SEDIMENTOLOGIC AND GEOMORPHIC PROCESSES AND EVOLUTION OF BUTTERMILK VALLEY, WEST VALLEY, NY

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INTRODUCTION

The purpose of this trip is to investigate the sedimentologic and geomorphic processes active in a small non-glacial gravel stream and on adjacent valley walls and tributaries. The work that led to this field trip is part of a larger geologic and hydrologic study by the New York State Geological Survey of the low-level nuclear waste-disposal site and other use areas of the West Valley Nuclear Service Center. The geomorphic study is being done to determine, as accurately as possible, the denudation rate in the Buttermilk drainage basin, and to estimate rate and magnitude of morphologic changes to the waste-burial site.

Buttermilk Creek, located in southwestern New York (Fig. 1), has a drainage basin area of 78.4 km^2 and is a tributary of Cattaraugus Creek. Figure 2 shows detail of that part of the drainage basin adjacent to the West Valley Nuclear Service Center (WVNSC).

GENERAL GEOLOGY

Surficial Geology

The area of interest is in the Ashford Hollow and West Valley 7½ minute quadrangles. The regional surficial geology has been mapped by Muller (1977) and discussed by Coates (1976). Wisconsinan glacial features and later Holocene modifications of the 2 quadrangles have been mapped in great detail by Lafleur (1979) and discussed by him on the 1980 Friends of the Pleistocene field trip (Lafleur, 1980). An upper plateau containing the waste-burial trenches, is underlain by till capped in places by a thin layer of fluvial gravel that marks the original fluvial surface immediately following the late Woodfordian deglaciation. Movement of groundwater in the vicinity of the waste-burial trenches has been investigated by Prudic (1979) and Prudic and Randall (1979). Mapping by Boothroyd et al. (1979, 1981) has further refined Lafleur's units in the vicinity of the WVNSC. There are eight till units, identified by age and present steepness of slope, and ten fluvial/alluvial fan systems ranging from the presently-active bar and channel system to late Woodfordian proglacial channels.

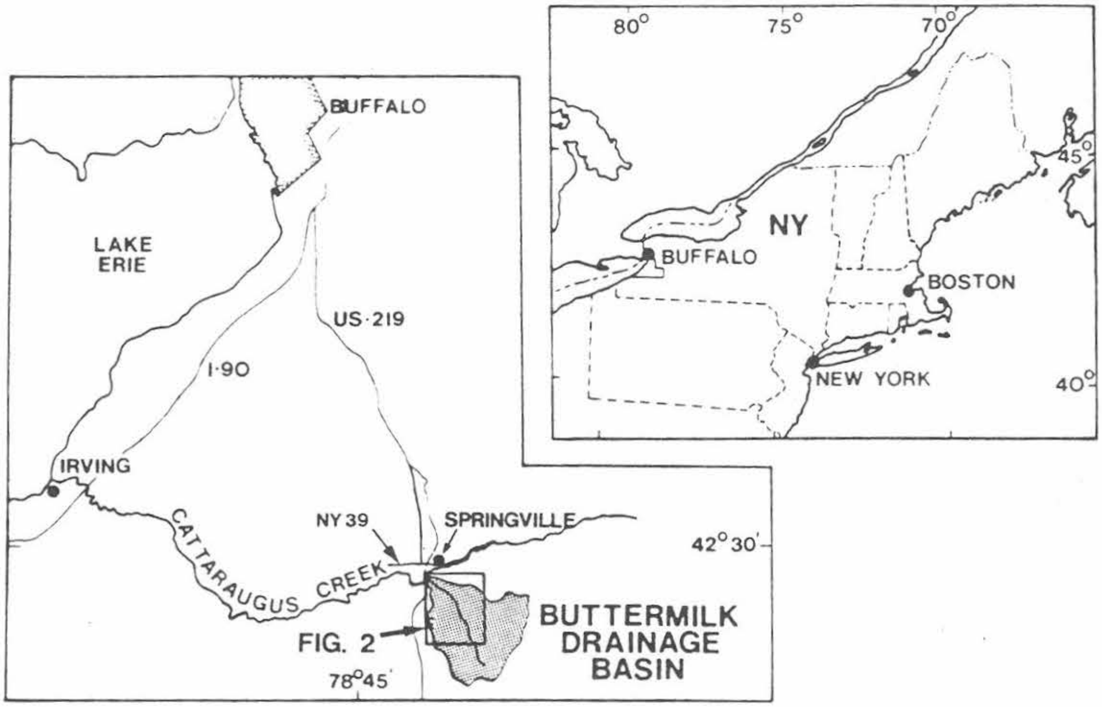

Figure 1. Location map.

Bar and Channel Pattern

At present, Buttermilk Creek and tributaries are incised up to 50 m into compact Lavery till. 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. 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. 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 channel-sweep diagrams constructed from sequential aerial photographs. The low-stage thalweg is bent around or cuts through bars, and thus is controlled in part by bar movement. Many inactive channels that have been cut off by sudden channel switching or by having chute heads filled by bar gravel.

Gradient and Clast Size

The mean gradient of Buttermilk Creek is 6.7 m km^{-1}, as measured along the low-stage thalweg. The longitudinal profile is segmented of varying spacing or wavelength (Fig. 3). The shortest segments, 50 to 100 m in length, are pool and riffle sequences developed over

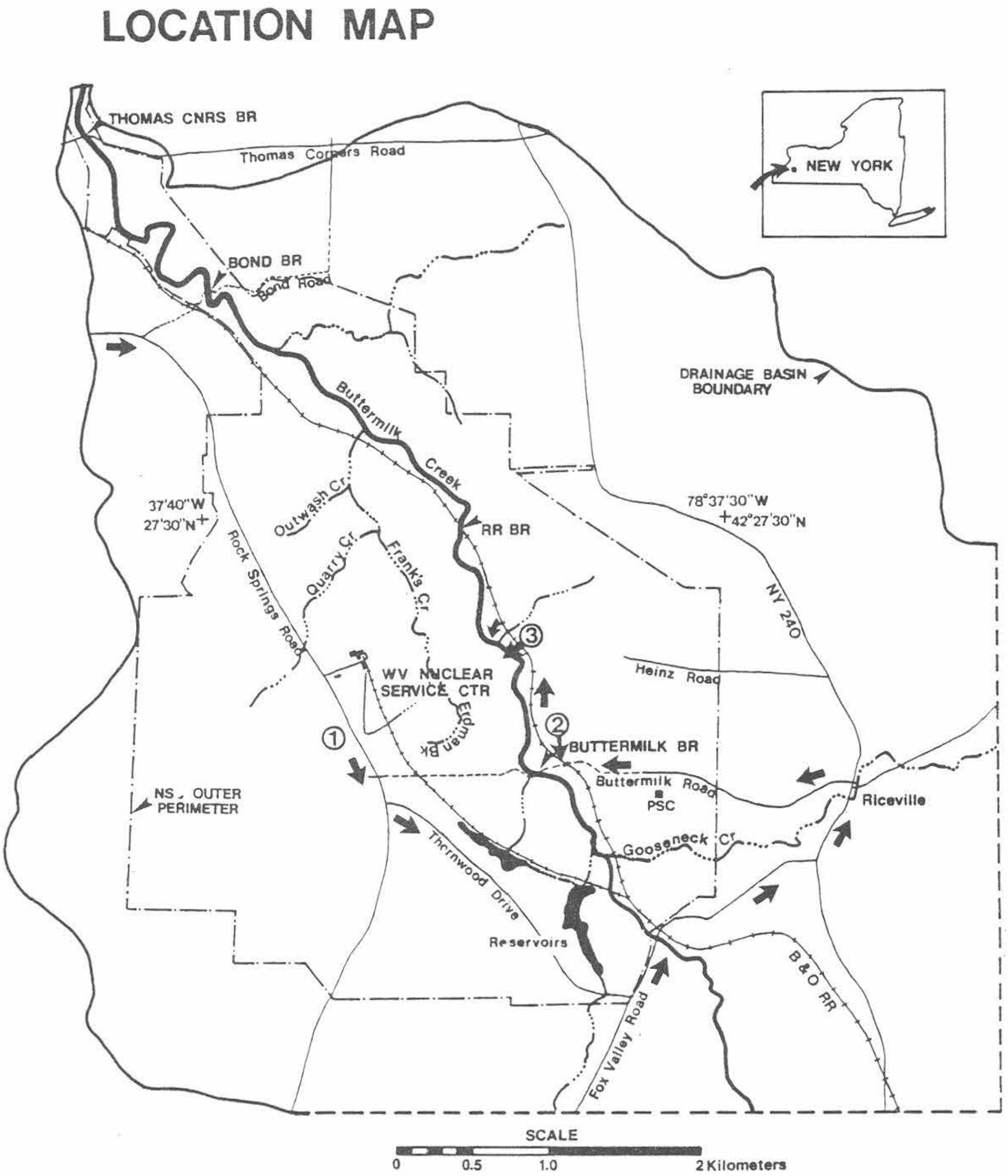

Figure 2. Portion of the Buttermilk drainage basin with detailed road map and stop locations.

