Processes and rates of formation of Holocene alluvial terraces in Harris Wash, Escalante River basin, south-central Utah

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ABSTRACT

Harris Wash, a tributary of the Escalante River in south-central Utah, has two well-preserved alluvial terraces of compound origin in its lower reaches. The alluvial stratigraphy of the deposits that compose these terraces reflects the complex processes of canyon filling and erosion. The compound terraces were formed by general aggradation of the valley, by deposition from large floods that also resulted in alluvial-fill incision, and by aggradation of flood-plain surfaces during periods of base-level stability. The alluvial chronology indicates that Harris Wash was aggrading for most of the Holocene and that only two late Holocene periods of rapid incision, between 2500 and 1900 yr B.P. and between 1000 and 300 yr B.P., are evident from the terrace stratigraphy. Rapid aggradation of flood plains during the past 150 yr produced historic flood-plain deposits 5 m above the elevation of the stream. The historic flood-plain deposits and other similar deposits in other Escalante River tributaries are attributed to increased runoff and erosion related to land-use changes in the basin during this time interval. Older alluvial deposits in Harris Wash cannot be correlated with alluvial sequences in other western tributaries of the Escalante River basin. In these drainages, valley aggradation and incision are apparently more sensitive to intrabasin processes of sediment production and storage and less dependent on regional factors such as climate change.

INTRODUCTION

The Quaternary alluvial history of the Colorado Plateau has been of interest to geologists since Dutton (1882) observed that its stream valleys were being choked with sediment and were aggrading. Gregory (1916, 1917), Bryan (1925), Gregory and Moore (1931), and Bailey (1935) later described the entrenchment of this pre-1880 alluvium, which indicated the beginning of a new "epicycle" of erosion. Other workers recognized that this recent period of valley incision was only the latest phase of numerous cycles of degradation and subsequent aggradation found in a complex Quaternary alluvial record (Hack, 1942; Bryan, 1954; Hunt, 1955; Cooley, 1962; Lance, 1963). Some investigators have made regional stratigraphic correlations of these alluvial sequences (Euler and others, 1979), whereas others have noted dissimilarities in the numbers and ages of alluvial deposits not only from basin to basin but even within a single drainage basin (Bailey, 1935; Cooley, 1962; Kottlowski and others, 1965).

Cyclic aggradation and degradation of semiarid stream valleys has been attributed to several mechanisms, which include: varying degrees of change in climate (Bryan, 1940; Leopold, 1951; Euler and others, 1979); adverse land-use practices, especially overgrazing (Dodge, 1902; Swift, 1926; Bailey and others, 1934; Hastings, 1959); and the inherent geomorphic processes by which sediment is produced and transported by streams in semiarid watersheds (Dellenbaugh, 1912; Thornthwaite and others, 1942; Schumm and Hadley, 1957; Patton and Schumm, 1981). Different causes can therefore account for the particular alluvial stratigraphy in separate watersheds. As a result, a universal cause for the aggradation and degradation of these stream valleys may not exist (Cooke and Reeves, 1976; Graf, 1983a). Instead, complex assemblages of alluvial deposits and landforms can be produced, depending on factors that control the processes of runoff, sediment production, and sediment storage (Schumm and Parker, 1973; Patton and Schumm, 1975; Womack and Schumm, 1977; Bull, 1979).

The purpose of this study is to describe the alluvial history of lower Harris Wash and to determine the processes and rates of terrace formation. The results of this study indicate that compound alluvial terraces are formed by several processes, which include (1) general aggradation of the valley, (2) deposition from large floods that mark periods of alluvial-fill incision, and (3) aggradation of flood-plain surfaces during periods of base-level stability. In general, aggradational periods span time intervals of thousands of years, whereas periods of alluvial-fill incision are significantly shorter.

Recognition and interpretation of the complex terrace stratigraphy has provided insight into the processes, timing, and relative magnitude of sediment production, as well as the position and residence time of sediment storage, within the Escalante River drainage basin. Data on the magnitude and residence time of stored sediment are necessary to create accurate sediment budgets, yet these data are seldom available from historical records alone (Graf, 1983b; Meade, 1982; Trimble, 1981, 1983). An understanding of past sediment budgets can also be used to evaluate the degree to which land-use practices alter the natural processes of sediment production, storage, and transport.

The detailed history of Harris Wash and adjacent streams on the Colorado Plateau is also important in determining the effect that climatic shifts, deduced from other evidence, may have had on these semiarid stream systems (Van Devender and Spaulding, 1979; Cole, 1982; Williams and Wigley, 1983). Finally, a better understanding of the alluvial history of streams on the Colorado Plateau will aid in fitting the extensive archaeological record (Jennings, 1966) to a paleo-environmental framework.

SETTING AND METHOD OF STUDY

Harris Wash has a drainage area of 707 km^2. The wash descends from an elevation of 2,800 m on the Kaiparowits Plateau to an elevation of 1,400 m at its confluence with the Escalante River (Fig. 1).

A detailed study was made of the alluvial deposits in the lowermost 17 km of the wash

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(Fig. 2), which is cut into the Mesozoic Navajo Sandstone, Kayenta, and Wingate Formations (Sargent and Hansen, 1982). Here, terrace deposits in large alcoves on the outside of incised meanders are well exposed and allow detailed study of their internal alluvial stratigraphy. Such exposures demonstrate that geomorphic terraces are constructed from deposits that differ in age and sedimentology. The excellent terrace exposures in this reach of Harris Wash permit a detailed reconstruction of the number of erosional and depositional periods related to each terrace.

The location and height above the modern stream of terrace remnants were measured at 46 sites (Fig. 2). Detailed stratigraphic sections were made at 35 locations where the terrace deposits were not obscured by bank collapse or slope wash. The ages of some alluvial deposits were determined by the radiocarbon dating of wood, charcoal, and organic-rich layers of leaves, seeds, and small fragments of wood found within the alluvium.

Radiocarbon dates for transported charcoal disseminated in alluvium are considered maximum ages for the zone from which the charcoal was collected (Blong and Gillespie, 1978). The radiocarbon dates that are the most stratigraphically consistent are those derived from fine-grained organic material. This organic material, reworked from surface litter, occurs as dense mats capping sedimentation units. Even these organic mats, however, yield maximum ages. The correlations that follow, therefore, rely mainly on the stratigraphic position of units within the alluvial sequence.

TERRACE DESCRIPTION AND ALLUVIAL STRATIGRAPHY

The geomorphic terrace surfaces can be divided into three groups based on elevation above stream level. First, the modern flood plain, which ranges from 1.5 to 3 m above the wash, is the most laterally persistent and youngest depositional feature. Second, a low terrace at heights from ~5 to 8 m above the wash is defined by a group of terrace remnants of diverse lithology and age and is compound in origin. Third, a high terrace is represented by only a few isolated remnants at heights >9 m above the modern stream. These latter remnants are the oldest deposits recognized in the canyon.

