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New Mexico Geological Society Guidebook, 43rd Field Conference, San Juan Basin IV, 1992

QUATERNARY HISTORY AND LANDSCAPE DEVELOPMENT OF SOME TRIBUTARY DRAINAGE BASINS NORTH OF THE CHACO RIVER

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Abstract—Topography in the northeastern tributary watersheds to the Chaco River is characterized by either subplanar alluvial surfaces or badland topography. The Alamo and Ah-shi-sle-pah watersheds contain extensive badland topography, whereas the Coal Creek and Tsaya basins are characterized by broad alluvial surfaces. Correlation of geomorphic surfaces between the drainage basins allows comparison of the responses each basin had to baselevel falls. The two oldest geomorphic surfaces extended beyond present-day drainage divides; drainage divides and the resulting proportions of sandstone and mudrock bedrock lithologies were inherited during the incision of these surfaces. Three younger geomorphic surfaces formed during periodic downcutting of the drainages. The character of drainage-basin evolution during regional dissection is a function of initial basin shape, relative relief of the drainage basin, distribution and proportion of mudrock to sandstone bedrock units, and distribution and preservation of sandy surficial deposits. Sandstone outcrop, elongate low-relief morphology, and accumulation of extensive sandy surficial deposits reduced sediment yield and downcutting in the Tsaya basin. Extensive badland development in the Ah-shi-sle-pah basin was augmented by the dominance of mudrock bedrock in the basin, a high drainage-basin relief ratio, and minimal preservation of sandy surficial deposits.

INTRODUCTION

The subtle topography in the northern tributaries to the Chaco River is interrupted locally by regions characterized by bedrock outcrop, high erosion rates and a badland topography. The Alamo, Coal Creek, Tsaya and Ah-shi-sle-pah drainage basins north of the Chaco River display a wide range of landforms and surficial processes characteristic of the region. The purposes of this paper are to describe the geomorphic history of the region and to discuss those geomorphic factors that have influenced drainage-basin evolution and the present distribution of the region's distinct landforms.

The northern tributary drainage basins to the Chaco River are oriented across the strike of northeast-dipping Cretaceous and Paleogene sandstones, mudrocks, coal and minor conglomerate in the southwestern San Juan Basin (Fig. 1). Bedrock formations crop out at similar distances upstream from the Chaco River in each of the drainage basins. Although similar bedrock units crop out in each basin, variable thicknesses of bedrock units results in different proportions of sandstone-to-mudrock among the study basins (Table 1).

LANDSCAPES

Landscapes of the northeastern tributary region of the Chaco River reflect erosional and depositional processes affected by bedrock control, alluvial sedimentation and periodic eolian activity. The upper and lower portion of the study basins are characterized by canyons, cuestas and mesas where resistant sandstone units control local relief. Along the outcrop belt of the Kirtland and Fruitland Formations, the landscape is characterized by either subplanar alluvial surfaces or badland topography (Fig. 2). This area, in the central portion of each study watershed, contains the most varied landforms among the study drainage basins because of the susceptibility to erosion of the mudrock-dominated bedrock.

The central portions of the Ah-shi-sle-pah and Alamo basins contain extensive badland topography and incised alluvial slopes. In contrast, the Kirtland and Fruitland Formations are mostly mantled by alluvial and eolian sediment in the Coal Creek and Tsaya basins; badland topography is limited to local areas (Table 1; Figs. 2 and 3). Whereas the Ah-shi-sle-pah and Alamo basins are undergoing widespread badlands erosion, Tsaya Wash and Coal Creek are discontinuous and currently depositing sediment. The distribution of badlands in the northern Chaco River drainage area is determined by a number of factors, including the local proportion of mudrock to sandstone bedrock, deposition of sandy mantles by fluvial and eolian processes, the amount of headcutting in any given stream, and the incision history and form of the drainage system (Wells, 1983; Smith, 1983a, b).

SURFICIAL GEOLOGY

Many of the low relief, vegetated landforms in the northern tributary drainage basins of the Chaco River are capped by alluvium that is part of a topographically stepped Pleistocene and Holocene sequence (Fig. 4). Regional correlation of these deposits allows comparison of the differing downcutting histories of the basins. These alluvial deposits range in topographic position from present-day drainage divides to terraces to valley floors (Fig. 5). These landforms and deposits represent a series of geomorphic surfaces, which are defined herein as subplanar topographic units, and associated alluvial deposits, that grade to a given baselevel. Surficial deposits and geomorphic surfaces were correlated between study basins by soil development and analysis of topographic

TABLE 1. Morphometric and areal characteristics of selected northern tributary drainage basins, Chaco River watershed.