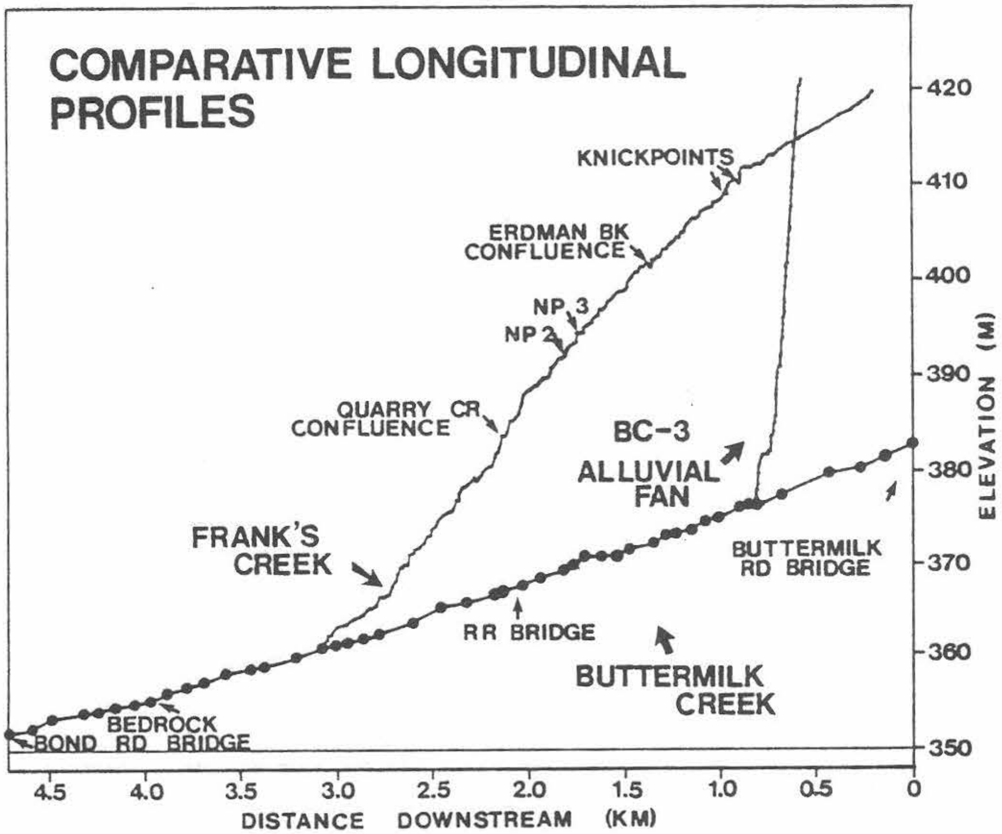

Figure 3. Longitudinal profiles of Buttermilk Creek; Frank's Creek, an important tributary; and a small valley-wall alluvial fan.

and around bars. Longer-spaced segments, on the order of 500 m to 1 km spacing, are due to the sediment load of inflowing tributaries that tends to flatten the gradient near the confluences. Several 200-300 m long flat spots in the profile are flood-bar surfaces and represent temporary storage of gravel in the bars. Average maximum clast size (long axes) is 25 cm and shows no systematic variation in a downstream direction. Clast size does not vary downstream because clasts are continuously supplied to the bars and channels along the reach by lateral erosion of valley walls and previously deposited terraces. 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; 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. The clasts are very bladed to very platy in shape, and consist mostly of Devonian sandstones, the most resistant bedrock of the area.

Grain Size

Large (150-225 kg) sediment samples were collected from the valley-wall till, gravel bars, and low terraces. Figure 4 illustrates the textural classes of those samples.

Till. The till samples are silt-rich, with 80-85% silt and clay that constitutes the suspended-sediment load of the fluvial system. Visual inspection of till cropping out at landslide localities and at the base of slope along scarps cut by the Buttermilk channel, reveals that few large clasts are contained in the till and that a low overall gravel percentage is in line with our two analyses. Lafleur (1979) and Dana et al. (1979, 1980) report similar findings at other outcrop localities and in research trenches cut in Lavery till on the plateau adjacent to the low-level, waste-burial site.

Bar Gravel. All samples contained 75-95% gravel with little sand matrix and very little silt and clay. Some sand, and all silt and clay, occurred as a falling-stage drape over the gravel with some infiltration downwards into available pore space.

Terrace Samples. Two samples are similar in gravel percent and overall grain-size distribution to the bar samples. These two samples represent previously deposited bar complexes resulting from the cross-valley channel sweep. The third sample, GS-3, is a fine-grained sandy silt with essentially no gravel. It was obtained from the topmost unit in the stratigraphic section upstream of transect 1, opposite bar complex 3. This sediment was deposited in a small depression (pond) on the gravel terrace at the base of a small alluvial fan.

GEOMORPHIC AND SEDIMENTARY PROCESSES AND LANDFORMS

Bar and Channel Geometry

Geometry. The bars in Buttermilk Creek are 100 to 200 m in length and exist as complex, elongate, erosional and depositional features flanked, and often cut, by the present low-stage channel (Fig. 5A, 5B). Riffles are present where the channel crosses over a large bar and in the vicinity of the downstream edges of the bars. Pools are present as deeper areas in the narrow thalweg and also as very deep scour holes between advancing bars and eroding banks. Dry chutes exist along the margins of many bars. The overall bar and channel pattern is similar to that of small, gravelly, braided streams (Boothroyd and Ashley, 1975; Smith, 1970). Some bar complexes have well-developed slip faces or depositional edges on their downstream margins. Depositional edges, gravel or sand, record the downstream growth of bars. 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,

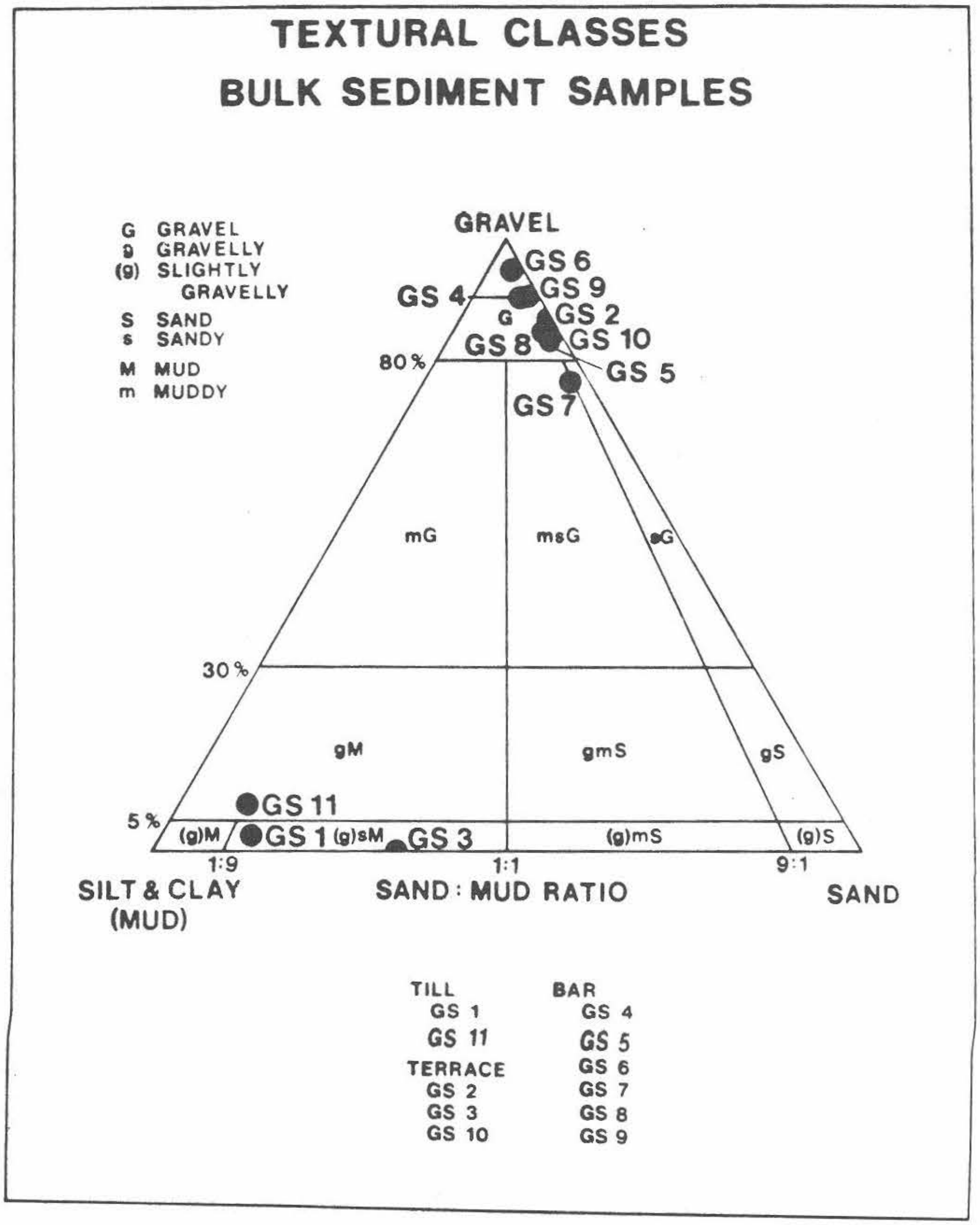

Figure 4. Textural classes of sediment from basal till, fluvial bar, and fluvial terrace depositional environments.

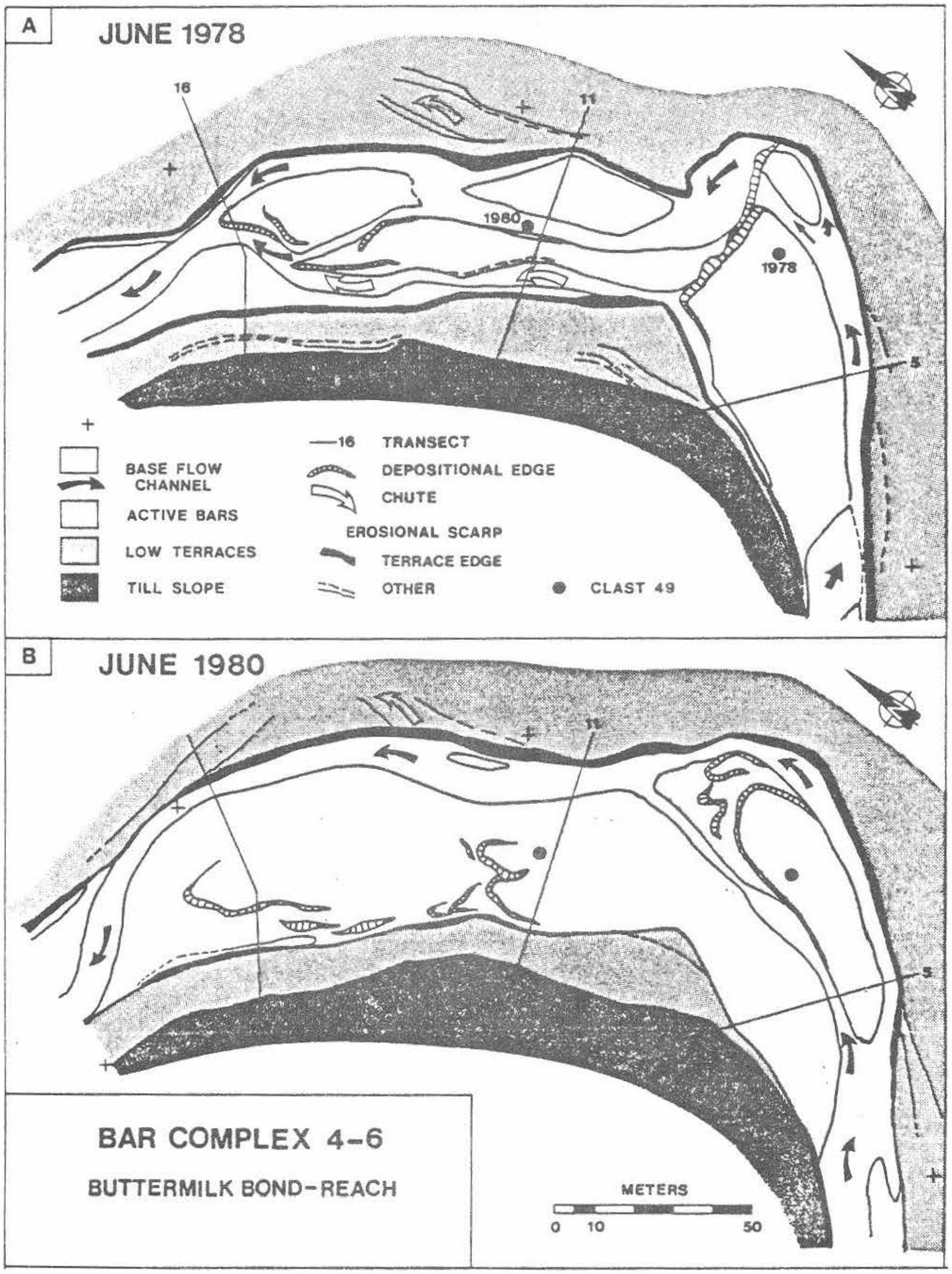

Figure 5. Bar complex 4-6. A. June 1978. B. June 1980.

