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Geomorphic and Erosion Studies at the Western New York Nuclear Service Center West Valley, New York

1741 211

Prepared by J. C. Boothroyd, B. S. Timson, R. H. Dana, Jr.

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The Mahoosuc Corporation

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1741 213

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ABSTRACT

This report is one in a series of related reports presenting the results of a study to evaluate the containment capability of a low-level, solid radioactive waste-burial ground at West Valley, N.Y. This project is the first portion of a detailed geomorphic and erosion study of the reach of Buttermilk Creek adjacent to the waste-burial site.

Buttermilk Creek valley is being actively modified by fluvial transport, lateral channel scour, and landsliding. High surface runoff rates create highly variable but enhanced stream flows that result in coarse-gravel sediment transport within the active channel. The active channel morphology indicates that braided stream processes are common in Buttermilk, leading to active channel down-cutting and lateral migration.

Where lateral migration of the active channel has undercut valley wall slopes, large-scale landsliding enhances valley wall retreat. A major site of historical and recent slide activity lies adjacent to the low-level burial trenches.

Initial, post-glacial Buttermilk Creek incision began before 9920 ± 240 B. P., the age of the oldest dated fluvial terrace. Future evolution of the system is expected to proceed by Buttermilk Valley lowering, tributary and landslide widening, and stream capture.

1741 214

SUMMARY

The New York State Geological Survey is the lead agency in an interdisciplinary research program to investigate the potential pathways of migration of low-level radioactive waste from a commercial shallow land-burial ground at West Valley, New York. This report is one in a series of related reports presenting the results of this project. The part of the project presented here is the first half of a study involving a detailed geomorphic and erosion study of the reach of Buttermilk Creek adjacent to the waste-burial site.

Three general approaches to the problem of estimating denudation rates are being employed in this study. First, sediment yield data from rivers in western New York similar to Buttermilk Creek are being analyzed to establish a reasonable range of erosion rates for Buttermilk Creek. Second, various discharge data are being collected directly from the study area. Buttermilk Creek stage height is being constantly monitored by a stage monitoring station and is tied in with periodic velocity measurements of measured cross sections in order to compute discharge. Bars and channels are being surveyed and clasts are being tagged to monitor movement. The third general approach to this study involves the mapping and dating of river terraces to establish a rate of downcutting for Buttermilk Creek.

The Buttermilk-Bond reach of Buttermilk Creek is a coarse-gravel, high-gradient, degrading stream with a gradient-clast size relationship similar to many gravel braided streams. The bar and channel geometry consists of large bar complexes with a complicated microtopography superimposed on the complexes. The low-stage thalweg is bent around the bar complexes and its location is determined by bar complex migration. Bar complex migration is determined in turn by the rate of braid bar movement on the surfaces of the complexes.

A few bar complexes are relatively simple gravel sheets ending in depositional edges, suggesting that the complexes migrate as a unit during catastrophic flood events. The temporary storage of gravel could affect the gradient downstream of the bar complex, resulting in enhanced sediment transport. Such a condition exists adjacent to the low-level waste burial site on Buttermilk Creek.

Buttermilk exhibits a highly variable stream hydrograph. Discharge rises from base-flow conditions to flood-stage in a few hours, and subsides just as quickly due to the impermeable nature of the till mantling the drainage basin. This high effective runoff enhances sediment transport in the

creek, probably in part because high stages allow more of the bar surface area to be covered and thus more bedload is available to be moved.

Holocene landscape evolution began after deglaciation when large alluvial fans debouched on the surface at the burial-site elevation and drainage from the fans flowed northward. The fan systems formed the loci for later development of the Buttermilk tributary systems. The agents responsible for lowering and widening of Buttermilk Creek are: a) fluvial transport of material down and out of the Creek causing lowering of the active bar and channel surface; b) lateral erosion of the active flood channel to remove previously deposited terrace material and valley-wall till; c) landslides that remove material from the valley-wall and deliver it to the valley bottom; d) sediment transport on alluvial fans that delivers valley-wall material to the Creek channel systems.

Channel sweep, leading to lateral erosion of older terraces and the valley wall till, is an extremely active process in the Buttermilk-Bond reach. Landslides occur in areas where the active channel system shows a history of valley-wall erosion. These landslides are not a major sediment provider to Buttermilk Creek except in the vicinity of the waste-burial site. Future landsliding is to be expected in this area.

Alluvial fans are an important denudation agent in the widening of the valley wall but the rate of fan processes is unknown at this time.

Migration of gravel at clast movement stations established on Buttermilk Creek has indicated that movement occurs at discharge peaks lower than the maximum recorded. This suggests that significant clast and bar movement occurs at peak flooding, particularly during spring runoff. In fact, catastrophic flood events may be the prime movers of bedload and suspended load.

Initial Buttermilk Creek incision began before 9920 $\pm$ 240 BP, the oldest dated terrace. Future evolution is expected to proceed by Buttermilk valley lowering, tributary widening and stream capture although, as yet, no rate has been established.

Two general approaches are recommended for the completion of this study: first, the continuation of the study by direct measurement of sediment discharge; and second, the continuation of the study of Holocene evolution of Buttermilk valley.

The first approach includes: 1) the remapping of several bar complexes to gain information on the rate of mass gravel

1741 216

174 215

movement; 2) continued measuring at clast movement stations to determine the rate of bedload transport and how often it moves; 3) the continued computation from velocity - cross-sectional area measurements of a few stage-discharge curves to be tied in with stage heights at clast movement sites in order to compute sediment transport rates; 4) the initiation of suspended sediment sampling; 5) the installation of a stage recorder on Frank's Creek and a suspended sediment pump station; 6) the determination of the ratio of potential bedload to suspended load from bulk sediment samples; 7) the sampling of bars to determine size distribution of bedload; 8) meaning sediment volume impounded in the two site reservoirs and computing volume/year; 9) monitoring spring freshet discharge and events; 10) the attempted sampling of bedload during a flood event to determine sediment transport rate; 11) the placing of a screen across the channel to sample total bedload above a given size over a given time; 12) the resurveying of a landslide to determine the magnitude of slumping; and 13) devising a system to monitor sediment transport on, and changes of, selected alluvial fans.

The second approach, the study of Holocene evolution, includes: 1) the correlation of mapped terraces downstream and across the valley to gain information on the early dimensions of the valley; 2) attempts to collect age-dateable material from the terraces; 3) assessment of tributary development in relation to topography, processes and gradient; 4) measurement of longitudinal profiles of tributaries for base line information on sediment transport; 5) construction of cross-sectional profiles in tributaries to assess the nature of valley development; and 6) the computing of sediment volume removed from Buttermilk Creek as a function of the ages of the terraces to obtain a volume/year.

1741 217

TABLE OF CONTENTS

1741 218

LIST OF FIGURES

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LIST OF ABBREVIATIONS

LLRWB	Low-level, radioactive waste burial
NRC	United States Nuclear Regulatory Commission
NYSGS	New York State Geological Survey
URI	University of Rhode Island
USGS	United States Geological Survey - Water Resources Division

1741 221

1.0 INTRODUCTION

1.1 General Introduction

The New York State Geological Survey (NYSGS) is the lead agency in an interdisciplinary research program to investigate the potential pathways of migration of low-level radioactive waste from a commercial shallow, land-burial ground at West Valley, N.Y. The study is funded by the U.S. Environmental Protection Agency, and the U.S. Nuclear Regulatory Commission, and involves cooperative programs with the U.S. Geological Survey, the N.Y. Department of Conservation, N.Y. Health Department, and the N.Y. Energy Office.

The West Valley commercial burial area is located 48 km south of Buffalo, N.Y., in northern Cattaraugus County, at the Western New York Nuclear Service Center (Figure 1). The major installation on the site is a nuclear fuel reprocessing plant not currently in operation. South of the plant area is the NRC-licensed high-level burial area. And to the east of that is the commercial low-level radioactive waste burial (LLRWB) area with which this study is concerned. The 6-acre LLRWB area consists of a series of 12 burial trenches approximately 180 meters long, 11 meters wide, and 6 meters deep. Between 1963 and 1975, these trenches were dug in a thick clay-silt till of low permeability and relatively high ion exchange capacity. As the trenches were filled, the uncompacted waste was covered with a 1 to 5 meter thick cap of soil, consisting of weathered and unweathered till.*

The geomorphic and erosion study described in this report is being carried out by Dr. Jon C. Boothroyd, a fluvial geomorphologist at the University of Rhode Island (URI) under the direction of the NYSGS with the assistance of Barry S. Timson. The project involves a detailed system and erosion study of the reach of Buttermilk Creek adjacent to the low-level radioactive waste burial (LLRWB) site (Figure 2). The primary goal of the study is to investigate sediment yield and mechanisms of erosion and mass-wasting in order to establish a rate of denudation for the drainage basin. Much of the data from this first period of study will gain significance only after another season of monitoring and measurement is complete. The technique for future erosion has been developed, but in many areas we have yet to measure the actual erosion.

* A more detailed description is available in references (1) and (2).

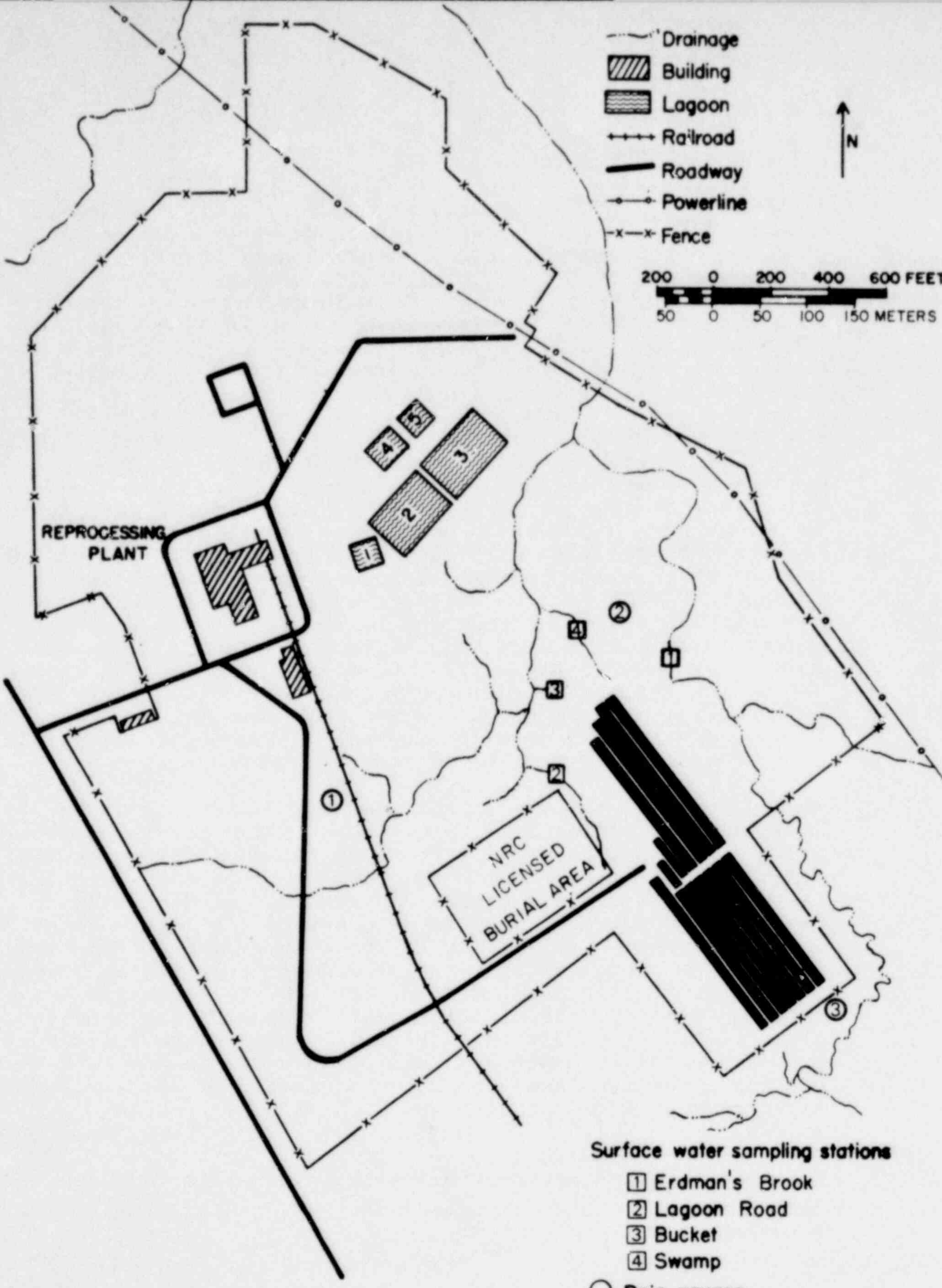

Figure 1. Western New York Nuclear Service Center

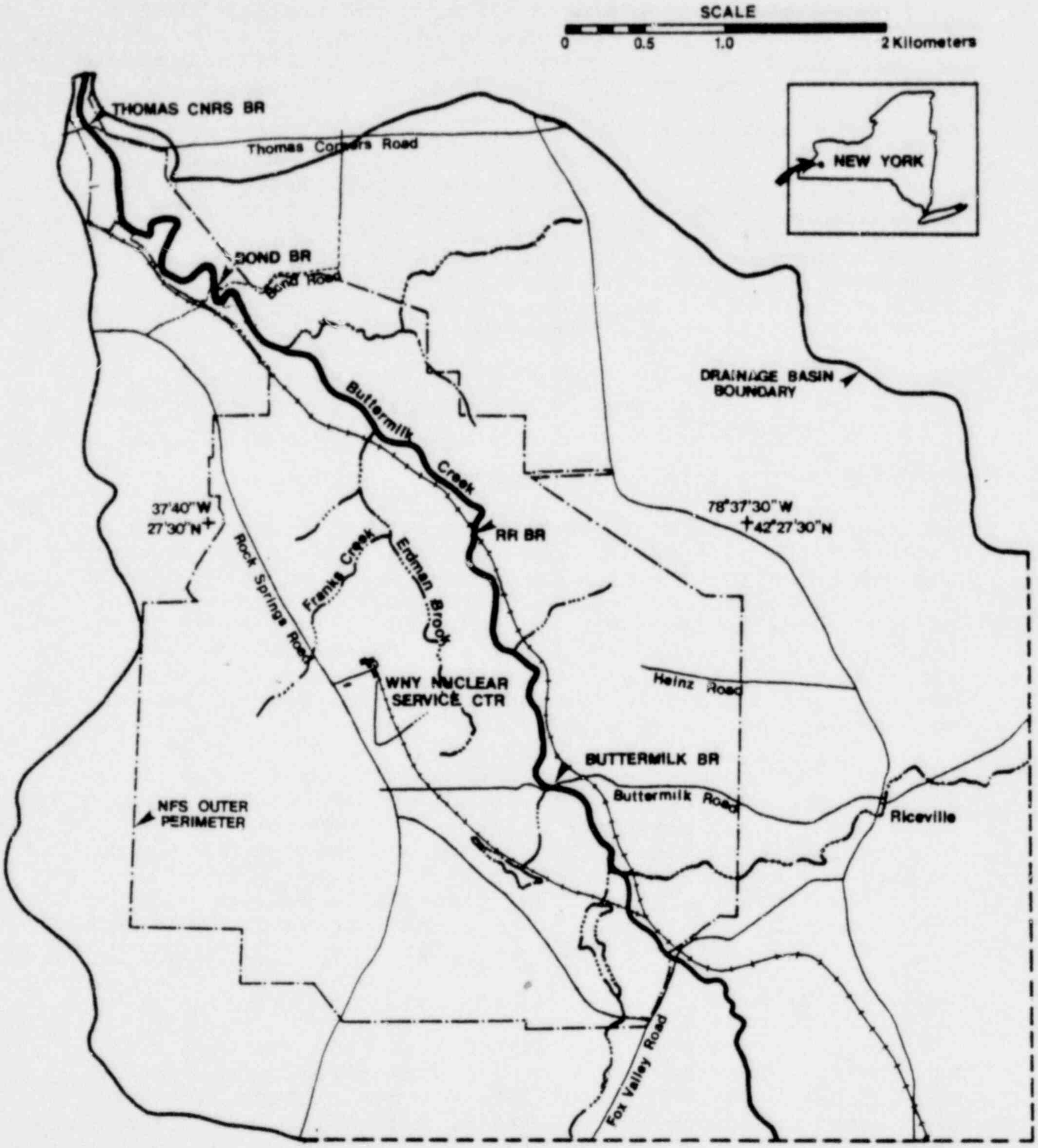

Figure 2. Map of north part of Buttermilk Creek drainage basin. Note location of Western New York Nuclear Service Center ("WNY Nuclear Service Center" on map).

