Channel trenching and climatic change in the southern U.S. Great Plains

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ABSTRACT

Fifteen alluvial sequences in Texas and Oklahoma exhibit the same late Holocene record of channel trenching at 1 ka. The erosion was preceded by slow alluvial sedimentation in most stream valleys, resulting in the formation of a cumulic, organic-rich flood-plain soil previously named the Copan Soil. The soil formed during a period of regionally moister climate, as indicated by pollen spectra, molluscan faunas, vertebrate faunas, sedimentary structures, and high alluvial water tables. At 1 ka, the regional climate changed from moist to dry, coinciding with an episode of channel incision of valley floors throughout the southern Great Plains. Channel trenching occurred simultaneously in both small and large streams in drainage basins of the Arkansas, Red, Trinity, Brazos, and Colorado rivers; the sequences are the first documented example of widespread Holocene incision accompanied by firm evidence for a synchronous change in regional climate.

INTRODUCTION

Correlation of alluvial cut-and-fill sequences is based primarily on the synchroneity of brief episodes of channel trenching, generally preceded and followed by longer periods of alluviation. Bryan (1941) first drew attention to the similarity of alluvial sequences across the semiarid U.S. Southwest, each sequence punctuated by erosional unconformities. Extensive radiocarbon dating of alluvial sequences has shown that similar chronologies of fluvial deposition and channel cutting correlate over broad regions, as summarized by, e.g., Haynes (1968) and Knox (1983), indicating that climate is a controlling factor in the Holocene-scale fluvial record.

The possible causes of prehistoric channel trenching have been widely debated and are not reviewed here (Graf, 1983). Of importance to this study, however, is that Antevs (1952) argued that when plant cover is reduced by drought or overgrazing, increased runoff and channel erosion result, in both prehistoric and modern time. Both Bryan (1941) and Antevs (1952) concluded that, hypothetically, a change in past climate to increased aridity would have been sufficient to reduce plant cover and to trigger the trenching episodes preserved as paleochannels in prehistoric alluvium. Although both recognized the occurrence of episodes of prehistoric channel cutting in the Southwest, a record of regional change in paleoclimate simultaneous with channelling was not then identified and was a topic of conjecture. The relation between prehistoric channel incision and climatic change is a historical question which can be addressed only by clear, unequivocal chronologies of alluviation, erosion, and paleoecology.

ALLUVIAL STRATIGRAPHY AND CHRONOLOGY

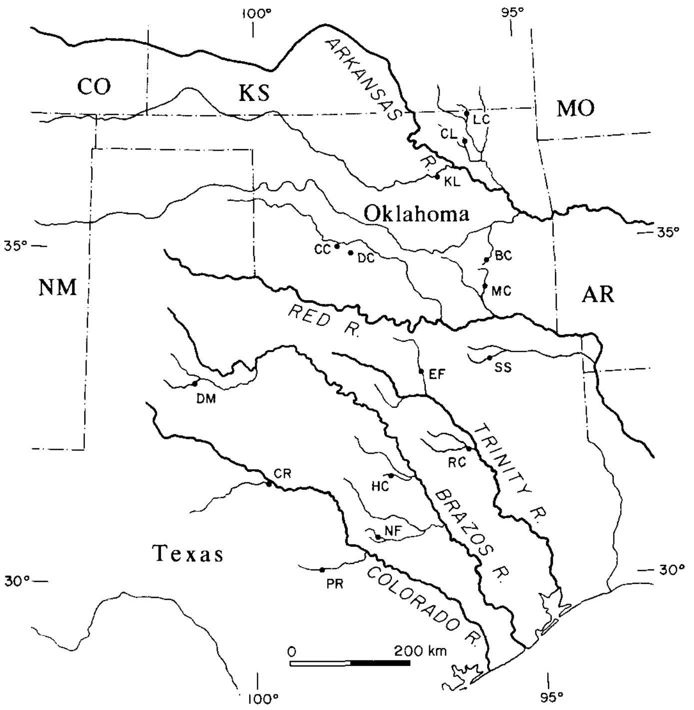

Figure 1. Alluvial sequences with channel trenching at 1 ka. BC = Brushy Creek (Ferring and Peter, 1982); CC = Carnegie Canyon (Hall, 1983; Hall and Lintz, 1984); CL = Candy Lake (Nials, 1980); CR = Colorado River (Blum, 1989a); DC = Delaware Canyon (Ferring, 1982, 1986a; Hall, 1982b); DM = Double Mountain Fork of Brazos (Blum, 1989b); HC = Hog Creek (Henry et al., 1980); EF = Elm Fork of Trinity River (Ferring, 1986b); KL = Keystone Lake (Salisbury, 1980); LC = Little Caney River and type locality of Copan Soil (Hall, 1977; Reid and Artz, 1984); MC = McGee Creek (Perttula et al., 1983); NF = North Fork of San Gabriel River (Hays, 1982); PR = Pedernales River (Blum and Valastro, 1989); RC = Richland Creek (Bruseth et al., 1987); SS = South Sulphur River (Bousman et al., 1988).