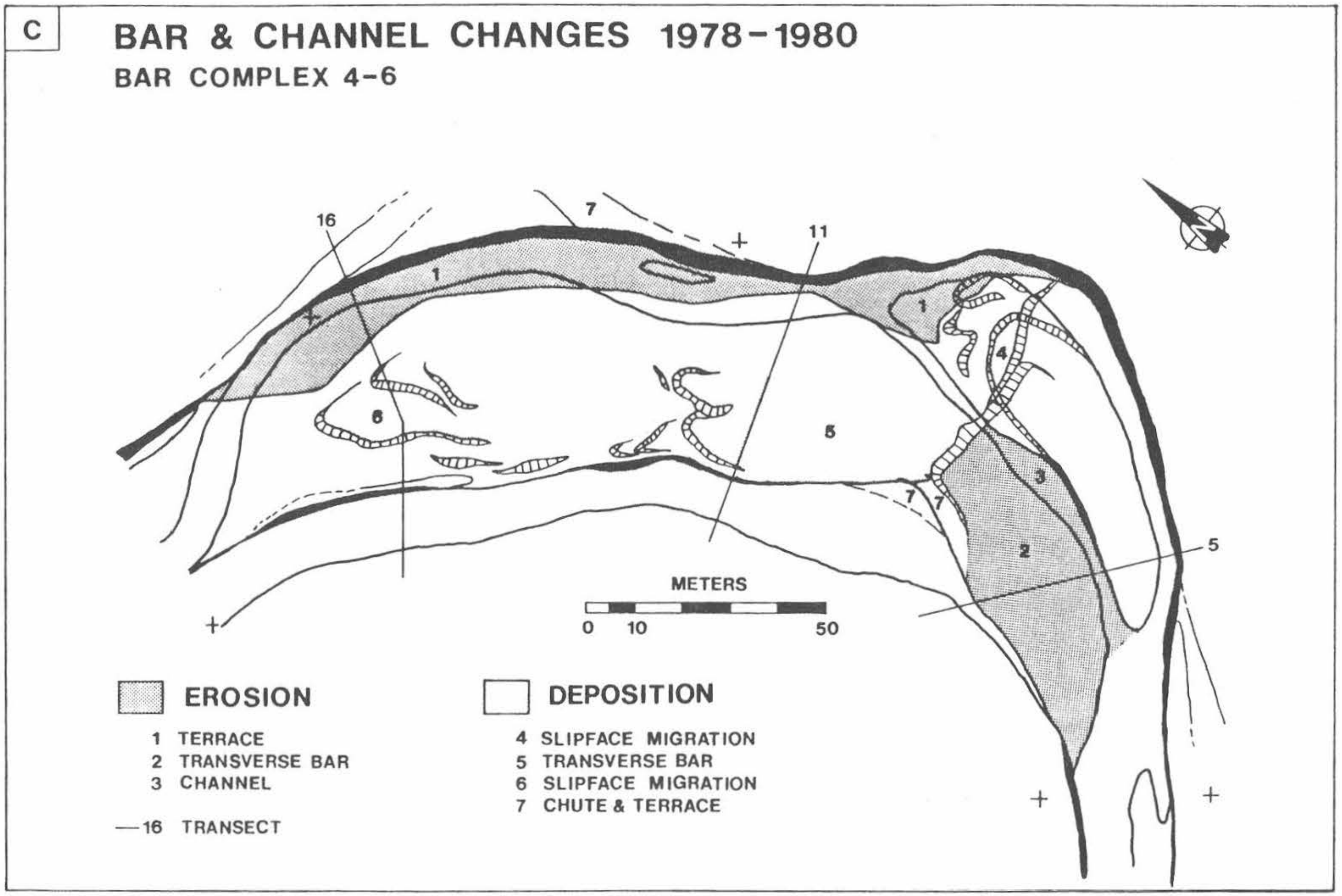

Figure 5C. Bar complex 4-6. Note changes between 1978 and 1980 (due to Hurricane Fredric flooding).

or by movement of diffuse gravel sheets. All of these features are well-displayed on many of the bar complexes, particularly on bar complex 4-6 (Fig. 5).

Bar Migration. Bar complex 4-6 (Fig. 5) was vastly changed by the flood event accompanying Hurricane Fredric on Sept. 8-9, 1979, mostly by the migration of large transverse bars in equilibrium with the high discharge depth and velocity conditions. The upper transverse bar (BC-4) attempted to migrate forward but the east side slipface encountered the debris pile and terrace at the kink in the channel (Fig. 5A). The intense turbulence created by this situation caused rapid erosion and removal of terrace gravel that resulted in a wider bend in the channel (Fig. 5B). The gravel was redistributed onto bars farther downstream, effectively recycling the low-active terrace material. The complete bar form migrated downstream approximately 60 m by a combination of stoss-side accumulation and bar slipface migration. Additions of east side terrace gravel resulted in the vertical accretion and slipface migration of smaller transverse bars on the downstream part of the complex (BC-5). In addition to removal of terrace material and recycling it back to active bars, bar gravel was deposited up on the low-active terraces as longitudinal bars during Hurricane Fredric. At bar complex 4-6, unvegetated chutes adjacent to active bars were filled and excess gravel deposited on the west side terrace. Higher elevation chutes on the terraces were activated during peak flooding, and gravel longitudinal bars accumulated in them.

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 junciton of tributary streams with Buttermilk Creek. All are heavily vegetated. The short fans begin part-way up the valley wall, with an entrenched stream 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 (Fig. 6). The larger fans also head in the valley wall, but the entrenched streams above the fanheads are incised into the upland surface. These fans contain both inactive and active segments with inactive lobes existing as terraces above incised, active streams that feed distal lobes. The fans may have multiple active lobes. The largest fans occur at the confluence of small tributary streams with Buttermilk Creek. They are similar to the medium-sized fans in appearance, except for larger size and deeper incision of the active stream.

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.

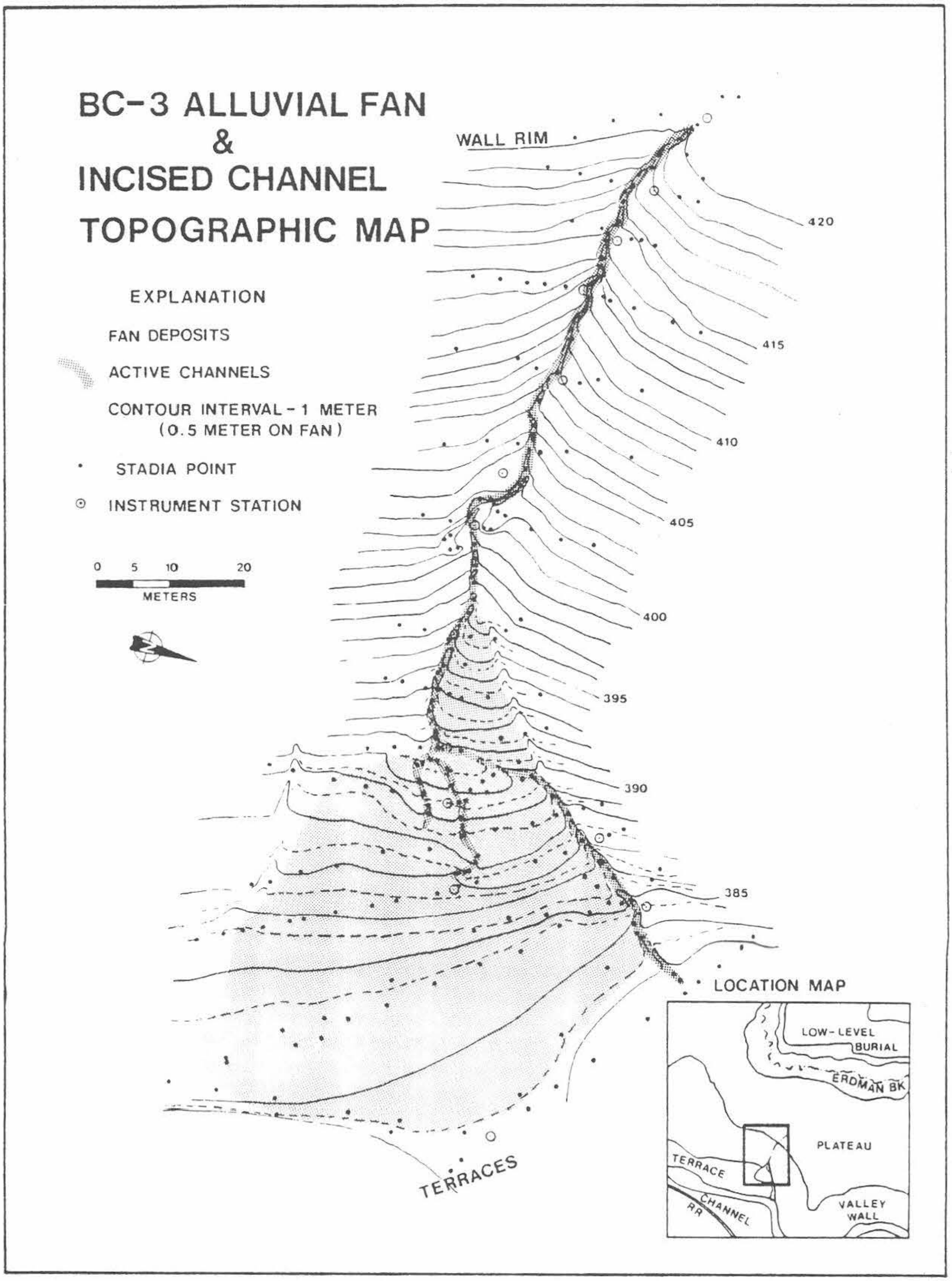

Figure 6. BC-3 alluvial fan.

