EXPERIMENTAL STUDY OF THE DEPOSITION AND DRYING OF BIJOU CREEK SAND IN A RECIRCULATING FLUME

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Pierre Y. Julien
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Prepared for

M. Guy Berthault

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Report CER ~~88-89~~ PYJ-YCC~~15~~

Engineering Research Center
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LIST OF SYMBOLS

D_{10}	=	Particle-size for which 10% of the sand is finer
D_{25}	=	Particle-size for which 25% of the sand is finer
D_{50}	=	Particle-size for which 50% of the sand is finer
D_{75}	=	Particle-size for which 75% of the sand is finer
D_{90}	=	Particle-size for which 90% of the sand if finer
f	=	Friction coefficient
Fr	=	Froude number
h	=	Depth of flow (cm)
H.Lam.	=	Horizontal lamination
Q	=	Discharge (cm^3/sec)
Shear	=	Bed shear stress (dyne/cm^2)
S_w	=	Water surface slope
U*	=	Friction velocity (cm/sec)
V_m	=	Mean velocity (cm/sec)
V_s	=	Water surface velocity (cm/sec)

1. INTRODUCTION

The structure, texture, and shape of sand material deposited provides a useful interpretation of the ancient deposits formed during floods. They also help in relating the types of structures in a recognizable flood deposit to the specific stage of flood deposition, or stream regime, and in distinguishing the deposits of a river channel from those of adjacent flood plains (McKee et al., 1967).

A former investigation of the deposits on Bijou Creek flood, June 1965 (McKee et al., 1967), was undertaken to determine criteria that might be used in the recognition of flood deposits in ancient rocks and a study of sedimentation in terrestrial environments.

The proposed laboratory experiments in a small recirculating flume are intended to examine the depositional characteristics of Bijou Creek sand under plane bed conditions with sediment motion.

A recirculating plexiglass flume has been designed at the Engineering Research Center of Colorado State University for the analysis of deposition processes under a wide variety of flow conditions (Julien and Chen, 1989a, 1989b). This flume recirculates both water and sediment under steady flow conditions during the course of each experiment.

This study is limited to horizontal deposition processes without bed forms because horizontal deposits constituted 90 to 95 percent of all deposits of the Bijou Creek flood (McKee et al., 1967). After each experiment, the sediment deposits were dried in the flume to examine the appearance of vertical cracks and stratification joints.

2. LITERATURE REVIEW ON BIJOU CREEK FLOOD, JUNE 1965

The heavy rains in June 1965 caused floods of unusual magnitude in the area drained by the South Platte River. The floodwaters spread extensive, locally thick deposits of sand and mud along the South Platte River and its tributaries. It was a good opportunity to study the distribution, texture, composition, and structures of sediment deposits under flood conditions. The deposits of Bijou Creek, a tributary of South Platte River, were investigated by McKee et al. (1967) in recognition of flood deposits in ancient rocks and in studies of sedimentation in terrestrial environments.

The geological environment of the area drained by Bijou Creek is underlain by the Pierre shale, Fox Hills sandstone, and Laramie Formation of Late Cretaceous age. These formations consist of poorly to moderately well consolidated shale, sandy shale, sandstone, and lignitic coal beds; they contain little or no coarse material, in contrast to younger deposits of this area. The surface material is confined within the older alluvial deposits on the channel and flood plain (McLaughlin, 1946).

The local rainstorms across eastern Colorado and heavy rains at Bijou Creek drainage area caused a flood peak discharge of 466,000 ft^3/sec near the mouth of the creek, breaking the former observed peak discharge of 282,000 ft^3/sec. A mean velocity of 16.4 ft/sec was reported for the entire cross-sectional area, and velocities up to 21.8 ft/sec for the main channel were reported (McKee et al., 1967). Four localities were studied along Bijou Creek including East and West Bijou Creeks for flood deposit of 1965 as shown on Fig. 1. There were 75 trenches dug in this area with depths ranging from a few inches to 12 feet deep and lengths from 2 to 12 feet. In each trench two

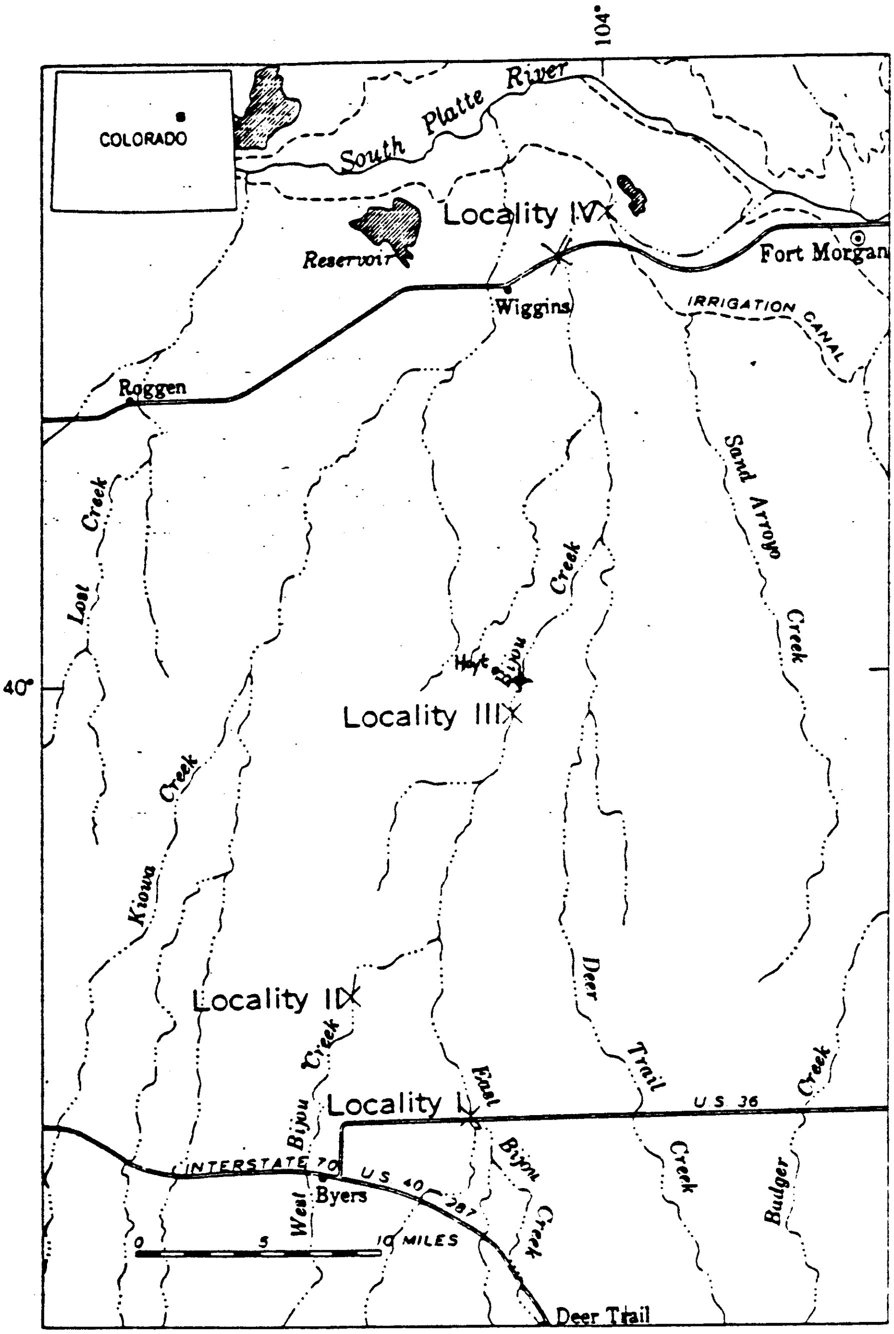


Fig. 1. Index map of Bijou Creek, north of Byers, Colo., showing localities where flood deposits of June 1965 were investigated (McKee et al., 1967).

Note: ✦ showing locality of sand samples in this experiment.

vertical faces at right angles were planed and the structures were recorded by field sketches and photographs. Measured thicknesses and angles of dip were recorded on the sketches. The investigated results in the report are summarized on Table 1 for each locality.

The maximum measured thickness of deposits attributable to the flood was about 12 feet and the thicknesses of 2 to 4 feet were common at all localities. However, within the main channel, most new deposits could not be distinguished from older ones as no soil or vegetation zone was present. The scouring and filling was continuously occurring in the cross-section during flow and may cause changes of 5 to 10 feet in elevation of the sediment-water interface during flooding.

At all localities sampled, the most abundant sediment was quartz sand of fine to coarse texture. Small amounts of silt and clay, mostly less than 2 percent, were intermixed with sand in some beds, and a few thin beds of silt, silty clay, and clay were noted in overbank deposits. Several samples from locality I contain 5 to 30 percent fine gravel and a few larger pebbles; however, samples for downstream localities yielded much less very coarse sediment. It was a sorting process along Bijou Creek from upstream to downstream.

