FIRST ANNUAL REPORT:

SEDIMENT MOBILITY WITHIN EDDIES AND THE RELATIONSHIP TO RAPID EROSION EVENTS

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ABSTRACT

Rapid erosion of channel margin deposits was documented during the 1990-1991 test flow period. When first reported, it was commonly believed that rapid erosion was caused by excess seepage stress created during daily flow fluctuation. However, during the attenuated interim flow prescription rapid events continue at similar rates and similar magnitudes, and are now known to be widespread . Field investigations conducted Summer, 1993, addressed general process hypotheses that might explain the rapid erosion phenomena.

Field methods included bathymetric and velocity mapping, and electronic motion sensing applied at short time-scales. The occurrence of a large erosion event at RM172L during field investigations provided a fortunate oppurtunity to take measurements for; two days prior, three days during, and eight days following the event. During that time, several processes were observed and measured as never before. The event supplied over 12,000 m^3 of stored sand to the channel. Following the rapid bank erosion event, stage/discharge relations changed over a three day period indicating channel degradation of 0.2 meters. Bedload discharge measurements indicate an initially high rate that diminished with time during the same period. An unifying hypothesis was developed that explains many of the observations and measurements made during the event.

INTRODUCTION

Rapid, often catastrophic, erosion of channel margin deposits was documented during the 1990-1991 test flow period with time lapse photography (Cluer, 1991) and water level sensors (Carpenter and others, 1991). Twenty rapid erosion and redeposition events were documented in nine months of test flows at eight sites and in every case bi-weekly re-evaluation surveys (Beus and others, 1991) were eluded by the importance of the sporadic dynamic activity. The rapid events made interpretation of some of the results very difficult (Beus and others, 1991).

When first reported, it was speculated that rapid erosion may be caused by excess seepage stress created during daily flow fluctuation. However, rapid events continue at similar rates and similar magnitudes, and are now known to be widespread during the attenuated interim flow prescription (Cluer and other, 1993). Also disfavoring explanation by seepage stresses was documentation of rapid erosion of low-angle reattachment bars that were nearly always submerged and able to drain in all directions when exposed.

Personal observations of one event confirmed that stream currents scoured 50% of the upstream end of a reattachment bar in a few hours (Cluer, 1992). Consequently, it was hypothesized that interaction between the sediments stored along channel margins and channel processes resulted in rapid erosion events. To this end, several hypotheses were formulated and a field investigation designed to address them.

This report presents results from data collected during the 1993 field season, and subsequent preliminary analyses. The goals of this research are to: 1)determine the fluvial processes that cause rapid erosion events; and 2)determine if the eroded sediment is retained in its eddy or transported downstream.

HYPOTHESES

Four broad hypotheses were empirically tested in 1993 or will be tested in 1994. They are:

(1) In response to daily fluctuations in discharge, bedload sediments are differentially mobilized in different reaches. A temporal pattern to rapid erosion events was suggested when it was documented that about half occurred during the first high flow following the typical weekend low flow pattern (Cluer, 1991).

(1a) Bedload deposition occurs during low flow periods in pools upstream of channel constrictions, and is mobilized and transported during high flow periods through the riffle and deposited in the lower pool. In a pool-riffle system, transient bedload in the riffle may continue to be transported during low flow and deposited in the downstream pool. If this hypothesis is true, the next high flow would encounter a different cross sectional geometry than existed when the eddy deposit was last reworked and scour of the eddy deposit might result.

(1b) Bedload in transport through a riffle at high flow remains in transport during low flow and is deposited in the

first pool downstream. This is similar to hypothesis *1a,* except that channel geometry is modified downstream of the riffle rather than upstream and downstream.

(2) Bank collapse is caused by formation and migration of bedload bodies such as sand waves or sediment pulses delivered from ephemeral tributaries. If this hypothesis is true, one would expect to see a progression of bank collapse events in the downstream direction as sediment loads are introduced to the river.

(3) Channel margin deposits are inherently unstable if standing at or near the angle of repose, and periodically slump, changing the local cross sectional channel geometry and recirculating flow patterns, resulting in bank scour. If true, then physical changes in deposit geometry drive changes in hydraulic geometry and the feedback results in bank collapse.

(4) Sediment eroded during bank collapse events is deposited in the eddy of origin and stored until redeposited at high elevation by the next high flow. If this hypothesis is true, then the long term effects of bank collapse events and processes depend primarily on subsequent peak discharges.

These hypotheses involve fluvial processes documented on many rivers, operating at accelerated rates in the regulated fluvial environment. Consequently, standard field methods are appropriate for their investigation, but repetition at short time steps is required.

1993 FIELD INVESTIGATIONS

The overall hypothesis tested in 1993 was that channel topography changes by measurable amounts during time spans as short as half a day during fluctuating flows. Also, that the magnitudes of change are great enough to affect flow patterns and in turn affect the stability of channel margin deposits. The objective of the first field session (July-August, 1993) was to precisely measure topography and velocity characteristics in two reaches where channel margin deposits are known to have high recurrence rates of rapid erosion events (from time-lapse photo records). The measurements were to be repeated twice daily (or possibly more often) for up to 14-days to document responses to the widest variety of fluctuating flow patterns available during interim flow regulation.

METHODS

Four techniques were utilized to measure and record changes in topography and hydraulic parameters at various time-scales. The primary technique employed was repeated hydrographic surveying of the channel from riffle to riffle at low and peak discharges each day. Simultaneously utilized was a broad-band acoustic doppler current profiler which measured and recorded the three-dimensional velocity field from a ship mounted sensor. The acoustic doppler also determined instantaneous discharge from velocity and area measurements and determined depth independent of the Super Hydro bathymetric mapping system. An array of 25 electronic land tilt sensors was used to detect rotational movement of eddy deposits at 10-minute intervals. The electronic recording system also included local river stage and temperature sensors. Daily time-lapse photography recorded subaerial exposure, subtle changes in topography, and relative river turbidity (details of this research/monitoring project are presented in a report by Dexter and Cluer).

Two reaches each 800-1000 meters in length were surveyed using the equipment and techniques described above during the 24-day period from July 14 to August 7, 1993. The study reaches included sandbar monitoring sites RM68R (near the Tanner Trail) and RM172L (near Mohawk Canyon).

Limitations

Because of a vertical angle recording problem with the Super Hydro system, topographic models of the channel and water surface are not yet available for analysis or discussion in this report. The problem has been resolved and it is anticipated that the nearly 800 transects will be corrected by mid-January, 1994 (Mark Gonzales, GCES, personal communication - December 21, 1993). Topographic map production will proceed shortly thereafter, concurrently with analysis . In lieu of maps, other field measurements obtained in 1993 provide insight to the processes that cause rapid erosion of channel margin deposits. The results presented in this report are from RM172L.

PRELIMINARY RESULTS

OBSERVATIONS AND MEASUREMENTS FROM A RAPID EROSION EVENT

It was fortuitous that a rapid erosion event occurred during the 1993 field investigation at RM172L. The event unfolded over three-days while twice daily topography and velocity surveys were conducted. During low river stage on the afternoon of July 25, the separation deposit (Fig. 1) began to scour in an area that eventually obtained dimensions of about 2x8 meters and 2.5 meters depth. As river stage began to rise, scour of the separation deposit decelerated, the event lasting about 2 hours. During peak discharge the night of July 25, deposition occurred on the eddy bar increasing its height about 0.15 meters. About 0.05 meters were deposited on the eddy bar during peak discharge on July 26.

The separation and eddy deposits were stable during the July 26 discharge fluctuation. However, as stage increased on July 27, rapid erosion of the eddy bar began. The first indication was slumping of blocks along a nearly vertical plane into strong recirculating current. Within about three hours 15 tilt sensors on the eddy bar face tilted off-scale (± 40°). The sensors recorded sequential erosion from downstream to upstream beginning at 8:30 p.m. and ending about 11:30 p.m. The survey following high flow (at 0600 July 28) revealed that the eddy deposit was scoured 5 meters deep over an area of about 2500 meters (12,000 m^3).

