Erosion and Deposition Produced by the Flood Of December 1964 On Coffee Creek Trinity County, California

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PHYSIOGRAPHIC AND HYDRAULIC STUDIES OF RIVERS

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By John H. Stewart and Valmore C. LaMarche, Jr.

ABSTRACT

On December 22 and 23, 1964, a flood having an estimated recurrence interval of 100 years occurred on Coffee Creek, a small high-gradient mountain stream in Trinity County in northern California. Discharge during the flood (estimated at 17,800 cubic feet per second) was more than five times greater than any previously recorded on the stream. The flood was produced by intense rains associated with warm temperatures and a rise of the snowline of several thousand feet. Flooding at this time occurred throughout most of northern California, Oregon, and southern Washington.

Coffee Creek drains an area of 119 square miles in the rugged Trinity Alps, part of the Klamath Mountains. The drainage basin ranges in altitude from 2,500 to 8,000 feet and is underlain by resistant metamorphic and intrusive igneous rocks. Most of the area is covered by a dense pine-fir forest.

The effects of the flood were studied by detailed mapping of erosional and depositional features on postflood aerial photographs (scale approx. 1 in.=200 ft) of a 6-mile reach of the stream starting half a mile above its mouth, and by the surveying of seven cross sections of the valley in this same reach. The extent of change in the location of channels and the amount of destruction of land and forests were determined by comparison with preflood aerial photographs taken in 1960.

The flood was unprecedented in the 110-year period since settlement of the area and had a catastrophic effect on the valley of Coffee Creek. Erosion destroyed large areas of meadowland and forests containing 200-year-old trees and many of the buildings and structures on the valley bottom. Local widening of the valley bottom resulted when the flood waters, by downward and lateral erosion, scoured deeply into older stream deposits and into colluvial and alluvial fan material along the margins of the valley. Some of the alluvial fan deposits removed by the flood were as much as 1,700 years old on the basis of radiocarbon dating. Destruction of large areas of mature forest and old alluvial fans suggests that a comparably large flood may not have occurred for several or many hundred years, far longer than the estimated 100-year interval considered to be the average length of time between floods of this size on Coffee Creek.

Deposits of sand and poorly sorted gravel laid down during the flood cover at least 70 percent of the flooded area. They lie either directly on a preflood surface or on a flood-erosion surface. The largest boulder transported was approximately 6 by 4 by 3 feet.

Natural levees formed during the flood occur along the sides of the main flood channels. These levees are composed of coarse bouldery gravel, are generally 30–50 feet wide, and slope gently away from the flood channel. They are topographically the highest depositional features within the flooded area and in places came within a few feet of the high-water surface of the flood.

Along much of the valley the amount of material lost from an area where the postflood surface is below the preflood surface (net scour) tends to be matched by a corresponding gain of material in nearby areas where the postflood surface is above the preflood surface (net fill). Such a balance of erosional and depositional events, however, did not occur in narrow steep reaches where the flood-water velocity was high. In these reaches, a large amount of material was lost. At the opposite extreme, however, in broad gently sloping reaches where the flood-water velocity was low, a large amount of material was gained.

The effect of the 1964 flood on Coffee Creek clearly indicates that it is catastrophic events of this sort that largely determine valley morphology, channel pattern and location, and the character of alluvial deposits. Apparently only in such extreme events can the coarse gravel that underlies much of the valley bottom be transported.

INTRODUCTION

On December 22 and 23, 1964, a flood of major proportions occurred on Coffee Creek—a small high-gradient mountain stream in Trinity County, Calif. The flood produced extensive erosion and deposition, and destroyed roads, bridges, homes, and forests. The flooding on Coffee Creek, and on many northern California streams, was the result of intense rains in a 3-day period beginning December 19. These rains fell on ground saturated by previous rainfall and were associated with high temperature and a rise of the snow level of several thousand feet. The meteorology of the storm is summarized elsewhere (Posey, 1965). The general character of the December 1964 floods in northern California also has been described (Rantz and Moore, 1965). Flooding at this time occurred throughout most of northern California, Oregon, and southern Washington.

Coffee Creek basin was selected for study because it shows unusually great modification by the flood—both erosion and deposition. Observations were made during a 3-week period in April and May 1965. Detailed study was limited to the area bordering a 6-mile reach of the stream starting about half a mile above its mouth. Large-scale aerial photographs taken in April 1965 served as a base for mapping features of the flooded area and for comparison with two sets of preflood aerial photographs taken in 1944 and 1960.

The help of the local residents of Coffee Creek is greatly appreciated. Preflood photographs were kindly supplied by Mrs. F. R. Kercher, Mr. J. H. Jessup, Mr. and Mrs. A. D. Rankin, and Mr. and Mrs. Joe Guggenmos. Pictures taken during the flood were supplied by Mr. Roger Wiborg of the U.S. Forest Service. Discussions of the flood and of preflood history of the area with these people and others were of invaluable help. The help of John Warnock, U.S. Forest Service, and of Mr. Roy Connelly and Mr. and Mrs. Harry Seymour is especially appreciated.

THE BASIN

Coffee Creek drains an area of 119 square miles in the Trinity Alps—an especially high and rugged section in the Klamath Mountains of northern California (fig. 1). It is an eastward-draining headwater tributary of the Trinity River, which is in turn a major branch of the Klamath River system. Coffee Creek joins the Trinity River 3 miles upstream from the head of Clair Engle Lake (Trinity Lake), a recently filled storage reservoir.

High relief and steep heavily forested slopes characterize the Coffee Creek drainage basin. Jagged peaks and rocky ridges along the divide reach altitudes of 7,500 to nearly 8,000 feet. The mouth of the basin lies 5,500 feet below the highest summits. Except in their glaciated upper reaches and near the deeply alluviated basin mouth, the valleys of Coffee Creek and its tributaries are steep-walled and narrow.

Most of the annual precipitation of about 60 inches comes in the winter months, but summer thunder-

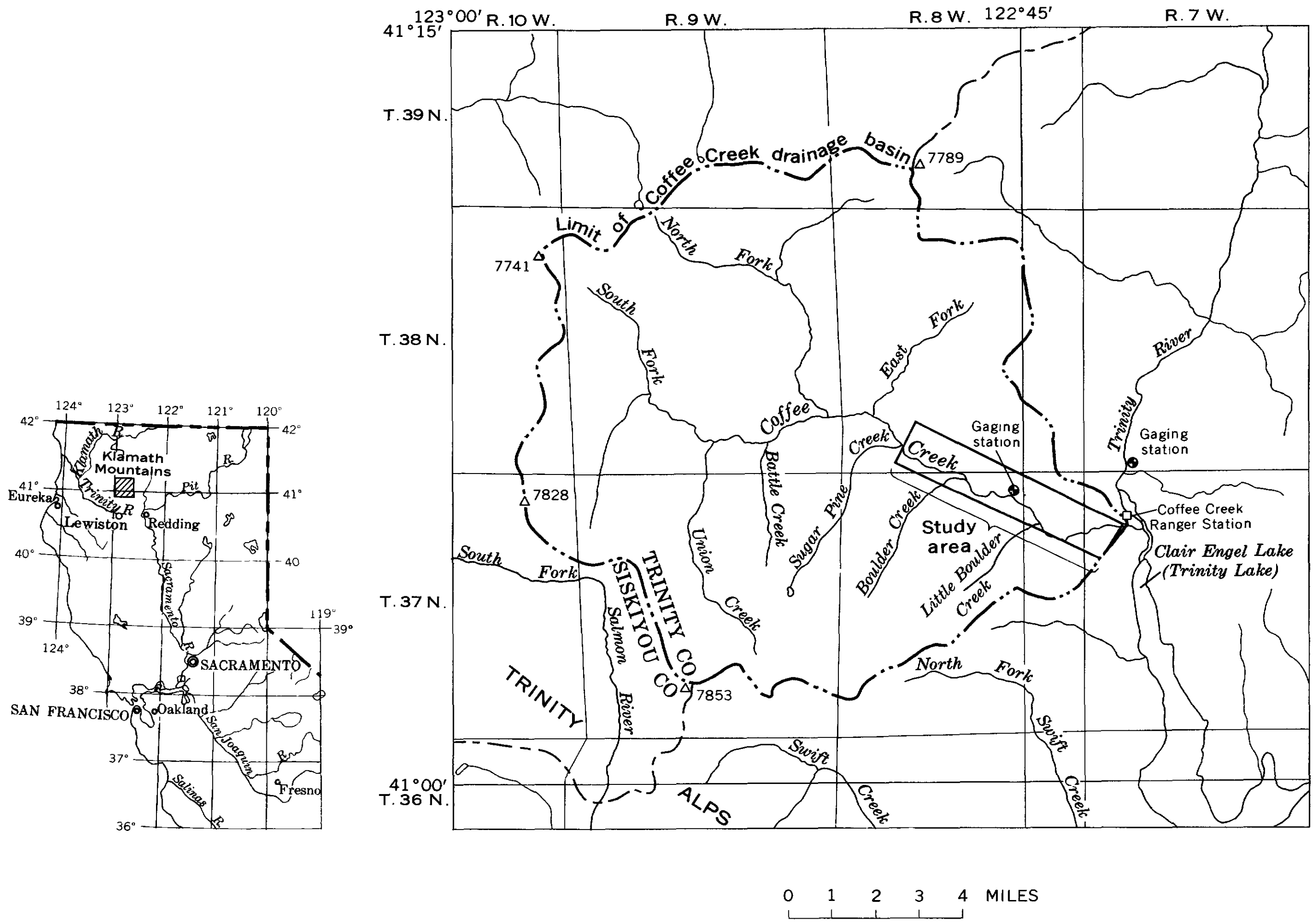

FIGURE 1.—Index map of Coffee Creek basin.

storms bring intense local rains. Precipitaton increases with altitude within the basin and is mostly in the form of snow at the highest altitudes. The relatively humid climate supports a dense pine-fir forest over much of the watershed, although large areas at lower altitudes and on south-facing slopes are brush covered.

The basin of Coffee Creek has been relatively unaffected by recent forest fires and by man's activities. Fire appears to have destroyed little, if any, of the forested or brush covered areas of the basin within several or many years preceding the December 1964 flood. Placer mining and some logging in the basin apparently have not significantly modified the original character of the area. Logging has taken place on only a few square miles of the 119 square miles of the drainage basin.

THE STREAM AND VALLEY

The flow of Coffee Creek is small, generally less than a hundred to a few hundred cubic feet per second throughout most of the year (U.S. Geol. Survey, 1964b). During the spring runoff from snow in higher parts of the basin, usually in April and May, discharge is commonly 500 to a few thousand cubic feet per second (cfs). The highest recorded discharge during a flood, prior to December 1964, was 3,360 cfs on October 12, 1962 (U.S. Geol. Survey, 1962, p. 443–444). This discharge was equalled (on the basis of estimates by the U.S. Geological Survey at the time of the installation of the gaging station) by the December 1955 flood—a major flood throughout northern California. The gaging station was destroyed by the December 1964 flood, but the Geological Survey, on the basis of flood marks, estimated the discharge at 17,800 cfs—more than five times greater than any previously recorded flood.

The upper 4 miles of Coffee Creek lies in a broad glaciated valley containing many meadows. The stream in this reach is small and has a relatively low gradient (about 0.025). The valley in the upper 4 miles trends north and is in line to the south with the uppermost part of the valley of the South Fork of the Salmon River. As described by Sharp (1960), Coffee Creek once extended to the south into this uppermost part of the valley of the South Fork but has been beheaded by the South Fork at the right-angle bend in line with Coffee Creek.