On the flood plain, the newly-formed flood deposits were mostly flat bedded. Low-to-moderate-angle foreset bedding formed where receding water poured back into the main or subsidiary channels or where it swirled around the bases of large trees. Climbing-ripple laminae and convolute structures were well developed in limited area. Cut-and-fill structures were present but common in overbank deposits. In channel deposits, both flat bedding and

Table 1. Summary of Bijou Creek Flood Deposits, June 1965

	Locality I	Locality II
Trench number	23	28
Thick-ness	*20-30 inches near cutbank along channel edge; *A maximum thickness of 40 inches in a trench; *In eastern 2/3 of the deposits, the sand maintain a thickness of 20 inches or more to within 100 ft of edge of deposition; *Northward (wooded area), the sand thinned irregularly across a distance of 1000 ft or more.	*Site A: A blanket ranging in thickness from 2 or 3 ft near bank to 1 ft or less at down-current margin; *Site B: Thickness is greater than that in most of the flood deposits; 12 ft of thickness is the greatest thickness observed during study; *Site C: Depth to the preflood surface was not determined, but deposits ranging from mud to coarsersand and including many mudball are exposed to 50 inches.
Struc-ture	*Dominately even-bedded, flat-lying or essentially horizontal strata; *Dips of less than 5 degree were most common; some were more than 10 degree; *Low-angle foreset bedding along outer margin and 28 deqree steeper foresets around trees; *Small scale cut-and-fill near top of one trench; *2 examples of deformation that shallow V's bent downward in a zone of near flat-lying laminae were noted.	*Site A: Relatively thin overbank deposits consist almost entirely of flat, nearly horizontal strata; *site B: Several of which indicate a lower flow regime like climbing ripple laminae, foresets forming tabular planar crossbedding, and convolute lamination; *Site C: Flat-lying layers of sand, sets of trough-planar crossbeds in 5 ft thickness, climbing ripple laminae near top layers, and layers or lenses of dominantly spherical mudballs.
Texture	*41% medium sand, 32% coarse sand and 14% fine sand in total 52 samples; *Sorting, according to the Payne scale, was fair in 50 sample, good in one, and poor in one; *Material larger than coarse sand was conspicuously present both within the bedded deposits and as a veneer over much of the surface of sand sheet. Very coarse sand and granules were interbedded with finer sand in some trenches; pebbles and cobbles up to 7 or 8 inches long were scattered through the sand and on the sand surface. *Small clay ball and large crumbling clay ball were exposed at upper surface of the sand deposit.	*Most in medium to fine dominant grain size among 40 samples; *Site A: Medium to coarse grains in essentially horizontal strata; most in sorting of fair; *Site B: 15 Of 24 samples in fine-grain; most of reminder are either slightly coarser or slightly finer; 21 samples in fair sorting, 2 poor and 1 good; *Site C: 6 of 11 samples in medium grain size and 8 samples in fair sorting and 3 in poor; *The dominant grain size in horizontal laminae ranges from very fine to very coarse; however ripple lamination and convolute structure are predominantly fine to very fine grained.

Table 1 (continued)

	Locality III	Locality IV
Trench number	17	7
Thick-ness	*The sand sheet is a lens bisected by the stream channel; the thickness of sand on the east flood plain is 72 inches at cutbank but decreases uniformly eastward to the margin of the deposits; *Thickness is 17 inches at cutbank and increases irregularly to 54 inches on west flood plain; *Thickness in main channel is unknown due to the difficulty in recognizing preflood surface.	*Two lens deposit on flood plain and main channel; *An asymmetrical lens on flood plain whose thickest part, near the north edge, is 34 inches; *Maximum thickness in main channel is unknown due to unrecognized preflood surface in a trench to 28 inches.
Struc-ture	*Laminated, flat-lying to near flat-lying beds on flood plain; dips of less than 5 degree in common; deposition near margin has dips of more than 10 degree; *Both cut-and-fill crossbedded and horizontally laminated sand deposits fill main channel; *Climbing-ripple bedding and cut-and-fill bedding along secondary channel at outer edge of west flood plain; *Along east bank of main channel two types of erosional structure: wedge-shape beds at channel edge against truncated, laminated deposit before flood and faults that formed at still water when slices of sand along bank slumped to channel floor.	*Horizontal to nearly horizontal layer across flood plain; less 5 degree of dip in common; *A lower unit of laminated sand, a middle unit of virtually structureless sand that contains thick laminae locally, and a local thin upper unit of horizontally bedded to crossbedded sand that is absent in 3 trenches on the flood plain. *In the channel the part of sand deposit exposed by two units of crossbedded sand separated by a horizontal layered, laminated unit; the lower unit has cut-and-fill bedding of well developed festoon pattern; in upper unit the crossbedding is more tabular and wedge shaped, but still has festoon pattern; and the surface of channel is marked by a series of megaripples.
Texture	*The predominant grain size is medium, but the degree of sorting is only fair in most samples; *The coarsest material in deposit is in main channel and decreases in both outer margin of flood plain direction; *The coarser sand not only is largely in main channel but most is associated with cut-and-fill crossbedding.	*Coarse grains dominate at this locality; however, a range of medium to very coarse grain size more nearly typifies the deposit as a whole; the vertical variation in grain size is more apparent than lateral variation; *At this locality stratigraphic units could be recognized by differences in grain size more readily than by structure; lateral variation in grain size is also apparent; *The distinctiveness of two main units across flood plain in the upper coarse-grained unit ranges from nonlayered to crossbedded indicate an increase both in water velocity and in bed load of coarse material.

festoon crossbedding were formed characterically. Those depositional structures are similar to the sedimentary structures investigated in the deltaic plain of Mississippi River (Coleman and Gagliano, 1965).

The analysis of the sedimentary characteristics for flood deposits should be useful in interpretation of depositional environments represented by ancient rocks. The flood plain deposits extended over several thousand feet in width and up to 12 feet in thickness, and were characterized by a variety of sedimentary structures accumulated during a few hours.

The strata of sand deposited by a violent flood contain dominantly horizontal layering characteristic of the upper stream regime. In contrast to the horizontal stratification of rapid flow characteristic, climbing-ripple lamination, convolute structures, festoon bedding, and scoured surfaces commonly result from the decrease of velocity during the waning stage of flood.

In contrast, the texture of sand, although it may record rapid flow relatively coarse grains and decrease in velocity with finer grains, can be deceptive. Relatively slow, receding water may rework coarse sediments deposited earlier and thus reverse a normal depositional sequence of texture.

The medium-to-large-scale festoon crossbedding and the megaripples, common to stream channels where flow is concentrated, contrast with the typical climb-ripple lamination and convolute structures of blanket deposits formed during the waning phase of flood plain deposition.

3. EXPERIMENTS

3.1 Equipment

The experiments are carried out in a tilting, recirculating plexiglass flume: 0.15 m wide, 0.15 m deep, and 2.40 m long. The flow rate is controlled by a gate valve and measured by a calibrated Venturi orifice. The deposition of sand in the flume is controlled by two kinds of tailgate in 0.02 m high and 0.04 m high. The depth of water and deposition is measured by an affixed ruler on sidewall of flume. The slope of flume can be adjusted by a screw jack which supports the front end of the flume.

Particular consideration in the design procedure has been given to the entrance condition of the flume. The return of water and sediment in the headwater box needs to be carefully designed in order to ensure complete mixing of the sediment particles and constant inflow of sediment under steady flow condition. The rounded entrance profile and the use of a movable plate provided excellent feeding conditions into the flume channel.

3.2 Sand Material

The sediment used in this experiment is natural sand from the surface of the main channel bed of Bijou Creek near Hoyt, Colorado as shown in Fig. 1. The locality of this sample is also near the Locality III in the investigation in McKee et al. (1967). Prior to the experiments, this natural sand has been sieved and the vegetation and pebbles were removed. The characteristics of the natural Bijou Creek sand are summarized in Table 2, and the particle-size distribution curve is shown on Fig. 2.

Table 2. The Bijou Creek Sand Size Distribution

Type	D_{10}	D_{25}	D_{50}	D_{75}	D_{90}
Bijou Creek sand	0.34 mm	0.52 mm	0.75 mm	1.10 mm	1.65 mm

The size of sand particles ranges from fine to very coarse sand and the silt and clay content (below #230 sieve) is only 0.1 percent according to Table 3 of sediment grade scale which is modified from the classification of the Subcommittee on Sediment Terminology of the American Geophysical Union (Lane, 1947). It is similar to the grain analysis in the report of McKee et al. (1967)--"At all localities sampled, the most abundant sediment was quartz sand of fine to coarse texture. Minor amounts of silt and clay, mostly less than 2 percent" (p. 831).

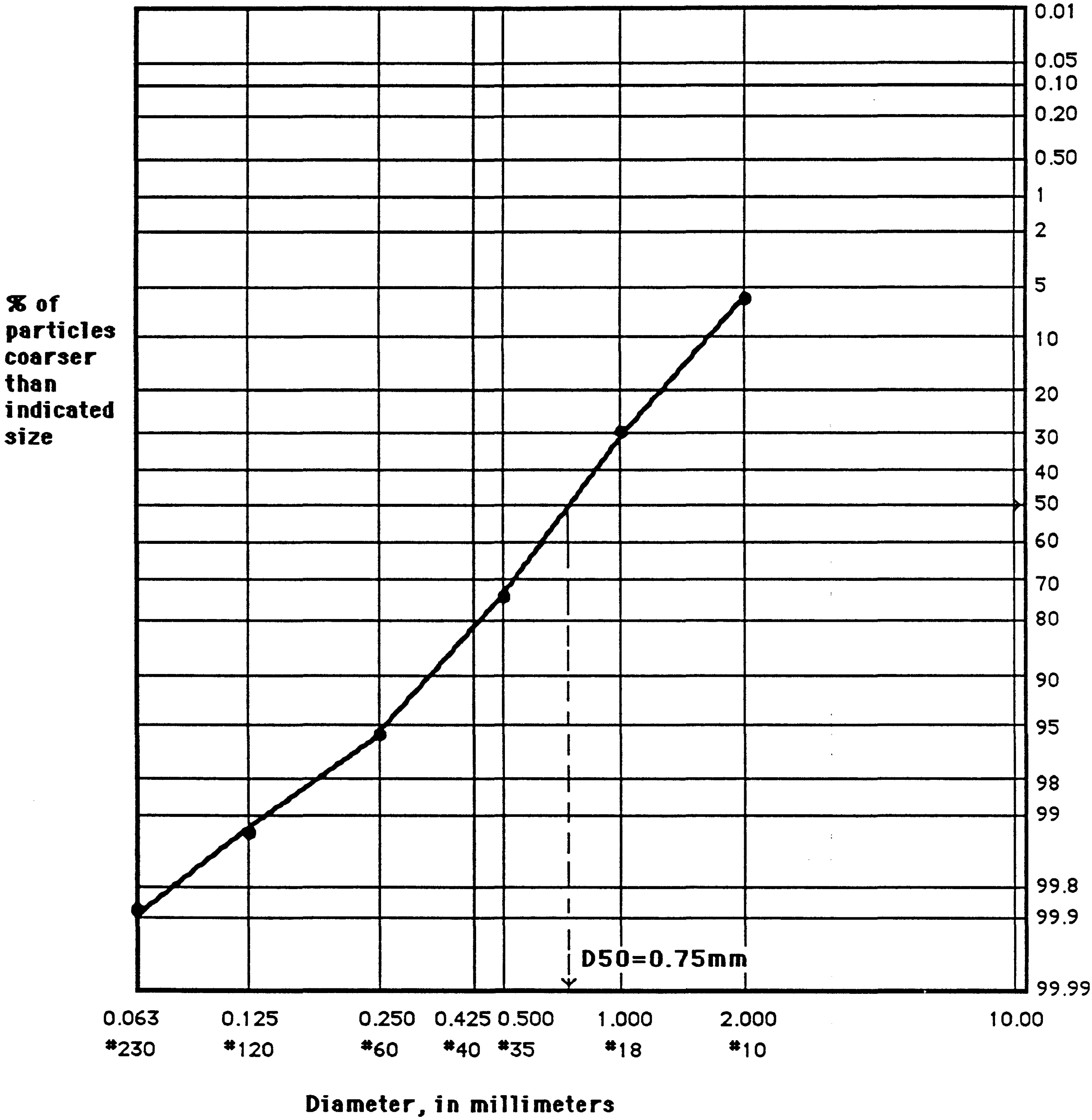


Fig. 2. Particle-size distribution for Bijou Creek sand.