The processes associated with alluvial-fan development are important agents in the widening of Buttermilk Creek and its tributaries. Gravel, sand, and some silt and clay eroded from the upper incised channels is deposited on the fans, whereas other silt and clay may collect in ponded depressions on the terraces. An unknown percentage of fine-grained sediment bypasses the fan and is fed directly as suspended-material load into Buttermilk Creek, or into tributaries and then into Buttermilk.

Landslides

Active landslides occur in areas where the channel impinges on, and cuts, the valley wall over a period of at least tens of years. Sequential aerial photographs showed that the Buttermilk channel was at, or near, the large landslide area on the west valley wall at bar complex 6, from 1939 to 1977. Monitoring of the BC-6 landslide (Fig. 7) showed downslope movement of 8 to 32 meters horizontally and 0.8 to 10 meters vertically during the time period 1978-1980. The movement actually occurs as a series of coherent slumps, 20-50 m wide at the top of the slide, changing to a hummocky, tension-cracked, earthflow mass at the toe of the slide. Downslope trajectories of the upper slide slumps are steeper than the lower earthflow, contributing to a pile-up of material at the base of the slide. This material can rapidly flow out onto Buttermilk bar and channel areas. The earthflow accumulation of material had been removed by April, 1980; the last was probably eroded by Hurricane Fredric flooding.

Buttermilk Terraces

153 separate fluvial terraces mapped within the Buttermilk-Bond reach of Buttermilk Creek are shown on Figure 8. Terraces have been grouped into categories according to their general elevation above active bar surfaces as follows: 1) low active (0-3 m); 2) low inactive (3-8 m); 3) middle (8-35 m); and 4) high (35 m). Arrays of terraces also can be grouped according to events that generated them, or allowed their preservation after they were formed.

The low-active terraces are associated with the present processes of Buttermilk Creek and its tributaries. 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. 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. The heavy vegetation cover of these terraces is confusing and serves to mask their degree of activity. Some terraces may be preferentially preserved as discussed below.

The largest number of terraces that are higher in elevation than the low-active level are associated with the confluence of tributaries with Buttermilk Creek. Gravel transported down the tributaries is

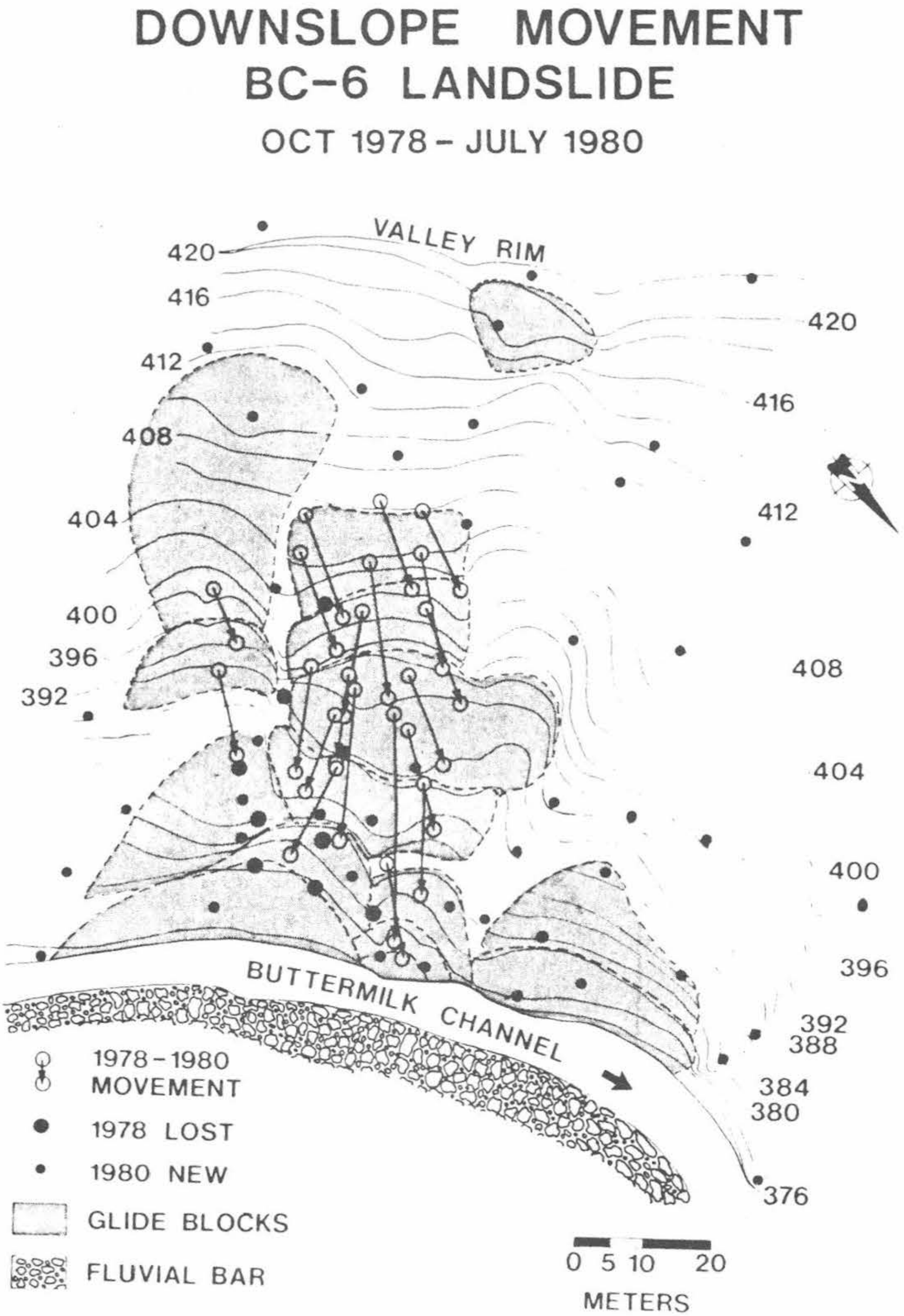

Figure 7. BC-6 landslide. Note location and amount of downslope movement of glide blocks.

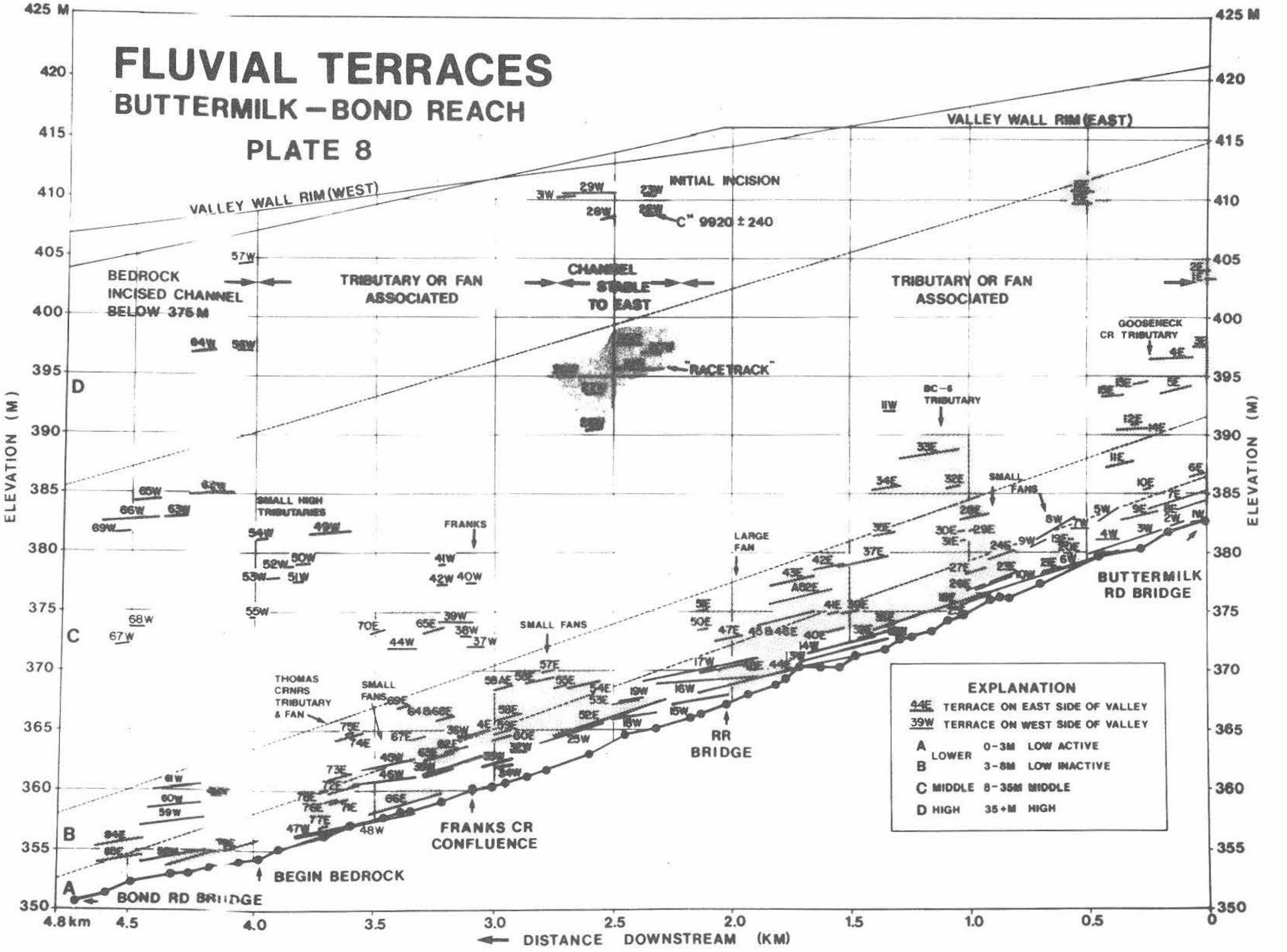

Figure 8. Fluvial terraces of Buttermilk Bond reach projected to low-stage thalweg. Note: C-14 date and initial incision; location of BC-6 tributary.

deposited as slightly dipping, fan-shaped bar complexes at the mouths of the tributaries. The fans are skewed in downstream direction relative to Buttermilk Creek, due to redistribution by Buttermilk bedload processes. Continued incision of Buttermilk Creek and the associated tributary leads to the abandonment of the bar complexes, and they become terraces by definition. The excess of gravel supplied over transport capacity may temporarily, or permanently, retard the lateral sweep of the Buttermilk channel and destruction of the terrace array. Other terraces were deposited in a similar manner at the base of, and adjacent to, alluvial fans that developed within Buttermilk valley. Some fans are small, such as the BC-3 fan, whereas others are larger, with upper drainages well incised into the plateau above Buttermilk valley.