In contrast to this broad valley, the next 7 miles of Coffee Creek is in a narrow canyon. The boulder-choked canyon bottoms are little wider than the channels of the streams that occupy them. The gradient of the stream in this reach is high (about 0.040). South Fork, Union Creek, North Fork, and East Fork—four large tributaries—join Coffee Creek in this reach.

The narrow canyon stretch of Coffee Creek is followed downstream by a generally open valley containing broad meadows. This lower 6-mile reach is the area of main interest (pl. 1). Its overall gradient is about 0.020, ranging from 0.013 to 0.032 within various segments of the valley. In the lower 2 miles, the valley bottom maintains a width of about 1,000 feet; at the mouth it broadens into a half-mile-wide alluvial fan that almost completely fills the valley of the Trinity River.

In the upper reaches of the stream, the water normally follows a single well-defined channel that has maintained its location for many years. In contrast, the stream is braided locally in the lower valley and in the alluvial fan area.

The braided channel pattern and prominent delta are old features of Coffee Creek, unrelated to man's activities in the watershed. Coffee Creek was described by an early visitor (Cox, 1858) as " * * * many-mouthed, like the Nile or the Mississippi." The deep alluviation of lower Coffee Creek valley apparently took place largely in Pleistocene time, when the headwater areas were being scoured by glacial ice.

BEDROCK GEOLOGY

The Trinity Alps are composed of relatively resistant metamorphic and intrusive rocks. A northeast-trending belt of quartz-mica schist and hornblende schist of possible Precambrian age underlies the western third of the Coffee Creek basin (Irvin, 1960; Strand, 1964). Ultramafic and mafic rocks, commonly serpentinized, are exposed in the central part of the basin and include peridotite, pyroxenite, dunite, and associated coarse gabbro. Several large granitic stocks have intruded the older schist and ultramafic rocks and underlie much of the eastern half of the basin. In the reach of the stream studied, the walls of the valley are composed mostly of mafic and ultramafic rocks from mile 0 to 2.9 and almost entirely of granitic rocks from mile 2.9 to 5.3. Reference miles are measured linearly along the four segments of plate 1, and thus do not indicate the total length of the winding stream.

The varied and contrasting lithologic character of different parts of the basin make it relatively easy to distinguish colluvium and alluvial deposits of local origin from the alluvium transported from headwater areas.

SURFICIAL DEPOSITS

Surficial deposits within the basin of Coffee Creek include older deposits such as glacial till, terrace gravels, and thick alluvial deposits and younger deposits consisting of stream gravel and sand and colluvial and alluvial fan material.

Glacial till, which was related to at least four separate glacial advances (Sharp, 1960), occurs in the headwater tributaries. The distribution of moraines indicates that the glaciers extended 3 miles down Coffee Creek from the present divide. Glaciers on Union Creek, Sugar Pine Creek, Boulder Creek, and Little Boulder Creek—all northward-draining tributaries of Coffee Creek—reached to within a mile of the main valley (Sharp, 1960).

A conspicuous alluvial fan, probably formed by outwash from a glacier, occurs at the mouth of Boulder Creek (mile 3.8). The deposit contains granitic boulders as much as 10 feet in diameter and forms the bed and right bank of Coffee Creek in this reach. These large boulders constitute virtually the only accessible alluvial material that resisted movement by the floodwaters in December 1964.

Terrace gravels occur locally, the most extensive forming a broad terrace directly north of Coffee Creek along the west side of the valley of Trinity River. The surface is about 15 feet above the modern valley bottom. A narrow terrace remnant at the same level is present a quarter of a mile upstream on the north side of the valley (section *G–G′*, pl. 2). Terrace deposits have been recognized elsewhere along Coffee Creek although none are as continuous or well defined as the one in the lower part of the valley. A gravel, consisting largely of thoroughly decomposed granitic boulders and thus probably older than any other observed, occurs near mile 2.3 (loc. 19, pl. 1). Here, as in many other exposures, the gravels are deeply mantled by colluvium and locally derived alluvium.

No evidence exists that the lower part of Coffee Creek was glaciated, but the stream terraces may be correlative with glacial deposits in the headwater areas. Sharp (1960, p. 339) has suggested that terrace along streams draining the Trinity Alps are related to Pleistocene glacial maxima, and he has tentatively correlated terrace levels with individual episodes of glaciation. Therefore, the older gravel may be of Pleistocene age.

The deposits of alluvium—mostly coarse gravel—in the lower part of the valley are thick. A gold dredge operating near Seymour's Ranch in about 1915 is reported to have penetrated 90 feet of alluvium before reaching bedrock. Much of this deep alluvial fill is probably related to the Pleistocene glaciation. The valley of the Trinity River is notably broad and flat near the mouths of these formerly glacial tributary streams, which in many places have built alluvial fans that fill the entire width of the main valley.

Although most of the deep alluvial fill may be of Pleistocene age, stream deposits adjacent to and immediately underlying those of the December 1964 flood are more recent. For example, sand transported by this flood in the lower part of the valley was generally deposited on a preflood surface underlain by older sand (section *G–G′*, pl. 2). At several places 1–3 feet of this older sand lies on coarse gravel. Because this low-lying area has been flooded frequently in historic times, the older sand probably represents deposits of one or more relatively recent floods. The underlying gravel must have been deposited, or at least reworked, in a major channel in the past.

Another kind of older deposit on the valley floor seems not only to mark the previous location of a major stream channel, but also to indicate the magnitude of past floods. In the area from mile 0 to 1.8 and from mile 4.2 to 5.3, several small areas were not inundated in the recent flood. Darkly stained, lichen-covered cobbles and boulders exposed at the surface in these areas contrast strongly with the fresh flood deposits around them. With their coarse poorly sorted texture, down-valley elongation, and sloping surfaces, these older deposits bear a striking resemblance to the natural levees that are the most prominent depositional features of the 1964 flood. In addition, the texture of the deposits, relatively fine on the inside of bends in channels (loc. 21, pl. 1) and much coarser on the outside of bends (loc. 23, pl. 1), is similar to the textural distribution in levees formed in the 1964 flood.

In the broad valley and in the alluvial fan area in the lower mile of Coffee Creek, unflooded areas make up an increasingly larger proportion of the total area of the valley. Here, although the material underlying the elongated areas of higher ground is coarser than that deposited nearby in the flood, there is no clear-cut relationship with continuous older channels.

The modern stream gravels and the older gravel deposits along the margins of the valley of Coffee Creek are locally overlain by unsorted angular detritus derived from adjacent hillslopes and very small tributary streams. This colluvium and alluvium of local origin typically has the form of coalescing alluvial fans or a continuous colluvial apron. Prior to deep erosion by the flood waters, great thicknesses of material accumulated in many places. For example, near mile 3.8 (section *C–C′*, pl. 2) poorly bedded granitic sand 20 feet thick filled the mouth of a ravine. This deposit overlies an irregular smoothly polished granitic bedrock surface. A few large exotic boulders lie in depressions on this surface—clearly the bed of Coffee Creek sometime in the past.

THE FLOOD

The runoff that produced the December 1964 flood came from intense rains and rapidly melting snow. The records from the recording rain gage (fig. 2) at Coffee

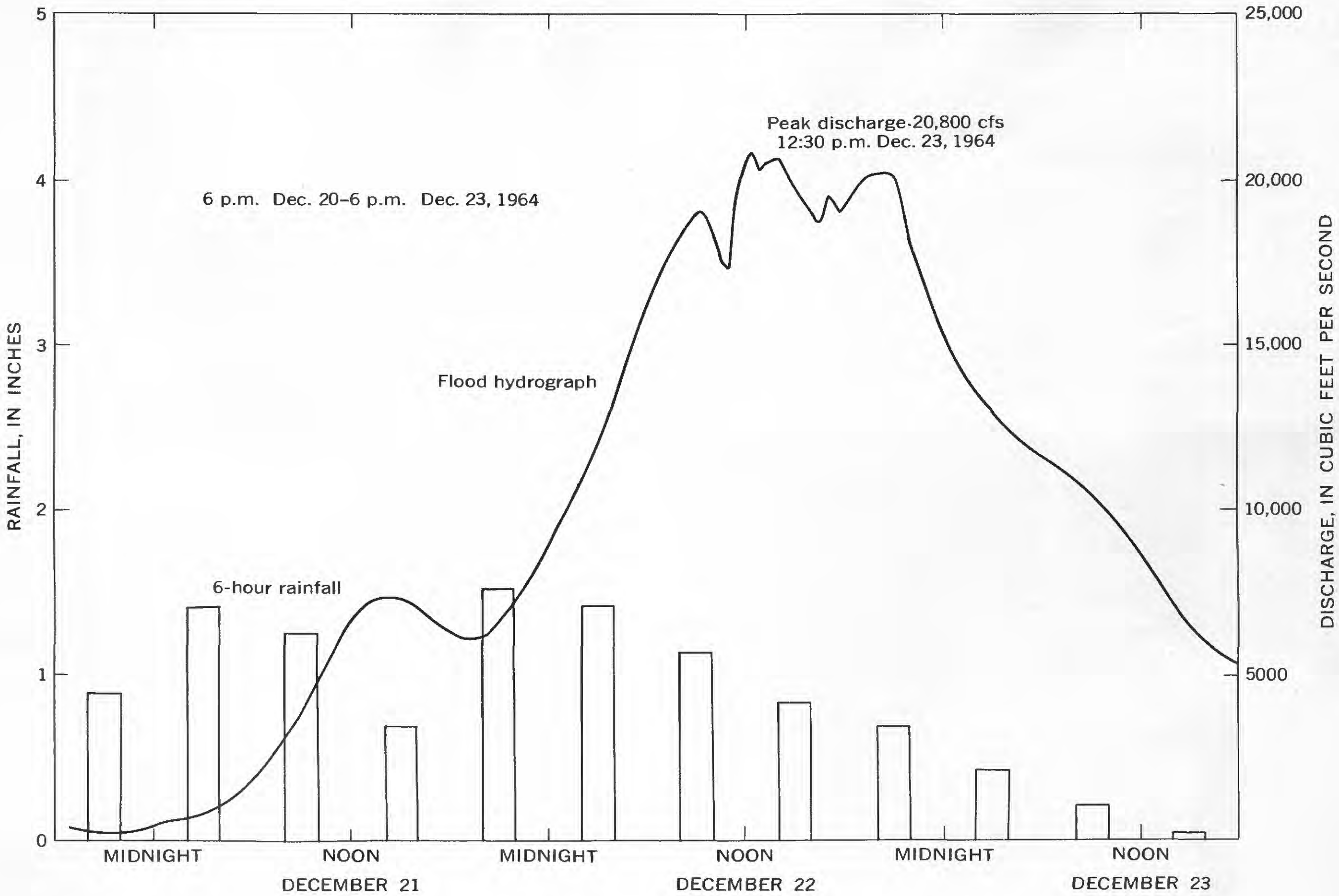

FIGURE 2.—Flood hydrograph on Trinity River above Coffee Creek and 6-hour rainfall measurements at Coffee Creek Ranger Station.

Creek Ranger Station (fig. 1), at the mouth of Coffee Creek, show a total rainfall of 10.7 inches in the 72-hour period beginning at 6:00 p.m., December 20. The maximum 1-day rainfall of nearly 5 inches occurred on December 21. Rainfall at higher altitudes in the basin may have approached the 10-inch 1-day rainfall recorded elsewhere in the northern coastal area (U.S. Weather Bur., 1964) during the same period.

Runoff from snowpack was produced by warm weather and rains at high altitudes. The days during and preceding the flood were warm for December, commonly described as "shirt-sleeve" weather by the residents along Coffee Creek. In the vicinity of the ranger station, several inches of wet snow melted during the night of December 21–22. At higher altitudes, the greater initial snow depth probably retarded melting somewhat, although even there most of the preexisting snowpack was removed during the storm. After the warm weather and rain, the snow cover was no more extensive than after the spring runoff, which generally occurs in April or May.

