horizontal of any of the lithologic interfaces. The upper surface of the clay, however, shows as much as 9 m (30 ft) of local relief.

The clay in Well 12 appears to have been leached of some of its iron and is strongly mottled to grays and pinks, but maintains its textural properties, continuity, and stratigraphic position fairly well. This is the only location on the site where the glacial-lake clay appears to be altered.

An exposure of reddish-brown, silty, glacial-lake clay near Larrys Creek, 13 km (8 mi) northeast of the site, is described by Sevon (1977) as having been deposited during early Wisconsinan (Altonian) time. He also noted that the clay, which is 1.5 m (5 ft) thick and occurs at an elevation of 181 m (595 ft), has "subvertical polygonal fractures (weathering prisms)" to a depth of at least 1 m (3 ft), and fractures leached to light-gray zones. These reduced fracture zones were also observed in many of the backhoe test pits on the eastern half of the site.

The clay-limit boundary on Figures 39 and 40 shows that the clay underlies all but the northern end of the eastern half of the site, but only a 4 hectare (10-acre) area in the southwestern corner of the western half of the site. The only surface exposure of the clay unit is in the drainage ditch approximately 61 m (200 ft) north and northwest of Well 6.

Fan Gravel

The clays are overlain almost exclusively by poorly-sorted, moderately well-rounded gravel, cobbles, and boulders in a matrix of orange-brown, sandy clay loam; sandy loam; loam and silt loam with pockets of silty clay loam; and clay loam matrix, ranging in thickness from 0.6 to 8.5 m (1 - 28 ft). The sandier textures seem to dominate, however, exceptions to this are the area around Well 5, where yellow silt loam lies on the clay and Well 6, where the fan gravel has been removed by excavation. The fan gravel is composed mainly of red, purple, white, and brown sandstone with minor amounts of weathered gray siltstones and shales, and goethite concretion fragments. Occasionally it has large masses (up to 1 ton) of reddish-brown silty clay incorporated in it, as was observed in trenches in the natural renovation landfill, in Wells 4 and 7, and in Test Pits 5 and 6.

Loess Silt

Over most of the site the fan gravel is covered by 0.6- to 3.7-m- (2- to 12-ft) thick lenses of yellow to yellow-brown silt loam (laboratory analyses show the texture is dominantly a loam). These silts have been observed in trenches at the existing landfill and appear to be channel fillings with broad concave bottom surfaces. They are generally free of coarse fragments, although lenses of poorly-sorted gravels occur occasionally; are strongly mottled (gray and orange) or gleyed; and have a high cation-exchange capacity.

Geologic History of the Unconsolidated Materials at the Landfill Site

We believe the unconsolidated deposits described above comprise deposits representing a complex sedimentological history for this site within the West Branch Susquehanna River valley. This history involved fluvial, glacio-fluvial, and mass wastage processes and is summarized below.

Of the units described from this site, the basal gravel was deposited first. It filled an east-west trending bedrock channel cut when the West Branch Susquehanna River flowed parallel to the base of Bald Eagle Mountain. The basal gravel deposit was subsequently eroded by a later, north-south-trending flow path of the river which cut the bedrock lower and left behind a thinner layer of fluvial gravel. This second flow path, located east of the lined disposal area, removed the residuum and colluvium from only the channel proper, leaving some residuum/colluvium on the flanks, especially on the north edge. Poorly-sorted, loamy gravels were then deposited discontinuously to an unknown thickness by either a small lobe of glacial ice or by alluvial and/or colluvial processes over the basal gravel and residuum/colluvium. We believe these events occurred during the Pleistocene period during Illinoian time or earlier. It is unclear to us whether the alluvium on the western half of the site pre-dates, post-dates, or is contemporaneous with these events.

During a later glacial stage, the "fining-upwards" sequence of sand-silt-clay was deposited in a glacial lake, a result of ice-damming down-river. We believe the sand washed in from the east, probably from Pine Creek, and formed a deltaic deposit. Once the influx of sand ceased, the silt and clay dropped out of suspension into waters displaying progressively lower energy. The elevation of the top of the clay, which comprises the bottom of the later stage of the lake bed, is at least 190 m (620 ft).

Many of these deposits, which apparently extended to the north side of the valley, were subsequently eroded by fluvial processes following the destruction of the ice dam. It is possible that the alluvium in the western half of the site is the sediment representing this phase. The fan gravel is judged to be colluvial in origin and is presumed to have moved northward out of the gap in Bald Eagle Mountain at McElhattan Creek, scouring and engulfing large blocks of the clay and silt, and covering the alluvium to the north.

The final event in the placement of the unconsolidated materials was the deposition of the silt loam on the undulating surface of the fan gravels. It accumulated to a thickness of between 0.6 m (2 ft) and 3.7 m (12 ft). This silt loam could represent loess that was blown directly into the broad depressions on the surface of the fan gravel or it may have washed in from wind-blown deposits formed up-river.

HYDROGEOLOGY

In order to determine the range of the hydrogeologic characteristics of the various geologic materials found at the site, pumping tests were performed on selected wells throughout the landfill area. In addition, water samples were collected quarterly (every three months) for one year from these same wells to determine the background water quality. These samples were analyzed for a rather complete list of organic, inorganic, and volatile organic compounds (VOCs) known as the PADER Form 8 list of compounds.

Hydrologic Characteristics

The lowermost aquifer that potentially could be impacted by the lined site is the groundwater-flow system in the bedrock. Wells MW2, NfvV4, and MW5 are completed in the Keyser and

Tonoloway limestones, the Marcellus shale, and the Onondaga calcareous shale, respectively. Well 15 is completed in the cherty siltstones and sandstones of the Ridgeley Member. The Onondaga shaly limestone in the upper part of Well 15 has been cased off. Well 20 is open both to the Onondaga and the Ridgeley. These wells are shown on Figures 39 and 40.

The aquifer above the bedrock comprises the sand and gravel units below the overlying glacial lake silt. The geologic log for Well MW3 is not very clear on the various units it penetrated, but it appears that the 19 m (63 ft) of steel casing was set through the glacial lake clay and silt and the well bottoms in the till or buried fan gravel. Thus, the hydraulic characteristics for this well should be representative of the till or buried fan gravel. Well 5 does not penetrate the sand enough to allow pumping the well, but samples were bailed from this well to characterize the water quality in the sand. Glacial sand was collected from Test Hole 2 and analyzed for particle size and "permeability," or, in this case, the hydraulic conductivity. The hydraulic conductivity of 1.8 x 10-5 cm/sec (0.38 gpd/ft^2) is within the expected range of a silty, fine-grained sand (see Table 25).

Table 26 summarizes the data from the pumping wells used to characterize the site. The calculations used to obtain the transmissivity, hydraulic conductivity, and average linear velocity for these wells are shown in Table 27. Table 28 summarized the data from the observation wells and the calculations necessary to obtain the transmissivities. Finally, Table 29 shows the calculations used to obtain the hydraulic conductivity and average linear velocity from the observation wells.

The calculated hydraulic conductivities of 3 to 250 gpd/ft^2 for the limestone wells are on the lower end of the range for a karst limestone. These lower numbers may be related to the lack of fracturing at Wells MW2, 1, 7, and 14 and the amount of fine sediment in the fractures and solution openings in the Keyser and Tonoloway limestones.

The Marcellus shale at Well MW4 has a relatively low hydraulic conductivity of 0.2 gpd/ft^2, which is typical for this formation. The hydraulic conductivity for the shale itself may actually be even lower, since the 15-cm (6in) steel casing was perforated from 9 to 15 m (30 - 50 ft), which can allow some groundwater to leak in from the overlying unconsolidated material.

The Onondaga calcareous shale does not normally have a hydraulic conductivity as high as the 1300 gpd/ft^2 found in Well 22, but the blown yield of 50 gallons per minute (gpm) noted during drilling suggests a significant fracture zone was encountered. Also, the pumping test in Well MW5 influenced the water level 180 m (590 ft) away along strike in Well 22 in less than 20 minutes, which suggests that the hydraulic conductivity along strike is much greater than across strike.

Wells 15 and 20 as discussed above are in similar geologic settings. Most of the yield of these wells came from the Ridgeley Formation. The hydraulic conductivities of 20 and 100 gpd/ft^2 are typical of a silty sand, which is consistent with the weathered Ridgeley in this area. The only bedrock that would have higher hydraulic conductivities would be those with highly fractured or solution-widened zones.

The "gravel" found at the bottom of Well MW3 must contain a fair amount of fines to produce a hydraulic conductivity of only 0.2 gpd/ft^2. This suggests that it may in fact be the glacial till that was identified east of this area.

In summary, the hydraulic conductivity of the bedrock aquifer at the site is controlled by the amount of fracturing that has occurred. In the case of the limestone, hydraulic conductivities will be reduced where the solution and fracture zones have been filled with fine sediment from the overlying unconsolidated material. The hydraulic conductivity of the sand and gravel aquifer above the bedrock will be controlled by the amount of clay and silt found in the unconsolidated material.

The storage coefficients listed in Table 28 range from 0.00007 to 0.00069 indicating a confined aquifer (i.e., < 0.001). All the storage coefficients that were calculated were for the bedrock aquifer, so it appears that the overlying unconsolidated material provides some confining effects on the bedrock. This may also explain why Well 22 responded as it did to the pumping in Well MW5. Even though most of the paired wells (wells near each other, but drilled to different depths) and multiple-point wells show a downward verticalflow component, the bedrock at some locations is apparently confined by the overlying sediments.

The average linear velocity calculated from the wells listed in Tables 27 and 29 ranges from 3 mm to 2.7 m (0.01 - 9 ft) per day. Realistically, the flow could easily be several decimeters (feet) per day in a bedrock fracture or solution zone. Where the rock is unfractured or the unconsolidated material contains fine-grained sediments, it could take hundreds of days for groundwater to move 0.3 m (1 ft).

Water-Table Configuration

Figures 44 and 45 show the water-table configuration for November 21 and 22, 1988. These maps were produced by measuring water levels in all available wells. Where there were multiple points in one well, the highest water level was used, except for Auger Wells A-2 and A-4, since the upper levels in these wells do not represent the regional water table.

Three types of features seem to play major roles in controlling the configuration of the water table beneath the landfill site: faults, a local groundwater mound, and a steep water-table gradient. Each of these is considered below.

First, two faults bring the weathered siltstone/sandstone of the Ridgeley Member through the site in two parallel bands (see Figures 39, 40, and 41). Along the southern thrust fault, the weathered portion of the Ridgeley appears to be almost entirely overlain by the less-permeable, calcareous shale of the Onondaga Formation, which maintains a higher piezometric level that is more representative of the regional water table. The water levels in Wells 15 and 20 represent the hydraulic head levels in the Ridgeley Member, which are deeper and appear to create a "trough" in the overlying water table. The northern normal fault fully exposes the Ridgeley Member at the bedrock surface and thus creates a more dramatic groundwater trough with a gradient perpendicular to the fault.

The second feature is a groundwater mound or high point as found around Wells 2, 12 and A-I. These wells are close to conical, topographic depressions that receive recharge directly from (1) precipitation events, (2) the overflow of the perched water found in nearby closed depressions, or (3) water moving laterally along perching zones below the surface. The water levels in the conical depressions fluctuate much more than the water levels in the broad shallow depressions that perch water nearly all year long. These conical depressions serve as injection points for the perched water to move vertically downward to the regional water table; creating mounds of various heights depending on the precipitation events. These mounds can have very steep gradients associated with them. The water table between Wells 12 and 13 has a gradient of as much as 22%, but the gradient south of Well 12 could be 100% or more. Water-level measurements from Well 12 suggest that these mounds are continuously saturated and are not perched zones.

The third feature is the steep, water-table gradient, shown by closely-spaced, water-table contours in the middle of the proposed lined site (eastern portion). On the western or upgradient side of this portion of the site, the water table is above the narrow portion of the buried river channel cut in the bedrock parallel to the base of Bald Eagle Mountain. Cross section A-A' (Fig. 41) between Wells 2 and 13 shows the eastern limit of the narrow portion of the channel cut into the bedrock. The cross-sectional area of the gravel in the buried bedrock channel west of cross section A-A' is much smaller than the sand and gravel fill in the broad, buried bedrock channel east of cross section A-A.' This increase in the cross-sectional area of the highly permeable unconsolidated material evidently results in a rather abrupt lowering of the water table as groundwater flows from west to east. This change in the water table is shown on geologic cross section C-C' (Fig. 41). In the larger cross-sectional area of sand and gravel, the water-table gradients are flatter, since it does not take as much hydrostatic head to drive the water through it. Thus, the water-table configuration is influenced by the thickening and broadening of the unconsolidated material going toward the east in the buried river channel.

Table XXVI Pumping-Test Data

Well No.	Total Depth of Well	Depth to Pump Intake	Pumping Rate-Q (gpm)	Static Water Level	Water Level @ End of Test	Drawdown	Length of Test (Minutes)	Date of Test	Specific Capacity (gpm/ft)
MW 2	133	100.6	9.8	56.39	83.85	27.46	300	11-29-88	0.4
MW 3	83	46.3	3.2	16.36	43.84	27.48	60	8-16-88	0.1
MW 4	100	83.3	3.3	12.31	55.70	43.39	60	8-17-88	0.1
MW 5	122	98.1	10.6	53.44	58.49	5.05	60	11-22-88	2.1
15	120	116	10.7	72.25	75.38	3.13	70	11-21-88	3.4
20	123	116	8.4	77.18	93.93	16.75	70	11-22-88	0.5

NOTE: All measurements are in feet and from the top of the steel casing unless otherwise noted.

Table XXVII Aquifer Characteristics of Pumped Wells

Well No.	Δ s (1) (ft)	Transmissivity T (2) (gpd/ft)	Gradient i (3)	Porosity n (4)	Saturated Thickness m (5) (ft)	Hydraulic Conductivity K (6) (gpd/ft2)	Average Linear Velocity $\bar{v}$ (7) (ft/day)	Aquifer Lithology
MW 2	12.7	200	0.05	0.2	76.6	3	0.1	limestone
MW 3	19.3	40	0.06	0.4	66.6	0.6	0.01	till or buried fan gravel
MW 4	53.5	20	0.06	0.05	87.7	0.2	0.03	shale
MW 5	0.7	4000	0.01	0.1	68.6	60	0.8	calcareous shale
15	0.6	5000	0.004	0.4	47.8	100	0.1	siltstone/sandstone
20	2.0	1000	0.004	0.4	45.8	20	0.03	calcareous shale & siltstone/sandstone

(1) Amount of water level decline over 1 logarithmic cycle of water-level measurements from pumping wells (Drawdown plots are not included).

(2) $T = \dfrac{264\,Q}{\Delta\ s}$

(3) From November 21 & 22, 1988 water-table configuration map except Wells 15 and 20 which are based on the water levels compared to each other since they are in the Ridgeley sandstone trough.

(4) From: Freeze, R.A. and J.A. Cherry, 1979, GROUNDWATER, Prentice-Hall, p. 37 and the drill logs.

(5) Saturation in the well bore at the time of the pumping test.

(6) $K = \dfrac{T}{m}$

(7) $\bar{v} = \dfrac{Ki}{n\ 7.5}$

Table XXVIII Calculation of Transmissivity and Storage Coefficient in Observation Wells

Observation Well No.	Date of Test	Pumping Well	Pumping Rate Q (gpm)	Static Water Level in Observation Well (ft)	s (1) (ft)	Transmissivity T (2) (gpd/ft)	t (3) (minutes)	t (day)	r (4) (ft)	Storage Coefficient S (5)
1	11-29-88	MW 2	9.8	56.50	3.35	770	115	.080	220	.00038
7 (140' pipe)	11-29-88	MW 2	9.8	59.59	0.21	12,000	27	.019	315	.00069
22	11-22-88	MW 5	10.6	34.41	0.50	56,000	11	.0076	590	.00037
14	11-21-88	15	10.7	66.58	0.82	3,400	30	.021	550	.00007

(1) Amount of water level decline over 1 logarithmic cycle of water level measurement from observation well (Plots not included).

(2) $T = \frac{264\ Q}{\Delta s}$

(3) Time at which extension of straight line of the water-level decline hits the original static level.

(4) Distance between observation well and pumping well.

(5) $S = \frac{0.3\ T\ t_0}{r^2}$ t_0 in days

Table XXIX Aquifer Characteristics of Observations Wells

Observation Well No.	Transmissivity T (1) (gpd/ft)	Gradient i (2)	Porosity n (3)	Saturated Thickness m (4) (ft)	Hydraulic Conductivity K (5) (gpd/ft2)	Average Linear Velocity $\bar{v}$ (ft/day)	Aquifer Lithology
1	770	0.05	0.2	52.3	15	0.5	limestone
7 (140' pipe)	12,000	0.03	0.2	80.7	150	3	limestone
22	56,000	0.005	0.1	44.9	1300	9	calcareous shale
14	3,400	0.02	0.3	13.9	250	2	siltstone/sandstone and limestone

(1) From Table 6.

(2) From November 21 & 22, 1988 water-table configuration map.

(3) From: Freeze, R.A. and J.A. Cherry, 1979, GROUNDWATER, Prentice-Hall, p. 37 and the drill logs.

(4) Saturation in the well bore of the observation well at the time of the pumping test.

(5) $K = \frac{T}{m}$

(6) $\bar{v} = \frac{Ki}{n\,7.5}$

Three-Dimensional Groundwater Flow

Wells 3, 7, 9, 12 and 13 were constructed with three separate piezometers sealed at various depths in the well bore. The piezometers consist of 2.5-cm (1-in) diameter PVC screens that are 3-m (10-ft) long with a sand pack around the screen portion, and have bentonite seals above and below the sand packs. A solid, 2.5-cm (1-in) diameter PVC pipe attached to each of the screen sections provides access from the surface to measure the piezometric levels in each of the screened zones. Water levels were measured in Wells 1 through 22, including all the piezometer points, eight times from September 1987 to November 1988. The dominant vertical-flow component for the multiple-point wells is downward. In general, the vertical flow component moves from the silt and clay, where it is below the water table, to the underlying sands and gravels, to the underlying bedrock. Fluctuations in the water table, however, can alter these directions.

When Well 20, with a total depth of 38 meters (126 ft), was pumped at 0.5 l/sec (8.4 gpm) on November 22, 1988, it had 5 meters (16.75 ft) of drawdown. Well 19, which is 5.4 meters (17.7 ft) from Well 20 and has a total depth of 19 meters (63 ft), had a static water level 6.5 meters (21.4 ft) *higher* than Well 20. Well 19 experienced only 0.05 meters (0.16 ft) of drawdown during the 70 minutes of pumping of Well 20, but experienced another 0.10 meters (0.35 ft) of drawdown 2.5 hours after pumping stopped. This rather unusual behavior of an observation well points out several things. The water in Well 19 is not perched because it was influenced by pumping in Well 20. The steep hydraulic gradient of approximately 121% between Wells 19 and 20 is controlled by the large, downward, vertical gradient between the moderately permeable, weathered, silty sandstone of the Ridgeley Member and the overlying, generally less permeable, Onondaga Formation into which shallow Well 19 is completed. Thus, this steep gradient does not represent the water table. Even if the Ridgeley sandstone is not exposed at the bedrock surface, it will tend to lower the water-table found in the overlying Onondaga shale to create the groundwater trough observed in the water table (Fig. 44). The unusually large amount of drawdown in observation Well 19 after pumping stopped shows the slow response in the shale to changes in the underlying sandstone. Because the shale will drain slowly into the underlying weathered sandstone, it may be weeks until the full drainage effects of the sandstone are seen in the water table after a recharge event. The groundwater trough in the northern thrust fault will not experience this vertical drainage, since the Ridgeley is fully exposed at the bedrock surface.

The three well points in Well 3 show a consistent upward vertical component from the bedrock into the overlying gravels, except for the reading on September 22, 1987. This is probably because the water table is approximately 18 meters (60 ft) above the bedrock surface and there is approximately 18 meters (57 ft) of gravel above the bedrock, so the gravel in the buried channel becomes the conduit of flow for the water moving toward the Susquehanna River at this location. The limestone bedrock in the areas outside of the buried channel generally seems to be the dominant groundwater conduit as evidenced by the downward vertical components into it.

The multiple points in Wells 7 and 9 and paired Wells 10 and 11, however, are in the buried channel and generally indicate a downward vertical component into the bedrock. Well 7 is apparently upgradient far enough in the buried channel and the gravel is thin enough that the limestone can still act as the major conduit for flow until the water table flattens and the gravels thicken east of Well 8. There is no gravel in the area of Well 9 and the sand is only approximately 3 meters (10 ft) thick below the water table, so the limestone still acts as the conduit for flow. Wells 10 and 11 apparently are upgradient far enough in the buried channel that the limestone can still act as the major conduit of flow.

Well 12 is located at the point of recharge from the adjacent conical depression, and the water table is at least 12 meters (40 ft) above the unconsolidated sand and gravel. In most cases, the sand and gravel has the lowest piezometric level, indicating that it is the zone into which vertical flow is moving. In almost all cases, there is only 3 decimeters (a foot) or less difference in water levels between the limestone and the gravel above it. In drier conditions, there can be as much as 3 meters (10 ft) of difference in the water levels for the screens in the silt and in the gravel. This suggests that the silt has a low hydraulic conductivity, thereby requiring more head to drain it into the underlying gravel. Because Well 12 is at the recharge point, the lag times since recharge events occurred will greatly affect the water levels observed in the three pipes.

There are no gravels in the area of Well 13 and the sand is approximately 6 meters (20 ft) thick above the bedrock. During drier times, the water table is only 1.5 meters (5 ft) above the sand and the bedrock seems to be the major flow zone since it has the lowest water level. During wetter times, however, when the water table is higher in the sand, the sand seems to be the major flow zone since its water level remains lower than the water level in the bedrock.

Based on the water levels seen in both the multiple-point wells and the paired wells, the landfill site is in a recharge area. This means that the groundwater in general has a downward vertical component. From a regional standpoint, groundwater is moving down slope toward the north off Bald Eagle Mountain. The buried river channel then has a tendency to direct the flow to the east for eventual discharge into the Susquehanna River east of the site. The two groundwater troughs also help to direct flow to the east for discharge into the Susquehanna River.

SITE DEVELOPMENT ISSUES

During our investigation of the site, we needed to be aware of the geologic and hydrogeologic conditions that could impact the design and the ultimate construction of the landfill site. These conditions included: (1) what materials at the site could be used in the construction of the landfill, (2) how would the karst setting impact the stability of the site, (3) how should the site be designed to address the regulatory issues relating to the groundwater systems at the site, and (4) where should the permanent monitoring wells be installed to evaluate the performance of the site.