The alluvial geology of numerous stream valleys in the southern Great Plains of Texas and Oklahoma has been investigated during the past 12 years in conjunction with archeological projects, resulting in 15 sequences of alluviation, soil formation, and channel erosion documented by more than 120 radiocarbon dates (Hall, 1986; Fig. 1). Three representative sequences are shown in Figure 2, and their accompanying radiocarbon dates are described in Table A.[1]

Valley fills in the region are predominantly Holocene alluvium; late Pleistocene deposits occur as terraces above the flood plain or as eroded benches buried beneath the younger alluvium. The valley fill exposed in

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[1] Table A, Radiocarbon Dates from Late Holocene Alluvium and the Copan Soil, Southern Great Plains, GSA Supplementary Data 9009, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301.

Note: Additional material for this article is Supplementary Data 9009, available on request from the GSA Documents Secretary (see footnote 1).

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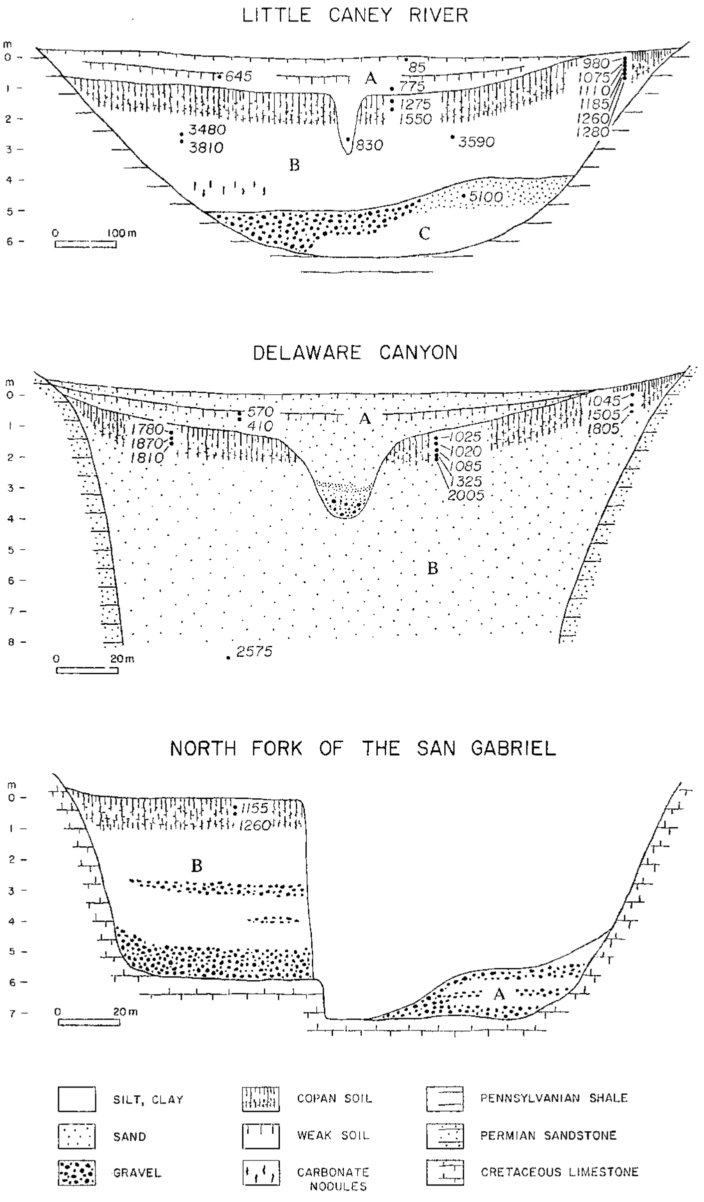

Figure 2. Radiocarbon-dated alluvial sequences from Little Caney River, northeastern Oklahoma (Hall, 1977; Reid and Artz, 1984); Delaware Canyon, southwestern Oklahoma (Ferring, 1982, 1986a; Hall, 1982b); and North Fork of San Gabriel River, central Texas (Hays, 1982). Radiocarbon dates are reported in Table A (see Footnote 1); see Figure 1 for site locations and Figure 3 for summary sequence.

sand quarries and along banks of stream channels is dominated by alluvium of late Holocene age.

