Syracuse Meltwater Channels

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INTRODUCTION

The channels carved by Pleistocene meltwater through the Syracuse area tell an interesting and complicated story. Their discharge, which rivaled Niagara's, spilled over waterfalls having the plan dimensions of Horseshoe Falls.

Examined in detail, the channels are determined to be products of multiple episodes of cutting, infilling, and reexcavation that collectively span several glacial epochs. The most recent history is complex, because the simple south-to-north activation sequence that has been preferred in the past, turns out to have been impossible. In its place is emerging a new sequence that involves piecemeal flushing of our most spectacular channel, multiple occupation of another, a minor ice readvance in late Pleistocene time, and catastrophic release of water from a large proglacial lake when a 100-ft drift dam failed.

The purpose of this trip will be to view the topographic features which document an ample flow of quantities of meltwater through the Syracuse area in late glacial time. It will focus, however, on the evidence for reinterpretations of the type previously mentioned. Observation will blend into inference, and inference into speculation. However, sufficient opportunities will be available for challenging the more outrageous claims that your leader, in the end, should not get away with too much sleight-of-Hand.

Regional Setting

Syracuse is located along the northern margin of the Appalachian Plateau where this province meets the Ontario Lowland. The Plateau is divided locally into segments by major north-south "through" valleys originally cut by streams flowing southward from somewhere north of the present Plateau margin. When glaciers invaded the region, these "through" valleys provide favorably oriented avenues for thick ice tongues and so became widened, deepened, and modified into U-shaped troughs. During deglaciation the troughs received deposits of till, outwash, lake clays, and delta sediments.

Some 12,000 yrs ago, as the ice withdrew from the Valley Heads Moraine (12 mi south of Syracuse), portions of the "through" valleys were occupied by elongate "finger" lakes. These lakes were filled with meltwater dammed by the Valley Heads Moraine and unable to escape northward because of ice in the Ontario Lowland. Initially, the lakes spilled southward across the moraine and into the Susquehanna drainage system. However, by the time the ice front had retreated to within 5 mi of downtown Syracuse, meltwater collected from much of central New York had begun to escape eastward along the ice margin and into the Mohawk Valley. Onondaga Trough (the "through" valley extending south from Syracuse; see Fig. 1) received substantial meltwater drainage from the west and discharged it, in turn, through any of several cross channels into a second, smaller lake in Jamesville Trough (=Butternut Trough). From there, the flow continued eastward across Moorehouse Flats or through High Bridge (=White Lake) Channel into a third lake in Fayetteville-Manlius Trough (=Limestone Trough).

SEQUENCE OF CHANNEL ACTIVATION

Smoky Hollow

The cross channels through which meltwater drained from Onondaga Trough Lake eastward into Jamesville Trough are shown in Figure 1. Southernmost of these channels is Smoky Hollow, a steep-walled gorge incised 100 ft into Hamilton Shale. A distinctive feature of this particular channel is an ingrown meander loop with neck cutoff isolating an umlaufberg. Inset till deposits show that Smoky Hollow originated prior to the last glaciation, but became filled with till during glacial advance and was subsequently reopened by meltwater drainage during deglaciation. Certain other cross channels (notably Poolsbrook Channel, an outlet for Fayetteville-Manlius Trough) also contain inset till deposits. Indeed most, if not all, of the Syracuse channels are presumed to have had similarly complex histories, although positive proof may be lacking.

When reexcavation of Smoky Hollow began, the surface of Onondaga Trough Lake stood at about 880 ft (Table 1). Flushing of drift from Smoky Hollow entailed a 90-ft drop in the level of Onondaga Trough Lake, bringing it to the present channel floor elevation of 790 ft. Delta gravels at the eastern end of Smoky Hollow resulted from flow into Jamesville Trough Lake, which at that time must have been about a mile wide and a little more than 4 mi long. Elevation of the lake surface was 800 ft, controlled by a spillway across Onondaga Limestone at Moorehouse Flats, 1 mi east of Jamesville.

Clark Reservation Channel

Smoky Hollow was abandoned once the ice margin had retreated to a position just north of Route NY173, and Clark Reservation Channel became active. The approach to Clark Reservation Channel was across a bedrock threshold at 770 ft (scoured clear of drift) and over a double waterfall. The water drop 30 ft over the first step, then plunged 100 ft into a great amphitheater-like basin now occupied by Green Lake, 57-ft deep. The 770-ft sill held the level in Onondaga Trough Lake nearly as high as it had been during the Smoky Hollow stage. However, the lake in Jamesville Trough by now must have dropped 160 ft, bringing it to the 600-ft level. (Otherwise, the main waterfall at the head of Clark Reservation Channel could not have functioned.) This implies that the outlet for Jamesville Trough Lake was no longer across Moorehouse Flats, but through High Bridge Channel (which must have been substantially cleared by then) and into a

Table 1. Proposed summary of major late Pleistocene drainage events, Syracuse area

Elevation of Onondaga Trough Lake (ft)	Drainage phase	Reason for diversion	Elevation of Jamesville Trough Lake (ft)	Outlet from Jamesville Trough Lake	Reason for diversion
1200	Primitive. Drainage southward across Tully loop of Valley Heads Moraine		1250	Southward across Jamesville Trough loop of Valley Heads Moraine	
880 to 790	Smoky Hollow	Ice retreat	760	Moorehouse Flats	Ice retreat
770	Clark Reservation	Ice retreat	600	High Bridge Ch.	Ice retreat
	Rock Cut (I)	Ice retreat	"	"	
760	(a) Trailer park plunge basin				
730	(b) Western plunge basin		"	"	
700	Nottingham Ch. (early)	Ice retreat	"	"	
560	Meadowbrook Ch.	Ice retreat	510(?)	Lyndon Ch. (?)	Ice retreat
700	Nottingham Ch. (late)	Re-advance of ice	600	High Bridge Ch.	Re-advance of ice
Catastrophic drop to 600	Rock Cut (II)	Failure of drift dam in Rock Cut	"	"	
550	Rock Cut (Rams Gulch)	Ice retreat	No lake; Channel drainage at 430	Northward to Lake Iroquois	Ice retreat
420	Erie Canal Ch.		(Dry)		

Unless otherwise noted, water levels reported in this paper are present elevations of spillways. They do not take account of flow depths across spillways, and are not corrected for post-glacial isostatic adjustments.

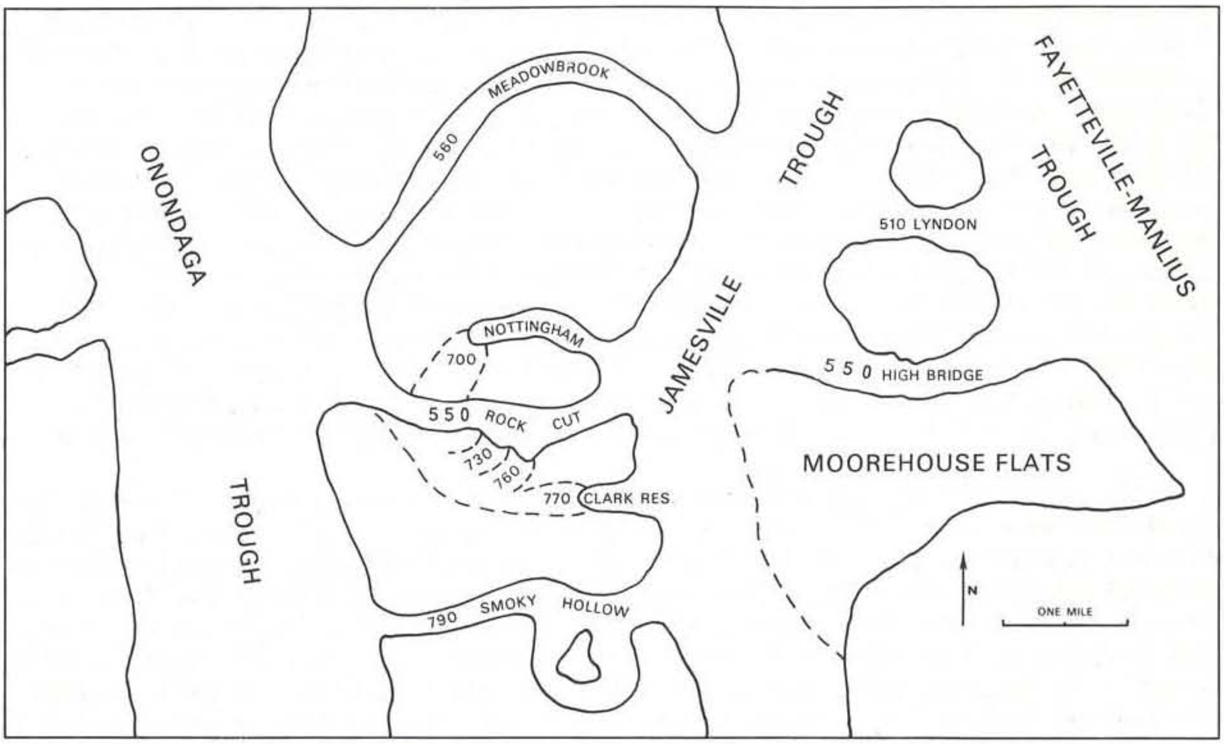

Figure 1. "Through" valleys, cross channels, and threshold elevations between Onondaga Trough and Fayetteville-Manlius Trough. 760 and 730 on south wall of Rock Cut apply to "trailer park" and "western" plunge basins, respectively.

lake in Fayetteville-Manlius Trough. The 600-ft base level seems to have been provided by Poolsbrook Channel (present floor elevation 580 ft) which extends eastward from Fayetteville.