The water in Coffee Creek rose rapidly during the night of Monday, December 21. By early Tuesday morning the crashing of the boulders sounded "like a cannon" and made sleep difficult for those residents who lived near the stream. The water continued to rise rapidly on Tuesday, and the road up Coffee Creek was closed because of landslides and washouts. High water forced the evacuation of the Coffee Creek Guard Station (mile 4.5) on Tuesday morning. The rising water breached the manmade levee on the north side of the stream near mile 0.3 to 0.4 before noon and near mile 0.7 late in the afternoon. The house near the main channel (about mile 0.6) is reported to have floated from its foundations around 5:00 p.m. The main house at The Cedars (mile 5.0), where 18 people had gathered because it was on high ground and believed to be safe, was evacuated shortly after 7:00 p.m. and engulfed at about 7:30 p.m. as the bank progressively eroded back. The highest flood stage was reached Tuesday night, probably near midnight. The water is reported to have started receding by 2:00 or 3:00 a.m. on Wednesday, but by midmorning was still only 2–3 feet below the crest (figs. 3, 4, and 8). A well-built house near mile 4.8 was not destroyed by flooding until 7:30 a.m. Wednesday.

The water subsided slowly Wednesday, but remained fairly high for several days.

The exact record of the high water of December 22–23 on Coffee Creek is not available because the gaging station was destroyed in the flood. Eyewitness reports, however, suggest that the flood hydrograph would have been similar in form to that on the Trinity River above Coffee Creek (fig. 2), although the flood on Coffee Creek lagged somewhat behind that on Trinity River. The maximum discharge on Coffee Creek during the flood was estimated by the U.S. Geological Survey from flood marks at the gaging station to be 17,800 cfs.

FIGURE 3.—Mad Meadows (mile 4.3) during flood, looking downstream. House in picture is at locality 11, plate 1 and figure 7. Picture taken during mid-morning, December 23, 1964, about 10 hours after crest of flood. Water is down 2–3 feet from crest. Photograph by Roger Wiborg.

FIGURE 4.—Near Coffee Creek Campground (mile 2.1) during flood, looking downstream. Picture taken about mid-morning, December 23, 1964, about 10 hours after crest of flood. Water down several feet from crest. View is southeast toward locality 20 (also loc. 20, pl. 1). Flood waters on right side of photograph have cut deeply both laterally and vertically into former land area. About 10 feet of bank erosion occurred after photograph was taken. East side of section *F–F′* (pl. 2) is near location of truck. Photograph by Roger Wiborg.

Many local residents suggested that the extreme flood of December 1964 was due to an upstream obstruction, such as a log jam or a large landslide, that blocked Coffee Creek and released a deluge of water when it broke. To check this theory, a large landslide at the junction of the North Fork with Coffee Creek was examined. This landslide, which was perhaps the largest in the basin to form at the time of the flood, extends several hundred feet up the south side of the canyon walls, but the trees still standing on the north side of the canyon opposite the slide indicate that the slide did not extend across the stream. In addition, the water marks upstream from the landslide were not at an unusually high elevation—a further indication that the landslide did not back up the water. Although the entire valley upstream was not surveyed, a landslide seems a highly improbable explanation for the high water on Coffee Creek. Some residents reported small surges in the flood water, but no large "wall of water" was described. Discharge was also large on the East Fork and indicates that the flood was due to a general runoff from the entire basin rather than to an unusual event on one branch of the stream. Furthermore, the runoff from Coffee Creek was not unusually large when compared with other streams in northern California.

EROSION AND DEPOSITION PRODUCED BY THE FLOOD

The effect of the flood of December 1964 on the valley of Coffee Creek was catastrophic. Erosion destroyed large areas of forest and meadowland, as well as many buildings and structures. In some areas, deposition buried the former surface under a thick cover of sand and gravel. The destruction was unprecedented in the history of the area and has drastically changed the character of the valley, which was formerly considered to be one of the most beautiful in northern California.

The area covered by the flood waters included almost all of the flat land in the valley of Coffee Creek. In places, such as in the first mile above the Trinity River Road, the flood waters spread across the entire 1,100-foot width of the valley bottom and covered more than seven times as much area as the postflood stream. The only large areas on the valley floor that were not flooded were higher than the surrounding land and either lay along straight reaches of the stream where the stream did not cut into its banks or were protected from the direct attack of the stream by resistant outcrops of bedrock.

METHODS OF STUDY

The effects of the flood were studied by mapping (pl. 1) the first 6 miles of Coffee Creek above the Trinity River Road at a scale of approximately 1 inch to 200 feet. Also in this same reach, seven cross sections of the valley were surveyed (pl. 2). The area between the Trinity River Road and the Trinity River was not mapped, because the effects of the flood here were minor and difficult to illustrate with the same standards used elsewhere.

The mapping of Coffee Creek was done on aerial photographs taken especially for this study on April 24, 1965, 4 months after the flood. During these 4 months, some of the debris from the flood—mainly trees containing salvageable wood—was cleared, and levees were constructed from mile 0 to 0.9 and 2.2 to 2.6. In a few places, road construction altered some of the flood features, and some sand and gravel was removed from the area near Seymour's Ranch (mile 0.6) and at Mad Meadows (mile 4.2 to 4.3). Aside from these minor alterations, the photographs show the valley as it must have looked directly after the flood. Few changes, except for local shifts in the location of the stream channels, were noted between the time the photographs were taken and the time of field mapping (May 8–22).

The map shows the damage to structures as well as to the natural terrane. Location and extent of bedrock exposures were mapped, but no attempt was made to show the geology of the surficial deposits within the valley bottom or on adjacent hillsides. The preflood channel shown on the map is from aerial photographs taken August 8, 1960, and the postflood channels are from photographs taken April 24, 1965.

The main geologic effects of the flood were erosion and deposition. The net effects of these processes outside the area occupied by the postflood stream channel are classified into the five categories shown on plate 1. The term "scour" as used in this report includes erosion of the preflood terrane and also erosion caused by caving and slumping along cutbanks; scour usually includes only erosion due to fluid flow (Colby, 1964, p. IV).

Areas covered by water could be recognized by the presence of flood debris such as plant material and sand and gravel, as well as by the erosional effects of the water. Scour or scour and fill are shown on the map where erosion of the preflood terrane could be seen directly or could be inferred either by the removal of trees or by projecting the old land surface into areas of erosion.

In places the map units grade one into the other, and their separation is difficult. For example, the distinctions between (1) scour and fill with fill less than scour, (2) scour and fill with fill greater than scour, and (3) fill with little or no scour are particularly difficult. All three types are covered by flood deposits and look the same on the surface. Where scour can be inferred from the removal of trees or from projecting the old land surface into the supposed area of scour, scour and fill is shown. Elsewhere fill alone is shown. The two types of scour and fill have been distinguished on the basis of whether the postflood surface is above (fill greater than scour) or below (fill less than scour) the preflood surface. This separation is difficult and uncertain in many places.

Different map units were used in the area occupied by the postflood stream (pl. 1). In most of this area, the effect of the flood could not be determined and this is so indicated on the map. In some places, however, net scour is shown and in other places net fill. Net scour is mapped where erosion is indicated by the removal of trees and where the streambed lies below the projected preflood surface. Net fill in the area of the postflood stream channel is shown on the map only at places in the reach from mile 4.8 to 5.3. Here trees on one or both sides of the channel are deeply buried by flood gravel; this relationship suggests net fill within the channel itself. In addition, preflood and postflood photographs in this area (fig. 10) indicate that the preflood channel has been largely filled. Net fill is also shown by the preflood and postflood profiles of the channel taken by the U.S. Geological Survey at the cableway (fig. 11), although this area of known fill is too small to show on the map. Local testimony also indicates that net fill has occurred (1) at the bridge where the Trinity River Road crosses Coffee Creek and (2) at a locality about 1,900 feet upstream from the bridge, although these possible areas of net fill are not shown on the map.

EROSION CAUSED BY THE FLOOD

Erosion is the most conspicuous effect of the flood. Extensive areas of flat or gently sloping meadow and forest land were eroded, and desolate expanses of flood gravel were left (figs. 5–7). In places, the valley sides were deeply eroded, particularly at bends in the river where the full force of the stream was directed against the bank (fig. 8).

Both older stream deposits and colluvial and alluvial fan material were eroded. From mile 4.1 to 4.8 (pl. 1), older stream deposits were extensively scoured, and locally a channel about 150 feet wide and 8 feet deep was cut. Other examples of the erosion of these stream deposits are shown on the valley cross sections near mile 5.1 (middle part of section *A–A′*, pl. 2) and near mile 2.1 (sections *E–E′* and *F–F′*, pl. 2).

The most spectacular erosion, however, was of colluvial and alluvial fan deposits along the sides of the valley. In the upper 2.4 miles studied, these deposits consist of easily eroded unconsolidated sand derived from granitic rock. Large amounts of this sand were washed away by the flood between mile 4.9 and 5.3 (left-hand part of sections *A–A′* and *B–B′*, pl. 2; figs. 5, 6),

A *B*

FIGURE 5.—Preflood and postflood photographs taken from approximately same position looking north-northeast at The Cedars (mile 5.0 to 5.1). Cabin (4) is the same in both photographs (also loc. 4, pl. 1). *A*, Photograph taken during late 1950's or early 1960's. Area looked virtually like this immediately prior to December 1964 flood. Picture supplied by J. Guggenmos. *B*, Photograph taken in May 1965; cabin has toppled off cutbank since the flood. Cutbank is an alluvial material derived from granitic rock; note dark soil below preflood surface at top of cutbank. All material in foreground up to cutbank was deposited by flood, after erosion of preflood terrane.

A *B*

FIGURE 6.—Preflood and postflood photographs taken from approximately same position looking upstream north-northwest at The Cedars (mile 5.0 to 5.1). House (5) is the same in both photographs (also loc. 5, pl. 1). *A*, Photograph taken during late 1950's or early 1960's. Area looked virtually like this immediately prior to December 1964 flood. Picture supplied by J. Guggenmos. *B*, Photograph taken in May 1965; cabin, beyond house, has toppled off cutbank since flood. This cabin is also shown in figure 5. Cutbank is in alluvial material derived from granitic rock. Note soil developed below preflood surface.

near mile 3.8 (section *C–C′*, pl. 2; fig. 8), and on the north side of the stream near mile 3.1 to 3.2. In the lower 2.9 miles studied, the colluvial material consists of large angular fragments of mafic and ultramafic rock,

A *B*

FIGURE 7.—Preflood and postflood photographs taken from approximately same position looking east at Mad Meadows (mile 4.3). House (11) is the same in both photographs (also loc. 11, pl. 1), and is also shown on figure 3. *A*, Photograph taken during late 1950's or early 1960's. Area looked virtually like this immediately prior to December 1964 flood. Irrigation ditch in foreground. Picture taken by A. D. Rankin. *B*, Photograph taken in May 1965. Road has been rebuilt since flood. This area lies 500–600 feet north of the preflood stream channel.