The late Pleistocene and early Holocene alluvial history of the region is not well established because of the paucity of deposits of that age. Even rarer are deposits dating from 7 to 5 ka; the middle Holocene is recognized in the Great Plains and adjacent Southwest as a period of hot and dry climate, characterized by wide and deep trenching of alluvial valleys and increased eolian sand deposition (Johnson, 1988; Hall, 1988; Haynes, 1968; Holliday, 1985, 1989; Holliday and Allen, 1987).

Fluvial deposition recommenced by 5 ka throughout the southern Great Plains and continued without major interruption for about 3000 yr in most stream valleys. Net sedimentation rates during the early late Holocene period depend in part upon stream order and valley geometry: the rates range from 0.02 to 0.04 cm/yr in wide valleys with currently meandering channels, to 0.65 cm/yr in ephemeral tributary valleys (Ferring, 1986a). Sedimentation rates play an important role in late Holocene alluvial geology in the southern Great Plains. Beginning about 2 ka in many of the stream valleys investigated, sedimentation rates slowed to one-third to one-tenth of those from the previous 3000 yr (Ferring, 1986a; Hall, unpub. data). Low rates of sediment deposition characterized flood plains of all stream orders in the region from about 2 to 1 ka, resulting in the formation of a soil characterized by a cumulic, organic-rich, over-thickened A horizon. The soil was first studied and dated in the Little Caney River valley, northeastern Oklahoma, and named the Copan Soil after a nearby community (Hall, 1977). Subsequently, a similar soil-stratigraphic unit has been recognized throughout the southern Great Plains, and because it is prominent in alluvial sequences, it serves as an important horizon marker in Holocene valley fill (Fig. 2). Equivalents of the Copan Soil have been referred to as the Caddo paleosol in southwestern Oklahoma (Ferring, 1982), and in north-central Texas, the West Fork paleosol (Ferring, 1986b) and the Navarro paleosol (Bruseth et al., 1987). The Copan Soil is both buried and exposed at the surface in its type area and elsewhere; where it is exposed, continued weathering with little or no sedimentation during the past 1 ka has produced a cambic horizon in the soil (Reid and Artz, 1984). At some sites, the top of the soil has been eroded. In most areas, however, the Copan Soil is a fossil soil, buried by younger deposits.

At 1 ka, based on numerous radiocarbon dates below and above the unconformity, channel trenching abruptly terminated a 4000 yr period of generally uninterrupted flood-plain deposition in the southern Great Plains. Channel deepening generally extended no more than 3 m below the flood plain, and channel width was probably less than 20 m, although it is not feasible to measure paleochannel width unless channel orientation is known. The channels that were eroded 1 ka are generally smaller than those formed earlier during the middle Holocene and later in the twentieth century. The channel-erosion episode was brief, lasting less than 200 yr. By 0.8 ka, fluvial sand and finer sediment had filled the paleochannels, and overbank fine-grained alluvium buried the Copan Soil and the eroded flood-plain surfaces. Fluvial deposition continued at increased rates on flood-plain surfaces without major change for the remainder of the Holocene. Variations on this style of alluviation occur in the upper Little Caney River valley of northeastern Oklahoma (Reid and Artz, 1984), in southeastern Oklahoma (Perttula et al., 1983; Ferring and Peter, 1982), and in central Texas (Hays, 1982), where the Copan Soil is not buried by younger alluvium but has continued its development on a late Holocene terrace (Fig. 2). In these places, post-1 ka alluviation has resulted in deposits inset against and topographically below the late Holocene terrace. Elsewhere in drier central and west Texas, flood-plain sedimentation rates did not slow and the cumulic Copan Soil did not develop (Blum and Valastro, 1989; Blum, 1989a, 1989b). Two Oklahoma valley fill sequences, Little Caney and Delaware Canyon, are characterized by a weak soil dated as 0.6 to 0.4 ka (Hall, 1977, 1982b), probably representing a brief slowing of alluviation during the peak of the post-1 ka dry episode.