1741 224

Three general approaches to the problem of estimating denudation rates are being employed. First, sediment yield data from rivers in western N.Y. that generally fit characteristics of Buttermilk Creek are being analyzed to establish a reasonable range of erosion rates for Buttermilk Creek.

The second general approach is the collection of various discharge data from the stretch of Buttermilk Creek adjacent to the burial site (between Buttermilk Road Bridge and Bond Road Bridge). Buttermilk Creek stage height is being constantly monitored by a stage monitoring station and is tied in with periodic velocity measurements done with a Price pygmy current meter at measured cross sections in order to compute discharge. Bars and channels are being surveyed and clasts are being tagged to monitor movement.

The third general approach to this study involves the mapping and dating of river terraces to establish a rate of downcutting for Buttermilk Creek.

1.2 Scope and Conditions of Study

The field area was confined to the reach of Buttermilk Creek between Buttermilk Road bridge and Bond Road bridge, including the valley walls, the high surface adjacent to the incised Buttermilk reach, and the mouth of tributary drainages (see Environmental Geologic Map, Plate 1, for locations). A brief inspection was made of the Frank's Creek/Erdman's Brook area. Limited field checking of environmental geologic map units was also carried out inside and outside the Western New York Nuclear Service Center boundary.

Working conditions were excellent for bar mapping and other field mapping during the summer of 1978 because of extremely low discharge in Buttermilk Creek. No flood-stage discharge measurements were made for suspended and bedload transport computation because no flood-stage discharges occurred during the field season. The original plan was to measure events during the 1978 spring ice breakup and melt water flooding, but the field program did not begin in time.

1.3 Previous Work

The glacial history of western New York that includes the Buttermilk Creek drainage has been summarized by Muller (3) and by Coates (4). Detailed 1:24,000 scale quadrangle mapping was carried out by LaFleur (5) and an interpretative report is being published by the U.S. Geological Survey (USGS). A gaging station was maintained on Buttermilk Creek at the Bond Road bridge from 1962-1968 (References 6 through 12). A special investigation was made by the USGS of the large-scale flood event of September, 1967 (13).

2.0 CONCLUSIONS

1) The Buttermilk-Bond reach of Buttermilk Creek is a coarse-gravel, high-gradient, degrading stream with a gradient-clast size relationship similar to many gravel braided streams.

2) The bar and channel geometry consists of large bar complexes with a complicated microtopography superimposed on the complexes. The low-stage thalweg is bent around the bar complexes and its location is determined by bar complex migration. Bar complex migration is determined in turn by the rate of braid bar movement on the surfaces of the complexes.

3) A few bar complexes are relatively simple gravel sheets ending in depositional edges, suggesting that the complexes migrate as a unit during catastrophic flood events. The temporary storage of gravel could affect the gradient downstream of the bar complex, resulting in enhanced sediment transport. Such a condition exists adjacent to the low-level waste burial site on Buttermilk Creek.

4) Buttermilk exhibits a highly variable stream hydrograph. Discharge rises from base-flow conditions to flood-stage in a few hours, and subsides just as quickly due to the impermeable nature of the till mantling the drainage basin. This high effective runoff enhances sediment transport in the creek, probably in part because high stages allow more of the bar surface area to be covered and thus more bedload is available to be moved.

5) Holocene landscape evolution began after deglaciation when large alluvial fans debouched on the surface at the burial-site elevation and drainage from the fans flowed northward. The fan systems formed the loci for later development of the Buttermilk tributary systems.

6) The agents responsible for lowering and widening of Buttermilk Creek are: a) fluvial transport of material down and out of the Creek causing lowering of the active bar and channel surface; b) lateral erosion of the active flood channel to remove previously deposited terrace material and valley-wall till; c) landslides that remove material from the valley wall and deliver it to the valley bottom; d) sediment transport on alluvial fans that delivers valley-wall material to the Creek channel systems.

7) Channel sweep, leading to lateral erosion of older terraces and the valley wall till, is an extremely active process in the

Buttermilk-Bond reach. Landslides occur in areas where the active channel system shows a history of valley-wall erosion. These landslides are not a major sediment provider to Buttermilk Creek except in the vicinity of the waste-burial site. Future landsliding is to be expected in this area.

8) Alluvial fans are an important denudation agent in the widening of the valley wall but the rate of fan processes is unknown at this time.

9) Migration of gravel at clast movement stations established on Buttermilk Creek has indicated that movement occurs at discharge peaks lower than the maximum recorded. This suggests that significant clast and bar movement occurs at peak flooding, particularly during spring runoff. In fact, catastrophic flood events may be the prime movers of bedload and suspended load.

10) Initial Buttermilk Creek incision began before 9920 $\pm$ 240 BP, the oldest dated terrace. Future evolution is expected to proceed by Buttermilk valley lowering, tributary widening and stream capture, although no rate has as yet been established.

1741 228

3.0 RECOMMENDATIONS

3.1 To continue the study by direct measurement of sediment discharge, the following should be carried out:

1) Remap bar complexes 4 through 6 and 11 to gain information on the rate of mass gravel movement down Buttermilk Creek.

2) Continue measurements at clast movement stations to determine rate of bedload transport for a small area, and how often bedload moves.

3) Continue velocity - cross-sectional area measurements in order to conduct a new stage-discharge curve. Tie this curve to stage heights at the clast movement sites in order to compute sediment transport rates.

4) Initiate suspended-sediment sampling with a pumping station at Thomas Corners Road bridge.

5) Install a stage recorder on Frank's Creek and a suspended-sediment pump station.

6) Obtain bulk sediment samples of valley-wall till to determine ratio of potential bedload to suspended load. Sample bars to determine size distribution of bedload.

7) Measure sediment volume impounded in the two site reservoirs and compute volume/year.

8) Monitor spring freshet discharge and events.

9) Attempt to sample bedload during a flood event to determine sediment transport rate.

10) Place a screen across the channel at Bond Road bridge to sample total bedload above a given size over a given time.

11) Resurvey landslide to determine magnitude of slumping.

12) Devise a system to monitor sediment transport on, and changes of, selected alluvial fans.

3.2 To continue the study of the Holocene evolution of Buttermilk valley, the following are suggested:

1) Correlate the mapped terraces downstream and across valley to gain information on the early dimensions of the valley.

2) Attempt to collect age-dateable material from the terraces.

3) Assess tributary development in relation to topography, processes, and gradient.

4) Measure longitudinal profiles of tributaries for base line information on sediment transport.

5) Construct cross-sectional profiles at selected locations of tributaries to assess the nature of valley development.

6) Compute sediment volume removed from Buttermilk Creek as a function of the ages of the terraces to obtain a volume/year.

4.0 PURPOSE OF STUDY

The major objectives of Period I of the landform modification study are to determine seasonal and annual modification of the Buttermilk Creek drainage adjacent to the low-level radioactive waste disposal site by: 1) mass wasting of slopes and delivery of sediment to Buttermilk Creek and its distributaries; and 2) transport of sediment down and out of Buttermilk Creek by bedload and suspended load processes.

4.1 Information Products

The following information products were proposed at the initiation of the study. Some were later modified as detailed in Section 4.2.

1) An environmental geological map at a scale to be determined by consensus between investigators from NYSGS and the URI work group. The regional extent of the area to be mapped is shown in Figure 2.

2) Map(s) showing sequential mass wasting and stream drainage patterns derived from the existing aerial photo coverage (1939 to 1977).

3) Graphic and tabular presentation of Buttermilk Creek discharge data which has been collected in past years by the USGS, including:
- a) stage-discharge rating curve
- b) hydrographs, both yearly and for specific flow events
- c) flow-duration curve
- d) flood-frequency curve

4) A feasibility study and preliminary work on suspended load and bedload data to include:
- a) suspended load and discharge versus time
- b) sediment rating curve (suspended load versus discharge)
- c) movement of clasts with time
- d) changes in bar morphology with time

5) Point-bar maps with topographic, sediment size, bedform, and vegetation information, and sequential maps of changes in these quantities.

6) Data on clast movement within the fluvial system characterizing the relationship between clast size, distance, and flow.

7) A photographic file of:
- a) geomorphic-sedimentologic units

b) stratigraphic units
c) bedforms
d) clast movement
e) stream stages
f) slumps

8) Preliminary work on computation of:
a) total suspended load removed from reach for specific flow events and a yearly average of suspended load;
b) total bedload transport for specific flow events and a yearly average.

4.2 Changes to Information Products

Environmental Geologic Map - It was originally envisioned that the map would be produced at a scale of 1:24,000 or 1:12,000. Subsequent discussions resulted in a decision to map at a scale of 1:4,800 on already existing maps of the 3300-acre area owned by Nuclear Fuel Services, Inc. Thus, a more detailed map was produced of a smaller area than that shown on Figure 2 (see Plate 1). In addition, the detail on the surficial geologic maps of the Ashford Hollow and West Valley 7½' quadrangles by LaFleur (5) make additional mapping unnecessary.

Terrace Mapping - The importance of older, elevated stream terraces was recognized after field work began and mapping at a scale of 1:4,800 was completed and added as a special component of the environmental geologic map.

Landslide Monitoring - A transit survey of one of the largest landslides was conducted for later resurvey and monitoring.

5.0 PROCEDURES

5.1 Field Methods

General Location - Field inspection of the Buttermilk Road to Bond Road reach of Buttermilk Creek revealed that the stream was divided into a series of emergent gravel-bar complexes separated by the low-stage thalweg of the stream. These bar complexes were numbered consecutively downstream (1 through 25) and marked by placing wooden stakes on the high points of the bar surfaces. The location and elevation of the tops of these stakes was determined during the survey of the longitudinal profile. Clast size and clast movement stations, bar maps, landslide maps, and location of features on the valley walls are referenced by bar complex or stake location.

Gradient - The gradient or longitudinal profile of the 4.8-kilometer reach from Buttermilk Road Bridge to Bond Road Bridge was measured by standard transit and rod leveling techniques to 0.01 feet horizontally. Backsight and fore-sight distances ranged from 150 to 400 feet. Because of the type of equipment available, distances were measured in English units and converted to the metric system. Stations were chosen at the water's edge of the low-stage thalweg. Stage height did not appear to vary during the 2 days the profile was obtained. The profile was tied to a USGS benchmark on the Baltimore and Ohio Railroad bridge located approximately halfway down the reach.

Clast Size - Clasts were measured at one station on each bar complex. The technique is as follows: 1) the bar complex was inspected for concentrations of large clasts and a likely location was chosen; 2) a 3-meter distance was marked in the direction of sediment transport; 3) the 10 largest clasts falling on or within one clast length of the line were marked; and 4) the 3 axes (L, I, S) were measured to 0.5 cm. This technique is similar to that followed in Boothroyd and Ashley (14) and Smith (15). Further rationale is included in the Results section.

Bar Mapping - Topographic surveys of 2 bar complexes were accomplished using two different techniques. Pertinent geologic information was recorded for each station. On bar complex 11, standard transit and rod techniques were used to determine distance and elevation along 18 transects for a total of 387 stations. The stations were tied by survey to the bar complex 11 location stake and hence to an absolute elevation. On bar complexes, 4, 5, and 6, the double rod

1741 233

and hand-level method was used to level along 21 transects for a total of 526 stations. The standard transit and rod method was used to obtain an additional 119 stations in geologically interesting areas between transects for a grand total of 645 stations. Three stations on each transect were tied to either the bar complex 4 or bar complex 5 location stake and thus to an absolute elevation.

Landslide Mapping - An active landslide on the west wall of the valley opposite bar complex 6 was surveyed by the transit and rod technique. Eight transects with a total of 35 stations were marked. The instrument station was marked and tied to the bar complex 6 stake of known elevation and location.

Clast Movement Stations - Nine stations along 5 transects on 5 separate bar complexes were selected for variation in geographic area, bar complex type, and topography. The technique is similar to that developed by Helley (16) to record gravel movement in Blue Creek, California.

The procedure was as follows: 1) four 10-meter transects were marked perpendicular to the sediment transport direction; 2) approximately 10 clasts of average maximum size (long axes of 21 to 30.5 cm) and 10 of smaller size (medium) were numbered and painted at each station (red = large, green = medium); 3) clasts selected were within several lengths upstream or downstream of the transect; 4) locations along, upstream and downstream of the transect line were measured to 1.0 cm; and 5) the transect line was marked with yellow paint to identify smaller clasts. A total of 146 clasts (red and green) were marked.

The transect lines were tied by survey to stakes placed on terraces on both sides of the active bar and channel system. Clast stations were located along transects from the topographic survey on bar complex 4 (transect 5) and bar complex 11 (transect 10).

Discharge Measurements - Five sets of discharge measurements were made on Buttermilk Creek at Thomas Corners Road bridge. Four low-flow data sets were obtained at a section measured perpendicular to the low-stage channel beneath the bridge, and a fifth at a slightly higher flow stage about 100 meters upstream of the bridge. Standard USGS techniques were used (17). Both Price type AA and Price pygmy current meters were used with a topset wading rod. Measurements were obtained at 0.6 depth every 0.5 meter across the section. Cross-sections ranged from 5 to 10 meters wide. The midsection method was used to compute cross-sectional area. Water-surface (stage) height was marked on the west abutment of

Thomas Corners Road bridge for later comparison with values from the stage-height recorder installed at the bridge.

Suspended-Sediment Samples - A single suspended-sediment sample was obtained from the midpoint of the channel during the measurement of each discharge data set by a depth-integrating, hand-type (DH 59) sampler (18).

Terrace Mapping - Fluvial terraces were mapped between Buttermilk Road bridge and Bond Road bridge on both sides of Buttermilk Creek valley and on the burial-site surface between Erdman's Brook/Frank's Creek and Buttermilk Creek. This was accomplished by walking the area and recording information directly onto 1:4,800 scale base maps. Terraces were recorded only if fluvial gravel was present in natural cuts or in 1-meter deep test pits. Thus, other terrace remnants may have gone undetected. Additional terraces were identified upstream of Buttermilk Road bridge by aerial-photo interpretation and were not field checked.