Regional Water Table

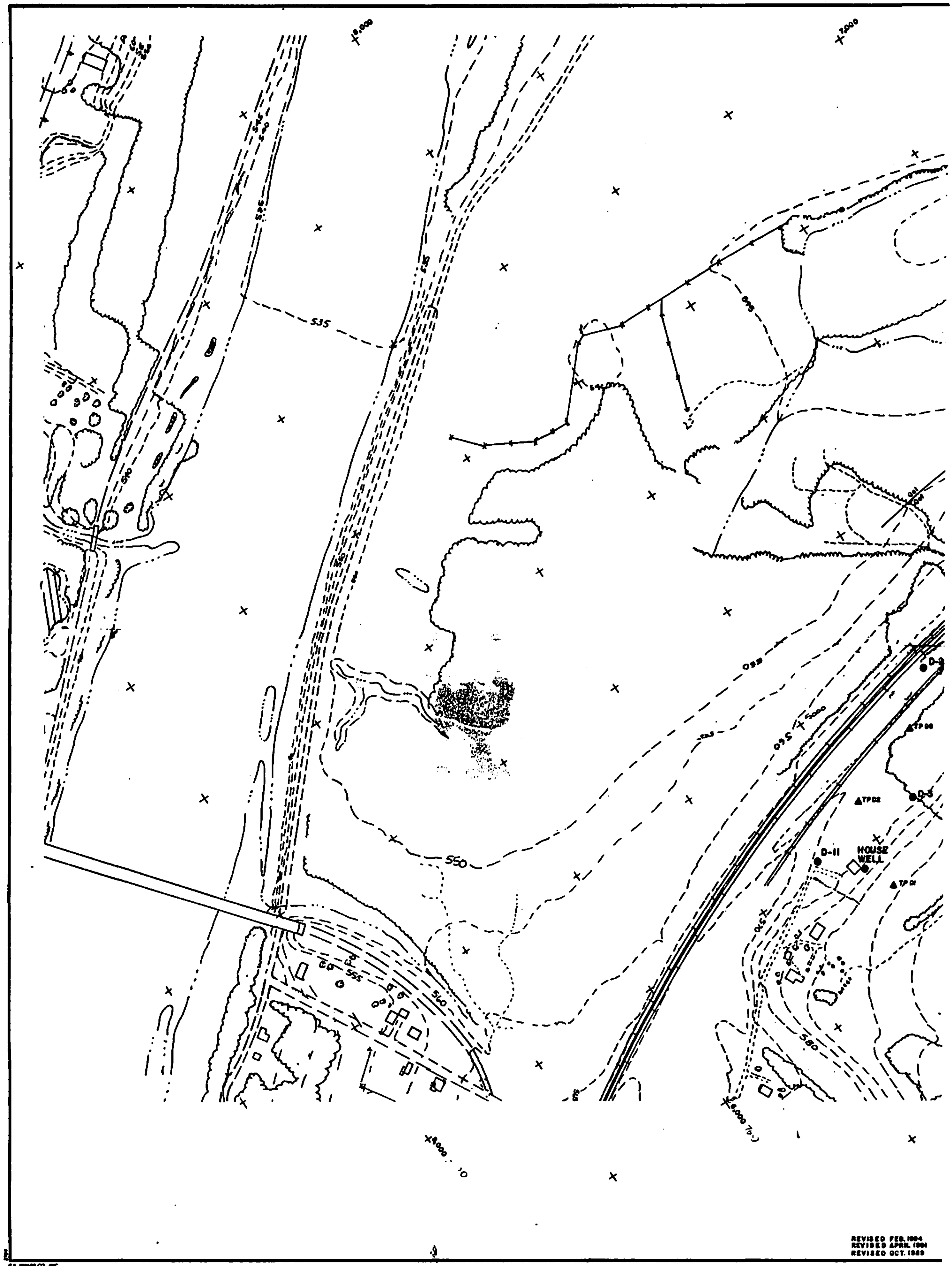
The PADER Municipal Waste Regulations require that at least 2.4 meters (8 ft) be maintained between the bottom of the subbase of the liner system and the regional water table, and the regional water table may not be artificially manipulated, i.e., lowered by any active or passive means. The depth to the regional water table ranges from as deep as 27 meters (87 ft) at Well 9 during dry conditions to as shallow as 2.7 meters (9 ft) at Well MW3 during wet conditions. Water-table fluctuations ranged from as much as 11 meters (35 ft) in Well 1 to as little as 0.5 meters (1.6 ft) in Well 21. In general, the water-table fluctuations were less than 3 meters (16 ft), and in many wells, were less than 2 meters (6 ft).

In order to comply with the 2.4-meter (8-ft) water-table separation requirement, we produced a "map" of the highest estimated, water-table configuration for the site by using the highest water-level elevations ever measured at a given well. Based on the amount of water-level fluctuation observed, the position of the well in the flow system, the depth to the water level and the geologic units penetrated by the well, an estimate of the maximum water level likely to occur above the highest observed water level was made. The design engineers for the site, Cummings & Smith, Inc., then used these maps to set the excavation grade for the site.

Perched Water

The PADER Municipal Waste Regulations require that at least 1.2 meters (4 ft) be maintained between the bottom of the subbase of the liner system and any perched water table. Gravity drainage systems may be utilized to maintain this 1.2-meter (4-ft) isolation distance, but the use of groundwater pumping systems is prohibited.

Perching of groundwater can occur throughout the fan gravel above the glacial lake clay. This is evidenced by the perched water at the surface found in many of the closed depressions, the mottled and gleyed conditions noted in the test pit logs, and, in some cases, water running into the test pits, especially in the area west of U.S. Route 220. Water observed under these conditions is perched since in almost all cases the water levels in the wells are substantially lower than the bottom of the fan gravel.



535
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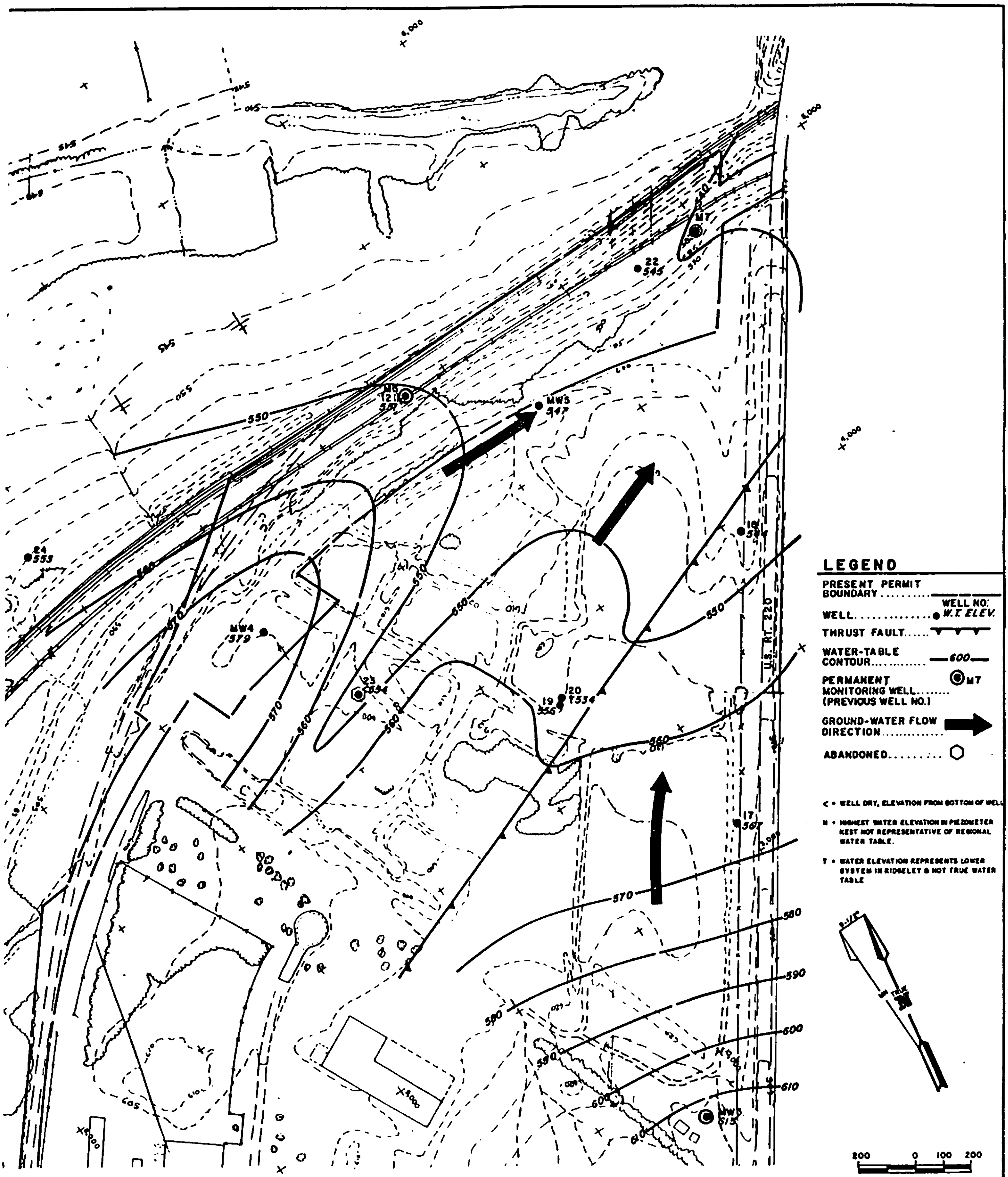
HOUSE WELL
D-11



MEISER & EARL, INC. / Hydrogeologists 1512 W. COLLEGE AVE STATE COLLEGE, PA 16801	CLINTON COUNTY SOLID WASTE AUTHORITY McELHATTAN, PENNSYLVANIA	WATER-TABLE CONFIGURATION NOV. 21 & 22, 1988
CUMMINGS & SMITH, INC. *Consulting Engineers* BRANDON, FL • UPPER MONTCLAIR, NJ HERSHEY, PA	WAYNE TOWNSHIP LANDFILL APPLICATION FOR PERMIT MODIFICATION	CRM (DRAWN) · RMH (CHECK) · APPROVALS · FEBRUARY 1989 (DATE) D (SIZE) - 8811 (PROJECT) - 6 (SUB) - 25 (NUMBER) · A (REV) · 25 OF 30 (SHEET)

Falling-head permeability tests were performed on "Shelby tube" samples of the glacial clay and silt. Shelby tubes are 9-cm (3.5-in) diameter metal tubes used to collect an undisturbed sample and allow measurement of representative permeability. The clay and much of the underlying silt had permeabilities of less than 5×10^7 cm/sec.

In order to collect any perched water above the glacial clay, a stone-filled trench with a 15-cm (6-in) diameter pipe at the bottom has been designed to ring the disposal site. The underdrain trench is beneath the liner and is approximately 30 meters (100 ft) or more from the outer edge of the liner. The trench is excavated after the final grade for the disposal area is reached. Any wet spots or seeps that exist upslope of the trench are connected to the main underdrain trench with stone and a lateral pipe to maintain the 1.2-meter (4-ft) separation. Typically, the bottom of the underdrain trench is excavated several feet into the glacial clay. Because the silt and clay has a low permeability and is stratified, it can perch some water moving vertically downward, but not transmit water laterally for any appreciable distance. The liner, however, will intercept all the recharge that could move vertically downward beneath the disposal area and the groundwater collection trench will cut off the limited amount of water moving laterally in the material above the clay.

Private Water Supplies

Based on our site investigation, we determined that the private watersupply wells of Donald Harris and John McHenry were down-gradient from the proposed lined landfill. Since these wells were more than 0.4 km (0.25 mi) from the originally permitted area, which is now also the limit of the proposed disposal area, they met the setback requirements set forth under the PADER Municipal Waste Regulations. The Municipal Waste Planning, Recycling, and Waste Reduction Act (Act 101) requires that all contiguous landowners to a municipal waste landfill have the right to have their private water supplies tested quarterly by the landfill. The CCSWA decided to connect both the Harris and McHenry homes and other nearby homeowners to the Lock Haven Municipal Water System at no expense to the homeowner. This does not reduce the CCSWA's responsibility to protect the groundwater, but it eliminates the CCSWA's cost of quarterly sampling of these wells.

Closed Depressions

The most striking topographic features at the landfill site are the closed depressions, some of which are deep and conical-shaped, such as the ones adjacent to Wells 12, 1, and A-l, which are 5 m (17 ft), 3.6 m (12 ft), and approximately 3 meters (10 ft) deep, respectively. Other depressions are relatively shallow and contain water throughout most of the year, such as those south of Well 7 and west of Well 12. As a result of the test-well drilling, it is obvious that the depressions are underlain by limestone of the Keyser and Tonoloway Formations which produce a karst or sinkhole-marked topography. The drilling also encountered some solution openings and clay-filled zones which are typical of a karst area.

We do not believe that the closed depressions at the site were created by the underlying limestone collapsing, but rather by subterranean water erosion or "piping" of sediment into the openings in the limestone. The limestone voids and/or the "pipes" to the limestone can eventually become plugged with fine-grained sediment which probably occurred in the shallow depressions at the site allowing wetlands to form in them.

The most active depression at the site from a water-flow standpoint was the conical one which was adjacent to Well 12 and received water from a second depression west of it ("Lake Wayne") during wet periods of the year. Both of these features have now been removed by excavation in preparation of the lined disposal site. The water from the conical depression appeared to have moved down through the unconsolidated material in the vicinity of Well 12 rather than in the vicinity of Well 13. This is supported by several observations. First, a groundwater mound appeared to have been centered around Well 12, with Well 13 less affected by the recharge water. Second, the clay that is normally red was more brown in Well 12, possibly caused by the water leaching out the iron. Finally, the unconsolidated deposits in Well 12 appeared to be disturbed, probably from the piping of nearby sediments.

For sinkholes to develop by piping, the underlying limestone voids typically must be above the water table. During the 14-month period of measurement, water levels were measured eight times in the 13 wells drilled into the limestone and at no time was the water table below the top of the limestone bedrock. During the same 14-month period, water levels in Wells 2, 13, 14 and 18 were within 1.5 meters (5 ft) above the top of the limestone. This suggests that most of the time, piping of sediment into the limestone bedrock will not occur, particularly since the water levels were measured during a fairly dry time. Many of the closed depressions at the site may instead have developed when the Susquehanna River was at a lower-level stage and the limestone bedrock was above the water table. We believe the closed depression between Well 12 and 13 is a karst feature that originally created a conduit into the underlying limestone. During the piping of the overlying sediments into the limestone, the clay and silt deposit above the sand and gravel was breached. The shallow-water levels suggest that the depression may no longer act as a conduit for flow into the bedrock, which may be plugged by sediment, but now allows the perched water to more easily pass through the clay and silt layer into the underlying sand and gravel.

The steep-sided conical depressions near Wells 1 and 12 are located at the edge of the buried river channel. This zone may represent a transition point where the bedrock surface is relatively shallow compared to the bedrock surface in the buried river channel. The result is that at these locations, the limestone bedrock may be in a zone of large water-table fluctuations, and therefore the water table may go below the bedrock surface under present-day conditions.

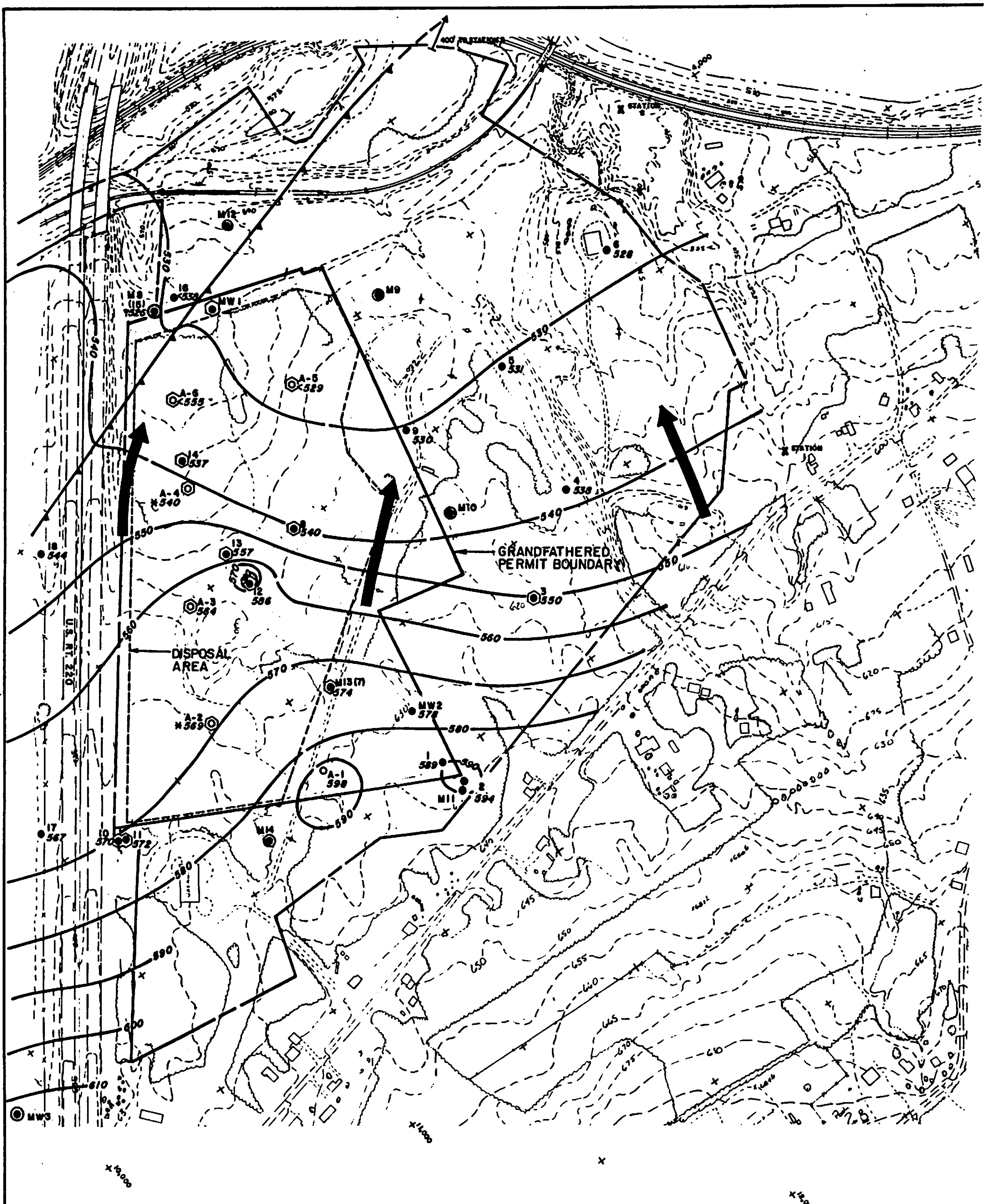
In summary, it appears that sinkhole development at this site has taken place only under very selective conditions, when the water table had dropped to an unusually low level followed by a large recharge event that transported sediment into the bedrock. It is possible that active soil piping into openings in the limestone bedrock may no longer be occurring within the proposed lined area east of US Route 220. The site is utilizing two synthetic liners that will collect recharge beneath the liner and thus eliminate the piping process which created the depressions.

Bedrock Stability

Fifteen wells were drilled 6 meters (19 ft) or more into the limestone bedrock at the site to determine the nature of the limestone bedrock. It was our intent to log any voids wherever possible even though they may have been partially or completely filled with sediment; however, only two voids were encountered. In Well 12, a possible void occurred from 33.8 to 34 meters (111 - 112.5 ft); and in Well 13, a void was noted at 19.5 to 19.8 meters (64 - 65 ft) even though there was no loss of air circulation and the drill stem did not drop in either well. In Well 1 we noted that there was no return of cuttings from 23.3 to 23.8 meters (76.5 - 78 ft), but this was due to the plastic nature of the material encountered, not because of a possible void. Well M11 encountered several 0.3- to 0.6-meter (1- to 2-ft) gravel-filled openings between 20.2 meters (66.5 ft) and 24.7 meters (81 ft).

Thirteen test holes were drilled in October of 1990 to establish the position and extent of the limestone which had been encountered in the excavation for the 1-meter (3-ft) stormwater drain. Two of these test holes (12-90 and 13-90) were drilled into the Keyser/Tonoloway limestone to refine the position of the eastern-most thrust fault, but only Test Hole 13-90 encountered a soft zone in the limestone. This zone, from 25.3 to 28.2 meters (83 - 92.5 ft), drilled like silt, but there were no cuttings circulated to the surface. We interpret this zone as either a silt-filled opening or weathered stratigraphic horizon composed of carbonate silt. Test Hole 1-90, drilled into the Shriver Limestone interbed, showed several 0.3- or 0.6-meter (1- or 2-ft) sand and gravel-filled openings.

Solution features were encountered in eleven different wells and one test hole. Solution features represent zones where the limestone has been dissolved, generally creating a smooth weathered surface that appears water worn. These features can develop in openings as small as 1.3 cm (0.5 in), as observed in outcrops east of the site. Solution features by themselves do not create a stability problem, but do indicate the ability of the bedrock to dissolve or weather over time. Large solution features were logged as voids or clay-filled zones.


GRANDFATHERED PERMIT BOUNDARY
DISPOSAL AREA
U.S. RT. 220
MW1
MW2
MW3
M9
M10
M11
M12
M13 (7)
M14
A-1
A-2
A-3
A-4
A-5
A-6
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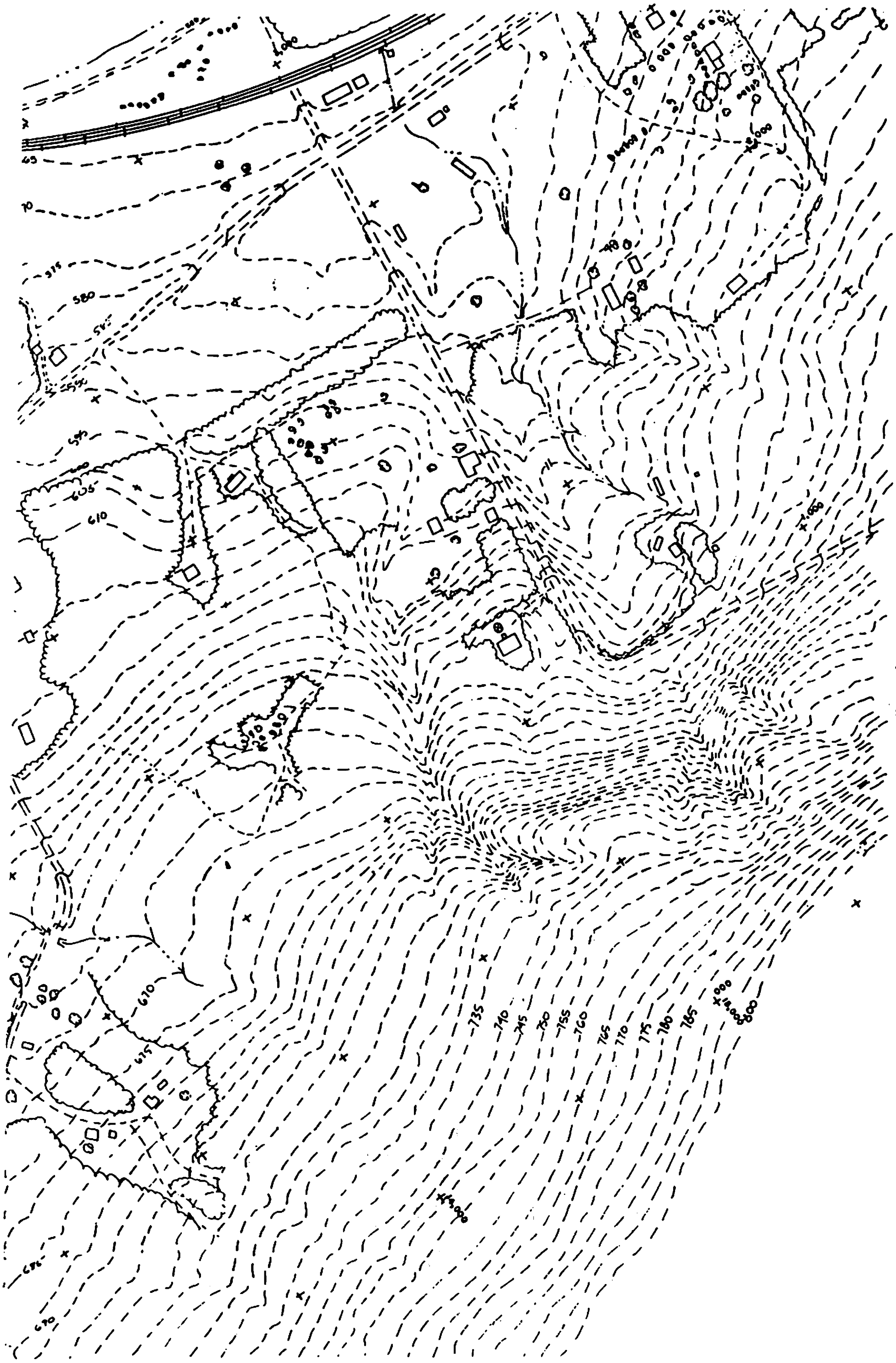
REVISED FEB. 1994
REVISED APRIL 1991
REVISED OCT. 1989



LEGEND

PERMANENT PERMIT BOUNDARY..........

WELL.............. WELL NO. W.T. ELEV.

THRUST FAULT.....

WATER-TABLE CONTOUR........... 600

PROPOSED MONITORING WELL.. (PREVIOUS WELL NO.) M4

SURFACE WATER SAMPLING POINT... X STATION 1

GROUND-WATER FLOW DIRECTION

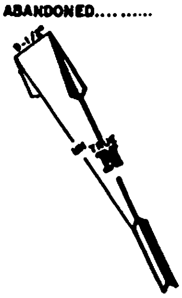
PERM. MONITORING WELL (PREV. WELL NO.) M12

< = WELL DRY, ELEVATION FROM BOTTOM OF WELL

H = HIGHEST WATER ELEVATION IN PIEZOMETER NEST NOT REPRESENTATIVE OF REGIONAL WATER TABLE

Y = WATER ELEVATION REPRESENTS LOWER SYSTEM IN RIDGELEY & NOT TRUE WATER TABLE

ABANDONED..........