Table 3. Sediment Grade Scale

Class Name	Size Range	Sieve Mesh (U.S. Standard)	Percentage
Gravel	above 2.00 mm	above #10	6.0%
Very coarse sand	2.00 mm-1.00 mm	#18	30.0%
Coarse sand	1.00 mm-0.50 mm	#35	74.0%
Medium sand	0.50 mm-0.25 mm	#60	96.0%
Fine sand	0.25 mm-0.125 mm	#120	99.2%
Very fine sand	0.125 mm-0.063 mm	#230	99.9%
Silt and clay	below 0.063 mm	below #230	100.0%

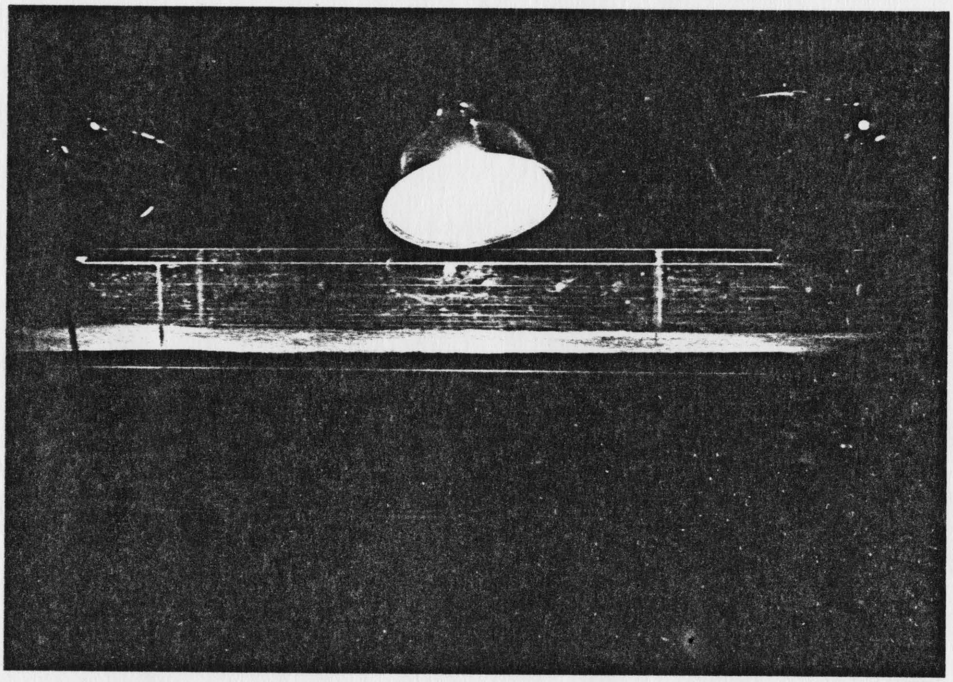
3.3 Procedure

In this experimental program, two runs are proposed for the Bijou Creek sand. Before each run, the flume slope is set horizontal and the valve is adjusted to control the flow rate which recirculates sediment and forms horizontal deposits. The flow discharge is then maintained steady during the course of each run.

For the first run (RUN #1) the water flows freely without gate control until the first deposition layer is formed. The first small gate (2 cm high) is then inserted at the downstream end and the second strata forms until equilibrium conditions are reached. The second gate (2 cm high) is then inserted to form the other strata superposed on the first one. During the equilibrium condition in each step we measure the discharge, depth of water, surface velocity and record the configuration of laminae deposition.

For the second run (RUN #2) the water flows freely without gate as the same condition as RUN #1. Sequentially, we put in a simple large gate (4 cm high) to form a thicker strata. However, the second gate is not introduced and the measurements are made after equilibrium conditions are reached.

After each run, solar lights (as shown in Picture 1) are set to dry the deposit of sediment for about one week. The purpose is to observe whether the sand deposit will consolidate and whether vertical cracks and stratification joints will occur or not. The reason why we are interested in the cracking phenomenon is that thin sun-cracked mud layers are often observed on the last sediments deposited during each flood--for example, the cracked surface of the Colorado River flood plain delta at Lake Mead, Arizona (McKee, 1965). In the experiments, the cross-sections are cut at SEC.1+00, and samples are taken from each strata for sieve analysis.



Picture 1. Three lights for drying the deposits.

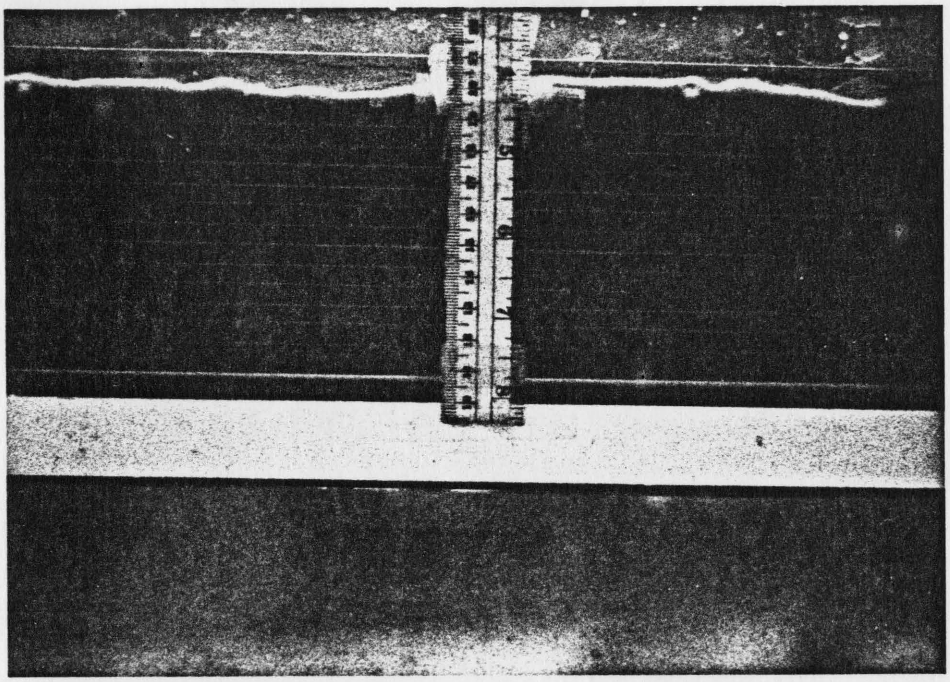
3.4 Data Measurement

During each run, several types of measurements are repeated to generate a data base of hydraulic conditions associated with observed formations of laminae and stratified deposits.

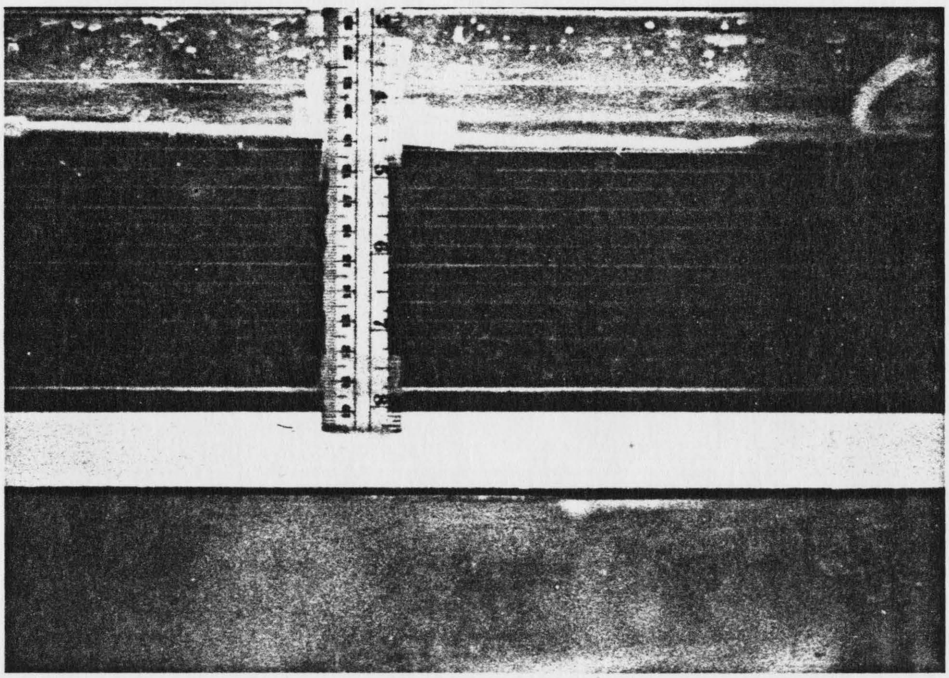
The flow discharge is measured by a Venturi orifice in which the manometer readings are transformed into discharge values through a calibrated chart.