Environmental Geologic Mapping - The environmental geologic map was field checked during the terrace mapping. In addition, the burial site surface outside of the high-security fence, Erdman's Brook and Frank's Creek valleys were inspected in detail. Other spot checks were made both inside and outside the high-security fence (see section 5.2 for more details).

Photographic Documentation - Approximately 600 color slide photos were taken during the field season of bar-surface features, landslide surface features, clast orientation, bed forms, bar and channel geometry, and terrace internal structure. Clast-movement stations were documented in detail.

5.2 Office Work

Environmental Geologic Mapping - The environmental geologic map was prepared on a 1:4,800 scale topographic base (Plate 1). The major sources of information were: 1) 1:24,000 surficial geologic mapping by LaFleur (5) of the Ashford Hollow and West Valley 7½ minute quadrangles; 2) 1966 (1:4,800 scale) and 1977 (1:4,800 scale) vertical aerial photographs; and 3) detailed mapping by Dr. Boothroyd in the Buttermilk-Bond reach and on the burial-site surface. Twenty-three units were delineated and transferred by hand to the base map. The time-stratigraphic interpretation of LaFleur (5) was followed, particularly in regard to Wisconsinan till units. Effort was concentrated on a detailed interpretation of Holocene fluvial and mass-wasting processes and products. This map is somewhat similar to those produced in the Texas coastal mapping program (19) and to that developed by Boothroyd and others (20) for the Alaskan Outer Continental Shelf

Energy Program (OCSEP).

Slope Map - The Buttermilk Creek drainage basin was delineated on the 1:24,000 scale topographic quadrangle maps (Ashford Hollow and West Valley) by inspection of topographic divides (Plate 2). Five slope domains were chosen and boundaries were mapped by measurement of contour density within the drainage basin area.

Channel Sweep - The active bar and channel pattern was determined on 5 series of vertical aerial photographs:

1) 1939 (1:14,400 scale)
2) 1961 (1:9,600 scale)
3) 1966 (1:4,800 scale)
4) 1968 (1:9,600 scale)
5) 1977 (1:4,800 scale).

The bar and channel boundaries were photogrammetrically transferred to a 1:4,800 scale base with a Bausch and Lomb Zoom Transfer Scope. This base was later reduced in scale with a Map-O-Graph. A map for each year and a composite change map were produced, with bar and channel boundaries illustrated with respect to base of valley wall, top of valley wall, and the low-level burial site (Plate 5).

6.0 RESULTS

The following discussion will make use of the environmental geologic map (Plate 1), the slope map (Plate 2), and a reproduction of a portion of LaFleur's (5) surficial maps (Plate 3). Please refer to them for location and details. An aerial view of the nuclear fuel reprocessing plant buildings, low-level waste burial site, and Buttermilk Creek is shown in Figure 3.

6.1 Environmental Geologic Map

The boundaries or contacts of Wisconsinan units, particularly till, follow those mapped by LaFleur (5). We have added additional units subdivided on the basis of slope gradient. The latest Wisconsinan (?) fluvial surface has been remapped and somewhat changed from LaFleur (5). The Holocene fluvial and mass-wasting environments have been subdivided in detail, and boundaries and interpretations may differ from those of LaFleur. The mapped area is divided into 23 units in 5 categories as noted below. Refer to Appendix A for a description of individual units. Descriptions of various environments are outlined in following sections and in the discussion.

Moraine Systems - Eight till units have been identified on the basis of LaFleur's boundaries (5), his stratigraphy, and slopes identified on the 1:4,800 scale map.

Fluvial/Alluvial Fan Systems - Ten units were identified ranging from presently-active active bar and channel systems to late Woodfordian proglacial channels.

Bedrock - Devonian sandstone and shale crop out in limited areas, mostly in deeply-incised channel bottoms and valley walls.

Lakes and Ponds - Most are quite small, either natural or man-made. The largest lakes are 2 reservoirs built for the Western New York Nuclear Service Center (Plate 1).

Man-made Fill or Excavation - These range from road grades and railroad grades to excavations inside the site high-security fence. Particularly important is the Baltimore and Ohio Railroad grade in the Buttermilk-Bond reach of Buttermilk Creek (Plate 1).

6.2 Gradient

The longitudinal profile of the Buttermilk-Bond reach is shown

Figure 3. A vertical aerial photograph of the Western New York Nuclear Service Center taken in April, 1977. The low-level waste-burial site is just left of center, Buttermilk Creek is along the right margin. The Western New York Nuclear Service Center complex of buildings is in the upper left corner. The open fields are on a high terrace surface, heavy vegetation mantles the steep valley walls. Downstream is up the page to the northwest. Distance across the photo is about 1 km.

in Figure 4, Graph A. The mean gradient is 6.76 m/km, as measured along the low stage thalweg (Figure 5).

The profile may be divided into a number of segments of varying downstream spacing, or wavelengths. The shortest segments, measuring 50 to 100 m are pool-and-riffle alterations discussed in the bar-description section 6.3. Some bar complexes 100 to 200 m long are also remarkably flat. Two examples are bar complex 4 and bar complex 8 (Figure 4, Graph A).

Longer-spaced segments are on the order of 500 m to 1 km in length. The gradient is steeper than the mean value from bar complex 2 to bar complex 8, that portion of Buttermilk Creek closest to the waste-burial site. An average segment extends from bar complex 8 to bar complex 15, where the slope becomes gentler than the mean value. This change to a shallower gradient begins at the confluence of Frank's Creek. The gradient becomes shallower still at bar complex 22, the beginning of bedrock exposures along the west side and floor of the low-stage channel.

6.3 Bar and Channel Geometry

The basic channel pattern of Buttermilk Creek is an entrenched meander system when the active, unvegetated bars and the low-stage thalweg are considered together as shown on Plate 1 (unit FA_{bc}) and Figure 3. The channel has several abrupt, 90° bends, as in the vicinity of bar complex 4 (Figure 6); some gentle meanders, as at bar complex 11 and 12 (Figure 7); some relatively straight reaches, such as above the confluence of Frank's Creek (Plate 1); and a reach with very sinuous meanders, adjacent to, and below the Bond Road bridge (Plate 1). The overall sinuosity, however, is low (21), measured as 1.14 along the low-stage thalweg.

Topographic Mapping - Two areas were selected to construct topographic maps of bar complexes and adjacent channels in some detail. These are bar complexes 4, 5, and 6 (Figure 6), and bar complexes 11 and 12 (Figure 7). These 2 locations are at thalweg bends, but represent a contrast in overall channel pattern, bar morphology, and detail on bar tops as described below. Bar complexes 4, 5, and 6 are shown on Plate 4.

Detailed Bar and Channel Pattern - Figure 6 illustrates detail of active bars of bar complexes 4, 5, and 6 at a flow-stage somewhat above base flow, but not in flood; Figure 8 is a simplified morphologic map of the same area. Plate 4 is a more detailed topographic map. The bars (100 to 200 m in length) exist as complex, elongate, erosional and depositional features, flanked by and often cut by the present low-stage

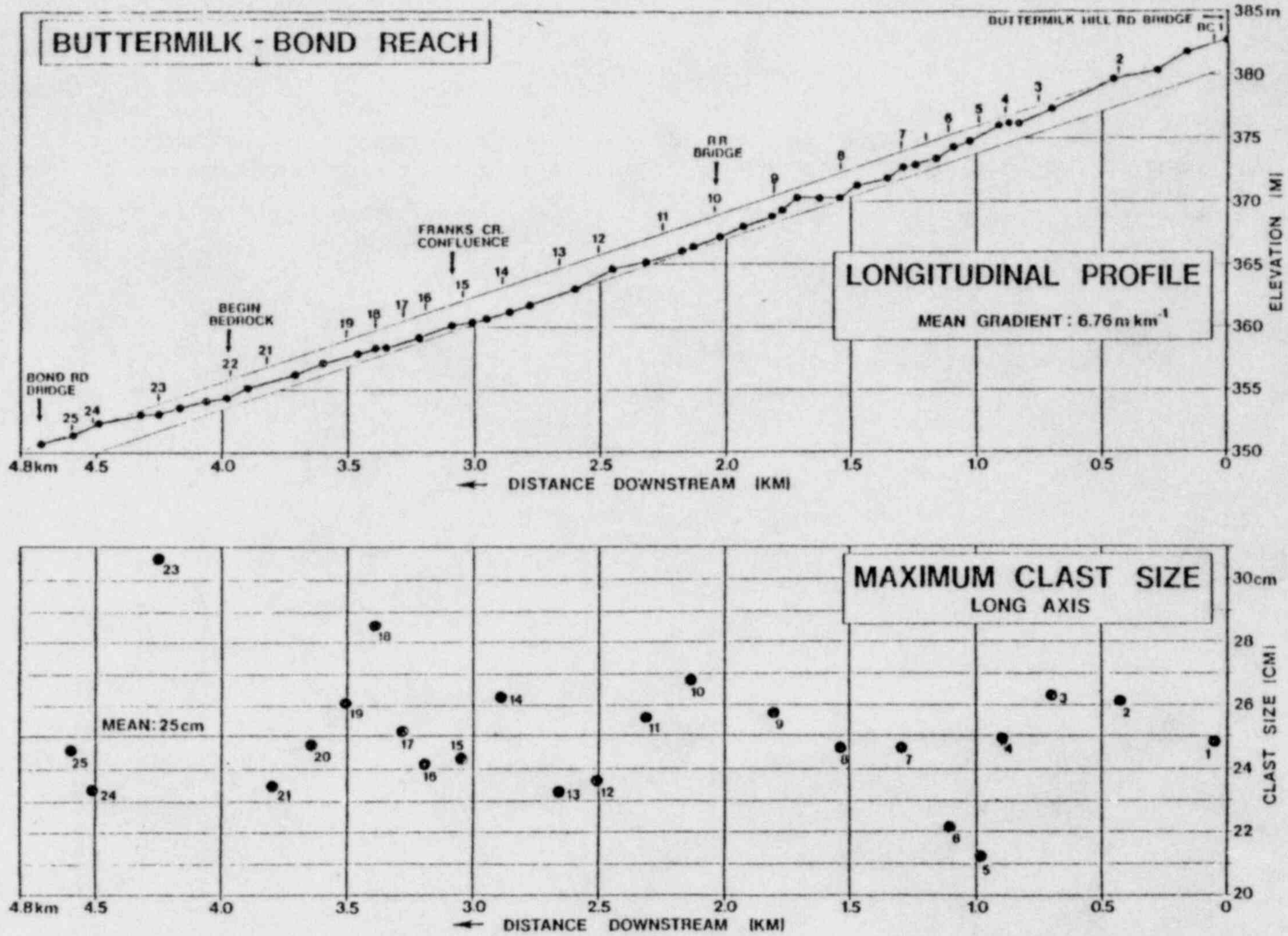

Figure 4. A. Longitudinal profile of Buttermilk-Bond reach. Numbers refer to bar complex stake locations.

B. Maximum clast size. Numbers beside the data points refer to bar complexes.

Figure 5. View downstream of a riffle at bar complex 17 showing the low-stage thalweg (base flow channel). A slightly higher stage elevation is indicated by the lighter-colored clasts on the bar. A low terrace is in the background.

Figure 6. Vertical aerial view of Buttermilk Creek at bar complexes 3-6. The lobe-shaped bar at the bottom of the plate is bar complex 4. Also shown are vegetated chutes, the steep valley wall and a small tributary stream at the upper right. Downstream is up the page to the northwest. Scale: photo width is approximately 350 m.

Figure 7. Vertical aerial view of bar complexes 8-13. Bar complex 11 is the large light area in the center; Bar complex 13 is at the top left of the page. Also shown are: the B & O railroad grade and bridge; a landslide to the right of creek's sharpest bend; and a large alluvial fan (lower right). Downstream is up the page to the northwest. Scale: photo width equals 500 m.

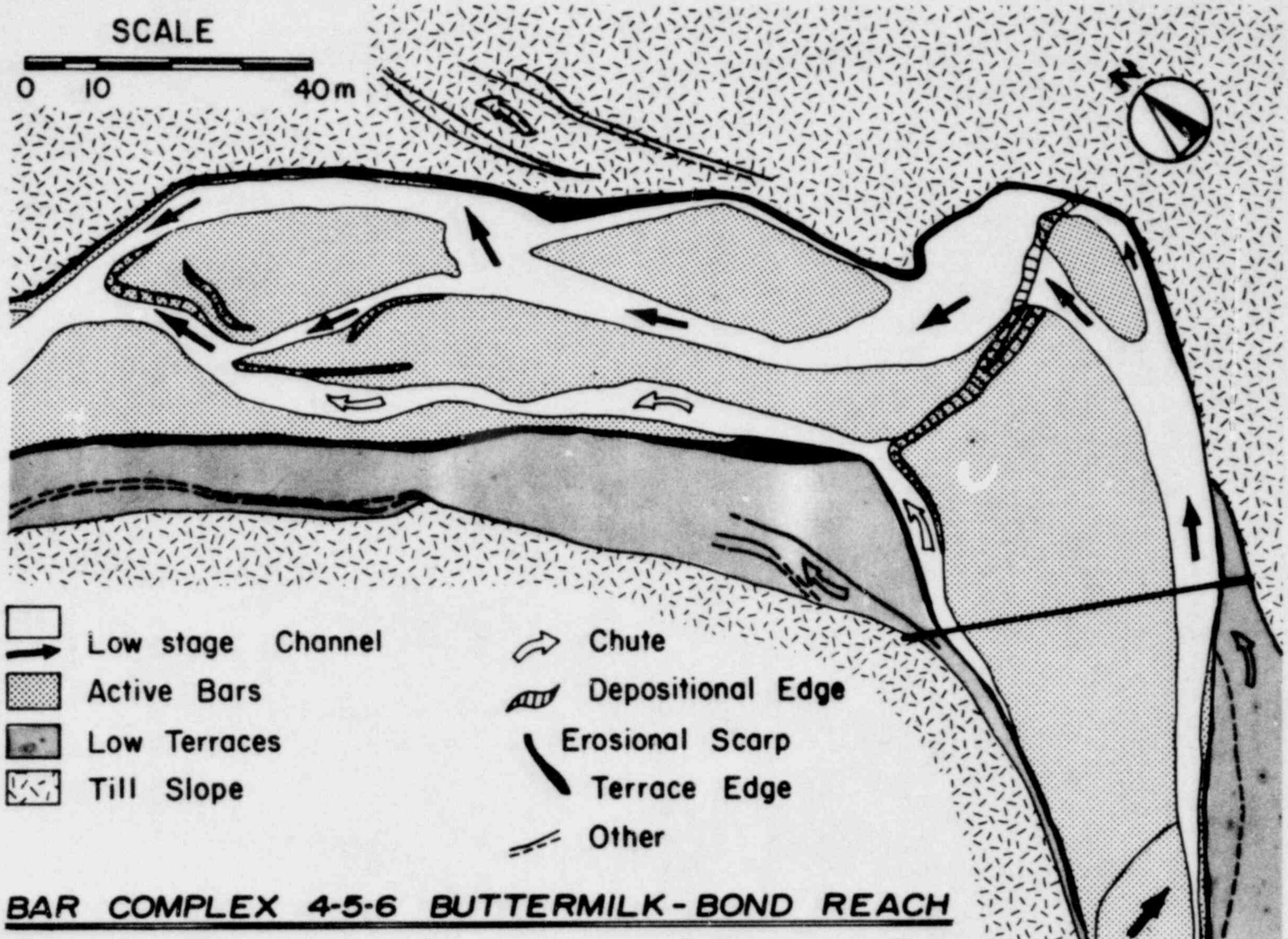

Figure 8. Simplified morphologic map of bar complexes 4, 5, and 6. Compare this map with the topographic map (Plate 4).

channel. Riffles are present where the channel crosses over a large bar and in the vicinity of the downstream edges of the bars (Figures 6 and 8). Pools are present as deeper areas in the narrow thalweg and also as very deep scour holes between advancing bars and eroding banks (upper right of Figures 6 and 8). Dry chutes (Figure 9) exist along the margins of many bars. The overall bar and channel pattern is similar to that of small, gravelly, braided streams (14, 15).