A *B*

FIGURE 8.—Preflood and postflood photographs taken from approximately same position looking downstream (southeast) at Coffee Creek Ranch (mile 8.7 to 8.8). House (16) is same in both photographs (also loc. 16, pl. 1). Section *C–C′* (pl. 2) is across area of deepest erosion starting off left-hand side of *B*. *A*, Photographs taken during early 1960's. Area looked virtually like this immediately prior to December 1964 flood. Photograph courtesy of Eastman's Studio, Susanville, Calif. *B*, Photograph taken during flood at mid-morning December 23, 1964, about 10 hours after crest of flood; water down about 3 feet from crest. Erosion has occurred at outside of prominent bend in stream. Photograph by Roger Wilborg.

seemingly more difficult to dislodge than the sand. Nonetheless, locally this coarser material was extensively eroded (left-hand side of cross section *F–F′*). Bedrock was exposed to the attack of the flood waters

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at only a few places (pl. 1) and was eroded only on the south side of the stream near mile 2.6 (outcrop too small to show on pl. 1) and on the north side of the stream at mile 4.5. At these places, a few joint blocks were dislodged.

Erosion took place both by downward scour into the preflood surface and by lateral cutting into banks. Downward scour is particularly well illustrated by the channel from mile 4.2 to 4.3 and in scours between mile 0.4 and 0.7. In many places, scour occurred along roads and minor preflood stream channels. Lateral cutting caused caving and slumping of banks and was most pronounced where the flood waters impinged on the outside of stream channels.

Resistant bedrock outcrops tended on the other hand to limit erosion. At the prominent bend at mile 3.6, for example, little erosion occurred on the outside of the bend even though the water must have had a very high velocity after passing through a straight upstream reach. A high velocity here is further indicated by a super-elevation of the flood water of 2–3 feet, as indicated by wash marks, on the outside of the bend.

Crude estimates were made of the area of net scour or fill, and of the net loss or gain of material, from different reaches of the stream (tables 1 and 2). "Net scour" and "net fill" as used here refer to the total effect of the erosional and depositional processes. Net scour, for example, in an area where the flood cut 5 feet into an older deposit and no deposition followed, is the same as in an area where the flood cut 10 feet into the older deposits and later deposition filled in 5 feet of the scour.

A net loss of material (table 2) occurred in the upper 3.4 miles of the area studied and this loss was greatest in the reaches of the upper 1.2 miles. This part of the stream is characterized by a valley of narrow to intermediate width, intermediate to high gradients, and intermediate to high estimated stream velocities.

The presence of readily erodible material seems to be a major factor in controlling erosion. The uncon-

TABLE 1.—*Summary of flood erosion and deposition*

Type of area	Mile 4.1 to 5.3				Mile 3.2 to 4.1				Mile 1.9 to 3.2				Mile 0.8 to 1.9				Mile 0 to 0.8			
	Size of area, in thousands of sq ft	Percentage of flooded area	Net fill, in thousands of cu ft	Net scour, in thousands of cu ft	Size of area, in thousands of sq ft	Percentage of flooded area	Net fill, in thousands of cu ft	Net scour, in thousands of cu ft	Size of area, in thousands of sq ft	Percentage of flooded area	Net fill, in thousands of cu ft	Net scour, in thousands of cu ft	Size of area, in thousands of sq ft	Percentage of flooded area	Net fill, in thousands of cu ft	Net scour, in thousands of cu ft	Size of area, in thousands of sq ft	Percentage of flooded area	Net fill, in thousands of cu ft	Net scour, in thousands of cu ft
Unflooded area within valley bottom	36				0				0				36				129			
Covered by flood, but unaffected or little affected by flood	399	10			33	5			153	7			150	4			528	14		
Fill. Little or no scour	1,819	43	3,400		200	28	300		859	38	1,400		1,266	34	2,100		2,629	66	6,200	
Scour followed by fill. Fill greater than scour	422	10	600		0	0	0		233	10	400		1,103	30	2,300		123	3	200	
Scour followed by fill. Fill less than scour	965	23		4,700	85	12		600	261	12		750	228	6		400	117	3		600
Scour. Little or no fill	64	2		100	1	1		1	78	3		450	297	8		1,600	124	3		600
Postflood stream channel:																				
Net fill during flood	140	3	400		0	0	0		0	0	0		0	0	0		0	0	0	
Net scour during flood	102	2		600	18	3		50	266	12		900	400	11		1,600	56	1		100
Net scour or net fill not determinable	285	7			380	53			392	17			287	8			333	9		
Totals	[1] 4,196	100	4,400	5,400	717	102	300	651	2,242	99	1,800	2,100	[1] 3,731	101	4,400	3,600	[1] 3,910	99	6,400	1,300

[1] Excluding unflooded area within valley bottom.

TABLE 2.—*Summary of physiographic characteristics of valley and effects of flood, based on data on plates 1 and 2 and table 1*

[Valley width: Narrow, <300 ft.; intermediate, 300–900 ft.; wide >900 ft. Valley gradient: Low, <0.020; intermediate, 0.020–0.025; high >0.025; based on data on plate 2. Mean velocity of flood water: Low, <6 fps; intermediate, 6–12 fps; high >12 fps; based on estimated peak discharge of the flood at the site of the gaging station and cross-sectional area of the flood waters (pl. 2). Length of valley measured approximately along centerline]

Reach	Valley width	Valley gradient	Mean velocity of flood water	Number of flood channels	Area of net scour—	Area of net fill—	Material gained (+) or lost (−) per mile of valley, in thousands of cu ft per mile
					Per mile of valley, in thousands of sq ft per mile		
Mile—							
4.1–5.3	Intermediate	Intermediate	Intermediate	2–4	900	1,800	−800
3.2–4.1	Narrow	High	High	1	120	25	−320
1.9–3.2	Intermediate to narrow	Intermediate	Intermediate	1–2	400	700	−190
0.8–1.9	Intermediate to wide	Intermediate to low	Intermediate to low	2–3	1,000	2,000	+700
0–0.8	Wide	Low	Low	1–2	160	3,200	+6,000

consolidated sand composing the colluvial and alluvial fan material in the upper 3.4 miles of the mapped area seemingly offered little resistance to the flood waters, and probably explains much of the net scour calculated for this area.

In any one reach, the amount of material lost from an area where the postflood surface was below the preflood surface (net scour) tended to be matched by a corresponding gain of material in nearby areas where the postflood surface is above the preflood surface (net fill). In the reach from mile 4.1 to 5.3, for example, the total volume of material gained in areas of net fill is 4.4 million cubic feet, whereas the volume of material lost in areas of net scour is 5.4 million cubic feet; there was thus a net loss, but a minor one, in the reach as a whole. The reach from mile 0.8 to 1.9 and from mile 1.9 to 3.2 shows a corresponding similarity in the estimates of volume of net scour and fill. The amount of erosion and deposition are distinctly unbalanced, however, in the reach from mile 3.2 to 4.1, where the amount of net scour was twice as great as the net fill. Here the valley is narrow and the valley gradient and stream velocity high, and the whole flooded area was virtually one flood channel. In the reach from mile 0.0 to 0.8, on the other hand, where the valley is wide and the valley gradient and flood velocities low, deposition far exceeded erosion.

DEPOSITION CAUSED BY THE FLOOD

Sand and gravel deposited during the flood cover at least 70 percent of the flooded area. In some places these deposits were laid down directly on the preflood surface (fig. 9) or in the preflood stream channel (figs. 10 and 11), whereas in other places the deposits formed in a two-stage cycle consisting of erosion of the preflood terrane followed by deposition of sand and gravel. Locally the sand and gravel was deposited in several episodes of erosion and deposition, during which flood deposits were laid down, eroded, and followed by the deposition of new sand and gravel.

Sand occurs at the surface on more than half of the area occupied by flood deposits (pl. 1). It is mostly in areas away from the main flood channel, or channels, and commonly within forests and brushy areas. In places, such as at Mad Meadows (mile 4.2 to 4.3) and Seymour's Ranch (mile 0.6), sand covered large areas

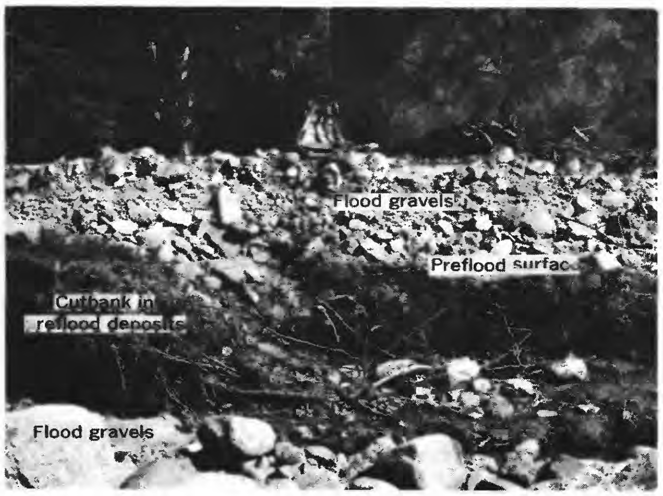

FIGURE 9.—Flood gravels, preflood surface, and cutbank in preflood deposits. View north toward locality 6 (pl. 1). Pack on top of gravel about 15 inches high.

A

B

FIGURE 10.—Preflood and postflood photographs taken from approximately the same position near mile 5.3; upstream view (north). House (1) is the same in both photographs (also loc. 1, pl. 1). Comparison of *A* and *B* indicates that 5 feet or more of deposition occurred during flood in the preflood channel. *A*, Photograph taken during the 1950's. According to residents, the stream channel looked approximately like this immediately prior to December 1964 flood. Picture supplied by J. H. Jessup. *B*, Photograph taken in May 1965. The stream channel here is not the same as that shown on plate 1 as a natural diversion has caused a shift in the stream channel between the date (April 24, 1965) the photographs used in preparing plate 1 were taken and the date of this photograph.

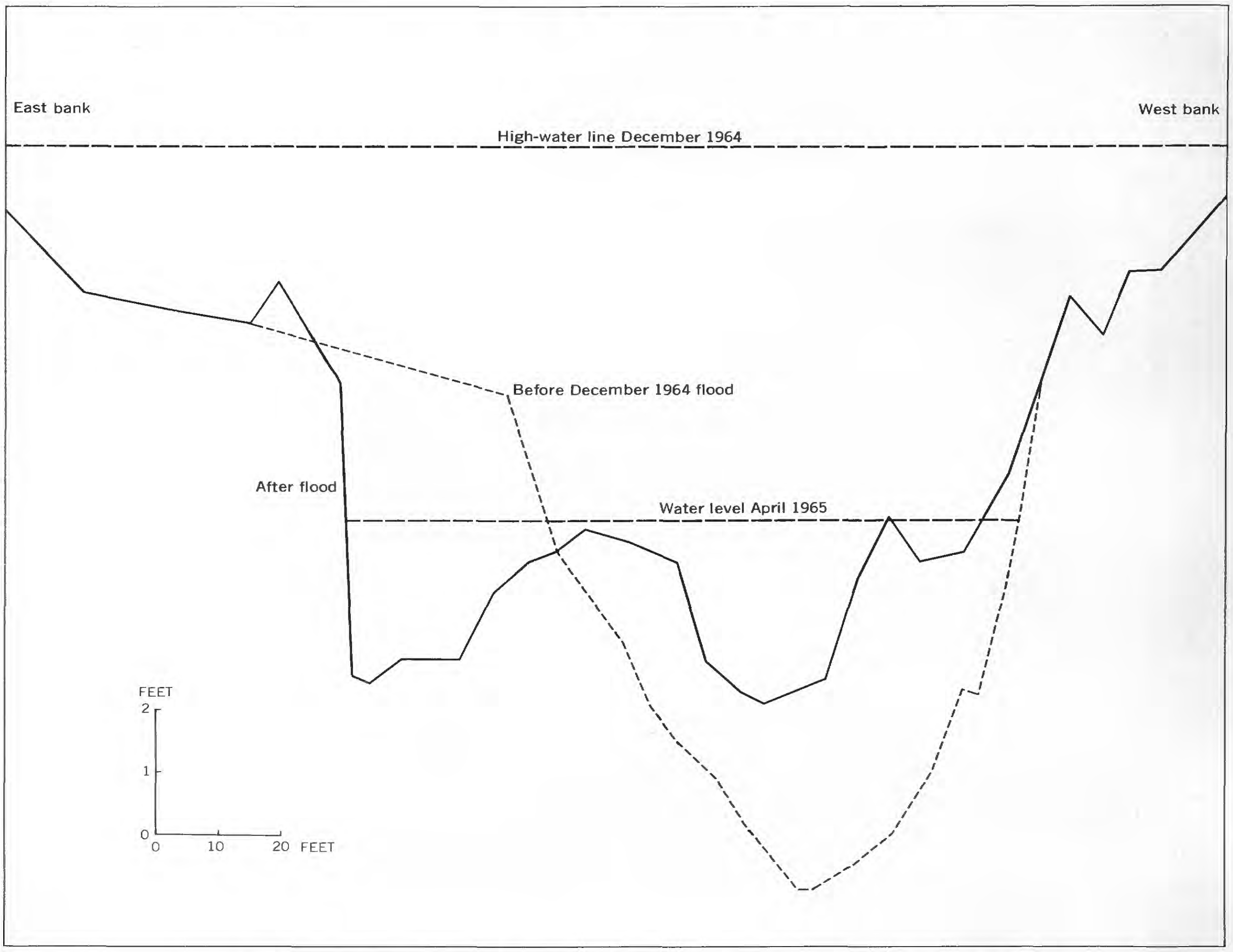

FIGURE 11.—Comparative preflood and postflood cross-channel profiles at cableway (mile 2.7) on Coffee Creek.

of meadowland. It also occurs locally as a thin (less than 1 ft) cover over gravel, where it may have been deposited in relatively slack water after the crest of the flood had passed or after a shift in the position of the main flood channel.