Rock Cut and Nottingham Channels

The next two channels farther north are Rock Cut and Nottingham Channels. It is clear that in their present form they postdate Clark Reservation Channel, but their relationship to one another is more problematic. Free drainage through Rock Cut (threshold at 550 ft) would have precluded later activation of Nottingham Channel which is farther north and accessible only across a sill at 700 ft. On the other hand, assigning Rock Cut a younger age than Nottingham violates the simple, south-to-north activation sequence that has been favored by most previous workers. One tactic has been to ignore Nottingham Channel altogether by assigning it entirely to an earlier interglacial epoch, but this is unacceptable in view of the fresh, well-developed plunge basin which occurs at the head of the channel. Alternatively, Nottingham Channel may have been carved not by through drainage, such as accounted for the other cross channels, but by off-ice or even sub-ice drainage unrelated to the lake in Onondaga Trough. Sissons (1960) has shown that certain of the smaller channelways in the Syracuse area were cut by waters flowing into or off of the ice itself. Such an explanation seems untenable in the present situation, however, because the shape of Nottingham Channel suggests inflow from the south, in size and form it resembers the other channels; the channel below the plunge pool is graded to the same 600-ft level as the Clark Reservation Channel, and the 700-ft access route is underlain by bedrock largely scoured free of till. Locally, the bedrock surface retains remnants of fluvial gravels deposited by the flow as it approached Nottingham Channel from the south.

An alternative interpretation, defended here, was proposed originally by Muller and Hand (1972) and Hand and Muller (1972). It argues that Rock Cut was opened in two stages, that flow through Nottingham Channel occurred between Stages I and II of Rock Cut, and that Stage II (final flushing of Rock Cut) involved catastrophic discharge from Onondaga Trough Lake. How the opening of Meadowbrook Channel fits into this sequence of events (Table 1) will be ignored here, but discussed in a later section. I will presume throughout that all the major channels existed in essentially their present form prior to the last glacial episode, and that what we are concerned with here is principally the history of reexcavation through flushing of drift fill. Of course this is not to deny bedrock scour or waterfall migration during the events that led to the channels' final form, but rather to emphasize that only minor carving of bedrock need have occurred in latest Pleistocene time.

The transition from Clark Reservation Channel to Stage I of Rock Cut was sloppy. Scour features and the absence of till across most of the upland surface between these channels indicate that abandonment of Clark Reservation Channel was gradual, as increasingly the flow was diverted northward, banked against the retreating ice front and shifting northward with it. When the flow "discovered" Rock Cut, it again became channelized, flushing unconsolidated drift fill from the eastern end of Rock Cut, at least to the 600-ft base level which prevailed yet in the Jamesville

Trough. However, it was only the eastern half of Rock Cut that was opened at this time. Rather than following Rock Cut for its entire length, the flow spilled in over the south wall (Fig. 2A). The best evidence for this is a pair of plunge basins incised into the south wall, about midway along Rock Cut. The more easterly of these plunge basins is a beautifully preserved amphitheater now occupied by a trailer park which occasionally is bombarded by blocks of limestone dislodged from the rim. The second plunge basin (immediately to the west) has been disfigured badly by quarrying operations, but its original form can be seen on topographic maps and early air photos. Rock thresholds in the approaches to these two extinct waterfalls are 760 ft and 730 ft, respectively.

Topographic constraints require that when the Rock Cut plunge basins were active, drainage from Onondaga Trough Lake passed for a short distance along the (buried) western end of Rock Cut, but then was deflected south of the gorge before entering by spilling over the south wall (Phase I of Rock Cut). This requires a barrier across Rock Cut about midway along its length. Indeed, for as long as the trailer park plunge basin was active, this barrier must have extended across the site of the second plunge basin (not yet activated). The probable composition of this barrier was drift. One alternative would be ice, but that seems unlikely because a portion of the barrier had to remain in place until after the ice margin had retreated to north of Nottingham Channel. A second alternative would be bedrock. However, this would indicate that the whole western half of Rock Cut (about 1 mi in length) is a first-generation channel. The following considerations argue against such a model:

(1) Inset till deposits along the south wall at the west end of Rock Cut imply that the channel predates the last glacial advance.
(2) The bedrock hypothesis would require nearly a mile of headward channel extension by waterfall migration in less time than it took the ice front to retreat 1000 ft. Such a phenomenal rate of bedrock excavation seems entirely out of line with the behavior of other waterfalls in the area. Taking Niagara Falls as a model, a mile of channel extension would have required about 1700 yrs.
(3) Sudden release of large quantities of water from Onondaga Trough Lake (indicated by other observations) seems more compatible with failure of a drift dam than with through-cutting of bedrock.
(4) Although the delta deposits that resulted from flushing of Rock Cut are composed largely of local bedrock clasts, exotics are also present. (Glacial drift in the Syracuse area is composed principally of clasts derived from local bedrock.)

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A drumlinoid deposit seems reasonable if only because the locality happens to be on the southern edge of a large field of drumlins.

Many drumlins in the Syracuse area seem to have been localized by bedrock highs. It is interesting in this regard that small bedrock knobs are located on both sides of Rock Cut immediately west of the second plunge basin, and that a chord between them would be nearly aligned with axes of nearby drumlins.

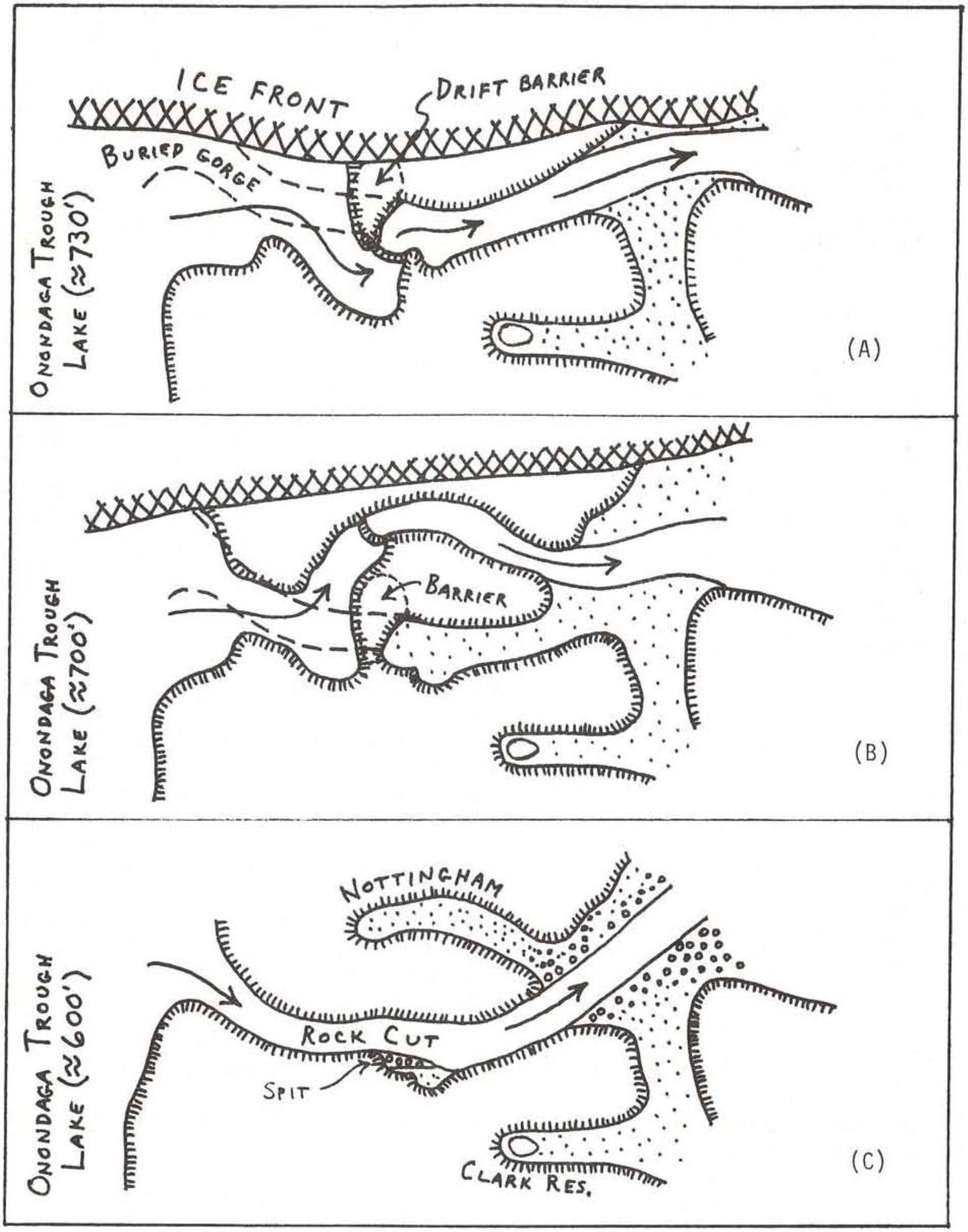

Figure 2. Evolution of drainage routes leading to the (re-)excavation of Rock Cut and Nottingham Channels. (A) Early Rock Cut phase, western plunge basin active. (B) Nottingham phase. (C) Late Rock Cut phase.