Some terraces at the lower end of the Buttermilk-Bond reach are bedrock defended; that is, the channel of Buttermilk is incised into Devonian bedrock on the west side of the valley preventing further channel sweep. We speculate that a third array of terraces, including the set that contained the dated wood fragmants and the set that includes the "Racetrack" (Fig. 8) have been preserved because the Buttermilk channel has remained stable on the east side of the valley for long periods of time. We do not know the cause for this channel behavior.

Reservoir Sedimentation

Sedimentation in two WVNSC reservoirs situated on tributaries of Buttermilk Creek (Fig. 2) was assessed to gain insight into the overall denudation rate and landscape evolution discussed in the next section.

The reservoirs are contained by earth dams constructed across separate tributary streams, with water accumulation beginning in 1963. The full stage for both is 412.4 m (1353 ft). A dredged channel connects the reservoirs allowing free flow between them and for the stages in each to equilibrate. Flood discharge is released through a pipe beneath the north reservoir, down the tributary, and into Buttermilk Creek just south of the Buttermilk Hill Road bridge. Extreme flooding results in overflow across a wide sluiceway east of the south reservoir and directly into Buttermilk Creek. The south reservoir is shown in plan view in Figure 9A.

The pre-reservoir valley cross-sections show a V-shaped form eroded in Lavery till, probably not unlike the present Frank's Creek. Sedimentation from 1963-1980 has been by: 1) progradation of a delta at the south end of reservoir; 2) density underflow of fine-grained material down the delta front and prodelta slope onto the reservoir floor, and 3) slumping and debris flow of the submerged valley walls down the side slopes.

Inspection of Figure 9A indicates that the delta plain has prograded about 140 m into the reservoir. The cross profiles near the delta front (8/21 and 9/22, Fig. 9B) show a flat to gently concave up reser-

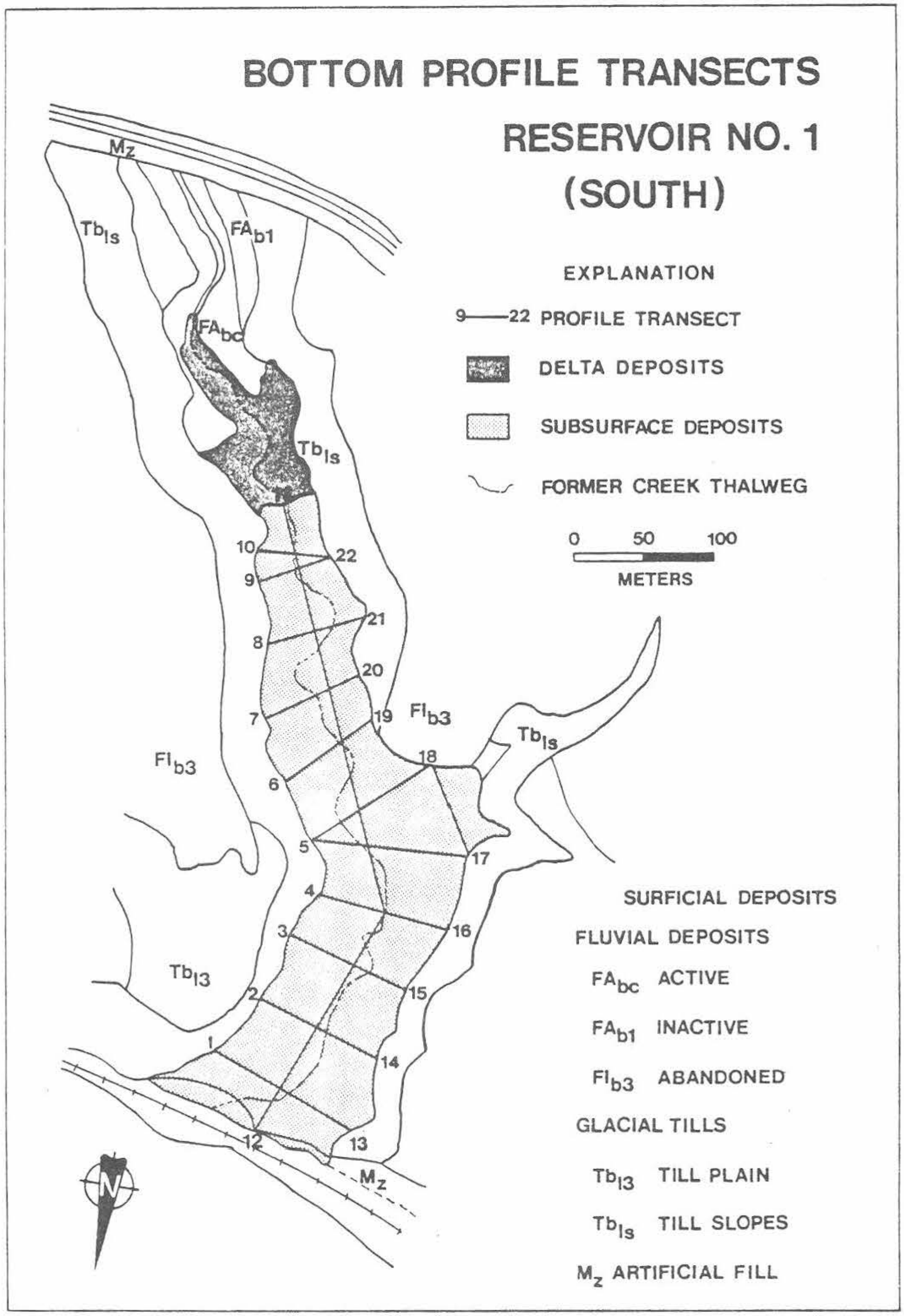

Figure 9. WVNSC storage reservoir No. 1 (south). A. Map with cross-profile locations.

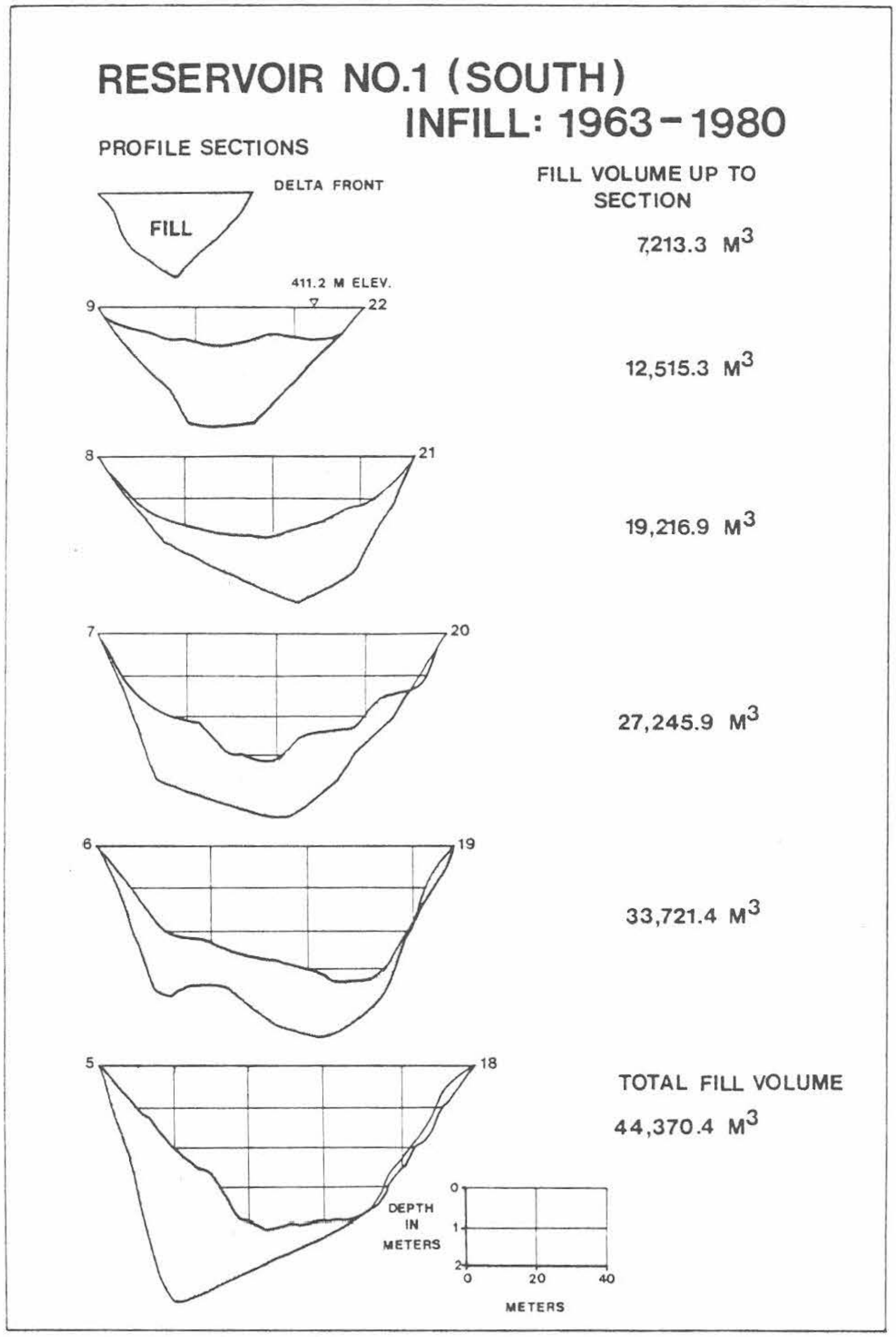

Figure 9. WVNSC storage reservoir No. 1 (south). B. Selected cross-profiles near delta front showing infill since 1963.

voir floor, whereas the cross profiles farther away show a more U-shaped section with terraces and uneven filling. The flat profiles probably reflect fill by density underflow, and the others, fill by a combination of slumping and underflow.

Buttermilk Stage and Discharge

USGS Gaging Data. The USGS operated a gauging station on Buttermilk Creek near the Bond Road bridge during water years 1962-1968 (USGS, 1962-1968). 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 (1968b).

A stage-discharge rating curve for Buttermilk Creek (Fig. 10), adapted from those compiled by the USGS (1968b), includes the highest discharge events for each year the stage-height recorder was in place. These readings (max = 110 m^3 sec) of instantaneous discharge indicate that peak flow events are much higher than those that appear as the daily summation (USGS, 1963-68). This means that peak discharge events are of extremely short duration, several hours in length.