200 0 100 200

SCALE (feet)

MEISER & EARL, INC. / Hydrogeologists 1512 W. COLLEGE AVE. STATE COLLEGE, PA 16801	CLINTON COUNTY SOLID WASTE AUTHORITY McELHATTAN, PENNSYLVANIA	WATER-TABLE CONFIGURATION NOV. 21 & 22, 1988
CUMMINGS & SMITH, INC. Consulting Engineers BRANDON, FL • UPPER MONTCLAIR, NJ HERSHEY, PA	WAYNE TOWNSHIP LANDFILL APPLICATION FOR PERMIT MODIFICATION	

DRAWN	CHECK	APPROVALS			DATE
CRM	RMH				FEBRUARY 1989

SIZE	PROJECT	SUBJ	NUMBER	REV	SHEET
D	8811	6	26	A	26 of 30

Fracture zones indicate where the bedrock has been broken either by closely spaced jointing or, less commonly, by faulting. Fracture zones occur in all types of bedrock in all geologic settings. Weathered zones are beds or fractures that have begun to chemically decompose or break down to a less competent state. We did not make a distinction between fracture zones and weathered zones. These zones can be areas of weakness, but due to their position between competent rocks and beneath great thicknesses of unconsolidated materials at this site, we do not see a load-failure problem associated with the fracture zones.

As a result of all of our test drilling at the site, we would not predict a failure of the bedrock that would compromise the integrity of the liners to contain the leachate.

On-Site Materials as Landfill Construction Materials

Due to the variety and consistency of the natural unconsolidated materials found at the site, several were tested to see if they could be used in the construction of the landfill liner system or as landfill cover material.

The Landfill Subbase is a 15-cm- (6-in-) thick layer of compacted soil that is placed beneath the secondary or bottom-most liner. Requirements that it must meet include: (1) be free of rock, plant debris, and other foreign material; (2) have a minimum bearing capacity of 3.2×10^6 kgs per square meter (4500 lbs per ft^2); and (3) be no more permeable than 1×10^{-5} cm/sec. The glacial lake silt and clay meet all the subbase criteria and, in particular, the compacted permeability is generally less than 1×10^{-6} cm/sec. The permeability, however, is not low enough to meet the remolded clay liner criterion of 1×10^{-7} cm/sec.

The Landfill Detection Zone is a 30.5-cm- (12-in-) thick layer between the secondary and primary liner. The Protective Cover is similar to the detection zone material except it is 45.7-cm (18-in) thick and is on top of the primary liner. Both of these materials must be at least as permeable as 1×10^{-2} cm/sec, and meet several other requirements. Initially, we had hoped that the glacial sand would be suitable, but laboratory tests showed that the sand had a permeability of less than 2×10^{-5} cm/sec. The fine texture of the sand, along with the 10% to 20% silt and clay made the sand too impermeable for use as flow-zone material.

The Landfill Cover Soil is used in 15-cm (6-in) layers to cover the exposed waste at the end of each day and in 30.5-cm (12-in) layers on waste that has reached a 2.4-meter (8-ft) thickness or on areas that will not receive additional waste for six months or more. Landfill cover soil must: (1) fall within the US Department of Agriculture textural classes of sandy loam, loam, sandy clay loam, silty clay loam, loamy sand, and silt loam; (2) have at least 40% by weight particles capable of passing a 2 millimeter (No. 10 sieve); (3) contain no more than 12% by weight of combustible or coal content; and (4) contain no rock fragments greater than 15-cm (6 in) in diameter. The only materials at the site that do not meet the textural requirements are the glacial clay and the fan gravel, which require screening to eliminate the 15-cm (6 in) diameter fragments and to reduce the overall coarse-fragment percentage to less than 60%. Figure 43 shows the textural classifications and coarse-fragment percentage of each unconsolidated unit. Due to the depth of the excavation for the lined area, which approaches 12+ meters (40 ft), there is excess cover soil available at the site.

Groundwater Quality

The background groundwater monitoring network consisted of Wells MW2, MW3, MW4, MW5, 5, 15, and 20, as shown on Figures 39 and 40. Water samples were collected from these wells in May, August, and November 1988 and February 1989 and were analyzed for 67 parameters, 37 of which were volatile organic compounds (VOCs). None of these samples indicated any obvious impact from the existing natural-renovation landfill, including Well 20, which is located in the center of that landfill. The most sensitive indicators of landfill contamination are the VOCs and none of the water samples from any of the wells detected any of these compounds.

Well MW3 does have elevated chlorides and sodium, and slightly elevated nitrate-nitrogen concentrations. Well MW3 is the most upgradient well at the site, so we believe that these elevated levels derive from the ditch that is approximately 46 meters (150 ft) east of Well MW3 and carries runoff including road salt from US Route 220. In general, Well MW3 should represent the water quality of the gravels below the glacial lake silt. Except for the elevated total dissolved solids (TDS), sodium and chlorides in Well MW3, and the naturally occurring iron and/or manganese found in most of the other wells, the water quality of the background monitoring wells meets the USEPA drinking water standards.

Well MW-2 seems to have water quality typical of a limestone bedrock with elevated bicarbonate and TDS. All the other wells contain water with little or no distinctive water-quality characteristics.

Permanent Groundwater Monitoring Plan

Based on the extensive groundwater investigation, Wells MW3, M6, M7, M8, M9, MIO, M12, and M14 were selected as the permanent groundwater monitoring system for both the natural renovation site (western half) and the lined site (eastern half). These wells are shown on Figures 39 and 40. Table 30 summarizes the geologic and construction details. Each well is fitted with a dedicated Grundfos Redi-Flo 2, 5-cm (2-in) diameter, submersible pump. These pumps utilize a frequency controller to vary the speed of the pump from 2300 to 23,000 rpm and can pump as much as 0.4 to 0.5 l per sec (7 - 8 gpm) for purging, and be slowed down to approximately 0.006 l per sec (0.1 gpm) for sampling.

Wells MW3 and M14 are the only wells upgradient of the waste disposal areas. Wells M7 and M8 are in the groundwater trough (Figs. 44 and 45) associated with thrust faults (Figs. 39 and 40). These wells are completed in the Ridgeley sandstone, one of the most conductive bedrock units found at the site. Table 31 summarizes the aquifer characteristics of the permanent monitoring wells from short-term pumping tests. Well 12 is completed in the Shriver siltstone/shale/limestone, which appears to be the well with the highest hydraulic conductivity found at the site. Wells M9 and MIO are completed in the Keyser and Tonoloway limestones, which also have relatively high hydraulic conductivities and thus should respond quickly to any releases that may occur at the site.

Table XXX Permanent Monitoring Wells Geologic and Construction Details

Well No.	(1) Total Depth (feet)	Steel Casing Above Ground (feet)	Casing Material	Diameter (inches)	Screened Interval (feet)	Typical Depth to Water	Saturated Zone (feet)	Geologic Material
MW3	84	1.8	steel	6	63 - 83 (2)	15	0 - 50	fan gravel
							50 - 83	clay/silt
MW6	78.7	2.5	PVC	4	17 - 77	27	25 - 48	weathered shale
							48 - 76	gray shale (Marcellus)
MW7	89.7	2.0	PVC	4	28.5 - 88	52	19 - 88	weathered sandstone (Ridgeley)
MW8	119.5	1.8	PVC	4	58.5 - 118	71	59 - 109	weathered black shale (Onondaga)
							109 - 120	weathered tan siltstone (Ridgeley)
MW9	118.8	1.9	PVC	4	58 - 117.5	87	34 - 100	glacial sand
							100 - 117	limestone (Keyser/Tonoloway)
MW10	119.6	1.9	PVC	4	58 - 118.5	84	67 - 118	limestone (Keyser/Tonoloway)
MW12	112.7	2.4	PVC	4	46 - 114	58	58 - 72	silty shale (Shriver)
							72 - 94	limestone (Shriver)
							94 - 109	black shale (Shriver)
							109 - 114	sandstone chert (Shriver)
MW14	101.2	2.0	PVC	4	29 - 100	35	33 - 45	glacial sand (Shriver)
							45 - 90	till
							90 - 99	limestone (Keyser/Tonoloway)
							90 - 99	limestone (Keyser/Tonoloway)

(1) Measurement from top of steel casing; all other measurements from ground level.
(2) Torch slotted steel casing.

Table XXXI. Permanent Monitoring Wells Aquifer Characteristics.

Monitoring Well No.	Δs (1) (feet)	Transmissivity T (2) (gpd/feet)	Saturated Thickness m (3) (feet)	Hydraulic Conductivity K (4) (gpd/feet^2)
MW3	19.3	40	67	0.6
M6	82.5	7	53	0.1
M7	0.5	5,600	41	140
M8	0.5	5,300	51	100
M9	1.5	1,700	35	50
M10	4.0	650	42	20
M12	0.3	18,000	57	320
M14	6.4	250	56	4

(1) Amount of water-level decline over 1 logarithmic cycle of water-level measurements from pumping wells.

(2) $$T = \frac{264\ Q}{\Delta s}$$

(3) Saturation in the well bore at the time of the pumping test.

(4) $$K = \frac{T}{m}$$

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EARLY PLEISTOCENE GLACIAL LAKE LESLEY DEPOSITS AT MCELHATTAN, CLINTON COUNTY, PENNSYLVANIA

Joan M. Ramage[1]

INTRODUCTION

Pleistocene ice sheets have repeatedly extended into north central Pennsylvania, leaving a complex record of advances and retreats. Pre-Late Pleistocene glaciation in the Williamsport area in the central Susquehanna River Basin extended well beyond any Late Pleistocene glaciations (Williams, 1920; Levererr, 1934; Baxter, 1983; Braun, 1993). However, the terminal position and ages are poorly constrained (Fig. 46). Recent work in the West Branch Susquehanna River (WBSR) valley (Gardner et. al., 1994) suggests that ice reached at least as far as Antes Fort, (Gardner et al., 1994) ~50 km up the WBSR valley and possibly as far as Lock Haven (Fig. 46) (Baxter, 1983; Braun, 1993), blocked the outlet at the nose of Bald Eagle Mountain near Williamsport, and created a proglacial lake.

Recently exposed sediments in the WBSR valley, especially at the Wayne Township Landfill at McElhattan, Clinton County, and the demonstrated utility of paleomagnetism to constrain age (Gardner et. al., 1994) give an opportunity to explore in greater detail the complex history of glaciation and proglacial lakes in the WBSR valley. Here I focus on the Early Pleistocene proglacial lake, Glacial Lake Lesley, which was first proposed by Williams (1895) as a deep lake filling the WBSR valley, and I use detailed stratigraphic sections of fluvial and glaciolacustrine deposits to reconstruct the depositional environment of Glacial Lake Lesley and detrital remnant magnetism to constrain the age range of the lake.

The age and extent, in terms of depth and elevation, of the ice-dammed proglacial lake are controversial, in part, because repeated Pleistocene glaciations of the region may have caused ponding in the WBSR more than once (Bucek, 1975). Lack of radiometric age control on deposits in the region and cryoturbation and colluviation of sediments during subsequent periglacial climates also contribute to the complex and controversial record. The maximum elevation of any proglacial lake is controlled by the lowest elevation along the drainage divide, upstream of the ice dam. In central Pennsylvania, this occurs at an altitude of ~340 meters at Dix, Pennsylvania, along the drainage divide between the Juniata River valley and Bald Eagle Creek, a tributary of the WBSR (Fig. 46). It was originally proposed that Glacial Lake Lesley reached its maximum elevation and "discharged a deep torrent through the Juniata" (Williams, 1895, p. 184). Glacial Lake Lesley at its maximum elevation of approximately 340 meters would have filled Bald Eagle Creek Valley, parts of Nittany Valley, and the WBSR Valley as well as many side tributaries. It would have been up to ~100 km long, contained about 100 km^3 of water, and had a depth of over 150 meters at the downstream end near Williamsport (Fig. 47; Sevon, 1994).

STRATIGRAPHY OF GLACIAL LAKE LESLEY

Glaciofluvial and proglacial-lacustrine sediments in the WBSR valley contain a record of deposition during glaciation and ice damming. Paleomagnetically reversed lacustrine beds at Antes Fort (Fig. 46) which interfinger with till establish that there was glaciation and a proglacial lake in the WBSR, probably at the end of Matuyama Reversed Polarity Chron during the Early Pleistocene (Gardner et. al., 1994). Glacial Lake Lesley sediments were deposited primarily at the mouths of Susquehanna River tributaries and buried under alluvial fan material (especially at Antes Fort and McElhattan). Any Early Pleistocene lacustrine sediment deposits which may have existed along the ridge slopes have been buried or destroyed by colluviation during subsequent periglaciation.

Deposits at McElhattan and Linden, combined with the evidence from Antes Fort, provide the best sedimentary record of Early Pleistocene Glacial Lake Lesley. Extensive deposits at McElhattan

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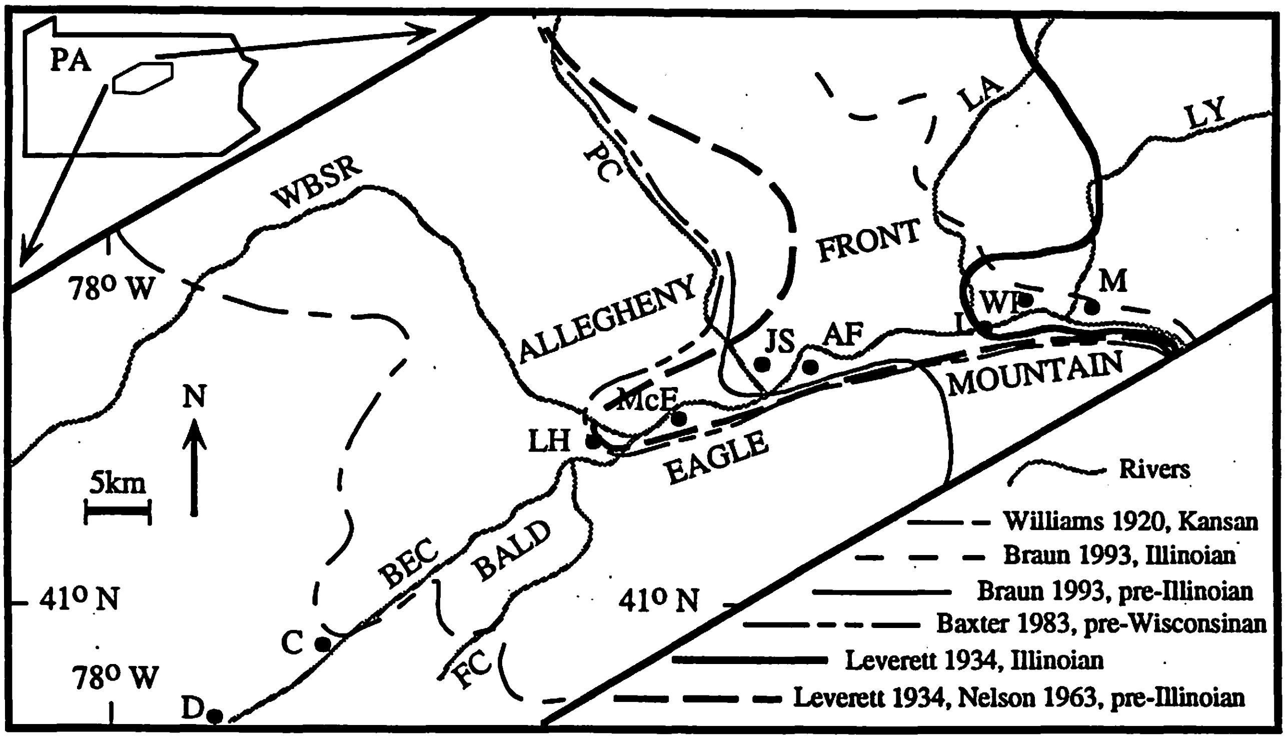

Figure 46. Map showing site locations and pre-Late Pleistocene glacial boundaries in the West Branch Susquehanna River Valley (WBSR). AF, Antes Fort; BEC, Bald Eagle Creek; C, Curtin; D, Dix; FC, Fishing Creek; JS, Jersey Shore; L, Linden; LH, Lock Haven; LO, Loyalsock Creek; LY, Lycoming Creek; M, Mountoursville; PC, Pine Creek; WP, Williamsport (modified from Gardner and others, 1994).

(Figs. 46 and 47) have been exposed recently in excavations at the Wayne Township Landfill, located on the McElhattan Run alluvial fan in the WBSR valley. At McElhattan, the unit overlying a bedrock unconformity is a diamicton which contains striated boulders and was reported to be till (Meiser and Earl, 1989). Above the till, up to 40 meters of sediments fine upward from stratified sands to laminated silt and clay, and are overlain unconformably by a diamicton (Fig. 48). There is no evidence of an erosional unconformity in the sediments from the base of the stratigraphic section described here to the beginning of the upper diamicton.

The lowest exposed sedimentary units at McElhattan are located at section A (Figs. 48, 49) and consist mainly of medium- to well-sorted sands that either coarsen or fine upwards. Some beds contain ripple- and trough-crossbedding and planar bedding. Sand beds between 166 and 171 meters are also interrupted by occasional laminated silt and clay beds up to 2 cm thick. Facies 1A is characterized by medium, rounded sands in 5-10 cm-scale fining-upward cycles with cm-scale trough- or ripplecross-stratification (Fig. 49). Facies 1B is massive, well-sorted, well-rounded, medium sands which grade upward into clayey silt (Fig. 49). Facies 1C is coarse, rounded to subrounded sands which normally grade upward into fine sands and commonly display low-angle cross stratification (Fig. 49). Interspersed between and above the crossbedded sands are units of clay and fine silt beds which display mm-scale parallel laminae and mottles.

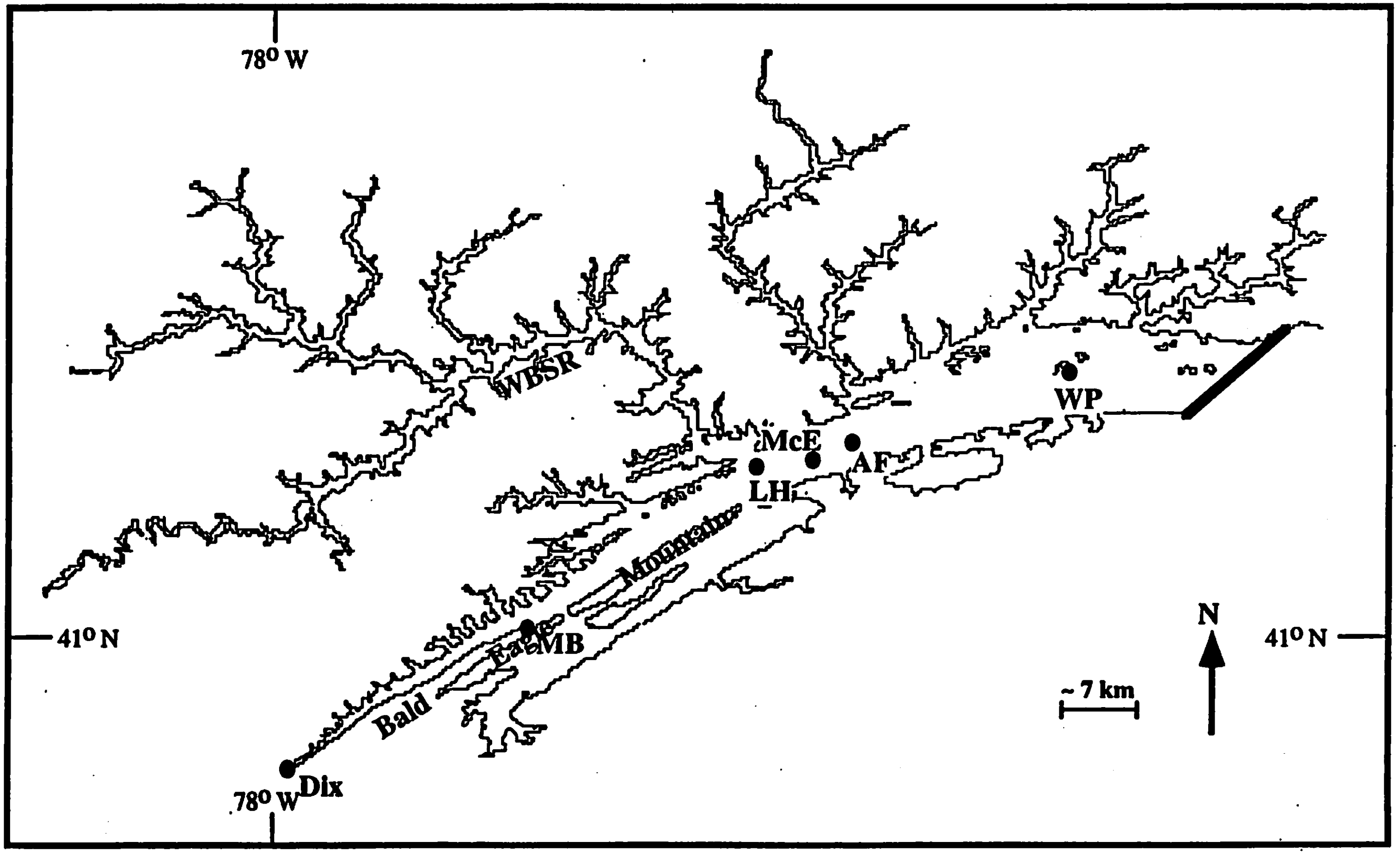

Figure 47. Extent of Glacial Lake Lesley at maximum elevation of ~340 m, controlled by the lowest drainage divide elevation at Dix. The heavy line indicates approximate location of the ice dam. AF, Antes Fort; LH, Lock Haven; McE, McElhattan; WP, Williamsport (modified from Sevon, 1994).

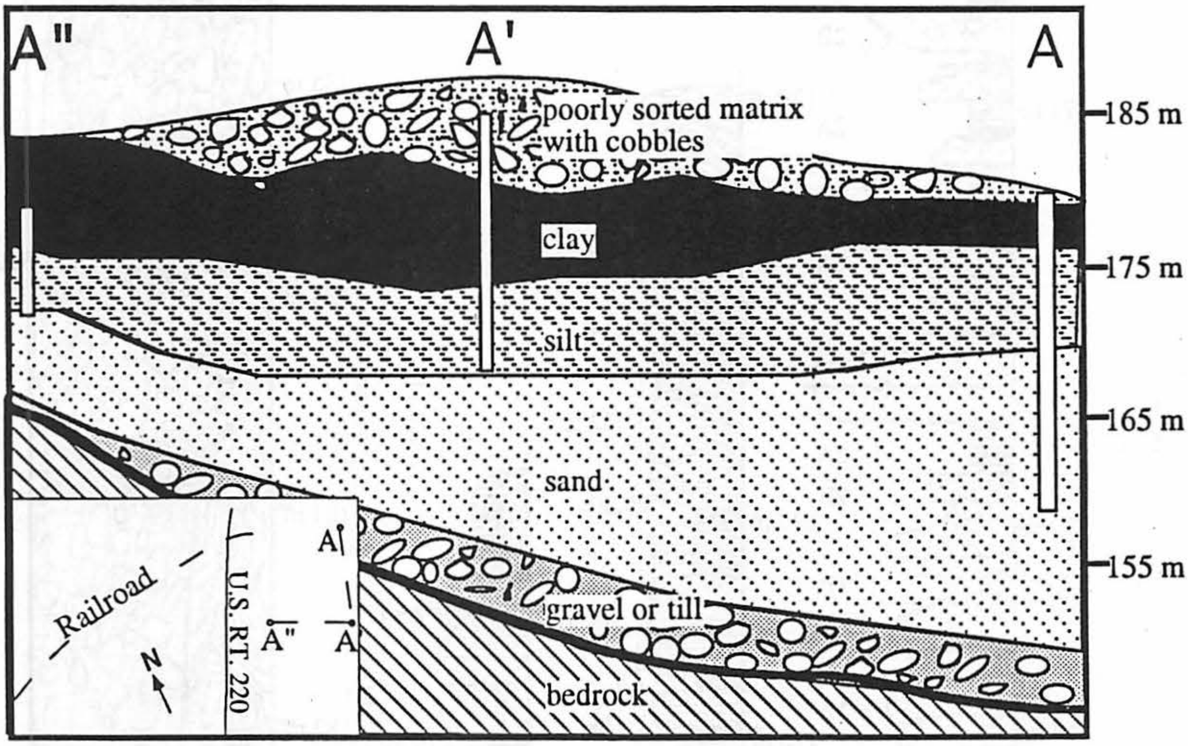

Figure 48. Summary diagram illustrating major facies exposed at Wayne Township Landfill, McElhattan. Sections A, A', & A" give locations of detailed stratigraphic sections in Figure 50. Inset is detail of stratigraphic column locations at Clinton County Landfill on south side of WBSR near McElhattan Creek (modified from Meiser and Earl, 1989).