Without a barrier in the position described, the point at which the flow entered Rock Cut would have shifted rapidly along the south wall until the channel was clear of drift. This did not happen. Rather, the flow was diverted northward (across the buried western portion of Rock Cut) to Nottingham Channel when that route became free of ice. This diversion gained some 40 ft of vertical advantage and caused abandonment of the plunge basins on the south wall of Rock Cut.

While Nottingham Channel was active (Fig. 2B), the postulated drift barrier must have been extremely vulnerable to headward sapping by gullies fed, in part, by seepage through the barrier. In time, the barrier was breached, releasing catastrophic flow through the entire length of Rock Cut. Initially, this discharge through Rock Cut flowed for 2000 ft over unconsolidated drift with a gradient of 6 or 7 percent. Behind this flow was Onondaga Trough Lake, with an area of 24 sq mi, whose surface fell 100 ft as Rock Cut was flushed. For every foot of downcutting in Rock Cut, another 15,000 acre-ft of reservoir volume was tapped in addition to the normal through drainage. Conditions were right for catastrophic failure, which cleared Rock Cut for its entire length to the 550-ft level (Fig. 2C).

In the terminology of Thorarinsson, a limnic hlaup had occurred.

Depositional evidence for major flow through Rock Cut included a boulder spit (pendant bar) constructed across the two plunge basins on the south wall of Rock Cut. Individual blocks in the spit measure up to 8 ft in length. Where the deposit has been truncated artificially at Cliffside Trailer Park, crossbedding shows that the spit widened by accretion back into the plunge basins while extending itself lengthwise. The top of the spit stands at an elevation of 640 ft, 90 ft above the present bedrock floor of Rock Cut.

At the eastern end of Rock Cut are remnants of a large (1 x 2 mi) delta (expansion bar) consisting of boulder gravels deposited where the catastrophic flow from Rock Cut expanded into the northern end of Jamesville Trough (Fig. 3). A portion of this delta forms a levee-like closure across the eastern end of Nottingham Channel. Thrivikramaji (1977) has shown that as this deposited is traced into Nottingham Channel (which at the time must have been a backwater area) it grades from boulder gravels to sand.

Boulders in the Rock Cut delta usually are 1 to 3 ft in length. Many of the largest clasts (exceeding 6 ft in length) were swept entirely across Jamesville Trough to the most distal (and highest) part of the delta. Some examples will be seen displayed as ornaments in the front yard of homes along Cedar Heights Drive.

The eastern margin of the Rock Cut delta is thought to be the original depositional slip face. Excavations west of Maple Drive (just north of Woodchuck Hill Road) have revealed angle-of-repose, delta-front crossbeds immediately beneath (and parallel to) the present face. At this locality, most of the material composing the deposit is pebble gravel, but a basal layer rich in very large boulders is present. This basal layer, whose clasts resemble the large boulders seen on top of the delta, is interpreted as having formed from over-large fragments which were swept to the lip of the delta and then rolled to the bottom of the slip face.

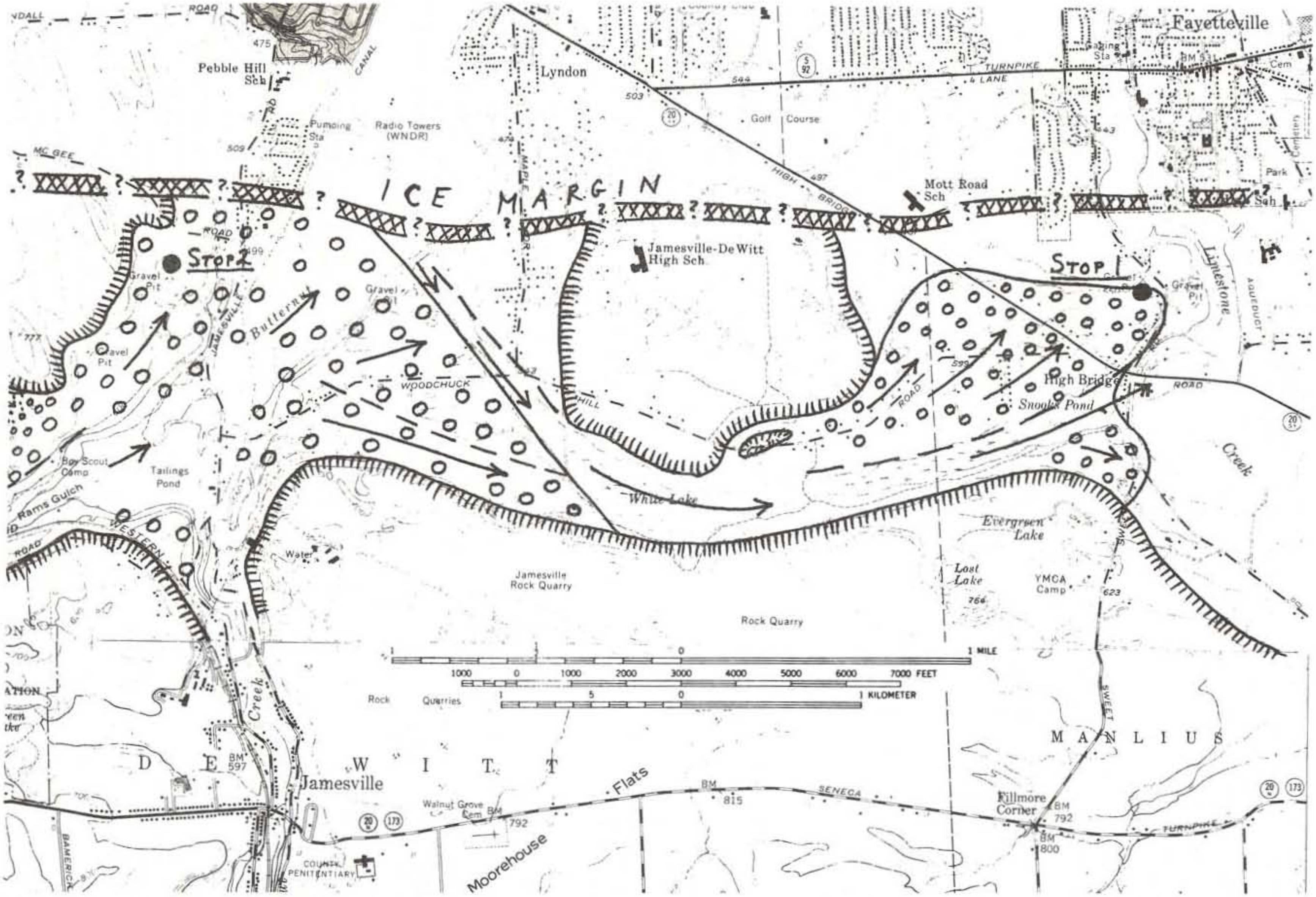

Figure 3. Rock Cut Channel and Delta during period of catastrophic discharge (Stage II of Rock Cut drainage).

Immediately east (in front of) of the delta deposits just described, limestone bedrock has been scoured bare. This is attributed to intense vorticity related to flow separation and reattachment in the lee of the delta. Indeed, it may be that helical flow confined between the advancing delta front and highlands east of Jamesville Trough ultimately limited forward growth of the deposit.

After discharging as a planar jet across the lip of Rock Cut delta, the flow was redirected southeastward parallel to the delta margin, following a southeasterly expanding scourway into High Bridge Channel. By this route, the flow traveled from Jamesville Trough to a lake in Fayetteville-Manlius Trough, where it built High Bridge Delta, another expansion bar similar in most repsects to Rock Cut Delta (Fig. 4). The deposits of High Bridge Delta will be seen in a gravel pit. Except for minor erosion by Limestone Creek, the morphology of High Bridge Delta is interpreted as primary. The deposit is divided into two unequal parts by a channelway 1000 ft wide and 70 ft deep which seemingly carried most of the discharge in the brief period during which the delta was constructed. The delta and scour levels near 600 ft elevation were adjusted to the same flow that deepened the floors of Rock Cut and High Bridge Channels to 550 and 530 ft, respectively, implying water depths of 70 to 80 ft in the more restricted portions. Such flow could have been sustained only by catastrophic release of water from Onondaga Trough Lake, an event whose duration probably was measured in hours.

Meadowbook Channel

The threshold of Meadowbrook Channel stands at 560 ft. Although this is higher by about 10 ft than the floor of Rock Cut, it would not necessarily preclude simultaneous occupation of both channels, provided both channels had achieved their present form. However, the level floor and uniform width of Meadowbrook Channel, and truncation of drumlins by the north wall, suggest that some indeterminate thickness of till has been removed from Meadowbrook by cross channel flow. If so, then flow through Meadowbrook must have been initiated across a higher threshold than exists today. It follows that Rock Cut could not have been fully open when Meadowbrook (farther north) became active. In other words, Meadowbrook must predate clearing of the west end of Rock Cut (Rock Cut Phase II), although it almost certainly followed Phase I of Rock Cut (south wall plunge basins) and probably the Nottingham phase.