	Alamo Wash	Coal Creek	Tsaya Wash	Ah-shi-sle-pah Wash
Area (km^2)	148	310	107	103
Relief (m)	360	370	283	231
Shape (km^2/km)	0.23	0.25	0.09	0.26
Relief Ratio (m/km)	14.1	10.4	8.3	11.5
Bedrock outcrop	64%	41%	41%	65%
Geomorphic surfaces	36%	59%	59%	35%
Sandstone Bedrock	20%	59%	67%	36%
Mudrock Bedrock	80%	41%	33%	64%

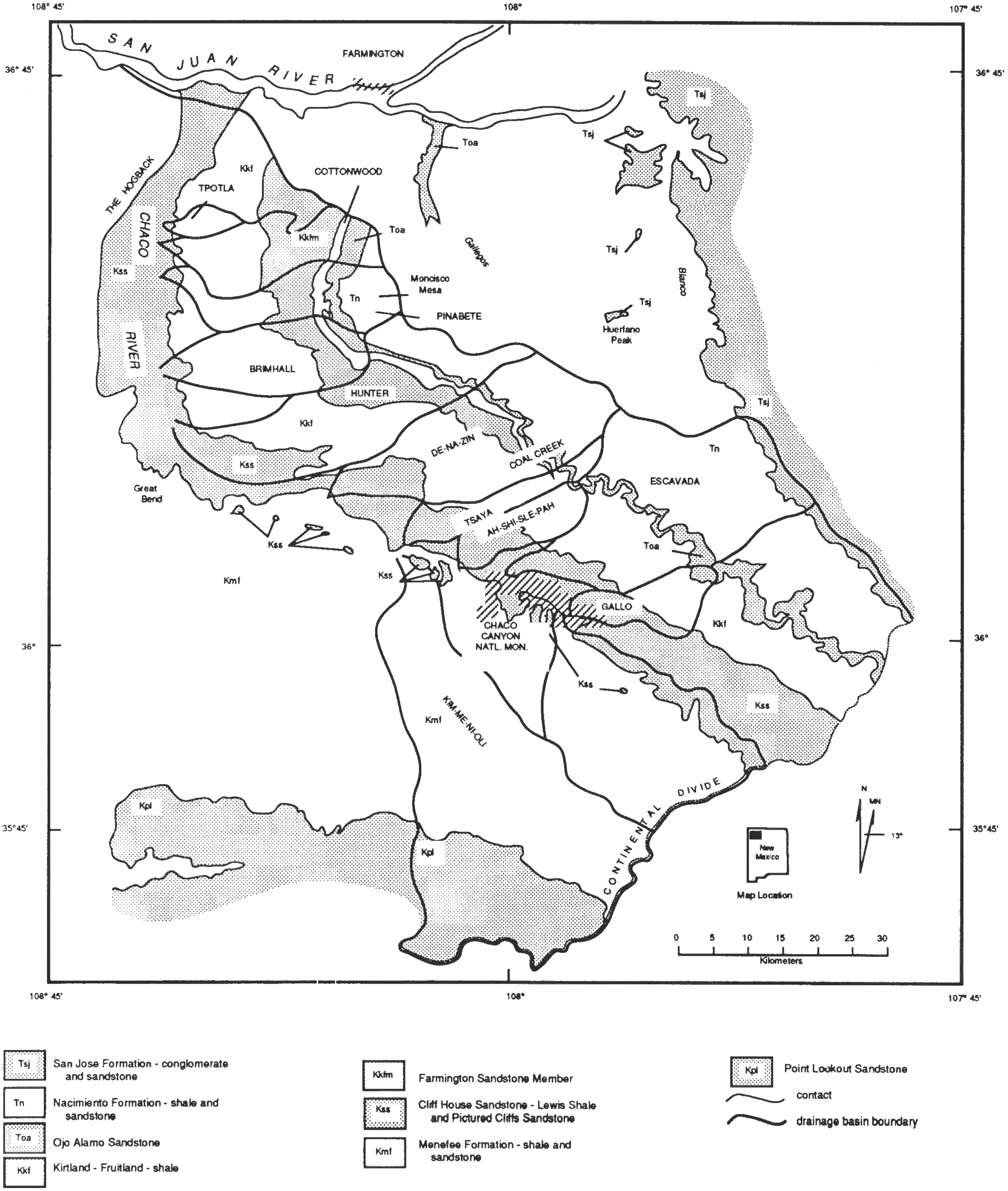

FIGURE 1. Location map and generalized map of bedrock geology of the northeastern tributary region of the Chaco River watershed.