The stratigraphy of the deposits that form the terraces reflects complex canyon filling and erosion within Harris Wash. Within these terraces, six stratigraphically distinct alluvial deposits are recognized and can be conveniently grouped by the geomorphic surfaces that they form (Fig. 3). The high terrace consists of two units: the high alluvial fill which forms the base of the terrace, and the old flood deposits which overlie it. The low terrace comprises three distinct alluvial stratigraphic units: the low alluvial fill which forms the base of the terrace, the historic flood-plain deposits which are inset against the low alluvial fill, and recent flood deposits which cap both the low alluvial fill and the historic flood-plain deposits. The youngest stratigraphic unit recognized is the modern flood-plain alluvium.

Low Terrace Stratigraphy

The low terrace is described first, as it has the best and most numerous exposures. In addition, an analysis of the low terrace stratigraphy provides a model which can be used to interpret the stratigraphy of the limited exposures of the high terrace.

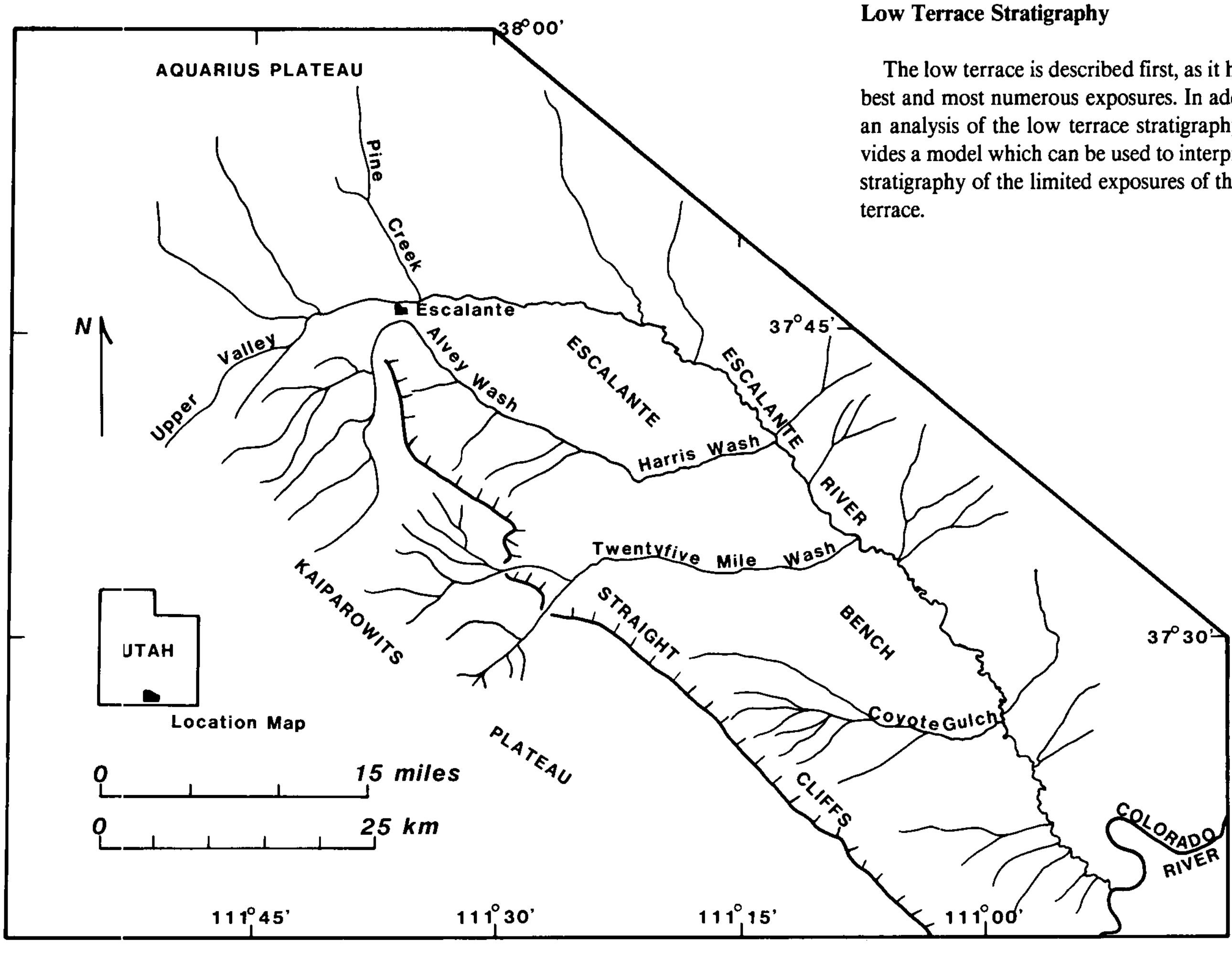

Figure 1. Map of the Escalante River basin in southern Utah.

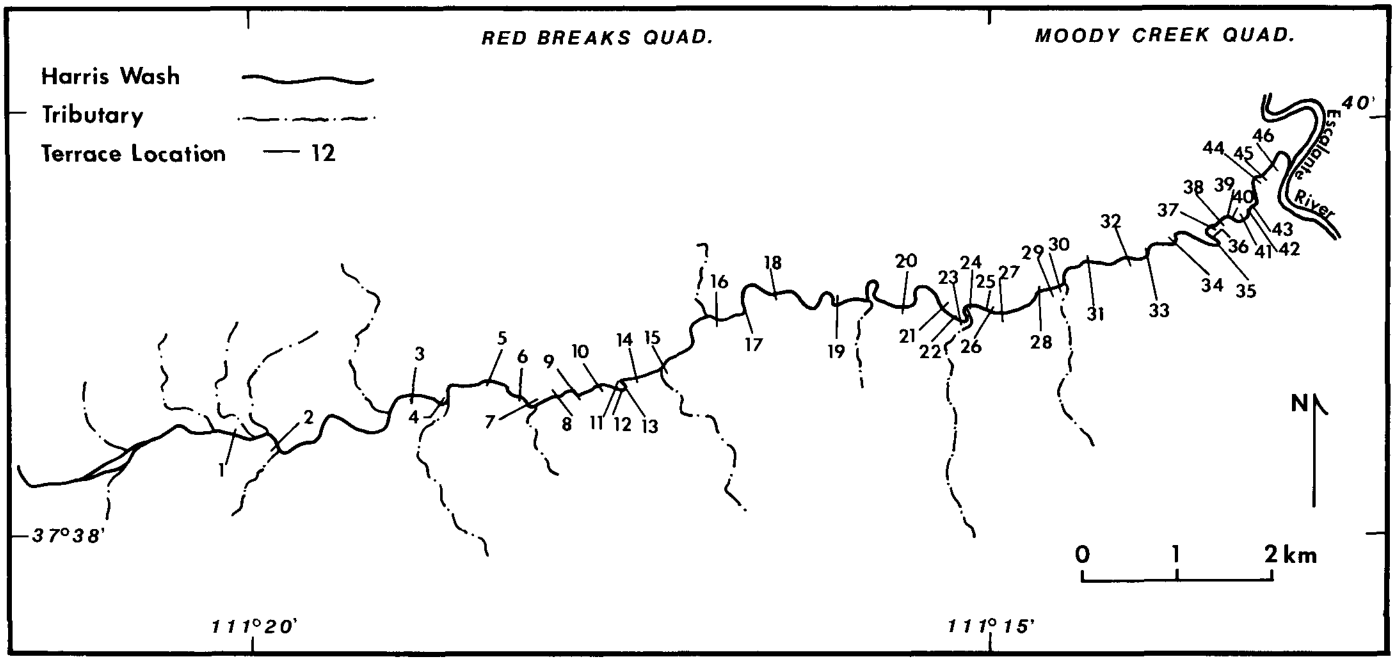

Figure 2. Map of lower Harris Wash, showing sites of measured terraces. This reach of channel corresponds to that of the longitudinal profile in Figure 7.