However, if we accept the constraint that flushing of Meadowbrook Channel must predate Stage II of Rock Cut drainage, it seems equally clear that the catastrophic flushing of the western end of Rock Cut (initiating Phase II) could not have been forced so long as Meadowbrook was open. This combination of requirements in fact seems impossible to satisfy without invoking a minor readvance of ice. With readvance, however, it becomes possible to view the Meadowbrook drainage phase as a brief interruption in the sequence of events described in the previous section as leading to catastrophic flushing of Rock Cut. In this scenario, ice retreat led to the succession: Rock Cut I, Nottingham, Meadowbrook. Readvance (probably expressed as tongues of ice advancing down Onondaga Trough and other

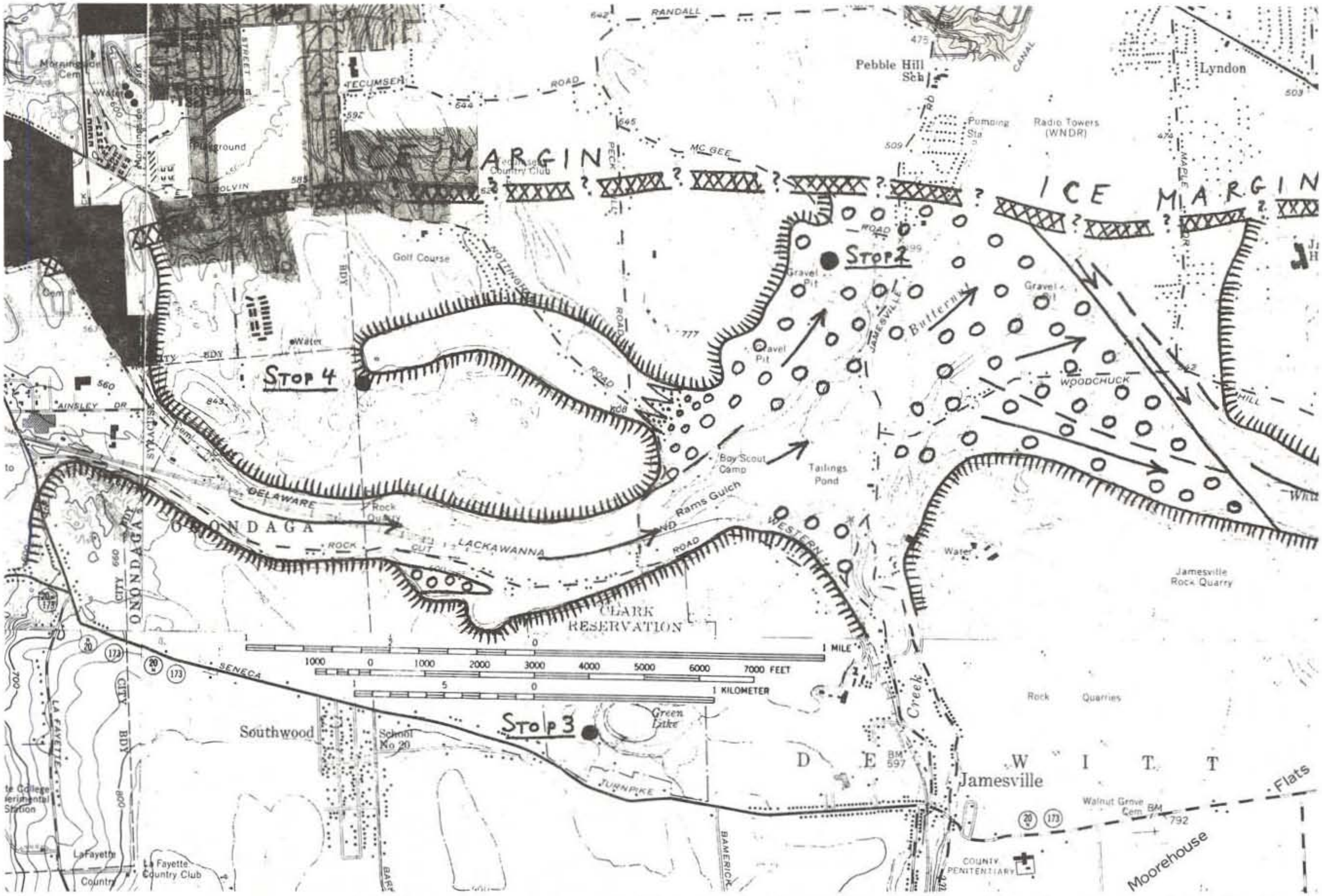

Figure 4. Rock Cut Delta, High Bridge Channel, and High Bridge Delta during period of catastrophic discharge (Stage II of Rock Cut drainage).

"through" valleys) then closed off access to Meadowbrook and forced reoccupation of Nottingham Channel until failure of the drift dam initiated Phase II of Rock Cut drainage.

Evidence of such readvance was uncovered recently in highway excavations at the west end of Rock Cut. There, varved lake clays (representing perhaps 100 yrs) directly overlie bedrock and the clays in turn are overlain by till or flowtill. The locality would have been directly in line with the approach to Meadowbrook Channel, so absence of till beneath the lake clays might well be attributable to scouring by the discharge from Onondaga Trough Lake as it approached Meadowbrook. (Indeed, such scour could have removed a significant amount of the drift plug that still clogged the west end of Rock Cut.) When access to Meadowbrook had become blocked fully by the advancing ice, Onondaga Trough Lake rose again to the 700-ft level and lake clays (containing dropstones) accumulated where scour had previously occurred. Presence of flowtill and till(?) above the clays indicates that the ice tongue ultimately extended at least as far as Rock Cut.

PALEOHYDRAULICS

Normal Discharge

Most, if not all of the Syracuse cross channels have been carved into bedrock by headward-migrating waterfalls. And most, if not all, have achieved their present form through repeated episodes of bedrock cutting alternating with glacial infilling and reexcavation. Their histories span several periods of glaciation and deglaciation, each perhaps with minor advances and retreats superimposed. Even within a single glacial cycle, conditions must have varied considerably. Estimating "the" normal discharge would be hazardous under the best of circumstances, but here we have the further complication that no one value can possibly reflect the actual range of conditions.

Nevertheless, the Syracuse channels are large and surprisingly uniform in character. They occur in a region where the stratigraphy is tailor-made for waterfall migration by continuous undercutting of massive capping units, reminiscent of the situation at Niagara Falls. Compared with Niagara Gorge, the Syracuse channels are only about half as deep (typically 100 ft, vs. 250 ft), but this is more a function of local baselevel controls, regional topography and details of stratigraphy than a reflection of discharge. Impressive is the fact that channel floor widths are comparable with the bottom width of Niagara Gorge (1200 ft for Rock Cut; 600-1000 ft for Niagara). Perhaps even more significant is the fact that the numerous abandoned plunge basins in the Syracuse area are nearly identical, in both shape and size, to Horseshoe Falls, which carries 90 percent of Niagara's discharge.

These observations suggest that the "normal" cross channel discharge through Syracuse rivaled that of the Niagara River at 200,000 cu ft per sec. Impressive as this may be, it can hardly account for the extremely coarse delta deposits at the east end of Rock Cut or the pendant bar composed of giant boulders 90 feet above the floor of Rock Cut. These features seem far better explained by appealing to a brief episode of catastrophic flow.

Catastrophic Discharge

Reference to Figure 2B shows that during the Nottingham phase of flow, all that prevented a 100-ft drop in lake level in Onondaga Trough was a drift barrier in Rock Cut no wider than a few hundred feet. Eventual failure of this drift barrier suddenly released some 60 billion cu ft of water through Rock Cut which swept out the remaining drift fill to bedrock at 550 ft. Dimensions of the cross channels that carried this flow (Rock Cut and High Bridge Channels) and their deltas require flow cross sections 1200-ft wide by 60 to 70-ft deep.

Upper limits can be placed on the Rock Cut flood by assuming instantaneous and complete failure of the drift dam. Although instantaneous failure is obviously impossible, the model may be approximately true viewed against the time scale of flood duration. Regardless, the assumption is useful for two reasons: (1) it greatly simplifies calculation of flood dynamics, and (2) it gives maximum values for velocity, discharge, water depth, etc., which could not have been exceeded without violating physical laws. In the end, these limiting values will be compared with flow conditions independently determined to have been required to transport the materials that were moved.

Simulation of flood dynamics presumed that Rock Cut and High Bridge Channels functioned as Venturi flumes connecting Onondaga Trough Lake, Jamesville Trough Lake, and Fayetteville-Manlius Lake (Fig. 5). Initially, the lakes in Jamesville and Fayetteville-Manlius Troughs stood at 600 ft, 100 ft below the level of Onondaga Trough Lake (700 ft). If the drift dam suddenly fails and the channels immediately assume their final geometries, the problem reduces to the draining of three interconnected bathtubs. In the model, water was assumed to escape freely from the easternmost of the three lakes (Fayetteville-Manlius), thereby maintaining its level at 600 ft. However, the lake in Jamesville Trough was allowed to rise or fall depending on the difference between inflow from Rock Cut and outflow through High Bridge Channel, taking account of the surface area of the lake at any particular stage. Meanwhile, the lake in Onondaga Trough fell at a rate that depended on its surface area, inflow from the west (the normal through drainage), and outflow through Rock Cut as estimated from available potential head and cross section of flow.