Facies 2A is characterized by dm-scale interbedding of clays and silts, some of which display parallel laminations up to 2 mm thick and some of which display massive character. Locally, they may contain pebbles, but no disruption of parallel lamination was observed. Silt color is 2.5YR 4/6 changing to 7.5YR 5/8 in the clay. Facies 2B contains fine to medium sand units with larger (> 2 cm) rock fragments of shale and sandstone which make up 1 to 3% of the unit. One sand bed contains numerous (~20%) striated and faceted pebbles. Some layers contain small lithic clasts of mixed lithology. The relative abundance of fine-grained, laminated and massive units increases upsection and there are fewer and thinner sand beds. Finer-grained sediments above the crossbedded sands and interbedded sands, silts, and clays at 173 meters were described at sections A' and A" (Figs. 48, 49).

Facies 3 consists of finely laminated silt beds which generally fine upward to fine silt or clay. Bed thickness ranges from mm-scale laminae to beds as thick as 2 or 3 cm. Massive clay beds of up to 3 cm are interbedded between silt layers. The dominant color is dark red-brown (7.5YR 5/8). There are occasional sand beds between 173 and 174 meters. Beds are parallel, sub-horizontal with a dip of about 20°SW, and are predominantly laterally continuous, although traceable beds do display occasional normal faulting. Offset is generally not greater than one centimeter. Massive clay units become more frequent between 175 and 177 meters. Thin sections from samples 11, 13, and 25 display well bedded, fining-upward silt laminae with some thin beds of coarse sand or clay interspersed (Ramage, 1995). Occasional pebbles were noted, as was one group of small angular to subrounded heterolithic pebbles in a dense, yellow (10YR 5/8) clay matrix.

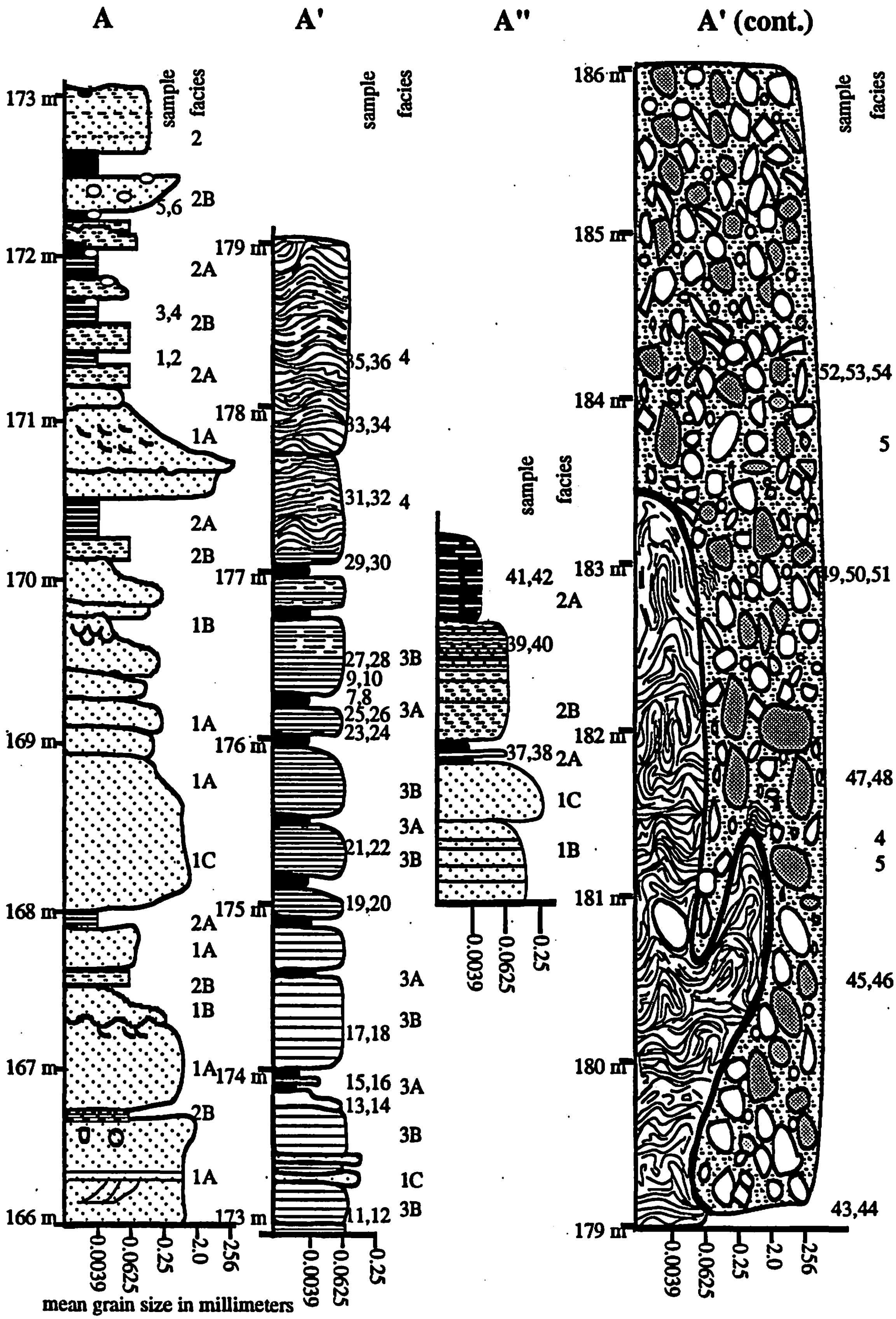

Figure 49. Composite stratigraphic section, McElhattan, Pennsylvania. Altitudes are shown to the left of each column. Sample identification and facies references are to the right of each column. Grain sizes are in millimeters. See Figure 49 for explanation of symbols and Figure 48 for location of stratigraphic columns.

Facies 4 ranges from interbedded silt and clay laminae which are laterally discontinuous (between 176 and 177 meters) to silt and clay laminae which become increasingly discontinuous toward the top of the section. Parallel bedding is lost, and sediments above 176 meters are increasingly convoluted and irregular. In detail, the laminations become increasingly discontinuous and convoluted tom 177 to 183.5 meters. Color of deformed sediments is similar to the laminated sediments below (7.5YR 5/8). Deformation of bedding is visible in outcrop and in thin sections from the same stratigraphic interval. Thin sections at locations 43 and 45 show faulted, discontinuous areas several millimeters across within which bedding is visible. No bedding is preserved in thin sections from samples 47 and 49 (Ramage, 1995). However, there are variations in grain size in zones across the slides.

The laminated silt and clay unit and the convoluted silt and clay are overlain unconformably by a diamicton (Facies 5). Facies 5 contains angular to subangular cobbles in a coarse, poorly sorted, sandy matrix. Some parts are clast supported, and others are matrix supported. Lithology is homogeneous; most clasts are of local origin, and many are likely from the Tuscarora Formation. Clasts show a range of weathering characteristics—some are only slightly weathered except for a thin rind, whereas a few are "ghost" clasts.

The upper 6.5 meters of laminated silt and clay (from 177 m to 183.5 m) at McElhattan are deformed at two scales. At the outcrop scale, the contact between the laminated silt and clay unit and the overlying diamicton is irregular and undulating in three dimensions, and there are zones of mixed cobbles and clay (Figs. 3, 4, 5). Cobbles are mixed into the silt and clay unit to a depth of 0.5 meters. Silt and clay fragments are mixed into the diamicton to 1.5 meters. Undulations have a wavelength of ranging from 30 to 40 meters and a height of about 5 meters.

INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS

The sedimentary sequence at McElhattan is interpreted to determine the environment of deposition. The thickness of units, roundness of grains, and sedimentary structures all suggest that the lower part of the exposed sequence (from 166 m to 171 m) is of glaciofluvial origin. Clay and silt at the top of massive, medium sand beds implies local ponded areas or incipient lacustrine deposition that subsequently became more established.

The zone of interbedded sands, silts, and clays above the crossbedded sands contains some coarse clasts; these beds may contain primary or reworked glacial-outwash deposits, although only one sand bed contains possible glaciogenic pebbles. The coarse bed at ~172.3 meters contains numerous striated and faceted pebbles and has about 20% coarse-grained material. Some layers contain striated and faceted cobbles and pebbles and indicate proximity to a glacial source; isolated pebbles may be dropstones. The group of heterolithic pebbles in a dense, fine-grained matrix is interpreted to be a till dropstone. The silts and clays may be lacustrine beds from an early phase of a proglacial lake which is still very much affected by fluctuations in sediment load and flow velocity. The thickness and uniformity of undeformed mm-scale silt and clay laminae and their stratigraphic position in an overall fining-upward succession is evidence for a lacustrine depositional setting. The transition from coarse, stratified sand to finely-bedded silts and clays at McElhattan reflects an overall deepening of the lake as it filled and an increasing distance from the sediment source with time. Extensive fine deposits could indicate a long stand at high elevation, perhaps at the maximum. The sedimentation rate or interval represented by each layer is not known. They may be annual, semi-annual, daily or intermittent.

The lacustrine beds are overlain unconformably by a diamicton containing locally derived, angular and rounded sandstone clasts in a poorly-sorted, sandy matrix. The diamicton is interpreted as an alluvial-fan deposit derived from McElhattan Run and may have been deposited rapidly by mass movements.

Deformation of the laminated silts and clays at McElhattan on two scales may be a result of progradation of alluvial-fan deposits across saturated lacustrine deposits. Differential loading by the overlying diamicton and partial fluidization probably caused the deformation seen as the irregular contact and the discontinuous, convoluted bedding. Laterally-continuous sand beds show that there was flow in the clay unit during deformation (Fig. 50). Rapid alluvial-fan progradation, as a result of

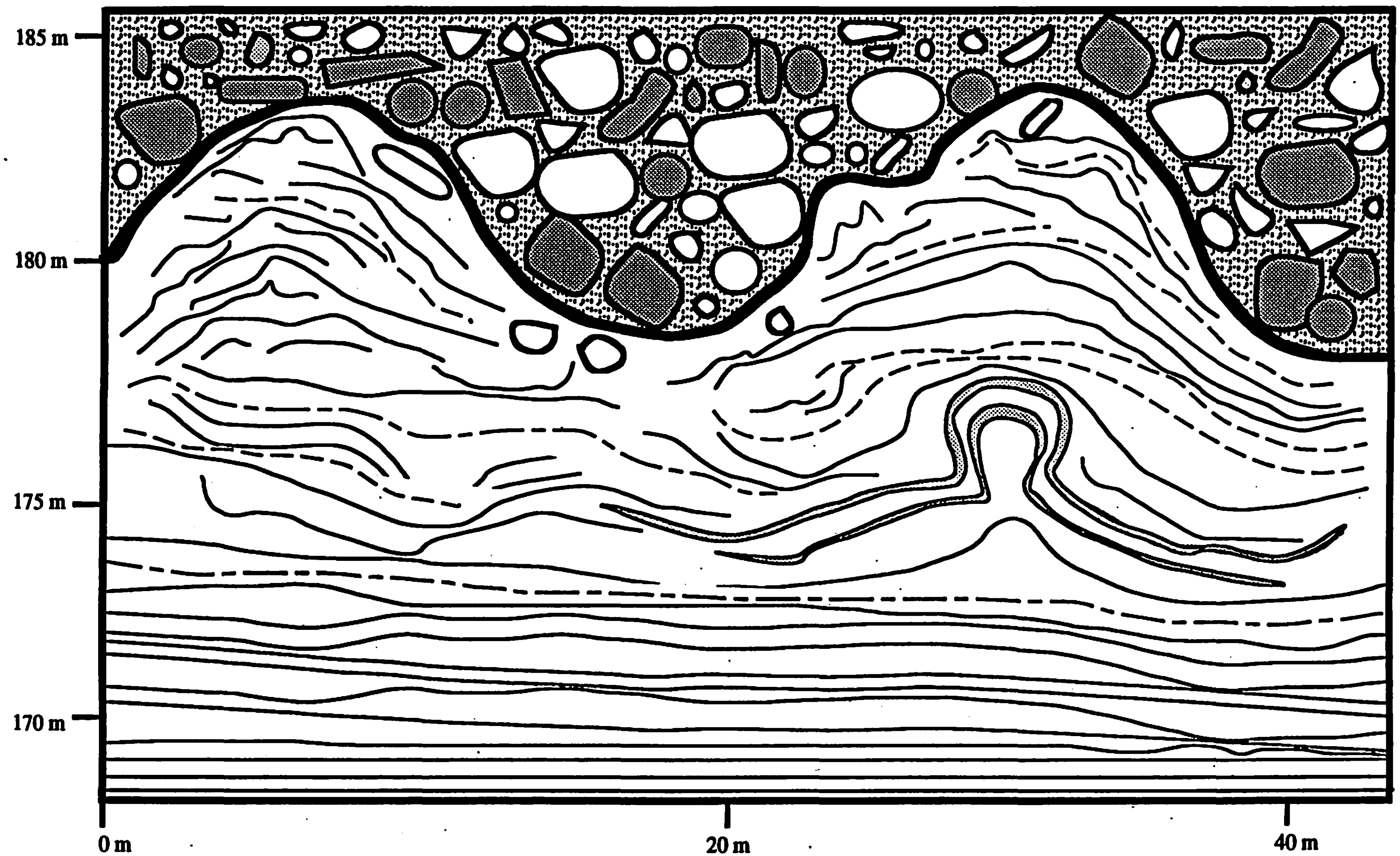

Figure 50. Schematic diagram of deformation due to differential loading and partial fluidization at McElhattan. See Figure 49 for a detailed stratigraphic section.

the drop in local base level when Glacial Lake Lesley drained, caused the loading which deformed the upper sediments. Alluvial-fan deposits which deformed saturated lake beds must have been deposited as the lake drained or shortly thereafter, rather than before drainage, for no *in situ* clay beds are preserved in the coarse tan material. Thus, the unconformity separating the glacio-lacustrine sediments from the overlying diamicton may be a disconformity.

Brittle faulting and tilting in the Quaternary sediments is probably due to subsequent and possibly ongoing karst collapse at the site. The glacial, fluvial, and glacio-lacustrine sediments overlie limestones of the Keyser and Tonoloway Formations which, under similar geologic conditions, have developed karst features at the surface (Meiser and Earl, 1989).

PALEOMAGNETIC DATA AND INTERPRETATIONS

While attention to the stratigraphy at McElhattan reveals numerous details about local environments surrounding Glacial Lake Lesley over time, another method must be used to establish when Glacial Lake Lesley filled the West Branch Susquehanna River and Bald Eagle Creek valley Paleomagnetic orientations of magnetic minerals in the sediment and the chronology of Pleistocene changes in the Earth's magnetic field constrain the age of Glacial Lake Lesley.

Fine-grained deposits which retain detrital remanent magnetism (DRM) record the Earth's polarity at the time of sediment deposition. Pairs or triplets of oriented samples (volume: 8-cm^3 plastic cubes) were collected from the finer-grained beds in all stratigraphic sections. Characteristic remanent magnetism (ChRM) was measured with a cryogenic magnetometer at the University of Pittsburgh's Paleomagnetism laboratory by Dr. Ira Sasowsky using alternating field (AF) demagnetization. Paleomagnetic data are displayed as vector endpoint diagrams (Zijderveld, 1967) to determine whether sample pairs were comparable and to determine the demagnetization strengths of interest for principal components analysis (Kirshvink, 1980). Site mean characteristics were calculated after Fisher (1953) and displayed as pole plots.

At McElhattan, samples 1 through 30 were from parallel-laminated beds in the lower part of the stratigraphic section (Fig. 49; 166 to 177 meters) and were corrected for bedding tilt. They show a mean inclination of 20.4°, a declination of 146.7°, and an α_{95} value of 17.7°. The α_{95} value and confidence interval indicate mean orientation for undeformed sites (sites 1-30). A typical vector-endpoint diagram is shown in Figure 6. Samples from this part of the stratigraphic section plot close together on the pole plot (Fig. 51A) in the southeast quadrant, indicating that the ChRM is reversed.

Samples between 177 and 178 meters (samples 31-34, 37-42) in the zone where horizontally bedded silts and clays become discontinuous and convoluted have a less-well constrained pole-plot orientation. They become oriented towards the North and East. Samples from above 178 meters (samples 35, 36, 44-51) are widely scattered within the northern hemisphere and were not well constrained. Samples taken at the contact are not clearly normal or reversed (Fig. 51A).

Because parallel-bedded sediments have a consistent orientation, and a mixed signal is superimposed only on discontinuous and deformed silts and clays, the ChRM is inferred to be predisturbance. Because disturbance occurs immediately after deposition, the ChRM is interpreted as DRM. Undeformed McElhattan beds display reversed DRM, as do those from Antes Fort (Gardner et.al., 1994) and were similarly assigned to the upper part of the Matuyama Reversed Polarity Chron, with a probable age range of ~970 to ~770 ka (Gardner et.al., 1994).

There are several possible explanations for the recorded shift from reverse to normal polarity at the same stratigraphic level as the transition from horizontally bedded clays to increasingly deformed clays. The normal polarity is either (1) a chemical remanent magnetism due to diagenesis, (2) magnetism acquired as a result of particle reorientation during deformation and fluidization, or (3) a result of physical reorganization of fragments of silt and clay during deformation. Each of these interpretations has its merits and weaknesses and are briefly addressed below.

(1) The entire lacustrine section originally had reversed detrital remnant magnetism. Normal-polarity chemical remnant magnetism (CRM) was acquired post deposition and post

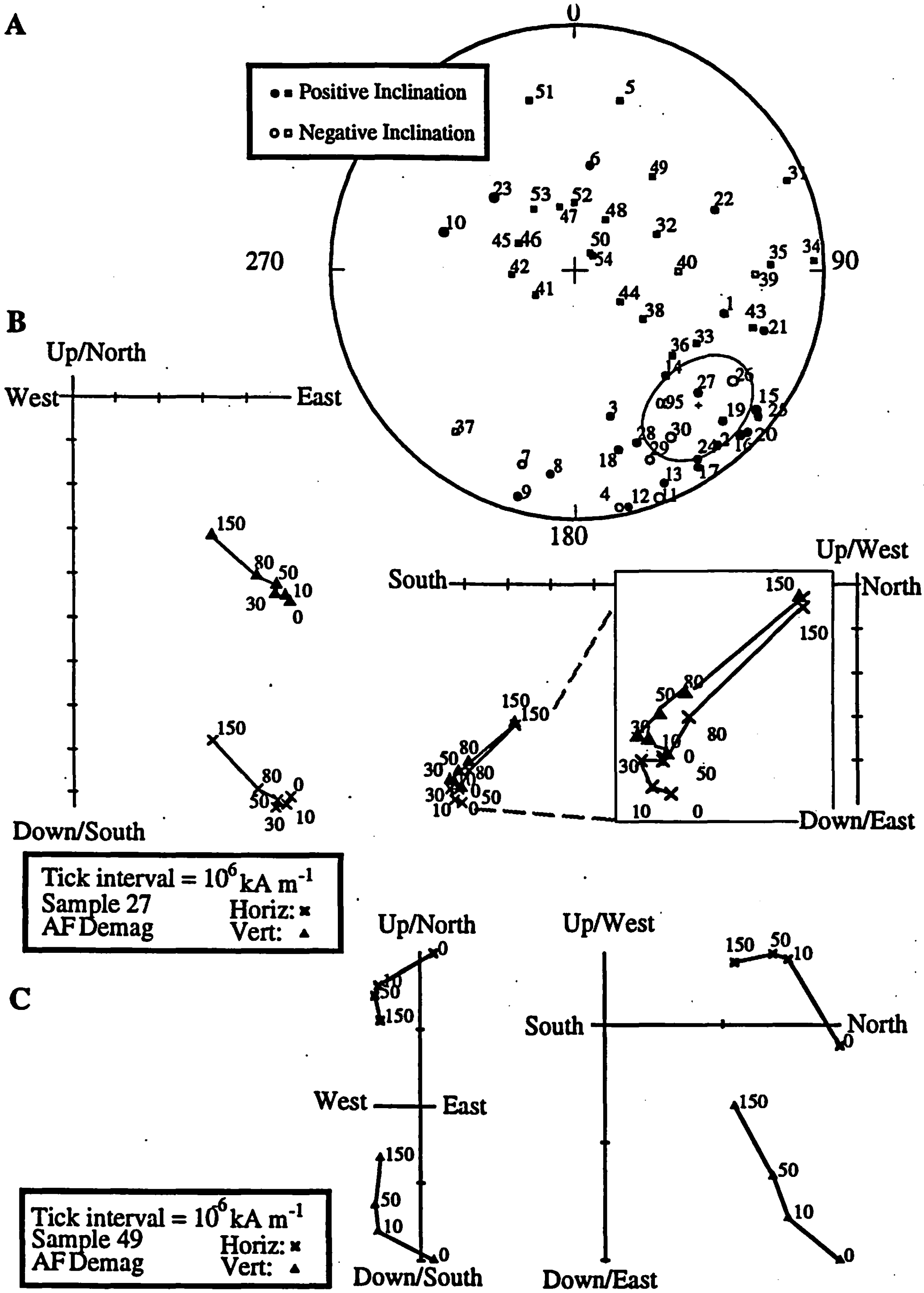

Figure 51. (A) Pole plot of paleomagnetic sample orientations at McElhattan. Round dots represent sampels 1 to 30; square dots are all others. The α_{95} shows mean and confidence interval for samples 1 to 30 only. I=20.4°, D=146.7°, α_{95} = 17.7°. (B) Vector endpoint diagram of sample 27. Alternating field (AF) demagnetization steps are in mT. Tick intervals are 10^{-6} KA m^{-1}. (C) Vector endpoint diagram of sample 49. Alternating field (AF) demagnetization steps are in mT. Tick interval are 10^{-6} KA m^{-1}.

deformation due to some difference in the permeability or weathering characteristics of the deformed sediments. This is not likely because sediment permeability is lowest in these fine grained sediments, and there is no physical evidence that the deformed silts and clays are more highly weathered than those which are undeformed. There is no mottling and color is consistent throughout the two units. There are occasional fractures or manganese stains, but neither is pervasive.

(2) At the time of deposition of the undeformed sediments, the Earth's magnetic field was reversed, but during the period of deformation polarity was normal; therefore the transition from reverse to normal sediment is at the Brunhes-Matuyama boundary. Both polarities are therefore DRM. Fluidization of part or all of the deformed sediments allowed magnetic particles to be resuspended and reoriented with respect to the Earth's new magnetic field. Saturation is a crucial factor in the deformation because compacted or unsaturated deposits are less likely to deform fluidly. If this is the case, then deformation occurred while the deposit was saturated, either coincident with lake drainage or soon after drainage. The change in the Earth's magnetic field occurred either during the latter part of lacustrine deposition or at the time of deformation. It is not possible in this scenario to tell whether the initial DRM of deformed sediments was reversed or normal, but there is no reversed orientation shown at higher demagnetization levels.

(3) The transition from reversed to normal polarity recorded in the stratigraphic section is merely a result of the deformation itself and does not represent a switch in the Earth's polarity. Due to the deformation , fragments of the silts and clay unit were physically reoriented; samples give a magnetic orientation which has not been corrected for the complex folding which occurred during deformation. This could explain the scatter seen in sites 31-54 (Fig. 51A). It is odd, however, that the orientations do not plot randomly in all quadrants. In partially deformed silt and clay, some reoriented fragments of intact bedding are preserved. However, most deformation observed*in situ* and in thin section, particularly in upper sediments, was minute and pervasive so it is unlikely that such good pairs and typical demagnetization level curves would result (Ramage, 1995). Paleomagnetic orientations are limited mostly to the northeast quadrant, perhaps indicating a preferred reorientation of fragments in the area which was sampled. Paleomagnetic orientations of undeformed layers indicate that lake sediments were deposited during a reversal. Since deformed samples give a normal, but less wellconstrained orientation, it is not certain when or how that orientation was acquired.

CONCLUSIONS

Glacial Lake Lesley has captured the imaginations of Pennsylvania geologists for 100 years. Williams hypothesized in 1895, based on physiography and ice extent in the West Branch Susquehanna River Valley, that a deep lake filled the valley and a torrent spilled out into the Juniata River basin. The existence of Glacial Lake Lesley has been controversial due to the difficulty of finding deposits, particularly at high elevations.

