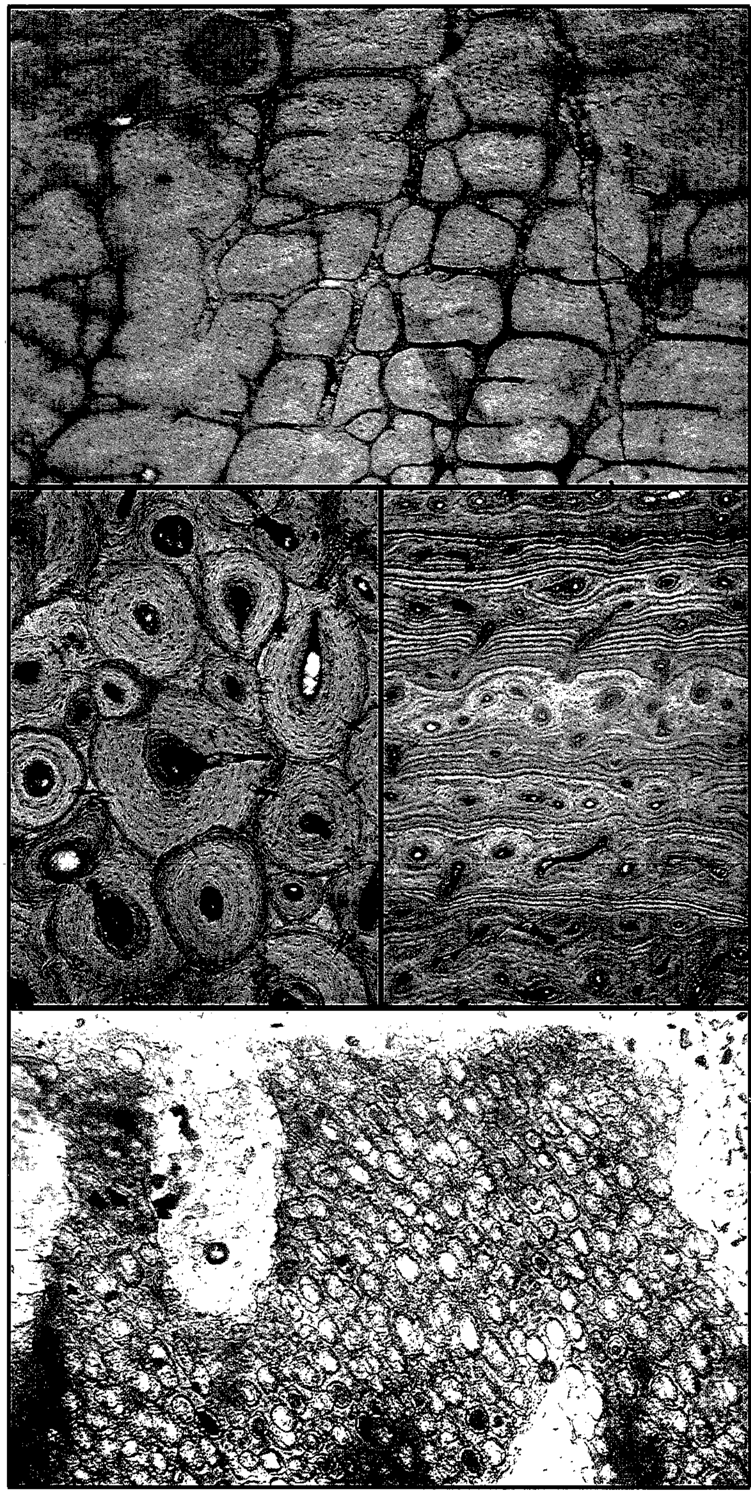
BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES



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CONTENTS

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Cover: Fossil tissues from Cleveland-Lloyd allosaurs.

Top: Uniform periosteal bone with reticulating primary vascular canals, some of which are aligned longitudinally (left to right) and radially. Caudal vertebra, centrum; longitudinal section; C-LQ 087.

Middle left: Vascular zonal bone with lamellated annuli and non-lamellated zones. Local development in a right radius; transverse section; C-LQ 109.

Middle right: Dense Haversian bone showing secondary osteons, secondary vascular canals at their centers, and the concentric arrangement of osteocyte lacunae (small dark bodies) around them. Dorsal rib; transverse section; C-LQ 106.

Bottom: Calcified cartilage showing the rounded form of the spaces (lacunae) once occupied by chondrocytes. Proximal end of a fibula; longitudinal section; C-LQ 014.

In all sections the direction of the external surface is upward.

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The Construction of a Fan-Delta

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ABSTRACT

The fan-delta described in this report was so clearly and completely displayed after deposition and subsequent exposure that it merits being compared with any sedimentation unit considered to be a fan-delta formed during the present or in the geologic past.

The fan-delta was constructed in a flood-control reservoir located in the upper part of an alluvial fan developed west of the mouth of Rock Canyon. This area is in the northeast part of the city of Provo, about 70 km south of Salt Lake City, Utah.

The formation of the fan-delta was the result of a single event, the severe flooding by Rock Canyon Creek in the spring of 1983.

Seepage from the flood-control reservoir dam caused the decision to be made to remove the floodwater from the reservoir. When this was done, the sediments that had been deposited in the reservoir were suddenly completely exposed in a pristine state unaffected by wave or current action or by later modifications. There were displayed a remarkable sharp topographic break and a color contrast between a blanket of dark brown, laminated, fine-grained bottom-set beds and a light gray gravel wall (the fan-delta front) that rose 2 m above the bottom-set beds at an angle of 30°.

Water in the waning stage of the flood eroded down through the exposed fan-delta gravel front wall and cut channels in the bottom-set beds, exposing the internal structure of these sedimentary features. Even more helpful in exposing the internal structure of the fan-delta was the decision, made months later, to use the gravels in the fan-delta to construct dikes around Utah Lake, which was flooding the countryside, and to use the bottom-set beds for topsoil. A systematic exposure of the internal structure from top to bottom of the entire fan-delta then took place as these beds were removed section by section. The bottom-set beds were shown to be uniformly laminated and fine grained, and the fan-delta front wall and the rest of the fan-delta behind it were shown to be very complex in terms of types of bedding, degree of sorting, and in grain size variation, with a high percentage of gravel being present.

All of the factors involved in the creation of the fan-delta were as easily determined as if this sedimentation unit had been produced under controlled laboratory conditions.

Information from this study should be of major interest for sedimentologists who work with very coarse grained sediments and who are frustrated with the limits of what they can test in the laboratory.

This fan-delta with its distinctive fine-grained, uniformly laminated bottom-set beds, typical of deltaic deposits, deposited at the same time and in close association with a very complex unit of rapidly changing sediments dominated by gravels, typical of alluvial fans, clearly merits being designated as a "fan-delta."

INTRODUCTION

There has been considerable discussion about the meaning and use of the term *fan-delta.* The definition given by Holmes (1965) is used for this report: "A fan-delta is an alluvial fan prograding directly into a standing body of water from an adjacent highland."

The major purpose of this report is to provide the reader with the statistics and descriptions associated with the location and environmental physical conditions present, the source of the sediments, the sequence of events, details showing the structure and composition of the fan-delta, and also to emphasize the fact that what was observed was not complicated by wave or current action or modification produced by later changes in processes or source of sediments.

A significant part of the report is a sequence of photographs that enable the reader to see for himself or herself what actually happened.