In contrast, Figure 7 illustrates bar complexes 11 and 12 (center to upper area), where the bar and channel pattern is relatively simple. The low-stage thalweg bends around the 2 large bar complexes. Riffles occur at the crossover points between bar complexes and also in a regular spaced (500 to 100 m) pool-and-riffle sequence in the low-stage thalweg. A high-stage chute (not visible on Figure 8) exists along the eastern terrace edge adjacent to bar complex 11. The overall bar and channel pattern is similar to that described as a coarse-grained meander pattern by McGowen and Garner (22), although the grain size is much larger in Buttermilk Creek.

The presently-active, mostly unvegetated, bars and channels are separated from adjacent, vegetated low terraces (unit FA_{b1}, Plate 1) by a 1 to 2 meter erosional scarp (Figure 8). The active bars are sometimes up to 1 meter lower than the surrounding terrace, but may be at the same elevation or slightly higher than the terrace. Bar complex 4 is an example of an elevated bar surface.

Bar Surface Features - Figure 5 shows a low-relief bar complex (bar complex 8); and Figure 10 a higher relief bar (bar complex 11). Figure 5 was taken at a time of extremely low flow (about 0.3 m^3/sec) over a riffle. A slightly higher discharge is marked by a light-colored, thin clay veneer over the gravel clasts. The unflooded portion of the bar is darker-brown (Figure 5). By contrast, Figure 10, a view looking downstream over the highest portion of bar complex 11, shows by density of vegetation that this surface is flooded only yearly, if then.

The surfaces of the large bar complexes, up to several hundred meters long, exhibit complicated microtopography and clast-size groupings. These forms are similar in size, shape, and clast concentrations to gravel, longitudual and unit bars of braided-stream, depositional environments (14, 15). Figure 11 shows one such "bar" on bar complex 7.

Surfaces of most bars have abundant features that record high-stage upper-flow regime transport. Transverse ribs (Figure 12) are one such feature. The ribs, preserved anti-

Figure 9. Upstream of a chute at bar complex 5. Often chutes are abandoned main channels. Dry chutes are activated as the flow-stage rises.

Figure 10. Downstream view of the highest surface of bar complex 11. This surface appears to be flooded yearly. The steep valley wall cut in till (Tb_{1s} on Plate 1) is in the background.

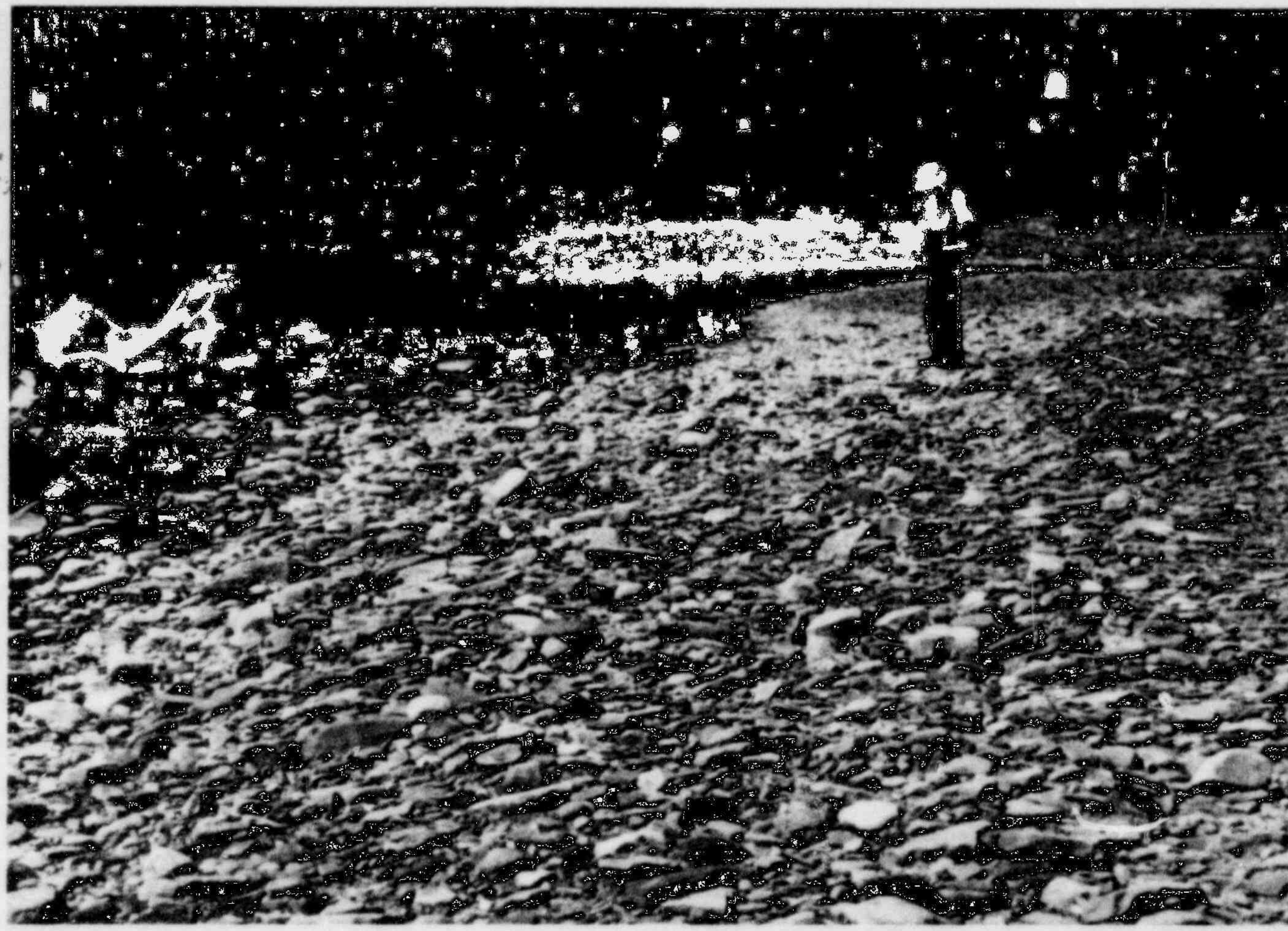

Figure 11. Downstream view of bar complex 7, adjacent to the low-stage thalweg. The concentration of coarse-grained gravel in the foreground is a small longitudinal or unit bar superimposed on the bar-complex surface.

Figure 12. View upstream at bar complex 9. Transverse ribs, indicative of upper flow-regime transport are well displayed in the foreground.

dune bedforms (15, 23), show clast size-spacing correlations similar to those described in other high-energy gravel streams.

Some bar complexes have well-developed slip faces or depositional edges on their downstream margins (Figures 8 and 13; Plate 4). Depositional edges may be gravel or sand. Figure 13 shows an example of a sandy slip face that is similar to sand-wedge slip faces of braided-gravel streams (24). Depositional edges record the downstream growth of bars and are particularly well-displayed on Plate 4.

6.4 Clast Size and Shape

Clast Size - Average maximum clast size (long axes) ranges from 21 to over 30.5 cm, but shows no systematic variation in a downstream direction (Figure 3, Graph B). The mean size of the average maximum clasts is 25.0 cm. The clasts are well imbricated and occur in groups or concentrations on the surfaces of bar complexes and in chutes. Clasts of all sizes form an armor on the bar, channel, and chute surfaces (Figures 9 and 11); about 2 percent of these clasts are much larger than the average maximum size; about 5 to 10 percent are of average maximum size, and the remainder are smaller. However, grain-size measurements of bulk samples were not carried out. In Figure 14, the green (large, light-gray) clasts are average maximum size, and the red (dark-gray) clasts are of medium size.

Clast Shape - A study of clast shape was carried out by C. Sherwood, University of Rhode Island, Department of Geology. Figure 15 shows a Folk form diagram for clast shapes. The clasts are very bladed to very platy in shape, and consist mostly of Devonian sandstones, the most resistant bedrock of the area (3).

Other Bed-Material - The bar surfaces have very little sand and few types of material other than gravel are exposed in cuts in the bars or terraces, because the valley-wall stratigraphy consists primarily of a clay-rich basal till (Tb_{ls}, Plate 1).

6.5 Stream Discharge

USGS Gaging Data - The USGS operated a gaging station on Buttermilk Creek near the Bond Road bridge during water years 1962-1968 (References 6-12). Stage-discharge rating tables and curves, and indirect measurement calculations for a large flood event are included in these publications and in a special report by the USGS (13).

Figure 16, Graph A, is a hydrograph of daily discharge for

Figure 13. View along a sandy depositional edge; or sandwedge slipface at bar complex 16. Downstream is to the right.

Figure 14. Clast size station on bar complex 4. The large, light-gray (green) numbered clasts were measured for average maximum clast size; the smaller, dark-gray (red) clasts are of medium-size. Downstream is to the left.

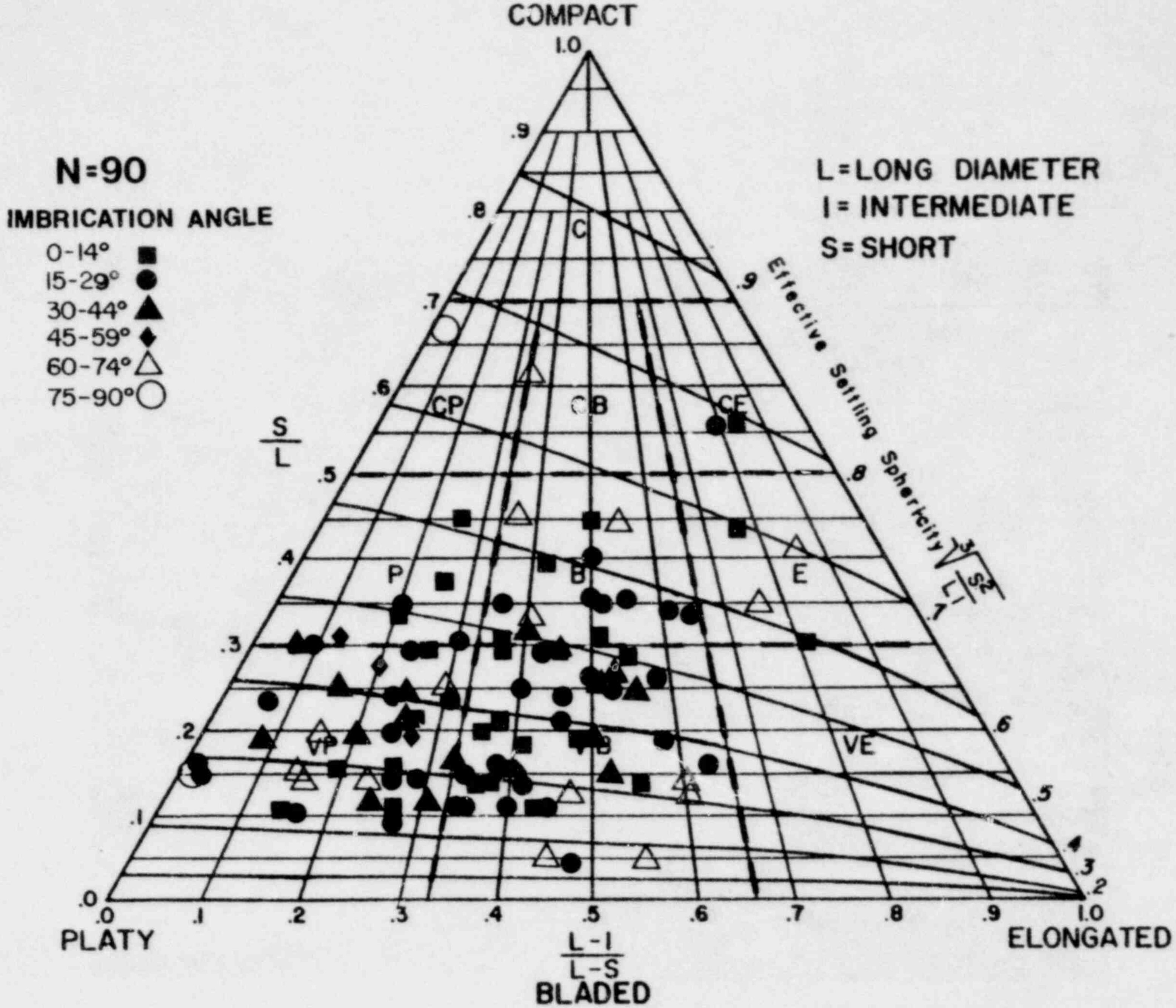

Figure 15. Folk form diagram for clasts shapes at bar complex 5. Clasts are very bladed to very platy in shape. (Courtesy of C. Sherwood).

