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EPISODIC EROSION IN STEEP TERRAIN. (U)  
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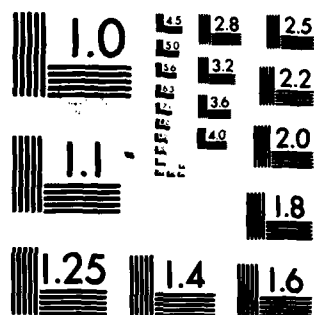
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## 20. ABSTRACT CONTINUED

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EPISODIC EROSION IN STEEP TERRAIN

FINAL REPORT

S. A. SCHUMM

19 August 1980

U. S. ARMY RESEARCH OFFICE

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Colorado State University

Fort Collins, Colorado

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The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

## STATEMENT OF PROBLEM

It has been suggested that sediment yields and landform evolution in steeplands of high-sediment production may be episodic; that is, the fluvial system is in metastable equilibrium, and periods of erosion are separated by periods of stability or deposition (Schumm, 1977). Evidence for episodic erosion, where it is preserved, is numerous unpaired and discontinuous terraces, and experimental investigations of alluvial fan development revealed that aggradation is interrupted by episodes of fan trenching (Schumm, 1977). Therefore, episodic deposition as well as episodic erosion, should be recognized in steeplands. The two when occurring within a fluvial system can be referred to as the episodic behavior of that system.

Episodic behavior is not controlled by hydrologic events but by geomorphic threshold conditions. Depositional and erosional processes tend to build landforms toward critically unstable forms (thresholds) which will eventually fail causing a series of erosional and depositional events. When the adjustments are minor, they are referred to as complex response. Such behavior may be intrinsic to the fluvial system (Schumm, 1977, 1980), and the threshold and complex-response concepts are integral parts of episodic landscape behavior.

In order to substantiate this model of fluvial system behavior, studies of long duration in steeplands are required, but what was, in effect, a model study of episodic behavior was made in the Kraft Badlands in eastern Wyoming during the summer of 1978 (Bergstrom, 1980).

In addition, experimental studies of sediment movement, drainage network and channel changes were carried out in the Rainfall-Erosion

Facility (REF), during the summer of 1978 and a field check on the experimental results was made in the Little South Fork of the Cache la Poudre River near Fort Collins, Colorado (Harvey, 1980) where a series of sediment samples were taken during the 1979 runoff season to document daily and hourly changes of sediment load and sediment type.

#### SUMMARY OF RESULTS

##### Kraft Badlands

The Kraft Badlands are located northeast of Lusk, Wyoming, and north of Pine Ridge, the southern boundary of the Cheyenne River Basin. Preliminary studies revealed that three zones can be distinguished in the badland drainage basins, as described in steplands elsewhere (Hayward, 1978 and O'Loughlin, 1980). Distinct changes of valley morphology generally mark the zone boundaries. Zone 1 is the head-water high-sediment-production zone. It is separated from Zone 2 by an abrupt increase in valley width and decrease in channel slope. Zone 2, an intermediate zone of sediment storage and production, in turn terminates at Zone 3, which is the downstream braided-channel zone. The observations in the Kraft Badlands during 1978 provide a basis for statements about the episodic behavior of the channels in the three zones.

Zone 1 - An idealized sequence of cross sections in lower Zone 1 is shown on Figure 1a. The numbers, 1 through 4, identify the attitude of the valley flow and channel at different times during the year. Winter sediment production covers the bedrock valley floor (1) and partly fills the valley (2a). Debris torrents during spring rains cause

further aggradation (2b). Precipitation on bare slopes and upstream bedrock yields flashy sediment-free runoff, which causes incision and removal of much of the stored alluvium (3) and subsequent runoff events cause further incision back to the bedrock valley floor (4) leaving a valley-side terrace (3).

Zone 2 - At stage 1 in Zone 2 (Fig. 1b), valley fill is present (1). Early spring runoff, incises the alluvium (2) and produces a terrace or multiple terraces. As sediment is introduced to Zone 2, as a result of major incision of the Zone 1 valley fill, aggradation raises the valley floor (3). When Zone 1 sediment production decreases, as the channels reach bedrock, the Zone 2 alluvial fill is eroded episodically (4a, 4b, 4c). Zone 2 is clearly out of phase with Zone 1. Zone 1 aggradation coincides with Zone 2 degradation and vice versa.

