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Kristian Soegaard and Kenneth R. Caldwell
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DEPOSITIONAL HISTORY AND TECTONIC SIGNIFICANCE OF ALLUVIAL SEDIMENTATION IN THE PERMO-PENNSYLVANIAN SANGRE DE CRISTO FORMATION, TAOS TROUGH, NEW MEXICO

KRISTIAN SOEGAARD and KENNETH R. CALDWELL
Programs in Geosciences, FO 2.1, The University of Texas at Dallas, Richardson, Texas 75080

Abstract—The Pennsylvanian-Permian Sangre de Cristo Formation in northern New Mexico represents a southward-thinning, coarse-grained clastic wedge of braided alluvial sediments deposited in response to orogenesis in the ancestral Rocky Mountains. The Sangre de Cristo Formation is subdivided into two alluvial megasequences which signify a temporal variation in style of sedimentation. The lower alluvial megasequence is composed of vertically stacked, tabular conglomerate units deposited on a proximal braided alluvial plain. The lower alluvial megasequence is aggradational and was deposited in response to an uplifted source in the Cimarron highlands to the north.

The upper alluvial megasequence consists of interbedded sandstones/conglomerates and mudstones. Depositional paleoenvironments for the upper megasequence are subdivided into two domains: major, coarse-grained, braided-channel-sandstone sequences and mudstone-dominated floodplain sequences. Deposition of coarse-grained, braided-channel-sandstone bodies was controlled by discharge from tectonic highlands in the Cimarron arch to the north and was dictated by allogenic mechanisms. A marginal muddy floodplain sourced subordinate sinuous channel sandstones on the distal fan to the south. In the north, lacustrine limestones are encased within floodplain mudstones implying an internal drainage system on the proximal fan. Overall retrogradation in the upper alluvial megasequence manifests source-area diminution due to cessation of uplift in the Cimarron arch.

The Sangre de Cristo Formation represents a foreland basin fill. Uplift associated with deposition of the succession was in response to convergent-margin faulting along the northern margin of the Taos trough. This late Desmoinesian-Wolfcampian, north-south compression in the trough is related to northward convergence in the Marathon foldbelt at that time.

INTRODUCTION

Coarse-grained feldspathic arenites and conglomerates of the Permo-Pennsylvanian Sangre de Cristo Formation record the second of two orogenic episodes during development of the Taos trough in northern New Mexico. The conglomerates and coarse arenites have previously been interpreted as braided-alluvial-channel deposits by Zeller and Baltz (1954), Tschanz et al. (1958), Clark and Read (1972) and Brown (1984). A curiosity of these braided-alluvial conglomerates is their close association with large proportions of maroon mudstones of obvious floodplain affinity. Associations of coarse-grained, braided-alluvial-channel sandstones, conglomerates and floodplain mudstones have been described by Fisk (1947), Blakey and Gubitosa (1984) and Gordon and Bridge (1987), among others. Nevertheless, existing braided alluvial models, such as those presented by Miall (1977, 1985), do not accommodate significant proportions of fine-grained, floodplain deposits as observed in the Sangre de Cristo Formation.

Factors controlling alluvial sedimentation can be attributed to either allogenic (extrabasinal) or autogenic (intrabasinal) mechanisms (Beerbower, 1964). Published facies models for braided streams place emphasis on autogenic channel processes. Intrinsic to these autogenic braided-alluvial models are unstable channel margins, and consequently, well-developed floodplain deposits generally are poorly preserved.

The objectives in this paper are to identify fluvial styles present during deposition of the Sangre de Cristo Formation and to evaluate the relative importance of allogenic versus autogenic alluvial processes responsible for the apparent anomalous sedimentary sequences observed. A case is made here that the association of braided-alluvial-channel sandstones and extensive fine-grained floodplain sediments in the Sangre de Cristo Formation is primarily caused by allogenic processes and that these processes are related to the tectonic development of the Taos trough and ancestral Rocky Mountains.

REGIONAL SETTING

The Sangre de Cristo Formation was deposited within the Taos trough, one of several active intraplate basins which developed during ancestral Rocky Mountain orogenesis in late Paleozoic time (Mallory, 1972; Kluth and Coney, 1981). The Taos trough is bounded to the north, east and west by positive elements and opens southward across the Pecos carbonate shelf (Sutherland, 1963) (Fig. 1).