Low Alluvial Fill Deposits. The low alluvial fill deposits consist of aggradational sequences that become thinner bedded and finer grained upward (Fig. 4). Typically, the lower part of the fill is uniformly thick beds of massive, tan sand which commonly contain gravel. If stratification is present, it commonly consists of parallel laminae. Individual beds of sand are separated by thin layers of mud, and the sand beds commonly decrease in thickness upward. Overlying the deposits, there are beds of red and tan, ripple cross-laminated sand, each commonly <15 cm thick (see, for example, the interval from 1.3 to 2.4 m in section 33, Fig. 4). Asymmetrical ripple-drift cross-lamination which preserves both lee and stoss slopes is the most common sedimentary structure of this type. The ripple cross-laminated beds also are separated from one another by thin layers of mud of uniform thickness. The top of the alluvial fill consists of flat-lying beds of red and tan mud which lack internal structure and which have abrupt parallel contacts that are traceable along the length of an outcrop, typically 10 m or more (an example is the interval from 4.2 to 5.7 m in section 19, Fig. 4). These beds commonly have mudcracks and contain organic debris. Colluvium, consisting of blocks of sandstone that are derived from the adjacent canyon walls, is commonly present in the alluvial fill (the interval from 3 to 4 m in section 34, Fig. 4). We interpret the low alluvial fill as a vertical sequence of channel, point bar, and flood plain deposits that were created during the gradual aggradation of the wash.

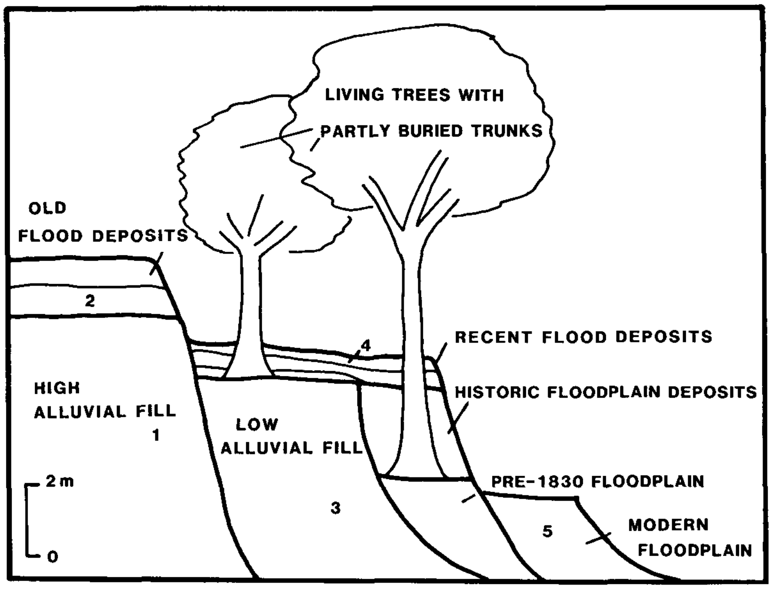

Figure 3. Schematic diagram of the composite stratigraphy of the terraces and flood plain of lower Harris Wash. The numbers refer to units listed with radiocarbon dates in Table 1. Unnumbered stratigraphic units have not been radiocarbon dated.

The surface of the low alluvial fill can in many cases be identified by the presence of a weakly developed soil which consists of a thin A horizon overlain by small fragments of organic litter. In places, the organic litter was burned, which left a black, carbonized horizon. The top of the low alluvial fill defines a surface which decreases in height above the stream from 7 m at the head of the study reach to slightly <5 m at the mouth (surface B in Fig. 7 below).

The age of the low alluvial fill has been determined by radiocarbon dating (Table 1). The oldest dates that are thought to be reliable are 1910 ± 150 yr B.P. (TX-4103) in section 15 and 1810 ± 150 yr B.P. (TX-4412) in section 34

TABLE 1. RADIOCARBON AGES FOR HARRIS WASH

Sample *no.*	Stratigraphic *section*	Material *dated*	^{14}C age	Geomorphic unit
TX-4101	16	charcoal	8,160 ± 380	1. High alluvial fill
TX-4105	8	wood	4,910 ± 990	
TX-4413	19	organic litter	2,520 ± 90	
TX-3938	19	charcoal	3,280 ± 430	2. Old flood deposits
TX-3937	33	organic litter	1,520 ± 430	3. Low alluvial fill
TX-4103	15	charcoal	1,910 ± 150	
TX-4411	34	charcoal	2,570 ± 70	
TX-4412	34	charcoal	1,810 ± 150	
TX-4414	19	charcoal + wood	1,050 ± 150	
TX-4124	45	charcoal	320 ± 70*	
TX-4125	45	charcoal	270 ± 90*	
TX-4100	20	wood	200 ± 80	4. Recent flood deposits
TX-4127	33	wood	330 ± 80	
TX-4104	8	charcoal	150 ± 80	5. Modern flood plain