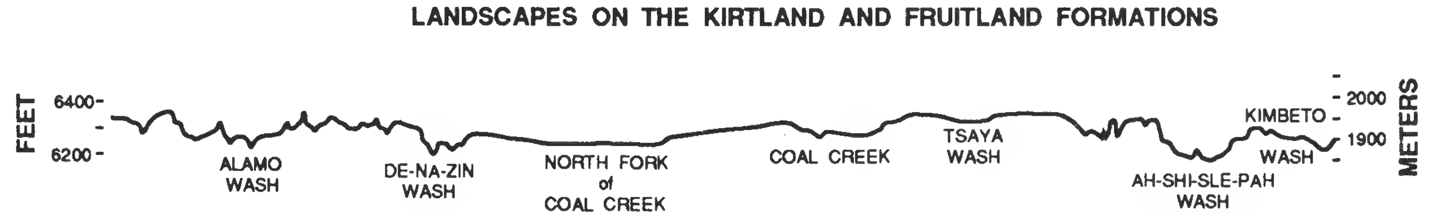

FIGURE 2. Topographic cross section through the central portions of the study basins. Topography is dominated by subplanar bedrock surfaces mantled by alluvium, and by badland topography in the Alamo and Ah-shi-sle-pah drainage basins.

FIGURE 3. Aerial photograph of part of the Tsaya and Ah-shi-sle-pah drainage basins. Alluvial surfaces appear as uniform gray tones; local mottling on these surfaces are sand dunes and blowouts. Note the extensive badland development in the Ah-shi-sle-pah basin, compared to the Tsaya basin. The field trip route is shown by a dotted line and arrows.

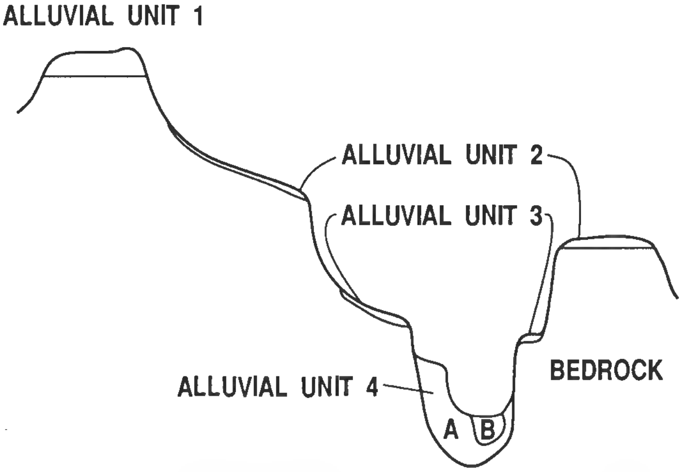

FIGURE 4. Generalized landscape positions of alluvial units in the study area. The landforms represented include mesas along drainage divides, fill terraces (of alluvial unit 4A), strath terraces (of alluvial unit 3) and alluvial slopes.

position of geomorphic-surface remnants. These geomorphic surfaces represent regionally correlative periods of landscape stabilization between downcutting events along the Chaco River.

Alluvial stratigraphy

Stratigraphic study of Quaternary alluvial and eolian sediment in the Chaco River drainage basin has been carried out by relative and numerical age dating (Schultz, 1980; McFadden et al., 1983; Smith, 1983b; Bullard, 1985; Wells et al., 1990). The oldest alluvium in the region crops out along the Chaco River drainage divide on Moncisco Mesa (Fig. 1; Table 2). Alluvial unit 1, the oldest extensively preserved alluvium, crops out on mesas along drainage divides of the study basins (Fig. 6). Alluvial unit 1 appears to bear no relation to modern drainage basin interfluves. The unit is interpreted to have been deposited on a broad southwest-sloping erosion surface that was bounded on the north by Moncisco Mesa.

Alluvial unit 2 lies on strath terraces and alluvial slopes that dip toward and along the modern axes of the study basin. Alluvial unit 3 is inset into and/or below alluvial unit 2 (Fig. 4). The upper Pleistocene or lower Holocene eolian unit 1 (Schultz, 1980; McFadden et al., 1983; Wells et al., 1990) locally buries alluvial units 1, 2 and 3, serving as a regional stratigraphic marker. Alluvial unit 4 includes older (4A) and younger (4B) alluvium, which are distinguished primarily by relative soil development (Table 2).