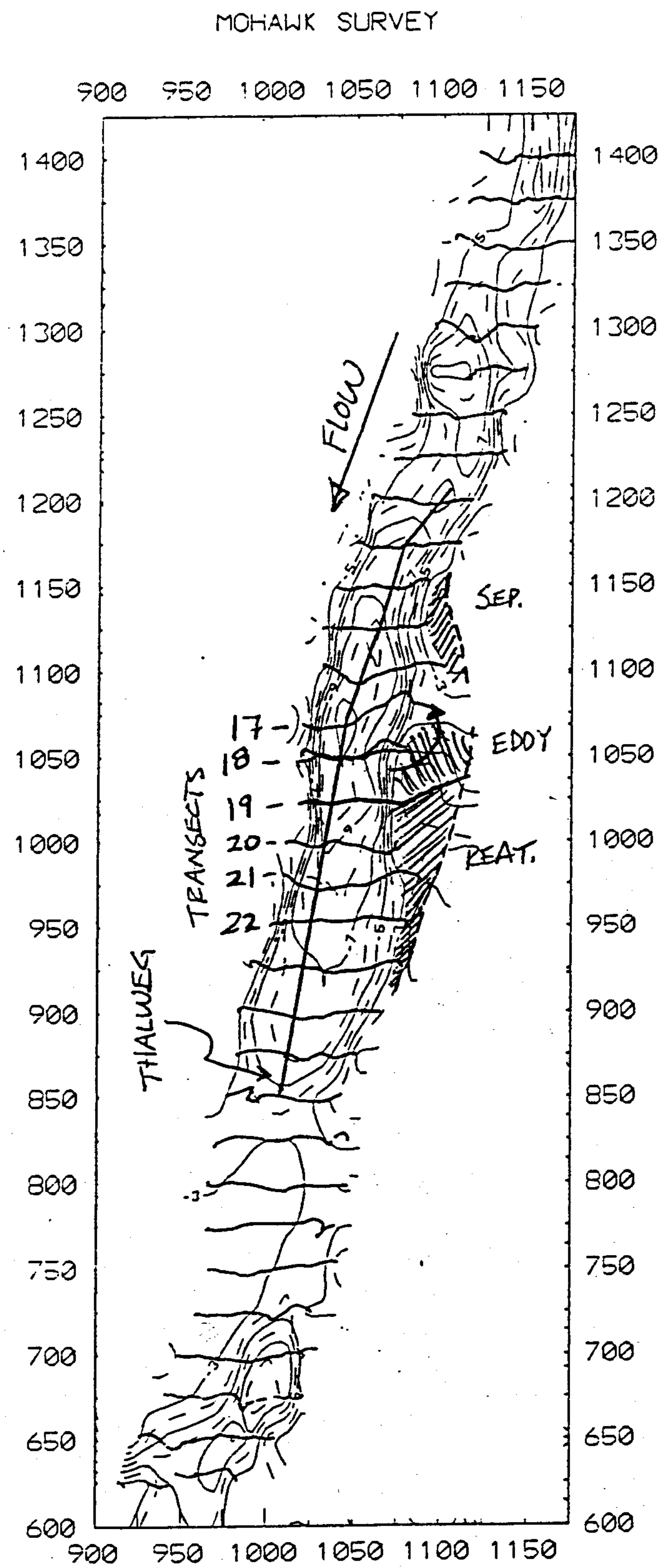


Figure 1. Field map of RM172L showing bed topography, navigation lines for bathymetric and velocity surveys, and general geomorphology of channel margin deposits studied.

Redeposition of the eddy bar was evident during the survey at 1700 July 28. Eight days after the scour event the new eddy bar had formed about 3.5 meters above the scour surface (Fig. 2).

Additional observations made during and following the scour events at RM172L are notable. Once the eddy deposit was eroded, the reattachment deposit (genetically an eddy deposit from flows exceeding about 31,000 cfs) also underwent rapid erosion. As stream current acted along the toe of the two meter vertical face, large blocks of slightly cohesive sediment separated from the bank along cracks, collapsed, and were entrained by recirculating currents. Total station plane surveys of the cutbank show that the face receded as much as 1 to 2.5 meters over a length of 70 meters.

Vegetation growing in the deposit was also entrained in the flow and deep rooted species provided no stabilizing effects whatsoever. Root crown cuttings were taken from one *tamarisk* and one *baccarus* before they were swept downstream. The stems had seven growth rings, indicating germination shortly after the high flows of 1986.

Consequently, a large portion of a deposit that was stable since 1986 was eroded during the interim flows. In general, the channel has widened in response to the lower peak/higher low interim flow pattern, at least at RM172L.

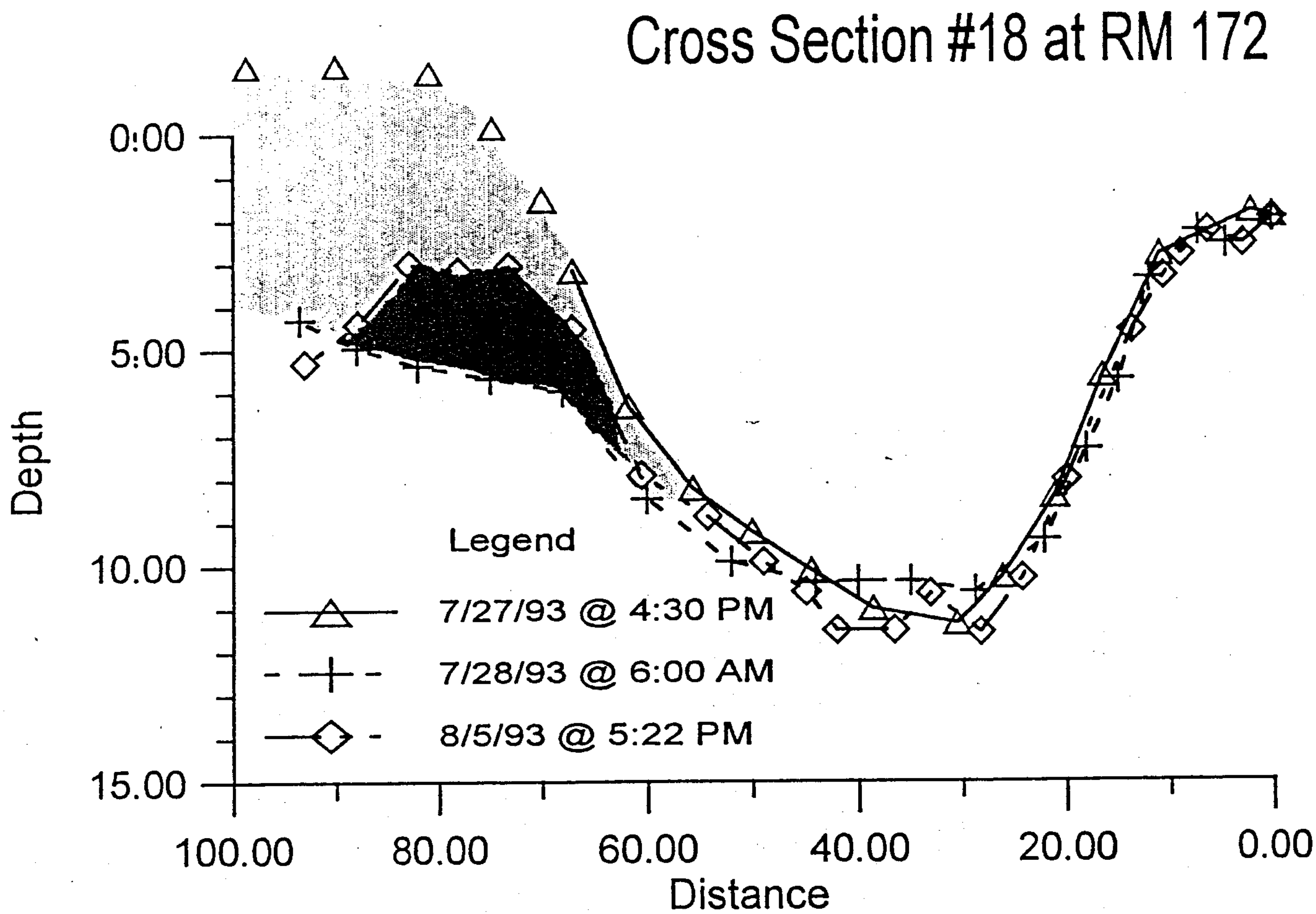


Figure 2. Downstream view of transect #18 (see figure 1) showing changes in bed and eddy deposit elevations at times specified.

FLOW DEPTH AND DISCHARGE

During two different types of fluctuation cycles, surveys were repeated over a limited river reach at RM172L at an hourly interval for 24-hours. The goal of hourly surveys was to contrast channel topography and velocity field differences between 'weekday' and 'weekend' discharge cycles.

The first 24-hour survey **(24A)** covered a 'weekday' discharge cycle. It was conducted from July 31 at 13:00 to August 1 at 12:00. The second 24-hour survey **(24B)** started on August 3 at 13:00 and ended on August 4 at 12:00, encompassing a 'weekend' discharge cycle. The hourly surveys repeated six bank to bank transects (17-22) in the recirculation zone and one 300 meter long thalweg profile extending from the beginning of the pool (about 50 meters upstream of the separation deposit) to the riffle downstream. See figure 1 for detail of area resurveyed hourly. Typically 20-30 minutes were required to complete each survey.

Because topographic models are not available for this report, the echo sounder charts were analyzed to determine flow depth along the thalweg. A 40-meter reach approximately 50-meters downstream of the reattachment point and 30 meters upstream of the riffle crest was selected because this area has fairly uniform depth. Average depth in the 20-meter reach along the thalweg (position constrained by distance marks from the Super Hydro navigation system) was correlated with discharge measured with the doppler velocimeter. During both surveys, flow depth increased and decreased roughly in phase with discharge, but discharge increased more linearly than it decreased (Fig. 3). During the declining portions of both fluctuation cycles, flow depth occasionally increased while discharge decreased. This is especially evident during survey 24B. This response can be explained by increased velocity through the same cross section or by a decrease in channel width which is unlikely. Adjustments in several variables could result in increased velocity, but a decrease in bed roughness is probable due to the bedform type and geometry observed in this area (following section).