* *The correlation of section 45 with the low alluvial fill is uncertain.*

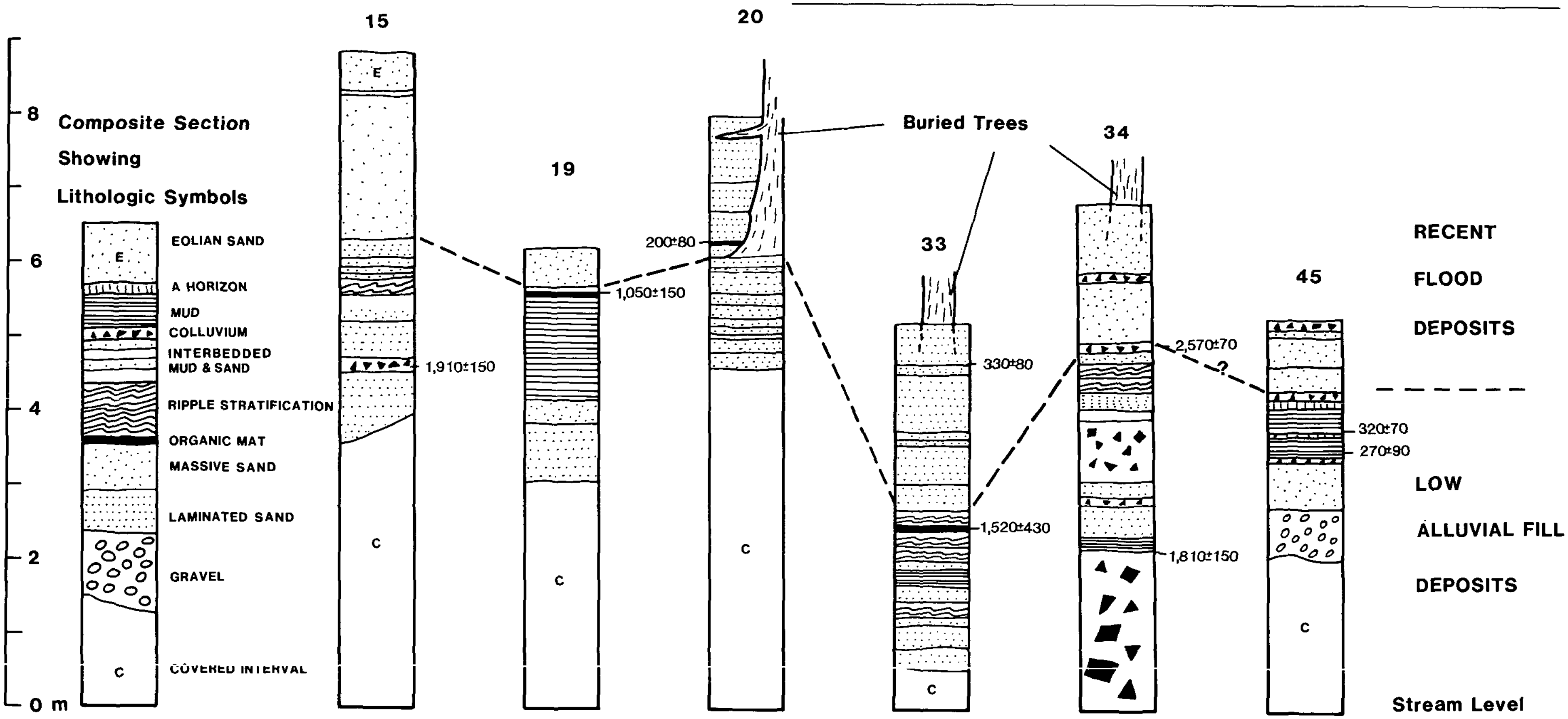

Figure 4. Representative stratigraphic sections of the low terrace, illustrating the sedimentary features, localities of pertinent radiocarbon-dated horizons, and relation between the low alluvial fill deposits and the overlying recent flood deposits.

(Fig. 4). The youngest dates that seem reliable are 1050 ± 150 yr B.P. (TX-4414) in section 19 and 1520 ± 430 yr B.P. (TX-3937) in section 33 (Fig. 4), which was obtained from organic debris near the top of the low alluvial fill.

In addition to the radiocarbon chronology, one archaeological site located on a low terrace remnant gives a limiting age for the aggradation of the low alluvial fill. The Circle Terrace site is on a low terrace, 5 m above stream level, ~6 km upstream from the mouth of Harris Wash (Fowler, 1962). Circle Terrace is near our section 19 and consists of a circular structure that has been excavated 25 cm into the low terrace alluvium and that has sandstone slab walls and a clay floor. Since occupation of the structure, it has been filled in with windblown sand and slope wash. The structure and associated cultural debris are related to the Fremont Culture, dated between 900 and 1275 A.D. (1050–675 yr B.P.), and are evidence that aggradation of the low terrace deposits had ended before the structure was built.

Historic Flood-Plain Deposits. The historic flood-plain deposits of the low terrace represent several metres of aggradation in the past 150 yr. The historic deposits accumulated on a low, pre-1830 flood-plain surface which formed after the low alluvial fill was incised (Fig. 3). The deposits of the historic flood-plain can be identified by the presence of cottonwood trees of large diameter that began to grow while the sediment was accumulating. The result is that the lower trunks of the cottonwood trees are buried by as much as 3 m of flood-plain deposits. The relationships of the cottonwoods to the historic flood-plain deposits are similar to those described by Hereford (1984) for the "cottonwood terrace" on the Little Colorado River. The best exposure of the historic flood-plain deposits is at section 34, where they bury a 0.75-m-diameter cottonwood tree (Fig. 5). The flared base of the tree is 2.2 m above the present stream bed, and the tree has been buried by 3 m of accumulated alluvium. The tree developed three sets of adventitious roots while the deposits were accumulating, which is evidence of the episodic deposition during the growth of the tree. Tree-ring cores taken 3 m above the base of the tree show that the tree began to grow at about A.D. 1827 (S. Clark, 1982, personal commun.). The historic flood-plain deposits aggraded to a level approximately equal in elevation to that of the low alluvial fill, but slightly lower than the surface defined by recent flood deposits (profile D; see Fig. 7 below).

Recent Flood Deposits. The recent flood deposits consist of thick, uniform beds of tan sand that cap both the low alluvial fill and the historic flood-plain deposits. Some low terraces consist entirely of these flood deposits and probably bury the low alluvial fill. At section 34, for example, recent flood deposits (Fig. 5) not only cap the low alluvial fill but also are plastered onto the eroded scarp of the low alluvial-fill deposits. Only a small exposure of the low alluvial fill pokes through this cover of flood sediment.

The flood deposits consist of sand, and individual beds are up to 135 cm thick. The beds are separated by thin layers of mud that contain organic detritus in many places. The sand is