PALEOENVIRONMENTAL HISTORY

Past climates must be evaluated through indirect lines of evidence. In the southern Great Plains, a wide variety of information from various localities converges toward a single paleoclimatic reconstruction. After a hot and dry middle Holocene, southern Great Plains climate became less warm and less dry until about 2 to 1 ka, when the region went through a wet period unprecedented in the late Holocene (Fig. 3). The interpretation of the 1000 yr period of moister-than-today climate is based on a number of diverse studies. In northeastern Oklahoma, increased hickory in Cross Timbers oak forest vegetation and the greater abundance of moist-habitat land snails in rock-shelter deposits (Big Hawk Shelter, Copperhead Cave, Cedar Creek Shelter, Sunny Shelter) indicate wetter upland conditions from about 2 to 1 ka, based on 19 radiocarbon dates on charcoal (Hall, 1982a). Historically, bison and deer have favored different climates, bison in the dry western plains and deer in moister areas to the east (Shay, 1978). Between 2 and 1 ka at Delaware Canyon in southwestern Oklahoma, increased numbers of deer relative to bison in Plains Woodland levels indicate that conditions were wetter then than now (Butler and Yates, 1982; Hall, 1988). Deep pools and associated channels, habitats for many species of aquatic snails and unionid clams, were extant at the same time as the formation of the Copan Soil, indicating higher water tables and permanent stream flow in many drainages throughout the southern Great Plains during the same period, 2 to 1 ka (Metcalf, 1980; Fullington and Fullington, 1982; Hall and Lintz, 1984). A grass-dominated pollen record from Little Caney River flood-plain deposits also indicates a high alluvial water table during the formation of the Copan Soil. (Many trees cannot tolerate water-saturated soils, and the result is low percentages of arboreal pollen in overbank alluvium deposited during periods of high water table [Hall, 1977].) A spring conduit with a diverse aquatic snail fauna was active at the elevation of the Copan Soil in Carnegie Canyon (Hall, 1983). Evidence from mollusks and a variety of fish faunal remains from flood-plain and rock-shelter sites (e.g., Delaware Canyon and Big Hawk Shelter) indicate permanent stream flow (Butler and Yates, 1982; Henry, 1978). The presence of ten species of small mammals at ten cave and rock-shelter sites west of their present range in the eastern plains suggests moister conditions in the region until about 1 ka (Hall, 1982a). The change to a drier climate at 1 ka at the same localities cited above is documented by the decrease in abundance of hickory in Cross Timbers oak forest, a decrease in abundance of moist-habitat land snails and the appearance and increased abundance of dry-habitat land snails in rock-shelter deposits, a shift to increased use of bison by Plains Village cultures, and the contraction of the western edge of the range of several species of mammals adapted to a more humid climate (see references above). Flood-plain–related evidence for drying may be local effects due to channel cutting and drawdown of adjacent water tables. Nevertheless, it coincides with evidence for a simultaneous shift to drier conditions in upland vegetation and faunas at 1 ka and includes local extinction of some unionid clam faunas, a decrease in numbers and diversity of aquatic snail fauna, and filling and burial of small lacustrine basins on the 1 ka flood plain. Additional details and discussion of the radiocarbon-dated paleoecological evidence can be found elsewhere (Hall, 1982a, 1988; Hall and Lintz, 1984).

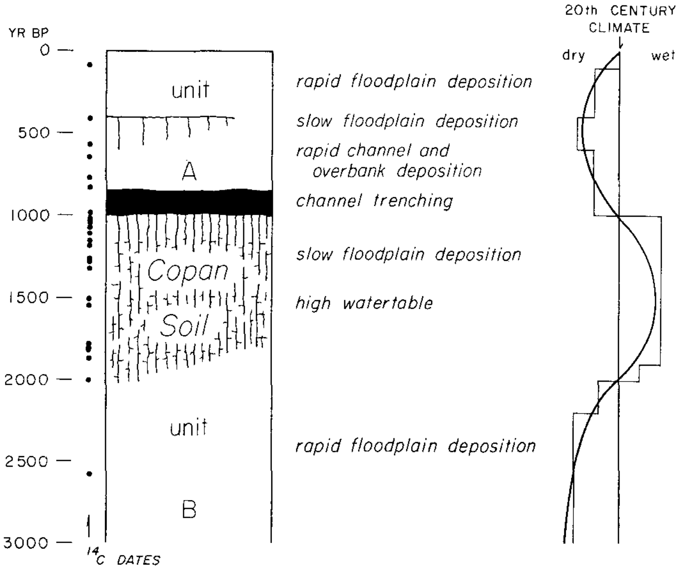

Figure 3. Summary of late Holocene alluvial chronology and paleoclimate, southern Great Plains. Radiocarbon dates are from three stream valleys shown in Figure 2 and listed in Table A (see Footnote 1). Climatic changes shown as both gradual and episodic trends—it is unclear from available paleoenvironmental data which reconstruction is more accurate.