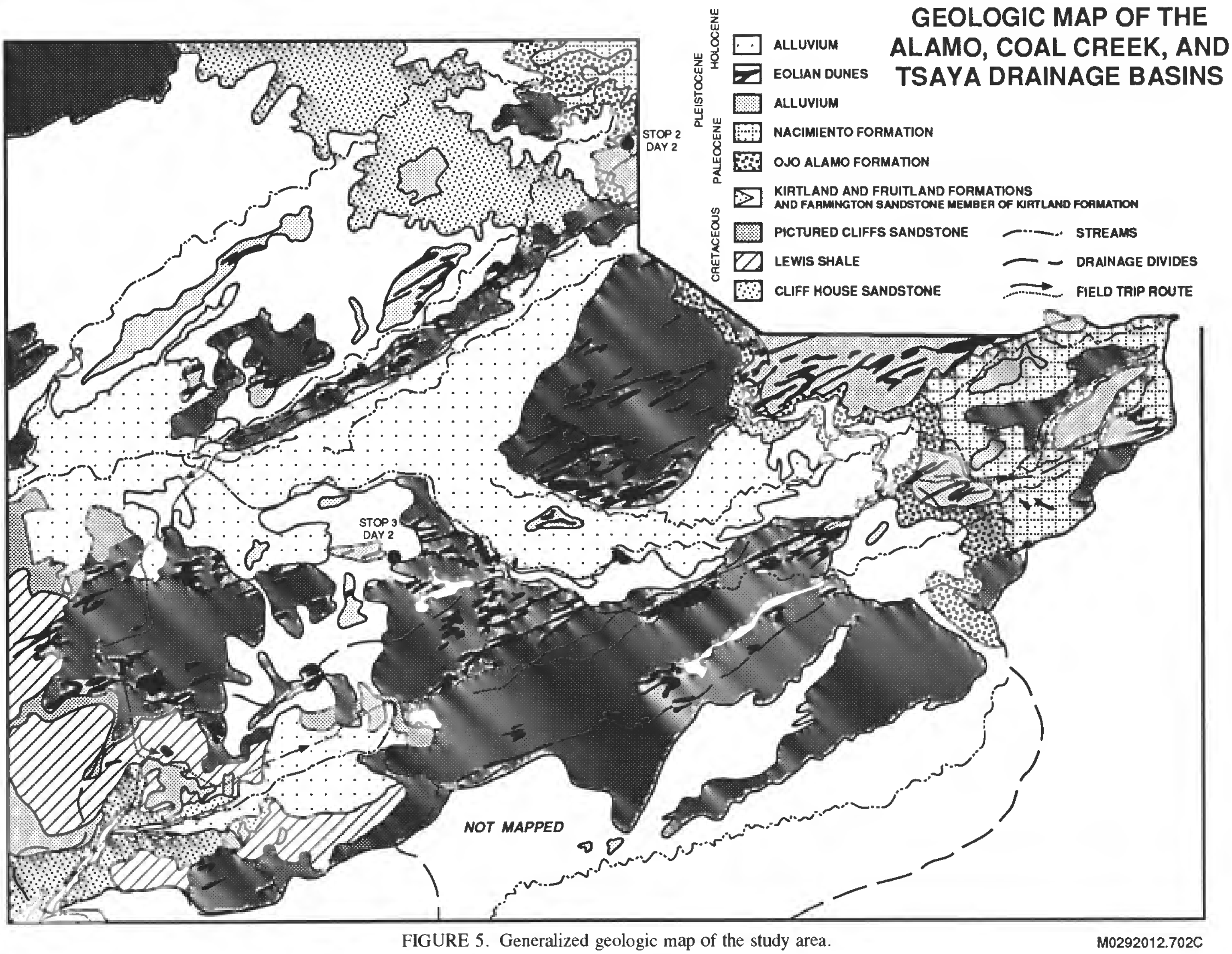

FIGURE 5. Generalized geologic map of the study area.

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Geomorphic surfaces and paleogeographic reconstructions

Terraces mantled by alluvial units 2, 3 and 4 near the Chaco River are correlative to those mapped by others (O'Sullivan et al., 1979, 1986; Weide et al., 1979; Love, 1980; Bullard, 1985; Strobell et al., 1985). The dissected alluvial units in the study area define the flight of geomorphic surfaces grading to an ancestral Chaco River that stood above the modern level (Fig. 7).