The author has deliberately chosen to not use certain terms and to avoid qualitative and quantitative comparisons with previous studies because many of them are very questionable and argumentive. The reader is encouraged to read the article by McPherson and others (1987) to gain an awareness of the varied uses and abuses of the term *fan-delta.*

The reader can use the statistical data provided and the sequential series of photographs to construct his or her own understanding of a fan-delta and to use this knowledge to assist in his or her own future investigations of fan-deltas or to evaluate the reports by others who have written about fan-deltas.

PHYSICAL ENVIRONMENT FACTORS

The fan-delta was deposited in a flood-control reservoir constructed in the proximal part of an alluvial fan near the mouth of Rock Canyon. This area is in the northeast part of Provo, Utah, 70 km south of Salt Lake City, Utah. The size of the reservoir was approximately 325 m north-south and 200 m east-west. The maximum water depth was 5 m. The general shape of the reservoir was similar to a human kidney. The bottom of the reservoir was essentially flat in the center and became more uneven and sloped upward away from the center. The general topography of the area is shown in Figure 1.

The alluvial fan was built by Rock Canyon Creek as it cut down through the Wasatch Fault escarpment and the terraces of Old Lake Bonneville that were deposited on it (Fig. 2). The fault scarp block consists of Precambrian and Paleozoic rocks (Fig. 3). The general slope of the upper alluvial fan is 5° to 7°.

Rock Canyon is a narrow canyon with steep rocky sides and a narrow streambed, which in places is less than 15 m wide. Rock falls, snow avalanches, and debris slides in the canyon contribute most of the sediment carried out of the canyon during the spring runoff by Rock Canyon Creek.

According to the Army Corp of Engineers (1971), the drainage basin for Rock Canyon Creek is 25.9 square km, and the highest elevation bordering the basin is 3,374 m. The climate for the area is semiarid, with an annual average rainfall of 43.18 cm in the lower elevations and 104.14 cm in the mountainous regions (Army Corp of Engineers, 1971). Rock Canyon Creek is an intermittent stream with surface flow on the alluvial fan occurring only during the spring runoff for two or three months.

Past history of the area indicates that several severe floods from Rock Canyon Creek caused significant damage in the lower part of the alluvial fan where real estate development had occurred. Most of these floods were the result of cloudburst storms centered on the Rock Canyon Creek drainage basin (Army Corp of Engineers, 1971). This past flood damage led to the development in 1934 of a debris basin to help control the flooding.

SEQUENCE OF EVENTS

The fan-delta was formed as the result of a single event—the severe flooding that occurred in the spring of 1983. Flooding was so severe throughout the state of Utah that 22 counties were officially designated as disaster areas (Alder, 1983).

The flooding of 1983 was the result of a combination of factors: a very wet previous year, a very heavy snow pack in 1982–1983, and a rapidly warming period in the spring of 1983. Moderate to heavy rainfall was also associated with the melting snow (Alder, 1983).

The weather station at Brigham Young University, in Provo, recorded a total of 66.65 cm precipitation during the water year 1981–82. The weather station also indicated that rainfall in May 1983 was 10.26 cm, compared with a normal precipitation for May of 6.19 cm. The temperature increased from 44°F on May 11 to 66°F on May 20 and 90°F on May 28, 1983.

Nick Jones, Provo city engineer, reported that the flooding of Rock Canyon Creek reached a maximum flow on May 28, 1983, of 5.66 cubic meters per second and continued for 12 days, fluctuating between 2.83 to 4.23 cubic meters per second. The severe flood phase (Fig. 4-A) lasted for 17 days. Flooding was repeated in the spring of 1984 at about two-thirds of the volume of 1983 (Jones, pers. comm.).

When the flood-control reservoir was filled, an emergency canal was excavated to divert part of the floodwaters down one of Provo's streets.

Seepage from the reservoir dam caused the decision to be made to completely drain the floodwater from the reservoir. When the water was removed, a remarkable sedimentary body was exposed in perfect complete form unaltered by wave or current action, unaffected by weathering or modification by organic or chemical action. In addition, this fan-delta when studied had not been affected by commonly described later modifications due to changes of climate, changes in source materials, etc. The general appearance of the fan-delta is indicated in Figures 4-C, D; 5-A, B, C, D; 6-A, B.

A dark brown blanket of fine-grained bottom-set beds extended from the dam to a light gray wall 2 m high and positioned at an angle of 30° to the horizontal surface of the bottom-set beds. The fan-delta front wall was composed primarily of coarse gravels (Fig. 5-A, B, C, D and Fig. 6-A, B).

After the fan-delta was exposed, by the draining away of the floodwaters in the reservoir, the waning floodwaters of 1983 cut down through the fan-delta front wall and the

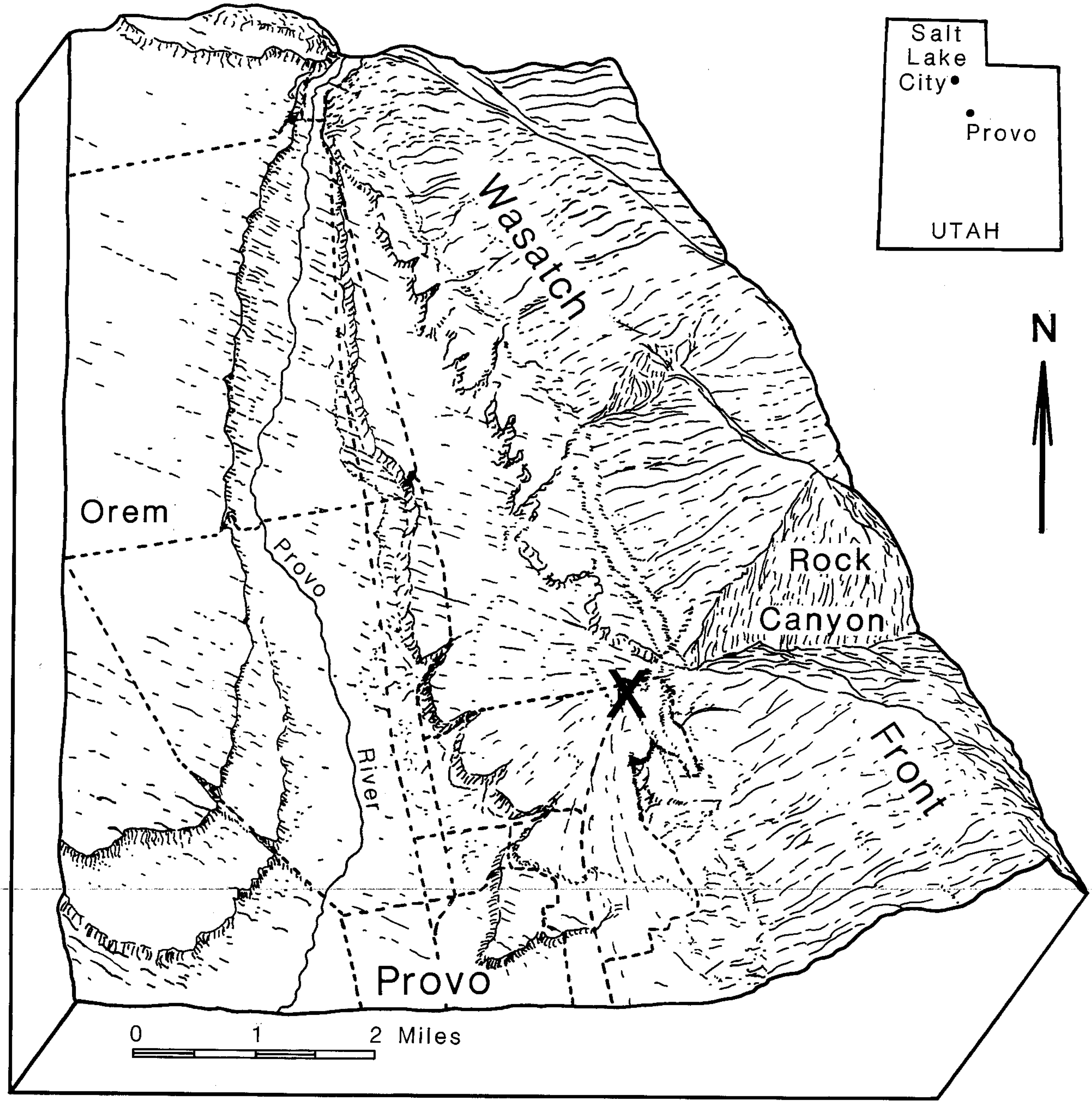

Figure 1. Physiographic diagram showing the topography of the area. The symbol "X" marks the location of the flood-control reservoir in which the fan-delta was formed. (Modified from Rigby and Hintze, 1968.)