Two distinct, orogenic clastic-basin-fill sequences are present in the Taos trough. Early to mid-Pennsylvanian sedimentation in the basin was almost exclusively marine. The marine sediments are referred to as the Magdalena Group by Read and Wood (1947). Coarse orogenic clastic sediments were shed from the Uncompahgre uplift into the western and northwestern part of the Taos trough and deposited along the Picuris-Pecos fault (Casey, 1980). These siliciclastic sediments constitute the Sandia Formation of Read and Wood (1947). Sutherland (1963) redefined the nomenclature of the Sandia Formation into a lower quartzose Flechado Formation and an overlying feldspathic Alamitos Formation. Fekete (1988) showed that feldspar composition in the Sandia Formation was attributed to diagenetic processes and that sandstone composition cannot be used for subdividing the stratigraphy in the western and northwestern part of the Taos trough. Consequently, the stratigraphic nomenclature of Read and Wood (1947) is retained in this paper.

A biostratigraphic study by Sutherland (1963) and Sutherland and Harlow (1973) indicated the Sandia Formation was deposited between Morrowan and early Desmoinesian time. Their study also revealed that the Flechado Formation interfingers with shallow-marine carbonates on the Pecos shelf to the south. These carbonates are referred to as the Madera Formation by Read and Wood (1947) and were subsequently redefined as the La Pasada Formation by Sutherland (1963). In mid-Desmoinesian time, shallow-marine carbonates of the Madera Formation prograded north and westward across the Sandia clastic wedge in response to reduced siliciclastic input from the west and north as a result of diminution of the Uncompaghre highlands (Casey, 1980). Rejuvenated tectonic activity in the Taos trough led to deposition of the Sangre de Cristo Formation in late Desmoinesian time, thereby signifying the second orogenic episode in the Taos trough. The base of the Sangre de Cristo Formation is defined at the top of the last marine carbonate bed in the Madera Formation (or Alamitos Formation of Sutherland, 1963). The Sangre de Cristo Formation received sediment exclusively from the Cimarron arch along the northern margin of the