Ice extent into central Pennsylvania reached as far south as Bald Eagle Mountain in the Williamsport area at least once during the Pleistocene, forming Glacial Lake Lesley in the West Branch Susquehanna River Valley. Glaciofluvial and proglacial lacustrine sediments deposited in this setting have been preserved at several sites in the valley. Stratigraphy of these glaciofluvial and proglacial lacustrine sediments at McElhattan and Linden, paleomagnetic orientations of the undeformed fine-grained sediments, and analysis of the bedrock topography at the maximum lake elevation were methods used to further constrain Glacial Lake Lesley's controversial history.

At McElhattan, 40 meters of fluvial and glacio-lacustrine sediments overlie till. Sediments consist of crossbedded sands which are overlain by interbedded silts, sands, and clays and a thick laminated silt and clay unit. An unconformity separates the lacustrine sediments from the overlying diamicton. Till and some sandy layers which contain striated pebbles probably indicate proximity to a glacial source. The interbedded sands, silts, and clays may be lacustrine beds from an early phase of a proglacial lake which is still very much affected by fluctuations in sediment load and flow velocity. Millimeter-scale silt and clay laminae in the overall fining-upward sequence above are evidence for a lacustrine depositional environment. The upper 6 meters of the silt and clay unit are discontinuous and convoluted. Soft-sediment deformation of the upper silts and clays at McElhattan occurred before compaction and when the deposit was still partially saturated, at least to the depth of deformation. Thus, it occurred at the time of or shortly after drainage of the lake.

Lacustrine beds are overlain unconformably by a diamicton containing locally-derived angular and rounded sandstone clasts in a poorly-sorted sandy matrix. The diamicton is interpreted as a typical alluvial-fan deposit, derived from McElhattan Run after deposition of the glaciofluvial and lacustrine beds. Partial fluidization and differential loading by the overlying diamicton deformed sediments at McElhattan as the alluvial fan prograded over top of still-saturated lacustrine deposits.

Paleomagnetic orientations of samples in the deformed sediments are normal, but they have a large range of orientations within the northern hemisphere. Because they are deformed, it is not surprising that they have lost the tight reversed grouping. The normal polarity is either a chemical remnant magnetism due to diagenesis, magnetism acquired by particle reorientation during deformation and fluidization, or a result of physical reorganization of fragments of silt and clay during deformation. Since fragment orientations were not visible, samples from deformed sites have not been reoriented to account for folding or faulting during deformation.

Differences between paleomagnetic orientations of deformed and undeformed sediments suggest that the paleomagnetism in undeformed samples is detrital remanent magnetism. Paleomagnetic analysis of fine-grained beds allows more rigorous age correlation than had previously been possible based solely on relative weathering characteristics. Predominantly reversed polarity in undeformed beds at Linden and McElhattan correspond to the end of the Matuyama Reversed Polarity Chron which has an age range of ~970 to ~770 ka (Gardner et. al., 1994) during the Early Pleistocene.

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Road Log—Day 1

Mileage Increase	Mileage Cumulative	
0.0	0.0	Leave Genetti Hotel traveling SOUTH on William Street crossing Fourth, Third, and Church streets.
0.3	0.3	TURN RIGHT onto Via Bella. MOVE to LEFT LANE and FOLLOW signs to US Route 15 North (also to US Route 220 South).
0.7	1.0	Passing Bethlehem Steel Wire Rope plant. Remediated hazardous-waste site located in open area behind Burger King.
1.1	2.1	FOLLOW US Route 15 North through Lycoming County and into Tioga County.
1.1	3.2	Brallier Formation (Db) on west (left) side of US Route 15 N. Channelized Lycoming Creek drainage basin using levees on east (right).
		Surrounding low-lying hills underlain by Devonian marine units including the Brallier, and Lock Haven (Dlh) formations.
2.4	5.6	Start of large roadcut in gently south-dipping siltstones and mudstones of the Lock Haven Formation (Dlh). Dips steepen considerably toward north end of exposure. The top of the outcrop displays an irregular weathered zone.
0.7	6.3	Begin second roadcut in the Lock Haven Formation. Third-order anticline with change to steep north dip in outcrops on both sides of the road. Wedge faulting in some of the coarser-grained beds. Two kink bands are well exposed at the north end of the outcrop (mile 6.5) with a 4th-order kink band adjacent to a nearly vertical fault surface. We are near the south-dipping Beautys Fault.
1.0	7.3	Third-order folds and a minor N-dipping reverse fault and wedge faults in an outcrop of the Lock Haven Formation (?) on the south-bound Hepburnville Exit ramp.
1.1	8.4	First, gently dipping to nearly flat lying redbeds of the middle Sherman Creek Member of the Catskill Formation (Dcs).
0.4	8.8	More steeply S-dipping Catskill Formation redbeds. Minor structures occur at the north end of the exposure.
0.7	9.5	Gently south-dipping Catskill Formation on both sides of the highway. Minor redbeds near the north end of the outcrop.
1.1	10.6	Gently north-dipping Catskill Formation on both sides of the roadway.
0.7	11.3	Well-exposed channel in Catskill Formation redbeds on west side of highway.
1.0	12.3	Temporary end of four-lane divided highway.
		CONTINUE on US Route 15 N.
0.6	12.9	New road construction for US Route 15 on west (left) side. Estimated completion of construction—November 1996.
1.0	13.9	Small exposures of Catskill Formation.
0.8	14.7	Divided highway begins. Climbing Allegheny Front.
0.3	15.0	Trout Run (PA Route 14 N) Exit. STAY on US Route 15 N.

0.9	15.9	Fining-upward cycles and channeled Catskill Formation outcrops begin on east (right) side of highway. Discontinuous, nearly horizontal redbed exposures for next 6.6 miles.
1.1	17.0	Channeling in Catskill Formation outcrops on east (right) side and for the next 2 miles.
2.5	19.5	Thicker, gray sandstones of the upper Duncannon Member (Catskill Fm.) (Dcd).
2.8	22.3	Crest of the climb up the Allegheny Front.
2.7	25.0	End divided highway. CONTINUE ON US Route 15 N.
1.6	26.6-26.9	Duncannon Member redbeds (Catskill Fm.) with grayish sandstones on west (left) side of road.
0.8	27.7	Gray, channel sandstones of the Duncannon Member (Catskill Fm.) on both sides of highway.
1.3	29.0	Very well developed channeling in Catskill Formation redbeds on west (left) side of the highway.
0.3	29.3	Tioga County line.
0.7	30.0	Liberty - Morris Exit (to PA Route 414).
2.8	32.8	Enter village of Sebring.
2.6	35.4	Rest Area on west (left) side of the highway. For the last mile, we have been in the Huntly Mountain Formation.
0.1	35.5	Just past rest area, TAKE LEFT to Arnot. (Caution: at this crossing point 2 south-bound lanes curve uphill; visibility for oncoming traffic is poor—a very dangerous crossing!) Use caution, this is a narrow, curving road.
0.4	35.9	Tioga State Forest. We are now in the Burgoon Formation.
1.7	37.6	Village of Arnot. We are in the Pottsville Group (IPp), just south of the nearly east-west trending axis of the Bossburg syncline.
0.4	38.0	TURN LEFT at stop sign onto Township Route 2016 (Main Street). St. Stanislaus R.C. (stone) Church on the right.
0.5	38.5	BEAR LEFT onto unpaved Landrus Road, an old railroad grade through Tioga State Forest. For approximately the first mile, it follows the axis of the Blossburg Syncline.
0.2	38.7	Small exposure of poorly sorted sand and gravel at the edge of the clearing to the right (north). This deposit contains boulders up to 0.6 m (2 ft) in diameter, very well rounded sandstone cobbles and pebbles, and a few small, sub-rounded coal fragments all set in a sandy to silty matrix.
0.2	38.9	Open swamps on both sides of the road. .
0.2	39.1	Open lake to the right (north).
0.3	39.4	Subsidiary road forks to the right; stay on main road.
0.4	39.8	Old railroad cuts in the Pottsville Group on both sides of the road.

0.3	40.1	STOP 1a. Buses will pull off before narrow bridge. Disembark and move to left (south) side of the road. Buses will move ahead beyond Stop 1b.
		Look for the small artificially dammed pond here on Lick Creek. Note the drain within the pond that empties into two pipes that move this surface water down-valley to the vertical well at Stop 1b. Presentations will be given at both sites.

STOP 1. **Surface-Water Diversion-Well Remediation Project, Lick Run, Babbs Creek Watershed.**

Discussants: J. H. Schueck, DEP
C. Crum, The Pennsylvania State University

0.1	40.2	Walk to STOP 1b. Following presentation, board buses.
0.1	40.3	Cuts in Burgoon Formation (Mb) on south (left) side of road. Flaggy cross bedding is prominent.
0.8	41.1	Scattered outcrops of the Huntley Mountain Formation continue along the south side of the road. Mass movement of surficial debris has blocked this road in the past.
1.7	42.8	Archeological site of Landrus (1880-1914). Home of the first electrified mine in the world. In its heyday, it had one company store, one post office, one school, two churches, one sawmill, and sixty-two homes. The town peaked in 1899.
0.5	43.3	Monument to Landrus (1882-1915) erected by the Tioga Historical Society.
5.8	49.1	T-intersection in Morris. CONTINUE STRAIGHT at stop sign.
		PROCEED SOUTH ONTO PA Route 287 beyond second STOP SIGN.
		CONTINUE ON PA Route 287 S. when PA Route 414 cuts to right.
4.2	53.3	Lycoming County line.
4.7	58.0	Outcrops of Burgoon Formation on left (east) side of the road.
2.1	60.1	Intersection with PA Route 284 from left (east).
0.7	60.8	Channeled red sandstones of the Duncannon Member (Catskill Fm) on right (west) side of the road.
0.4	61.2	TURN RIGHT (following sign to Waterville). Enter the village of English Center.
0.5	61.7	BEAR AROUND TO THE RIGHT following English Run and Shingle Mill Branch. Do not cross bridge over Little Pine Creek to Waterville and Little Pine Creek State Park.
0.3	62.0	Paved roadway ends. Route alternates between paved and unpaved roadway.
3.7	65.7	Entrance to Fisher Mine, Stop 2.

STOP 2. **Fisher Mining Company, Little Pine Creek Coal Field.**

Discussants: M. Smith, District Mining Operations, DEP,
C. H. Dodge, PA Geological Survey, DCNR

To continue road log, mileage begins at mine entrance. Retrace route to English Center

4.0	69.7	Stop sign. CONTINUE STRAIGHT AHEAD through English Center. Do not turn right across bridge over Little Pine Creek.
0.5	70.2	TURN RIGHT onto PA Route 287 S. Cross Little Pine Creek.
1.0	71.2	Beginning of discontinuous redbed exposures of the Catskill Formation over next 12 miles.
2.9	74.1	PA Route 184 to left. Continue on PA Route 287.
13.0	87.1	TURN RIGHT onto US Route 220 S at traffic light.
4.2	91.3	Clinton County line, Pine Creek.
1.9	93.2	TAKE AVIS EXIT.
0.2	93.4	TURN RIGHT at stop sign at end of ramp.
0.4	93.8	At stop sign, TURN LEFT onto PA Route 150 S and proceed toward Lock Haven.
1.0	94.8	Take DOGLEG LEFT TURN onto River Road and descend onto the West Branch Susquehanna River floodplain.
2.8	97.6	View of Bald Eagle Mountain to left (south) across the floodplain. Blocks of Tuscarora Formation (St) comprise the boulder colluvium "bare spot" on the North-facing flank of the mountain.
1.1	98.7	TURN RIGHT onto Fargus Island Road just before the bridge over the West Branch Susquehanna River leading to Great Island. Caution, this road narrows as it twists up off the floodplain.
0.8	99.5	TURN LEFT onto PA Route 150 S and once again proceed toward Lock Haven. Outcrop directly ahead comprises siltstones and mudstones of the Devonian Mahantango Formation. A borrow pit directly uphill and out of view supplied some of the locally-derived fill used in Lock Haven's Flood-Protection Project.
1.2	100.7	Crossing the Constitution Bridge over the West Branch Susquehanna River. Buses will slow down to provide participants with an opportunity to view a portion of Lock Haven's recently completed Flood-Protection project which stretches along the southern shore of the river in both the upstream and downstream directions.
0.2	101.9	Entering the city of Lock Haven. Buildings on the left (south) were part of the now-closed Piper Aircraft manufacturing complex which for many years was a major employer in the city. Piper closed here in 1984 and moved its operations to Florida.
0.3	101.2	TURN LEFT onto unmarked street at the west end of Piper Memorial Airport. The western-most end of the runway was recently extended as part of the Dike-Levee Project. Proceed to "T" intersection.
0.1	101.3	TURN RIGHT onto East Bald Eagle Street. Houses on immediate right have been moved prior to the construction of the Dike-Levee Project. Prior to the completion of the project, any construction in this area was required to meet existing floodplain regulations; thus the houses were raised onto one-story concrete block foundations. Route passes through Lock Haven Gardens,

housing which was build after the 1972 Agnes Flood event to meet the needs of the displaced, low-income city residents.

0.3 101.6 At stop sign TURN RIGHT onto Hanna Street and continue for two blocks.

0.1 101.7 TURN LEFT at traffic light onto East Main Street (also PA Route 150) and continue for two blocks.

0.2 101.9 TURN RIGHT onto Henderson Street and continue for one block.

0.1 102.0 At stop sign TURN LEFT onto East Water Street and continue for two blocks.

0.1 102.1 Just before stop sign at the intersection of Jay Street and East Water Street buses will pull off to allow participants to disembark.

0.2 102.3 Buses will then move straight ahead (west) two blocks to the re-boarding location in the levee-access parking area adjacent to (east) Vesper Street.

At street level, note the stone monument indicating individuals and a brief summary of events relating to Lock Haven's Flood Protection project.

Participants should move up the ramp, onto the levee, proceed down the steps of the amphitheater on the river side, and gather on the lower-level seating.

STOP 3a. Lock Haven's Dike-Levee Flood Protection Project

Discussant: R. Yowell, Williamsport Regional Director, DEP

Following the discussion, and assuming the river level permits, participants should walk west along the river's edge, pass beneath the Jay Street Bridge, and continue up the ramp and onto the levee. Proceed along the top of the levee for another block to the stairs leading down to the circle and parking area.

Along this walk, take note of the following:
(1) the up-river view,
(2) the fallen trees on the south side of Boom Island,
(3) the lighted paved pathway used by walkers and joggers,
(4) the recreational facilities, specifically the bathhouse and beach at the river's edge.

Move down the stairs and re-board buses. Buses TURN LEFT out of parking area onto Vesper Street.

0.1 102.4 TURN LEFT onto East Water Street and proceed two blocks to Jay Street.

0.2 102.6 At 4-way stop sign TURN LEFT onto and across the Jay Street Bridge.

(This route will change slightly in the event of foul weather).

Note concrete closure-structure framework on both sides of levee here.

The bridge crest allows good view of the levee up and down the river. Note the fallen trees on the south side of Boom Island to the northwest. Lock Haven University sits on the hillside a bit farther upriver, and, other than for the lower level of the student union, the campus buildings are completely above the floodplain.

0.2 102.8 TURN RIGHT at the northern end of the bridge following PA Route 664 sign.

0.3 103.1 TURN RIGHT into the Lockport Recreational Area's parking lot built as part of the Flood Protection project. This Woodward Township facility provides a marina and recreational access to the river.

LUNCH STOP

The stone framework remains of a canal lock are visible at the south end of the parking area. This canal, part of the Pennsylvania Canal, West Branch Division, was built between 1828 and 1834 and linked Lock Haven to Northumberland and points south. Until 1889, boats carried iron, lumber, and manufactured items from this area down river to eastern markets.

Across the river, the Bald Eagle Cross-Cut Canal joined the West Branch Division about a block east of the Jay Street Bridge. The canal transected the city using two locks, a dam, and a tow path to connect Bald Eagle Creek with the West Branch Susquehanna River. This canal cut through land that is now part of the Drake Superfund Site, STOP 4, and served as a dump site for the city subsequent to its abandonment as a transportation channel.

To the north across the road, steep banks marking the northern edge of the floodplain expose the Mahantango Formation. About 0.1 mile west, beyond the northern end of the Jay Street Bridge, the upper Tully Member outcrops. The lower portion of this carbonate member is cyclic and the upper portion, near the contact with the Harrell Formation (Dh), is fossiliferous.

0.2 103.3 RETURN to main road and TURN LEFT.

0.3 103.6 Stop sign. TURN LEFT and re-cross Jay Street. Framework of the closure structure is visible at the south end of the bridge.

0.2 103.8 At the 4-way stop sign TURN LEFT onto East Water Street and continue straight ahead.

0.8 104.6 The field-trip route passes under the Constitution Bridge. Here a concrete wall replaces the earthen levee structure.

0.5 105.1 The field-trip route passes directly over the earthen dike.

The Piper Memorial Airport is off to the right (south).

Memorial Park, on the left (north) between the earthen dike and the river, was the site of an archaeological investigation, required as part of the flood-protection project.

(The) Great Island lies across bridge straight ahead (east). Many Native American nations have occupied these lands completely surrounded by the river. Paths from all parts of the Six Nations country converged on Great Island. Trails led from the Genesee, Ohio, Potomac, and North Branch Susquehanna rivers. Warriors Path ran up (southwest) Bald Eagle Valley to Bald Eagle's Nest (Milesburg) and then on south to the Carolinas. The Shamokin Path followed the Susquehanna in this region linking the Sunbury area to the south with the Allegheny Mountains via Snow Shoe and Moshannon to the west. Delawares and Shawnees reportedly stopped here on their migration westward to Ohio prior to the French and Indian War.

0.1	105.2	DO NOT CROSS BRIDGE. TURN RIGHT just before the bridge over the Susquehanna River. Road runs south between the northern end of the airport landing strip and the river.
0.2	105.4	TURN RIGHT (following signs to Castanea Fire Company's Picnic Grounds) and once again cross over the earthen dike.
0.3	105.7	Buses stop under trees and participants will disembark. Once unloaded, buses turn around in parking lot ahead and return, parking on the straight-away parallel to the dike beyond the curve. (Picnic grounds will serve as the lunch stop if weather is inclement.)

Participants walk behind buses and move southeast across the field to the closure structure where railroad tracks pass through earthen dike.

STOP 3b. Lock Haven's Dike-Levee Flood Protection Project: Surficial and bedrock geology relative to the foundation design and completion of a major closure structure in this valley setting.

Discussant: T. Swanson, US Corps of Engineers

Following the discussion, participants board buses. Retrace route to Water Street.

0.6	106.3	Stop sign. TURN LEFT onto East Water Street. CONTINUE STRAIGHT AHEAD.
1.4	107.7	Stop sign at Jay Street. CONTINUE STRAIGHT AHEAD on West Water Street.
1.2	107.9	TURN LEFT onto Vesper Street.
0.1	108.0	Traffic Light at Main Street. CONTINUE STRAIGHT AHEAD on Vesper Street.
0.1	108.1	Stop sign at East Church Street. CONTINUE STRAIGHT AHEAD on Vesper Street.
0.2	108.3	Stop sign. TURN RIGHT onto East Walnut Street and CONTINUE STRAIGHT AHEAD for one block.
0.1	108.4	Stop sign. TURN LEFT onto East Park Street and CONTINUE STRAIGHT AHEAD for two blocks.
0.2	108.6	TURN LEFT onto unmarked road (Myrtle Street) and proceed to gate and guardhouse.
0.1	108.7	Stop at guardhouse. Proceed to parking area behind shopping center.

Participants disembark and await further instructions.

STOP 4. Drake Chemical Company—EPA Superfund Cleanup Site

Discussant: R. Schrock, US Environmental Protection Agency

Following discussion, board buses and return to intersection with East Park Street.

0.1	108.8	Stop sign. TURN RIGHT onto East Park Street and CONTINUE STRAIGHT AHEAD for two blocks.
0.2	109.0	Stop sign. TURN RIGHT onto East Walnut Street and CONTINUE STRAIGHT AHEAD for two blocks. (Pass entrance to BiLo strip mall on right.)
0.2	109.2	TURN RIGHT onto entrance ramp to four-lane, limited-access highway (Paul Mack Boulevard)
0.3	109.5	Overview of Drake Chemical Company site on right (west) side of highway.
0.1	109.6	MOVE TO LEFT LANE and follow signs to US ROUTE 220 N (Williamsport).
0.2	109.8	Proceed under US Route 220 and TURN LEFT onto entrance ramp of US Route 220 N. Cross dike-levee
		Entrance ramp crosses dike-levee and this earthen structure parallels this east-bound section of US Route 220 N. Stream off to the right (south) is Bald Eagle Creek here flowing along the base of the northwest-sloping flank of Bald Eagle Mountain.
0.8	110.6	Small borrow pit developed on the flank of Bald Eagle Mountain exposes the Silurian Mifflintown Formation (Sm). Calcareous mudstones and thin-bedded limestones served as another local source of material used in the construction of Lock Haven's Flood-Protection project.
0.8	111.4	Begin bridge across Bald Eagle Creek.
0.2	111.6	The prominent borrow pit on the right (south) exposes upper Mifflintown Formation and contact with lower Bloomsburg Formation (Sb). Material removed from this pit was used for the construction of this portion of US ROUTE 220. Here large bedding surfaces of the Mifflintown are covered with megaripples and thumb-size fragments of straight cephalopods are common. This site, aka "Save the Seals" because this memorable phrase had been painted in sprawling white letters on one bedding surface but now long gone, was Stop VIII on the 1983 Pennsylvania Field Conference of Geologists' field trip (Nickelsen & Cotter).
0.5	112.1	Buses pull off as far as possible on the right shoulder. Participants should disembark and move immediately up the grassy slopes of the embankment.
		UNDER NO CIRCUMSTANCES ATTEMPT TO WALK ON THE HIGHWAY SIDE OF THE BUSES OR TO CROSS THE HIGHWAY. STAY ON THE UP-HILL SIDE OF THE BUSES.
		Buses will pull forward to a point about 0.1 mile ahead.
		NOTE: the group will proceed from road level up the slope and across upper surface of the mass surficial debris along the tree line and finally back down through one of the major scarps. There will be four lettered stops along the way. The ground is very uneven and there are many larger rocks, downed trees, and scarp faces to climb around. The route will be flagged and it is not particularly rigorous; however, please exercise extreme caution and pace yourself along the route.

STOP 5. Slope-Stability Problems and Remediation Procedures Associated with US Route 220 east of Lock Haven.

Discussant: G. M. Ulh, PennDOT, Engineering District 2-0, Clearfield

Generally hummocky topography, tilted trees, patches of unvegetated soil exposing blocks of surficial material, and lobe-shaped masses of debris that ooze muddy water in the highway gutter during periods of abundant precipitation all serve as indicators that mass wastage processes are actively operating here. Out of sight to the vehicle operators driving by this site, large-scale, multiple vertical-scarp faces farther upslope behind the jumbled mass of surficial debris provide confirming evidence for these ongoing processes. A stand of cattails at the base of this debris mass indicates "wetland" territory in this vicinity as well. Efforts to re-engineer slopes in order to prevent the continuation of these mass wastage processes have met with limited success in this area and slope-stability problems continue to plague portions of the northwest-facing slope of Bald Eagle Mountain along US Route 220 .

Several massive earthflow events occurred in the Tyrone area prior to and following the opening of the US Route 220 bypass farther to the southwest in fundamentally the same geologic setting. An large, amphitheater-shaped scar remains to this day as a reminder of the scope of these problems. In contrast, however, the newest portion of this four-lane divided highway corridor between Altoona and Grazierville to the north displays slopes covered with gravel riprap, french drains and Y-drains, appearing like large, branching "gravel trees," underdrains, and catchment ponds. All of these features are designed to address the abundance of water moving down off the flanks of these ridges and through the thick surficial deposits that veneer the slopes.