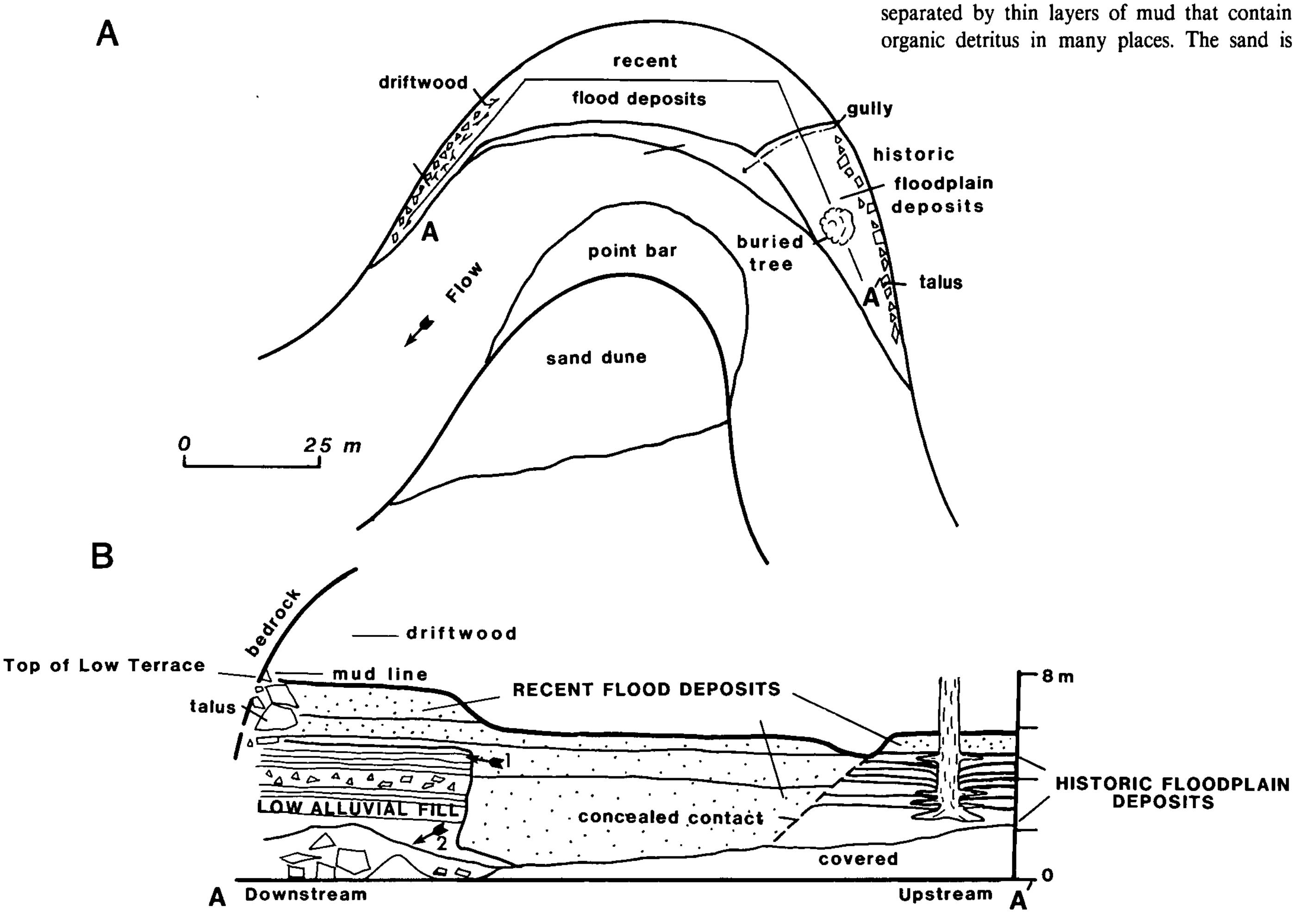

Figure 5. Sketch map (A) and cross section (B) of the low terrace at section 34. The terrace consists of low alluvial fill deposits buried by recent flood deposits. Historic flood-plain deposits, also buried by recent flood deposits, are inset against the terrace. Arrows in B point to position of radiocarbon samples (1) TX-4411 and (2) TX-4412 (Table 1).

either massive or laminated, and the laminae are inclined either upstream or downstream. Like the historic flood-plain deposits, the recent flood deposits bury the trunks of living trees (for example, sections 20, 33, and 34; Fig. 4). Unlike older deposits, these massive flood sedimentation units do not have significant accumulations of talus on their surfaces. Recent deposition by floods has buried any colluvium on the former surface of these terraces.

The combined stratigraphic evidence indicates that the most recent deposits were emplaced by flows capable of overtopping the present terrace surfaces—in some cases, 8 m above the present elevation of the wash. The mud lines on the bedrock canyon walls 7–8 m above the modern wash and the driftwood on some terrace surfaces are additional evidence that recent flood flows do reach these heights.

Thick sequences of recent flood deposits were preferentially deposited in alcoves on the outside margins of highly sinuous, bedrock meanders. The ratio of the radius of meander curvature to channel width for many of these bedrock meanders in lower Harris Wash is <2, a value which indicates that the meanders have hydraulically inefficient forms (Bagnold, 1960). During floods, this tight meandering form will produce large flow-separation zones along the downstream edge of meander spurs. The flow-separation zones created at these meanders are the loci of flood deposition. Climbing ripples oriented upstream, as found at section 19, and upstream-inclined laminae observed at several other exposures may represent sediment transport in a resulting turbulent eddy. The characteristically thick sedimentation units of the flood deposits suggest rapid deposition of sediment from suspension as the velocity of the flow was reduced at these sites. Protection by bedrock meander spurs upstream of the terrace deposits probably accounts for their preservation during periods of incision.

Recent flood deposits several metres thick are found on top of low alluvial fill deposits in eight sinuous meander alcoves (sections 8, 11, 15, 19, 20, 33, 34, 41). Correlative massive sand deposits 0.75–1.5 m thick are found on top of the low alluvial fill deposits in 16 remnants of the low terrace (for example, sections 15 and 45, Fig. 4). These massive sand layers bury thin-bedded, ripple-stratified sand and mud beds typical of the low alluvial fill. At 12 of the 16 terrace sites, layers of organic litter or soil A horizons mark the contact between the low alluvial fill and the massive sand deposits. The flood deposits are commonly less bioturbated and less indurated than are the underlying low alluvial fill deposits, which indicates that flood deposition occurred after a period of nondeposition. Based on their similar stratigraphic position above the low alluvial fill, these massive, tan sand deposits are tentatively correlated with the thicker accumulations of flood sediment found in the meander alcoves. The recent flood deposits decrease in height above the stream from 8 m at the head of the study reach to 6 m near the mouth (profile C, Fig. 7).

Organic debris buried by thin layers of mud in the recent flood deposits at sections 20 and 33 were radiocarbon dated at 200 ± 80 yr B.P. (TX-4100) and 330 ± 80 yr B.P. (TX-4127) (Fig. 4 and Table 1). Radiocarbon dates younger than ~600 (radiocarbon) yr B.P. are problematic because fluctuations in atmospheric ^{14}C result in multiple dendroyear correlations (Stuiver, 1982). For example, using the high-precision calibration curve for the radiocarbon time scale (Stuiver, 1982), the radiocarbon age of 200 yr B.P. corresponds to dendroyear dates of either 290 or 150 yr B.P. The radiocarbon age of 330 yr B.P. is converted to dendroyear dates of either 450 or 330 yr B.P.

The radiocarbon dates from the recent flood deposits are for stratigraphic sections that include buried trees. At section 20, the radiocarbon date was obtained from organic debris near