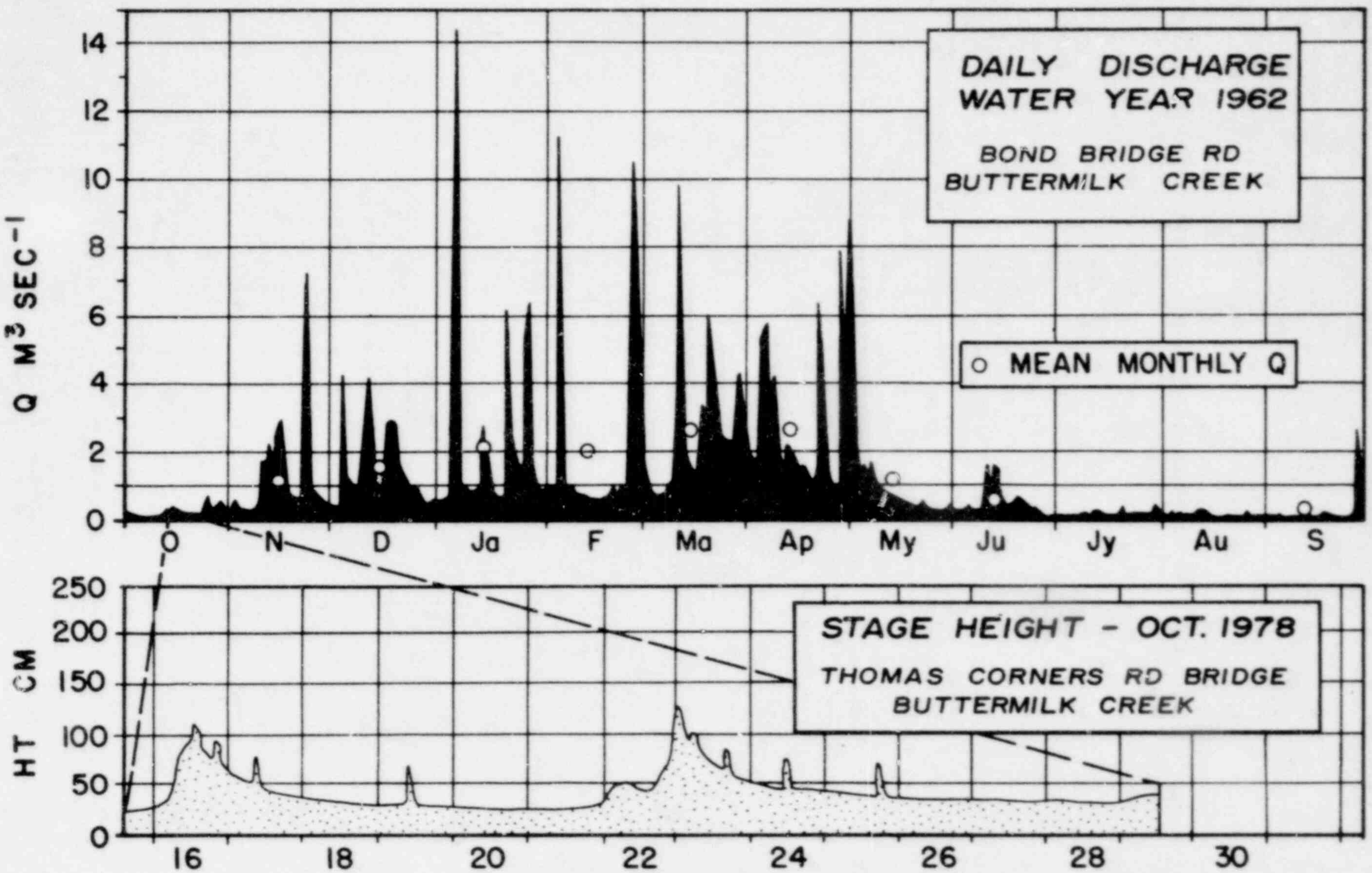

Figure 16. A. Daily discharge for water year 1962 (7). Note the "spikey" nature of the hydrograph.
B. Stage height record for October 15-29, 1978, at Thomas Corners Road Bridge. Clast movement occurred during the event of October 23.

water year 1962. The hydrograph is very "spikey" with high discharge flow events lasting only a day or two. Base-flow occurs from early summer to mid-fall and is approximately $0.3 m^3$/sec or less. The fall and winter peaks represent discrete rainstorm or thaw events. Spring runoff from snow melt is punctuated by rainfall events. The mean monthly discharge is much less (maximum = $2.5 m^3$/sec in May) than the summation of daily discharge that includes a rainfall peak ($14.5 m^3$/sec, max).

A stage-discharge rating curve for Buttermilk Creek (Figure 17), adapted from those compiled by the USGS (13), includes the highest discharge events for each year the stage-height recorder was in place. These readings (max = $110.65 m^3$/sec) of instantaneous discharge indicate that peak flow events are much higher than those that appear as the daily summation (Figure 16, Graph A). This means that the large discharge events are of extremely short duration, probably several hours in length.

Because instantaneous discharge data were not available, a flow duration curve was not constructed. The daily discharge information does not yield sufficient detail for a meaningful duration curve. Also, because there are only 8 years of record, construction of a flood-frequency curve is not justified.

Stage-Height Records (new) - A stage-height recorder was installed at Thomas Corners Road bridge on August 28, 1978 by the NYSGS (recorder on loan from USGS). The Bond Road site previously used by the USGS was not reoccupied because the road is no longer passable to vehicles, thus there is no easy access. A section of the record from October 15-29 is shown in Figure 16, Graph B, with 2 rainstorms recorded. The numerous small "spikes" are the result of automatic dumping of excess accumulation in the site reservoirs (see Plate 1 for location). No stage-discharge relations have been measured except for October 28, 1978 (noted below). The stage recorder is operational at present.

Discharge Measurements (new) - Five discharges were measured during the summer and fall. They are as follows:

1) June 26	$0.31 m^3$/sec
2) July 17	$0.16 m^3$/sec
3) July 21	$0.72 m^3$/sec
4) July 27	$0.23 m^3$/sec
5) October 28	$1.4\ m^3$/sec

Figure 18 shows the October 28th measurement in progress about 200m upstream of the Thomas Corners Road bridge; the others

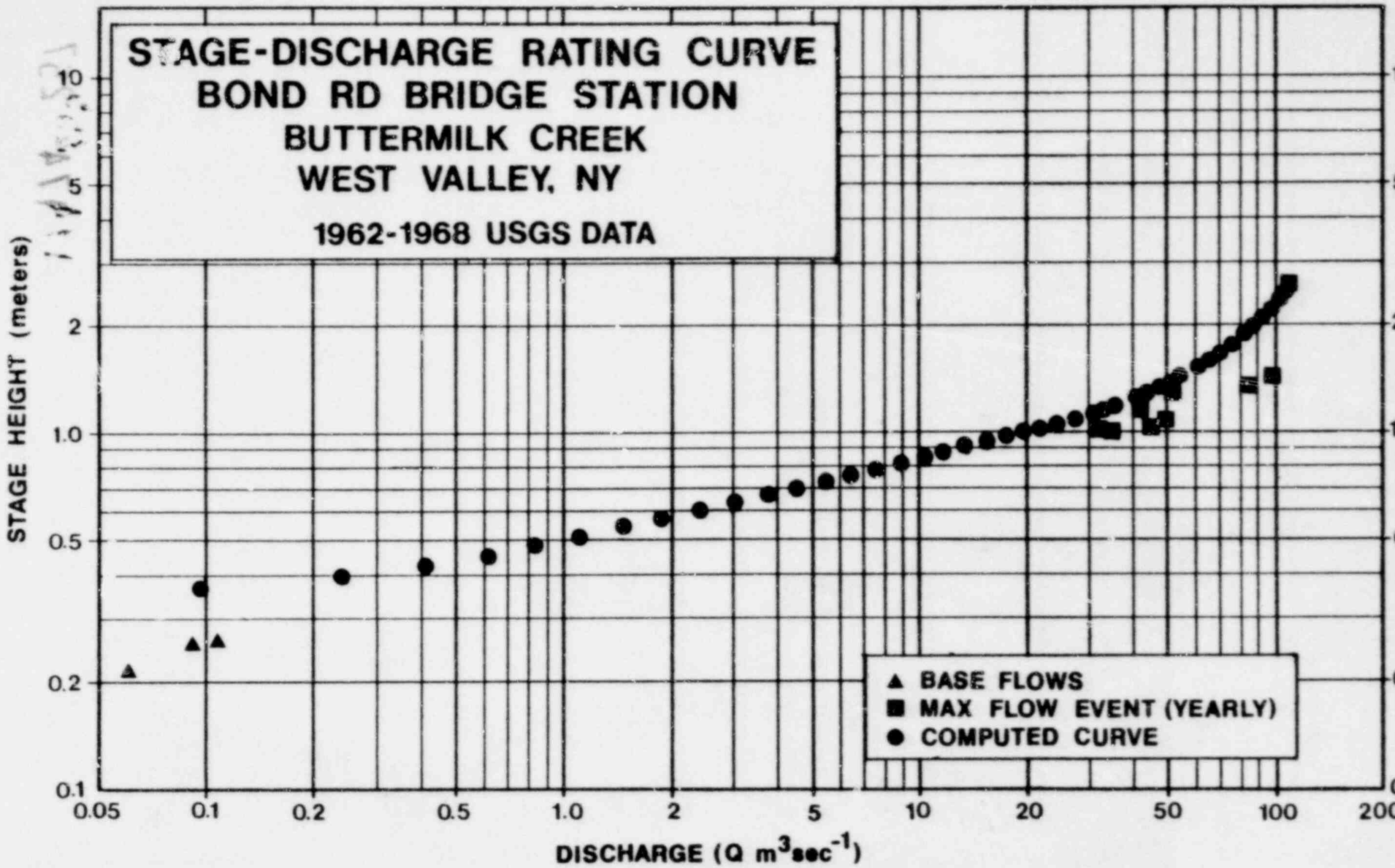

Figure 17. Stage-discharge rating curve for Buttermilk Creek obtained by USGS during water years 1962-1968 (13).

Figure 18. Velocity and cross-sectional area measurement, Buttermilk Creek, October 28, 1978. Discharge is 1.4 m^3/sec. View is downstream to Thomas Corners Road bridge in the background.

were obtained at low-flow stages (non-flood events), except for three that were made during base-flow conditions.

6.6 Clast Movement

Figures 19 and 20 illustrate a typical clast movement station. The lines reached to the low-stage channel (Figure 19) and care was taken not to disturb the natural sedimented positions of the clasts, including imbrication or burial of the various sizes (Figure 20).

Recorded Movement - Movement of clasts occurred at transects on bar complexes 1, 4, 10, and 11 between August 26 and October 29, 1978. Inspection of the stage-height records from the Thomas Corners Road station indicates that the most probable time of movement was during the October 23, 1978 event that had a stage increase of about 100 cm above base flow (Figure 16, Graph B).

Clast distribution after the flow event at bar complex 11 is shown in Figure 21. The maximum distance moved for a medium-size clast was 19.1 cm; and maximum distance moved for any clast (of those located) was 1491 cm (2.0 cm L-axis). The clasts tended to move at an angle to the direct downstream direction, across the bar surface toward the low-stage channel. The original position of clasts along the yellow base line (YL) was not recorded. The depth of flow over the station is not known.

Multiple Station Transects - Figure 22 illustrates 2 of the 3 clast movement stations at transect 5, bar complex 4. The positions of clasts at the stations is shown, as well the location of the stations on the bar and channel cross-section. Some clast movement has occurred at station 1 close to the low-stage channel.

Base-flow stage is indicated on the cross-section, in addition to the stage at which chute flow would occur. Bankfull discharge stage is also shown. These varying discharge conditions would be needed to activate clasts at the 3 stations.

6.7 Channel Sweep

The active bar and channel system is that area of the Buttermilk reach that is flooded at least once yearly, as determined by debris lines and amount of vegetation cover. The location of channels in relation to the bars also changes annually. Location of the 1978 system is shown on Plate 1. Some of the lowermost terraces (FA_b1, Plate 1) are also flooded during large flood events, perhaps yearly.

Figure 19. Clast movement station at bar complex 20. View is toward the low-stage thalweg; downstream is to the left. Average maximum clasts are painted green (light gray); medium are painted red (dark gray); and the yellow painted line under the tape marks smaller clasts as well as the base line.

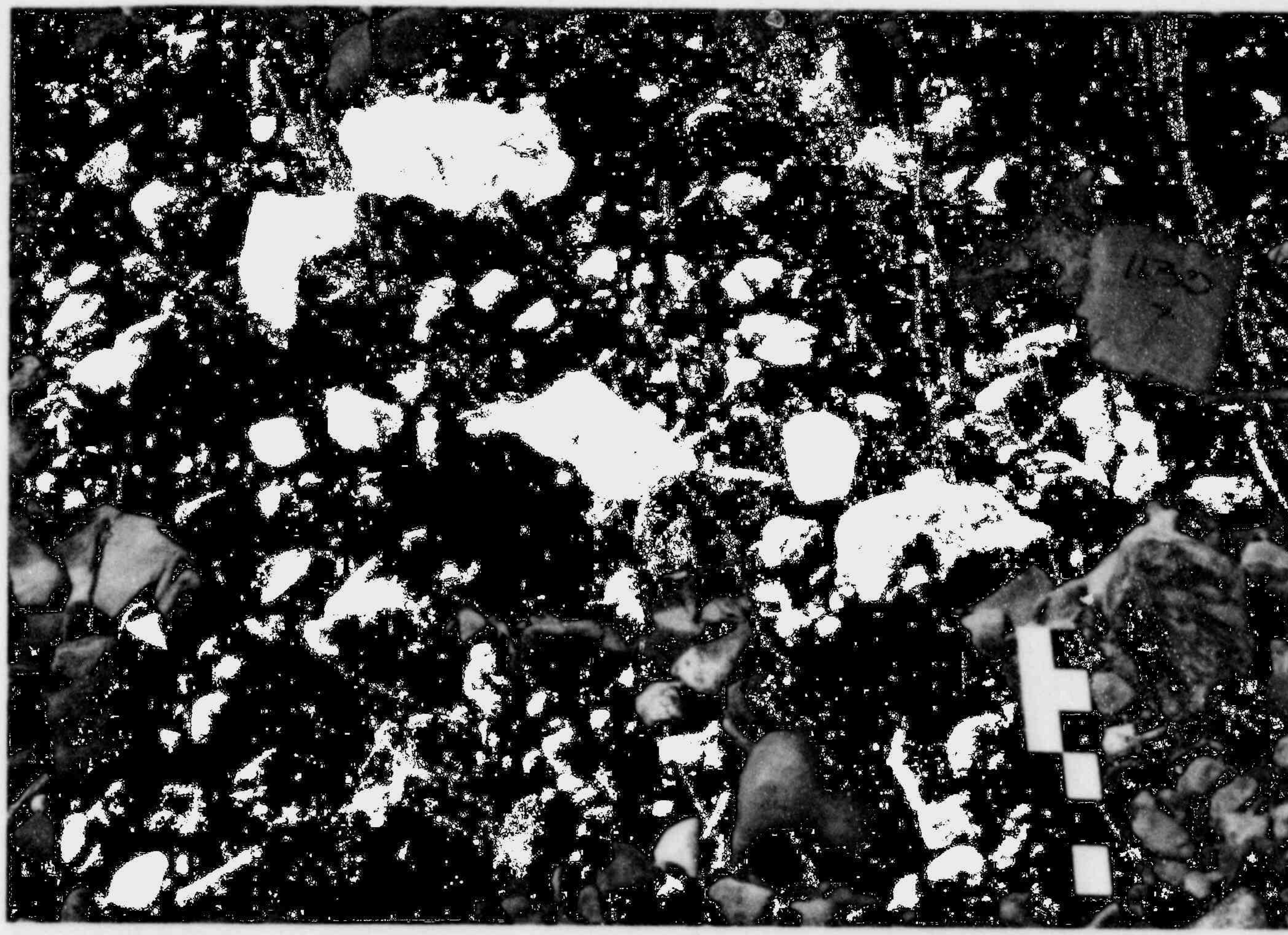

Figure 20. Closeup of clasts at movement station on bar complex 11, station 1. Color scheme is the same as in Figure 19. Downstream is to the top of the photo; scale is 30 cm.