Figure 5 shows diagrammatically that either of two flow situations could have existed in a cross channel at a particular moment. When the difference in elevation between the two lakes ($H_1 - H_2$) is greater than $H_1/3$ (Fig. 5A), the second lake might as well be a free overfall. (Note that heads are measured relative to the floor of the interconnecting channel.) The cross channel under these circumstances functions as a broad-crested wier, in which water depth adjusts to 2/3 of H_1 and velocity head becomes 1/3 of H_1. Flow velocity U then can be calculated:

$$U = \sqrt{\frac{2gH_1}{3}}$$

When the two lakes differ in elevation by less than $H_1/3$ (Fig. 5B), the second lake provides a tailwater effect and potential energy available

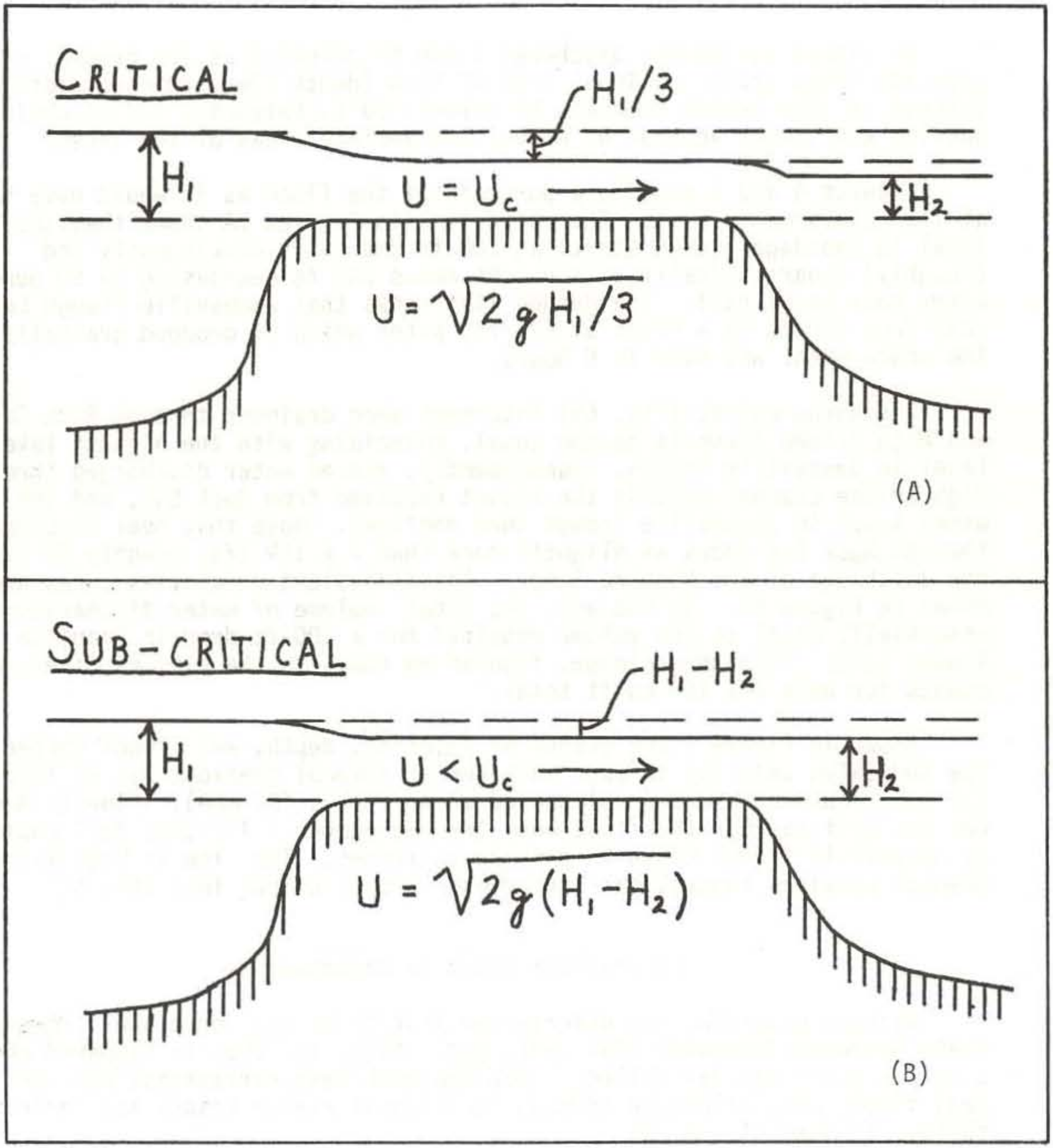

Figure 5. Alternative flow conditions for channel connecting two standing bodies of water. Channel is assumed to function as a venturi flume (broad-crested wier). A. Critical flow prevails when $H_2 \leq H_1/3$, B. Subcritical flow prevails when $H_2 > H_1/3$.

for conversion to velocity is $H_1 - H_2$:

$$U = \sqrt{2g\ (H_1 - H_2)}$$

In either situation, discharge Q can be computed as the product of velocity times cross-sectional area of flow (depth times channel width). Changes in lake levels then can be calculated by balancing inflow against outflow and taking account of prevailing surface areas of the lakes.

Figures 6 and 7 provide a portrait of the flood as it would have been at its catastrophic best. The solid line in Figures 6A shows that the lake level in Onondaga Trough starts at 700 ft and falls continuously and (roughly) logarithmically, its height above 600 ft decreasing by 50 percent every hour and a half. The dashed line shows that Jamesville Trough Lake rose from 600 ft to a crest at 625 ft, after which it dropped gradually. The whole event was over in 6 hours.

Discharge curves (Fig. 6B) intersect when drainage through Rock Cut and High Bridge Channels become equal, coinciding with the highest lake level in Jamesville Trough. Subsequently, stored water discharged through High Bridge Channel exceeds the amount received from Rock Cut, and the water level in Jamesville Trough then declines. Note that peak discharge through Rock Cut shows as slightly more than 7×10^6 cfs, roughly 35 times the discharge of the Niagara River. The equivalent cumulative cures are shown in Figure 6C. In the end, the total volume of water discharged is essentially equal to the volume required for a 100-ft drop in Onondaga Trough Lake. Through drainage, figured as equal to the Niagara River, accounts for only 4×10^9 cu ft total.

Shown in Figure 7 are graphs of velocity, depth, and Froude number. The indicated velocity through Rock Cut at time of breakout was 57 ft/sec (39 mph). White Lake Channel peaked at 40 ft/sec (27 mph). Flow in Rock Cut was critical for the first hour (Froude number = 1), then fell rapidly as Jamesville Trough began to provide tailwater. The flow in High Bridge Channel remained subcritical throughout (Froude number less than 1).

Calculations Based on Competency

Without question, the description just given is over-blown. However, field evidence indicates that there was a flood and that it happened when a narrow drift barrier failed. But how much less extravagant was the real flood, once allowance is made for natural energy losses and noninstantaneous failure of the dam.

The 6-ft boulders that occur on the highest and most distal parts of the Rock Cut delta were swept into position after climbing an adverse slope leading up from the floor of Rock Cut. Geometries of this deposit and High Bridge Delta require that while the deltas were being built, flow through the cross channels was at least 60 to 70 ft deep.

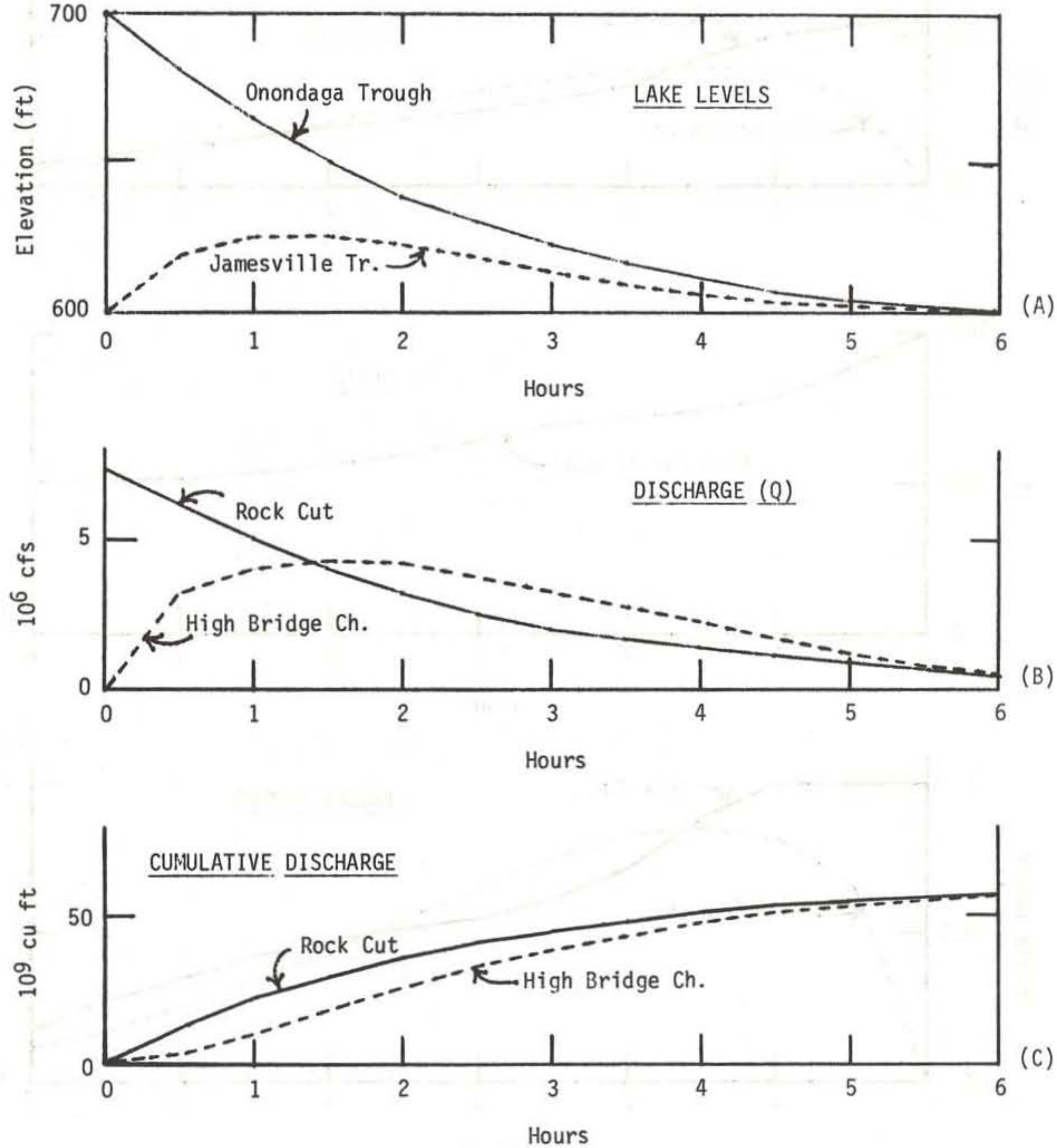

Figure 6. Lake levels, discharge rates, and cumulative discharge computed for Rock Cut flood, assuming instantaneous failure of drift dam, present geometry of cross channels, and zero flow resistance.