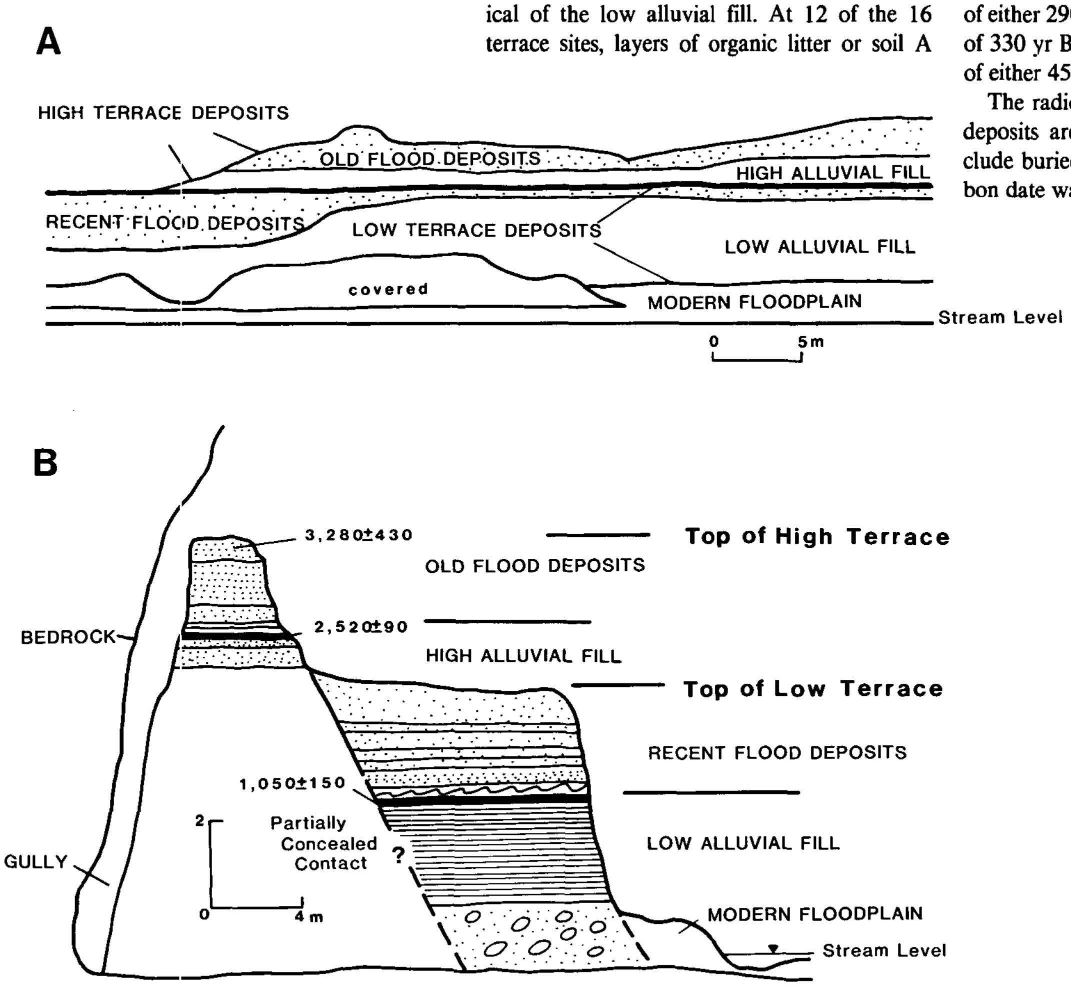

Figure 6. Longitudinal section (A) and cross section (B) of the deposits exposed at section 19, illustrating the relation between the high and low terraces. For an explanation of the symbols, see Figure 4. Cross section of the low terrace is through the thicker recent flood-deposit sequence at the downstream end of the exposure.

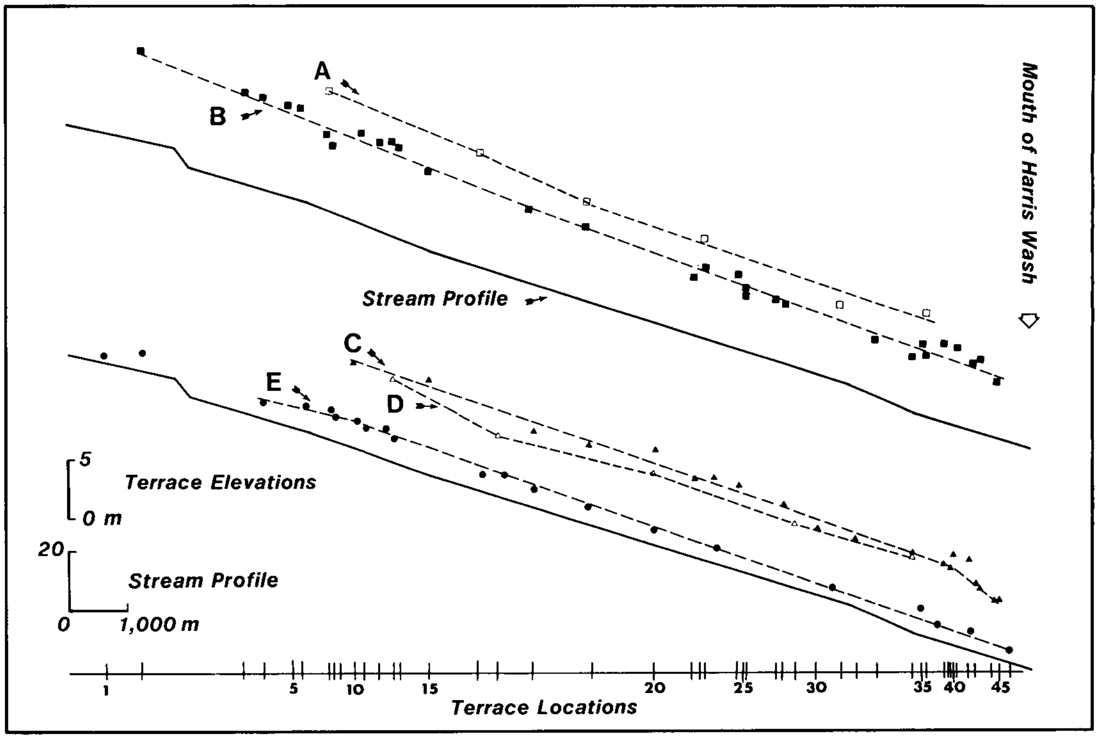

Figure 7. Longitudinal profile of Harris Wash and the interpolated longitudinal terrace profiles drawn on top of the geologic units as follows: (A) high alluvial fill, (B) low alluvial fill, (C) recent flood deposits, (D) historic flood-plain deposits, and (E) modern flood plain.

the base of a buried cottonwood tree similar in diameter to that of the dated tree at section 34. The association of the radiocarbon age with the cottonwood tree suggests that the younger dendroyear age is the more reasonable and that the upper 3 flood deposits have accumulated during the past 150 yr. At section 33, the radiocarbon date is associated with buried box elder trees of unknown age but which are most likely younger than 330 yr. This date should be interpreted as a maximum age for this deposit.

Correlation Problems. One dated low terrace remnant is not easily placed into one of the three stratigraphic units. Near the mouth of the wash, an exposure of the low terrace (section 45, Fig. 4) reveals a fining-upward sedimentary sequence capped by a weakly developed soil which is, in turn, buried by two massive, tan sand beds. This deposit has the characteristics typical of the low alluvial fill deposits buried by recent flood deposits. Radiocarbon dates for charcoal obtained 60 cm and 80 cm below the surface of the terrace (Fig. 4), however, were 320 ± 70 (TX-4124) and 270 ± 90 yr B.P. (TX-4125). These dates are significantly younger than are the other dates for the low alluvial fill. The deposit may represent either the continued aggradation of the low alluvial fill at the mouth of the wash after deposition of the low alluvial fill had ceased upstream or the development of the inset historic flood-plain deposit. Given the similarity of these two units, there is no way at present to better define the stratigraphic position of this terrace deposit.

High Terrace Stratigraphy

Remnants of high terraces occur along the margins of the canyon ~2 m above the surface of the low terrace. The high terrace is much eroded and mantled in many places by falling dunes and colluvium. Two stratigraphic units can be identified from a limited number of exposures.