The stage/discharge relationships differ considerably between surveys 24A and 24B (Fig. 4). For a given flow depth, there is as much as 60-70 m^3/s difference in discharge between the two surveys. This figure also indicates that flow depth increased 0.2 meters at the 580 m^3/s discharge level over the time interval from July 31 to August 4. Apparently, channel geometry or hydraulic parameters were adjusting during this short period of time.

BEDLOAD DISCHARGE

Dune bedforms were consistently observed on the thalweg echo sounder charts in the exit ramp area of the pool at RM172L. The hourly surveys described above allowed determination of the migration distance of individual dunes as flow depth and discharge varied during two hourly interval 24-hour surveys. Dune geometry (height and length) and the migration rate can be used to directly determine bedload discharge.

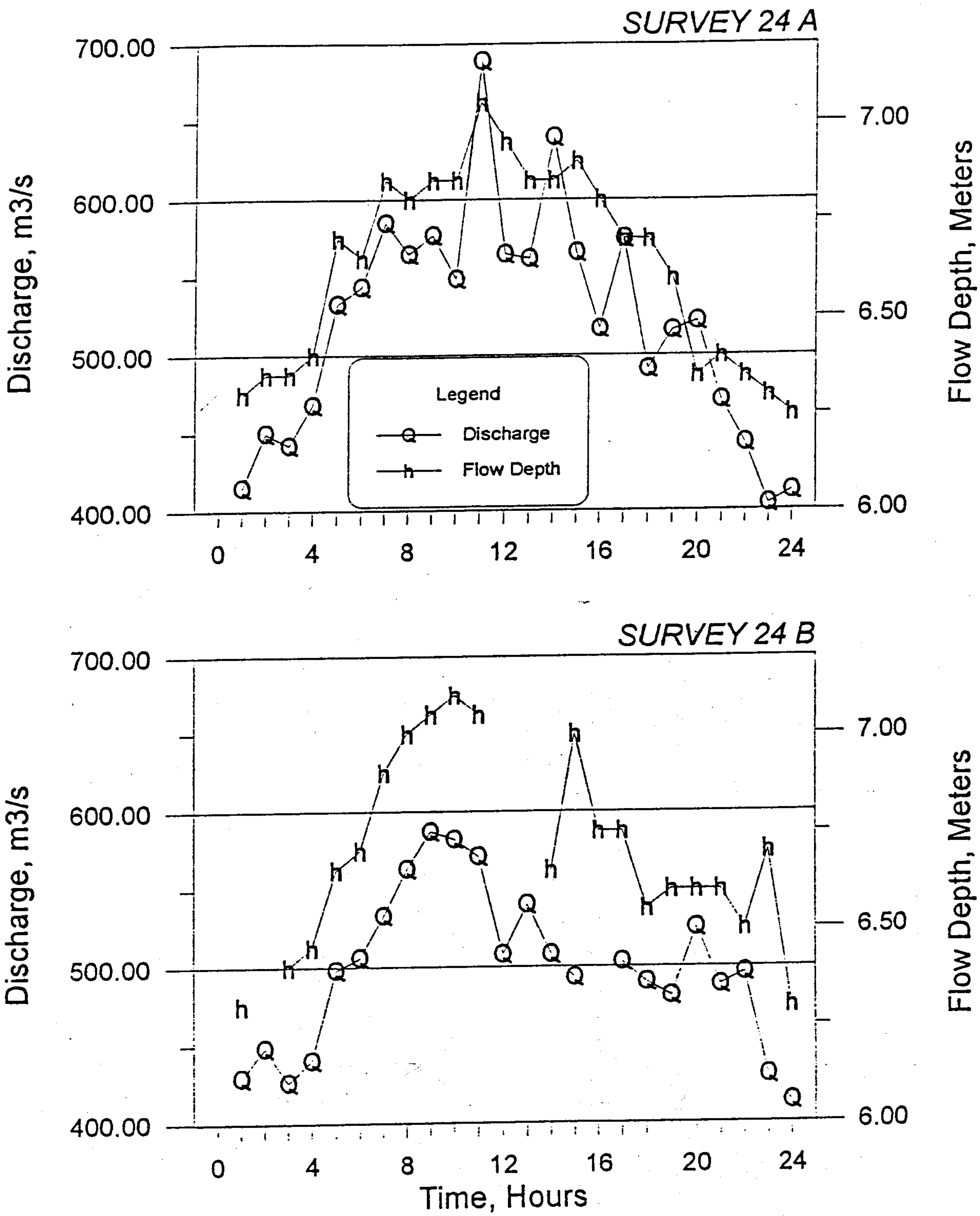


Figure 3. Plots of discharge and flow depth versus elapsed time during hourly surveys 24A and 24B.

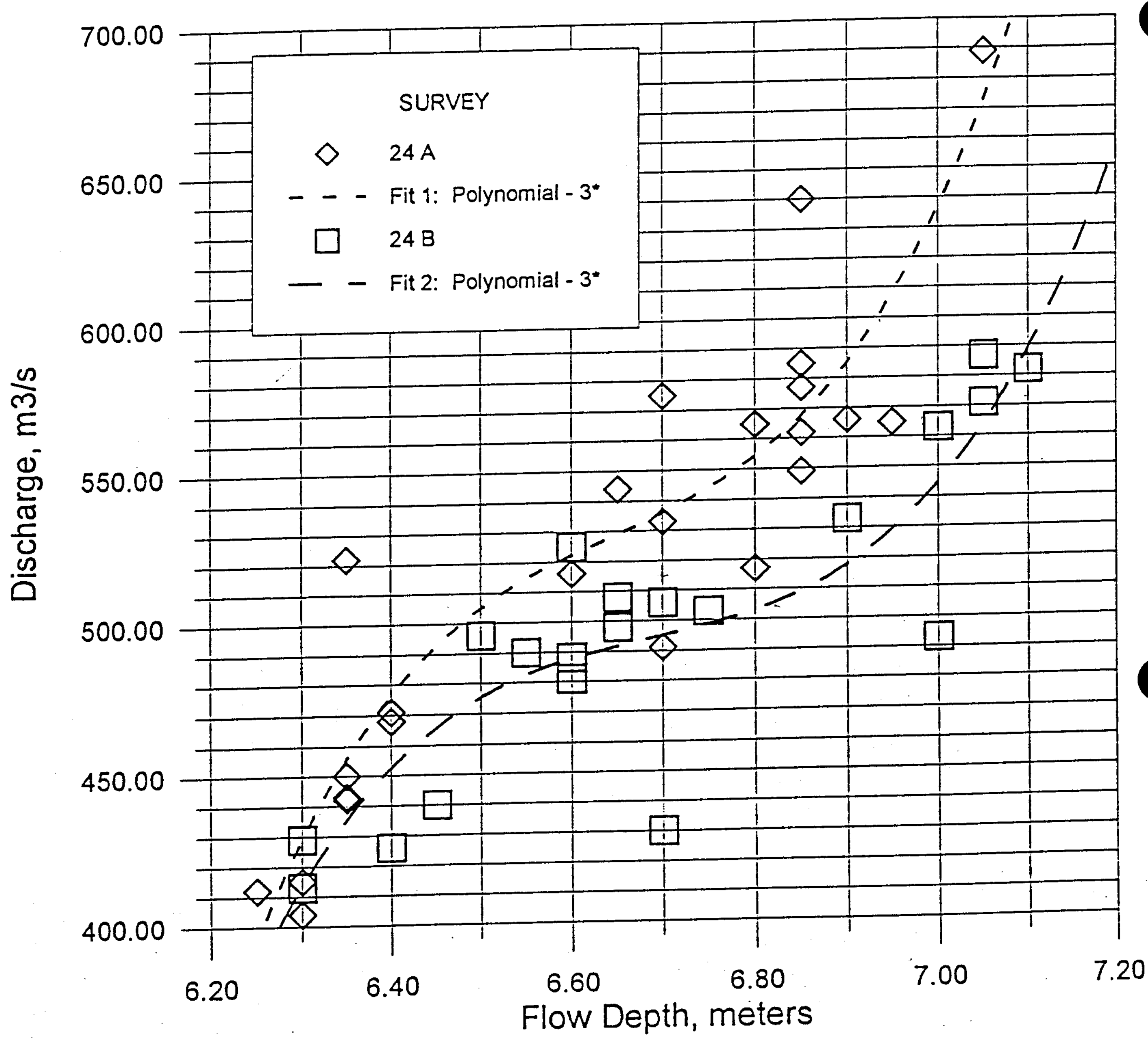


Figure 4. Stage-discharge plot for RM172L showing variation in hydraulic geometry between surveys 24A and 24B.

Methods

During the hourly surveys described in the previous section, channel cross sections were linked together with one sounding trace along the thalweg. For bedload analysis a 20 meter portion of the channel thalweg was chosen where bedforms were persistent and the flow depth was nearly uniform. Each echo sounder chart obtained along the thalweg was digitized, the vertical and horizontal axes adjusted to the same scale, and positioned to the same downstream reference distance along the thalweg navigation line (Fig. 1).