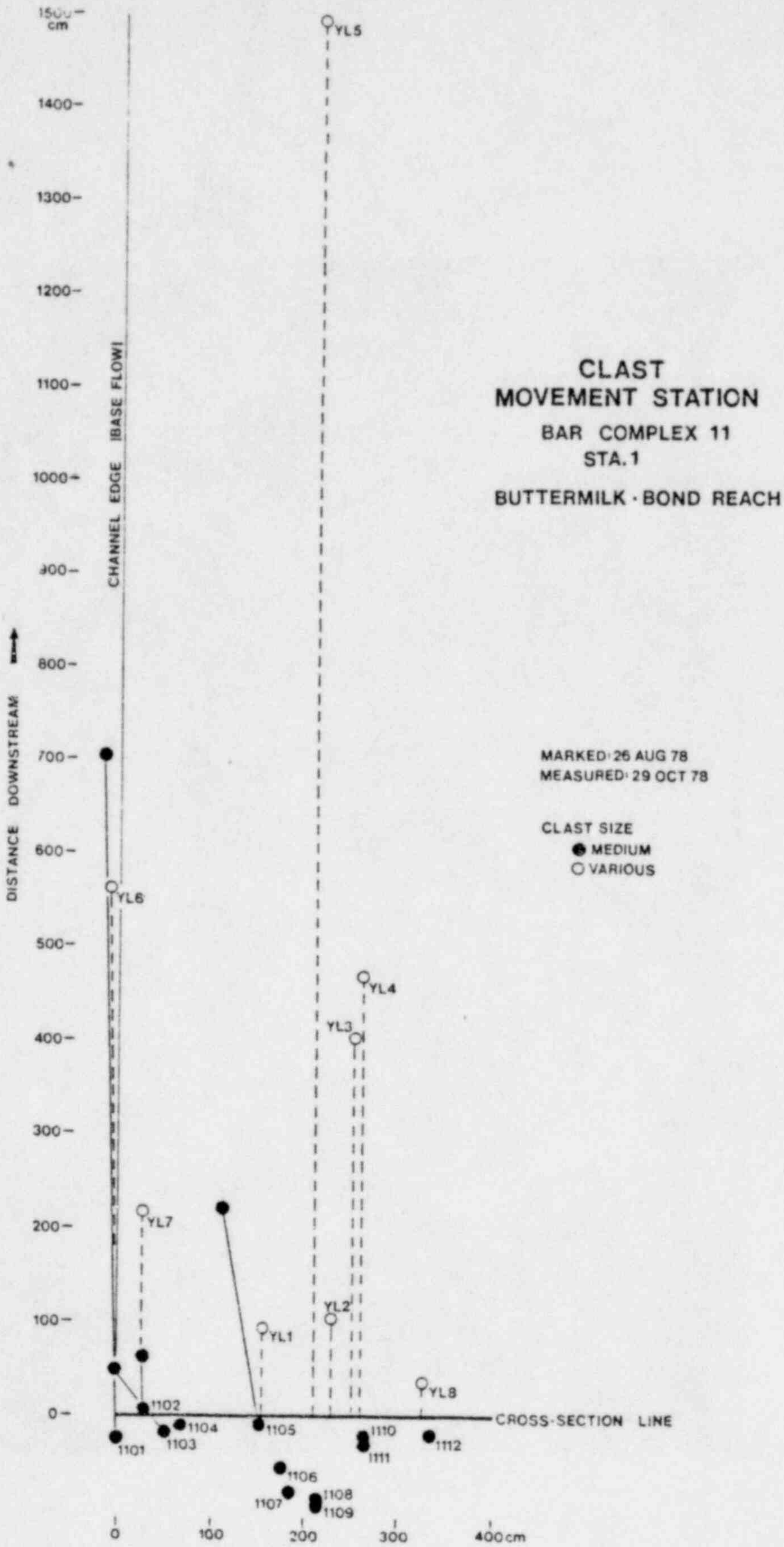

Figure 21. Recorded clast movement at bar complex 11. Greatest distance moved was 1491 cm; largest clast was 19.1 cm (long axis).

1741 261

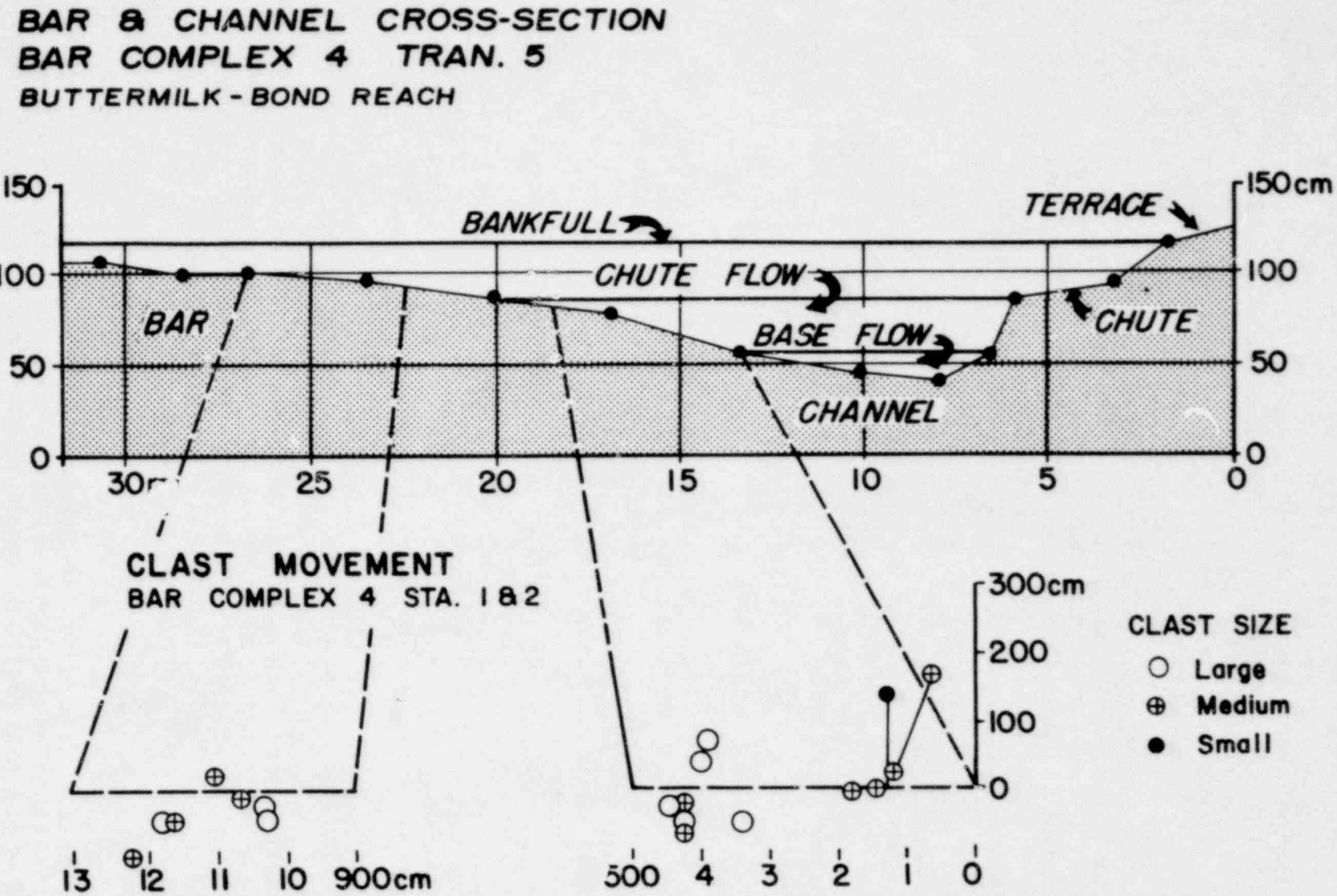

Figure 22. Bar and channel cross-section and clast movement stations at bar complex 4. Note the projected stage heights in relation to the movement stations.

A series of 6 maps of channel positions have been compiled from aerial photographs (Plate 5); five are maps of particular years, and one is a composite map. The area between the two valley walls includes both low and high terraces (FA_{bl}, FI_{bl}, Plate 1). An inspection of the maps (Plate 5), particularly the composite, indicates that since 1938, 30 to 40 percent of the valley-flood area has been swept by the active bar and channel system. The swept area increases to over 50 percent if the inactive terraces (FI_{bl}, Plate 1) are removed from consideration. In addition, the channel is constrained by the railroad embankment on the east side of the reach from bar complex 2 to bar complex 9 (Plate 1).

The lateral movement of the active channel places the stream in a position to erode the valley-wall till (Tb_{ls}, Plate 1) (Figure 23). Younger terraces provide little resistance to lateral erosion and are either quickly removed or again eroded. Landslides (Plate 5; Plate 1, Tb_{ll}) initiate where channel sweep has resulted in prolonged erosion into valley-wall till.

6.8 Active Landslides

Active landslides occur in areas where the active channel has continuously impinged on the valley wall over a time at least as long as the time of photo documentation (Plate 5). These slides may be, but are not always, on the outside of low-stage thalweg meander bends (Plates 1 and 5).

The landslides are actually slumps with slide scars up to 100 meters wide. Coherent slump blocks measure 20 to 50 meters wide. Most slides have a debris-flow base where the coherent blocks have broken into a hummocky, tension-cracked topography. All the above features are illustrated in Figure 24, a view of the slide at bar complex 6.

An inspection of Plate 5 indicates that the landslide zones have shown repeated activity, resulting in the formation of new scars and slide masses over the 1938-1977 timespan of photo documentation. The landslide at bar complex 6 (Figure 24) was marked with a series of stakes in October, 1978, but has not been resurveyed as yet. Observations of older stake fields by Prudic and Molello (personal communication) indicate meters of downslope movement over three years time.

6.9 Stream Terraces

Fluvial terraces of the Buttermilk-Bond reach are surfaces with grass and shrubs or heavy vegetation that retain much of their original bar, channel, and chute topography (Figure 6). Most terrace surfaces are covered with bar-top gravel,

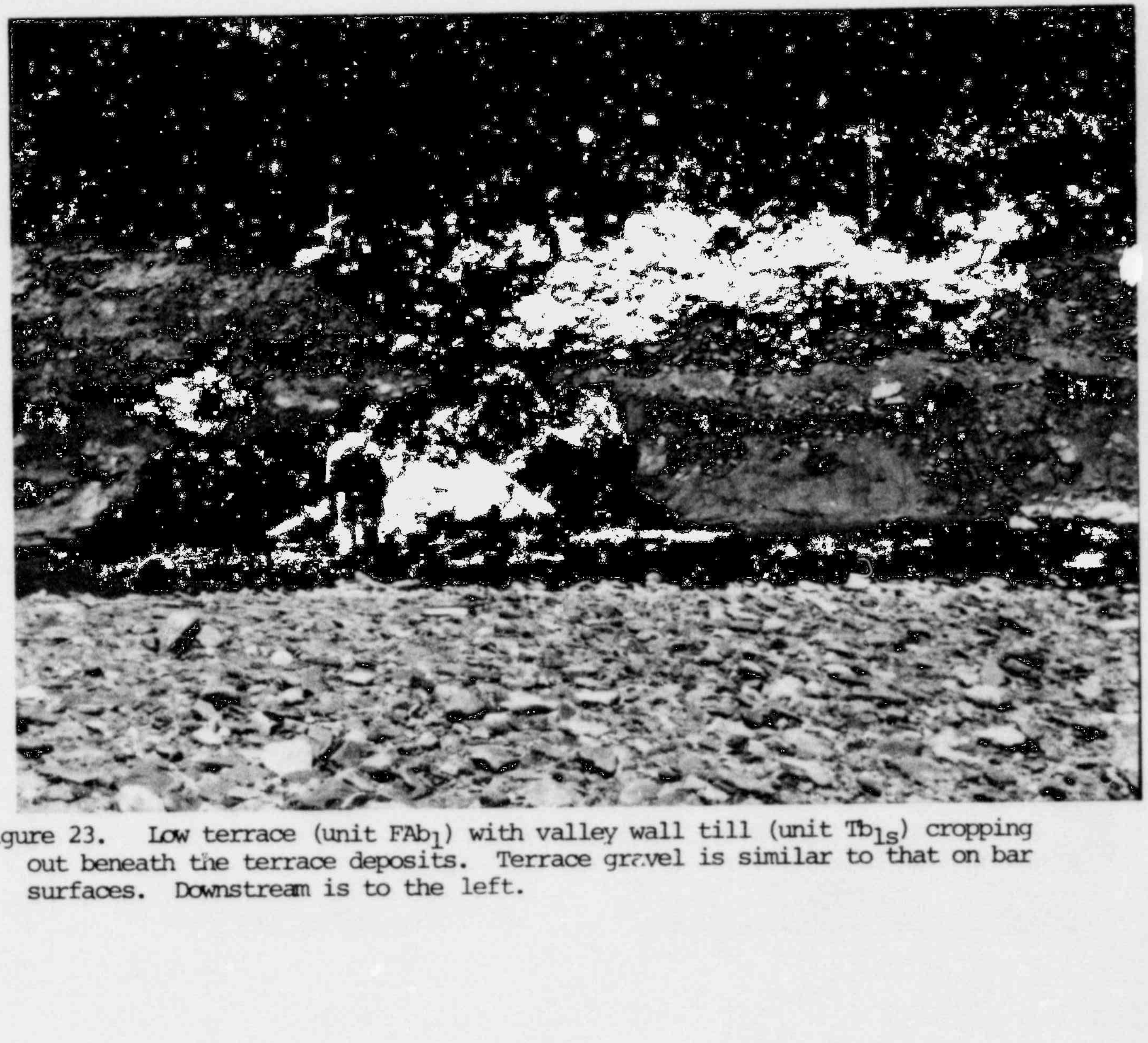

Figure 23. Low terrace (unit FAb_1) with valley wall till (unit Tb_{1s}) cropping out beneath the terrace deposits. Terrace gravel is similar to that on bar surfaces. Downstream is to the left.

Figure 24. Landslide at bar complex 6. A fresh scar is high on the valley wall with slump blocks beneath. The lower part of the slide exhibits hummocky, debris flow topography. Note the stake locations.

although small areas of flood-plain marsh and swamp do occur (FA_{b2}, Plate 1). Cuts in the lower, inactive terraces (FI_{b1}, Plate 1) also reveal a gravel fabric similar to that of active bars (Figure 23).

Detailed mapping revealed the existence of 14 terrace levels ranging from 1 meter above presently-active bars (Level 1; FA_{b1}, Plate 1) to a fluvial gravel on the burial-site surface, 35 meters above the bar surfaces (Level 14; FI_{b3}, Plate 1; Wfg, Plate 3, LaFleur, 1975). These terrace levels are grouped in 3 categories according to general elevation: 1) low (FA_{b1}), up to 3 meters above bar surfaces; 2) middle (FI_{b1}), 3 to 8 meters above bar surfaces; and 3) high (FI_{b2}), all higher terraces.

An attempt has not been made to correlate terraces either along the reach or across the valley at a given cross-section. Many separate terrace levels occur within the middle group (FI_{b1}, Plate 1) particularly on the east side of the valley. Most of the highest terraces exist on the west side of the valley. Figure 25, a portion of Plate 1, shows the highest terrace group, partly inset into the burial-site surface. The arrow points to a trench location where wood fragments buried 50 cm below the surface in fluvial gravel were determined to have an age of 9920 $\pm$ 240 BP (uncorrected ^{14}C years, dated by Richard Pardi, Queens College). This appears to mark the initial stages of downcutting of Buttermilk Creek after the recession of the Woodfordian glacier.