High Alluvial Fill. The base of the high terrace consists of an alluvial fill unit which, where exposed, has the same lithologies and sedimentary structures as has the low alluvial fill. The similarity in sedimentology makes discrimination of the low alluvial fill from the high alluvial fill difficult. Furthermore, where high terrace remnants occur adjacent to low terraces, there are no distinct differences in the degree of soil development. Discrimination between the high alluvial fill and the low alluvial fill is, therefore, based on elevation above the wash, on contacts between the deposits, and, where possible, on radiocarbon age determinations (Table 1).

The high terrace is exposed at section 19 (Fig. 6) along the margin of an alcove behind an exposure of the low terrace. The contact with the low alluvial fill can be seen in a rill along the back edge of the alcove. The high alluvial fill consists of a sequence of tan sand beds that are overlain by thin-bedded mud layers. A radiocarbon age for an organic mat exposed at the contact between the mud and sand beds of 2520 ± 90 yr B.P. (TX-4413) is the terminal date for aggradation of the fill at this bend (Fig. 6).

Two other exposures of the high alluvial fill yielded radiocarbon ages of 8160 ± 380 yr B.P. (TX-4101) (section 16, Fig. 7 and Table 1) and 4910 ± 990 yr B.P. (TX-4105) (section 8, Fig. 7 and Table 1). Both of these age determinations are for retransported material and should be considered maximum ages for the alluvium which contains them.

Because of the similarity of the alluvium which makes up the two fill terraces and the lack of relative age indicators, deposits grouped with the low alluvial fill may be the eroded remnants of the high alluvial fill. Only six deposits were unequivocally identified as high alluvial fill, and these deposits define a surface 2 m above and parallel to the surface of the low alluvial fill (profile A, Fig. 7).

Old Flood Deposits. At three localities, sections 8, 16, and 19, thick beds of tan, indurated sand overlie the high alluvial fill. Like the sands of the low terrace, the tan sand units on top of the high alluvial fill represent a coarsening-upward sedimentary sequence. Based on their position on top of the high alluvial fill and their similarity in sedimentary structure to the recent flood deposits, these sand beds are interpreted as the deposits of floods that occurred after the aggradation of the high alluvial fill.

The radiocarbon age for charcoal disseminated throughout the uppermost bed of the old flood deposits at section 19 is 3280 ± 430 yr B.P. (TX-3938) (Fig. 6 and Table 1). This date is older than that obtained for the organic mat at the top of the high alluvial fill at this same section. The age reversal is probably caused by retransported charcoal which was incorporated in the old flood deposit.

DISCUSSION

Interpretation of Alluvial Stratigraphy

The alluvial stratigraphy of Harris Wash has been produced by deposition during both periods of valley aggradation and at times of channel incision. The high and low alluvial fill units, thick accumulations of thin-bedded, fining-upward alluvial sequences, represent long-term aggradation of the wash. The stratigraphic evidence suggests low rates of sedimentation but large volumes of sediment storage during long time periods. The periods of aggradation can be determined from radiocarbon dates that bracket the alluvial fills. Based on a few dated deposits, aggradation of the high alluvial fill may have taken nearly 6,000 yr. In contrast, the better-dated low alluvial fill probably aggraded during 1,000 yr.

The high and low alluvial fill units are overlain, respectively, by the old and recent flood deposits. We interpret the flood deposits on top of the alluvial fill units as indicators of the time and process of channel incision. The stratigraphy suggests that large floods initiated the erosion of the alluvial fills. Some of the sediment produced from the erosion of the alluvial fills was redeposited downstream as flood deposits. The best evidence of this redeposition is the sequence of recent flood deposits which buries the soil A horizons developed on the low alluvial fill.

The recognition of depositional units that mark periods of channel incision has important implications for future studies of alluvial stratigraphy in semiarid watersheds. Because of the high rate of sediment production during alluvial-fill incision and the discontinuous nature of sediment transport in semiarid streams, such deposits are likely to be common in the stratigraphic record. Identification and dating of these deposits will help to refine the alluvial history of streams in this region.

Limiting ages for the time of incision can be interpolated from the youngest age for an alluvial fill unit and the oldest age for the succeeding alluvial unit. For example, the incision of the high alluvial fill must have occurred after 2500 yr B.P., the youngest date for the surface of the high alluvial fill, and before 1900 yr B.P., the oldest reliable date for the base of the inset low alluvial fill. The timing of incision of the low alluvial fill is not as tightly constrained. Incision occurred after 1000 yr B.P., the most reliable age for the end of aggradation of this unit, based on radiocarbon dates and evidence from the Circle Terrace archaeological site. Dates for the beginning of flood deposition on this surface indicate that the incision may not have begun until as late as 300 yr B.P. Also, if the anomalous radiocarbon ages for section 45 represent the end of aggradation of the low alluvial fill at the mouth of the wash, then the incision of the wash must have occurred during the past 300 yr.

Finally, the historic flood-plain deposits and the modern flood plain represent the aggradation of inset alluvial surfaces after the incision of the low alluvial fill to the present stream bed. Aggradation of these deposits represents sediment deposition during floods smaller than those that have emplaced the recent flood deposits on top of the low alluvial fill during the past 150 yr. Flood-plain formation probably represents only minor volumes of sediment storage and implies a close equilibrium between sediment supplied to the channel and sediment yield at the outlet of the basin.

The buried trees within both the recent flood deposits and the historic flood-plain deposits indicate that these deposits accumulated contemporaneously. Deposition of the historic flood-plain deposits occurred during moderate floods that did not top the low alluvial fill surface, whereas the recent flood deposits were emplaced by larger floods that covered the low alluvial fill. Where the historic flood-plain deposits have accumulated to the level of the low alluvial fill, as is the case at section 34, recent flood deposits cover both the low alluvial fill and the historic flood-plain deposits. The historic flood-plain deposits and the recent flood deposits thus reflect the entire spectrum of flood magnitude which controlled the aggradation of two distinct surfaces in the canyon over the same time period.

Regional Correlations

The causes for the cyclic storage and removal of sediment in Harris Wash can be evaluated by comparing its alluvial chronology with that of other streams in the Escalante basin. Unlike the uniformity observed in other studies of alluvial stratigraphy on the Colorado Plateau (Euler and others, 1979), significant differences exist in the alluvial chronologies among the western tributaries of the Escalante River (Boison, 1983; Boison and Patton, 1985). Figure 8 summarizes the alluvial chronologies for Harris Wash, Twentyfive Mile Wash, and Coyote Gulch (Fig. 1).

In lower Coyote Gulch, the oldest Holocene terrace occurs nearly 20 m above modern stream level and was produced by the reworking of landslide debris derived from the Straight Cliffs, beginning ~2000 yr B.P. (Fuller and others, 1981; Boison, 1983; Williams, 1984; Boison and Patton, 1985). A younger terrace in the downstream reaches of Coyote Gulch and its major tributary, Dry Fork, represents erosion of the alluvium in the oldest Holocene terrace and its redeposition beginning ~1000 yr B.P. (Boison and Patton, 1985). Coyote Gulch has a third, still younger terrace characterized by large, buried cottonwood trees that we correlate to the historic flood-plain deposits in Harris Wash.