The thalweg navigation line was selected along the deepest part of the channel, determined from a topographic map produced in the field. Step-wise migration of individual dunes can be seen in figure 5 by comparing bedform positions in subsequent hourly cross sections. The dune geometry is clearly depicted and cross sectional area and migration distance were measured from the sequential plots.

Results and Discussion

The methods outlined above result in hourly sampling of bedform geometry and migration distance. Bedform height multiplied by the migration distance during the time interval between surveys results in the volumetric unit bedload discharge in m^2/h. Unit bedload discharge (qbv) varied over a range of about 0.4 to 2.6 m^2/h during the first survey (24A) and from about 0.4 to 2.1 m^2/h during the second survey (24B) (Fig. 6).

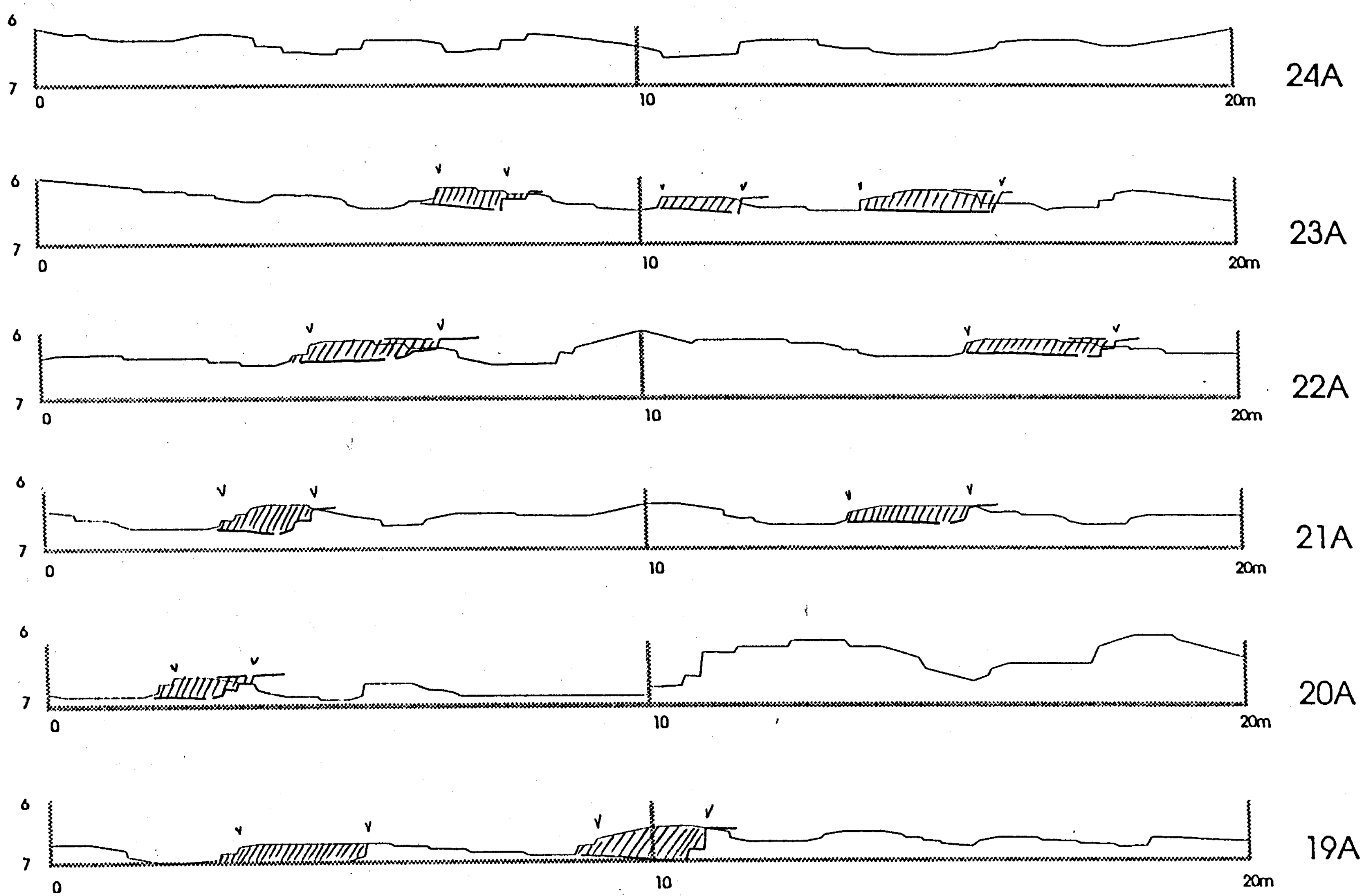
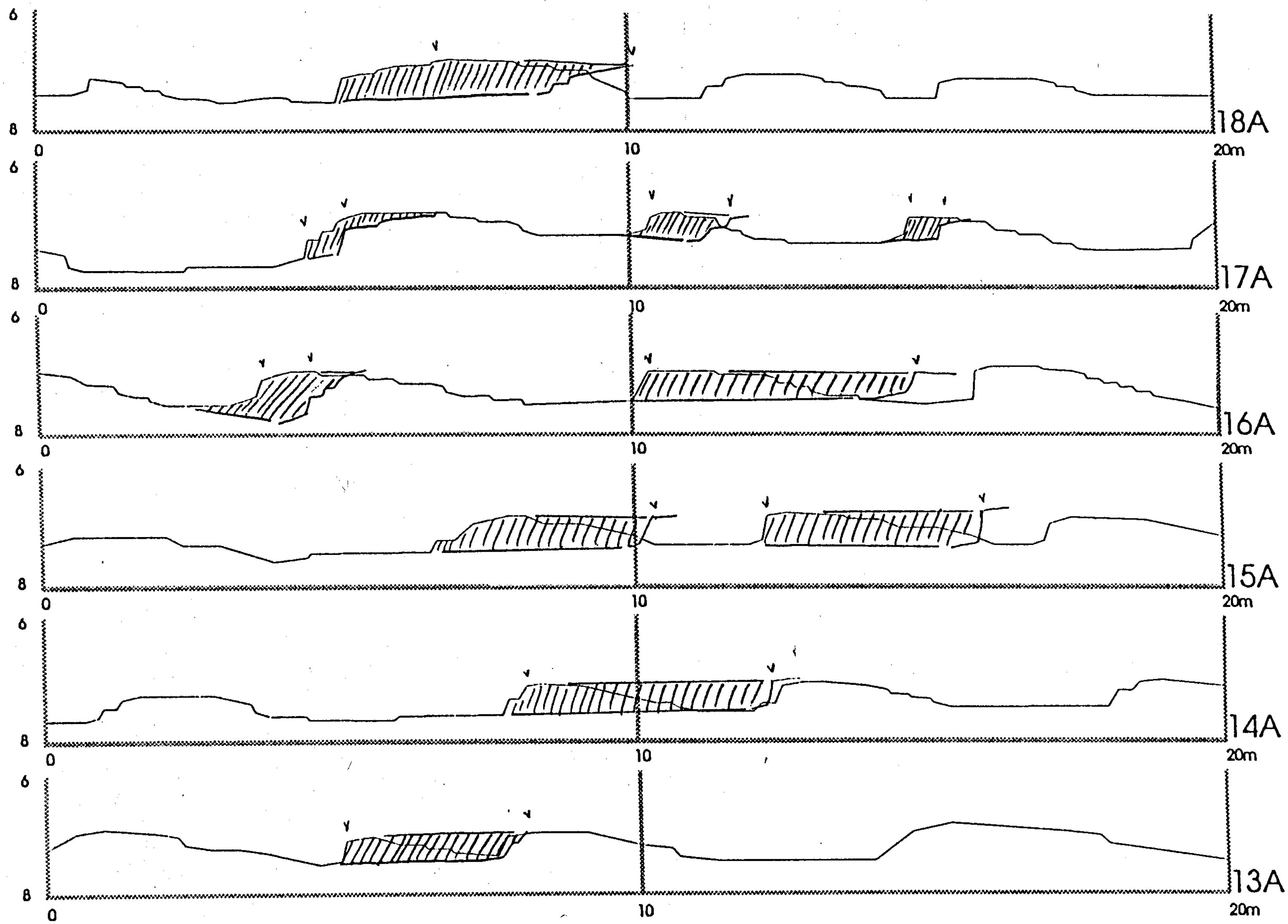


Figure 5. Cross sections of a 20 meter reach of thalweg. Flow is from right to left. Hachured areas represent bedform displacement from position in previous hour.