The hydraulic characteristics of flow depth and flow velocity are measured with the water surface slope. The water depth is measured with a ruler affixed on the flume sidewall at several sections including SEC.1+100. The water surface slope is determined from the difference in water surface elevations between two sections. The surface velocity is measured by the travel time of floating particles between two cross-sections. Average flow velocity is calculated from discharge and cross-section area.

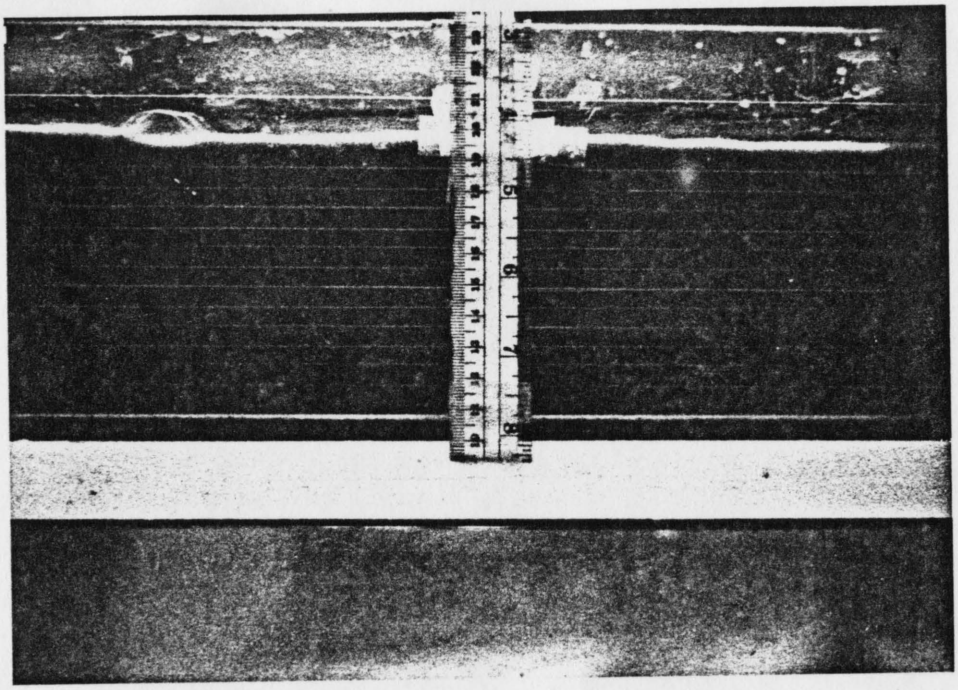
The thickness of horizontal laminae deposits are measured from the ruler affixed on flume sidewall at SEC.1+00. After each run the deposition of sediment is dried out with solar lights. The representative grain size of each stratum is measured by sieve analysis of the samples taken at cross-section SEC.1+00.



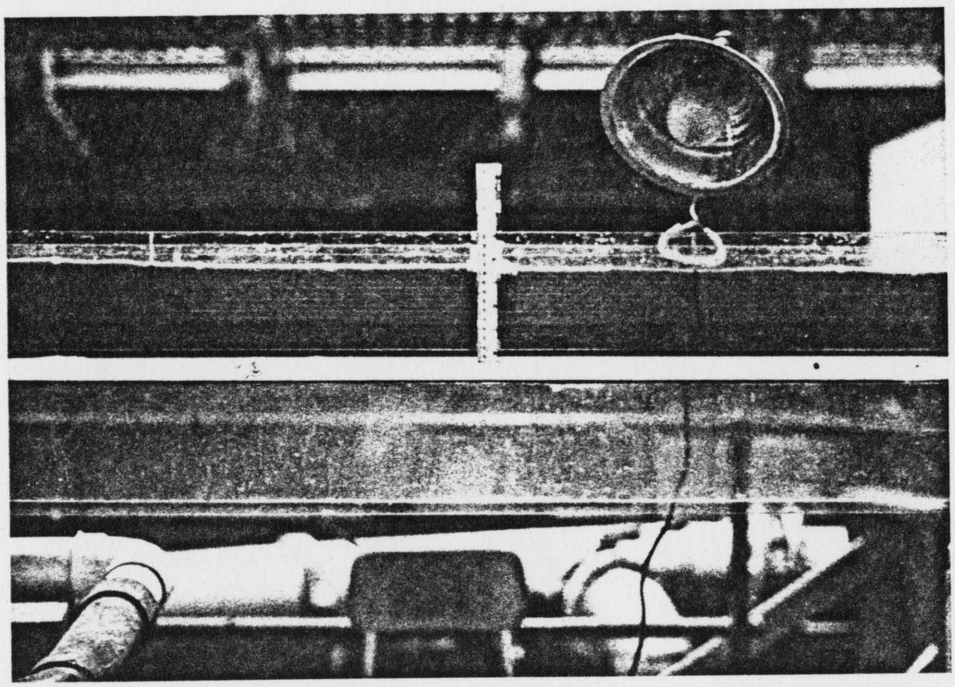
Picture 2. The propagation of the thick delta.



Picture 3. The propagation of delta downstream.



Picture 4. Deposition of fine particles.



Picture 5. Low-relief sandwaves migrate downstream when the horizontal laminae are formed.

4.1 RUN #1

(1) Experimental conditions and data summary:

- Horizontal flume
- D_{50} = 0.75 mm
- Two small tailgates (2 cm high each)
- Deposition is shown in sequence on three photographs:

  without gate - Picture 6

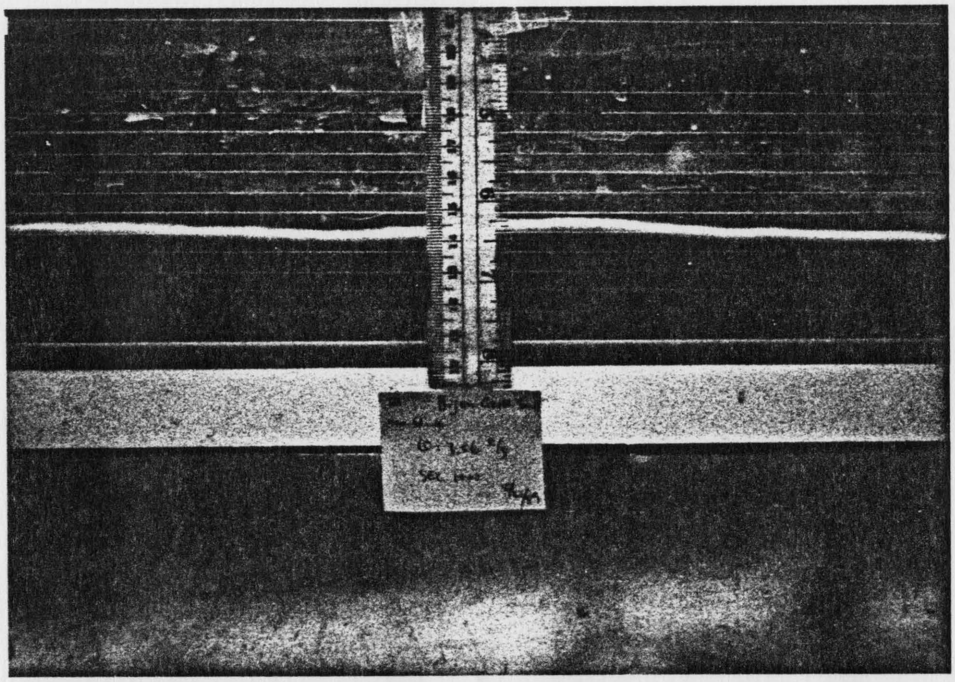
  first gate - Picture 7

  second gate - Picture 8
- The data for this run are summarized in Table 4 below.