NYSGS Gauging Data. The stage recorder installed at Thomas Corners Road bridge by the NYSGS in August 1978 was removed by Hurricane Fredric flooding in September 1979 and was reinstalled in July, 1980. Selected stage-height records for the summer and fall of 1980 are shown in Figure 11. Velocity-area information collected during the summer-fall period, along with suspended sediment samples, are shown on the stage-discharge, suspended sediment concentration-discharge plot (Fig. 10).

Flood Events. The hydrographs of three flood events are illustrated in Figure 11; a relatively low-discharge event (Oct. 12), a moderate event (Aug. 11), and a high-discharge event (Oct. 25-26). The moderate and high events show the "spikey" nature of the flooding, particularly the rapid rise in stage to peak flow in a matter of hours. A review of the USGS stage-discharge data and rating curve (USGS, 1968b) reveals that the October 25-26 flood is within the range of the yearly maximum discharge event as determined by the USGS for 1962-1968. The Hurricane Fredric flooding that carried away the stage recorder was probably equal to, or greater than, the indirect measurement of 110 m^3sec^{-1} determined by the USGS (1969b) for a large flood in 1967. The flood level, as determined by debris in trees, is shown in Figure 12 for bar complex 4-6, transect 5. Also show is the base-flow water-surface elevation, and the flood flow of October 25-26, 1980.

The suspended sediment concentration at a given discharge increases rapidly with increase in discharge during a flood event, peaks early, and then falls off more rapidly than a proportional decrease in discharge (Fig. 11C). This relationship is common to small streams with rapid runoff and little infiltration (Gregory and Walling, 1973).

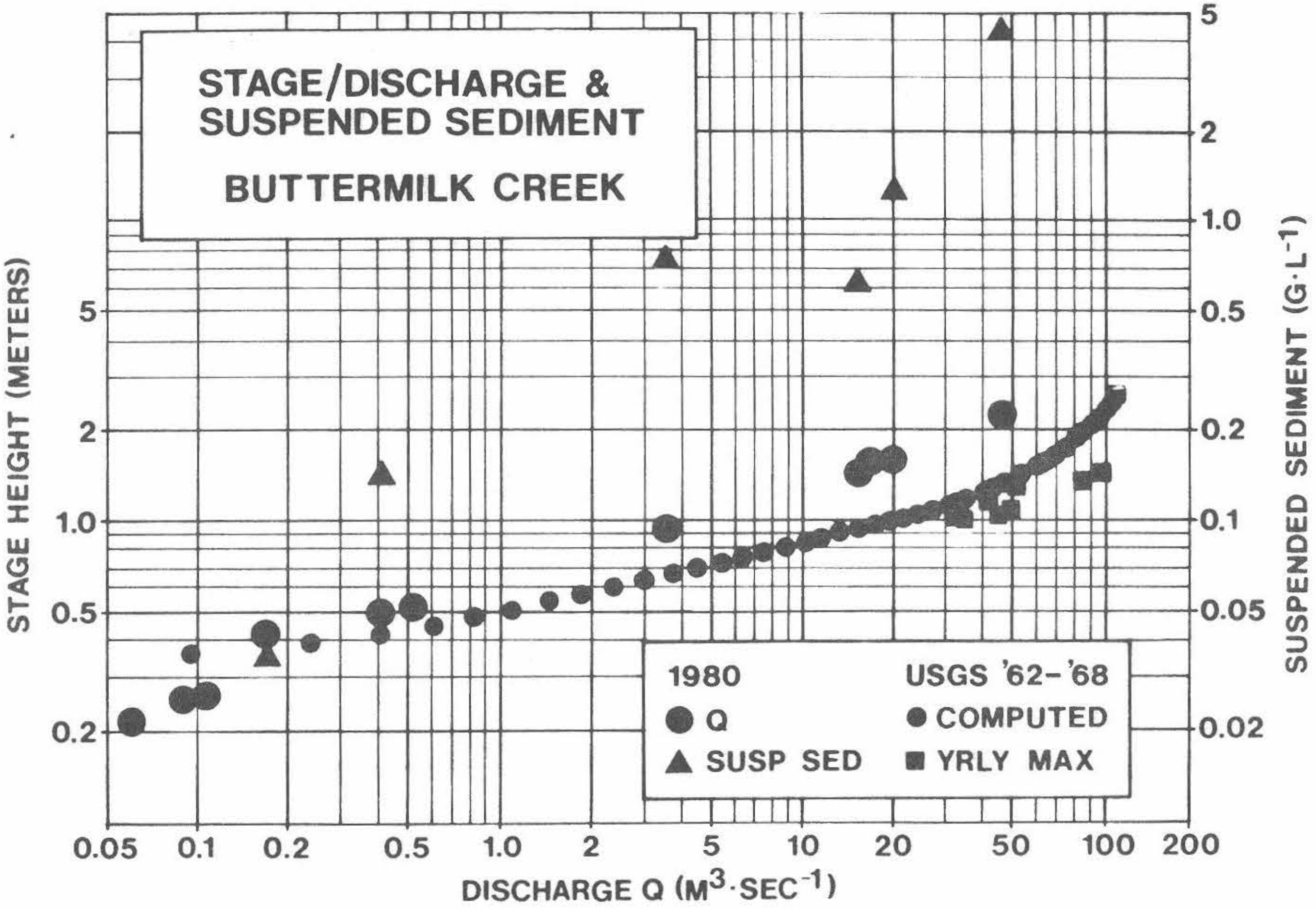

Figure 10. Stage-discharge, and suspended sediment data, Buttermilk Creek. USGS gauge at Bond Rd. bridge; 1980 data obtained from Thomas Corners Rd. bridge (Fig. 2).

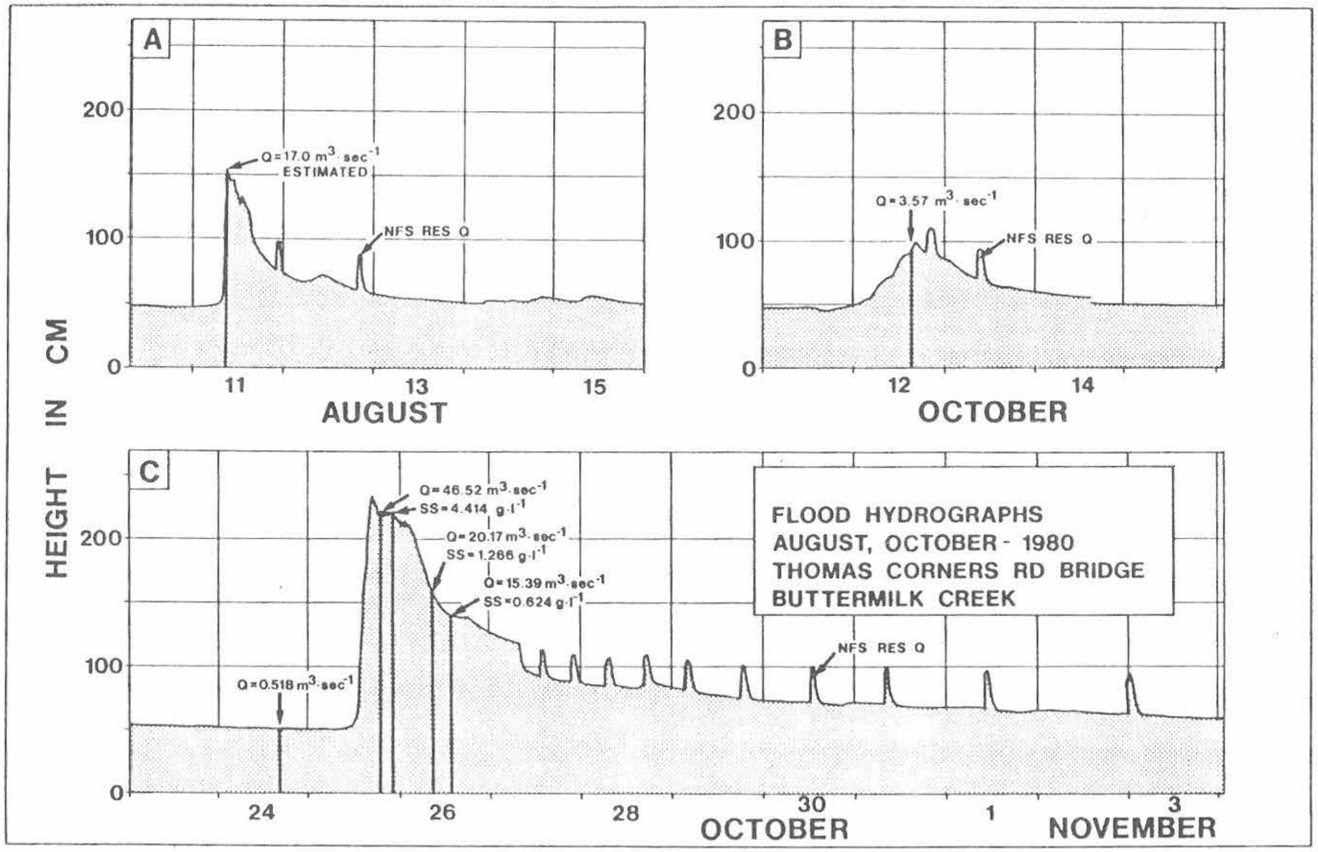

Figure 11. Flood hydrographs, Buttermilk Creek, 1980. Note suspended sediment values and reservoir slug discharge. Hydrograph C estimated to be mean annual flood.