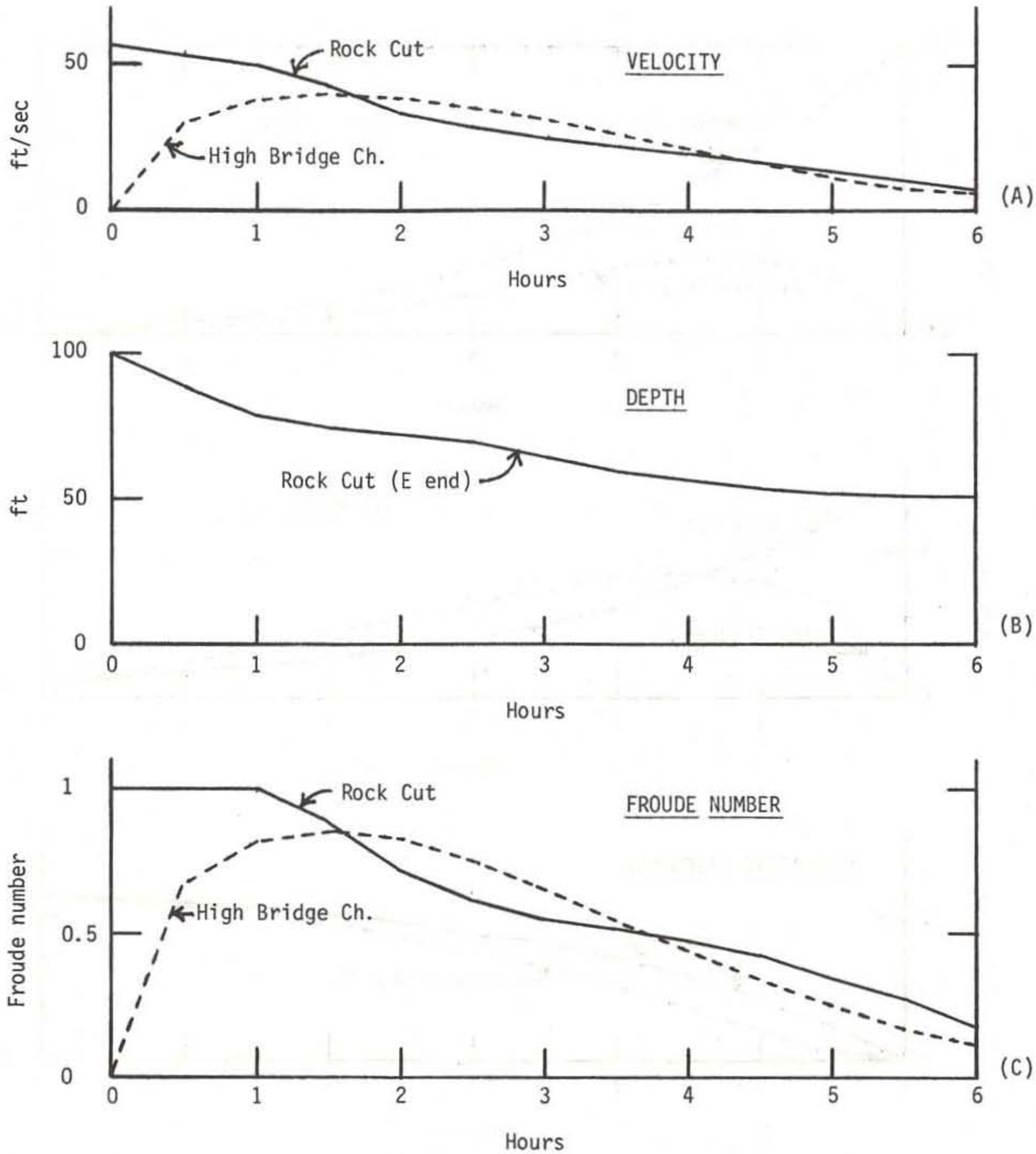

Figure 7. Velocity, depth, and Froude number computed for Rock Cut flood, assuming instantaneous failure of drift dam, present geometry of cross channels, and zero flow resistance.

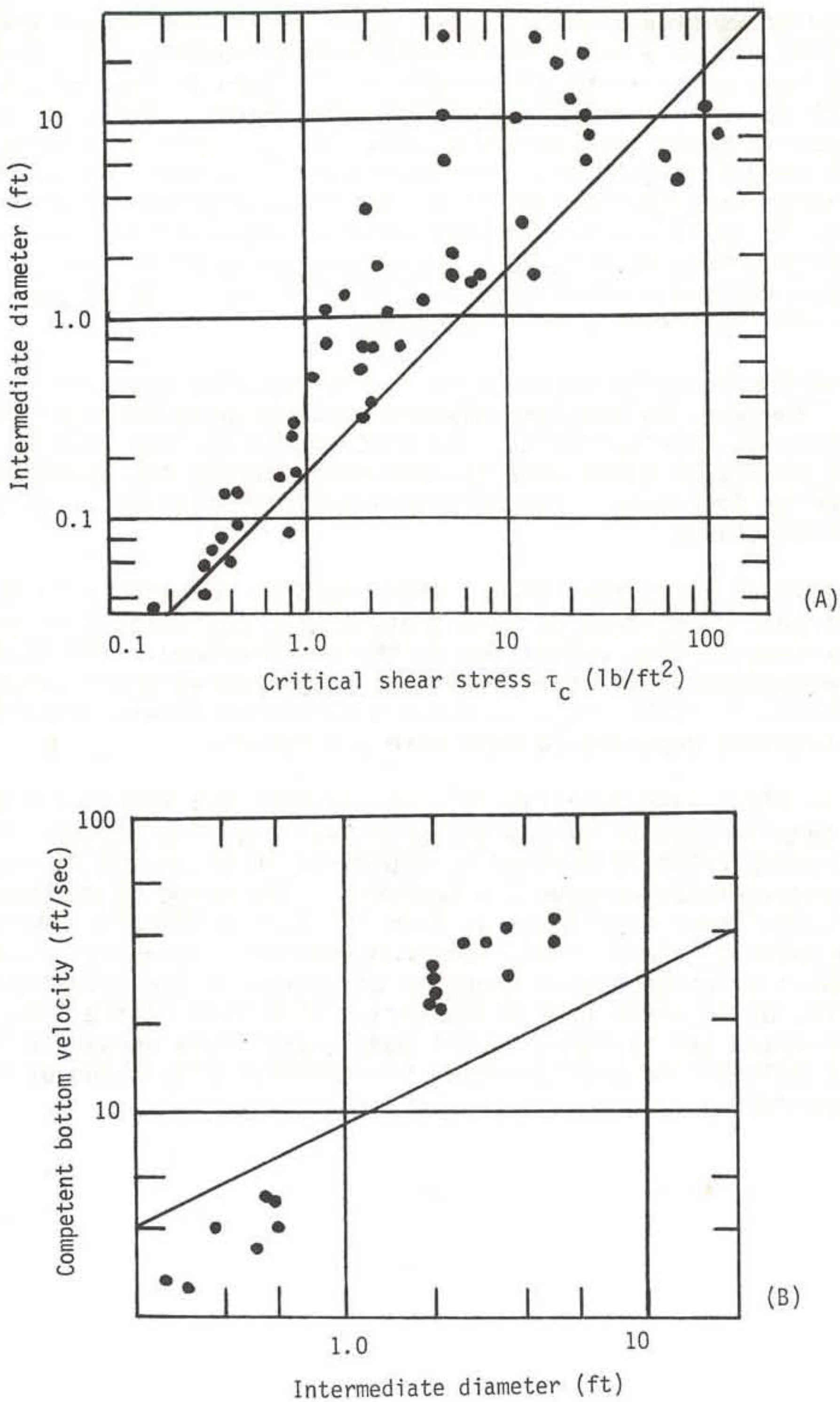

Figure 8. Conditions required to transport quartz-density particles in water. Data from multiple sources. After Baker (1973). A. Particle diameter vs. critical tractive force. Solid line is Shields equation. B. Relation between near-bottom velocity and particle size.