In Twentyfive Mile Wash, the highest and most ubiquitous terrace level yields radiocarbon ages that range from 7000 yr B.P. to >30,000 yr B.P. (Boison, 1983) (Fig. 8). A Holocene terrace of intermediate height is dated at between 940 ± 60 yr B.P. (TX-4406) and 450 ± 80 yr B.P. (TX-4401) based on charcoal found in paleochannels that occur within the alluvium. There is also a low terrace, containing large, buried cottonwood trees, which is correlated with the historic flood-plain deposits in Harris Wash and Coyote Gulch. With the exception of this terrace, the stratigraphy of Twentyfive Mile Wash does not resemble that described for Harris Wash or Coyote Gulch (Fig. 8).

Figure 8 illustrates the timing of the most recent period of alluvial-fill incision and the beginning of deposition of younger alluvial units. The upper part of Coyote Gulch began to be incised ~1000 yr B.P. (Boison and Patton, 1985); Twentyfive Mile Wash, ~450 yr B.P. (Boison, 1983); and Harris Wash, between ~1000 and 300 yr B.P. The differences in the timing of erosion for these streams cast doubt on the extent to which basin-wide phenomena may have controlled their geomorphic development.

An explanation for this dissimilar alluvial stratigraphy may be that deposition and erosion in Harris Wash, Twentyfive Mile Wash, and Coyote Gulch were controlled mainly by local processes of sediment production, storage, and transport. As noted, mass-wasting on the Straight Cliffs resulted in terrace formation in Coyote Gulch (Williams, 1984; Boison and Patton, 1985). Fuller and others (1981) have mapped older, degraded landslides along the headwaters of Twentyfive Mile Wash and Harris Wash, and field reconnaissance has identified

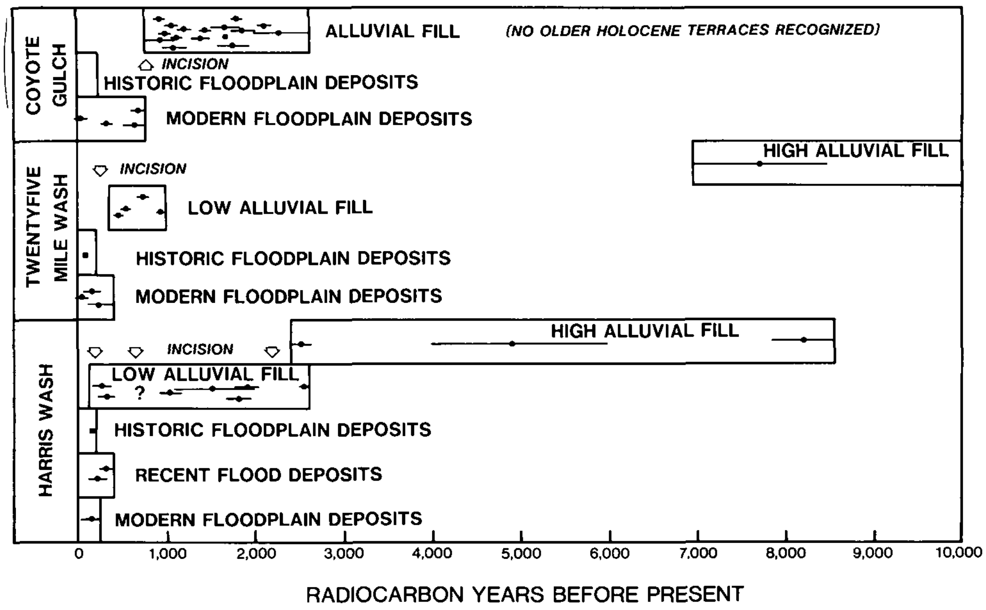

Figure 8. Holocene alluvial chronology for the three largest western tributaries of the Escalante River. Solid dots with horizontal lines are radiocarbon ages with error bars. Tree-ring dates are solid squares without error bars. The historic flood-plain deposits in Coyote Gulch are identified by the presence of cottonwood trees that have diameters similar to those of trees growing on the historic flood-plain deposits in Harris Wash and Twentyfive Mile Wash. The boxes represent the time periods for the formation of the geologic units. The time periods of incision are indicated by arrows. Two possible time periods of incision exist for the low alluvial fill in Harris Wash, the result of the questionable correlation of section 45 with the low alluvial fill. The radiocarbon dates for Harris Wash are listed in Table 1. Those for Twentyfive Mile Wash are given by Boison (1983). Those for Coyote Gulch are also given by Boison (1983), and some of them are further discussed by Boison and Patton (1985).

debris flow deposits on the interfluves of the tributaries of these streams. These deposits may represent the influx of sediment to the basins which controlled the timing of some of the aggradational periods. An additional factor which must affect the hydrology of these basins is the increasing drainage area from south to north for the tributary basins that drain the margins of the Kaiparowits Plateau (Fig. 1). The increase in drainage area is mainly the result of incision through the Straight Cliffs into the highly erodable, fine-grained Cretaceous strata of the Kaiparowits Plateau. Changes in sediment yield between drainage basins may account for differences in the alluvial stratigraphy. It is possible, therefore, that the hydrologic effects of postulated regional climatic change during the Holocene have been modified by local processes of sediment transport and storage in these streams. One consequence of this view, if correct, is that the abandonment of the canyons by the Fremont Culture cannot be tied to a single contemporaneous change in stream regimen as supported by Jennings (1966).

The historic flood-plain deposits, which contain large, buried cottonwood trees, compose one unit which can be correlated between these streams. In Twentyfive Mile Wash, these trees are ~100 yr old (S. Clark, 1982, personal commun.) slightly younger than the tree dated in Harris Wash. In all three basins, burial of the trees documents an increase in overbank floods during the past 100–150 yr. Further evidence of flooding during this time comes from a study of trees damaged by floods in the Pine Creek watershed on the southern margin of the Aquarius Plateau (Laing and Stockton, 1976). There, the frequency of floods increased after about 1880 and became most intense after 1909 (Laing and Stockton, 1976). The time of increased floods corresponds to the settlement of Escalante in 1875, the introduction of large herds of sheep and cattle (Woolsey, 1974), and the beginning of lumbering (Laing and Stockton, 1976). The onset of increased floods at about this time is further shown by the entrenchment of the Escalante River in Upper Valley, beginning around 1890 (Bailey, 1935), and enlargement of Alvey Wash near Escalante, beginning about 1920 (E. Alvey, 1981, personal commun.).

Major changes in land use in the western tributaries of the Escalante River, therefore, may have caused increased runoff, erosion, and sediment production in the headwaters of the basins. This resulted in the aggradation of flood-plain surfaces in the downstream reaches, which formed the historic flood plain. Aggradation of this flood-plain during the past 100–150 yr is evidence that the hydrologic response of these streams can be similar when the streams are influenced by similar hydrologic and geomorphic conditions. The lack of correlation of the older Holocene record of these streams implies that, prior to 150 yr ago, each drainage basin evolved independently.

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