Zone 3 - Only during the largest hydrologic events did runoff occur throughout the three zones. During small storms, when Zone 1 and/or Zone 2 were actively producing and transporting material, Zone 3 received little flow capable of modifying the valley fill (Fig. 1c (1)). Therefore, sediment was stored in Zone 3 (1, 2, 3a) and in-channel fans, which were obvious sites of maximum storage formed. When runoff occurred in Zone 3, the fans were incised, and sediment was moved out of the basin (3b). As sediment continued to be contributed from Zone 2, a particular cross section would alternately aggrade and degrade (4a, 4b), depending on whether a fan was being constructed or eroded. Therefore, reaches of channel in Zone 3 were frequently out of phase at any given time.



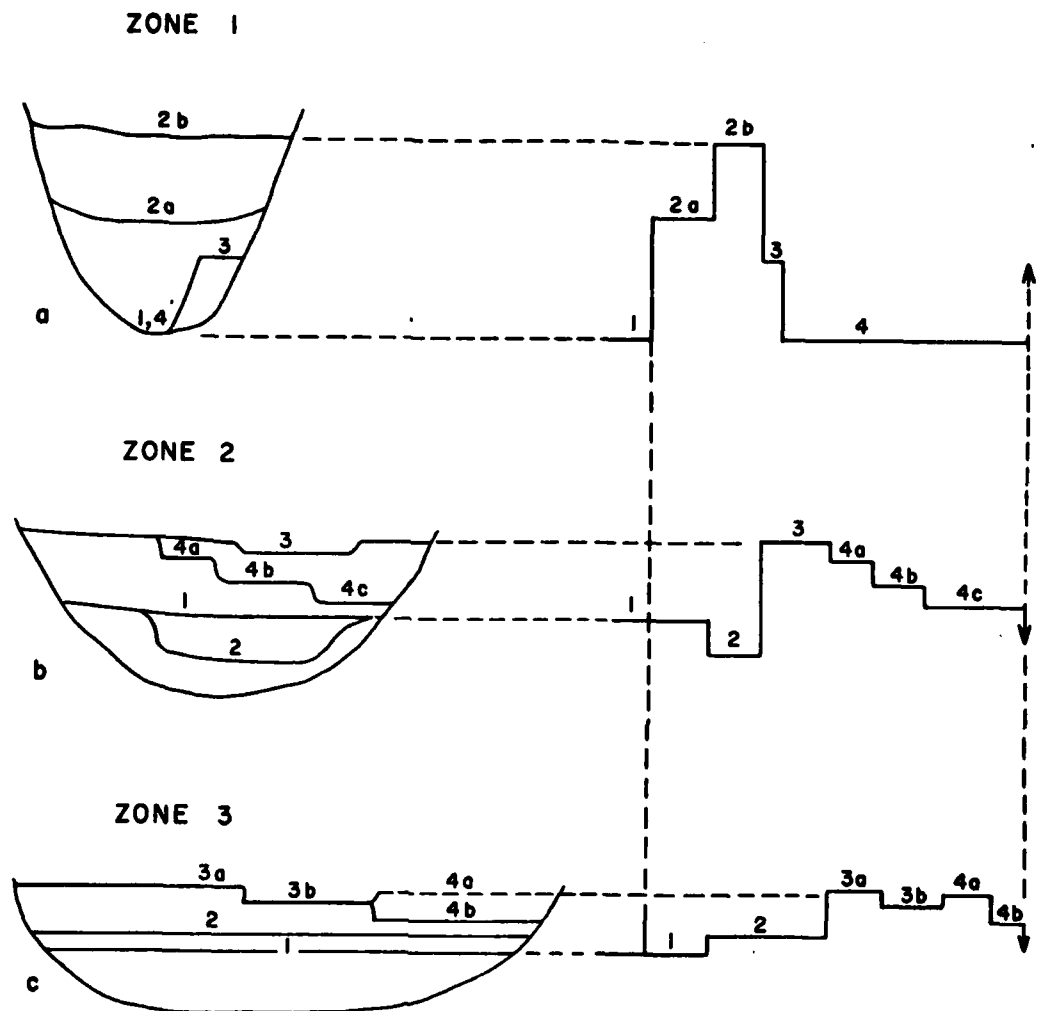


Figure 1. Idealized cross sections showing changes in Zones 1, 2, 3 during one season in the Kraft Badlands. Diagram to right of each cross section illustrates channel behavior in each zone.

## SUMMARY

In steep terrain, as exemplified by the Kraft Badlands, sediment production is not uniform during time or in space. Widespread mass wasting of slopes and the incision of channel-stored sediment in Zone 1 produce large quantities of sediment that is delivered to Zones 2 and 3. The main channel is overloaded and channel filling and storage is followed by erosion and sediment transport. Deposition and erosion alternates episodically through time within the three zones. The three zones are usually out of phase with one another at a given time. Zone 2 initially acts as a source of sediment and Zone 3 acts as a sink. As Zone 1 begins to produce sediment, Zone 2 and 3 both aggrade. Finally, Zone 2 acts as a conveyor of material temporarily stored at the Zone 1-Zone 2 boundary and Zone 3 acts as both a sink and a source of sediment as in-channel fans form and are incised.