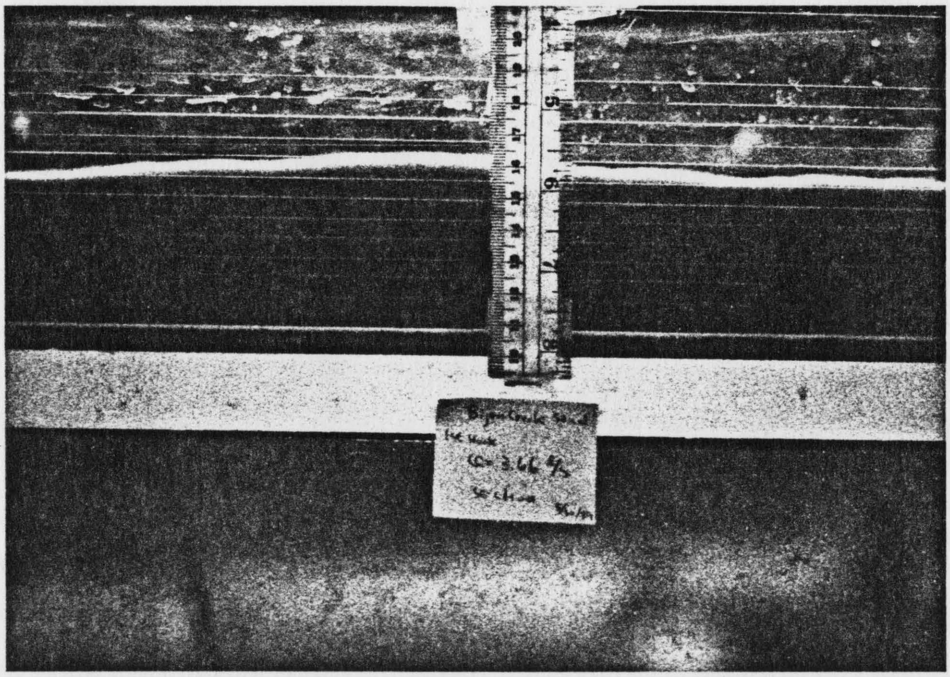
Table 4. Data Summary for RUN #1

RUN: horizontal flume, D_{50}=0.75 mm

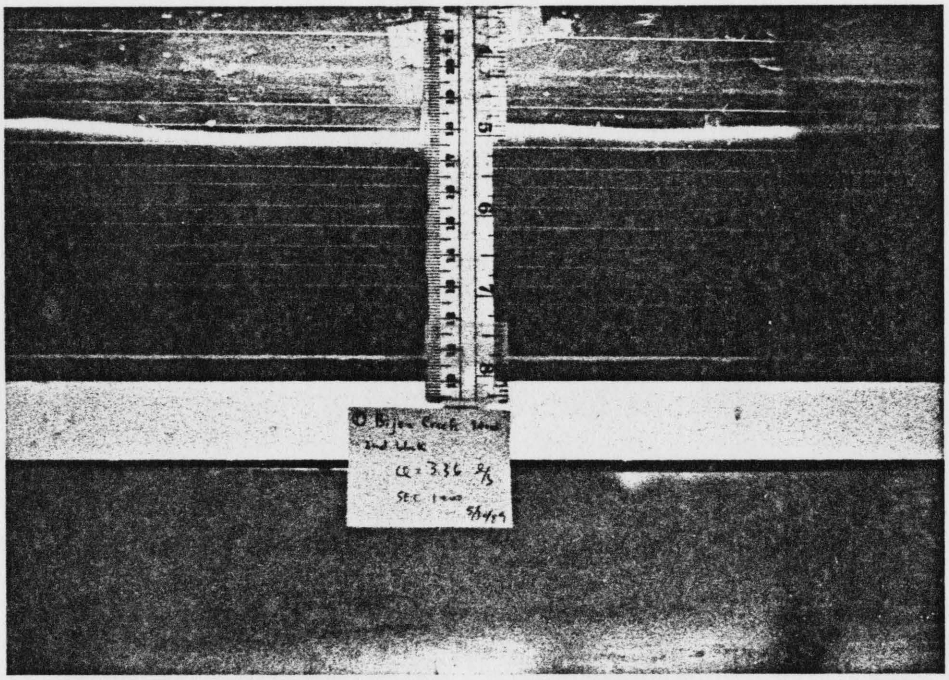
Gate	Q cm^3/s	h cm	V_m cm/s	V_s cm/s	S_w	Shear dyne/ cm^2	F_r	U* cm/s	f	Thickness (mm) H.Lam.	Delta
No	3558	4.20	54.65	58.49	0.010	26.69	0.85	5.17	0.072	1	0
First	3665	5.60	42.22	55.57	0.005	15.93	0.57	3.99	0.071	3	14
Second	3357	5.33	40.63	47.35	0.006	18.57	0.56	4.31	0.090	4	7



Picture 6. Deposition without gates (RUN #1).



Picture 7. Deposition using one gate (2 cm high; RUN #1).



Picture 8. Deposition using two gates (2 cm high; RUN #1).

(2) Results and conclusions of RUN #1:

a. The horizontal lamination layer thickness for the second tailgate condition is a little thicker than that in the first gate condition although the velocity if reduced in the second gate condition as shown on Table 4. However, we find that the bed shear and shear velocity is a little higher in the second gate condition. We also can find similar conditions in the results of Julien and Chen (1989b) where the horizontal lamination thickness increased by increasing not only flow velocity but also bed shear or shear velocity. Therefore, the horizontal lamination thickness seems dependent on the bed shear or shear velocity as well as flow velocity. The deposition of this run is sketched on Fig. 3.

b. After seven days of exposition under solar lights, clear layers of finer and coarser material are shown on Picture 9. There is no vertical crack as shown (Picture 10). However, we can see horizontal cracks after we cut the cross-section at SEC.1+00 as shown on Picture 11. We can peel the separated layers of finer sands and coarser sands easily as shown on Picture 12.

c. Samples from each layer were taken for analysis. The particle-size distribution curves are drawn on Fig. 4 for each layer. The medium grain size (D_{50}) and grade scale classification for each layer are shown on Fig. 3. We also find that silt and clay content is less than 1 percent on the top finer layer. it may explain that no vertical crack appeared on the surface.

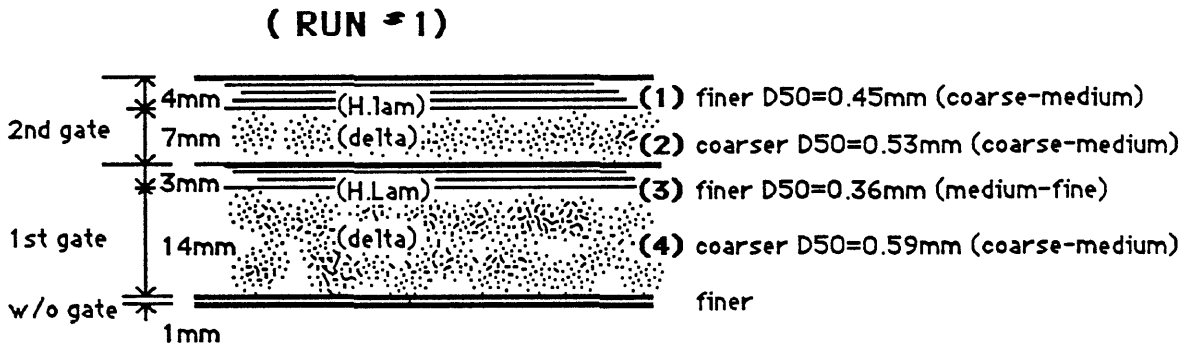
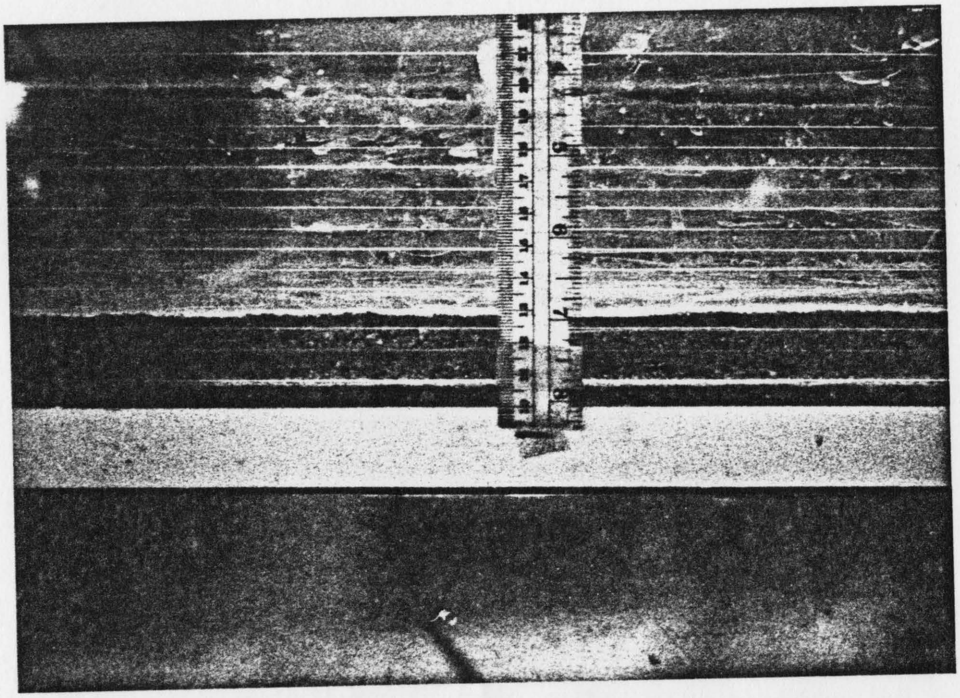
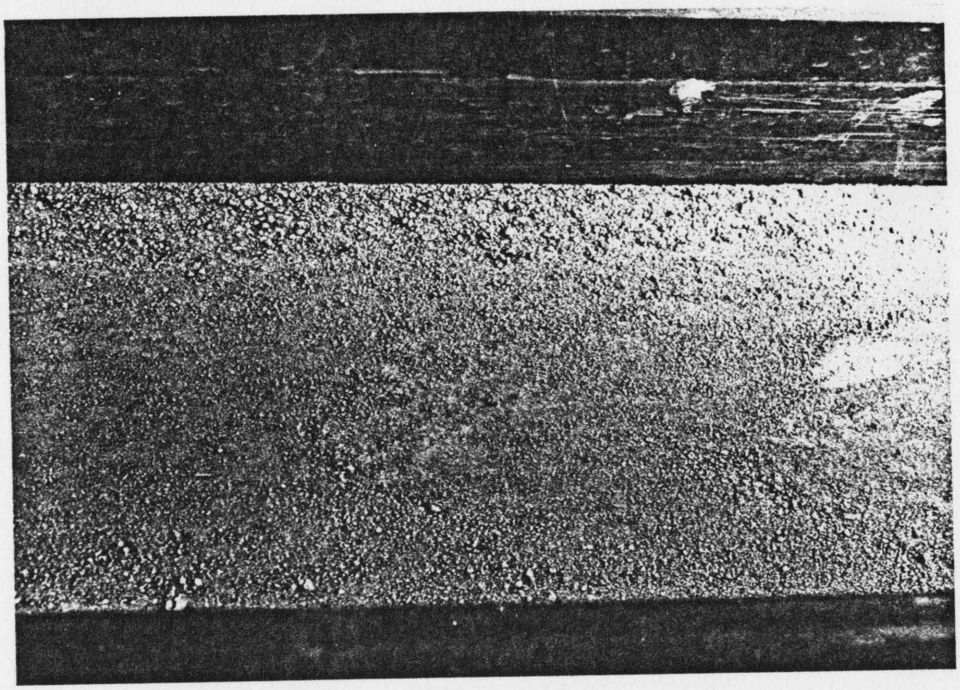