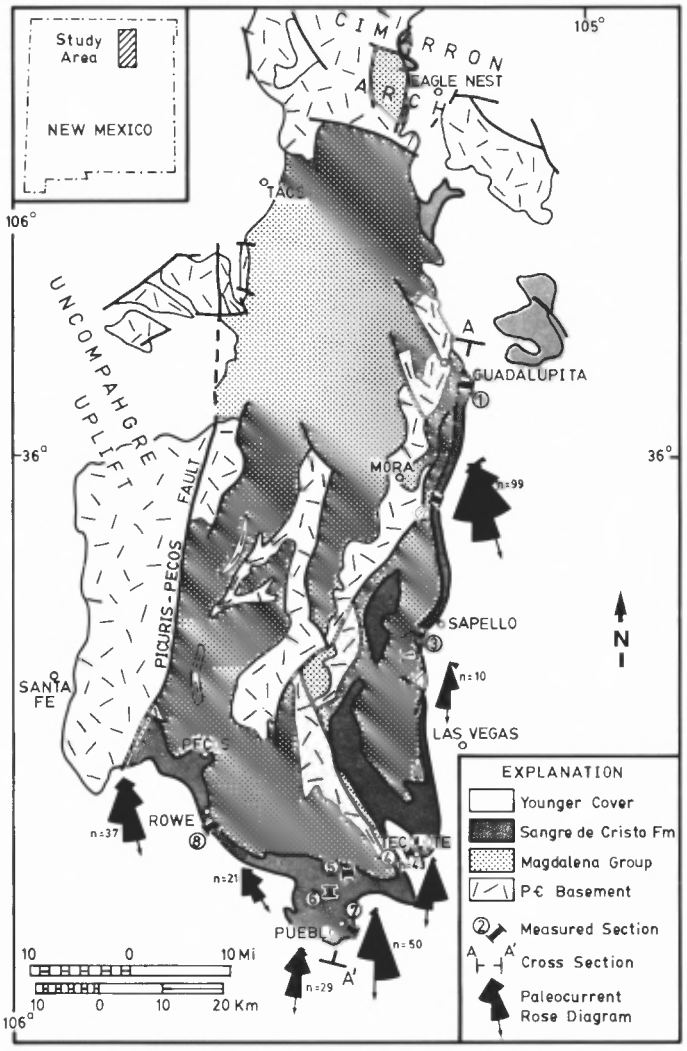


FIGURE 1. Geologic map of exposed western half of the Taos trough exhibiting locations of measured sections and composite paleocurrent data for the Sangre de Cristo Formation. Paleocurrent data are exclusively from trough crossbeds. Measured sections are indexed as follows: Section 1, Guadalupita (Tschanz et al., 1958; Brown, 1984); Section 2, Mora; Section 3, Sapello (Baltz, 1965); Section 4, Tecolote; Section 5, Flying Diamond (FD) Ranch; Section 6, Los Trigos; Section 7, Pueblo; Section 8, Rowe. For precise location of sections see Caldwell (1987). A-A′ represents location of cross section in Figure 2.

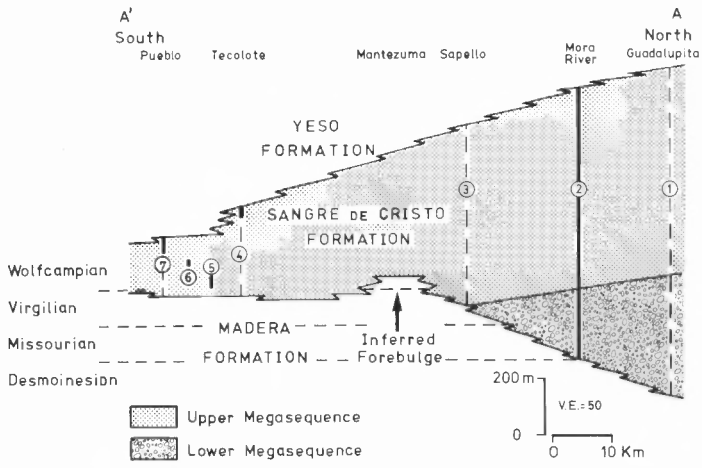


FIGURE 2. Cross section of Sangre de Cristo Formation. Vertical sections measured in this study are depicted as heavy solid lines. Thicknesses at Guadalupita from Tschanz et al. (1958), and at Sapello from Baltz (1965). Thicknesses of Sangre de Cristo for sections 4 through 7 are determined from Johnson (1970). Biostratigraphic zonal boundaries depicted as dashed lines in Madera Formation are cited from Sutherland and Harlow (1973) and Baltz and Myers (1984). Location of cross section A-A′ is shown in Figure 1.

trough (Caldwell, 1987) and prograded southward across the Pecos carbonate shelf. This produced a southward decrease in age of the contact between the Sangre de Cristo Formation and Madera shelf carbonates (Sutherland and Harlow, 1973; Fig. 2). Shallow-marine siliciclastic and evaporite sediments of the Early Permian (Wolfcampian-Leonardian) Yeso Formation interfinger with uppermost Sangre de Cristo alluvial sediments (Fig. 2). The Yeso Formation was not restricted by late Paleozoic tectonic elements of the ancestral Rocky Mountains, indicating that the Taos trough no longer existed as a basin by Early Permian time.

Late Cretaceous to early Tertiary compression during the Laramide orogeny caused uplift and exposure of the western half of Taos trough stratigraphy. At present, the Sangre de Cristo Formation crops out along an arcuate belt for more than 145 km through a series of discontinuous exposures from Pecos, New Mexico, through Las Vegas and northward to Eagle Nest in the Cimarron Mountains in northernmost New Mexico (Fig. 1).

DEPOSITIONAL ENVIRONMENTS

The Sangre de Cristo Formation is subdivided into two megasequences based upon observed facies associations. Figure 3 illustrates the major megasequences represented in the Mora section. The lower megasequence (0–245m) is characterized by a thick succession of very coarse-grained to gravelly sandstones with negligible amounts of finer-grained sandstone and mudstone. The upper megasequence constitutes the remainder of the Mora section (245–923m) and all sections south of Sapello (Fig. 2). The upper megasequence exhibits a conspicuous increase in mudstones which encase thinner sequences of feldspathic, coarse-grained to gravelly sandstone. Horizons of concretionary limestone nodules and a few laterally extensive, unfossiliferous lime-mudstone beds are common in mudstone intervals (Fig. 3).

The following discussion considers the two megasequences by outlining component sedimentary facies, interpreting depositional processes and reconstructing paleoenvironments.