blanket of bottom-set beds, exposing in detail the internal structure of these features.

Considerable diking was needed to control the water of Utah Lake, which was flooding the countryside. The decision was made to use the gravels of the fan-delta for this purpose, and the bottom-set beds were also removed for use as topsoil. The systematic removal of bottom-set beds and the gravels of the fan-delta made it possible to get a meter-by-meter exposure of the internal structure of the fan-delta. At my request, several cross sections were excavated perpendicular to the front wall of the fan-delta during the removal of the fan-delta sediments. Figures 5-C, D and Figures 7-A, B are good examples of cross sections at the front wall of the fan-delta.

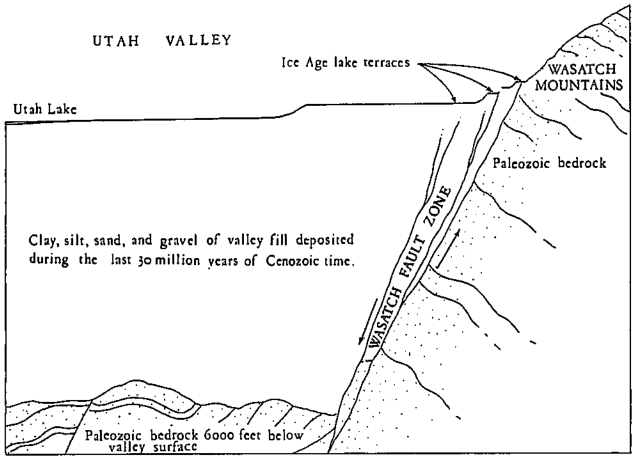

Figure 2. Generalized cross section from Utah Lake and Utah Valley through the Wasatch Fault Zone to the Wasatch Mountains. Lake terraces are shown produced by ancient Lake Bonneville. From Rigby and Hintze 1968.

The investigation of the development and removal of the fan-delta sediments took place over a period of several months during 1983 and 1984. More than a thousand photographs were taken to record all the distinctive events and sedimentary details that were revealed. The photographs were taken on a regular schedule to make sure that all significant changes were noted.

A select number of photographs are included in this report. The photographs are arranged in a sequence so that the reader can take a self-guided tour to see what was involved in the building of the fan-delta and also to see what was systematically exposed as the fan-delta was removed.

SOURCE OF THE SEDIMENTS

Rock Canyon Creek could carry sediments derived from all parts of its drainage basin into the flood-control reservoir. However, the stream channel east of the mouth of Rock Canyon showed only a moderate amount of erosion during the flooding of 1983, suggesting that a limited amount of flood sediment was contributed by that part of the stream course. The major part of the sediment carried to the flood-control reservoir during the flood of 1983 came from the unconsolidated sediments contained in the upper part of the Rock Canyon alluvial fan. These unconsolidated sediments were quickly eroded and transported to the flood-control reservoir. The volume of sediments deposited in the fan-delta appeared to be comparable to the volume of sediments removed from the upper alluvial fan.

The erosion and undercutting of banks that took place in the upper alluvial fan is shown in Figure 4-A. This picture with the reservoir visible in the background indicates the short distance that most sediments were transported before they were deposited in the reservoir. Most of the flood sediments were transported less than 1,000 m, and a major part less than 500 m. Figure 8-D shows a more extensive exposure of the eroded alluvial fan.

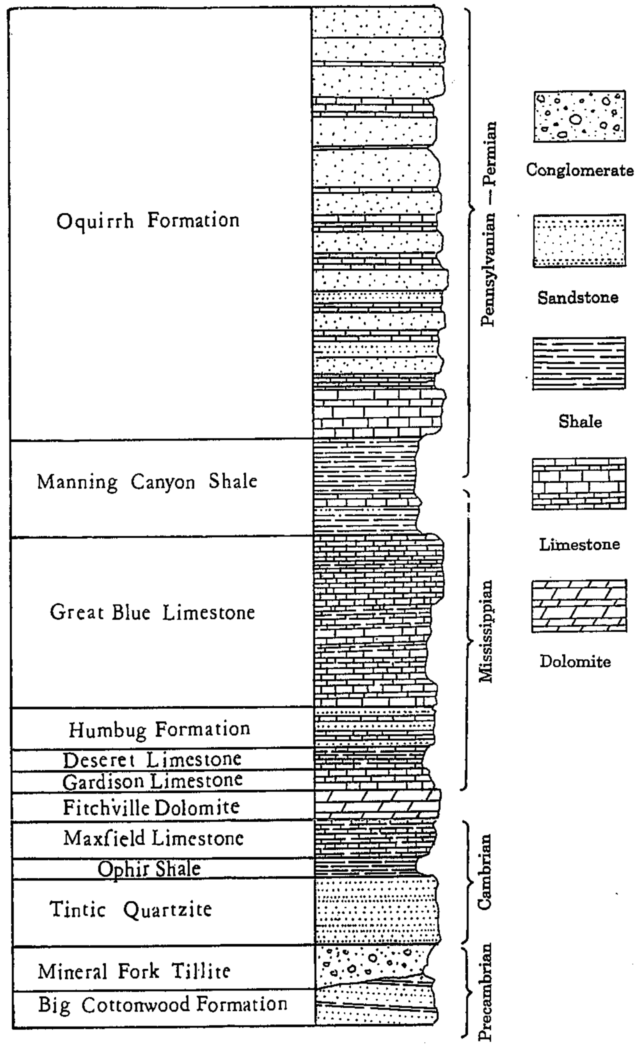

Figure 3. Stratigraphic column of rocks exposed in the Wasatch Mountains in the vicinity of Provo. From Rigby and Hintze 1968.

The flooding of 1984 partially filled the flood-control reservoir and also made it possible to see floodwater at work recreating some of the sedimentary structures found in the fan-delta that had been constructed during the flooding of 1983 (Fig. 9-A, B, C).

The stratigraphic section (Fig. 3) shows the rock types in the Wasatch Front bedrock that contributed sediment to the alluvial fan. The most common rock types found in the upper alluvial fan gravels were limestone, dolomite, quartzite, and sandstone.

In addition to the sediments derived from formations exposed in the stratigraphic sequence of the fault block, a significant source of sediment eroded to construct the alluvial fan was the unconsolidated material contained in the ancient lake terraces of Pleistocene Lake Bonneville (Fig. 2) that had been deposited on the face of the fault block. As Lake Bonneville subsided, the terrace material, formed by it, was quickly eroded and added to the alluvial fan.