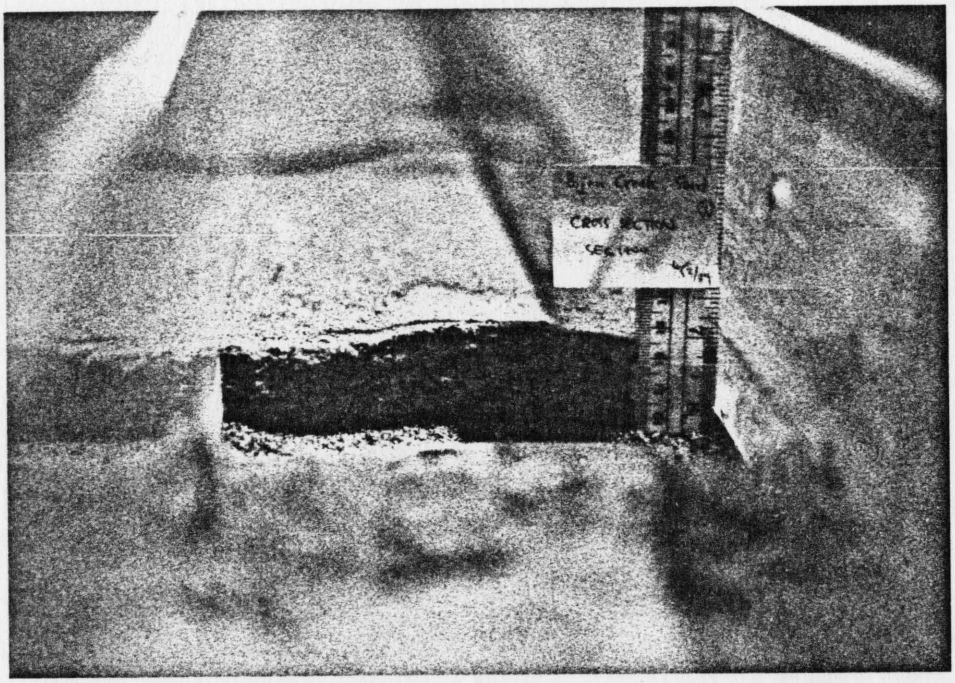
Fig. 3. The deposition of Bijou Creek sand at SEC.1+00 (RUN #1).



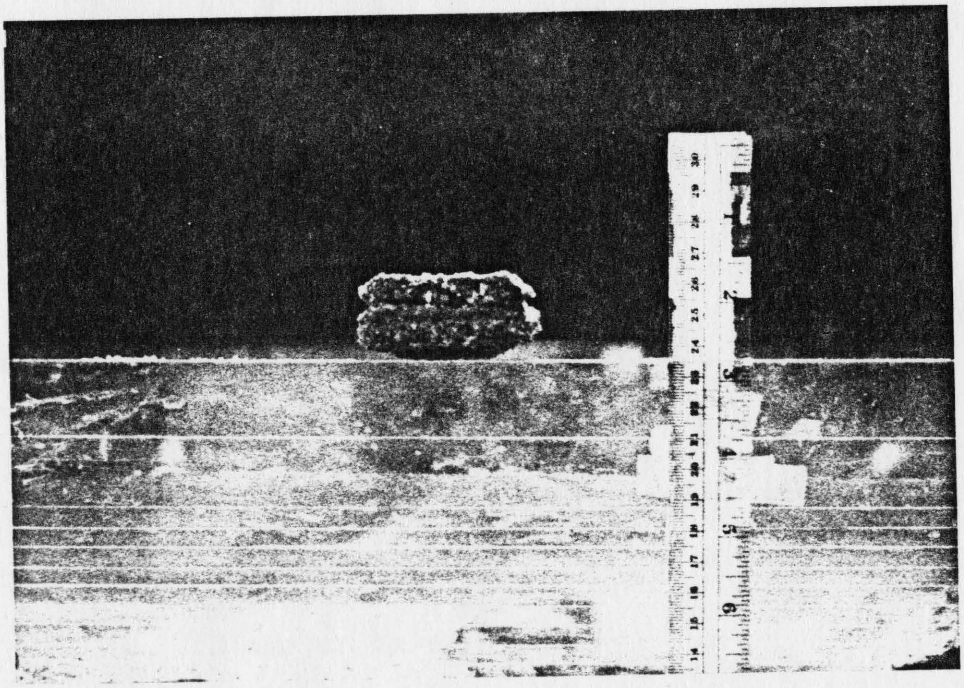
Picture 9. Clear layers of deposition are shown after drying by solar lights.



Picture 10. No vertical crack occurs on the top layer of deposition.



Picture 11. Cross-section is cut at SEC.1+00. Horizontal cracks and separated layers are shown clearly.



Picture 12. Separated layer can be peeled easily.

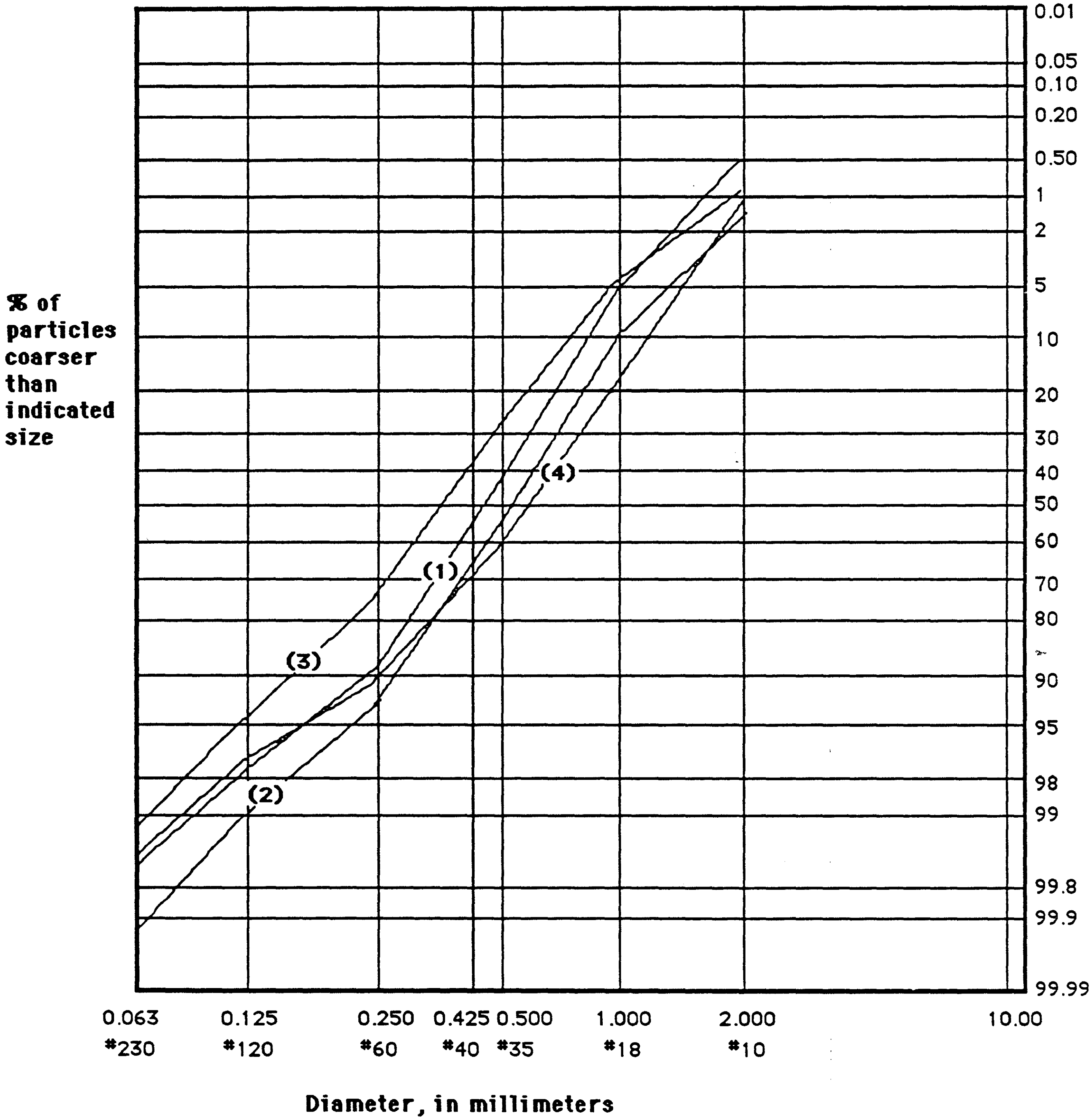


Fig. 4. Particle-size distribution for each stratum of RUN #1.

4.2 RUN #2

(1) Experimental conditions and data summary:

- Horizontal flume
- D_{50} = 0.75 mm
- One larger tailgate (4 cm high)
- Deposition features are shown on the following photographs:

  without gate - Picture 13

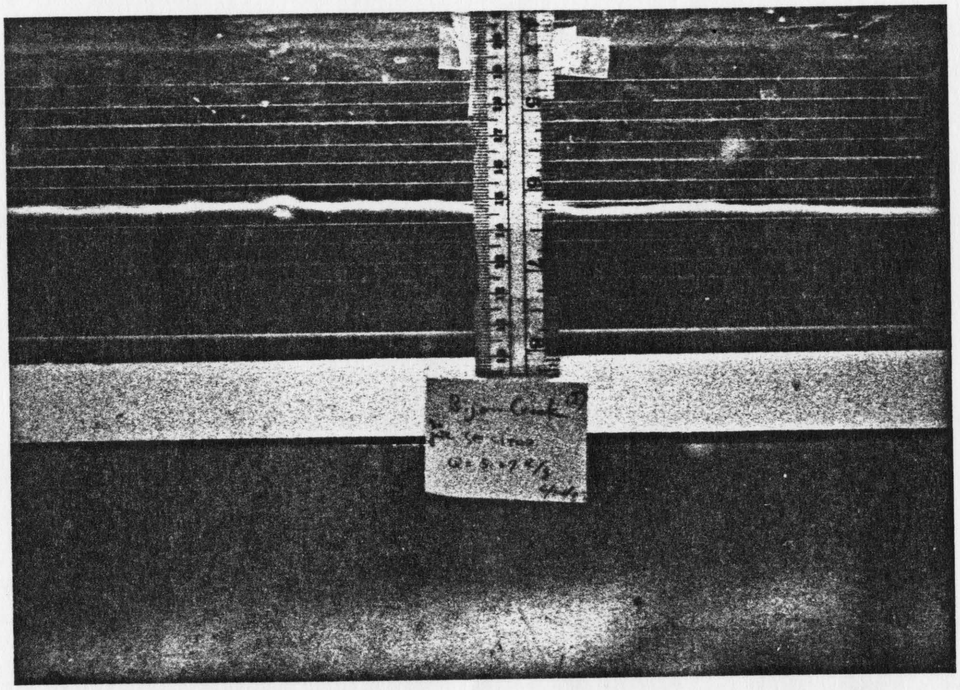
  first gate - Picture 14

  second gate - Picture 8
- The data for this run are summarized in Table 5 below.