Lower amalgamated sheet-conglomerate megasequence

The lower megasequence is exposed in the basal 245 m of the Mora section along State Highway 518 and is characterized by multi-story, very coarse-grained sandstone to conglomeratic bodies which form tabular units extending for 100's of meters along strike. A southward-thinning geometry is inferred from the presence of thick sheet conglomerate and gravelly sandstones in the lower Sangre de Cristo Formation to the north around Guadalupita (Brown, 1984) and Eagle Nest (Clark and Read, 1972) and the absence of basal amalgamated sheet conglomerates south of Sapello (Fig. 2). Moreover, the lower portion of the Sangre de Cristo Formation is older north of Sapello than the basal portion of the section in the southern part of the basin (Sutherland, 1963; Sutherland and Harlow, 1973).

Sediments in the lower megasequence contain 30–45% feldspar, are poorly sorted, and grains are angular to subrounded (Caldwell, 1987). Extraformational pebbles of quartzite, vein quartz and granite are common, along with a limited number of schistose pebbles. Well-developed vertical grain-size trends are lacking within depositional units, but abrupt upward-fining sequences produced by rapid gradation into thin intervals of finer-grained sediments are the norm. Maximum clast size remains remarkably constant at 3–6 cm in diameter upward through the section at Mora as well as laterally in the region between Guadalupita and Sapello. Single depositional units average 2–3 m in thickness, and amalgamated units attain a maximum thickness of 25 m. Basal contacts

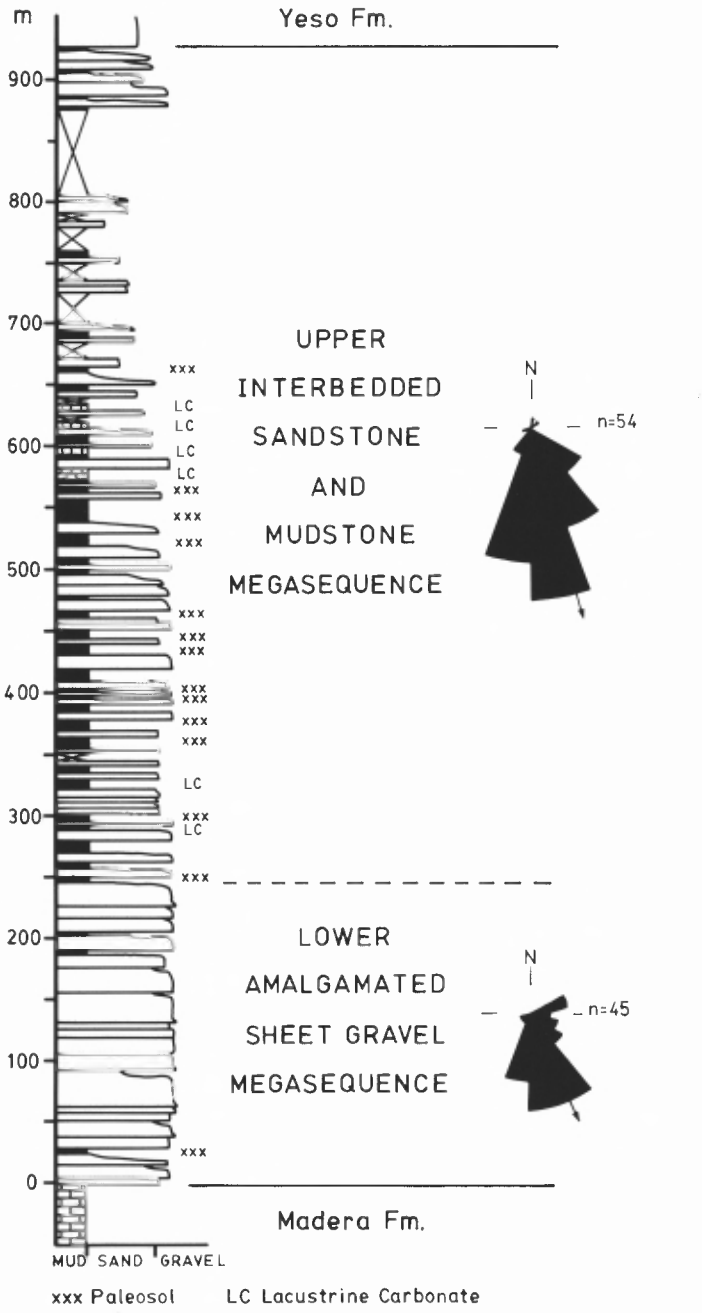


FIGURE 3. Columnar representation of Sangre de Cristo Formation at Mora section illustrating the two principal alluvial megasequences discussed in text. Paleocurrent data from trough crossbeds for the respective megasequences are plotted as rose diagrams.