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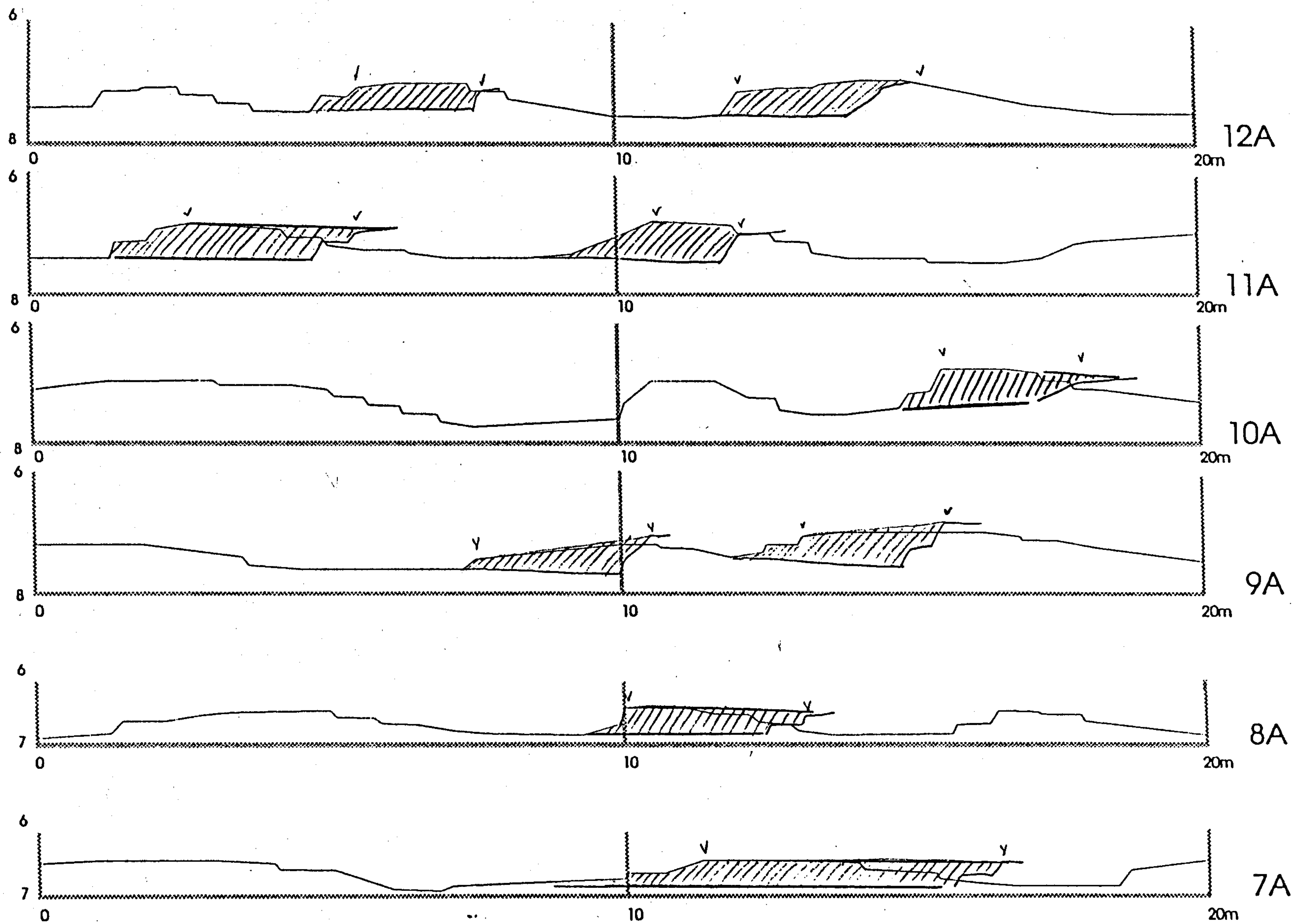

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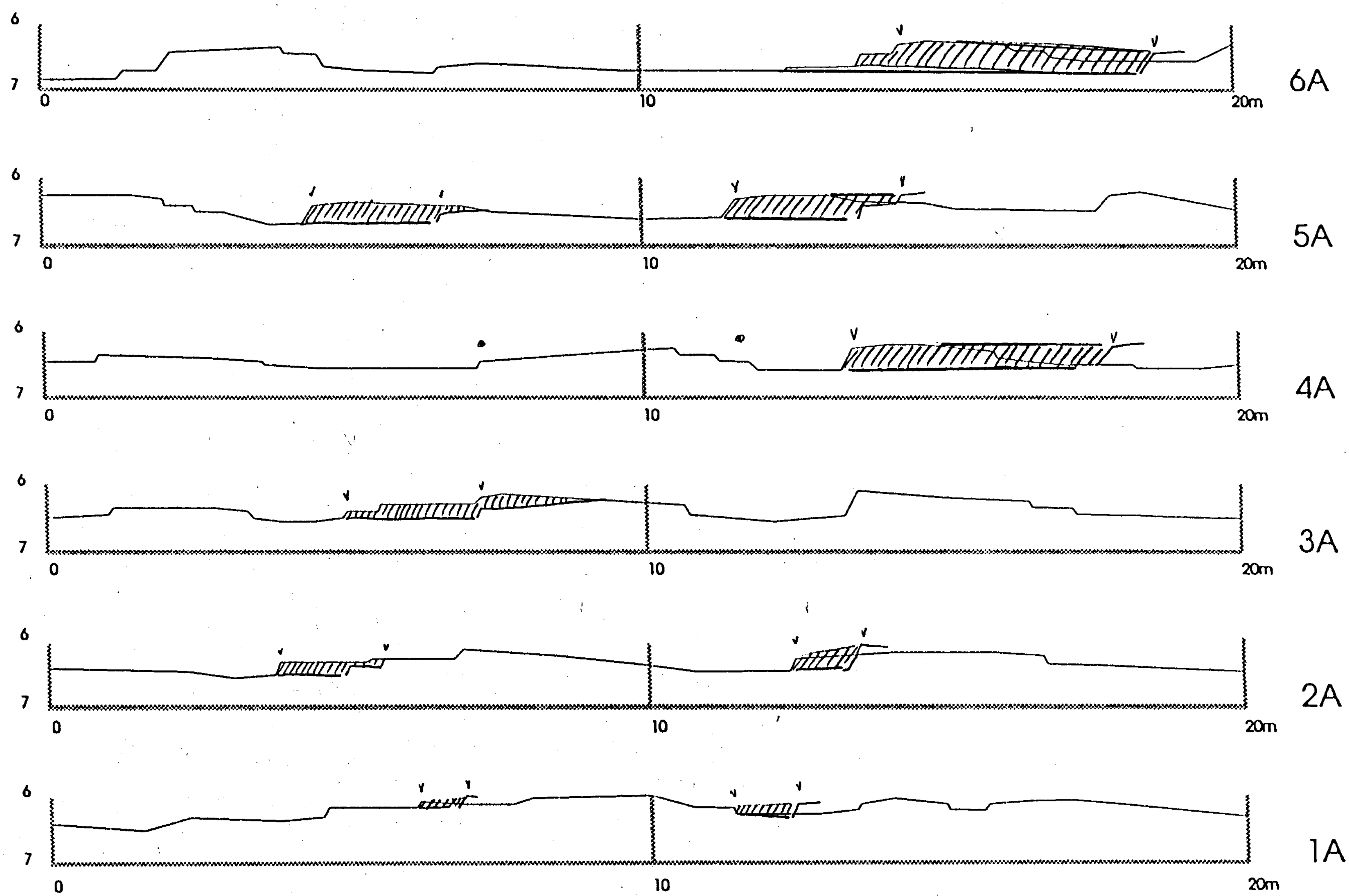

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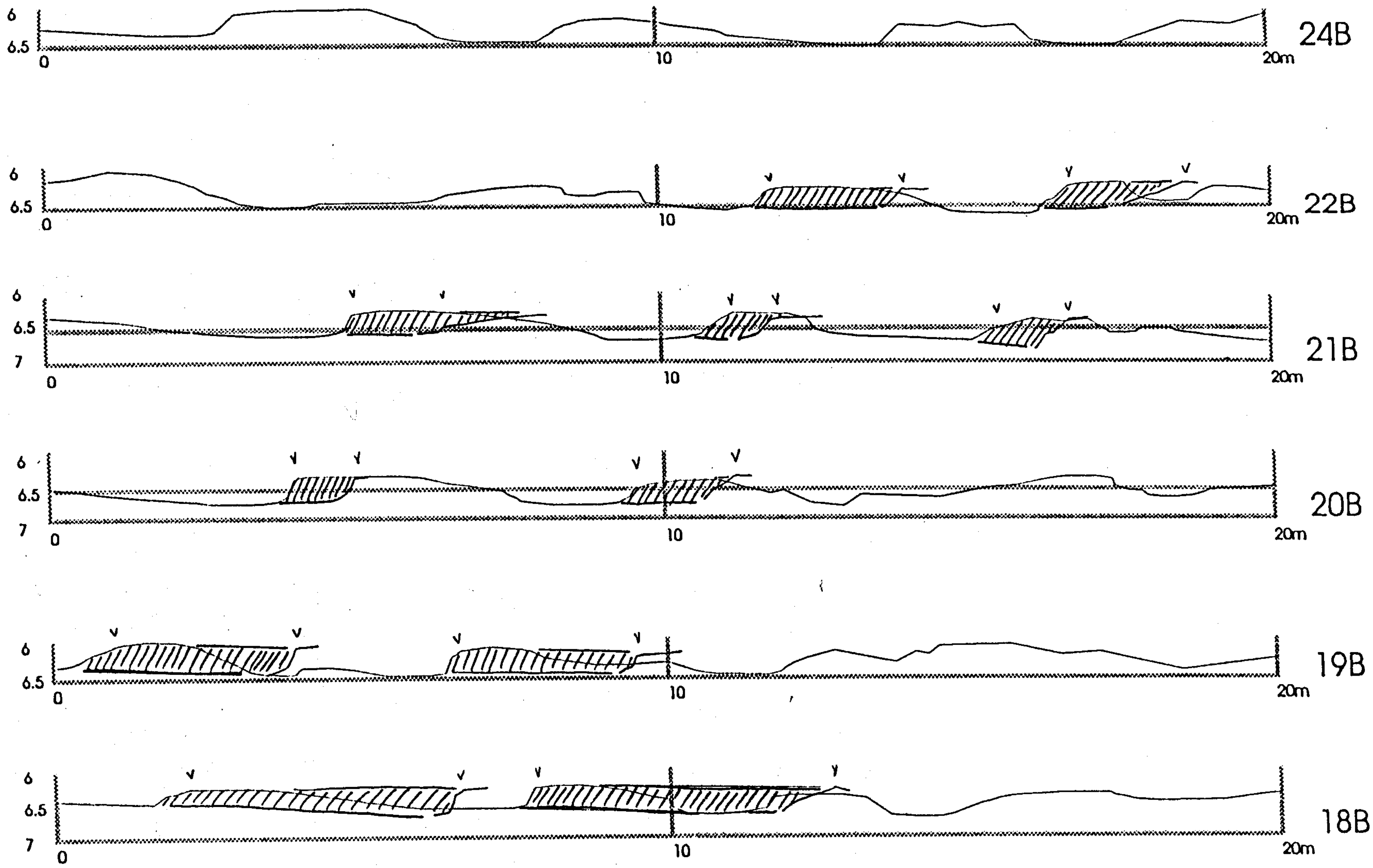