0.1	112.2	Participants should board buses.
		Please, take care to STAY ON HIGHWAY SHOULDER AND DO NOT WANDER NEAR TRAFFIC LANES.
1.1	113.3	Additional earthflow and slump areas in colluvium on right (south) side of the highway.
1.4	114.7	McElhatten water gap in Bald Eagle Mountain on right (south) side. Interchange constructed upon a thick wedge of surficial materials, the upper portions of which comprise an alluvial fan deposit. STOP 7 is located in this vicinity and the region and its surficial units will be discussed fully tomorrow.
		Pine Creek exits the Allegheny Plateau through the valley visible on the left (north).
0.8	115.5	The exposed pile of soil on the left (north) side of the road is the site of the recently closed former natural-renovation landfill operated by the Clinton County Solid Waste Authority and known as the Wayne Township Landfill.
0.1	115.6	The active landfill on the right (south) side of US Route 220 is the new, lined site principally being used by Clinton and Centre counties.
0.7	116.3	US Route 220 highway bridge crosses West Branch Susquehanna River. Bald Eagle Mountain stands out against the skyline to the south, here trending to the northeast.
3.2	119.5	Lycoming County Line (Pine Creek).
1.6	121.1	A borrow pit on the north side of the highway exposes the Hamilton Group (Marcellus (Dm) and Mahantango (Dmh) formations).
		The Jersey Shore Fault, running parallel to and just north of the highway at this point, brings the Hamilton Group into contact with the Lock Haven Formation.
2.9	124.0	Mudstones and siltstones of the Brailler Formation are exposed along the railroad tracks on the left (north) side just before highway goes under the Conrail bridge.

0.7	124.7	The Brailler Formation is exposed in a borrow pit on the left (north) side of the highway. Discontinuous exposures of this formation over the next mile.
2.1	126.8	The Mahantango Formation is poorly exposed on both sides of the highway.
0.5	127.3	A deposit of surficial materials is exposed on the left (north) side of US 220 at the intersection of Northway Road (Woodward Township Route 372). This deposit is 2 to 3 meters thick. Clasts range from subangular to subrounded cobbles and pebbles grading down to clay. The clasts are mainly siltstone. Smaller clasts, +/- 1 cm tend to display better rounding. Many of the larger clasts have been rubified. Similar material is poorly exposed on the south side of the highway.
1.3	128.6	Poor exposures of the Brailler Formation occur on the left (north) side of the highway.
2.2	130.8	The Brailler Formation is exposed in a large borrow pit seen off in the distance to the left (north) of the highway.
0.8	131.6	US Route 220 crosses Williamsport's flood protection structure, an earthen dike comparable to those in Lock Haven. For the next several miles, the highway follows the levee on the north shore of the Susquehanna River. To the north of the highway, there is a substantial amount of industrial development on the floodplain that is protected by this structure. Bald Eagle Mountain continues to dominate the skyline to the south. In this area, it trends more east-northeast, and farther to the east, beyond Williamsport, it displays an east-west trend.
2.2	133.8	Bridge over Lycoming Creek just upstream from its confluence with the West Branch Susquehanna River to the south.
1.7	135.5	TAKE HEPBURN STREET EXIT off US Route 220. MOVE TO THE RIGHT LANE before going under the overpass.
0.6	136.1	MOVE TO LEFT LANE and TURN LEFT at first traffic light onto William Street.
0.2	136.3	Traffic light at West Third Street. CONTINUE STRAIGHT AHEAD.
0.1	136.4	Traffic light at West Fourth Street. Genetti Hotel and Convention Center on the left.

END OF DAY 1. SEE YOU ALL BRIGHT AND EARLY FOR DAY 2.

Road Log—Day 2

Mileage Increase	Mileage Cumulative	
0.0	0.0	Leave Genetti Hotel traveling SOUTH on William Street crossing Fourth, Third, and Church streets.
0.3	0.3	TURN RIGHT onto Via Bella. MOVE to LEFT LANE and FOLLOW signs to US Route 220 South.
14.6	14.9	TAKE EXIT for Jersey Shore, Main Street, PA ROUTE 44 South, and follow this route into the town of Jersey Shore.
1.2	16.1	Before traffic light at Allegheny Street, MOVE TO RIGHT LANE and CONTINUE STRAIGHT on Main Street through traffic light. (Out of town, this street becomes Tiadaghton Drive).
0.6	16.7	Note small, private dike around a local business—Packaging Service Group.
1.6	18.3	TURN RIGHT onto Pine Creek Avenue (unmarked here) just before the one-lane bridge crossing Pine Creek.

Across the bridge over Pine Creek and around the first bend in the road stands the Tiadaghton Elm. A Pennsylvania Historical and Museum Commission marker indicates that under this elm on July 4, 1776, resolves declaring independence from Britain were drawn by pioneer settlers of the West Branch prior to news of action by Congress in Philadelphia. Characterized as representing the spirit common to the frontier, this expression of resolve was led by the famous Fair Play men.

0.8	19.2	Buses pull off on right side of Pine Creek Avenue and participants disembark.

CAUTION: Participants should take care in crossing the road. Vehicles frequently move through this area at high rates of speeds.

STOP 6. Jersey Shore Limestone Quarries

Discussants: C. R. Carnein, Lock Haven University
R. W. Pollok, Meiser & Earl Inc.

The 3 small quarries on the east side of Pine Creek, just west of Jersey Shore, are part of a section of Upper Silurian through Lower Devonian rocks rarely so well exposed in this part of Bald Eagle valley. A preliminary map of the Jersey Shore quadrangle by D.M. Hoskins was included in Pennsylvania Geologic Survey Map 61 (Atlas of Preliminary Geologic Quadrangle Maps of Pennsylvania, 1981). A part of that map is included in the figure accompanying this stop. Stop 6 will be divided into 3 parts, as shown on the figure:

STOP 6A. will be used to orient participants to the local stratigraphy. We will walk northward from the buses (follow the flagging) to see nearly continuous exposures with relatively simple structure. We will begin at a small quarry (marked **6A** on the accompanying figure) in which the Tonoloway and Keyser formations are well exposed in a tight anticline. From the quarry, we will proceed northward (up section) through good outcrops of the Keyser Formation and the Helderberg (Corriganville), Mandata, and Shriver members of the Old Port Formation. Participants are encouraged to collect samples for comparison with rocks exposed at Stops 6B and 6C.

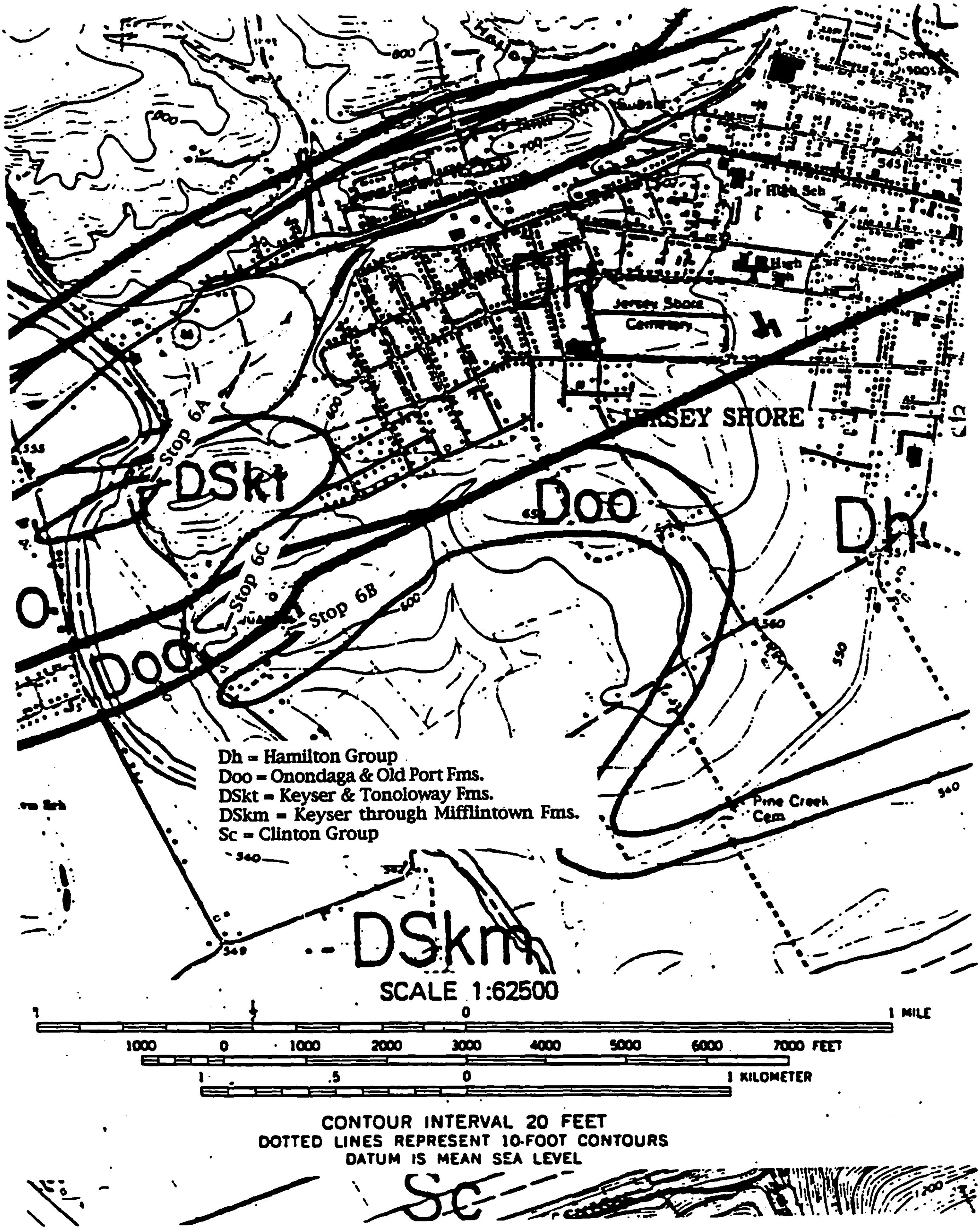


Figure 52. Geologic map of a portion of the Jersey Shore quadrangle, showing locations of Stops 6A, B, and C. (From Pennsylvania Geologic Survey Map 61, Preliminary Geologic Quadrangle Maps of Pennsylvania, 1981).

STOP 6B. Once you are familiar with the section, we will walk southward, past where we left the buses, and into the southernmost of the 3 quarries (**6B**). This quarry and the one just to the north are owned by Bognar and Company of Pittsburgh. They once manufactured refractories here for use in steel furnaces and for other applications. Remnants of flint-clay stockpiles occur at the west end of the quarry; this transported material came from near Philipsburg.

Notice that bedrock occurs in scattered outcrops in the quarry floor. See if you can identify it, along with the rocks making up the quarry walls. For your convenience, a blank cross section is included in the back of this Guidebook; at next year's Field Conference, a prize will be awarded for the most imaginative cross section drawn by a participant and submitted to Bob Carnein at L.H.U.

STOP 6C. We will follow the flagged route out of the south quarry, seeing exposures on the "hump" separating the 2 quarries, and then proceeding into the middle quarry (**Stop 6C**). Here, you are asked to focus on the overall structure shown by exposures at Stops 6B and C. There will be ample opportunity to discuss the geology and finish your cross section over coffee and doughnuts before we return to the buses.

0.7	19.9	Stop sign. CONTINUE STRAIGHT on Pine Creek Avenue.
0.2	20.1	BEAR LEFT onto Glover Street. STAY on Glover Street to Allegheny Street.
0.4	20.5	Stop sign. TURN RIGHT onto Allegheny Street.
0.1	20.6	At flashing light TURN LEFT onto Bridge Street which becomes Thomas Street and follow signs to US ROUTE 220..
0.3	20.9	Cross over US Route 220 and TURN LEFT onto the entrance ramp down onto US Route 220 S.
1.1	22.0	Clinton County Line (Pine Creek).
3.1	25.1	Cross West Branch Susquehanna River bridge.
0.4	25.5	Wayne Township Landfill on both sides of US Route 220 here. Old, closed natural-renovation landfill site on the right (north) side of highway. New, active, double-lined facility on left (south) side of the highway.
0.9	26.4	TAKE McELHATTEN EXIT.
0.3	26.7	Stop sign. TURN RIGHT and follow this road (L.R. 18032) north toward McElhatten.
0.5	27.2	TURN RIGHT into access road leading to Wayne Township Landfill.
0.5	27.2	Proceed along the Landfill's paved access road to the office and scale building.

This landfill is a non-profit, publicly owned and operated facility providing a site for municipal-type solid wastes including household waste as well as demolition and approved, non-hazardous, industrial-residual wastes. The principal users of this facility include local haulers from Clinton County, individual county residents, and, under an agreement with the Centre County Solid Waste Authority, solid waste is transported here from a transfer station in Centre County. The operation is overseen by the Clinton County Solid Waste Authority (CCSWA), a board comprising 11 volunteer members, all of whom are appointed by the Clinton County Commissioners.

Once past the office and scales, the extensive area to the right (south) comprises the site of original, natural-renovation landfill which is now closed and in the process of being capped. This nearly 100-acre tract, developed on the north side of US Route 220, was permitted by PADER on August 20, 1973, and, subsequent to the adoption by the Pennsylvania legislature in 1988 of new regulations governing solid-waste disposal facilities statewide, was forced to close and accepted the final load of waste in 1990.

1.0 28.2 Continue approximately 1.0 mile further to the Landfill's maintenance building.

In order to fulfill the responsibility charged to it under the county-wide, solid-waste management plan, i.e., to continue to provide long-term, solid-waste disposal capacity for the citizens, businesses, and industries of Clinton County, the Authority is presently in the process of developing and operating a new, state-of-the-art, double-lined disposal site on the south side of US Route 220.

STOP 7. Clinton County Solid Waste Authority's Wayne Township Landfill

Discussants: R. M. Hershey, R. W. Pollok, G.F. Lacy, C. Xethakis, J. Munro, and J. M. Ramage

The field trip route passes under the US Route 220 bridges. Once on the south side of this four-lane, please refer to the accompanying map for the locations of the lettered stops as outlined below.

Participants will disembark buses at the Landfill's maintenance building. Proceed north approximately 300 feet through the trees to STOP A.

STOP A. Sand Pit

This exposure was originally excavated for general-fill material by a private-property operator. At one point, the sand reportedly was used in elevated sand mounds for on-lot sewage-disposal systems. This exposure consists of the glacial sand overlain by the glacial-lake silt and clay respectively.

Walk back past the maintenance building and follow the road south. Approximately 900 feet past the maintenance building, turn left at the road intersection and approximately 300 feet on the left will be a long dozer trench.

STOP B. Trench Excavation

This excavation exposes the contact between the fan gravel and the underlying glacial-lake clay. The undulating nature of this contact will be examined.

Walk back approximately 300 to the road intersection . Go straight ahead for 750 feet and turn left at the "T" intersection. Proceed another 900 feet and turn left off the road.

STOP C. Wetland Reconstruction Area

Wetlands that were removed for the construction of the lined landfill were replaced by this wetland. An overview of the problems of wetland construction will be discussed.

Lunch Stop

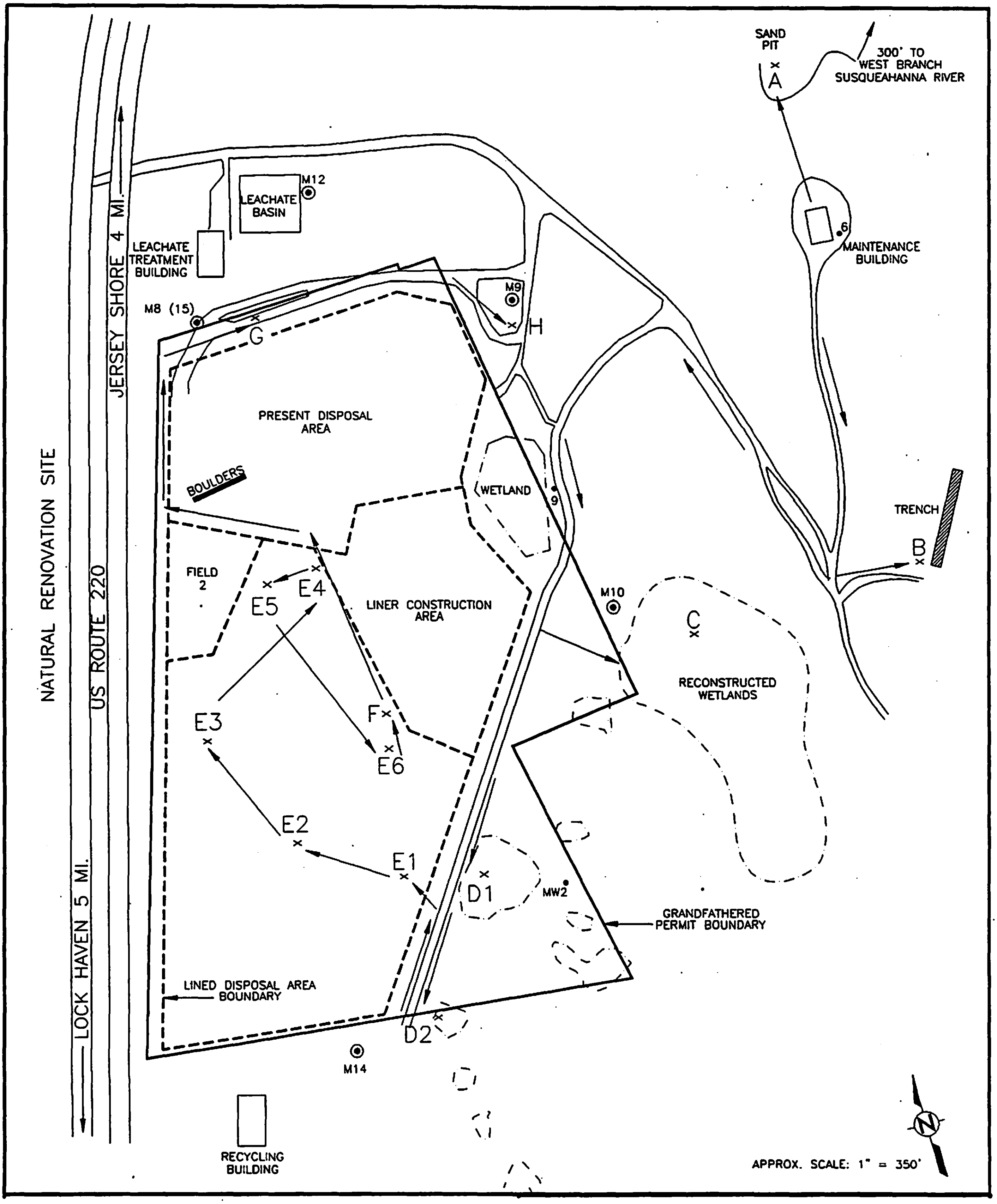


Figure 53. Field Stop Locations A through H at the Wayne Township Landfill

Participants will be free to wander about this site during the lunch stop. However, please stay in this vicinity in order to facilitate regrouping and continuing the field trips.

Walk back to the road intersection and turn left. Approximately 600 feet and 1,000 feet on the left side of this road are undisturbed wetlands.

STOPS D1. and D2. Undisturbed Wetlands

Two natural wetlands will be examined. These wetlands are typical of the those that were removed from the lined site and reconstructed on its margins.

Proceed back to the road intersection several hundred feet.

STOP E. Unconsolidated Stratigraphic Sequence Exposures (follow the signs to the E-series stops)

E1 Peat excavated from Lake Wayne, formerly the largest wetland at the site.

E2 Loess deposit over fan gravel.

E3 Fan gravel deposit over glacial-lake clay.

E4 Silt deposit over glacial sand.

E5 Excavation exposes glacial till or residuum beneath glacial sand.

E6 Relict karst feature where fan gravel has moved through the underlying unconsolidated materials into the Keyser and Tonoloway limestones.

STOP F. Overview of Lined Landfill Construction

The new operation is centered around a liner system comprising two, 100-mil High-Density Polyethylene (HDPE) geomembranes, a clay blanket under the primary liner, geonets, as well as piping for an extensive leachate collection system. The development of this site involves the sequential construction of seven fields designed to extend the lifetime of this facility to the year 2015 and beyond.

Go north to the road at the base of the active disposal area and proceed approximately 1,400 feet around the edge of the fill to sign G.

STOP G. Overview of Leachate Treatment System

All of the liquids that moves through the waste material, including precipitation, is collected by a piping system on top of the primary liner. These liquids or leachate is pumped from the disposal area to the leachate basin. The leachate is pre-treated before it is discharged to the Pine Creek Municipal Authority's sewage-treatment facility.

Continue on the road approximately 700 feet to the last stop at sign H.

STOP H. Striated Boulder

This boulder was removed from till exposed beneath the glacial sand during the excavation for the portion of Field 2 that is now covered by the present disposal area. The boulder is believed to be Keyser limestone. Note both the striations, clearly different from bruises created in moving this behemoth to its present site, as well as the pockets of "till" still clinging to some of the sheltered indentations on the boulder's surface.

Board buses at this location. Buses will proceed back out to the paved road.

0.2	27.9	Stop sign at end of access road. TURN LEFT toward US Route 220.
0.3	28.0	Proceed under US Route 220 and TURN LEFT onto US Route 220 N and continue east to Williamsport.
20.8	48.8	TAKE HEPBURN STREET EXIT off US Route 220. MOVE TO THE RIGHT LANE before going under the overpass.
0.6	49.4	MOVE TO LEFT LANE and TURN LEFT at first traffic light onto William Street.
0.2	49.6	Traffic light at West Third Street. CONTINUE STRAIGHT AHEAD.
0.1	49.7	Traffic light at West Fourth Street. Genetti Hotel and Convention Center on the left.

END OF DAY 2. Thanks for attending. Have a safe trip home.

Appendix A

Air Photo Plates of Field Conference Stops

Air Photo Plate Captions

PLATE I Red Hill (between Hyner and Renovo), *Hynerpeton basetti* tetrapod locality, Clinton County

A. View almost due east of the highway cut along PA Route 120 exposing redbeds of the Duncannon Member of the Catskill Formation. Here, the West Branch Susquehanna River is flowing southeast and railroad tracks run along the northeast shore between the river and the road. Note the nature of the skyline reflecting the topography characteristic of the Mountainous High Plateau Section of the Appalachian Plateaus Physiographic Province, the western-most province in the Appalachian Mountain system.

B. View nearly due north of this extensive roadcut. Bedding is gently dipping to nearly horizontal. This exposure is on the south limb of the Clearfield-McIntyre syncline (refer to Fig 1., Woodward and others, 1995, manuscript in this guidebook).

C. A slightly closer view of the cut face. Lighter-colored bands are the finer-grained sandstone and siltstone beds. Refer to Figure 3, Woodward and others, 1995, for a detailed illustration of the lithofacies' relationships developed here.

PLATE II STOP 2. Fisher Mining Co., Inc., Little Pine Creek Coal Field, Lycoming County

A. Overview of the Fisher coal mining operation looking to the east. The active face, illustrated more closely in B, is toward the treeline in the center. Note: the long building in this photo is the same as in B, but not as in C.

B. View in south-easterly direction looking down parallel to the working face.

C. The working face is in the foreground with the draglines for scale. View is roughly southwest.

PLATE III STOP 3. Lock Haven Dike-Levee Project, Clinton County.

A. View looking east, down the West Branch Susquehanna River. The levee runs along the southern shore. (1) Jay Street Bridge, (2) Constitution Bridge (PA Route 150), (3) Piper Memorial Airport, (4) Great Island, (5) US Route 220, (6) Bald Eagle Mountain, (7) borrow pit ("Save the Seals") exposing Mifflintown and Bloomsburg formations, (8) "Snoopy on skis" (a boulder-colluvium patch).

B. View in south-easterly direction looking at the city of Lock Haven. (1) Jay Street Bridge, (2) beach and bath-house recreational facility, (3) concrete viewing stand, (4) Piper Memorial Airport, (5) US Route 220.

C. View is roughly east-northeast. (1) Bald Eagle Creek, (2) International Paper Company plant and ponds, (3) Drake Chemical Company Superfund site, (4) West Branch Susquehanna River, (5) Clinton County Court House.

PLATE IV STOP 4. Drake Chemical Company Superfund Site, Lock Haven, Clinton County.