6.10 Alluvial Fans

Alluvial fans along Buttermilk Creek can be classified into 3 groups: 1) short, steep active fans, measuring 100-200 m long; 2) larger fans with both inactive and active segments; and 3) large fans at the junction of tributary streams with Buttermilk Creek (Plate 1). All are heavily vegetated. The short fans (unit AA_b) begin part-way up the valley wall, with an entrenched steam extending to the top of the wall. The fanhead may or may not contain an incised stream with the fan commonly having a single active lobe. An example is the small fan at bar complex 3, on the west wall, adjacent to the waste-burial site (Plate 1). The larger fans (units AA_b and AI_b) also head in the valley wall, but the entrenched streams above the fanheads are incised into the upland surface (units Tb_{13}, Tb_{14}). These fans contain both inactive and active segments with inactive lobes existing as terraces above incised, active streams that feed distal, active lobes. The fans may have multiple active lobes. An example is located on the west side of Buttermilk Creek, south of the confluence at bar complex 18-19 (Plate 1). The largest fans occur at the confluence of small tributary streams with

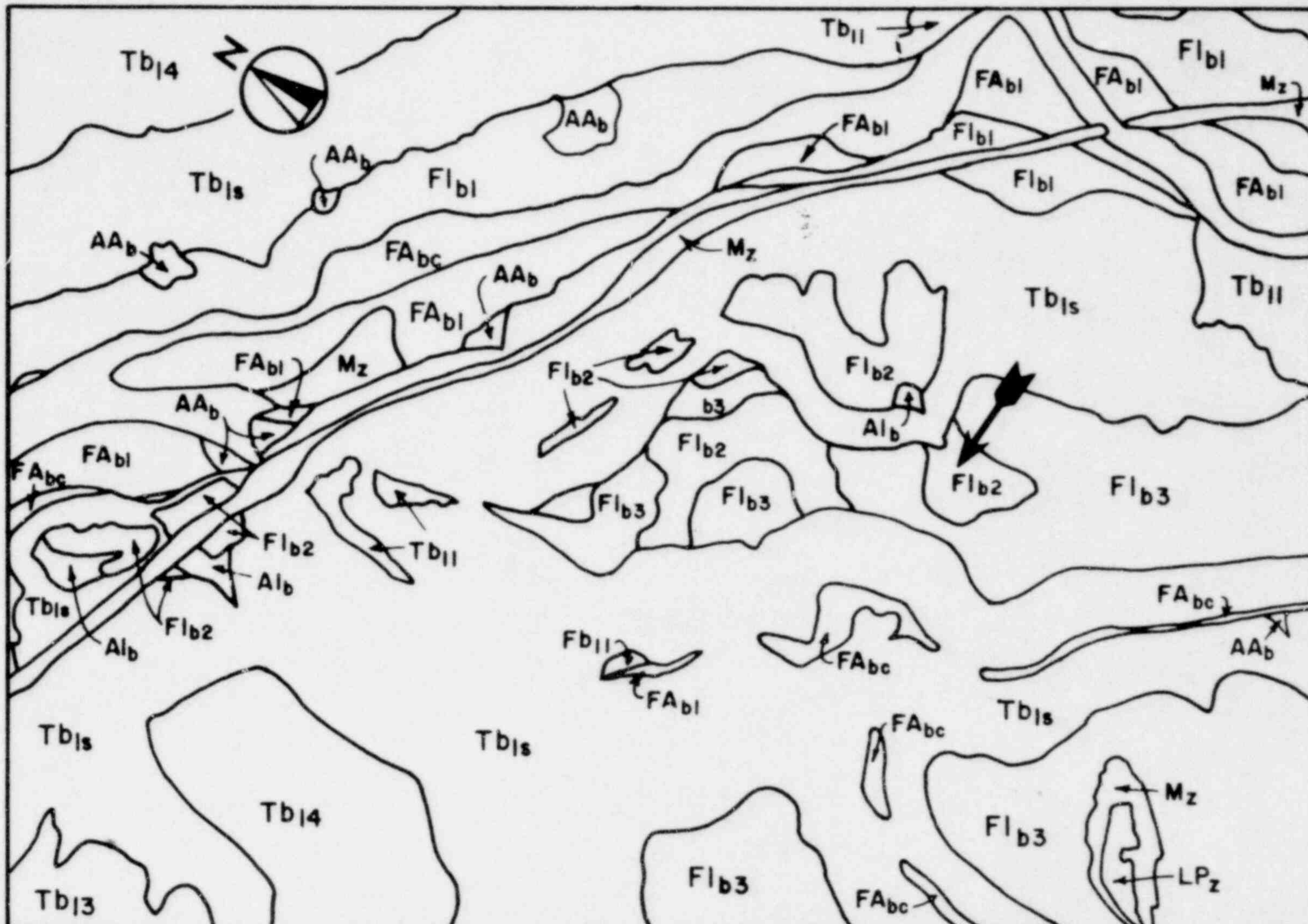

Figure 25. A segment of the environmental geologic map illustrating the highest terrace complex (center). Arrowpoint to trench that contained wood sample dated at 9920± 240BP.

1741 267

Buttermilk Creek. They are similar to the medium-sized fans in appearance, except for larger size and deeper incision of the active stream. The best example is at the mouth of an unnamed eastern tributary just upstream of the highest bedrock exposure in Buttermilk Creek (Plate 1).

The small fans are active only during rainfall events and have dry channels the rest of the time. The larger fans remain active during lower-flow stages, even though runoff is very low. The largest tributary fans have an active low-flow channel even during base-flow conditions. During flood stage, overbank flow can reactivate fan lobes.

1741 268

7.0 DISCUSSION

7.1 Bar and Channel Geometry

Meander Pattern - Most, if not all, aggrading streams with gravel bed-material of the size and quantity of Buttermilk Creek exhibit a braided-channel pattern with multiple meandering low-stage thalwegs. Buttermilk Creek is obviously a degrading system with what appears to be a meandering channel pattern. However, most of the meandering appearance is a valley-wall feature with a secondary low-stage thalweg pattern that is usually in phase with the valley wall meanders (Plate 1).

Thalwegs and Chutes - The meander wavelength of the valley wall (500+ meters) is many times longer than the wavelength of the low-stage thalweg as indicated by shorter-term fluctuations (years) on the channel-sweep diagrams (Plate 5). An inspection of Figures 6, 8, and Plate 4 indicate that the low-stage thalweg is bent around or cuts through bars, and thus is controlled in part by bar movement. Many inactive chutes (Figure 9) mark the location of 1938-1977 active channels (Plate 5) that have been cut off by sudden channel switching or by having chute heads filled by bar gravel.

Bar Surfaces - The complicated microtopography of the bar complexes is very similar to that of a braided-stream environment (14, 15). The fact that the bar complexes may be treated as braided-stream features at high-flow stage means that observations and conclusions regarding braided-stream gravel transport in other areas apply to Buttermilk Creek. Masses of gravel may move by growth of longitudinal bars, formation of unit bars, or by movement of diffuse gravel sheets (25). All of these features are well-displayed on many of the bar complexes, particularly on bar complex 11 (Figures 7 and 10). It was for this reason that bar complex 11 was chosen for topographic mapping.

Flood Bars versus Bar Complexes - Bar complex 11 has the gross morphological form of a 200 m long point bar with the low-stage thalweg against an erosional terrace on the west and an inactive chute on the east (Figure 7). As noted above, the bar surface has braided-stream forms super-imposed upon it.

By contrast, bar complex 4 (Figures 6 and 8; Plate 4) is a relatively simple gravel sheet ending downstream in an 80 cm high depositional edge. The bar gradient dips gently upstream and the top surface is close to adjacent terrace elevations (Figure 22). The bar is interpreted as a feature in equilibrium with very large floods, and thus is migrating downstream during large discharge events. This migration has resulted in a channel constriction downstream of the bar and an abrupt 90-degree bend in the low-stage thalweg. Scour around piled-up tree debris has deeply eroded the channel (Plate 4).

Topographic Mapping - The mapping was done in an attempt to measure sediment transport at a magnitude and time frame midway between clast movement on bars and general stream-reach degradation. The two areas, bar complex 4 and bar complex 11, represent contrasts in morphology and, perhaps, rates of sediment movement. The maps will only be useful for this purpose if they are compared with other maps constructed after sediment transport has occurred.

7.2 Clast Size and Gradient

Gradient versus Clast Size - The mean gradient of 6.7 m/km does not vary greatly downstream, even though the Buttermilk-Bond reach is segmented (Figure 4, Graph A). Clast size also shows no systematic variation downstream (Figure 4, Graph B). Clast size does not vary because clasts are continuously supplied to the bars and channels along the reach by lateral erosion of valley walls and previously deposited terraces. When clast size versus gradient of the Buttermilk-Bond reach are plotted on graphs, such as that of Boothroyd and Nummedal (26), the reach plots in the area of proximal alluvial-fans. This indicates that the discharge conditions that control the gradient for those fans would also operate to control clast size and gradient on Buttermilk Creek.

Variation in Gradient - There are 2 harmonics or wavelengths of variation in gradient. The smallest is represented as 200- to 300-meter long flat spots in the longitudinal profile (Figure 4, Graph A). These are the surfaces of flood bars and represent the temporary storage of gravel in the bars.

The longer wavelength variations are due to various causes. The gradient-decrease downstream of the Frank's Creek confluence could be due to the influx of material from the Frank's Creek/Erdman's Brook drainage basin. The further lessening of gradient downstream is a function of increased resistance to downcutting when Buttermilk Creek encounters bedrock, and is possibly also due to sediment influx from the unnamed creek upstream of the Bond Road bridge.

The steepening gradient downstream of bar complex 2 and particularly bar complex 4 could be a short-term adjustment to temporary storage of material in the flood bars. The steeper gradient would result in enhanced sediment transport through that reach (bar complex 4 through 8) until bar complex 4, a flood bar, migrated into the area. Note that this area is the closest approach of Buttermilk Creek to the waste-burial site.

7.3 Discharge Events and Sediment Transport

Stream hydrograph - The "spikes" in the stream hydrograph (Figure 16, Graph A) are the result of the extreme impermeability of the clay-rich till that underlies the drainage basin (Plate 3; Reference 5). Runoff percentage is high, as rainfall is quickly transformed to streamflow (effective rainfall, (27)). Instantaneous discharge (Figure 17) is higher than that given in the daily averages (References 6 though 12); thus, storm hydrographs would show even more rapid changes than the daily averages.

The stage-height record obtained thus far (Figure 16, Graph B) does not contain a large flood event, but there are several minor storm peaks. Until additional discharge data are gathered and a stage-discharge curve constructed for the new recorder site, there is no means to quantitatively evaluate the stage peaks in the record. We speculate that the October 23 flood peak corresponds to a discharge of about 3 m^3/sec on the 1962 graph (Figure 16). If this is true, it would suggest that gravel transport on bars occurs many times a year in Buttermilk Creek, since some gravel movement was recorded during this event (Figure 21).

Clast Movement - Sediment moving as bedload in Buttermilk Creek is predominantly gravel, due to the scarcity of sand in the source matter. The clast movement stations were developed in an attempt to assess this movement. Several sizes of clasts were marked because it was uncertain how often and how far the various sizes would be transported. Since the gradient and discharge are sensitive to the average maximum clast size, this group may form an upper limit on sizes moved yearly. Smaller sizes may move too rapidly to be recovered. The stations were placed on bar surfaces to evaluate different flood stages (Figure 22). Movement did occur as noted previously (Figures 21 and 22) during a small storm event. The data are as yet too scanty to combine discharge, movement, and depth conditions to test field results against bedload transport equations.

No stations were placed in the low-stage channel due to location and sampling problems. This could be done in future studies. Sampling during flood events (28) could also be carried out, as well as erecting a screen to catch bedload moved at a specific site (29). All clast movement work must be regarded as very preliminary at this point.

Suspended Sediment - No provision was made in this study for suspended sediment sampling during flood events. Several samples were obtained during discharge measurements, but these were during low-flow conditions. Suspended sediment is being measured in Erdman's Brook as part of the surface water study of the burial site.

Bulk sediment sampling of the valley wall (unit Tb_{ls}, Plate 1) would reveal the percent of silt and clay to gravel-sized material. Since this fine material would be rapidly transported out of the reach, a sampling system is needed to assess this rate. This could be in the form of a pumping station at Thomas Corners Road bridge.

Catastrophic Flooding - A developing body of literature suggests that catastrophic events, in this case large floods, accomplish much of the geologic work in a given area (30). This means that the September, 1967 flood event (13) must be quantitatively assessed for magnitude of bedload and suspended load transport.

7.4 Channel Sweep, Lateral Erosion, and Landslide Occurrence

Channel Sweep and Low Terraces - It is evident from examination of historical aerial photographs and field mapping that the active bar-and-channel lateral movement incorporates the lower terraces and reactivates them as active bars (Plate 4). Catastrophic floods may serve to devegetate the low terraces and convert them to active surfaces. Large uprooted trees are common as flood debris on bar surfaces and in channels. All areas mapped as unit FA_{bl} on the environmental geologic map (Plate 1) could thus be included in the short-term channel sweep (years to a few tens of years) with little lateral erosion necessary. The heavy vegetation cover of these terraces is confusing and serves to mask their degree of activity.

Landslides and Lateral Erosion - Slumps within the Buttermilk-Bond reach usually occur where the active channel system is cutting into the valley wall on the outside of meander bends, and where the thalweg is bent around bar complexes. We do not agree with LaFleur (5) that slumps are preferentially located where outcropping kame delta sand has destabilized the valley-wall slope. Historical photos (Plate 4) indicate that the slumps have reoccurred in the same general area, but the timing has coincided with channel cutting into the toe of the valley wall at the potential slump area.

Alluvial Fans and Channel Position - Terrace mapping revealed the presence of many tributary alluvial fans within the Buttermilk-Bond reach (Plate 1). Sedimentation on the distal margins of some fans may cause relocation of the Buttermilk Creek thalweg toward the opposite valley wall. Examples are at bar complex 6 (east side fan and stream) and bar complex 18 (west side fan, south of Frank's Creek confluence).

Future Landslide Locations - If the channel sweep hypothesis is correct, slope failure and slumping should develop at the sharp bend just above bar complex 4. Figure 26 illustrates this area, where a 6-meter till scarp has developed adjacent to a medium-level terrace remnant. A second potential location is just upstream of the Frank's Creek confluence on the west side of the valley. Slope failure by slow creep is occurring in spite of attempts by Baltimore and Ohio railroad crews to stabilize the slope by redirecting the channel and placing fill at the toe of the slope (Plate 1).

The Baltimore and Ohio railroad grade is located between the active channel and the medium-level stream terraces on the east side of Buttermilk Creek, from bar complex 2 to bar complex 8. The embankment is armored in places and effectively prevents channel sweep to the east, that is, away from the valley wall closest to the waste burial-site. We do not know whether this embankment location contributes to landslide initiation.

7.5 Buttermilk Creek Denudation

The agents responsible for lowering and widening of Buttermilk Creek are: 1) fluvial transport of material down and out of the Creek causing lowering of the active bar and channel surface; 2) lateral erosion of the active flood channel to remove previously deposited terrace material and valley-wall till; 3) landslide activity that removes material from the valley wall and delivers it to the valley bottom; and 4) sediment transport on alluvial fans that delivers valley-wall material to the Creek channel system. A quantitative estimate of denudation rate is beyond the scope of this study at this time, but some qualitative observations may prove useful.

Fluvial Transport and Lateral Erosion - The mode and relative activity of these processes has been discussed above, but the rate at which they lower the valley is unknown. A key to this rate is the ages of the many terrace levels along the valley wall. A very gross estimation is possible by taking the age of the highest terrace of known age (9920 $\pm$ 240 BP), and dividing it into some volume of material removed from Buttermilk valley. This would give a gross rate per year.