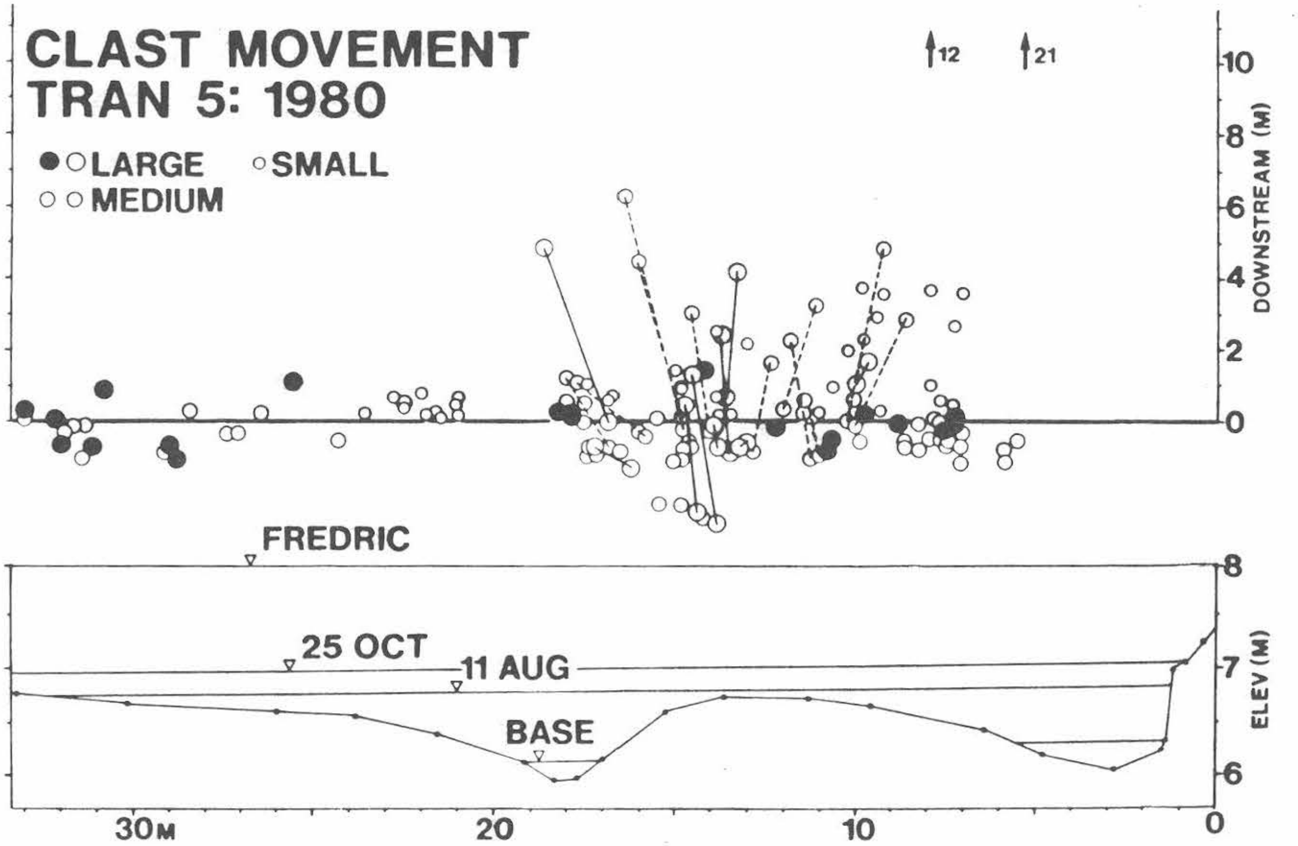

Figure 12. Clast movement, transect 5, bar complex 4-6, that occurred during Oct., 1980 flood event.

The sharp spikes on the hydrograph of about one hour duration represent controlled releases from the WVNSC reservoirs (Fig. 2,11). The gate at Dam No. 2 (north) opens automatically when the reservoir stage rises 30 cm (1 ft) above full 412.4 m (1353 ft). Discharge is through a 91 cm (36 in) pipe at a rate of 5.66 m^3sec^{-1} (200 cfs) until the water level in the reservoirs is lowered enough to allow the gate to close.

Clast Movement. The August 11 flood was probably the threshold event for initiation of movement of medium-sized clasts on the lower bar surfaces. An event of this discharge (17 m^3sec^{-1}, estimated) (Fig. 11A) occurs several times a year based on the USGS (1968b) data. The October 25-26 event (46.52 m^3sec^{-1} measured; 60 m^3sec^{-1} estimated) moved some large clasts on the bar edges and shoulders an average of 3 m (Fig. 12). This event may be considered to be just above the threshold of movement for large clasts, although not all of them moved. A flood of this discharge falls in the range of events with a one year recurrence interval (USGS, 1968b).

BUTTERMILK VALLEY DENUDATION

Sediment transport rates have been calculated or estimated for the various processes that were described above. Space permits only a summary here; refer to Boothroyd et al. (1981) for a more detailed discussion. Table 1 is a summary of transport rates and volumes discussed below.

Simple Denudation Rate

The volume of sediment removed from Buttermilk valley as a function of time can be calculated using the age of terrace 22W (9920 ± 240 BP) (Fig. 8) as being close to the time of initial incision and downcutting of Buttermilk Creek. The total volume of sediment removed, neglecting tributaries, was: 65,923,331 m^3 (Table 1).

The simple denudation rate is:

$$\frac{65{,}923{,}331\ m^3}{10{,}000\ \text{yes}} = 6592\ (6600\ m^3yr^{-1})$$

The denudation value represents the amount of bedload and suspended-load transport necessary, per year, by Buttermilk Creek, to remove valley fill and arrive at the present configuration. Variations in rate due to short or long-term climatic change have been ignored.

Gravel Movement

The Buttermilk valley sediment aggregate is composed of about 5 percent gravel, 85 percent fine sand, silt and clay, and 10 percent coarse and medium sand (Fig. 4) (Hoffman et al., 1980). Using the

TABLE 1. SEDIMENT TRANSPORT RATES

PROCESS	VOLUME (m^3 yr^{-1})	WEIGHT (kg yr^{-1})	TOTAL VOLUME (m^3)
Gravel bar migration	85		
Gravel volume deficit	116		
Suspended sediment			
Instant discharge		205 kg sec^{-1}	
Peak discharge	3000	4,800,000	
Total discharge	3770	6,033,000	
Landslide	150	250,050	10,500
Gravel, sand	23	37,510	
Fs, Si, clay	128	212,540	
Reservoir			
No. 1 south	736		
No. 2 north	379		
Buttermilk valley			
Simple denudation	6600		66,000,000
Basin sediment loss	6979		
Gravel denudation	330		3,300,000
Gravel terraces and bars			570,000 (1m) 1,140,000 (2m)
Fs,Si,Cl denudation	5610		56,100,000

denudation rate and sediment distribution, the volume of each available size can be calculated and a transport rate determined.

Volume of gravel available is:

$$66{,}000{,}000 \text{ m}^3 \cdot 0.05 = 3{,}300{,}000 \text{ m}^3$$

Gravel available per year for transport is:

$$6600 \text{ m}^3\text{yr}^{-1} \cdot 0.05 = 330 \text{ m}^3\text{yr}^{-1}$$

There is temporary storage of gravel in the bars and the low-active terrace systems. The gravel stored in a one meter thick section is: 570,000 m^3; and in a two meter section: 1,140,000 m^3.

A comparison of all the derived gravel transport rates reveals that: 1) The gravel bar migration rate plus volume deficit rate agrees quite well with the amount of gravel provided by simple gravel denudation.

The bar migration rate is low because it is based on movement of large clasts only. More information is needed on small-clast movement. 2) The amount stored in the bar and terrace system is about 20-35 percent of that made available by denudation per year. This material is recycled at an unknown rate, but the volume deficit for bar complex 4-6 may be a good indication of rate. If so, then there is a gravel deficit that must be up from more gravel-rich units upstream in Buttermilk or in the tributaries.

Suspended Sediment Transport

Utilizing the simple denudation rate and the selected grain-size distribution of till, the fine-grained material available per year can be calculated.

Volume of fine sand, silt and clay available is:

$$66{,}000{,}000\ \mathrm{m}^3 \cdot 0.85 = 56{,}100{,}000\ \mathrm{m}^3$$

Fine sand, silt and clay available for transport is:

$$6600\ \mathrm{m}^3\mathrm{yr}^{-1} \cdot 0.85 = 5610\ \mathrm{m}^3\mathrm{yr}^{-1}$$

The cumulative suspended-sediment discharge of the October 25-26, 1980 event (one year storm), a conservatively calculated value, was 67 percent of the simple yearly suspended-sediment denudation rate. Because fine-grained material is transported even during small floods, and most gravel is not, the total yearly transport of fine-grained material appears to balance that estimated to be eroded from the Buttermilk-Bond reach plus an added, unmeasured contribution from the tributaries and upper Buttermilk Creek. Additional information is needed on the tributary contribution, particularly the Frank's Creek drainage.

Sediment Loss in the Buttermilk Drainage Basin

A sediment loss value derived for the reservoir drainage basins can be applied to the total Buttermilk drainage basin with the understanding that the relationship of sediment loss to basin area may not be linear.

Reservoir No. 1 (South). The volume of fill, including delta plain to cross-profile 9/22, is: 12515 m^3 (Fig. 9B). Infill has occurred from 1963 to 1980 (17 yrs).

Volume of infill per year is:

$$\frac{12515\ \mathrm{m}^3}{17\ \mathrm{yrs}} = 736.2\ \mathrm{m}^3\mathrm{yr}^{-1}$$

The drainage basin of the south reservoir is 806.8 ha. A simple calculation of amount of sediment supplied per year per unit area indicates a sediment loss rate in the drainage basin (Gregory and Walling, 1973).

Drainage basin sediment loss per hectare per year is:

$$\text{South reservoir: } \frac{736.2\ m^3yr^{-1}}{806.8\ ha} = 0.91\ m^3ha^{-1}yr^{-1}$$

The average of both reservoir basins is: $0.89\ m^3ha^{-1}yr^{-1}$.

Buttermilk Creek. The sediment loss per unit area per year in the Buttermilk drainage basin is:

$$7841.5\ ha \cdot 0.89\ m^3ha^{-1}yr^{-1} = 6979\ m^3yr^{-1}$$

The sediment loss result compares well with the simple denudation rate (Table 1). The larger value is to be expected because it includes the tributary and upper Buttermilk Creek sediment contribution.

HOLOCENE LANDSCAPE EVOLUTION

Tributary Development

The larger tributaries of Buttermilk Creek are inherited from the late-glacial and early Holocene drainage systems. The segments of the tributaries aligned parallel to Buttermilk Creek originally flowed as separate streams down the 3 m km^{-1} paleoslope toward Cattaraugus Creek. These parallel segments are now entrenched and link with upper drainages that are incised within, or at the margin of, the Holocene alluvial fans of Lafleur (1979).

Some of the smaller tributaries head in the uplands adjacent to Buttermilk, but others began as small fans on the Buttermilk valley wall. Headward erosion of the upper drainage results in incision of the Lavery till plateau. Stream capture, such as may have occurred to the Frank's/Erdman system, can redirect stream patterns and result in rejuvenation due to lowered base-level.

Figure 3 illustrates a range of gradients of longitudinal profiles of streams in the Buttermilk basin from the steep BC-3 alluvial fan, to the lower-gradient Buttermilk Creek. The middle example, Frank's Creek, can be subdivided into morphologically distinct segments above and below the knickpoints of the Erdman Creek section. The valley above the knickpoints is not being actively incised at the present time. The valley walls appear to have mass-wasted, either by earthflow or soil creep, onto the valley bottom. The flat floor of the valley is not composed of gravel terraces, but consists of hummocky till with tension cracks. The incision will resume as the knickpoints progress up the valley.