Sediment production from a basin will vary greatly, as sediment is stored and remobilized. This was observed during experimental study of drainage-network rejuvenation (Schumm, 1977) and sediment delivery ratios will exceed one during episodes of major sediment export.

The sequence of events that takes place during a single year in the Kraft Badlands may be analogous to much longer periods of sediment storage and removal on larger steep-land watersheds.

## RAINFALL-EROSION FACILITY

A model drainage basin was sculptured in the REF, and the water and sediment delivered from this drainage basin was conveyed through

a 14 m channel to the outlet of the REF.

After each experimental run, longitudinal profiles and cross sections were measured in both the drainage basin and in the long channel. Water and sediment were collected during each run.

Mass movement and channel erosion in the upper basin caused episodic sediment transport in the lower basin and long channel. Temporary storage of sediment in valley-fans and channel plugs, which subsequently failed, produced surges or waves of sediment that migrated through the system, either continuously as a moving surge of sediment or discontinuously as the sediment was deposited and remobilized.

Sediment yields from the REF were highly variable, reflecting the movement of bed-load waves. In addition, the nature of the sediment changed among and during runs with bed-load being dominant during middle and late periods of a runoff event.

Movement of bed-load surges through the channel caused alterations of channel morphology from a single-thalweg slightly-sinuuous channel to a braided pattern. It is suggested that variations in channel patterns in nature and the locations of area of bank instability and local navigation problems may be related to megawaves of sediment in large rivers.

Sediment yields, during the course of individual runs, showed a hysteresis effect with a major decrease in sediment loads at a given discharge as the proportion of the total load that is suspended sediment decreased early in a run prior to the hydrographs peak.

The percentage of the total load that was bed-load was highest at the inception of runoff as stored sediment was remobilized; then a

second peak occurred when discharge was greatest, and a third peak occurred during waning flow due to minor channel scour.

#### FIELD STUDY

Sediment waves were not recognized in the gravel and cobble bed South Fork Cache la Poudre River, but considerable variations in the quantity of sediment load and type of sediment load were identified during daily and hourly sampling periods.

The reach of river investigated is undersupplied with sediment, as a gravel armor partly protects the stream bed.

During the annual snow-melt season, sediment supply and quantity changes significantly as:

- (1) during the rising limb of the snow-melt hydrograph sediment is derived from available in-channel sediment (small bars, and sediment in the lee of cobbles and boulders);
- (2) near the peak of the seasonal hydrograph the armor is breached and "protected" sediment is released, with a major increase of stream bank erosion;
- (3) on the falling limb, the conditions revert to that of condition 1 with armor refirming and local storage of sediment.

Diurnal fluctuations of stages also influence sediment movement, especially when the daily peak is great enough for bank attack to be important.

In the South Fork Cache la Poudre both daily and seasonal variations of sediment loads are great and order of magnitude changes are common.

The great variations in both amount and type of sediment load measured in the field and in the REF render the development of an accurate predictor of sediment difficult if not impossible.

#### SUMMARY

The episodic behavior, as identified in the Kraft Badlands and during the experiments, if present in steep land watersheds will have significant effects on channel stability and may explain bridge failures under presumably safe hydraulic conditions.

Of great significance is the large magnitude of sediment transport variations and the channel changes associated with them. Engineering designs based on short-term sediment yield records and existing channel morphology in steep land basins may prove to be wholly inadequate in a situation where there is episodic behavior of the drainage system.

It is possible that episodic behavior and resulting sediment surges are significantly affecting many modern rivers. For example, sediment introduced into the Mississippi River by the New Madrid earthquake may be moving as a surge that is creating bank stability and navigation problems downstream on a small scale. The conclusions relate to the different behavior seen along the longitudinal profile of steep land catchments in New Zealand and Southern California. Hayward (1978), O'Loughlin (1969) and Kelsey (1977) all describe a change in form and process downstream. Their descriptions fit well with the three-zone badland model and observations in the REF.

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PERSONNEL SUPPORTED

- S. A. Schumm, Principal Investigator, Professor of Geology
- M. D. Harvey, Research Assistant and Research Associate. Ph.D. Degree will be awarded in December 1980.
- F. W. Bergstrom, Research Assistant, M.S. Degree to be awarded in September 1980.
- C. Lidstone, Research Assistant - partial support from project as field and laboratory assistant. M.S. Thesis in preparation.
- N. Wildman, Research Assistant - partial support as field assistant. M.S. Thesis in preparation.