Because we have information on water depth and channel width, it is possible to assume a value for effective bed roughness and to compute bed shear stress, τ_0, for any discharge, Q. It then is feasible to use a diagram such as Figure 8A (modified after Baker, 1973), which relates competency (largest transported clasts) to τ_0. Because intermediate diameter is used in this plot, our requirement is for 3-ft boulders. Figure 8A shows that boulders of this size require shear stresses ranging from 2 to 20 lb/ft^2, with a middle value of about 6 lb/ft^2. Taking effective bed roughness as 1 ft (0.3 m), discharge equal to that of Niagara would have exerted a shear stress of 0.04 lb per sq ft of bed, or enough to move sand particles 2 mm in diameter.

Competency can be improved by decreasing flow depth for a given discharge. However, by the time Niagara could move boulders of the size which occur in Rock Cut Delta, its depth would be less than 10 ft and it would be unable to climb over its own delta (whose top stands 50 ft above the floor of Rock Cut). The only satisfactory solution is to dramatically increase discharge.

Figure 8B (also from Baker, 1973) relates competency to flow velocity near the bed. According to this plot, particles having 3-ft intermediate diameter require flow velocities in the neighborhood of 40 ft/sec. (Recall that the computer simulation predicted a maximum velocity through Rock Cut of 57 ft/sec.). Velocity of Niagara's discharge flowing through Rock Cut at the required depth would have been 2.4 ft/sec.

As a final exercise (Fig. 9), we can plot for Rock Cut a diagram relating shear stress to discharge, given various flow depths. The shaded area at upper right is bounded by depths of 60 ft and 90 ft and by shear stress requirements to move 1-m boulders. The range of discharges compatible with these conditions is from 1.3 to 6 x 10^6 cfs. Moreover, an average value of shear stress (based on center of gravity of published data) would correspond to a probable discharge in our situation of about 3 x 10^6 cfs, or 15 times that of Niagara. This is a little less than half what was predicted by the original model, and close enough to it (in the writer's opinion) to justify using the computer simulation as a guide to what occurred.

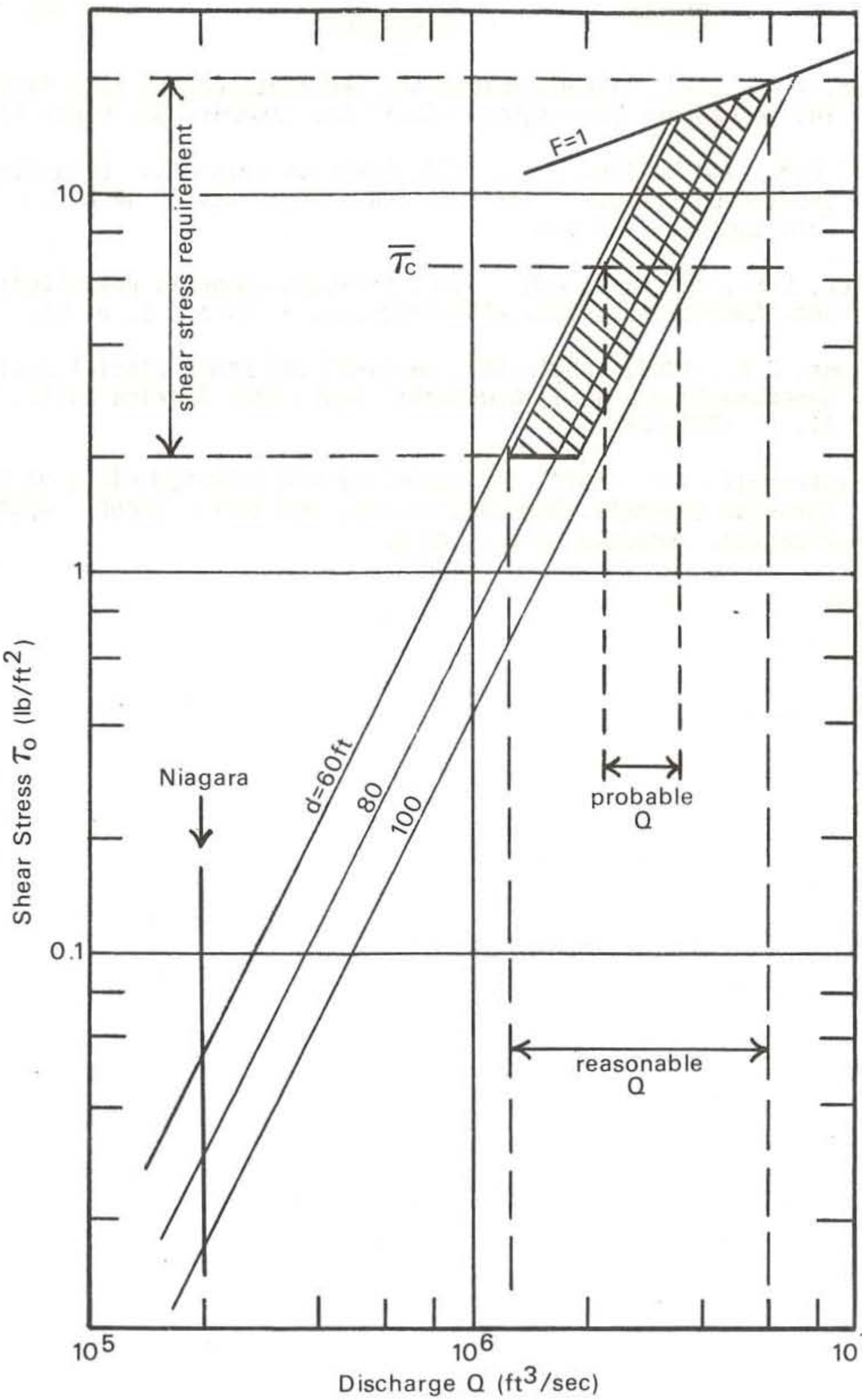

Figure 9. Bed shear stress vs. discharge for water depths d = 60, 80 and 100 ft, through channel having dimensions of Rock Cut and roughness elements of 1 ft. Shaded area is for Rock Cut at time of catastrophic flow.

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Road Log

Note: The field trip passes across the following USGS 7 1/2 minute quadrangles:

Syracuse West
South Onondaga
Jamesville
Syracuse East

Total Mileage	Miles from Last Stop	Route Description
0.0	0.0	Leave Manley Field House (intersection of Comstock Ave. and Colvin St.), heading south on Comstock
0.6	0.6	Turn half-right onto Jamesville Ave.
0.9	0.3	Turn right onto Ainsley Drive. At T-intersection with Brighton Ave., view ahead (west) looks across northern end of Onondaga Trough. Downtown Syracuse is two miles to the right, at the north end of Onondaga Trough.
1.6	0.7	Turn left onto Brighton Ave. Intersection is at west end of Rock Cut cross channel. Elevation of channel floor (road level) is 550 ft Floor of Onondaga Trough is at about 400 ft, so depth of Onondaga Trough Lake was 150 ft when this threshold controlled. Approach to Meadowbrook Channel also was through this area. Highway excavations on left briefly exposed the following sequence: till flowtill varved lake clays (about 100 yrs; upper part contorted by ice thrusting) bedrock (Bertie Formation) Interpretation: Bedrock was cleared of drift by drainage from Onondaga Trough Lake when Meadowbrook Channel was active. (Western end of Rock Cut was still drift-filled.) Readvance of ice blocked Meadowbrook outlet, raising level of Onondaga Trough Lake from 550 ft to 700 ft, reactivating Nottingham Channel. Lake clays were deposited in this interval. Upward increase in dropstones indicates approach of ice front. Ice over-ride then contorted upper part of clay and deposited flowtill and till. This minor re-advance is thought to have been limited to tongues of ice extending southward into "through" valleys.

Total Mileage	Miles from last stop	Route Description
2.1	0.5	Turn half-right onto Lafayette Rd.
3.4	1.3	Smoky Hollow Channel on left.
3.6	0.2	Turn half-right on Graham Rd.
4.0	0.4	Spectacular view of Onondaga Trough. We are approximately on the shoreline for the lake as it would have been during the Smoky Hollow Stage. The lake was 2 mi wide, 350 ft deep, and extended to the Tully Loop of the Valley Heads Moraine, 13 mi south.
4.3	0.3	Turn left on Sentinel Heights Rd.
4.6	0.3	Turn left on Dave Tilden Rd.
5.1	0.5	Turn right on Lafayette Rd.
6.3	1.2	Turn left on Brevity Lane
6.4	0.1	Turn left on Barker Hill Rd, heading north.
6.8	0.4	Cut-off meander loop of Smoky Hollow Channel is on right. Loop surrounds an umlaufberg. 3 mi to the east can be seen the east side of Jamesville Trough, and beyond it (about 8 mi away) the far (east) wall of Fayetteville-Manlius Trough.
7.0	0.2	Begin descent into Smoky Hollow.
7.3	0.3	Turn right onto Smoky Hollow Road. This road follows the main Smoky Hollow Channel.
7.4	0.1	Loop channel on right.
7.7	0.3	Umlaufberg on right.
7.9	0.2	Loop channel returns from right.
8.5	0.6	Continue on Smoky Hollow Road, half-left across intersection.
8.8	0.3	Turn right (south) on Apulia Rd.
9.7	0.9	Jamesville Reservoir (artificial lake) on left.
10.5	0.8	View (southward) of Jamesville Trough.