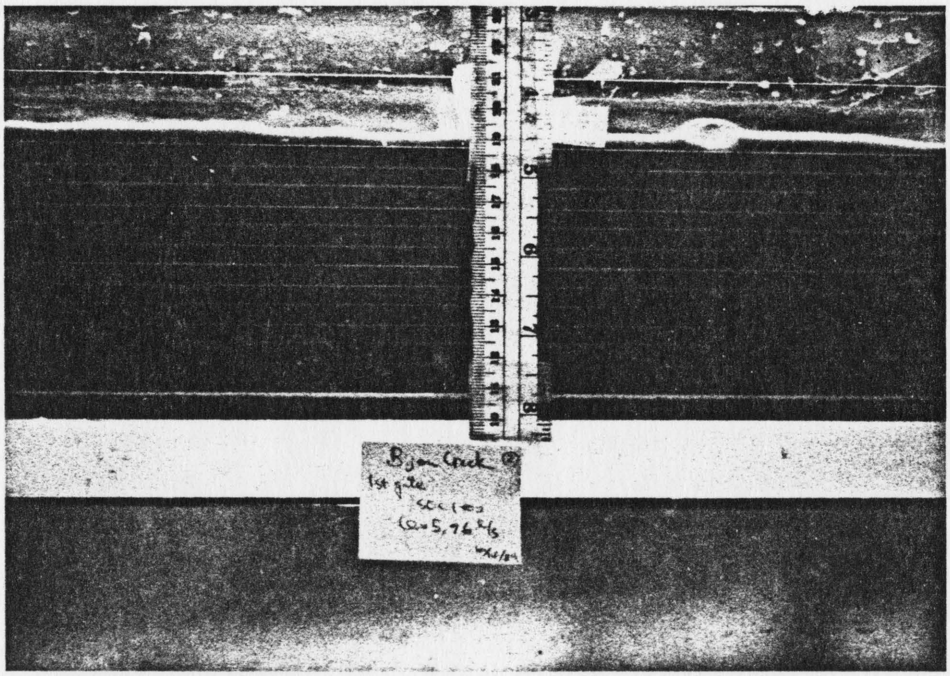
Table 5. Data Summary for RUN #2

RUN: horizontal flume, D_{50}=0.75 mm

Gate	Q cm^3/s	h cm	V_m cm/s	V_s cm/s	S_w	Shear dyne/ cm^2	F_r	U* cm/s	f	Thickness (mm) H.Lam.	Delta
No	5272	4.07	83.56	85.45	0.016	41.84	1.32	6.47	0.048	9	0
First	5958	5.33	72.13	84.77	0.014	43.33	1.00	6.58	0.067	9	22



Picture 13. Deposition without gates (RUN #2).



Picture 14. Deposition using one gate (4 cm high; RUN #2).

(2) Results and conclusions of RUN #2:

a. Comparing to the results of two conditions of larger gate and without gate, we find that the larger tailgate only increases the thickness of the deltaic deposit but not the horizontal lamination deposit. The horizontal lamination layer thicknesses are comparable during similar bed shear and shear velocity. The deposition of this run is sketched on Fig. 5.

b. The layers of fine and coarse deposits are shown on Picture 15 after the exposing of solar light in seven days. The surface layer still shows no vertical cracks (Picture 16). Horizontal cracks between each layer are seen after preparing a cross-sectional cut at SEC.1+00 (Picture 17). We can separate the layer of finer sands from the layer of coarser sands easily as shown on Picture 18.

c. The particle-size distribution curves of those three depositional layers are drawn on Fig. 6. The medium grain size (D_{50}) and the grade scale classification for each layer are shown on Fig. 5. The silt and clay content is less than 1 percent in the top layer as in RUN #1, which may explain why no vertical cracks are seen on the surface.

d. A series of low-relief sandwaves migrate under critical flow conditions (Froude number equal to unity) which is similar to the result reported by Julien and Chen (1989b).

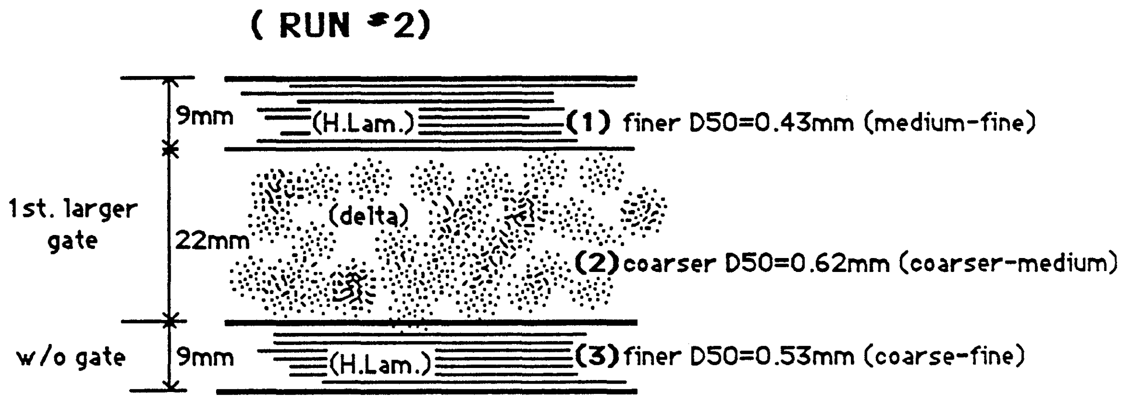
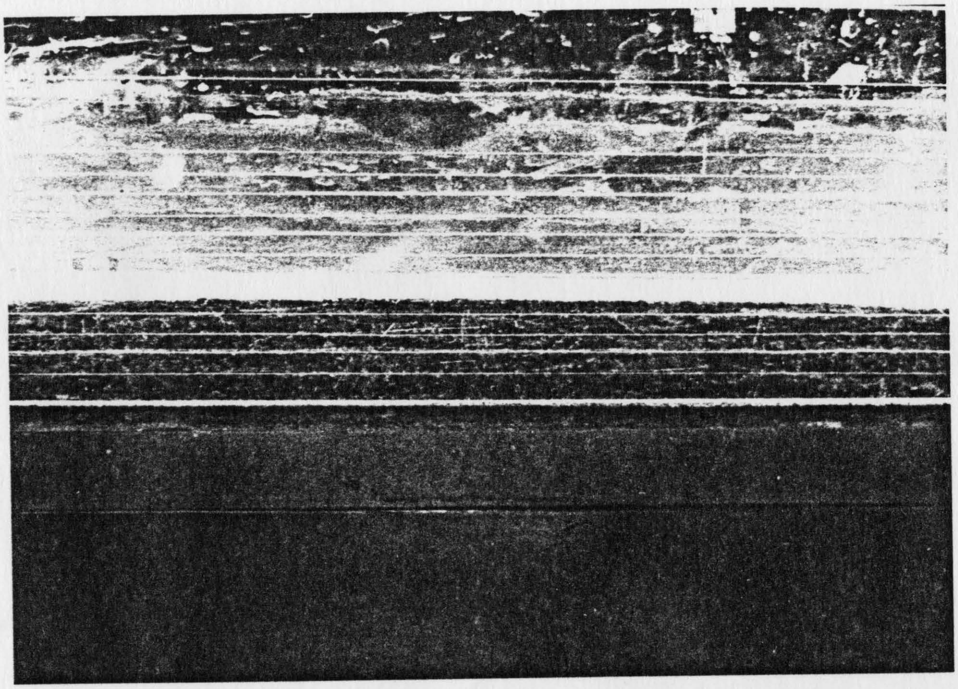
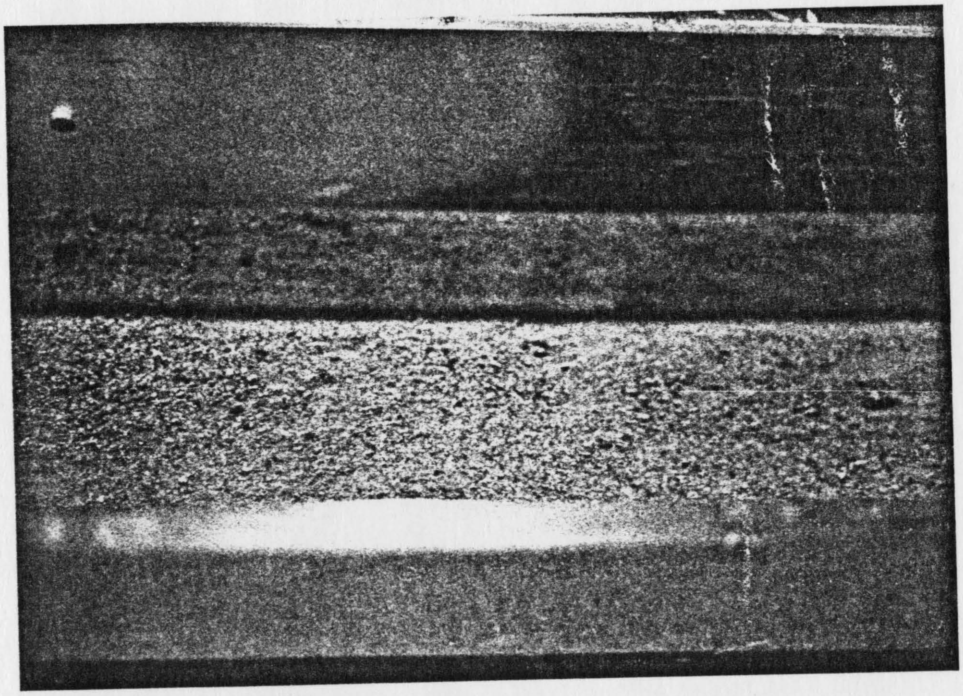