The average grain size of the sand deposits is variable, ranging, in the samples studied (fig. 12, table 3), from fine to very coarse. The sand is moderately sorted and commonly contains some fine gravel. The amount of silt and clay mixed with the sand is small, being less than 6 percent in all but one of the samples (sample at loc. 29); this latter sample contains 23 percent silt and clay and was specially selected to represent fine-grained material.

In most places, the sand deposits are structureless or nearly structureless, although a crude horizontal layering or indistinct cross-stratification occurs rarely. The sand deposits are generally from a few inches to 2 feet thick, although locally they are 4 feet or more thick (pl. 1).

The sand deposits commonly occur in flat-topped and steep-sided bars (fig. 13) that are irregular in shape and elongate in the direction of streamflow. They lie between minor flood channels and apparently formed in relatively slack water between channels of more rapid flow. The top surface of these bars must have been commonly within a few inches of the mean high-water surface.

The gravel deposited by the flood is widespread, although not as widespread as sand, and occurs near or within flood channels, where the velocity of the water presumably was high. The gravel deposits are broadest in areas where the stream channel is braided, such as mile 0.8 to 1.6 and mile 4.9 to 5.2, reaching a width of more than 500 feet near mile 5.0.

At the surface, where the coarse flood deposits ap-

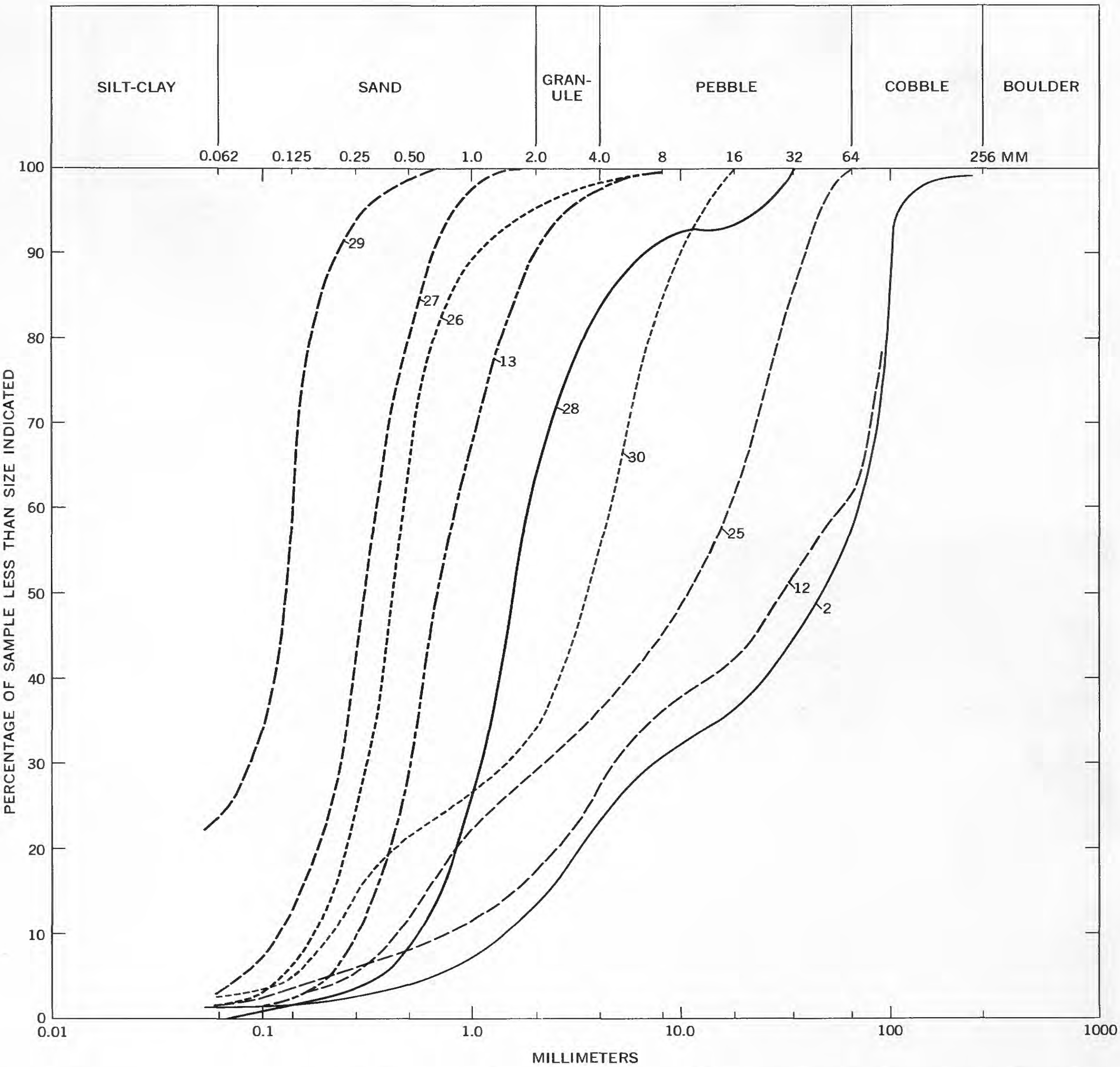

FIGURE 12.—Cumulative curves of grain-size distributions of flood deposits. Number indicates locality (pl. 1) from which sample taken. Sample described in table 3.

parently have been "washed" and the sand removed, the gravel contains little, if any, sand, and is well sorted; but below the surface it is poorly sorted and contains 13–34 percent sand. The subsurface deposits also contain a large proportion of boulders and cobbles, as much as 42 percent in one sample (loc. 2, fig. 12). The gravel is mostly structureless; rarely, a crude horizontal layering occurs. The gravel is commonly thicker than the sand deposits, being, in places, as much as 8 feet thick; it may be even thicker where gravel has filled preflood stream channels.

The largest material transported by the flood (table 4) was more than 6 feet in maximum diameter and almost 5 feet in intermediate diameter, and many boulders 3–5 feet in maximum diameter and 2–4 feet in intermediate diameter were moved. Movement of these boulders is indicated by their occurrence within or at the top of gravel that rests on a preflood terrane and that thus was clearly deposited during the flood. At other places, where the identification of flood deposits is obscure, movement is indicated by the presence of transported plant debris directly below the boulders.

TABLE 3.—*Size analysis of flood deposits*

Locality (pl. 1)	Median diameter D50 (mm)	First quartile D25 (mm)	Third quartile D75 (mm)	Sorting coefficient ($\sqrt{D75/D25}$)	Description of sample
2	46	4.8	91	4.3	In natural levee deposit, 3 ft below top. Top of natural levee composed of large boulders, the largest 5.5 ft in maximum diameter. Sample near and in material similar to that shown in fig. 17.
12	30	3.7	90	4.9	½ ft above base of 2-ft-thick layer of gravel at side of small tributary flood channel bordering major flood channel. Gravel layer rests on uneroded preflood surface. Largest boulder in gravel near sample is 1.4 by 0.8 by 0.8 ft.
13	.70	.46	1.3	1.7	2 ft below top of 6-ft-thick flood deposit. Lower 3 ft of deposit is sandy gravel, upper 3 ft is sand. Deposit borders 3-ft-deep plunge pool cut into preflood terrane.
25	11	1.3	26	4.5	From 5-ft-thick bedded flood deposit. At base is 2 ft of sandy cobble gravel, which is overlain by 2 ft of bedded coarse sand (sample 26) that in turn is overlain by 1 ft of sandy gravel (sample 25). At top of section, only ½ ft below peak water level, is a pavement of cobbles as large as 4 in. in diameter.
26	.42	.28	.58	1.4	
27	.31	.22	.44	1.4	Samples from deposits in area of heavy brush and young forests; deposits in form of flat-topped bars separated by channels. Samples 27 and 28 are representative of most deposits in area. Sample 29 is a finer grained deposit in a willow thicket. Sample 30 is gravelly sand in a flood channel.
28	1.6	1.0	2.8	1.7	
29	.12	.072	.16	1.5	
30	3.5	.8	6.4	2.8	

FIGURE 13.—Flat-topped bar formed during flood and composed of sand and fine gravel. View east-northeast from locality 31 near mile 0.3. Dark area in lower left corner is grass-covered preflood surface that elsewhere in the area photographed lies 2–3 feet below the new gravel. Scale indicated by pick in center of photograph.

TABLE 4.—*Some maximum sizes of transported material*

Locality pl. 1	Size (feet)	Type of material	Note
3	4.4 by 3.8 by 1.8	Granitic	On top of natural levee 8 ft above adjacent streambed.
	5.5 by 3.4 by 2.2	do	
	3.5 by 3.3 by 2.4	do	
	3.5 by 3.2 by 2.5	do	
	2.9 by 2.3 by 1.7	do	
	3.5 by 2.8 by 1.6	Aplite	
	2.9 by 2.0 by 1.3	do	
7	5.0 by 4.0 by 2.9	Granitic	In flood channel.
8	3.5 by 2.1 by 2.1		On natural levee.
9	3.0 by 2.3 by 2.2		About 2 ft below 5-ft-thick natural levee deposit.
10	4.1 by 3± by 2.8		In flood channel.
14	5.0 by 3.5 by 3.0	Diorite	In flood channel.
15	4.2 by 2.9 by 2.8	Granitic	Lodged in tree 6 ft above ground surface. Estimated mean velocity across flood area 15 FPS.
	2.3 by 1.4 by 1.2	do	
17	6.2 by 4.8 by 3.3	Granitic	On top of natural levee.
	4.4 by 3.2 by 1.9	do	
	4.3 by 3.0 by 2.1	do	
	6.4 by 2.8 by 1.5	do	
	5.0 by 2.9 by 2.0	do	
	4.1 by 2.9 by 2.0	do	
	4.5 by 4.2 by 2.2	do	
	4.8 by 2.9 by 1.3±	Peridotite	
	4.8 by 4.3 by 1.7	Granitic	
22	2.8 by 2.7 by 1.8	Peridotite	On top of 5-ft-thick natural levee deposit, 15 ft above streambed.
24	5.6 by 3.9 by 2.7	Concrete	Bridge abutment probably from vicinity of Coffee Creek Campground (site) 1.7 miles upstream.