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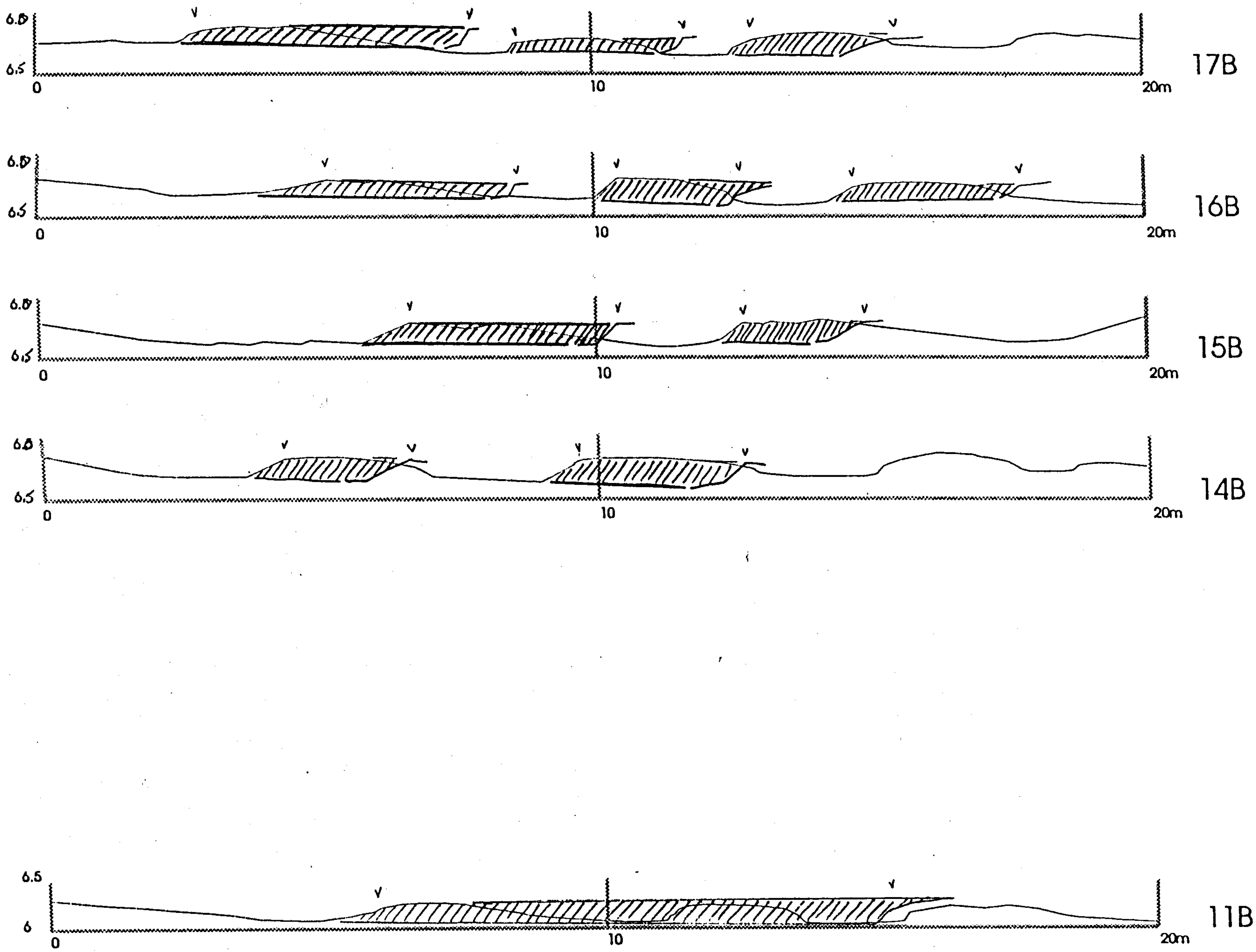

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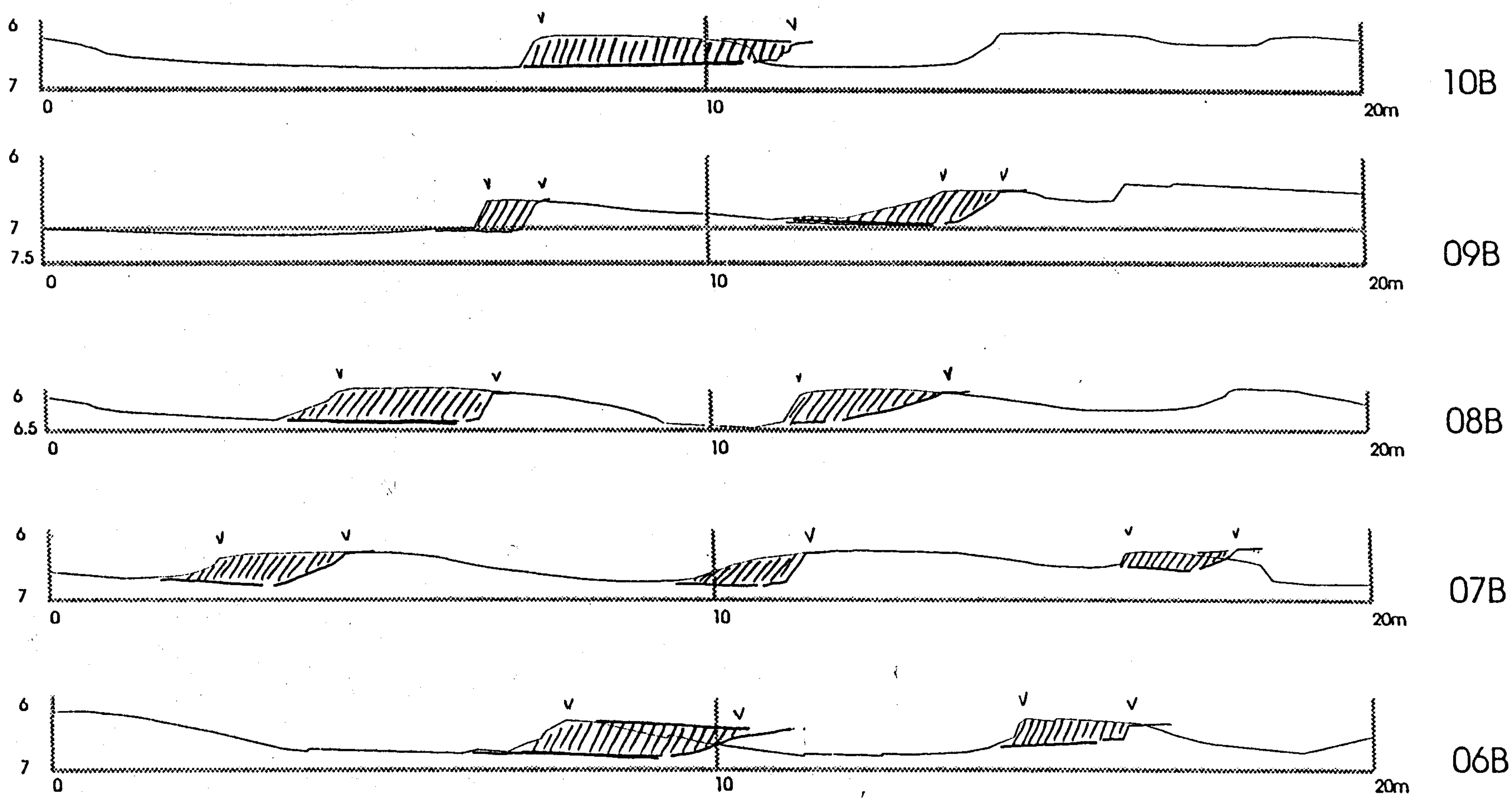