The Lake Bonneville terraces were examined both north and south of the alluvial fan to determine what they were composed of. Recent rock falls and landslides were found on top of the lake terrace material (Fig. 10-A). The nature of the unconsolidated lake-deposited material was complex and changed rapidly both laterally and vertically. There were beds of coarse gravels (Fig. 10-B), beds of laminated fine-grained sediment (Fig. 10-C), beds of interlayered coarse- and fine-grained sediment (Fig. 10-D), and exposures of boulders in direct association with laminated fine-grained sediment (Fig. 10-E). It is important to keep in mind the fact that older Rock Canyon Creek alluvial fans deposited their sediments in these ancient Lake Bonneville terraces.

Some similarities were noticed between the lake terrace sedimentary patterns and those in the fan-delta.

PHYSICAL CHARACTERISTICS OF THE FAN-DELTA

The draining of the flood-control reservoir left exposed in striking clarity and completeness the fan-delta.

The bottom-set beds of the fan-delta formed a blanket of dark brown, finely laminated silts and clays with very limited amounts of sand (Figs. 5-A, 6-A). The sand was more evident near the fan-delta front wall (Fig. 6-B). The limited amount of sand in the fan-delta probably reflects the limited sand present in the upper alluvial fan that contributed the major part of the sediments to the fan-delta. The dark brown color of the bottom-set beds changed to a light gray color as they weathered and dried out.

The blanket of bottom-set beds extended from the dam of the flood-control reservoir 100 m eastward to the fan-delta gravel front wall and continued underneath the gravels at least 15 m farther to the east, as seen in the continuous cross section of Fig. 7-A. The bottom-set beds extended laterally in a north-south direction, approximately 225 m. The maximum thickness of the bottom-set beds was 1.5 m. This thickness changed to just a few centimeters at the margins of the basin to the north and to the south. The systematic removal of the bottom-sets showed no significant variation in the grain size or in the uniform laminations of the beds throughout the entire extent of the bottom-set beds.

The contact between the bottom-set beds and the front wall of the fan-delta was remarkably distinct because of the color change from dark brown to light gray and because of the change in texture from fine-grained uniformly laminated sediments to complexly bedded coarse gravels (Fig. 4-D; Fig. 5-A, B, C, D; Fig. 6-A). The sharp topographic break between the two units was also very distinct with practically no variation all along its extent. The front wall of the fan-delta maintained an almost constant angle of 30° (Fig. 4-C, D; Fig. 5-A, B, C; Fig. 6-A) and extended in an arc about 200 m long with a maximum height of 2 m above the flat surface of the bottom-set beds. There was no significant slumping or spreading out of the gravels from the front wall of the fan-delta onto the flat surface of the bottom-set beds.

The dominant grain size in the fan-delta front wall was gravel. Gravel sizes changed abruptly, sometimes occurring in strips 1 to 2 m wide running down the front wall and stopping abruptly at the contact with the bottom-set beds (Fig. 5-B; Fig. 6-A, B). In some locations the coarse-grained materials on the fan-delta front wall continued without change onto the flat surface above (Fig. 5-B, C). In other locations fine-grained sediments exposed in the upper part of the fan-delta front wall continued the same onto the nearly flat upper surface of the fan-delta.

The fan-delta front wall was characterized not just by grain-size variations from coarse gravel to silt and clay but also by significant variations in bedding types, degree of sorting, etc. Excavation and removal of the fan-delta showed that this complexity extended back into the body of the fan-delta 40 to 50 m.

One of the most remarkable features of the fan-delta was the striking difference between the constancy of the fine-grained size and uniform laminations of the bottom-set beds and the great variation in grain size and structural complexity of the fan-delta front wall and the sediments behind it.

Several cross sections of the fan-delta front wall were studied. Figure 5-C shows an example of a cross section at the front wall where bedding was absent. Figure 5-D shows inclined bedding developed at the fan-delta front wall, and Figure 7-B shows inclined bedding with abrupt changes in grain size and the presence or absence of matrix to support the grains. This cross section (Fig. 7-B) was just a short distance behind the front wall of the fan-delta. Horizontal bedding was also present in the body of the fan-delta, and, in places, distinctive tongues of coarse gravel were enclosed by beds of fine-grained sediments (Fig. 6-C). Exposures of poorly sorted, matrix-supported units with no apparent bedding were common in the fan-delta (Fig. 7-C, D).

The complexity of grain size, sorting, bedding types, etc., lying directly on the very uniform bottom-set beds presents a very different picture of what is usually thought of in connection with delta deposits. The term *fore-set* *beds* would be difficult to apply properly and consistently to what is found between the top-set and the bottom-set beds of this fan-delta.

Figures 5-C, 6-B, and 7-A, B, C, D all show very limited erosion at the contact between the gravel beds and the underlying bottom-set beds. Figure 7-A is of a cross section perpendicular to the fan-delta front wall to the right of the picture. The contact with the underlying bottom-set beds remains pretty much the same even though the bedding and the texture of the overlying units vary significantly from left to right. The similarity in the nature of the contact between bottom-set beds and the overlying beds, wherever it was exposed, suggests that as the gravel-dominated fan-delta beds advanced over the bottom-set beds, very little erosion or slumping took place.

The nearly flat surface on top and behind the fan-delta front wall, which merged with the alluvial fan sediments to the east, showed a complex pattern of change in terms of grain size, sorting, and shape of sedimentary structures (Fig. 8-A, B, C). This complexity and evidence of rapid change had much in common with sedimentary patterns exposed in the body of the fan-delta when it was excavated. Figure 8-D shows the surface of the alluvial fan east of where sediments were deposited in the flood-control reservoir.

When the flooding of 1984 took place at two-thirds the volume of the 1983 flooding with its associated erosion, transportation, and deposition, it was possible to see repeated the development of some of the sedimentary relationships that had been created in the fan-delta of 1983. Keep in mind that the erosion, transportation, and deposition of 1984 took place in the same locations in which they occurred in 1983. The source of the sediments was the same, the slope of the alluvial fan was the same, etc.

Figure 9-A shows a braided-stream pattern that developed in 1984. As this pattern was studied, the different stream courses were seen to change in terms of where they flowed and in terms of water volume and velocity. Figure 9-B shows a tongue of gravel extending out over fine-grained mud. This is not due to slumping. Figure 9-C shows currents bearing silt and clay moving along both sides of a tongue of gravel to deposit the fine-grained material out in the reservoir. Figure 9-D shows a diverted streamlet that eroded down over a bank of the alluvial fan, extracting the fine-grained material and leaving behind the gravels to be moved later by a stronger current of water. Note the composition and texture of the alluvial fan to the right of the eroded area.

CONCLUSIONS AND DISCUSSION

The events that occurred in 1983 and 1984 associated with the creation of a unique sedimentary deposit and its later removal from a flood-control reservoir provided data that was carefully monitored, recorded, and evaluated. The conclusion derived from this data is that alluvial fans with sufficient slope, depositing in standing bodies of water, can create distinctive sedimentary bodies that can be properly designated as fan-deltas. All of the features studied and photographed were related to a very short period of time and were not complicated by changes due to later events or to such actions as wave or current movement.

The sedimentary units formed in this fan-delta showed characteristics and relationships that bring into question previous definitions, restrictions, and interpretations related to fan-deltas that have been presented in previous studies.