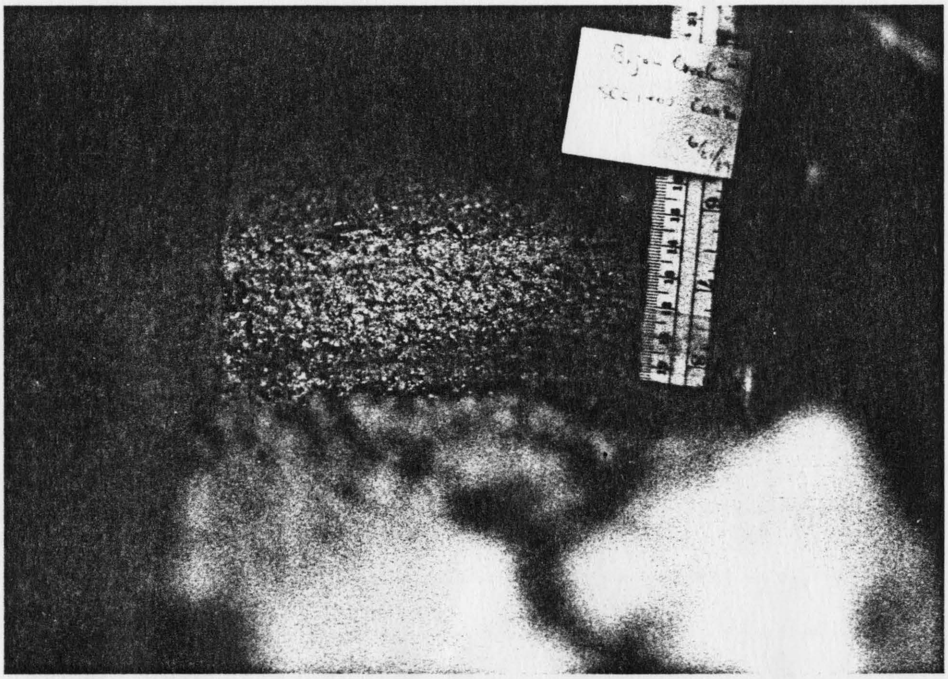
Fig. 5. The deposition of Bijou Creek sand at SEC.1+00 (RUN #2).



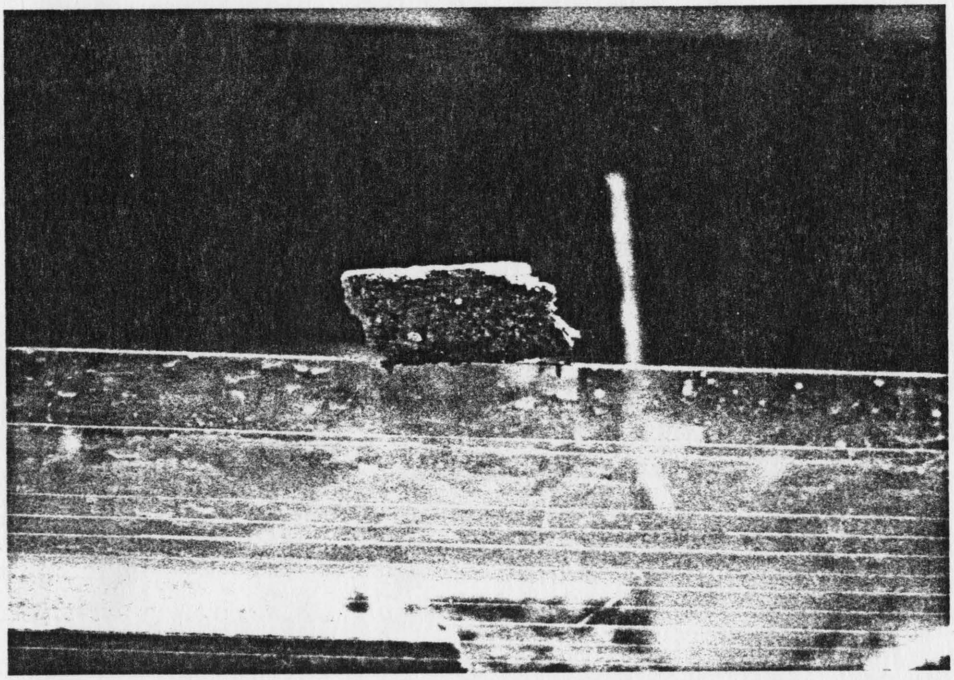
Picture 15. Clear layers of deposition are shown after drying by solar lights.



Picture 16. No vertical crack occurs on the top layer of deposition.



Picture 17. Cross-section is cut at SEC.1+00. Horizontal cracks and separated layers are shown clearly.



Picture 18. Separated layer can be pealed easily.

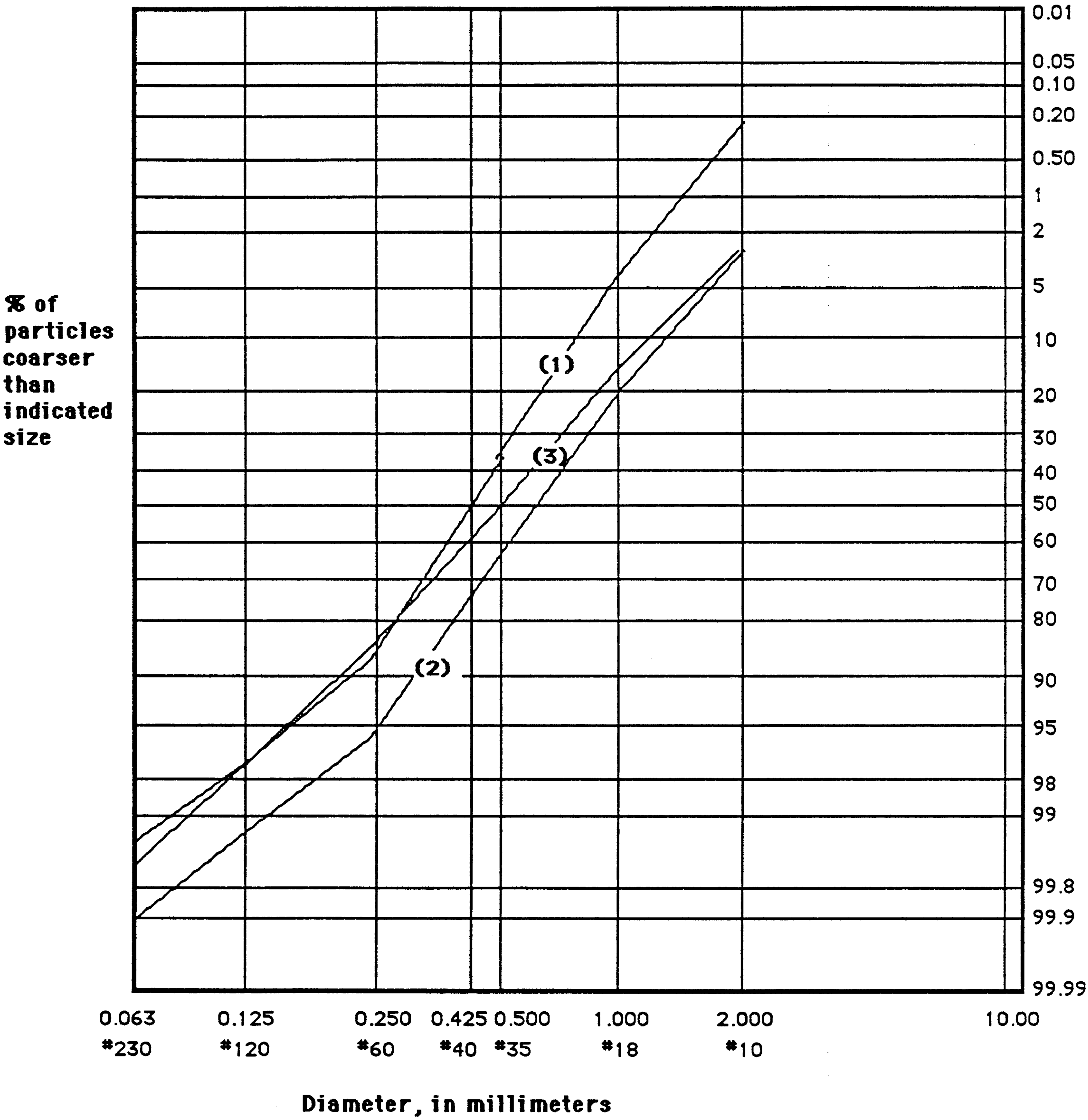


Fig. 6. Particle-size distribution for each stratum of RUN #2.

5. SUMMARY AND CONCLUSIONS

A primary feature of the experimental program is the use of natural sand from Bijou Creek, Colorado and investigate the features of the major deposits observed during the Bijou Creek flood in June 1965. Laboratory experiments in a recirculating flume have been conducted on the process of horizontal deposition under flatbed condition with sediment transport.

The deposition of crossbedding under lower flow regime as well as horizontal laminae under upper flow regime observed in the investigation of the Bijou Creek flood by McKee et al. (1967) was reproduced by the experiment of Julien and Chen (1989a). The results of this experiment should correspond to the field observations as well.

The results of the experimental program detailed in this report can be summarized as:

1. The thickness of the horizontal lamination layer should depend on bed shear and shear velocity as much as flow velocity mentioned in the report of Julien and Chen (1989b). Further experiments should clarify which of these variables is dominant.

2. The thickness of the delta increases with the size of tailgate. For downstream control, the thickness of the layer of horizontal laminae remains unchanged regardless of tailwater condition.

3. The low-relief sandwaves can still be seen in the formation of horizontal lamination under critical flow condition.

4. The small content of silt and clay in the top layer of the deposits may explain why no vertical cracks have been observed at the surface of the deposits after 7 days of drying under solar lamps. However, the horizontal

cracks and the consolidation for each layer make the finer and coarser depositional layers separate easily.

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