The extremely poor sorting of the flood sand and gravel seems to indicate rapid deposition from water containing a large quantity of sediment. At times the manner of sediment transport may have been similar to that of a debris flow or mudflow. The deposits are texturally similar to mudflow sequences illustrated by Fahnestock (1963, fig. 15–17), but the deposits on Coffee Creek apparently cannot be considered to be true mudflows, because they lie below the highwater marks of the flood and in places contain current featues that indicate a subaqueous origin. Furthermore, no source area, such as a landslide, that could produce a debris flow or mudflow was found in the reach studied. Some landslides occur upstream from the study area and must have contributed sediment to the flood waters, but the size of the slides is insignificant in relation to the amount of material moved by the flood.

Features considered to be natural levees commonly occur along the edge of the main flood channel. These features apparently formed during the flood when coarse material was transported out of the channel, where the water velocity was high, and deposited in the area of relatively low velocity flow to the side of the main channel. Fahnestock (1963, p. A50) has described apparently similar features in coarse gravel along a glacial stream on Mount Rainier, Wash.

The natural levees are generally 30–50 feet wide and have a steep slope into the adjacent channel and a gentle slope (commonly 3°–4°) away from the channel (figs. 14, 15, and 16). The crest of the levee is, in most places, topographically higher than the surrounding terrane and lies 8–10 feet above the streambed of the adjacent channels and 2–4 feet above the general level of the valley bottom away from the channel and levee. The surface of many of these natural levees was probably only about 0.5–3 feet below the high water of the flood, on the basis of the projection of the water level from nearby wash marks or other features indicating the height of the flood crest. In places, some of the large boulders may have projected above the mean high-water surface.

The natural levees are composed of poorly sorted gravel (sample at loc. 2, fig. 12; fig. 17) and have a fairly high content of sand. The surfaces of the levees, however, are composed mainly of coarse gravel with little, if any, sand. The gravel at the surface appears coarser than that within the deposit, but this difference cannot be conclusively demonstrated. The natural levees on the outside of the bends in the stream are composed

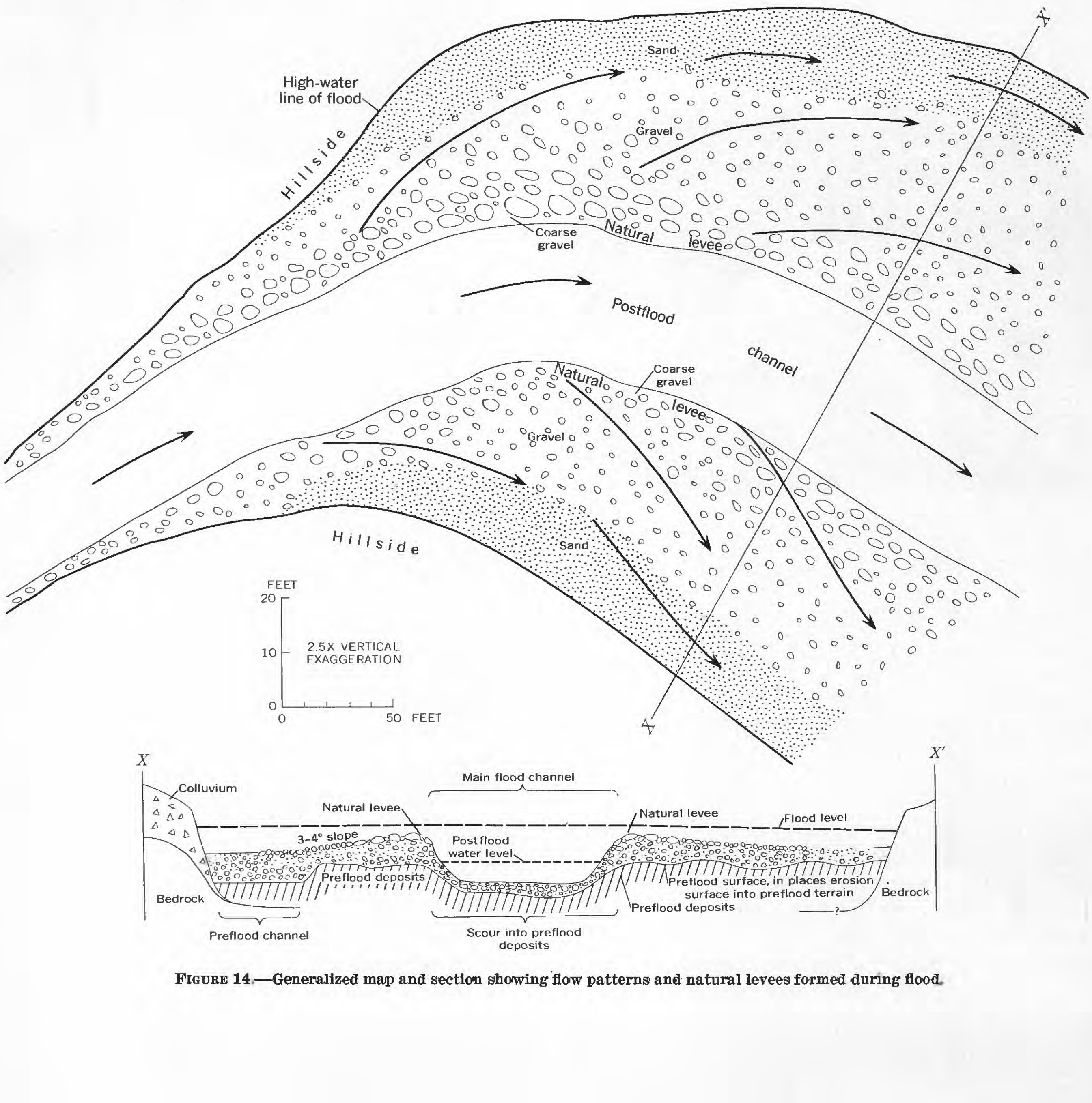

FIGURE 14.—Generalized map and section showing flow patterns and natural levees formed during flood.

FIGURE 15.—Natural levee at The Cedars (mile 5.0) formed in flood. Large boulders occur at surface of levee, and levee slopes gently to left away from stream channel. View is downstream toward southeast. Detailed photograph (fig. 17) of levee deposit taken at locality 2 (also loc. 2, pl. 1).

FIGURE 16.—Natural levees formed in the flood, near mile 3.1, looking southeastward. Stream is confined by the levees in this reach. The natural levees slope gently away from the stream. Locality 18 shown on plate 1.

of coarser gravel than the natural levees along straight reaches, whereas the material on the inside of the bend is composed of finer material.

Deposition was greatest in the lower 1.9 miles of the valley, and in this area a net gain of material occurred during the flood (table 2). In the lower 0.8 mile studied, this net gain was about 6 million cubic feet per mile of valley, a volume equivalent to a layer 1.3 feet thick across the 1,100-foot-wide valley bottom.

Deposition was most conspicuous in broad valley areas where the valley gradient and stream velocity were low. This relationship is clearly shown in the lower 0.8 mile studied, where the valley is broad and gently sloping, and stream velocities were low.

FIGURE 17.—Sandy gravel in natural levee at The Cedars (mile 5.0; loc. 2, pl. 1, fig. 15). Length of scale is 2 feet. Plant debris in deposit was transported during flood.

FLOOD CHANNELS

The type and character of the flood channels differ considerably within the 6 miles mapped along Coffee Creek and appear to be determined by such interrelated factors as the width of the valley, the valley slope, and the stream velocity.

In the widest reach of the stream (about 1,100 ft), from mile 0 to 0.6, the water spread out into a broad, relatively shallow stream. Part of the main flow was in the area of the preflood channel along the south side of the valley bottom, and part was in the northern valley bottom near Treasure Creek, but compared to other reaches of the stream the flow was relatively unconcentrated. At section *G–G′* (pl. 2) in this reach, the mean velocity of the flood waters was 5.1 fps (feet per second) on the basis of estimated peak discharge of the flood at the site of the gaging station and the cross-sectional area of the flood waters. This mean velocity is the lowest indicated in any of the measured cross sections. The average valley slope near section *G–G′* is 0.13, the lowest slope measured along the valley. As indicated, this reach of the valley contains the largest accumulations of flood deposits.

In areas where the valley has intermediate widths (500–800 ft), such as near mile 2.1 and from mile 5.0 to 5.1, the flood-water was concentrated into two or more major flood channels, commonly braided. Three major flood channels occur at mile 5.0 to 5.1 (section *A–A′*, pl. 2) and two at mile 2.1 (section *F–F′*, pl. 2). In these areas, where the valley bottom is of intermediate width, the mean velocity of the flood waters has an intermediate value (6.5 to 7.0 fps at mile 5.0 to 5.1 and 7.9 fps at mile 2.1). The valley slope at mile 5.0 to 5.1 (approx. 0.024) and at mile 2.1 (approx. 0.022) is also intermediate between the slope of the wide-valley reaches and narrow-valley reaches.

In areas where the valley is narrow (100–200 ft), such as from mile 3.7 to 3.8 (sections *C–C′* and *D–D′*, pl. 2), the flood water occupied a single channel. At mile 3.7 to 3.8, the mean velocity of the flood waters (14.7 fps) and the slope of the valley (approx. 0.032) are the highest estimated anywhere along the lower 6 miles of Coffee Creek.

SHIFTS IN STREAM CHANNELS

Changes in the position of the channel of Coffee Creek appear to have been greater during the December 1964 flood than during at least the previous 110 years of historical record. During the 1850's, a trail which in many places was along the stream, was built up Coffee Creek valley. This trail had withstood all previous high water until the 1964 flood (Roy Connelly, written commun., 1965). In addition, the position of the stream channel on photographs taken in August 1944 is virtually the same as on photographs taken in August 1960, except in the braided reach of the stream between the Coffee Creek Campground (mile 2.1) and Seymour's Ranch (mile 0.6), where some conspicuous channel changes took place between August 1944 and August 1960 (fig. 18).

Many new channels were established during the flood. In some places, such as the braided reaches from mile 4.9 to 5.3 and from mile 0.8 to 1.6, the old channels were filled and the postflood stream follows an entirely different course. Elsewhere, the flood water occupied both the preflood channel and newly formed channels. In some places the flow in the new channel became the permanent stream, whereas in other places the old channel was reoccupied.

A conspicuous new channel system formed on the north side of the valley from mile 4.1 to 4.8, in an area where the valley is of intermediate width. In places this system consists of more than one channel, but from mile 4.1 to 4.5 the water formed a single channel about 150 feet wide and 8 feet deep. No water course had existed in this area before the flood. After the flood, according to residents, the flow reverted naturally to the old preflood channel, although a low levee (manmade) was later constructed to assure this flow pattern. Channel shifts also occurred from mile 1.9 to 2.2 and from mile 2.4 to 2.6. In these places, according to residents, the water flow persisted in the new channel after the flood until it was diverted back to the preflood channel by manmade levees.

The shifting of channels, as well as the location of scour, was influenced by the piling up of logs and other debris. Much of this debris was removed before the authors visited Coffee Creek after the flood and before the postflood aerial photographs were taken. No attempt was made to show the location of debris on the map. Nonetheless, log jams commonly formed at the upstream limit of the forests and deflected the main flow of the flood to other parts of the valley. The residents also described examples of debris piles that blocked main channels and diverted the flow to other areas.