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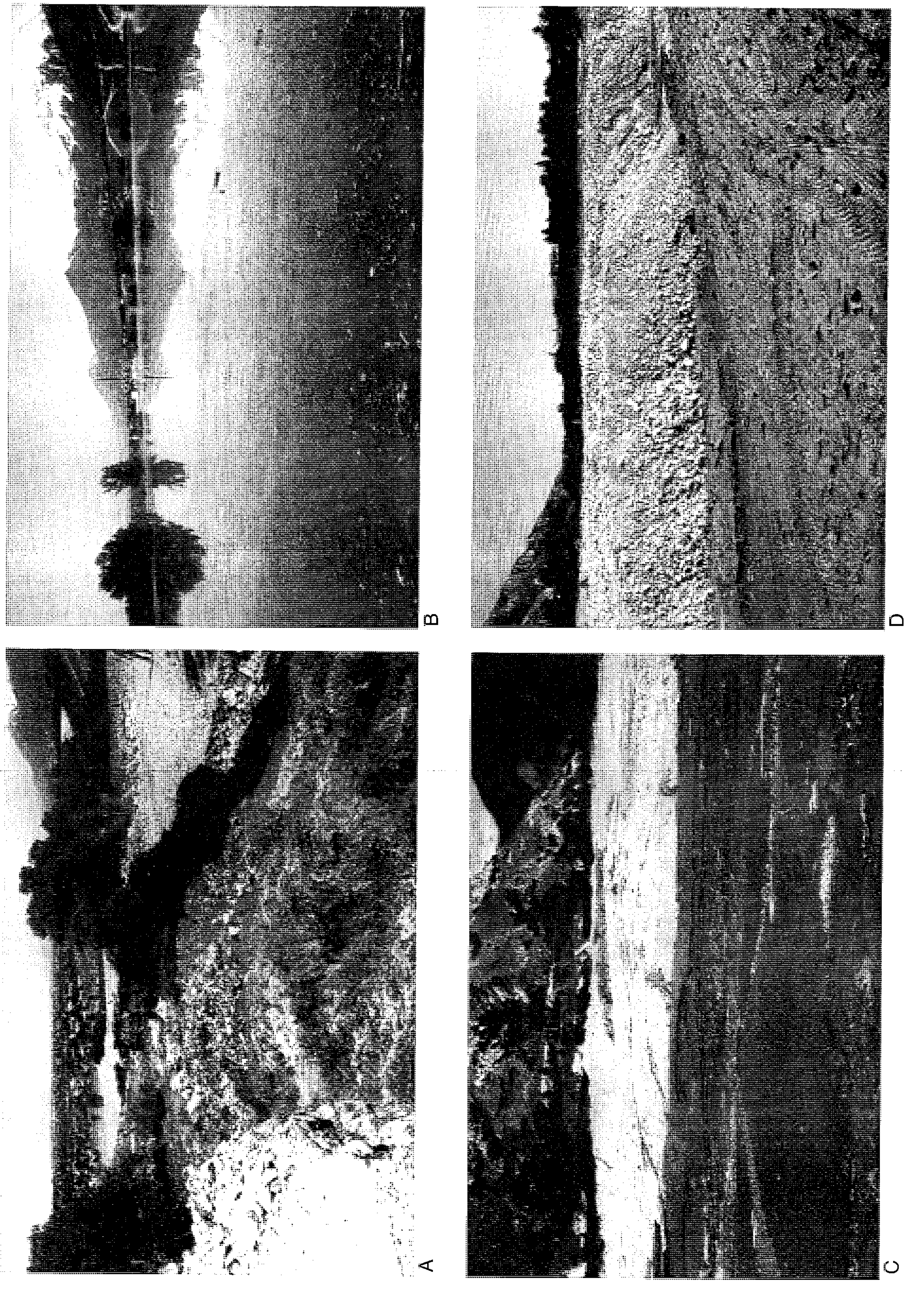

Figure 4. (A) Rock Canyon Creek in flood (1983) cutting through road and the alluvial fan. Note the undercut banks of alluvium and the flood-control reservoir in the background. (B) The filled reservoir (1983). (C) The dark brown blanket of bottom-set beds in sharp contact with the gravel front wall of the fan-delta (1983). (D) The 2-m-high front wall (1983).

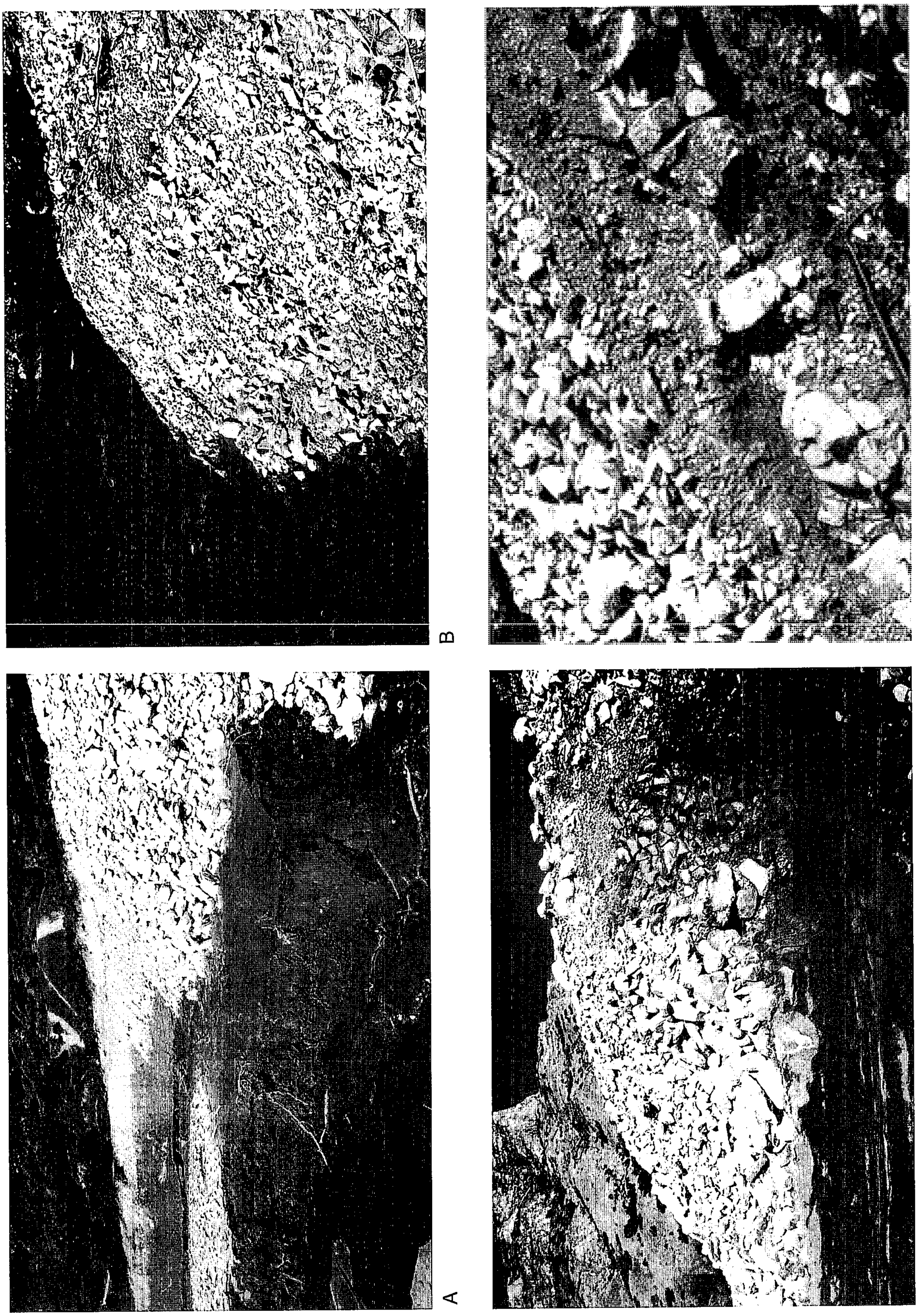

Figure 5. (A) Fan-delta front wall of light gray gravel in sharp contact with dark brown bottom-set beds. (B) Note strips of coarser gravel running down the front wall. (C) Cross section of fan-delta front wall showing gravel with no apparent bedding and clast supported. (D) Cross section of fan-delta front wall showing inclined bedding.