Total Mileage	Miles from last stop	Route Description
11.4	0.9	Turn left onto Smith Rd (unmarked).
12.2	0.8	Turn left onto Ransom Rd (unmarked).
12.9	0.7	Turn left on NY91. Excellent view of Jamesville Trough.
13.8	0.9	Turn right on Taylor Rd.
14.1	0.3	Stay left at Y.
14.5	0.4	Crossing southernmost scourway of Moorehouse Flats.
15.2	0.7	Moorehouse Flats for next 0.4 mi. Discharge from Jamesville Trough Lake swept eastward (to right) across this threshold on Onondaga Limestone during the Smoky Hollow Stage.
15.6	0.4	Turn right (east) on NY173. Artificial barrier on left partially hides Jamesville quarry of Allied Chemical Corp, which extends for 1.5 miles along the route. Quarry is in Onondaga and Manlius Formations.
17.7	2.1	Turn left on Sweet Rd.
18.6	0.9	Crossing axis of High Bridge Channel (left) where it enters Fayetteville-Manlius Trough (right).
19.1	0.5	Half-left, continuing on Sweet Rd.
19.4	0.3	Underpass.
19.8	0.4	Turn left into gravel pit operated by Jake Hullar.
19.9	0.1	STOP 1. High Bridge Delta, an expansion bar built where White Lake Channel entered Fayetteville-Manlius Lake. At least the final shaping is attributed to catastrophic discharge which occurred when a 100 ft drift dam failed in Rock Cut Channel. Observe large-scale cross-stratification, clast size (mostly sand and pebble gravel, with larger clasts to 6 ft or more), and clast lithology (dominantly carbonate, but some exotics). Till occurs immediately below a cemented gravel zone in the deeper parts of the quarry.

Total Mileage	Miles from last stop	Route Description
20.0	0.1	Leave quarry, turning right (south) on Sweet Rd.
20.3	0.3	Turn right on unmarked road immediately before underpass. Climb delta face. Main channel on left.
20.6	0.3	Cross High Bridge Rd, continuing on Woodchuck Hill Rd. Road is on top of High Bridge delta (expansion bar), elevation 600 ft. Floor of channel (on left, not clearly visible) is at 530 ft. If the topography here is essentially primary, as it appears, flow in the main channel was 60-70 ft deep during delta construction (Rock Cut flood).
22.5	1.9	Descend into scour channel maintained by vortex in lee of Rock Cut Delta. The near (northeast) wall of this scour channel is bedrock while the southwest side is the depositional front of Rock Cut Delta.
22.7	0.2	Turn right onto Maple Dr. Bedrock exposures on left.
22.9	0.2	Left on Bovington Lane.
23.0	0.1	Bedrock behind houses on right was swept bare by vortex scour.
23.1	0.1	Dead ahead is slip face of Rock Cut Delta. Delta forests here consist of pebble gravel, with basal layer of boulders thought to have been emplaced by rolling down the delta face. Some of these boulders are used as yard ornaments. Return to Maple Drive.
23.3	0.2	Turn right on Maple Drive.
23.5	0.2	Turn right on Woodchuck Hill Road. Cross scour channel and climb delta front.
23.7	0.2	Turn right onto Cedar Heights Drive. Here on top of Rock Cut Delta the favored lawn ornaments are boulders 4 to 6 ft long. Most are of local bedrock types, but some are exotics. These boulders occur at an elevation of 600 ft, about 50 ft above the floor of Rock Cut Channel, along which they were transported.

Total Mileage	Miles from last stop	Route Description
24.1	0.4	Turn left on Will-O-Wind Dr (the second time you encounter it).
24.2	0.1	Turn right on unnamed exit road, then right again on Woodchuck Hill Rd, heading west. Immediately after turning onto Woodchuck Hill Rd, note the broad, channel-like depression to the left on the grounds of the Dewitt Fish and Game Club. This scourway is 700 to 1000 ft wide; its axis lies about 35 ft below the adjacent delta surface and slopes gently westward, i.e., up-current. It is interpreted as having developed during catastrophic discharge from Rock Cut Channel, when water level stood near 500 ft elevation. Presumably, most, if not all, of the delta surface was under water at one time, but scourways such as this accommodated a disproportionate part of the flow.
24.6	0.4	Fluvial boulder gravels in road cut on left. The valley into which we are now descending was cut subsequent to formation of Rock Cut Delta and so transects the delta, isolating the remnant we have just crossed from other remnants on the west side of Jamesville Trough.
24.7	0.1	Turn left on temporary road (construction in progress).
24.8	0.1	Right on Jamesville Rd.
25.2	0.4	Till in roadcut on left shows that the flow which sectioned Rock Cut Delta (Rams Gulch phase) cut completely through the delta gravels and into glacial deposits underneath.
25.4	0.2	STOP 2. Turn left into abandoned gravel pit. Large boulders near entrance are common constituents of this segment of the Rock Cut Delta. Whether this pit can be examined in detail depends on interstate highway construction and other factors. However, under favorable conditions one can see imbricate boulder gravels and crossbedding that document radial flow from the mouth of Rock Cut. The till surface on which the delta was built forms the floor of the quarry over large areas. The edge of this delta spills northwestward into the mouth of Nottingham Channel, clearly indicating that the flood gravels (which initiated State II of Rock

Total Mileage	Miles from last stop	Route Description
		Cut drainage and built most of this delta) are younger than the most recent flow through Nottingham.
25.7	0.3	Leave quarry, turning right (south) on Jamesville Rd.
26.7	1.0	Left at intersection to Jamesville.
27.6	0.9	Turn right (east) on NY173.
28.2	0.6	Gravels beyond houses on left are part of the delta built by discharge from Smoky Hollow spilling into Jamesville Trough Lake.
28.8	0.6	Turn right into Clark Reservation State Park. Proceed to parking area.
29.0	0.2	STOP 3 and LUNCH. (Parking lot, Clark Reservation.) From main overlook, observe the steep-walled plunge basin at the west end of Clark Reservation Channel. This dry waterfall, 120 ft high, has plan dimensions nearly identical with those of Horseshoe Falls, which today carries 90 percent of Niagara's discharge. Presumably, the normal flow through Clark Reservation in Late Pleistocene time was comparable to that of the present Niagara River. Green Lake, which now occupies the plunge basin, is about 55 ft deep. A second, smaller plunge basin (Dry Lake) is located immediately upstream from the lip of the main falls. Its height was only about 50 ft. Hike from the parking lot north, then west, following park boundary service roads and foot trail to the south rim of Rock Cut Channel. From the overlook one can see the trailer park plunge basin 170 ft below. This was the earlier of two south-wall plunge basins to be active during Phase I of Rock Cut drainage. By this time, drift had been flushed from the east end of Rock Cut, at least to the 600 ft level. The proposed Rock Cut drift barrier was located immediately west of here. The boulder spit partially barring the plunge basin was constructed by catastrophic discharge when the dam failed. Return to NY173.
29.3	0.3	Turn left on NY173.
30.6	1.3	Left onto Jamesville Rd.

Total Mileage	Miles from last stop	Route Description
31.4	0.8	Stay left (straight ahead, along railroad) onto Rock Cut Rd.
31.9	0.5	Dramatic view of Rock Cut, looking upstream (west).
32.6	0.7	Trailer Park plunge basin on left.
32.7	0.1	Turn left into Cliffside Trailer Park.
32.8	0.1	Turn right and circle park on perimeter road. (This is private property, so permission should be requested.) Immediately after turn, note artificially truncated spit on right. Boulder layers dip southward at angle of repose, indicating accretion into plunge basin accompanied lengthwise growth. Original basin form has been modified through removal of talus and addition of about 30 ft of fill. Boulders have been known to tumble to the base of the talus or slightly beyond, and have caused some concern.
33.0	0.2	Leave trailer park, turning left on Rock Cut Rd.
33.2	0.2	On left was location of the second (western) plunge basin which was operative immediately prior to diversion of the flow to Nottingham Channel. The basin has been enlarged by quarrying operations, and effectively destroyed. The ridge immediately south of the road is what is left of the boulder spit, which once completely barred this plunge basin. Its top stands more than 80 ft above the floor of Rock Cut. Some individual boulders exposed during excavation were 8 ft long.
33.5	0.3	Location of drift barrier which diverted flow to south wall plunge basins, later to Nottingham Channel, and finally failed, releasing the Rock Cut flood.
34.8	1.3	Turn right on Brighton Ave.
34.9	0.1	Turn right on Ainsley Dr.
35.2	0.3	View into Rock Cut, looking downstream.
35.3	0.1	Left on Jamesville Ave.

Total Mileage	Miles from last stop	Route Description
35.7	0.4	Stop sign. Turn half-right on Comstock Ave.
36.3	0.6	Turn right on Colvin St.
36.5	0.2	Turn right on Skytop Rd.
37.4	0.9	Pass Skytop offices of Syracuse University.
37.5	0.1	Continue on dirt road. Stay left.
37.6	0.1	Stay left at Y.
37.7	0.1	STOP 4. You are parked in the approach to Nottingham Channel. Incision is not obvious because the flow was spread wide. However, much of the bedrock has been scoured free of till, and there remain patches of gravel that were deposited by the meltwater. Walk NE into the wooded area, to view the plunge basin at the upstream end of Nottingham Channel. Return to paved road.
37.9	0.2	Paved road begins.
38.8	0.9	Turn left on Colvin St.
39.0	0.2	Manley Field House. END OF TRIP.