Longitudinal projection of the S1 surface in the Alamo Wash drainage (Fig. 7a) suggests that at one time the S1 surface extended eastward over its present headwater divide. Accordant remnants of the S1 surface on interfluves between the study basins suggest that at one time the S1 surface was a broad, subplanar surface, which extended beyond the present basin divides and into which the present drainage basins have developed. The topographic positions and lithologic properties of alluvium on Moncisco Mesa and the S1 surface suggest ancestral drainage basins headed in outcrops of the San Jose Formation, as the Escavada drainage basin does today (Fig. 1).

The morphology and position of the S2 surface indicates that initial incision of the S1 surface occurred near the axes of the present basins. The amount of local baselevel lowering between the S1 and S2 surfaces (the difference in the height of the surfaces above local baselevel) in the central portions of the study basins ranges from 49 to 58 m. This consistency in relief suggests that each basin downcut a similar amount by S2-time. Degradation to the S2 surface may have occurred over a

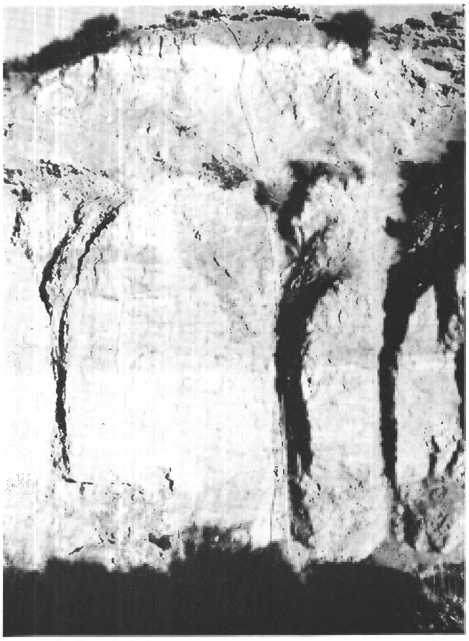

FIGURE 6. Photograph of 8 m of alluvial unit 1 overlying Fruitland Formation along the interfluve between the Coal Creek and Tsaya Wash drainage basins. Stage III calcic horizon near the top of the exposure is responsible for the white coloration. Locations: SW¼ NE¼ sec. 34, T23N, R12W.

TABLE 2. Lithologic and pedologic properties of alluvial units in the study area. *—after Gile et al. (1966); **—based on morphology of calcic horizon as compared to soil chronosequences in New Mexico (Bachman and Machette, 1977), Lava Creek Ash site in Colorado (Gillam, 1982) and Holocene ^{14}C age-dates in and near the study area (Wells, 1982; Smith, 1983a).

Unit	General Lithology	Thickness	Calcic horizon		Approximate
			morphology	Thickness	
Alluvium on Moncisco Mesa	locally conglomeratic very coarse- to fine-grained gray sand in cross-cutting lenticular channel-fills.	8 m	Stage III	75 cm	mid Pleistocene
Alluvial unit 1	locally conglomeratic very coarse- to fine-grained gray sand in cross-cutting lenticular channel-fills.	5-7 m	Stage III-IV	20-40 cm	mid-late Pleistocene
Alluvial unit 2	locally conglomeratic very coarse- to fine-grained gray sand in cross-cutting lenticular channel-fills.	1-6 m	Stage II-III	30-100 cm	late Pleistocene
Alluvial unit 3	fine- to coarse-grained brownish gray sand in channel-fills; gravel lags on strath terraces.	1-2 m	Stage II-III	20-100 cm	late Pleistocene
Alluvial unit 4	commonly muddy, fine- to coarse-grained brown and gray sand in channel fills and tabular sheet-wash deposits.	2-4 m and 12 m	Disseminated and Stage I	0-100 cm	Holocene