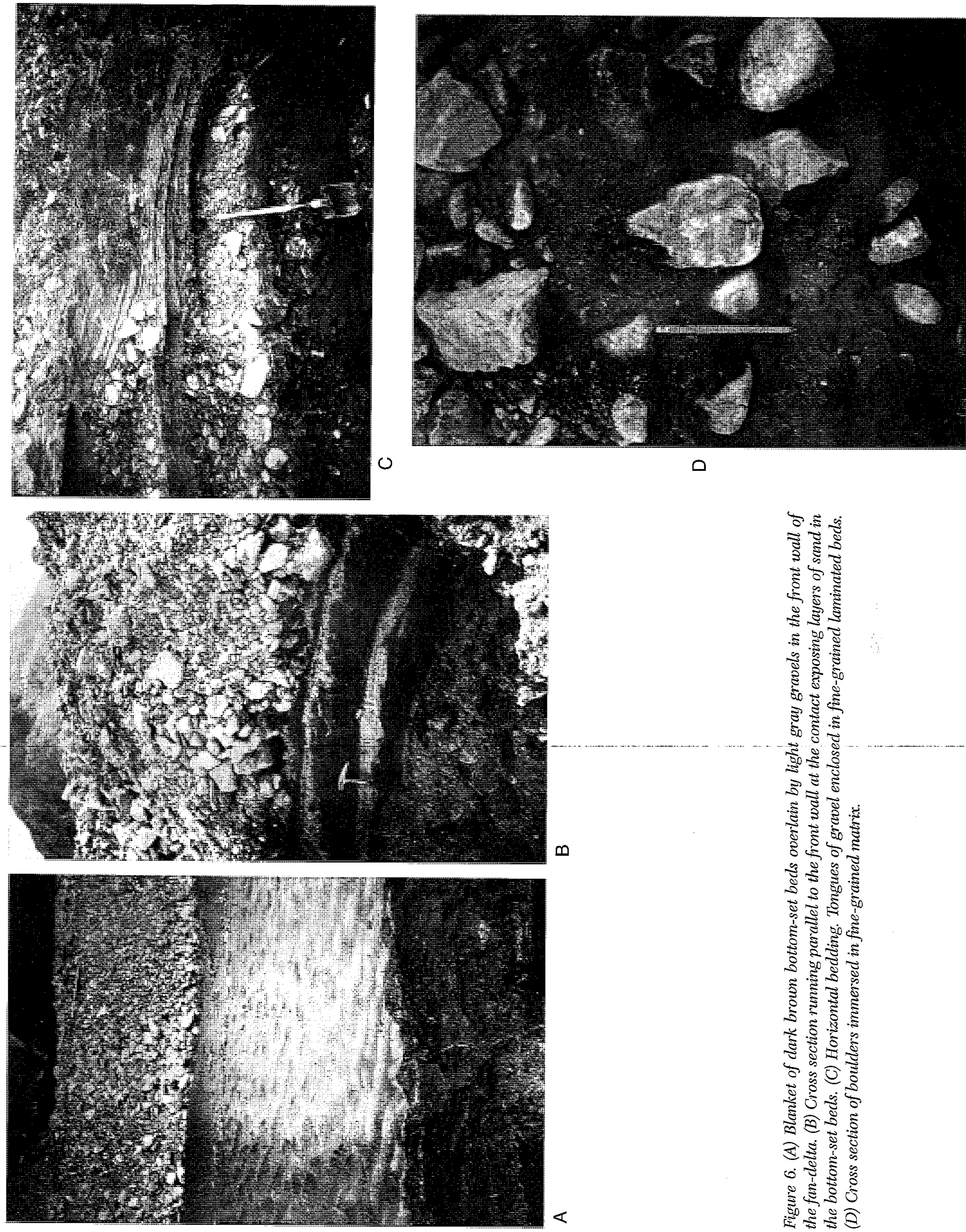

Figure 6. (A) Blanket of dark brown bottom-set beds overlain by light gray gravels in the front wall of the fan-delta. (B) Cross section running parallel to the front wall at the contact exposing layers of sand in the bottom-set beds. (C) Horizontal bedding. Tongues of gravel enclosed in fine-grained laminated beds. (D) Cross section of boulders immersed in fine-grained matrix.