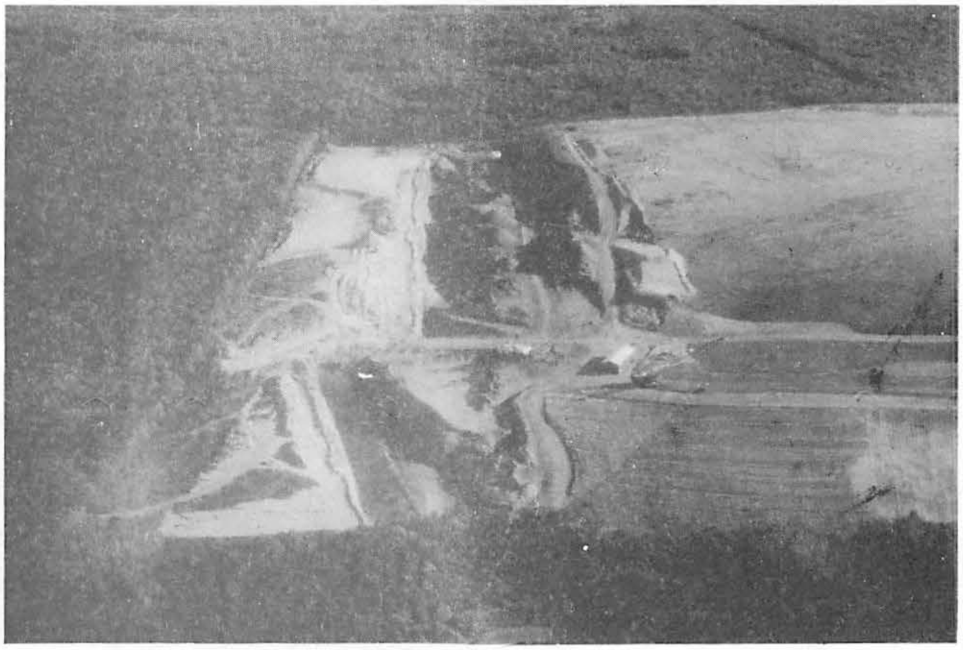
A. View looking west-northwest across the Lock Haven interchange on US Route 220. The Drake Company Superfund site (1) is near the center of the photo.

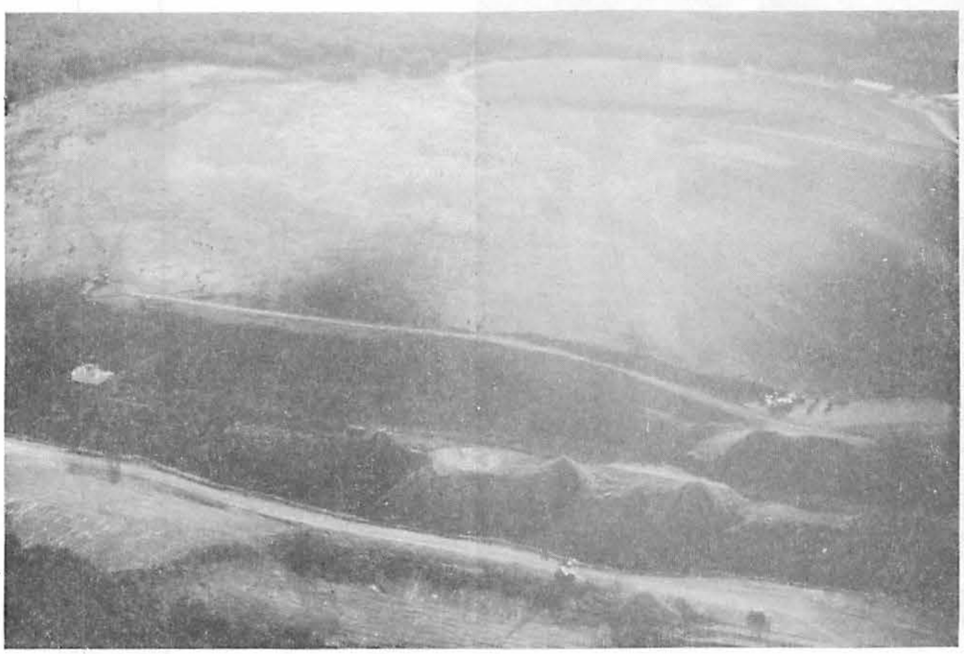
B. View toward the north of the Drake Superfund site (1) and the adjacent American Color and Chemical Company site (2). The straight-line utility corridor (3), running nearly parallel to the boundary between the two sites, roughly corresponds to the old Bald Eagle Cross-Cut Canal linking Bald Eagle Creek with the West Branch Susquehanna River.

C. View looking southwest down on the Drake Superfund site and facilities presently under construction. (1) housing for the secondary combustion chamber, quencher, and baghouse, (2) the water-treatment facility, and (3) the utility corridor.

PLATE I

PLATE II





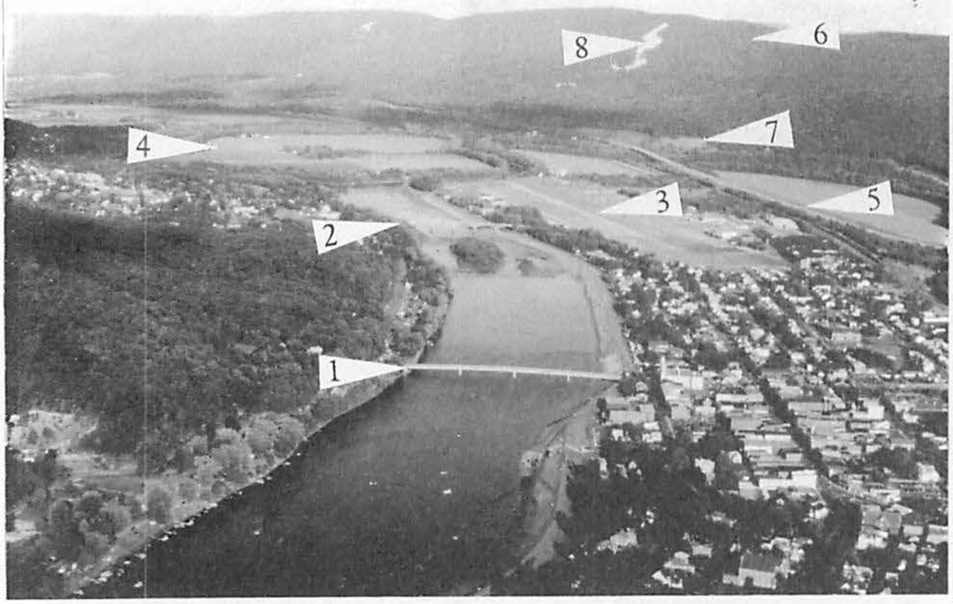
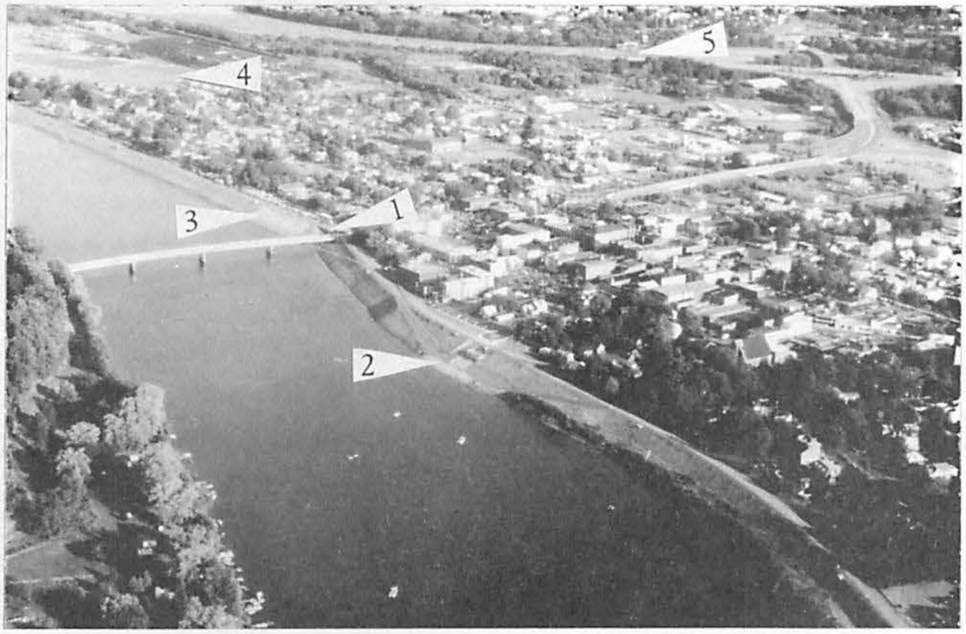
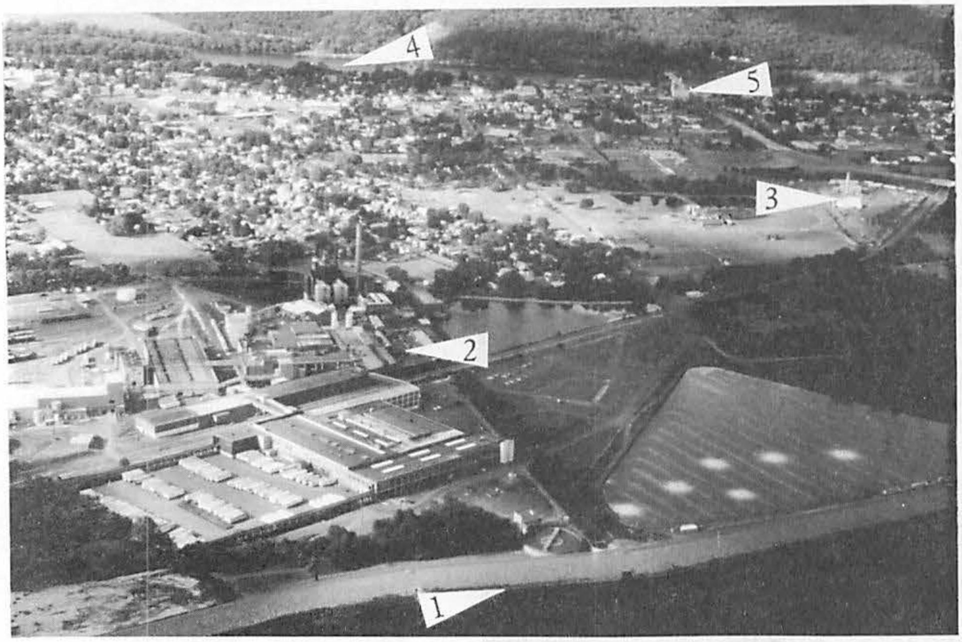


PLATE III





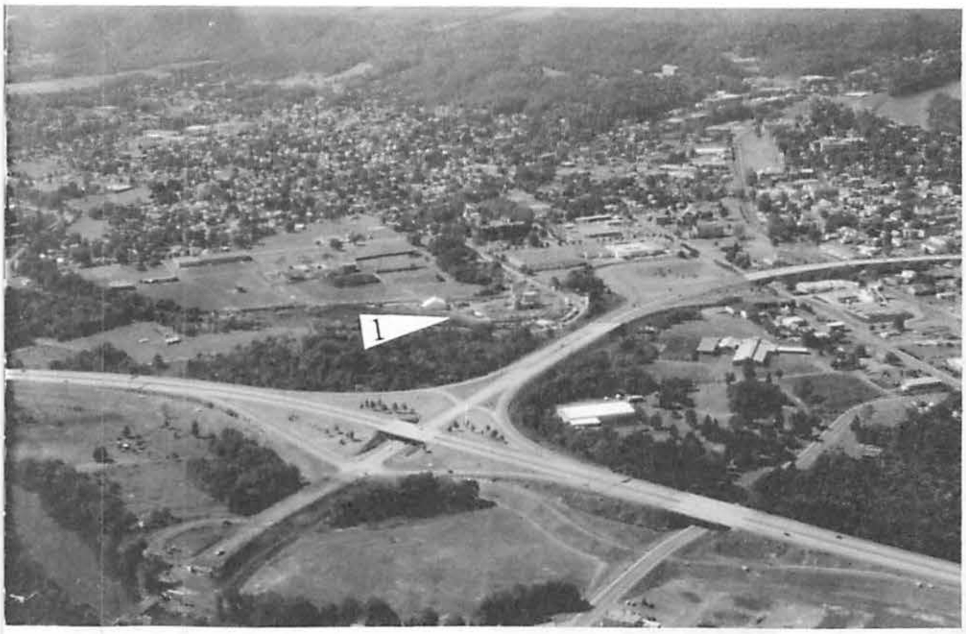


PLATE IV

PLATE V

PLATE VI

PLATE VII

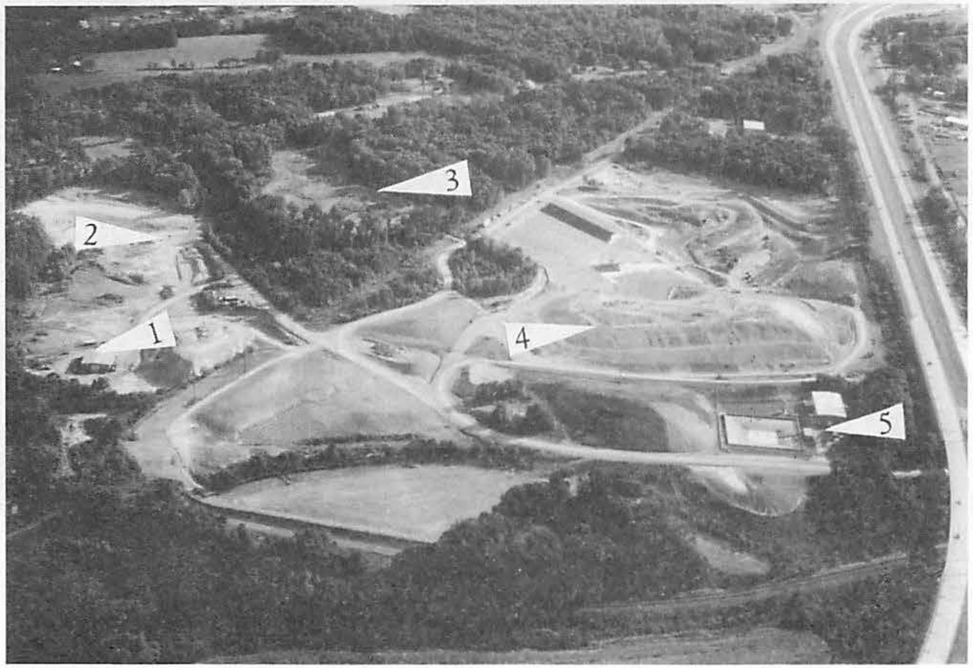


PLATE V STOP 5. US Route 220 Slope-Stability Problems

A. View looking southwest toward one of the areas on the northwest-facing slope of Bald Eagle Mountain that has experienced extensive downslope movement of surficial materials as a result of the construction of US Route 220.

B. Somewhat closer view of the same area as in A (above). Note: (1) the "Y"-surface drains, (2) the edge of a mass of moving debris, and (3) unvegetated patches corresponding to portions of the slope that have undergone relatively recent movement.

C. View along another nearby stretch of US Route 220 experienced a similar fate.

PLATE VI STOP 6. Jersey Shore Abandoned Limestone Quarries

A. Looking east toward two, structurally complex quarries developed in the Lower to Lower-Middle Devonian carbonates. Pine Creek is in the foreground.

B. A third quarry northwest of the two in the previous photo appears structurally less complex. Here, Upper Silurian and Lower Devonian carbonates have been folded into an anticline. Again, Pine Creek is in the foreground.

PLATE VII STOP 7. Clinton County Solid Waste Authority's Wayne Township Landfill

A. Looking east down the West Branch Susquehanna River Valley. Bald Eagle Mountain is in the upper right-hand corner. The presently operating, double-lined landfill is in the center. The newly installed liner, here appearing as a black "pentagon," serves as the protective layer preventing leachate from infiltrating the soil beneath the solid waste. The four-lane US Route 220, appearing in the lower third of the photo, separates the new lined landfill to the south from the natural-renovation landfill on the north.

B. Overview to the northwest of (1) the new, double-lined landfill operation, (2) the old, natural-renovation landfill, (3) the recently-installed liner, and (4) the leachate-treatment facility.

C. Looking to the southwest at the active landfill operation including: (1) the maintenance building, (2) the clay-pit operation, (3) the reconstructed wetland, (4) steadily growing mound of municipal solid waste, and (5) the leachate-treatment facility.

Appendix B

Pre-Conference Field Trip Guidebook to Red Hill, *Hynerpeton basetti* tetrapod locality, Clinton County

STRATIGRAPHIC, SEDIMENTOLOGIC, AND TEMPORAL FRAMEWORK OF RED HILL (UPPER DEVONIAN CATSKILL FORMATION) NEAR HYNER, CLINTON COUNTY, PENNSYLVANIA: SITE OF THE OLDEST AMPHIBIAN KNOWN FROM NORTH AMERICA

Donald L. Woodrow [1], Ruth A. J. Robinson [2], Anthony R. Prave [3], Alfred Traverse [2], Edward B. Daeschler [4], N. Doug Rowe [5], and Norman A. DeLaney [6]

INTRODUCTION

An extensive (~ 1-km long) exposure of red Upper Devonian strata occurs on the north side of PA Route 120 just west of the village of Hyner and approximately 35 km northwest of Lock Haven. It is the only major exposure of Upper Devonian rocks between those exposed along U.S. Route 15, ~45 km to the east and those ~65 km to the west along U.S. Route 322. Red mudstones and fine-grained sandstones are found at the base of this roadcut and are overlain by fining-upward cycles of coarse-grained, gray-green sandstone and red mudstone. The characteristic red coloration gives the exposure the name Red Hill.

Renewed interest in the Red Hill exposure comes not only from its extent, location, and superb sedimentary structures, but also because it contains vertebrate fossils of a quality and diversity not seen in Upper Devonian rocks elsewhere in the central Appalachians. The best-preserved vertebrate material (including the oldest amphibian remains in North America) occurs in the fine-grained strata at the base of the exposure toward its eastern limit. Other concentrations of vertebrate material are found in 4 distinct horizons within the lower-most gray-green sandstones toward the middle and west end of the exposure.

NOTE: The fossil vertebrates from Red Hill are of great interest for studies of the evolutionary history of several groups of fishes, the origin of tetrapod limbs, and Late Devonian diversity and ecosystems. Research by the University of Pennsylvania and the Academy of Natural Sciences of Philadelphia is ongoing at this important site. Because of the delicate nature of the fossil material, we ask that collecting be restricted to the talus slopes.

STRATIGRAPHIC POSITION OF THE RED HILL STRATA

Both the Geologic Map of Pennsylvania (Berg and others, 1980) and the Geologic Map of the Renovo East Quadrangle (Berg and Dodge, 1981, p. 477) indicate that the Catskill Formation (mapped here as Dck undivided) is exposed at Red Hill and that the Huntley Mountain Formation (MDhm) underlies the slopes about 100 meters above the roadcut (Fig. 1). Further detail is provided by the Stratigraphic Correlation Chart of Pennsylvania (Berg and others, 1983) which indicates that the rocks in the exposure are likely part of the Duncannon Member of the Catskill Formation. That stratigraphic assignment is reasonable because the youngest member of the Catskill should be in the exposure at road-level if the Huntley Mountain Formation is mapped at a position 100 m higher.

Assigning the exposed strata to the Duncannon Member of the Catskill Formation implies, according to the Stratigraphic Correlation Chart of Pennsylvania (Berg and others, 1983), that they developed during latest Devonian time and may be assigned to the Famennian Stage. The Duncannon is recognized over much of northeastern and north-central Pennsylvania and is thought to be the

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[6] 268 Pennsylvania Ave., Renovo, PA 17764

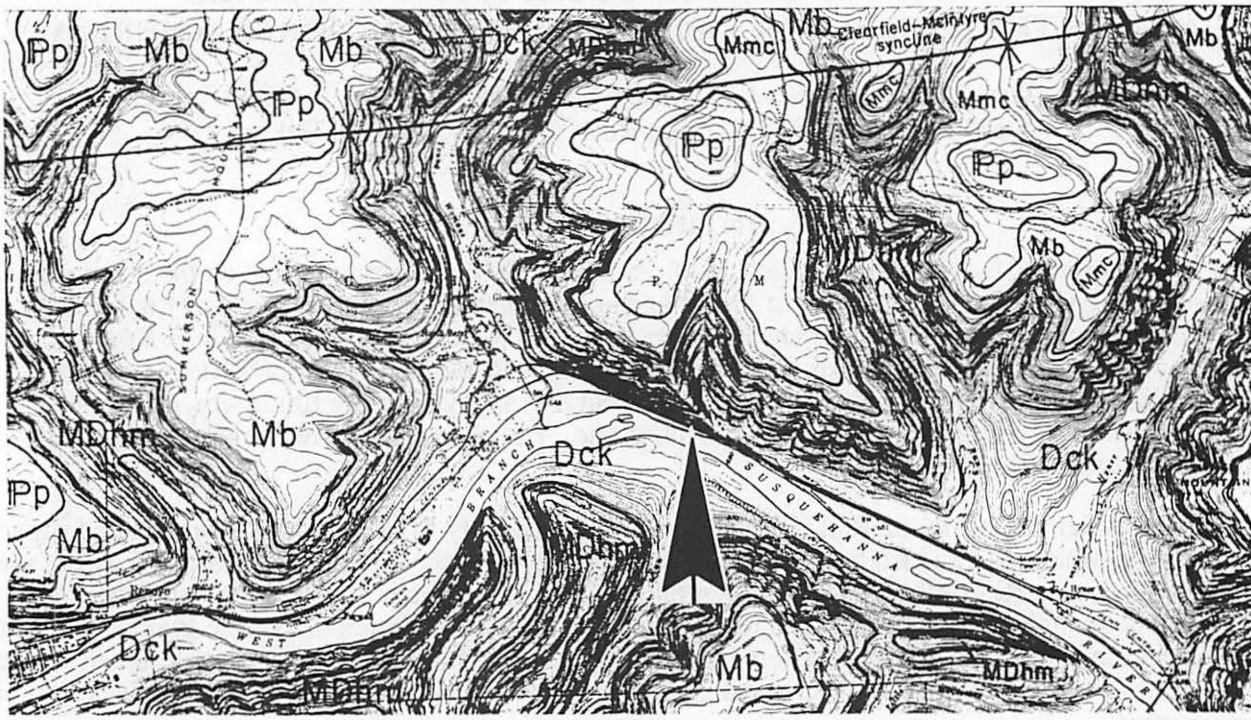

Figure 1. Bedrock geologic map of the northern half of the Renovo East quad. The Red Hill roadcut, on PA Route 120 north of the West Branch Susquehanna River, is indicated at the point of the arrow. Hyner, to the southeast, and Renovo, to the southwest, are located on PA Route 120 (from Berg and Dodge, 1981, p. 477).

lithologic correlative of the Venango Group of northwestern Pennsylvania, the Hampshire Formation of Maryland and West Virginia, and unspecified rock units within the Conewango Stage of New York (Berg and others, 1983; Sevon and Woodrow, 1985). However, part of the Stratigraphic Correlation Chart of Pennsylvania (Berg and others, 1983) covering the latest Devonian is mostly unconstrained by paleontologic data, and chronostratigraphic relationships between rock units are often uncertain. In this paper, Traverse presents palynological data from the basal part of the Red Hill exposure that establish age relationships with respect to recognized Devonian/Carboniferous floral zonations.

The combined sedimentology and lithologic and paleontologic correlations form the basis for interpreting the depositional environments at the site. These rocks represent deposition within and between channels of streams meandering across a low-relief alluvial plain not far above sea level and are part of a facies belt common to the entire extent of the alluvial plain bordering the Catskill Sea. The range of sediment characteristics so notable upsection in the Red Hill roadcut are typical of much of the Middle and Upper Devonian clastic wedge within the Appalachians. As such, this exposure, with its great lateral extent, ease of access, and abundance of vertebrate and plant fossils, is an ideal one to gain insights into the links between sedimentary processes and terrestrial life.

FACIES DESCRIPTIONS AND INTERPRETATIONS

Three sections along the eastern part of the Red Hill exposure were measured in detail and form the database for our facies descriptions and interpretations (Figs. 2 & 3). Four lithofacies have been recognized from this part of the outcrop; each is discussed separately below. The superbly exposed gray sandstones characterizing the cliff-like exposure along the western part of the outcrop (several hundreds of meters west of and stratigraphically well above the fossil-fish localities and *Hynerpeton* site quarried by Daeschler, Rowe, DeLaney, and colleagues) are not described herein.