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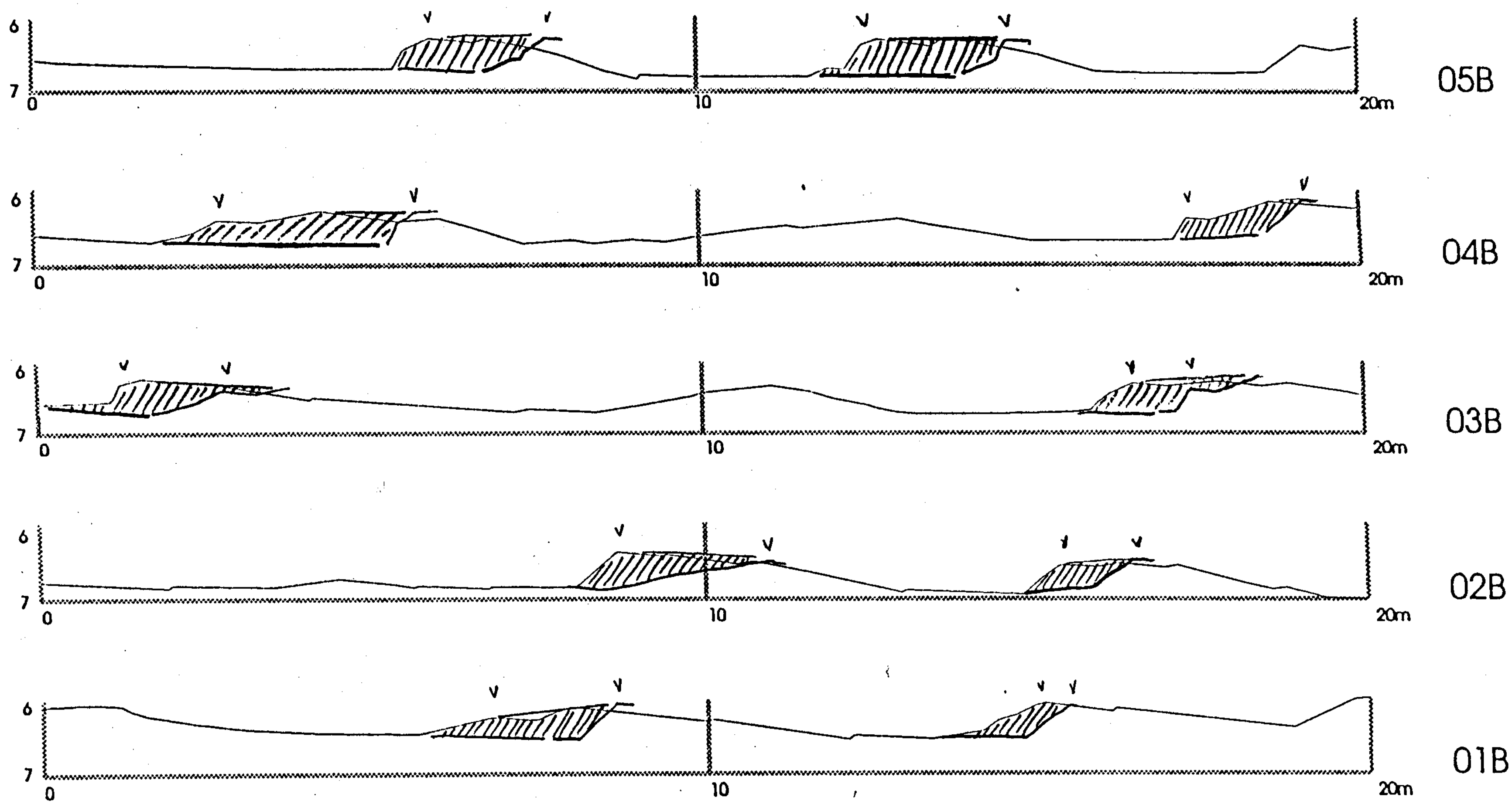

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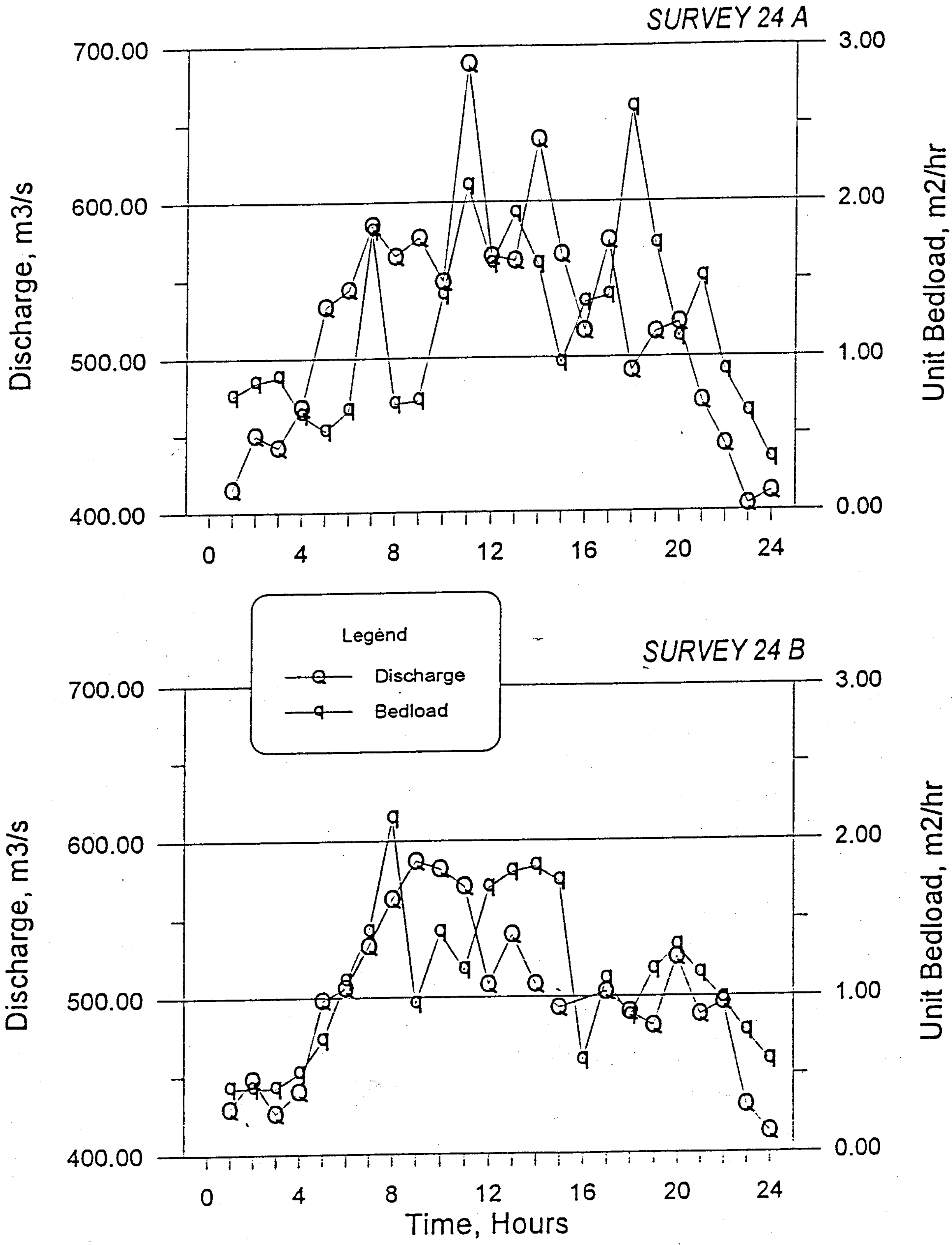

Figure 6. Plots of discharge and unit bedload versus time for surveys 24A and 24B. Notice pulsed behavior of both data and lag of bedload peak behind discharge peak.

Stream discharge varied from about 404 to 688 m^3/s during survey 24A, a 'weekday' fluctuation, and from 412 to 585 m^3/s during survey 24B, a 'weekend' fluctuation (Fig. 6). Daily qbv values were 31.2 m^2 for survey 24A and 26.4 m^2 for survey 24B. Least squares linear fits of the rising and falling stage unit bedload for both surveys shows that bedload during rising stage was about 40% greater for survey 24A than during the fall stage, or during 24B (Fig. 7).

The measured qbv values represent minimums because the physical outline of the bed does not account for sediment that is near the threshold of suspension and thus not depicted on the echo sounder chart. Several empirical equations have been developed to calculate maximum unit bedload and provide estimates where direct measurement of bedform migration is not possible. However, in order to apply such equations it is necessary to know the energy slope or the water surface slope. This information will be available once maps of the water surface are produced.