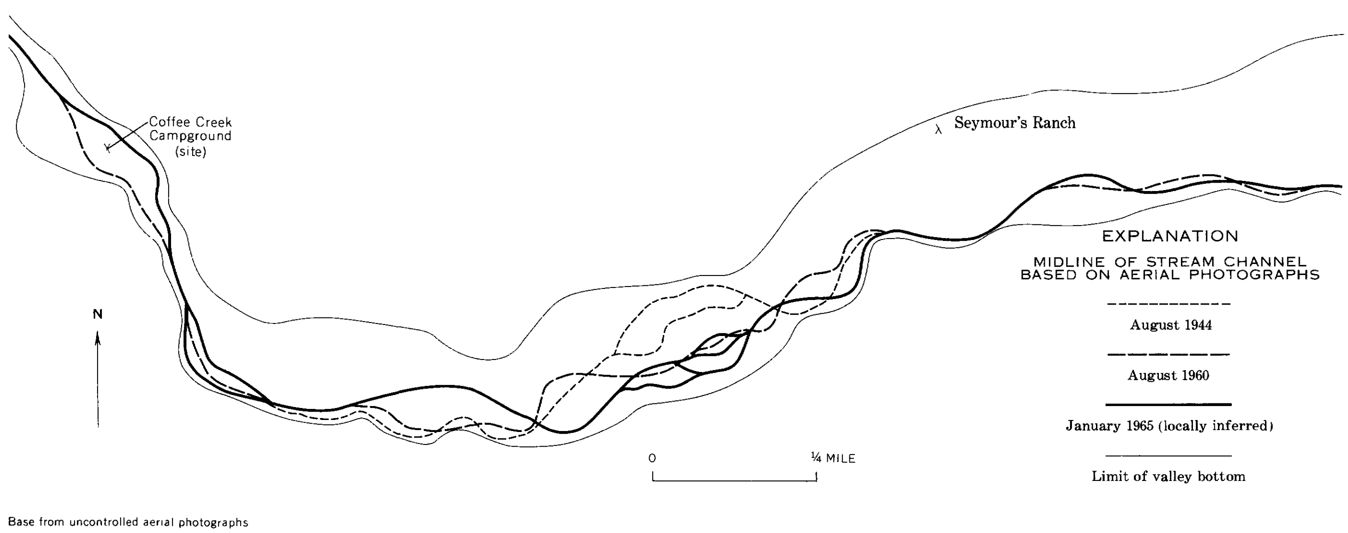

FIGURE 18.—Channel changes between site of Coffee Creek Campground (mile 2.1) and Seymour's Ranch (mile 0.6).

FLOOD FREQUENCY

The problem of the frequency of occurrence of catastrophic floods such as that on Coffee Creek is of both geologic and hydrologic interest. The time that has elapsed since an event of similar magnitude can be estimated from historical, botanical, and geologic evidence. Alternatively, a measure of the recurrence interval of extreme floods can be obtained through flood-frequency analysis based on regional hydrologic data.

Although accurate flood records are available for the past 7 years only, accounts of local residents indicate that the December 1964 flood greatly exceeded any previous flood on Coffee Creek during the 110-year period since original settlement of the area. Even the December 1955 floods, the greatest since the near-legendary deluge of 1861 in most of the region, were not of great magnitude in the upper Trinity River basin. The gage height of the 1955 flood peak on Coffee Creek (estimated by U.S. Geol. Survey from flood marks at the time of gaging-station installation) was equaled by a flood in February 1958 and one in October 1962 (U.S. Geol. Survey, 1962, p. 443–444). In 1955 and in 1958, and in the flood of 1937 as well, flood waters covered the road (U.S. Geol. Survey, 1960, p. 638–639) in the lower Coffee Creek valley to a shallow depth. Some bank erosion and local channel changes took place, but the overall effects were insignificant compared with those of the catastrophic flood of December 1964. The discharge of 17,800 cfs on December 22, 1964, is more than five times greater than that of October 12, 1962 (3,360 cfs) (U.S. Geol. Survey, 1962, p. 443–444), the highest flood previously recorded.

Other evidence suggests that recent floods have been relatively less severe in Coffee Creek than on most nearby streams. For example, comparison of floods related to winter storm runoff (fig. 19) shows that during the 7-year period prior to the December 1964 flood, the peak discharge per square mile of drainage area has been two to three times greater on Trinity River (drainage area 149 sq mi) than on Coffee Creek (drainage area 107 sq mi). Further, the preflood appearance of Coffee Creek valley differed from that of nearby streams of comparable size. The channel of Coffee Creek had been bordered for much of its length by large mature trees, whereas the low-water channels of the Trinity River and lower Swift Creek were flanked by broad, barren gravel flats.

Part of the reason for the differences in frequency and magnitude of flooding on Coffee Creek in comparison with nearby streams may be the relatively high altitude of its drainage basin in the Trinity Alps. Although the mouth of Coffee Creek lies at an altitude of less than 2,500 feet, 40 percent of the drainage basin is above 6,000 feet. Only about 20 percent of the basin of the Trinity River above Coffee Creek is at comparable altitude. Winter snowfall and snowmelt runoff would thus be expected to be more important in the hydrologic response of the higher basin. For example, in 1960 the peak discharge for the year occurred in February on the Trinity River. On Coffee Creek, the peak discharge associated with the same winter storm was exceeded by snowmelt runoff in June. Thus, the combination of prolonged high temperatures and intense rainfall, which were features of the December 1964 storm, and melting of much of the preexisting deep snowpack in the Trinity Alps triggered the tremendous runoff from the Coffee Creek basin.

The flood-frequency on Coffee Creek cannot be analyzed directly, as a single-station analysis as described by Dalrymple (1960), because of the brevity (7-year period) of the streamflow record. However, an attempt was made to extend this record synthetically through correlation of the flood peaks with those recorded at the long-term station on the Trinity River at Lewiston. Because the correlation is very poor within the period of overlap in the records, a regional-analysis approach was used.

In a comparative study of six methods of flood-frequency analysis applied to coastal basins in California, Cruff and Rantz (1964) concluded that the two Geological Survey methods, the index-flood method and the multiple-regression method, give better results where historical evidence of great floods is available. They concluded that of these two, the multiple-regression method was superior.

A series of regression equations, based on correlation of peak discharges of a given recurrence interval with the watershed variables of area, mean basin altitude and mean annual basinwide precipitation, has been developed from analysis of records of long-term gaging stations in northern California that include the December 1964 flood peaks (R. W. Cruff, written commun., 1965). The calculated flood-frequency curve for Coffee Creek, together with the confidence limits, is shown on figure 20. This indirect analysis indicates that a flood discharge similar to that of the 1964 flood will probably occur, on the average, about once in 100 years in a drainage basin having the location and gross physical characteristics of the basin of Coffee Creek.

A minimum estimate of the time that has elapsed since a flood of a magnitude comparable to that of December 1964 is provided by the rings of many of the trees uprooted in the flood. Although individual old trees along a stream course may be undermined from time to time by lesser floods, extensive destruction of large areas of pine-fir forest such as occurred in Coffee

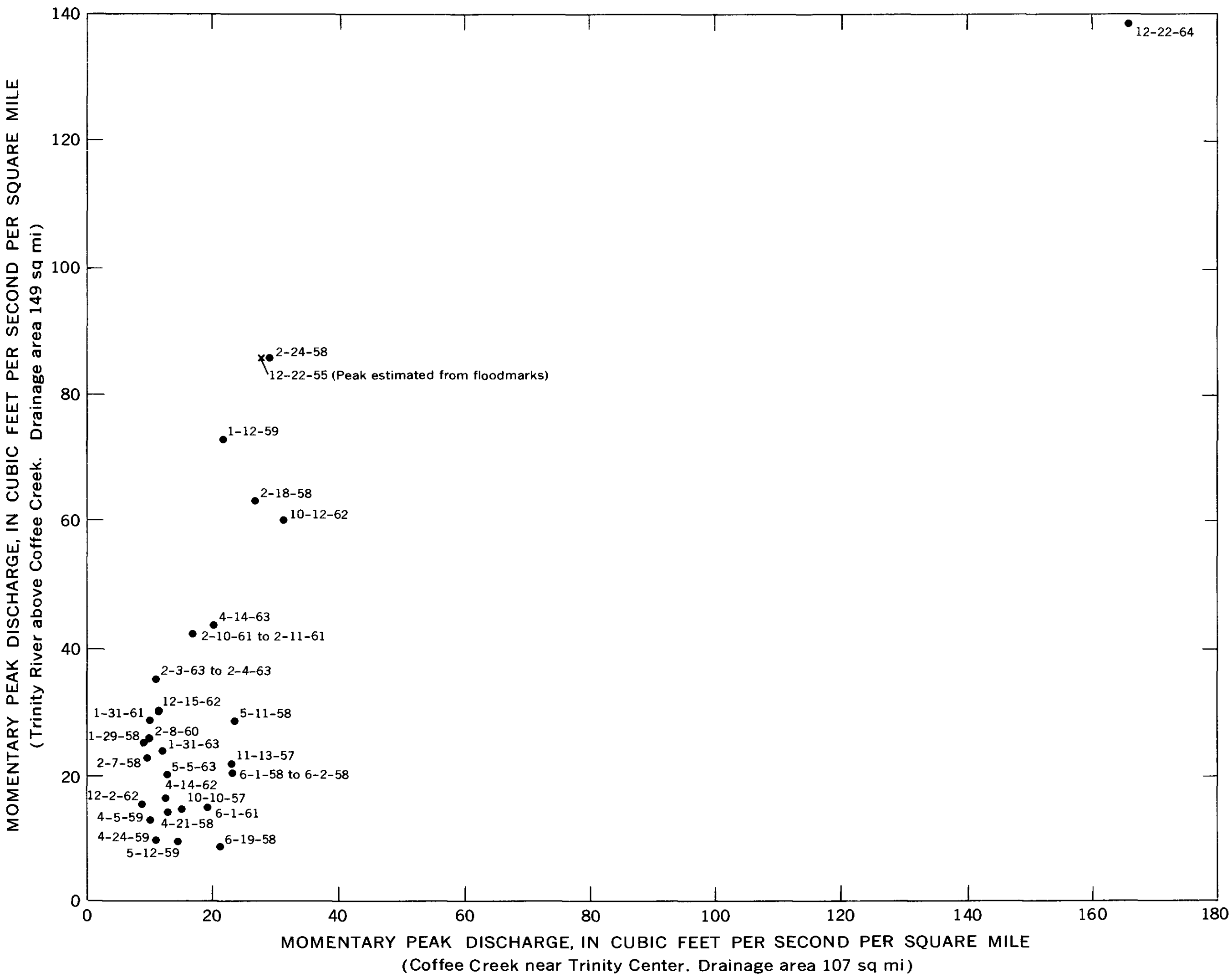

FIGURE 19.—Concurrent peak discharge per square mile of drainage area of Trinity River as compared with Coffee Creek. Numbers indicate month, day, and year of event. Data from U.S. Geological Survey (1960a, b; 1961a, b; 1962; 1963; 1964a; written commun., 1965).

Creek valley is much rarer. The dating of logs reclaimed from trees in debris piles near mile 1.7 to 1.8 shows that many of them were 200–300 years old. A fir on the streambank between mile 3.4 to 3.5 had attained the age of 420 years when it was toppled across the stream during the flood. The site of Coffee Creek Campground (mile 2.1) was almost entirely forested before the flood, but now only a few pines 2–3 feet in diameter, said to be representative of the preflood forest, remain between the main flood channels. Dating of three of these through counting of rings exposed in increment cores gives ages of 150, 160, and 275 years. The largest trees near the north bank of the flood channel have similar ages. Upstream, near mile 5.2, two trees were found to have ages of 180 years. The tree-ring dating of both overturned and standing trees, together with general observations of the dimensions of trunks in the debris, clearly indicates destruction of extensive forested areas that have survived all the floods within at least the previous 200 years.