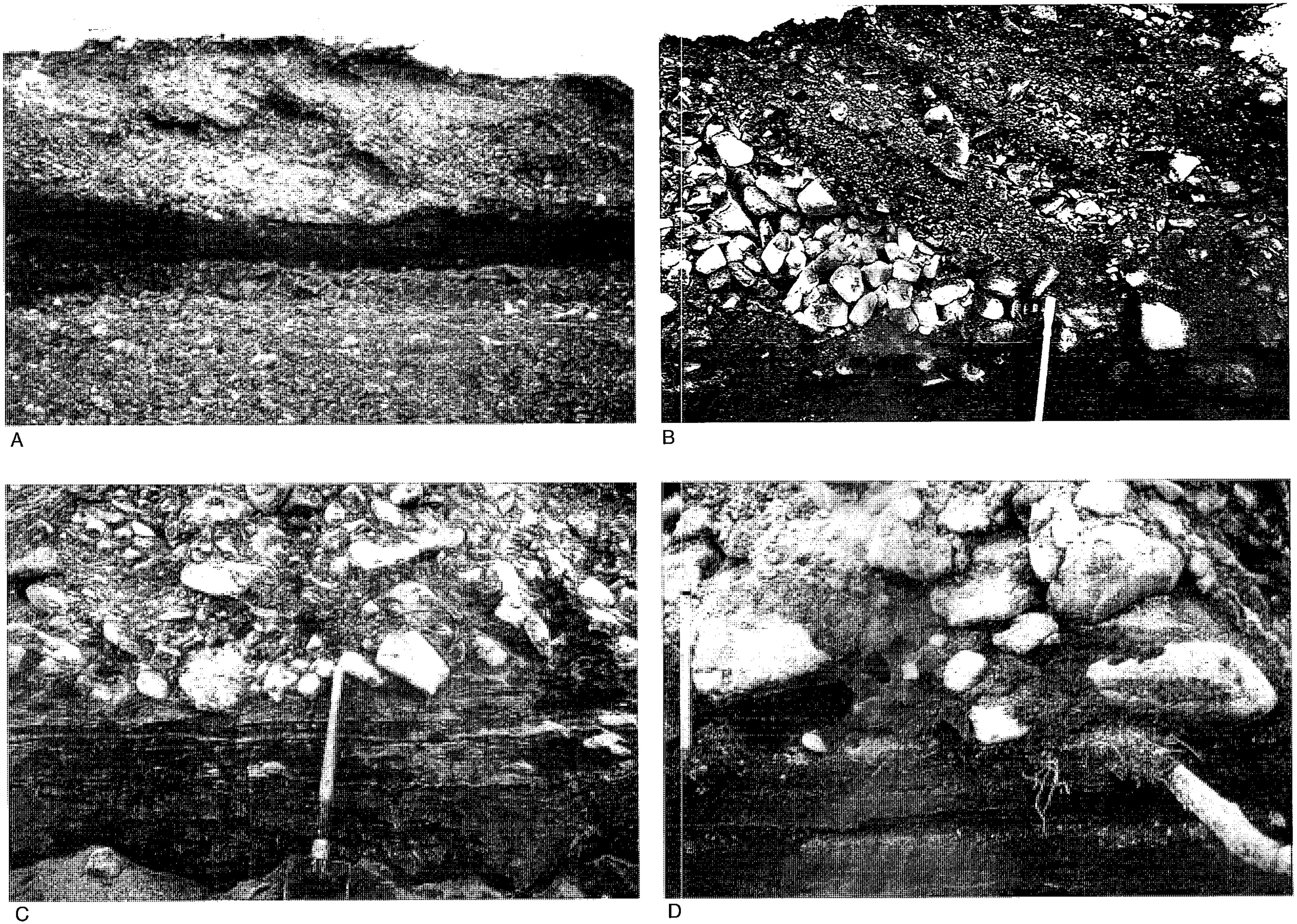

Figure 7. (A) This cross section is perpendicular to the fan-delta front. Notice the limited erosion along the contact with the bottom-set beds. (B) This is an enlargement of the right side of 7-A. Notice the inclined bedding and abrupt changes between beds. (C and D) The contact shows limited erosion below matrix-supported gravels.

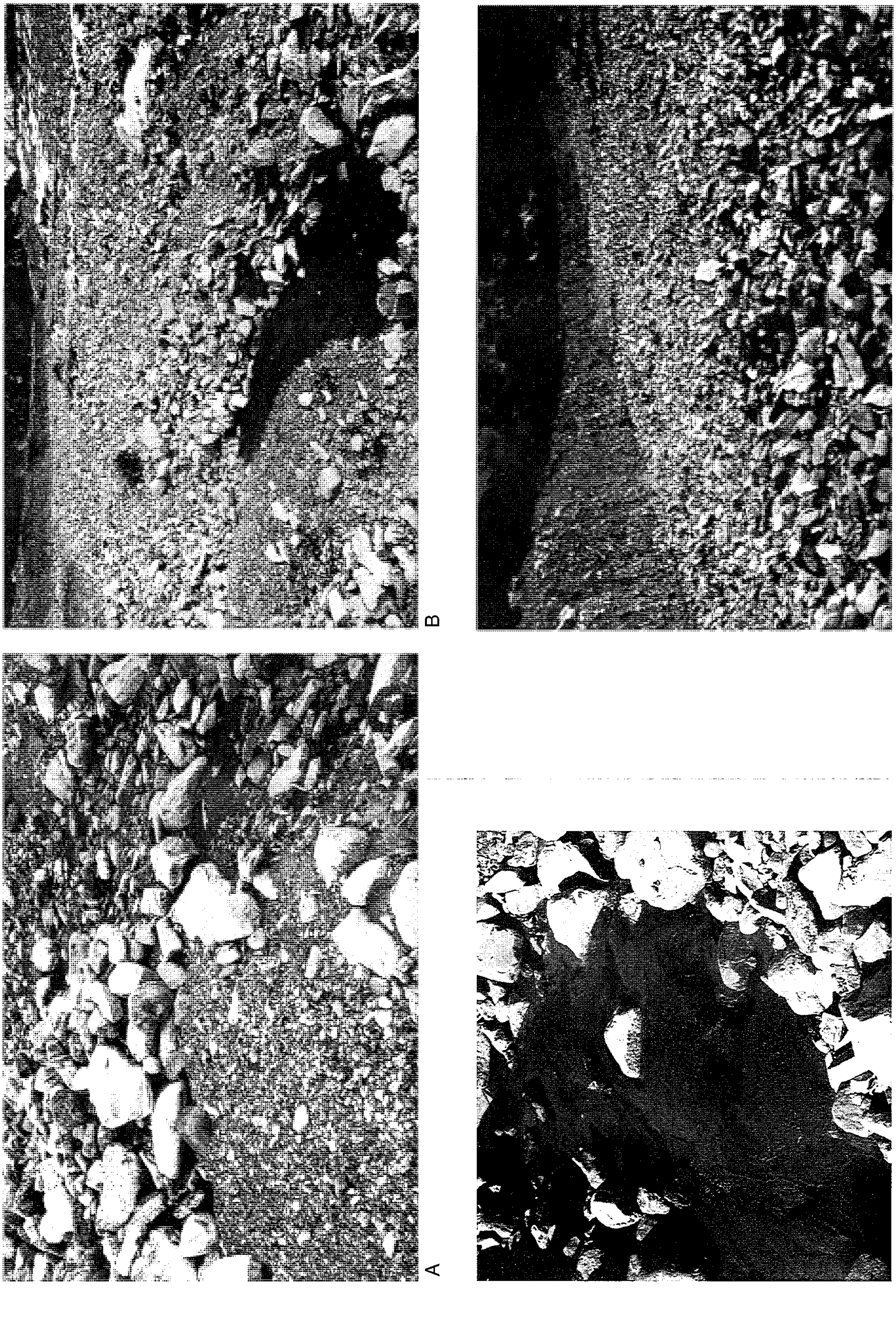

Figure 8. (A, B, C) Upper surface of fan-delta. (A and B) Rapid change in degree of sorting and grain size present. (C) Patch of mud with imbedded cobbles. (D) Farther to the east, surface of the alluvial fan not covered by the water of the reservoir.