PREHISTORIC CHANNEL TRENCHING AND CLIMATE CHANGE

The trenching of flood plains and erosion of the Copan Soil at 1 ka coincide with evidence for simultaneous regional climatic change from wet to drier conditions (Hall, 1982a, 1988; Hall and Lintz, 1984). The change in climate at 1 ka, recognized in well-dated upland and flood-plain paleoecologic sites alike, was the beginning of a drying trend that culminated about 0.6 to 0.4 ka, after which precipitation increased to present average values (Fig. 3). Flood-plain incision at 1 ka is the only major episode of late Holocene erosion of valley-fill sediments in the southern Great Plains (Hall, 1977, 1988).

Further information on the nature of the channel-trenching episode is provided by its broad distribution in multiple drainages (Fig. 1; see caption). Incision is documented at 1 ka in streams within the Arkansas River and Red River basins in Oklahoma, which join with the Mississippi River. In Texas, the same erosion simultaneously affected streams in the basins of the Trinity, Brazos, and Colorado rivers; these rivers flow directly to the Gulf of Mexico. Late Holocene sea levels have been slowly rising, and there is no evidence for sea-level lowering that could account for stream-channel incision due to headward cutting from lowered oceanic base level (Nelson and Bray, 1970; Bloom, 1983). Headward erosion would also be halted by the first bedrock knickpoint, and channel cutting would be time-transgressive upvalley, rather than time parallel. Furthermore, investigations of Mississippi River alluvial geomorphology and chronology have led to the conclusion that sea-level changes may have had little effect on Quaternary rivers entering the Gulf of Mexico (Saucier, 1981).

The implication of the above is that basin-specific variables such as climate, vegetation, runoff, and sheet-erosion rates may control Holocene-scale flood-plain processes and landform development, rather than changes in base level or a surpassing of intrinsic thresholds of stability (Schumm, 1977). In the southern Great Plains, greater precipitation at 2 to 1 ka may have promoted an increase of ground cover, resulting in greater infiltration, lower sheet-erosion rates, and higher local alluvial water tables. These conditions persisted for 1000 yr, evidently ending abruptly at 1 ka, as documented at a wide variety of well-dated alluvial sequences and upland paleoecologic sites. The climatic change from high to low precipitation probably decreased ground cover, producing greater runoff and higher basin-wide discharge from rainfall and initiating incision and widening of both high- and low-order stream channels; lowered alluvial water tables and drying of the Copan Soil would increase the susceptibility of the flood plain to erosion. Although the above mechanism is, in part, speculation, paralleling classic discussions by Bryan (e.g., 1940) and Antevs (e.g., 1952), it is consistent with new converging geomorphic and paleoclimatic data from the southern Great Plains. Comparisons of the subhumid Great Plains with other areas may be misleading, however, because of differences in climate, vegetation, and soils that result in regional differences in sensitivity to change (Knox, 1984).

CONCLUSIONS

Detailed stratigraphic analysis and radiocarbon dating of 15 alluvial sites in the southern Great Plains, in conjunction with many convergent lines of well-dated paleoenvironmental evidence, document an episode of late Holocene channel trenching occurring at the same time as a change in regional climate. A period of moist climate at 2 to 1 ka resulted in permanent stream flow but slow fluvial sedimentation in many valleys, probably because of increased plant cover and decreased sheet-erosion rates. Slow sedimentation promoted the formation of the organic-rich Copan Soil on flood plains throughout the region. At 1 ka the climate became drier; decreasing plant cover and increasing runoff and discharge from rainfall led directly to deepening and widening of stream channels in the Arkansas, Red, Trinity, Brazos, and Colorado river basins. The episode of erosion was rapid, lasting less than 200 yr, and was followed by renewed alluviation during a period of dry climate (Fig. 3). The climate-caused channel cutting at 1 ka in the southern Great Plains may not have parallels in other areas or during other periods in the Holocene because of unique combinations of regional geomorphic and climatic histories.

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