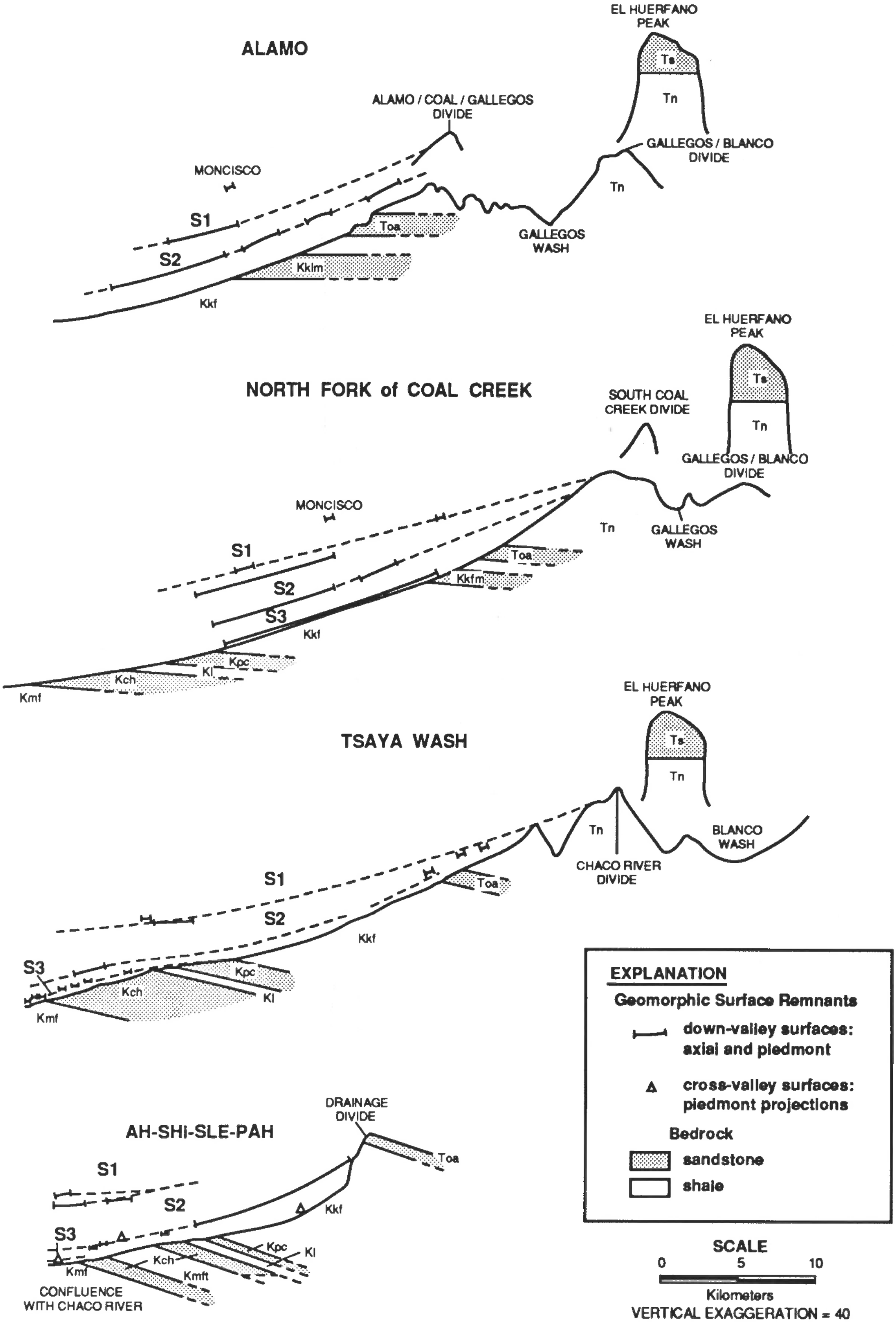

FIGURE 7. Longitudinal profiles along the Alamo, Coal Creek, Tsaya and Ah-shi-sle-pah drainage basins showing the positions of geomorphic surfaces and bedrock units. Shown are valley profiles and topography near the basins' divides. Solid lines with bars represent the positions of outcrops of geomorphic surface remnants projected onto the profile. Dashed lines are interpreted S1, S2 and S3 valley profiles. Bedrock along valley floors includes: Kmf—Menefee Formation; Kch—Cliff House Sandstone; Kmft—tongue of Menefee Formation; Kl—Lewis Shale; Kpc—Pictured Cliffs Sandstone; Kkf—Kirtland and Fruitland Formations; Kkfm—Farmington Sandstone Member of the Kirtland Shale; Toa—Ojo Alamo Sandstone; Tn—Nacimiento Formation; Tsj—San Jose Formation.

period of time, or in a Pleistocene climate, that allowed uniform valley profile lowering. Relief between the S2 and S3 surfaces in the central portions of the basins indicates that Tsaya Wash locally has remained undissected since S2-time, compared to the other study basins (Fig. 7). Remnants of the S3 surface are extensively preserved in the Coal Creek and Tsaya basins (Fig. 5). Extensive areas of badlands in the Alamo and Ah-shi-sle-pah basins developed during recent (post mid-Holocene) degradation (Wells and Gutierrez, 1982). Variation in the amount of degradation among the S2 and S3 geomorphic surfaces and modern valley floors, as well as the distribution of badland topography, in the study basins indicates a complex response of the fluvial systems since the development of the S2 surface.