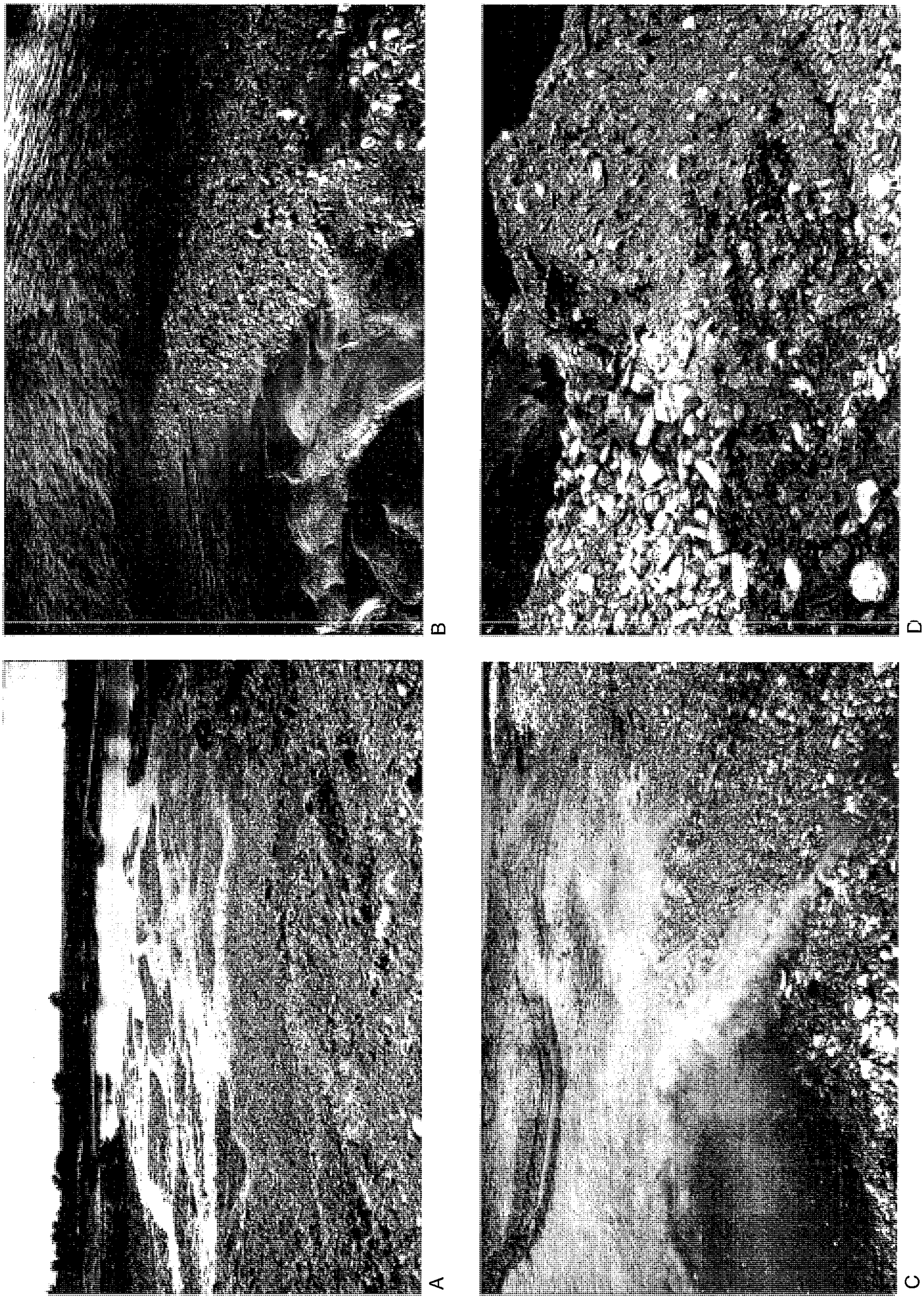

Figure 9. (A) Braided stream pattern—flood of 1984. (B) Tongue of gravel deposited on mud—flood of 1984. (C) Currents of muddy water moving along sides of a tongue of gravel—flood of 1984. (D) Small stream extracting finer grains from alluvial fan mixture. Note the alluvial fan composition to the right.


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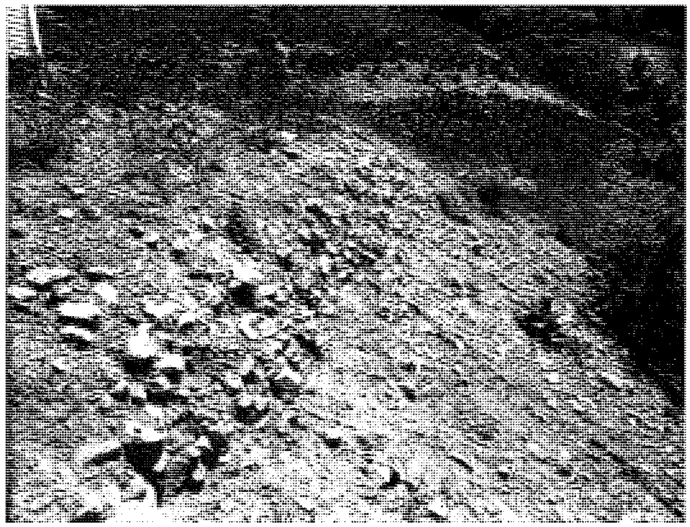
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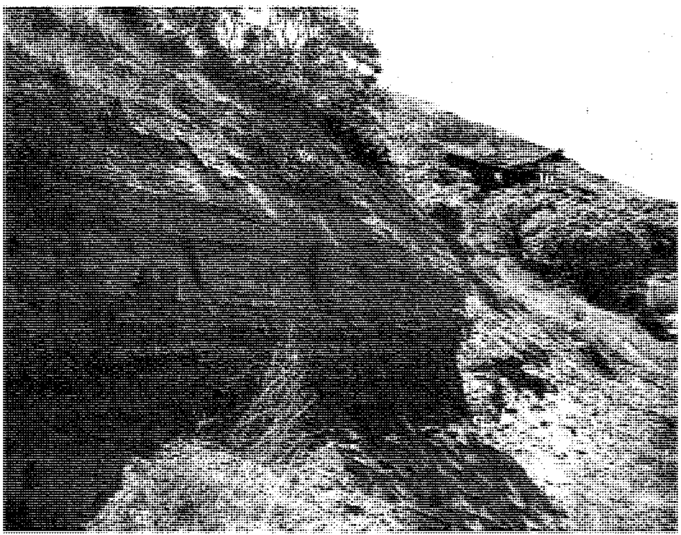
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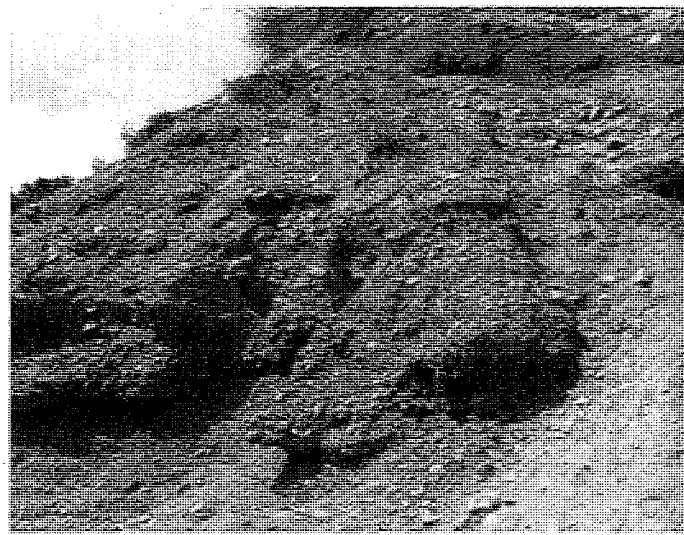
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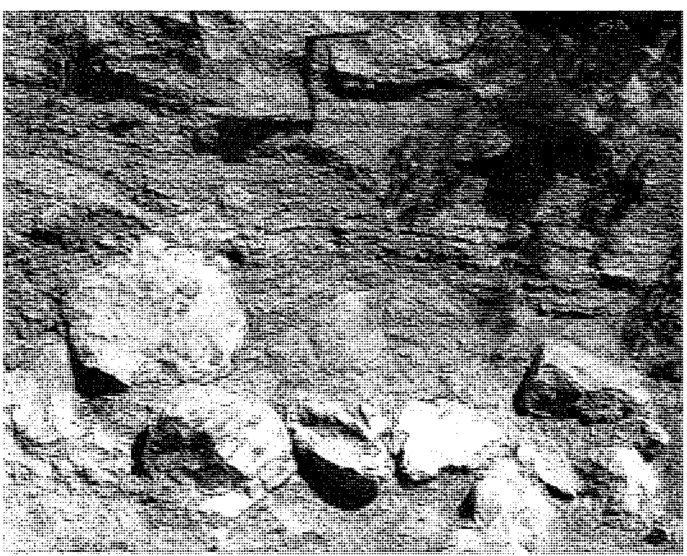
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Figure 10. (A) Rock-fall debris and landslide debris on surface of old lake terrace. (B) Gravel bed part of old lake terrace. (C) Fine-grained laminated sediments in old lake terrace. (D) Interbedded coarse- and fine-grained sediments in old lake terrace. (E) Coarse boulders imbedded in fine-grained sediments of old lake terrace.