of individual tabular-conglomerate bodies are always abrupt with limited erosional relief (<50 cm) and rarely display thin basal lags of pebble conglomerate. Lesser amounts of interbedded finer-grained sandstone and mudstone are laterally restricted (10's m) and truncated by thick sandstone sequences. A low diversity of primary sedimentary structures characterizes the lower megasequence and includes small- to medium-scale trough crossbeds, horizontally stratified conglomerates and tabular- and wedging-planar crossbeds.

Trough crossbedded facies

Small- to medium-scale trough crossbeds comprise more than 90% of the lower megasequence. Crossbeds are 5–30 cm thick and commonly occupy entire 2–3-m-thick tabular sheet sandstones (Fig. 4). Large-

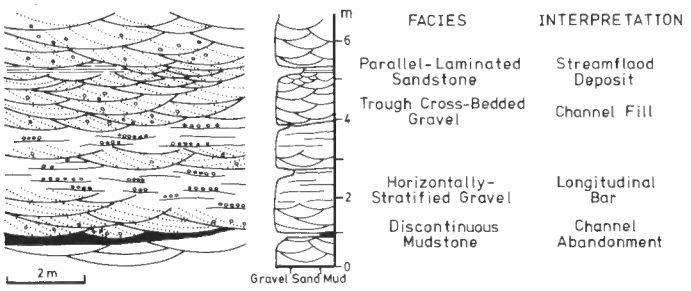


FIGURE 4. Field sketch of amalgamated sheet conglomerate interpreted as stacked braided channel complexes (Mora section, interval 153–160 m in Fig. 3).

scale trough crossbeds with thicknesses in excess of 50 cm are rare. A trend toward decreasing trough amplitude upward through a depositional unit is rare in conglomerate sheets. Paleocurrent trends of trough crossbeds define a narrow spread about a southward-oriented mean (Fig. 3).

Massive and horizontally stratified conglomerate facies

Massive to crude, horizontally stratified conglomeratic sandstones constitute about 7% of the lower megasequence, typically occupying the upper portions of tabular depositional units (Fig. 4). Crude horizontal stratification is defined by discontinuous stringers on a centimeter scale. The massive to horizontally stratified conglomerates are typically less than 1 m in thickness and abruptly overlie the trough crossbedded facies. Upper contacts of horizontally stratified conglomerates are scoured by medium-scale trough crossbeds (Fig. 4) and may be laterally transitional into wedging-planar crossbeds.

Planar crossbedded facies

Crossbeds with planar foresets constitute <2% of the lower megasequence. Foresets are sharply inclined at 25–30° against the lower set boundary and display inverse and normal grading. Two subfacies identified on the basis of overall crossbed geometry are tabular-planar crossbeds and wedging-planar crossbeds. Tabular-planar crossbeds are 30–50 cm in thickness and occur as solitary sets with lateral continuity of several meters across the extent of the outcrop. Wedging-planar crossbeds are smaller in scale (10–25 cm) and are truncated over lateral distances of 1–3 m. Wedging-planar crossbed sets commonly display multiple reactivation surfaces (Fig. 5) and are laterally transitional into horizontally stratified conglomerates. The upper boundaries of both planar crossbed subfacies types are usually scoured. Foreset azimuths of planar crossbeds may diverge by as much as 100° from the paleoflow direction of the trough crossbedded facies (Fig. 5).