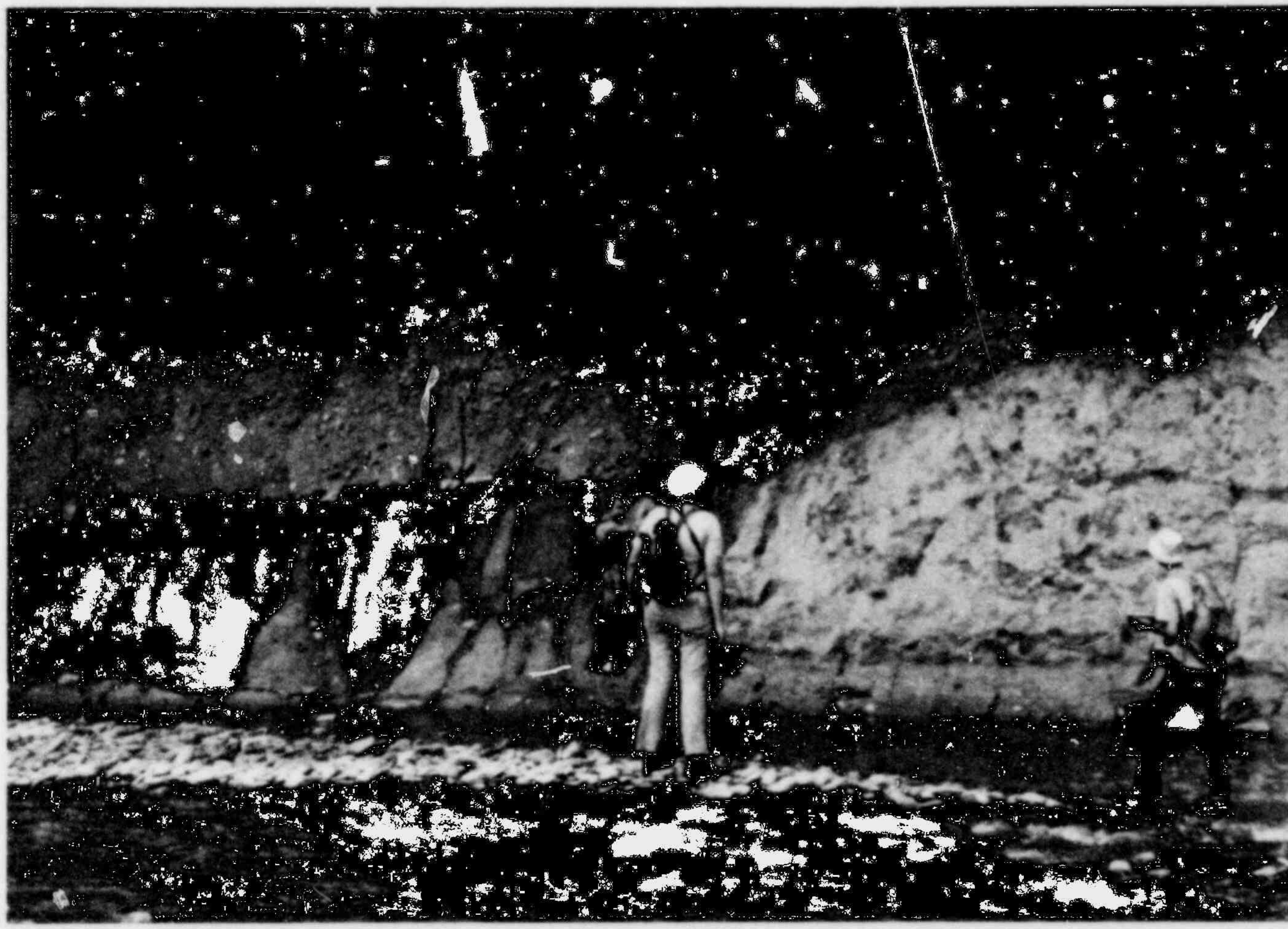

Figure 26. High scarp with valley-wall till (Tb_{1s}, Plate 1) right, and medium-level terrace (Flb_1) on the left. This area at bar complex 3 is a potential landslide site if lateral erosion continues. Downstream is to the right.

Perhaps lowering of the creek bed is accomplished by catastrophic flood events, when accumulated gravel is flushed out of the Buttermilk system. However, much more information is needed on the rate of gravel movement and volume of suspended sediment transported.

Alluvial Fans - Alluvial fans that act as denudation agents were relatively unknown until the detailed mapping program uncovered their abundance. Sediment transport on the fans occurs with every rainfall event with active fan lobes burying younger stream terraces and incising and removing material from older terraces.

We believe that the alluvial fans and their incised upper drainages are important agents in the widening of the valley wall of Buttermilk Creek. An example is the fan closest to the south LLRWB trenches (Plate 1). Although this is a small fan, the incised upper drainage extends to the burial-site surface where it is then visible as a marshy sag in the surface. It is possible that this stream could capture an Erdman's Brook tributary resulting in a drainage reversal and increased incision due to lowered base level.

Landslides - We do not believe that landslides are significant providers of sediment or denudation agents, except in the area of bar complexes 6 through 8, adjacent to the waste-burial site. They are volumetrically small in comparison to alluvial fans, although the relative rates of activity are unknown.

7.6 Holocene Landscape Evolution

This discussion is extremely speculative and is confined to the general area shown on Plate 1. LaFleur's (5) mode of deglaciation and ice-marginal positions are adopted and followed, although some unit boundaries are quite different, most notably Flb3 and Al_b (Wtg and Haf, respectively, on LaFleur's map: Plate 2 and Appendix B).

Pre-Buttermilk Drainage - The late-glacial/early post-glacial upland drainage was dominated by large, alluvial fans such as the one on which the site reprocessing plant is located. These fans debouched onto a surface at the present burial-site elevation. This surface slopes northward toward Cattaraugus Creek at a gradient of 3 m/km. Drainage from the fans flowed northward and deposited gravel that is most abundant immediately adjacent to the fans (Flb3). The fan systems formed the loci for later development of the Buttermilk tributary systems.

Initial Buttermilk Incision - As deglaciation was completed, and the volume of meltwater-transported sediment diminished, the Buttermilk system entered a degradational regime due to lack of sediment supply. The oldest dated terrace (9920± 240 BP; Figure 25) is 2 terrace levels below the upper surface, indicating that incision began before that time. The Buttermilk base level is controlled by Cattaraugus Creek, thus rates of Buttermilk incision are somewhat dependent on the lowering of the Cattaraugus valley floor.

Tributary Development - As Buttermilk downcutting proceeded, so did tributary incision and headward erosion. Incision occurred in the upland fans, the northeast and southwest flowing streams, and in the initial valley surface, resulting in northwest flowing streams. Later stream capture resulted in the somewhat rectangular tributary drainage pattern. This is best exemplified by Erdman's Brook. Knick points in the tributaries may form in response to catastrophic flushing events in Buttermilk Creek proper.

Future Evolution - Further downcutting of Buttermilk Creek would probably result in downcutting and enlargement of the tributaries. An inspection of tributary size ordering suggests that Erdman 's Brook would evolve by valley widening and tributary capture to the dimensions of Frank's Creek, and Frank's Creek to the dimensions of the unnamed, lower east side tributary. Valley widening of Buttermilk Creek would continue at an, as yet, unspecified rate.

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APPENDIX A

EXPLANATION FOR PLATE 1

ENVIRONMENTAL GEOLOGIC MAP

Western New York Nuclear Service Center
West Valley, New York

By

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EXPLANATION

Lakes and Ponds (LP)

LP_n Natural lakes, ponds and swamps

LP_z Man-made lakes, ponds and swamps

Fluvial-Alluvial Fan Systems (F or A)

FA_b Buttermilk Creek and tributaries (active)

c Active channels and bars
Channel and bar positions change annually. Gravel bars and channel floor, sand may cover bar tops. Higher bar surfaces may be covered with grasses and emergent plants.

1 Fluvial terrace surfaces flooded by annual flood waters
Terrace surfaces exhibit ridge and swale topography; heavily vegetated with trees and/or saplings; ponded water in abandoned chutes. Surfaces veneered by overbank muds.

2 Creek flood plain swamp and marsh
Mud and clay sediments adjacent to low gradient creek channels.

FI_b Buttermilk Creek (early phases or inactive)

1 Abandoned Terraces
Terrace surfaces no longer flooded annually. Heavily vegetated with trees. Surfaces veneered

by overbank muds. Many surfaces and terraces show dissection by surface drainage processes.

2 High, early-phase terraces
Terraces incised into upper valley walls and upper valley margin. Surfaces veneered by overbank muds over fluvial gravels.

3 Initial Buttermilk fluvial surface
Valley fill clay tills (Tb_1) veneered by thin fluvial gravels.

AA_b Alluvial fans within the Buttermilk Creek basin (active)
Fan deposits of clay and mud, incised by channels actively transporting suspended mud and gravel. Gentle to moderate slopes. Clay-rich soils. Vegetated with grasses, shrubs and trees.

AI_b Alluvial fans within the Buttermilk Creek basin (inactive)
Abandoned fan surfaces. Channel remnants may be preserved on fan surface. Forest vegetation or grasses where tilled for agricultural purposes. Gentle to moderate slopes. Clay-rich soils within Buttermilk Valley. Gravel surfaces on larger, older fans.

FA_c Cattaraugus Creek (active)

c Active channels and bars

1 Fluvial terrace surfaces flooded by annual flood waters.

Proglacial

FI_u Proglacial meltwater channels, undifferentiated. Channels eroded into till deposits. Channel bottom veneered by gravels.

Moraine Systems (T)

Tb_1 Basal clay till deposited during Lavery advance

1 Active landslides developed on steep till surfaces. Unit includes slide deposits and landslide scar surfaces. Bare soils or grass vegetation.

S Steep till slopes exhibiting soil creep and surface block slumping.

Surfaces exhibit corrugated topography and may be vegetated by grasses or forest vegetation. Rotated slump blocks may exhibit tension cracks or swamp depressions on back margins.

3 Moderate-to gently-sloping till surfaces
Marginal to creek valley upper margins or at the margins of the till with topographically higher tills. Surfaces moderately drained.

4 Flat, hummocky till surfaces
Surface is poorly drained with closed depressions filled with swamp sediments or ponded water.

Trm Recessional moraine
Tills interbedded with sand and gravel sediments. Constitutes elongate ridges oriented perpendicular to larger valley axes or parallel to valley margins. Well-drained surfaces of moderate slopes.

Tb_k Basal tills deposited during the Kent advance

b Basal tills mantling lower hill slopes
Above elevations of 1425 ft. Tills of mixed clay, silt, sand, gravel and boulders. Slopes on this unit are moderate.

t Basal tills occupying upper elevations
Till slopes are moderate to gentle.

s Steep till slopes created by stream incision
Slopes exhibit slow soil creep and block slumping

Bedrock (B)

BD_t Bedrock, Devonian mudstones and sandstones; dashed unit boundary where covered by a thin veneer of till.

Other

M_z Man-made fill or excavation

M_z Pipeline trenching filled to original topography

Inter-unit boundary

Intra-unit boundary

1741 282

APPENDIX B

GLACIAL GEOLOGIC COLUMN

AND

LEGEND FOR PLATE 3

GLACIAL GEOLOGIC MAP

from

R. G. LaFleur, 1975

1741 283

APPENDIX B

LEGEND FOR PLATE 3

GLACIAL GEOLOGIC MAP

Western New York Nuclear Service Center and Vicinity

Ashford Hollow, West Valley, portions of the Ellicottville, Ashford Hollow, Springville and Sardinia Quadrangles

R. G. LaFleur 1975

LEGEND

HOLOCENE			Hfp	Flood plain; gravel, silt alluvium
			Hmf	Mudflows; pebbly silt, marginal to flood plains, derived from silty till (Wtc)
			Htl	Landslides, slumps; developed on exposures of clayey till (Wtc)
			Hft	Low terraces of Cattaraugus Creek and tributaries; ferruginous gravel and silt, wood-bearing
			Hht	High terraces of Cattaraugus Creek and tributaries; younger terraces underlain by ferruginous gravel and silt alluvium, wood-bearing; older terraces, commonly developed on dissected outwash gravel, are in part of Woodfordian age.
			Haf	Alluvial fans; channery gravel, sand
WISCONSINAN	WOODFORDIAN	Lake Escarpment	Wos	Late outwash; pebble gravel, sand; incised into earlier outwash
			Wog	Outwash, cobble gravel, sand
			Wls	Lacustrine sand, silt, some pebble gravel
			Wkg	Ice-contact cobble gravel, sand; kamic

1741 284

WISCONSINAN	WOODFORDIAN	Defiance	Wdo	Outwash; pebble gravel, sand; along ice margin, westward draining, overlying clayey till (Wtc)
WISCONSINAN	WOODFORDIAN	Defiance	Wfg	Fluvial gravel, sand, derived from upland drainage, hummocky where laid over thin ice; overlies silty till (Wtc)
WISCONSINAN	WOODFORDIAN	Lavery	Wtc	Till, clayey with pebbles and cobbles; deformed silt stringer, minor overridden pebble gravel, sand, mainly reworked lacustrines. May include Hiram equivalent till in upper few feet.
WISCONSINAN	WOODFORDIAN	Erie Interstade		
WISCONSINAN	WOODFORDIAN	Kent	Wrg/ Wsd	Ice-contact gravel, sand; kame terraces (Wrg). Recessional kame delta sand, silt, clay (Wsd) beneath clayey till (Wtc).
WISCONSINAN	WOODFORDIAN	Kent	Wrm	Ground moraine; mixed stony till, stratified drift; ice marginal
WISCONSINAN	WOODFORDIAN	Kent	Wem	End moraine; mixed gravel, sand, till; distal limit of bright stratified drift
WISCONSINAN	WOODFORDIAN	Kent	Wvt	Valley train, outwash gravel, sand; distally from bright drift limit
WISCONSINAN	WOODFORDIAN	Kent	Wlb	Lacustrine silt, clay; bordering end and recessional moraines; includes later bogs
WISCONSINAN	WOODFORDIAN	Kent	Wlt	Lodgment till, >5' thick, stony, silty, variously bright and drab
WISCONSINAN	WOODFORDIAN	Kent	Wtt	Lodgment till, <5' thick; occasional rock outcrop
WISCONSINAN	ALTONIAN?	Olean	Atc	Colluvium; till, talus
WISCONSINAN	ALTONIAN?	Olean	Als	Lacustrine silt, clay, marginal to ice-contact deposits
WISCONSINAN	ALTONIAN?	Olean	Arm	Ice-contact gravel, sand; ground moraine; drab

1741 285

WISCONSINAN	WOODFORDIAN	ALTONIAN?	Olean	Alt	Lodgment, ablation till, stony, silty; >3' thick, drab
				Att	Lodgment, ablation till, <3' thick; frequent rock outcrop
Devonian				Dr	Bedrock outcrop; shales, siltstones, sandstones of the Canadaway and Chadakoin Formations

Meltwater ch‿nnel, with direction of flow

1741 286

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16. ABSTRACT *(200 words or less)* This report is one in a series of related reports presenting the results of a study to evaluate the containment capability of a low-level, solid radioactive waste-burial ground at West Valley, N. Y. This project is the first portion of a detailed geomorphic and erosion study of the reach of Buttermilk Creek adjacent to the waste-burial site.

Buttermilk Creek valley is being actively modified by fluvial transport, lateral channel scour, and landsliding. High surface runoff rates create highly variable but enhanced stream flows that result in coarse-gravel sediment transport within the active channel. The active channel morphology indicates that braided stream processes are common in Buttermilk, leading to active channel down-cutting and lateral migration. Where lateral migration of the active channel has undercut valley wall slopes, large-scale landsliding enhances valley wall retreat. A major site of historical and recent slide activity lies adjacent to the low-level burial trenches.

Initial, post-glacial Buttermilk Creek incision began before 9920 ± 240 B.P., the age of the oldest dated fluvial terrace. Future evolution of the system is expected to proceed by Buttermilk Valley lowering, tributary and landslide widening, and stream capture.

17. KEY WORDS AND DOCUMENT ANALYSIS
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