Erdman Brook, below the knickpoints, and Frank's Creek are undergoing active incision resulting in an extreme V-shaped cross-profile. Terraces are rare along the Frank's Creek segment, but do exist along Erdman Brook. A small fan-shaped bar complex is present at the mouth of Quarry Creek, perhaps the forerunner of a terrace array. The reason for the steeper gradient along this section is unclear. As downcutting continues, both Frank's and Erdman valleys can be expected to widen by parallel retreat of slopes due to slumping of wall material and rapid removal by flood events.

Future Evolution

The base-level of Buttermilk Creek is controlled by the elevation of Cattaraugus Creek at the Buttermilk confluence. The Cattaraugus is entrenched in bedrock about one-half kilometer below the confluence, as is Buttermilk near the Bond Road bridge (Figs. 1,2,8). The bedrock retards downcutting of the active channel which in turn results in a decreased gradient and a decrease in sediment transport capacity. The effect of the bedrock temporary base-level is not yet reflected in the gradient of Buttermilk Creek and is interpreted not to be important over the 'middle' term (tens to hundreds of years).

We believe that tributary lowering and widening will occur somewhat independent of the lowering of Buttermilk Creek. The convex profile of Frank's Creek/Erdman Brook is interpreted to mean that it is unstable and will be subject to continued downcutting and widening even if the base-level at the confluence does not change. At some future date, as yet undetermined, a combination of tributary widening, alluvial-fanhead incision, and drainage capture will encroach on the waste-burial site and it will be destroyed.

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REFERENCES CITED

Boothroyd, J.C., Timson, B.S., and Dunne, L.A., 1981, Geomorphic processes and evolution of Buttermilk Valley and selected tributaries, West Valley, NY: Final report (phase II), Fluvial system and erosion study, low-level nuclear waste burial site, West Valley, NY; NY State Geological Survey, 68 p. plus appendices, 10 plates.

Boothroyd, J.C., Timson, B.S., and Dana, R.H. Jr., 1979, Geomorphic and erosion studies at the Western New York Nuclear Service Center, West Valley, NY: US Nuclear Regulatory Commission Technical Report NUREG/CR-0795 (NYSGS/79-2406 RE,RW), 66 p.

Boothroyd, J.C., and Ashley, G.M., 1975, Processes, bar morphology, and sedimentary structures on braided outwash fans, northeastern Gulf of Alaska: p. 193-222 in Jopling, A.U., and McDonald, B.C. (eds.) Glaciofluvial and glaciolacustrine sedimentation, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 23, 320 p.

Coates, D.G., 1976, Quaternary Stratigraphy of New York and Pennsylvania, in Mahaney, W.C. (ed.), Quaternary stratigraphy of North America; Dowden, Hutchinson, and Ness, Inc., Stroudsberg, Pennsylvania.

Dana, R.H. Jr., Fakundiny, R.H., Lafleur, R.G., Molello, S.A., and Whitney, P.R., 1979, Geologic study of the burial medium at a low-level radioactive waste burial site at West Valley, New York: New York State Geological Survey Final Report NYSGS/79-2411, to US Environmental Protection Agency, 70 p.

Dana, R.H. Jr., Ragan, V.S., Molello, S.A., Bailey, H.H., Fickies, R.H., Fakundiny, R.H., and Hoffman, V.C., 1980, General investigation of radionuclide retention in migration pathways at the West Valley, New York low-level burial site, Final Report, 1978-1980: US Nuclear Regulatory Commission Technical Report NUREG/CR-1565 (NYSGS/24.01.029, RE,RW), 140 p.

Gregory, K.J., and Walling, D.E., 1973, Drainage basin form and process: John Wiley and Sons, New York, 458 p.

Hoffman, V.C., Fickies, R.H., Dana, R.H. Jr., Ragan, V., 1980, Geotechnical analysis of soil samples and study of a research trench at the Western New York Nuclear Service Center, West Valley, NY: US Nuclear Regulatory (NYSGS/24.01.030, RE,RW), 70 p.

Lafleur, R.G., 1979, Glacial geology and stratigraphy of Western New York Nuclear Service Center and vicinity, Cattaraugus and Erie Counties, New York: US Geol. Survey Open-file Report 79-989, 17 p.

Lafleur, R.G., 1980, Late Wisconsin stratigraphy of the upper Cattaraugus basin: Guidebook for 43rd annual reunion, Northeast Friends of the Pleistocene, 64 p.

Muller, E., 1977, Quaternary geology of New York, Niagara sheet: New York State Geol. Survey Map 28.

Prudic, D.E., 1979, Recharge to low-level radioactive-waste burial trenches 11 through 14, West Valley, New York: US Geol. Survey Open-file Report 79-990, 5 p.

Prudic, D.E., and Randall, A.D., 1979, Groundwater hydrology and subsurface migration of radioisotopes at a low-level solid radioactive-waste disposal site, West Valley, New York: p. 853-882 in Carter, M.W., Moghissi, A.A., and Kahn, B., eds., Management of low-level radioactive waste, v. II, Pergamon Press.

Smith, N.D., 1970, The braided stream depositional environment, comparison of the Platte River with some Silurian clastic rocks, north-central Appalachians: Geol. Soc. America Bull., v. 81, p. 2993-3014.

US Geological Survey, 1962-68a. Surface water records for New York, 1962-68a: Water resources data for New York.

US Geological Survey, 1968b. Buttermilk Creek near Springville, NY, Flood of Sept. 28, 1967, contraction measurement: US Geol. Survey open file report, 42 p.

ROAD LOG

Itinerary

The trip will consist of an overview and orientation stop; a stop to park vehicles and assemble for the rest of the field trip; and one very long stop that will be a walking tour of selected features. We will cover 4-5 km on foot, including several stream crossings and a climb up and down steep slopes. Water depths may be ankle to knee deep depending on stream discharge. Plan to have wet feet or wear hip boots. We will be on NY State property adjacent to a nuclear reprocessing and waste-burial facility; prior permission to enter the property must be obtained.

Distance (in miles)		Route and Stops
Pt. to pt.	Cum.	
	0.0	Start at Buffalo Marriott Inn parking lot. Turn right onto US 263 south (Millersport Highway).
0.3	0.3	Turn right onto I-290 east. I-290 merges into I-90 (NY Thruway). Follow signs for: Thruway Westbound, Erie).
11.4	11.7	Exit 55. Exit right to US 219 south, Orchard Park, Springville.
23.8	35.5	Expressway ends at junction of US 219 south and NY 39 near Springville. Turn left and proceed east on NY 39.
0.2	35.7	Turn right onto US 219 south.
2.7	38.4	Cross bridge over Cattaraugus Creek gorge, go 200 meters, turn left on Rock Springs Rd.
2.9	41.3	West Valley Nuclear Service Center (WVNSC) entrance. Continue southeast on Rock Springs Rd.
0.3	41.6	Stop on Rock Springs Rd. for overview of WVNSC and associated waste-burial trenches.

STOP 1. Overview of the West Valley Nuclear Service Center. The buildings housing the nuclear fuel reprocessing facility are to the

left, waste-burial trenches are to the right. The land and buildings inside the high-security fence are owned presently by the U.S. Dept. of Energy and operated for them by the Westinghouse Corp. Westinghouse is carrying out the West Valley Demonstration Project, a program to solidify the high-level liquid waste stored on site, for later isolation in a still-to-be chosen facility. The NRC-licensed intermediate-level burial trench (left) is also operated by Westinghouse; the low-level trenches (right) are owned by the NYSERDA and are no longer accepting waste material.

The buildings are situated on an early Holocene alluvial fan; the waste-burial trenches are excavated in late Woodfordian Lavery till (Lafleur, 1979). The plateau containing the trenches marks the surface elevation of Buttermilk valley in early post-glacial time. The plateau beyond the trenches is covered by a thin veneer of fluvial gravel deposited in the ancestral late-glacial to early post-glacial Buttermilk Creek. Initial incision and downcutting began sometime before 9900 BP (Fig. 8), and continues to the present. The field trip discussion will focus on the manner and rate of erosion that will, in time, remove the plateau, and with it the waste-burial trenches.

0.2	41.8	Old schoolhouse at junction of old Buttermilk Creek Rd.
0.2	42.0	Turn left on Thornwood Drive. Proceed toward the hamlet of West Valley.
1.1	43.1	Look for south reservoir in valley on the left.
0.1	43.2	Turn left on Fox Valley Rd. Cross Baltimore and Ohio railroad tracks.
1.0	44.2	Turn left on NY 240 north. Go to hamlet of Riceville.
0.1	44.3	Turn left on Buttermilk Rd. Dead end.
0.8	45.1	New York State Plutonium Storage Facility. End of paved road. STOP. Obtain prior permission to proceed on dirt road. CAUTION. This road is rough and steep. Trucks and/or 4 WD vehicles needed in wet weather. Go downhill and cross B & O RR tracks.
0.4	45.5	Old Buttermilk Rd. and B & O RR work road. Watch for trains, this is a well-traveled way.

STOP 2. Assembly point. Park vehicles so they do not block the B & O work road or access up and down the hill. Old Buttermilk Hill Rd. continues to Buttermilk Creek (100 m), the bridge has been removed. The surveyed section (Buttermilk-Bond reach) begins at the former site of the bridge and extends downstream to the north. Reservoir slug discharge enters from the west just below the bridge site.

	0.0 km	Walk north along the B & O RR tracks. Pass section of double track.
0.35	0.35 km	Active channel of Buttermilk is undercutting railroad embankment. View of bar complexes and low terraces.
0.75	1.10 km	Small railroad bridge over tributary stream. Turn left (downstream) and follow stream to Buttermilk Creek.
0.10	1.20 km	Buttermilk Creek valley bottom.

STOP 3. Gravel-bar complexes, valley-wall landslides and alluvial fans, and Buttermilk fluvial terraces. The tributary stream enters Buttermilk Creek at bar complex 6, opposite the BC-6 landslide (Fig. 7). Extending 250 m upstream, to your left or south, is the BC 4-6 bar complex (Fig. 5). Just upstream of BC 4-6 is the BC-3 alluvial fan, situated on the west wall of the valley (Fig. 6). Fluvial terraces at several levels are preserved on the east side of the valley at the BC-6 tributary and on the west side adjacent to the BC-3 alluvial fan (Fig. 8). We shall discuss each of these features in turn, including gravel movement on the bars (Fig. 12). Please take care not to disturb any of the painted clasts.

Return up the tributary and along RR tracks to the vehicles. End of trip.