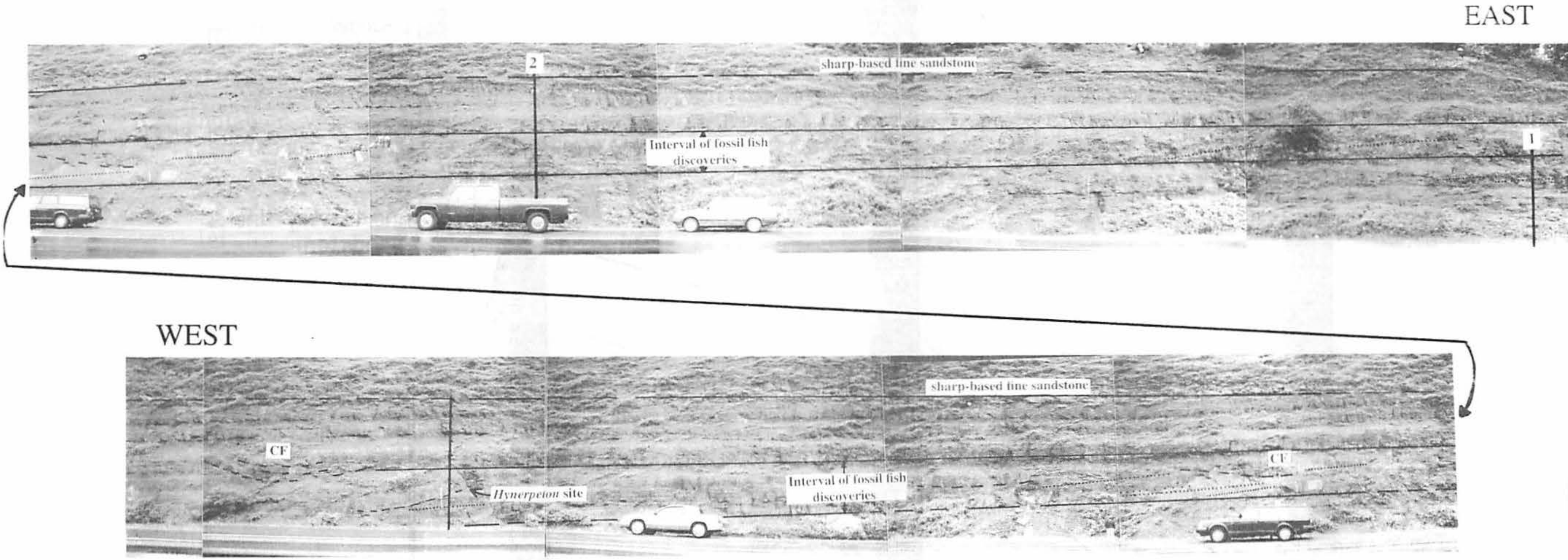

Figure 2. Photo mosaic of the eastern part of the Red Hill exposure. The location of measured sections 1, 2, and 3 are shown by the thick vertical lines. The laterally continuous fish-fossil-producing horizon is outlined. The lighter solid lines denote laterally traceable lithofacies (e.g., the sandstone body near the top of the photos, and a prominent red-mudstone horizon above the fossil-producing interval). The dotted lines indicate examples of surfaces of downlap (lateral accretion) toward the major bounding surface defining the base of the fossil-producing interval. Note that most of these surfaces yield northerly migration directions (inspection of the outcrop from across PA Route 120 will reveal many other such surfaces). CF represents locations of cut-and-fill features (i.e., erosive-based channels infilled by slightly coarser facies) which are highlighted by dashed lines. The majority of fossil quarries are between sections 2 and 3.

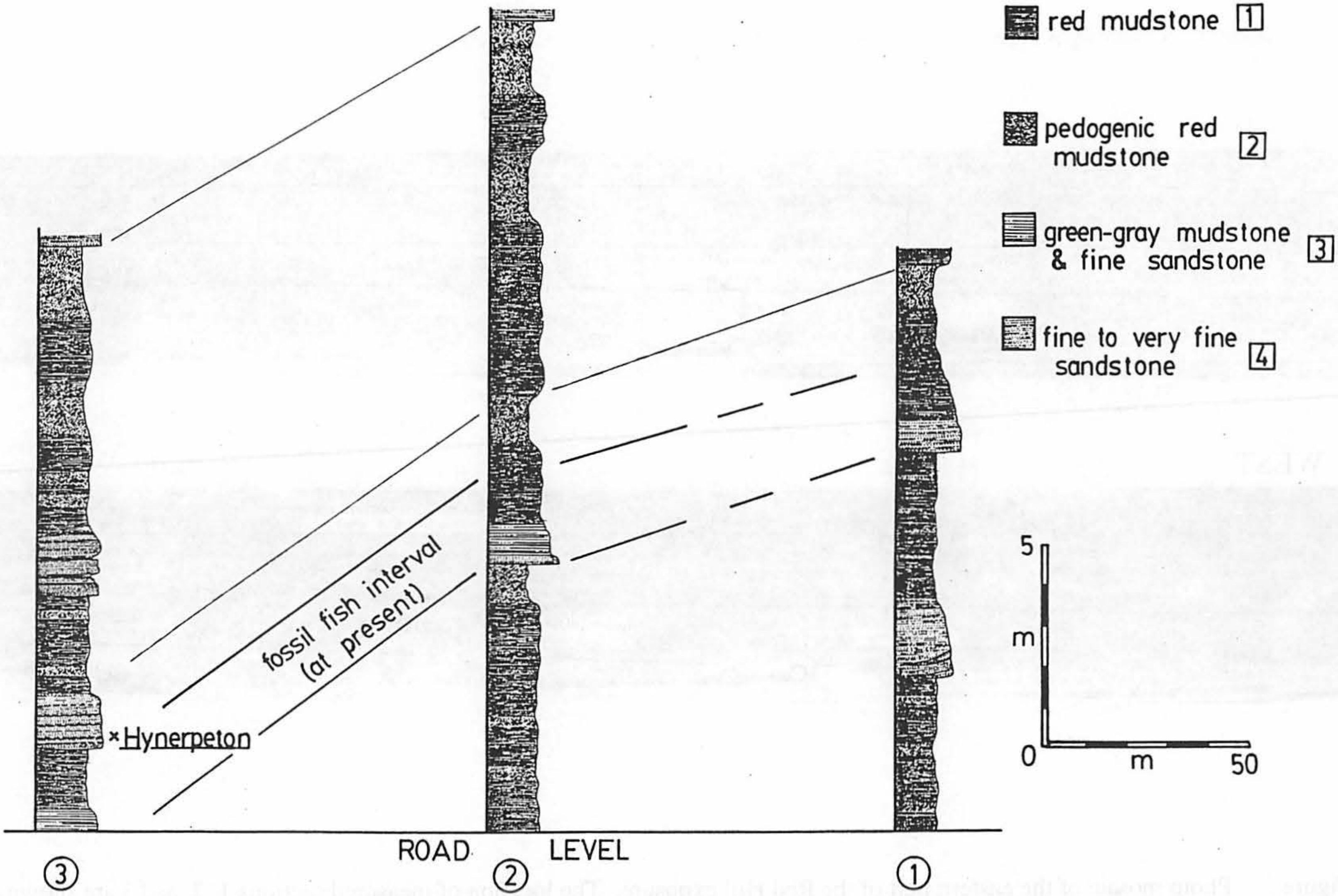

Figure 3. Sketch of stratigraphic sections 1, 2, and 3 illustrating the distribution of the four defined lithofacies. The boxed numbers to the right of the lithofacies designation are keyed to those described and interpreted within the text. These sections are located 40 m, 100 m, and 165 m, respectively, west of the end of the guardrail at the eastern end of the roadcut. Refer to Fig. 2 for the section locations relative to the photo mosaic.

Lithofacies 1: Red Hackly-Weathering Mudstone

This facies comprises the dominant lithological character of the eastern part of Red Hill and consists of red mudstone in laterally continuous intervals several decimeters up to a couple of meters thick. Beds commonly appear massive, but individual bedding surfaces can be readily observed when viewed from a slight distance. Local occurrences of flat-based, 1- to 5-cm-thick lenses of coarse siltstone are particularly useful in facilitating recognition of individual beds. Internally, the siltstone beds commonly exhibit faint, flat laminations and, in places, their upper surfaces display small-scale undulations suggestive of ripples. Many bedding surfaces, including the coarser siltstone layers themselves, are gently inclined relative to the significant bounding surfaces that separate the more laterally continuous lithofacies (see dotted lines highlighting such surfaces on Fig. 2). This implies that deposition initially occurred on a surface oriented with a slight angle of downlap relative to the basal bounding horizon. The monotony of red rock is broken in many places by an irregular network, typically several decimeters thick, of widely-spaced, thin (1 to 10 mm), subhorizontal and subvertical, greenish-gray siltstone stringers. Some display downward-branching and tapering geometries reminiscent of root traces, whereas others are coincident with fractures and joints and therefore are clearly post-depositional.

Fragments of fish teeth and scales, shark spines, and plant remains are dispersed throughout this facies (refer to detailed descriptions by Daeschler, Rowe, and DeLaney below). Trace fossils include simple vertical burrows (typically a few millimeters in diameter with lengths varying between several to many centimeters) and lungfish burrow casts (generally 5 to 7 cm in diameter). The latter are difficult to observe in outcrop, but the float at the base of the exposure (particularly between measured Sections 1 and 2) reveals numerous fragmented examples of such casts.

Lithofacies 2: Red Pedogenic-Mudstone

Acknowledging the pitfalls of circular reasoning, we incorporated the genetic qualifier 'pedogenic' within our description of this facies because the features displayed by these rocks are so characteristically pedogenic. This particular facies consists of red mudstone exhibiting pedogenic anticlines ('tepees' or 'gilgai') and slickenlines. It also contains abundant caliche nodules (0.2 to 2 cm in diameter) and root-like traces (i.e., those which taper downward exhibit acute-angle branching into thinner traces and commonly display sub-parallel, filament-like ornamentation along traces). The caliche nodules can occur as single clasts widely disseminated within the mudstone matrix or as amalgamated networks of coagulated masses several decimeters thick which may be laterally continuous for many meters. Recessed intervals, up to several decimeters in thickness, exclusively comprise such pedogenic horizons. This facies is intercalated with Lithofacies 1 in many places.

Lithofacies 3: Greenish-Gray Mudstone and Very Fine Grained Sandstone

This lithofacies is significantly subordinate to the red mudstone lithofacies and occurs only as a 50 to 150-cm-thick layer near the base of the fossil-fish-producing horizon (Figs. 2 & 3). It consists of thin-bedded, flat-laminated, greenish-gray mudstone, commonly with abundant fish and plant fragments. In several localities these fragments are highly concentrated and form thin (1 to 5 cm thick), fossiliferous lags (one such example, located several meters west of the base of Section 3 , occurs near the base of what Rowe and DeLaney have informally termed "the pond"). As one traces the greenish-gray mudstone horizon eastward toward Section 1 (Figs. 2 & 3), thin lenses (1 to 5 cm thick) of sharp-based, flat-laminated, very fine grained sandstone become common until the entire interval undergoes a facies change to flat-laminated sandstone (described below).

Lithofacies 4: Flat-Laminated Gray Sandstone

Lithofacies 4 comprises decimeter- to meter-thick beds of flat-laminated, sharp-based, fine- to very fine grained sandstone. Bed geometries vary (see Fig. 2) and range from channel-shaped (e.g., those just west of Section 3 and the *Hynerpeton* site), to convex-upward and lens shaped (e.g., the sandstone body below the cut-and-fill structure between Sections 2 and 3), to flat-based, laterally continuous but broadly wedge-shaped (e.g., the upper sandstone bed which laterally flares into a many-meters-thick sandstone body in the cliff-like portion of the Red Hill roadcut to the west). Locally, interbeds of centimeter- to decimeter-thick red mudstone layers and partings provide a slight variant of this facies.

Lithofacies Interpretation

When examined from a distance, it becomes apparent that the lithofacies at Red Hill are arranged in crudely fining-upward packets several meters in thickness. Lateral tracing of individual bedding surfaces within the various mudstone and fine-grained sandstone units define downlapping surfaces that shallowly dip north-northwestward. We interpret these as recording the lateral migration of the gently inclined margins of broad channels (Lithofacies 3 and 4). The widths of such channels must have been rather large because, over the length of the exposure of red beds at the Red Hill outcrop, no convex-downward, erosive-based thalweg surface is developed. The limited occurrence of coarser sandstone and siltstone lenses and the overall fine-grained nature of the channel-margin infill is evidence that flows through and along these channel margins were sluggish and shear stresses were low.

Although we have not made detailed measurements of paleocurrent indicators, our reconnaissance observations indicate that the azimuths of trough cross-beds and their associated axes (particularly in the thicker sandstone bodies in the cliff-like outcrop at the western end of the Red Hill outcrop) record west-northwest sediment transport. This observation is consistent with the more northerly dipping orientations of the laterally accreting channel-margin surfaces as well as those made by other workers on similar age Catskill rocks elsewhere in the central Appalachians.

The intercalation of both channel margin and pedogenic red mudstone (Lithofacies 1 and 2) implies that water depths within the channel setting were shallow and that periodic drying was common; the lungfish burrow casts support the latter inference. The development of laterally continuous pedogenic intervals capping the channel-margin facies attests to the inference that the channels eventually infilled and succumbed to widespread pedogenic processes. Admittedly our data are limited, but it appears that the thickness of well-defined pedogenic intervals increases upward (e.g., Section 2, Fig. 3). To speculate freely, such a trend may reflect an encroaching proximity of the Catskill Sea; as the area became closer to base level, it experienced more prolonged and intense periods of pedogenesis.

The cut-and-fill geometries exhibited by some of the fine-grained sandstone and coarser-grained siltstone occurrences (e.g., those adjacent to the *Hynerpeton* site and Section 3, Fig. 2) indicate that smaller but more strongly flowing channelized fluvial systems migrated across the channel magins and infilled channel areas, similar to chutes on modern point bars. These small-scale channels most likely foreshadow the return of the larger trunk streams represented by the overlying coarser and thicker sandstone complexes exposed along the extensive cliff-like roadcut to the west.

When viewed within the context of the Catskill Delta complex as a whole, the depositional scenario proposed herein is typical of those inferred for Caksill rocks throughout the central Appalachians. Those rocks record the generally westward advance of alluvial systems formed from the fluvial redistribution of detritus shed off the rising Acadian highlands to the east.

PALYNOLOGY OF THE RED HILL EXPOSURE

On August 24, 1994, A. Traverse visited the Red Hill outcrop near Hyner on the invitation of E. B. Daeschler; N. D. Rowe joined them there. Traverse collected two samples of suitably silt-rich gray shale (Lithofacies 3) for palynological analysis with the aim of sharpening the "stratigraphic call" for the by then already well known vertebrate locality. Spores have proven very useful in non-marine Devonian rocks by providing correlation between marine sections, which contain both conodonts and spores, and non-marine strata yielding only spores.

In the laboratory, the two samples (labelled: 94-1, Maceration PRC-3188 and 94-2, Maceration PRC-3189) proved to be richly palyniferous, and the palynomorphs are exceptionaly well preserved. Sample 94-2 was very rich in fragmentary plant fossils. Both of the productive samples came from an area about 150 m west of the vertebrate locality and 2.5 m and 2.0 m, respectively, below its level.

The palynoflora is dominated by species of *Grandispora*, *Retusotriletes*, *Rugospora*, and *Verrucosisporites*; many other taxa are represented. Typical taxa of the latest Devonian (Tournaisian), such as *Retispora lepidophyta* and *Vallatisporites vallatus*, as reported for the Horseshoe Curve section (Streel and Traverse, 1978) are lacking (the Horseshoe Curve section is located about 110 km southwest of Red Hill near Altoona). On the other hand, the overall cast of the flora is similar to that of other well known Famennian palynofloras in North America and Europe (e.g., Traverse,1988, p. 167). Forms characteristic of the Givetian/Frasnian levels in Pennsylvania and New York (cf., Traverse and Schuyler, 1994) are not present.

There is no significant sedimentary break between the level of the two productive samples and that of the vertebrate locality from which Daeschler has obtained his amphibian remains. Now that it is established that levels of suitable lithologic composition at this outcrop can be palyniferous, it would be desirable to sample more extensively and at closer intervals, but considerable experience with the palynology of Devonian outcrops in Pennsylvania and southern New York suggests that different ages would not be forthcoming from a more detailed study of this outcrop.

The whole section probably falls within a relatively small part of one Devonian stage. The Red Hill samples are certainly Famennian and probably late Famennian (~ 365 to 363 Ma). The exact substage will depend on more thorough study of the the florules and comparison of the results with the schemes of Richardson and McGregor (1986), Streel and others (1987), and other studies of Late Devonian palynofloras.

VERTEBRATE FOSSILS FROM THE RED HILL EXPOSURE

The fauna recovered from the fossiliferous interval at Red Hill is the most diverse vertebrate assemblage collected from the Catskill Formation to date. The faunal list includes placoderms (armored fish), primitive chondrichthyans (cartilagenous fish), acanthodians (spiny sharks), early actinopterygians (ray-finned fish), several sarcopterygians (lobe-finned fish), and the early amphibian *Hynerpeton** (Daeschler et al., 1994). Biostratigraphic correlation with other non-marine faunas from Upper Devonian deposits is difficult because many of the taxa from Red Hill are new and await formal description and comparison.

Although the abundant vertebrate fossils from the sampled interval are generally disassociated, they are well preserved and uncrushed suggesting minimal postmortem weathering and reworking. For example, in the lens where the early amphibian was found, two left-shoulder girdles were located several centimeters apart while few other skeletal elements were present. Several bedding planes have been located that preserve closely-associated skull material of large lobe-finned fish indicating quiet-water deposition and a lack of reworking.

The fish from the Red Hill assemblage range from a 5-cm-long ray-finned form to the carnivorous lobe-finned fish *Hyneria lindae*, which reached lengths over 4 meters. The amphibian *Hynerpeton* , creeping animal from Hyner (Fig. 4), was about 1 m long and fed on small fish and possibly insects. The shallow-channel-margin regions (Lithofacies 3) were certainly habitat for some of the taxa preserved there, but other forms may have washed into this depositional setting. Thus, although the depositional setting of the fossiliferous interval is clear, a paleoecological reconstruction is still premature.

* Systematic paleontology of *Hynerpeton (= Hynerpeton bassetti)*: Group Tetrapoda, Order Ichthyostegalia Säve-Söderbergh 1932 (tentative), Family Incertae Sedis, *Hynerpeton bassetti* gen.nov.sp.nov. The etymology is Hyner, in reference to the type locality; *herpeton*, Greek for a creeping animal; and *bassetti*, in honor of Edward M. Bassett (1863-1948) for inspiring a love of science and nature in his family (Daeschler et al. 1994, p. 642).

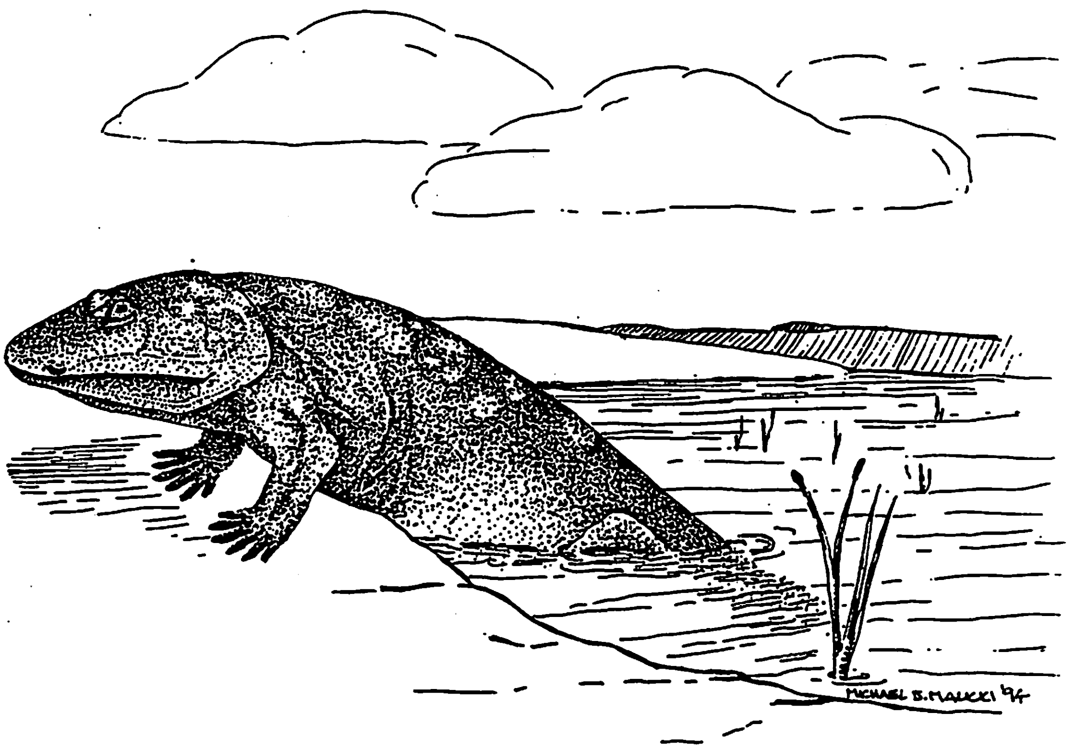

Figure 4. Cartoon of *Hynerpeton bassetti,* creeping animal from Hyner (sketch by M. B. Malicki).

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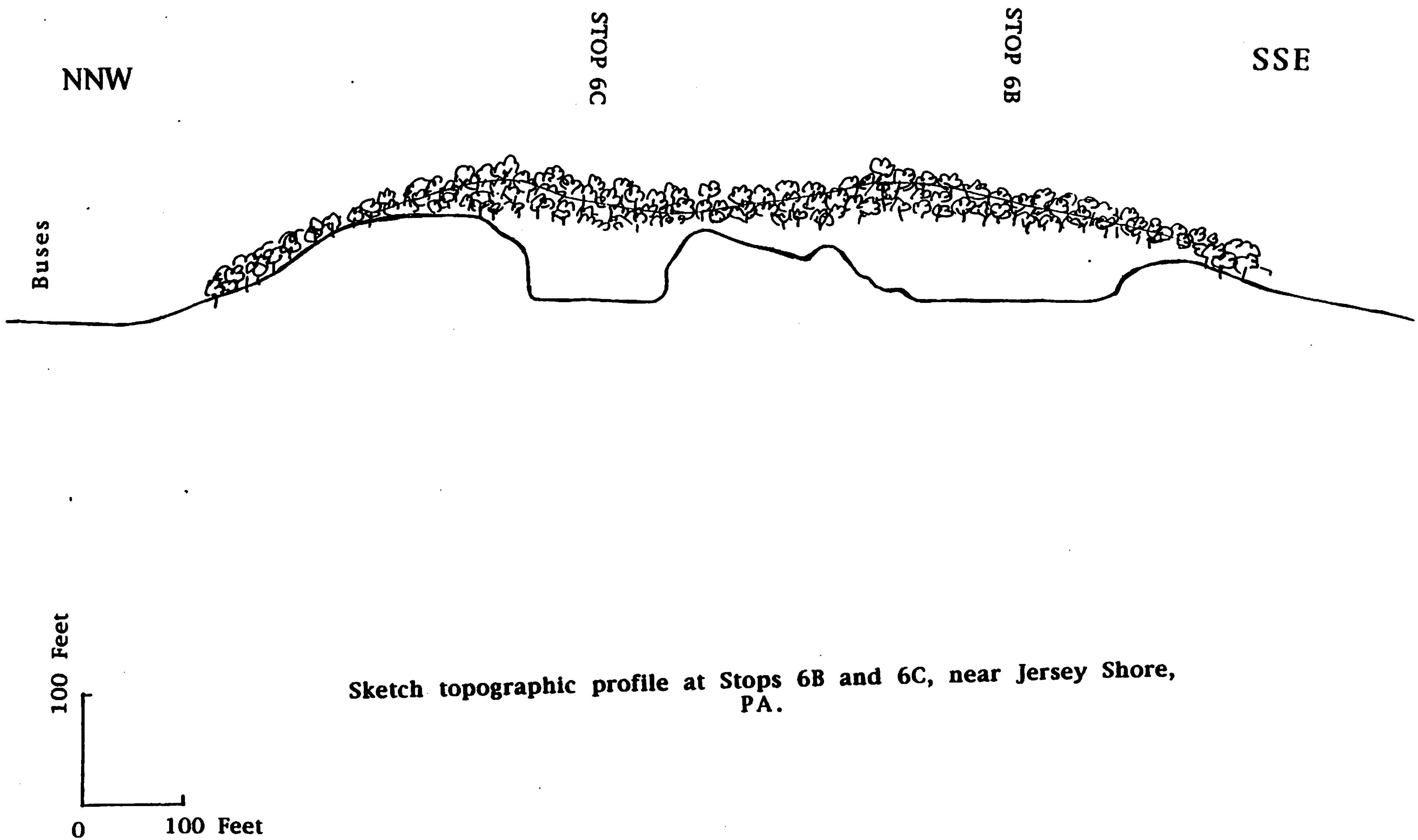

Sketch topographic profile at Stops 6B and 6C, near Jersey Shore, PA.