Interpretation of lower megasequence

Coarse grain size and poor sorting, lack of well-developed vertical textural trends in single depositional units, the amalgamated nature of conglomerate bodies with multiple internal scour surfaces, high sandstone and conglomerate-to-mudstone ratio, extreme lateral persistence of depositional units, abundant crossbedding, low variance in paleocurrent data, and abrupt upward-fining sequences at the tops of sheet conglomerates suggest deposition by braided fluvial processes (Rust,

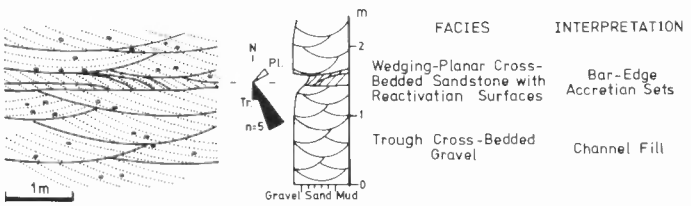


FIGURE 5. Field sketch of the wedging-planar crossbedded facies with well-preserved, convex-upward reactivation surfaces within lower megasequence (Mora section, interval 122–124 m in Fig. 3).

1972, 1978; Miall, 1977). Rapid lateral and vertical facies transitions, and thin, fine-grained drapes are characteristic of deposition from pulsating discharge with multiple high-energy flood events (Smith, 1970; Miall, 1977, 1985).

Trough crossbedding is produced by migration of sinuous-crested (lunate) megaripples or dunes under conditions of confined, unidirectional flow (Allen, 1963; Harms et al., 1982). Trough crossbedded sequences in fluvial sections represent deposition within channels and are not associated with mid-channel bar formation (Miall, 1977). Cant and Walker (1978) observed that megaripples are the most common bedform in channels of the South Saskatchewan River in Canada at all stages of flow and that scale of bedforms can be related to water depth. Shallow channel depths, therefore, are inferred from absence of large trough crossbeds in the lower alluvial megasequence. The overwhelming predominance of trough crossbedded facies in the Sangre de Cristo Formation implies that vertical aggradation of channel-fill deposits was the dominant depositional process (Fig. 6). Stacked channel-fill sequences are inherent to braided fluvial systems (Moody-Stuart, 1966; Coleman, 1969; Cant and Walker, 1976; Miall, 1977). The absence of intraformational clasts in basal lags of channel-fill units and gently dipping foresets of trough crossbeds indicate rapid flow in shallow channels of considerable width and negligible bank stabilization.

Crude horizontal stratification is characteristic of proximal, longitudinal gravel bars which are aggradational features in braided systems (Smith, 1970, 1974; Rust, 1972; Miall, 1977). Mid-channel bars are initiated when decreased stream competence causes deposition of the coarsest bedload and subsequent upbuilding and trapping of sediment on topographically elevated channel segments (Leopold and Wolman, 1957; Coleman, 1969). Williams (1971) has proposed that longitudinal bar deposits of sandy ephemeral streams in central Australia are the result of high stage flow and become stranded by waning flood. The crude horizontally stratified conglomerate facies in the Sangre de Cristo Formation is interpreted as vertical aggradation in response to successive streamflood events. Horizontally stratified streamflood conglomerates were deposited on topographically elevated portions within the channel by virtue of their consistent position in the upper portion of tabular conglomerate units and are interpreted as mid-channel longitudinal bars (Fig. 6). The overlying and adjacent trough crossbedded facies implies frequent post-depositional scouring by laterally migrating channels (Smith, 1970; Cant and Walker, 1978). Thus, low abundance of mid-channel bar deposits in the lower alluvial megasequence is a function of preservation potential and not a result of paucity of mid-channel bars during sedimentation. Additional evidence of elevated mid-channel bars is provided by the presence of the wedging-planar crossbedded subfacies which are laterally transitional from horizontally stratified conglomerates. Small sets of wedging-planar crossbeds in close association with horizontally stratified streamflood deposits are typical of bar-edge accretion deposits (Rust, 1972) (Fig. 6). Multiple reactivation surfaces within the wedging-planar, crossbedded facies imply episodic accretion along mid-channel bar margins and result from fluctuating discharge (Collinson, 1970).