The widespread erosion of thick alluvial and colluvial deposits along the margins of the valley is a geologic event of rare but unknown frequency. Deposits such as the alluvial fans of granitic sand at mile 3.8 and 5.0 are known to have changed little in the 100 years prior to the 1964 flood. The sparsely wooded, flat or gently sloping areas of alluvial soil overlying deeper gravels "* * * alike inviting to the miner or grazier * * *" (Cox, 1858), long a feature of Coffee Creek valley, no longer exist. The depth of soil and rock debris from adjacent slopes, 10–20 feet in many places, indicates that this debris must have been accumulating undis-

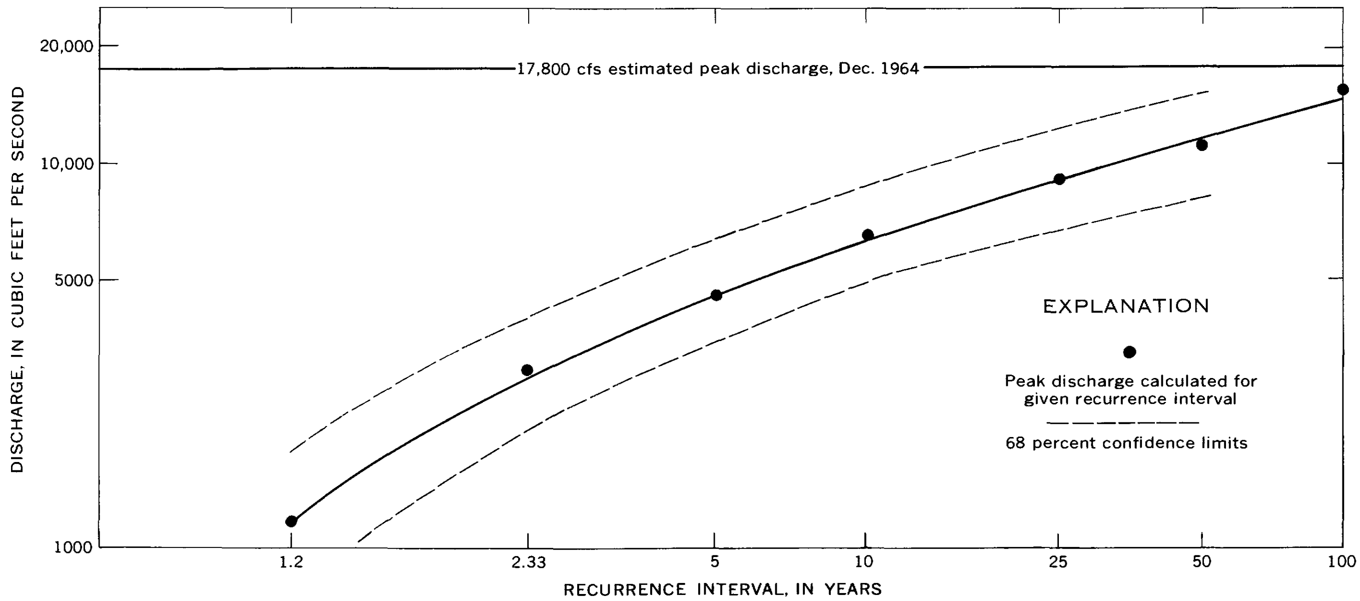

Figure 20.—Flood-frequency graph for Coffee Creek by multiple-regression analysis (after R. W. Cruff, written commun., 1965).

turbed for several or many hundred years[1] prior to its removal by deep lateral erosion during the 1964 flood.

Indirect calculations thus suggest that a flood similar in magnitude to the 1964 event might be expected to occur no more than 10 times in 1,000 years, perhaps much less often. Botanical and geologic evidence indicates that the lower valley of Coffee Creek has not been similarly inundated for several or many hundred years.

Although a great destructive flood is very infrequent event, it is apparently not unprecedented in the geological history of Coffee Creek. The ridgelike deposits of older gravel at several localities in the valley are clearly ancient natural levees formed in much the same way as those of the recent flood. It is important to note that the highest of the older deposits were not covered by the 1964 flood water but were as much as 2 feet above the level of the water surface in nearby channels. This implies a previous flood or floods that reached stages comparable to that of the immense flood runoff of December 1964 unless the stream had progressively degraded its bed during the intervening period.

[1] Subsequent to preparation of this report, four radiocarbon dates were obtained by the writers on charcoal in alluvial fan deposits in the valley of Coffee Creek. The charcoal was exposed in cutbanks formed in the flood. These dates are:

1. <205 years B.P., 4.7 ft. below preflood surface, near mile 3.2, north side of valley (I–2390)
2. 830±90 years B.P., 5.8 ft. below preflood surface, near mile 3.2, north side of stream, 30 ft. east and 7 ft. below sample I–2390 (I–2389)
3. 1,650±100 years B.P., 10.0 ft. below preflood surface, total depth of alluvium 16.6 ft., near mile 3.8, north side of valley (I–2391)
4. 1,710±100 years B.P., 12.4 ft. below preflood surface, total depth of alluvium 14 ft., near mile 5.2, south side of valley (I–2392).

SUMMARY AND CONCLUSIONS

The December 1964 flood on Coffee Creek was of rare frequency and unprecedented in historic time. Erosion and deposition during the flood were catastrophic and significantly changed the character of the valley. Some of this erosion and deposition was similar to that described by Hack and Goodlett (1960, p. 48–51) for northern Virginia. Large areas of colluvial and alluvial material along the sides of the valley were eroded. Within the valley, the preflood channel was commonly filled, and new channels formed at entirely different locations. Deposition of sand and gravel occurred over a large part of the valley floor, covering, in places, large areas of meadowland.

Along much of the valley, the volume of material lost in areas of net scour was about the same as that gained in nearby areas of net fill. Such a balance of erosion and deposition, however, did not occur in narrow steep reaches where the flood-water velocity was high; in these reaches, erosion far exceeded deposition. At the opposite extreme, in broad gently sloping reaches where the flood-water velocity was low, deposition far exceeded erosion. Although the entire 6 miles of the valley studied apparently gained more material than it lost, this gain was small. Nonetheless, a vast amount of material, some of it large boulders, was moved during the flood. The flood was primarily a transporting event during which erosional and depositional factors tended to be balanced.

Physiographic changes were most pronounced where the valley is of intermediate width and moderate gradient. In these reaches, erosion significantly widened the valley bottom by removing colluvium and alluvial fan deposits that had accumulated over a long period along the margins of the valley, encroaching on the valley bottom. Physiographic changes were minor in narrow high-gradient reaches and in wide low-gradient reaches, and were caused largely by scour in the former and by aggradation in the latter. There was little tendency for lateral cutting where the valley is wide. The contrast in effects of the flood in relation to the character of the different reaches may reflect different stages in valley evolution. Downcutting of the channel first establishes a smooth longitudinal profile; this downcutting is followed by lateral erosion that widens the valley floor and permits a flat valley to form.

The flood was competent to transport material as large as 6 feet in maximum diameter and more than 5 feet in intermediate diameter. The highest mean velocity for the stream, based on the cross-sectional area of the stream and an estimate of the peak discharge, is 14.7 fps at the Coffee Creek Ranch. Maximum velocities were undoubtedly higher, but the velocity near the streambed could, in many places, be lower than the mean value. In any case, a velocity of 14.7 fps seems to be adequate to move the large boulders. Fahnestock (1963, fig. 30 and p. A30) indicates that velocities of 7 fps were sufficient to transport material having an intermediate diameter of 1.8 feet. Projection of his data to fragments of large size indicates that velocities of about 12 fps are needed to transport material as large as that in Coffee Creek. Some of the material transported on Coffee Creek is comparable in size to that transported in the August 1955 flood in Connecticut (Wolman and Eiler, 1958, table 1).

Natural levees are one of the prominent depositional features produced by the flood. They are 30–50 feet wide, 2–4 feet above the general level of the adjoining flood deposits, and 8–10 feet above the adjoining streambed. In most places the levees are topographically the highest depositional features of the flood. The surface of the levees is composed of coarse gravel; in places, some of the largest boulders that were transported in the flood lie on these levees. The depth of the water over the levees, however, was relatively shallow, probably about 0.5–3 feet. In places, some of the large boulders may even have projected above the mean high-water level of the flood.

Old natural-levee deposits that are widespread on the valley bottom indicate former floods of large magnitude. They are elongate bouldery areas topographically higher than the general level of the valley. Many of the old natural-levee deposits were islands within the area flooded in December 1964.

Channel changes and sediment deposition on a high mountain stream such as Coffee Creek seem to occur in a manner different from that described in many other streams. Wolman and Leopold (1957) have emphasized that the flood-plain deposits that they studied consist predominantly of channel deposits (point bars) formed by the slow lateral migration of the stream across the valley bottom. They further emphasize that overbank deposition accounts for only a small part of the flood-plain deposit. On Coffee Creek, on the other hand, lateral migration of the stream seems to be negligible, except in the highest floods, and overbank flow lays down most of the coarse "channel" deposits on the valley bottom. Slow lateral migration seems to be nearly impossible on Coffee Creek because the natural levees are composed of coarse material that apparently can be transported only in the largest floods. The natural levees that form in great floods retain the water in the channel during lesser floods. Overbank flow, which apparently is a rare event along much of Coffee Creek but did occur in the December 1964 flood, caused a marked change in the entire character of the valley. Areas that were formerly dry land were converted into stream channels, and preflood stream channels were in places filled and abandoned. During this catastrophic change, coarse "channel" deposits were laid down on the valley bottom in areas far removed from the preflood channel.

The recurrence interval of floods on Coffee Creek of a size comparable to that of December 1964 is estimated to be about 100 years on the basis of analysis of the expectable flood-frequency of a basin of the size, altitude, and rainfall of Coffee Creek in relation to other streams in northern California. This 100 years indicates the estimated average interval between floods, but the actual interval between any two floods of comparable size may be shorter or longer than the average, depending on chance conditions. On Coffee Creek, no flood of comparable size has occurred within the 110 years of historical record, and destruction of large areas of land containing 200-year-old trees and of alluvial fan material as much as 1700 years old suggests that the valley has not been similarly flooded for many hundred years.

The morphological and sedimentary features of the valley of Coffee Creek are apparently in adjustment to present climatic conditions although other geologists have questioned such an adjustment in many glaciated mountain streams. Wolman and Miller suggested (1960, p. 67) that coarse gravel in many glaciated mountain areas may be a relic of glacial times when the stream had a high competence and that such gravel may be too large to be moved by modern floods. Alternately, Wolman and Miller (1960, p. 67) suggested that modern catastrophic floods may have been competent to move the coarse material, although they thought this explanation less likely. The record from Coffee Creek is clear, however, that a modern flood is competent to move all but a few exceptionally large boulders. But without the knowledge of the 1964 flood, the coarse gravel in the stream channel and on the valley bottom of Coffee Creek might have been interpreted as a relic of glacial time, and the large colluvial deposits along the sides of the valley might have been considered to have accumulated since glacial time.

The catastrophic flood of 1964 on Coffee Creek largely determined valley morphology, channel pattern and location, and the character of alluvial deposition, and apparently floods controlled the formation of these features in the past. Only in extreme events can the coarse material that makes up these features be transported. Wolman and Miller (1960) have suggested that fairly frequent events of moderate magnitude commonly do more "work" and are more important in establishing specific landscape features than are catastrophic events. The total amount of sediment transported during the 1964 flood cannot be determined from information available, but extreme events clearly are more important than lesser ones in the formation of the landscape features on Coffee Creek.

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