The total bedload discharge (Qbt) through the cross section at RM172L can be estimated by integrating qbv over the channel width (100 meters). Daily Qbt values for 24A were 3120 m^3 and 2640 m^3 for 24B. This results in total annual bedload transport ranging from 1.3 to 1.5 million metric tons when extrapolated to one year. These values exceed the bedload balance considered to be about equal to the mean bedload material yielded from the Paria River, 0.79 million metric tons annually (Smillie and others, 1993). As noted above qbv is probably underestimated by the direct nature of the methods employed in this analysis, but integrating over the entire channel width probably overestimates Qbt as does extrapolating to a year two days of record immediately following a large introduction of sediment. Consequently, the bedload values reported should be treated as reasonable approximations indicating that caution should be exercised in measuring and managing bedload as local factors as well as measurement errors can affect values by 50%.

Approximately 12,000 m3 of sediment was eroded from the eddy deposit on July 28. The unit bedload discharge measurements indicate that over 3,100 m3 were transported out of the pool during survey 24A and slightly less during 24B. At this rate, all of bedload derived from the eddy deposit would be transported downstream in approximately four days. The diminishing rate of bedload transport shown in figure 7 indicates that a substantial quantity of the sediment mobilized from the eddy deposit three days prior to survey 24A was transported downstream.

In retrospect, continuous hourly surveys over a longer period of time would be vastly informative, although it is nearly impossible to sustain these measurements for more than a few days. These results indicate that rapid erosion of the channel margin deposits was followed by increased bedload transport and the rate diminished within a few days of the event. This suggests that at least some of the sediment yielded during rapid erosion events is transported out of the eddy of

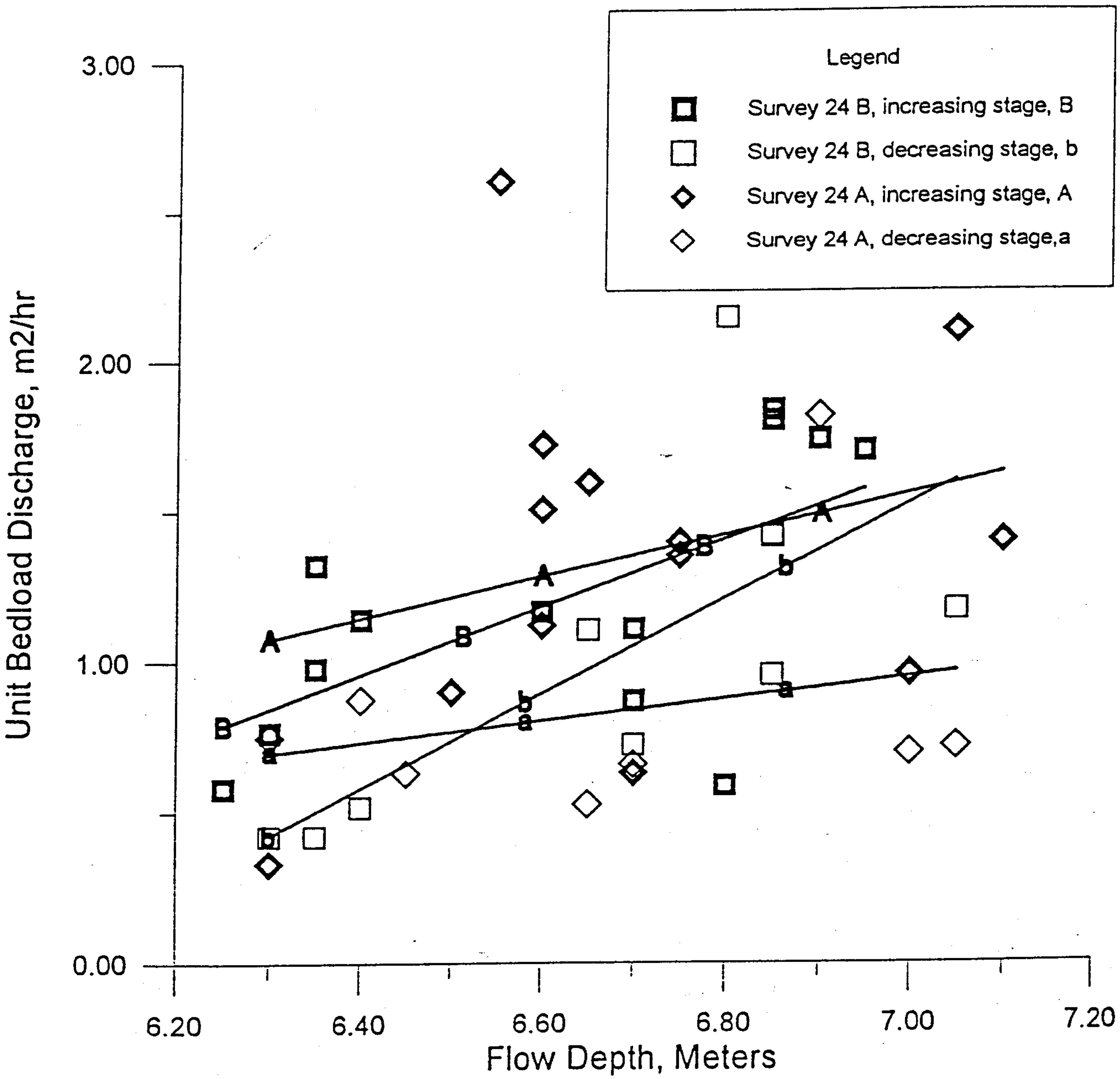

Figure 7. Least square fits of flow depth and unit bedload discharge for rising and falling stages, surveys 24A and 24B.

origin, not stored for future deposition. The topographic models will confirm this preliminary result.

DISCUSSION

The preliminary results presented in this annual report represent substantial progress toward the goal of determining the fluvial processes that cause rapid erosion events even though the bulk of field data are yet to be analyzed. Field investigations conducted Summer, 1993, addressed several general hypothesis that could explain the rapid erosion phenomena as known when the hypotheses were formulated.

The fortunate occurrence and documentation of a large erosion event at RM172L during field investigations allowed measurement of channel topography and current velocity fields for two days prior to the event, for three days during the event, and for eight days following quiescence. During that time, several processes were observed and measured as never before.

However premature it may ultimately prove to be, an alternative or refined hypothesis resulting from the preliminary analyses is presented in the following section. It unifies elements of the original hypotheses and explains many of the observations and measurements from the rapid erosion event documented at RM172L in July, 1993. Refining original hypotheses is a natural result of the scientific process that helps focus subsequent research and analysis on the causal processes of interest, in this case - rapid bank erosion.

REFINED HYPOTHESIS

The observations made at RM172L during the bank erosion events and analysis of depth/discharge, bedload, and tilt sensor records has led to a refined process based hypothesis that explains the sequence of events. Starting with one premise that seems reasonable given the present state of knowledge, a series of processes and results are hypothesized.

Premise: the separation deposit, stable at high discharges, is unstable at low discharges. This may be due to a combination of excessive slope angles of the deposit and non-steady streamlines near the channel constriction/expansion where small changes in geometry easily perturb flow paths. Hypothesis: in any case, erosion of the separation deposit appears to exceed a channel stability threshold and initiates a sequence of events that causes feedback between the geometry of the channel, flow hydraulics, and channel margin size and stability.

Erosion of the separation deposit quickly introduces a large quantity of sediment into the channel, in the size range of bedload, that is transported through the pool and temporarily deposited on the exit slope (negative slope) of the riffle downstream.

The temporary deposit raises the channel bed and decreases cross sectional area. Both adjustments increase shear stress, increasing sediment transport capacity over the riffle to compensate for the increase in bedload. The channel adjustment also backs water upstream in the eddy or pool because the elevation of the channel and the water surface have temporarily raised over the riffle. The backwater effect promotes elevated deposition on the eddy bar. These are temporary adjustments lasting only as long as is required for the stream to transport the sediment slug on the exit slope over the riffle and into the next riffle-pool complex.

Once the bedload slug is transported over the riffle, the channel and water level return to their previous elevations. The recently enlarged eddy bar then becomes unstable because it now stands at an elevation greater than the maximum stage, shunting recirculating currents in the eddy and constricting the width of the main channel. The decreased cross sectional area in the channel adjacent to the eddy leads to increased shear stress and turbulence along the eddy shear zone, resulting in rapid erosion of the eddy deposit during rising stage when shear stress and turbulence are greatest. Rapid head cutting of the eddy bar might result.

This refined hypothesis explains the observed sequence of events at RM172L between July 25 and 27, 1993 and channel processes documented four days later. Water surface and channel geometry models in addition to velocity field models will confirm this refined hypothesis and indicate if further modifications are necessary in the field investigations or analyses.

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Inventory of Property Aquired During the Reporting Period

Laptop PC
accesories: spare battery; 12v power cable; 4MB memory expansion; carry case
software: Grapher, Surfer, Excel, Word

Portable printer
accesories: sheet feeder; carry case

Belden cable
4000 feet 4 conductor

Tilt Sensors
20 each

Field camera
lens, carry case, filter

Inflatable Kayak
pump, paddle, throw bag

Portable Sand Shaker

50 meter Fiberglass Tape