GEOMORPHIC FACTORS INFLUENCING COMPLEX DRAINAGE-BASIN EVOLUTION

After the S2 surface was dissected, each watershed downcut by differing amounts, producing variations in longitudinal profiles, areal extent of surficial deposits and areal extent of badlands. Factors recognized here and by previous workers to be important in drainage-basin evolution include relative relief ratios and the morphology and slope of the contributing area in drainage basins (Horton, 1945; Schumm, 1956; Parker and Schumm, 1982); distribution of bedrock lithologies (Hack, 1957; Morisawa, 1964); and distribution of surficial processes and their associated deposits (Wells, 1982; Wells et al., 1982).

Influence of the morphology and slope of the contributing area

Initial relief or slope of pre-incision topography has been associated with the processes of initial development of stream systems (Horton, 1945; Parker and Schumm, 1982) and drainage-basin evolution (Schumm, 1956; Morisawa, 1964). In the present study area, the approximate boundaries and shape of the present-day drainage basins were initially developed when the S1 surface was dissected.

Schumm (1956) pointed out that for eroding drainage basins the basin elongation and relief ratio and resulting character of topography are influenced by the slope direction of a surface along the headwaters. Schumm noted that streams formed on a sloping surface tend to elongate and form drainage basins with lower relief ratios and subdued topography, whereas streams that head along surfaces that slope in a direction opposite to drainage do not tend to elongate. This latter process tends to increase profile gradients, maintains high relief ratios during downcutting, and produces more rugged topography in the drainage basin.

Comparison of stream profiles (Fig. 8), relief ratios (Table 1) and plan views (Fig. 5) of the Tsaya and Ah-shi-sle-pah basins to the model of Schumm (1956) suggests the modern morphologies of the Tsaya and Ah-shi-sle-pah basins are at least partially due to the initial geometries of their pre-incision topographies. The ancestral Tsaya Wash was superimposed across the strike of the Ojo Alamo Sandstone from the S1 surface (Fig. 7c), which resulted in an elongate basin with a low relief ratio (8.3 m/km). The ancestral Ah-shi-sle-pah basin apparently headed along the scarp slope of the Ojo Alamo Sandstone cuesta (Fig. 7d), which has given the basin a high relief ratio (11.5 m/km).

Tsaya and Ah-shi-sle-pah basins have similar drainage-basin areas and valley gradients in the lower and central portions of the basins; thus, the greater elongation of the Tsaya Wash basin leads to relatively less relief in the headwater region. Higher relief in the Ah-shi-sle-pah basin may enhance erosion, as compared to the Tsaya basin, during dissection of the S2 and S3 surfaces.

Influence of distribution and lithology of bedrock

The badlands-dominated Ah-shi-sle-pah and Alamo basins contain greater proportions of mudrock bedrock than the less incised Coal Creek and Tsaya basins (Table 1). Bedrock influences the morphologies of the study basins by its resistance to erosion and by controlling the production and composition of surficial deposits (Wells, 1982; Wells et al., 1982).

Stream and valley gradients in the study basins are partially controlled by bedrock lithology and drainage-basin area (Smith, 1983b). Because valley gradients are greater in sandstone than in mudrock (Fig. 5), variation in sandstone thickness in the lower reaches of the study basins affects the amount of incision along a stream valley with respect to a given datum (i.e., the S1 surface). The thickest section of sandstone in the study basins exists along the lower reaches of Tsaya Wash (Fig. 7c), which has contributed to the minimal incision in the upper portions of the drainage basin.

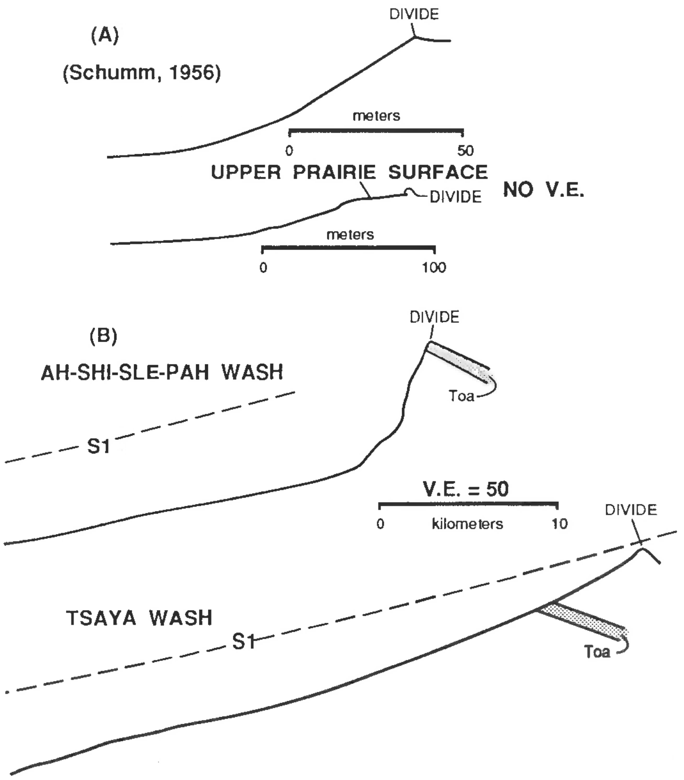

FIGURE 8. A, Two longitudinal profiles of streams surveyed in Badlands National Monument (from Schumm, 1956). The upper profile is from a drainage basin with the same area as the lower, but greater relief ratio and amount of dissection. B, Stream profiles of Ah-shi-sle-pah and Tsaya washes, which have the same areas but differ greatly in dissection (see text for discussion).

Influence of surficial deposits

Regions in the study area covered by sandy eolian and alluvial surficial deposits produce less runoff and sediment than regions where bedrock is exposed (Wells, 1982). Morisawa (1964) showed that stream networks on sandy surficial deposits adjust to baselevel changes and precipitation events more slowly than those on silty surficial deposits because of differences in infiltration and discharge. She concluded that areas of sandy surficial deposits of resistant lithologies in a drainage basin may tend to downcut more slowly than regions composed of silty surficial material. Thus, factors that control deposition of, and trigger dissection of, sandy units profoundly influence the distribution of badland topography.

Sandy surficial deposits are common as alluvium and sheetwash on S2 and S3 surfaces and along valley floors, and as sheetwash and colluvium on hillslopes in the upper portions of the Coal Creek and Tsaya basins. Sandy alluvium is derived from the Ojo Alamo and Nacimiento formations, which are more extensive and more actively eroded in the Coal Creek and Tsaya basins than in the Alamo and Ah-shi-sle-pah basins (Figs. 1, 3). Badlands develop where sandy surficial deposits are stripped during incision of highly erodible bedrock (Gutierrez, 1980). For example, in the northeastern headwaters of Ah-shi-sle-pah Wash, the Ojo Alamo Sandstone has been removed, reducing the supply of sandy surficial sediment to the S2 surface. Badlands development has been the greatest in this area of the Ah-shi-sle-pah basin (Figs. 3, 5; Wells, 1982).

Eolian deposits exist throughout the Tsaya and Coal Creek basins. The low relief valley floors and orientation of Coal Creek and Tsaya Wash parallel to the N60–70E predominant wind direction (Schultz, 1980) allow sand to be transported up the valley floors and onto hillslopes. Rugged badland morphology of the central portion of the Ah-shi-sle-pah and Alamo basins preclude transportation and preservation of substantial amounts of eolian sediment. This blockage and removal of eolian sediment from badland systems acts as a positive feedback system that encourages badland development (Wells and Gutierrez, 1982).

The preservation of alluvial unit 4A along valley floors and upper Pleistocene and Holocene eolian units over large areas of Coal Creek and associated basins have likely reduced stream discharge and downcutting relative to other study basins. Distributary drainage in the central portions of Coal Creek and the basins (Fig. 5) indicates the streams are transporting sediment out of the upper basins and depositing it in the central portions of the basins. This suggests stream transport conditions are not adjusted to the presently large amount of sediment produced in the headwaters of the drainage basins.

SUMMARY

The character of drainage-basin evolution for tributaries to the Chaco River during regional dissection is a function of initial basin shape, relative relief of the drainage basin, distribution and lithology of bedrock units, and distribution and preservation of surficial deposits. The relative importance of individual factors that control basin evolution is affected by the geomorphic history of the drainage basin. Dominance of sandstone outcrop, elongate low-relief morphology, and accumulation of extensive sandy surficial deposits reduced sediment yield and downcutting of the S2 and S3 surfaces in the Tsaya basin. Extensive badland development in the Ah-shi-sle-pah basin was augmented by the dominance of mudrock bedrock in the basin, a high drainage-basin relief ratio, and minimal deposition and preservation of sandy surficial deposits in the basin, relative to the other study basins.

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