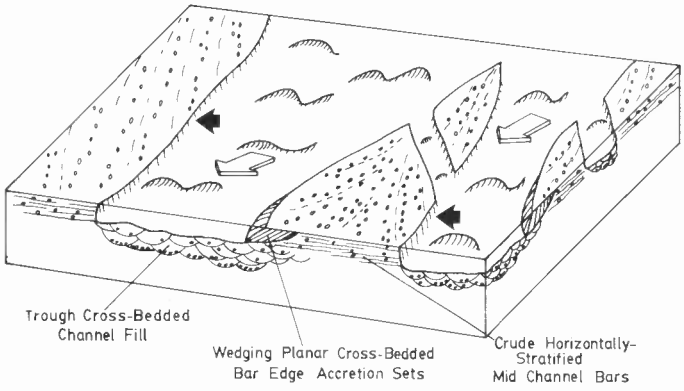


FIGURE 6. Schematic diagram of inferred depositional components within braided alluvial channel complex in lower megasequence. Large arrows indicate primary flow direction inferred from trough crossbeds. Lateral migration of channels (black arrows) eroded topographically elevated mid-channel bar deposits resulting in selective preservation of stacked sequences of trough crossbedded, channel-fill deposits.

Tabular-planar crossbeds in the lower alluvial megasequence resulted from propagating straight-crested sand waves under lower flow regime conditions in less restricted unidirectional flow compared to migrating dunes (Harms et al., 1982). Inversely graded foresets were generated by intermittent avalanching of coarse and fine material down slipfaces. Planar foresets were generated by shallow-water flow over bartops which were elevated above the active channel floor (Smith, 1972). Tabular-planar crossbeds represented downstream migration of transverse bars at high flood stage (Smith, 1970; Cant and Walker, 1976; Miall, 1977). Solitary sets imply deactivation of the slipface during waning flood stage as opposed to superimposed cosets caused by continuous sand-wave migration within more perennial streams (Smith, 1970, 1972). Thus, existence of solitary tabular-planar crossbeds in the lower alluvial megasequence further supports unsteady discharge which typifies braided streams.

Upper interbedded sandstone and mudstone megasequence

The upper megasequence constitutes the upper 680 m of the Sangre de Cristo Formation at Mora and all exposures south of Sapello, and represents a distinct change in depositional style from the lower alluvial megasequence discussed above (Figs. 2 and 3). The upper megasequence differs from the lower alluvial megasequence by virtue of: (1) a conspicuous increase in finer grained sandstone and mudstone units, (2) existence of sandstone bodies with well-developed, moderately steep erosional surfaces outlining channel margins, (3) abundant concretionary limestone horizons and thick-bedded (1–8 m), laterally extensive, unfossiliferous limestones in the northern Taos trough and (4) occurrences of deformed bedding in channel sandstones in the southern part of the basin. The upper megasequence displays a southward thinning geometry from nearly 700 m at Mora to 200–300 m at the southernmost exposures of the study area (Fig. 2). The distinctive association of thick, feldspathic, coarse-grained sandstone bodies with thick mudstone deposits permits subdivision of the upper megasequence into two separate facies associations: major coarse-grained sandstone sequences and mudstone-dominated sequences.

Major coarse-grained sandstone facies association

Major sandstone and conglomerate bodies in the upper megasequence are similar to sheet-conglomerate bodies of the lower alluvial megasequence both in terms of texture and internal facies architecture. At Mora, sandstone bodies average 3–4 m in thickness, whereas amalgamated units achieve thicknesses of 12 m. Sandstone-body thickness decreases upwards within the section at Mora, reaching maximum values of 8 m for amalgamated units in the uppermost 300 m. Sandstone bodies decrease in thickness in a southward direction, with average values of 2–3 m at Tecolote, FD Ranch, Pueblo and Rowe and achieve a maximum thickness of just 5 m for amalgamated units at Los Trigos. Moreover, overall grain size decreases upward and to the south from gravels to medium-grained sandstone. Numerous internal erosional surfaces result in multi-story sheet sandstones composed of overlapping channel-sandstone bodies (see Friend et al., 1979). Channel-form geometries, with broadly concave-upward lower contacts and nearly horizontal upper contacts, abruptly truncate underlying mudstones (Fig. 7) and contrast with the ubiquitous sheet-like nature of amalgamated conglomerates in the lower alluvial megasequence. Discrete channel-form sandstone bodies exposed south of Tecolote are laterally continuous for 250–400 m perpendicular to flow. These channel sandstones taper into thin marginal sandstone beds and thick interbedded mudstones.

As in the case of the lower megasequence, medium-scale trough crossbeds dominate depositional units. Infrequent occurrences of large-scale, 50–90 cm thick, trough crossbeds may occupy channel sandstones. Mudstone intraclasts within basal trough-lag deposits are unique to the upper megasequence. Solitary sets of tabular-planar crossbeds,

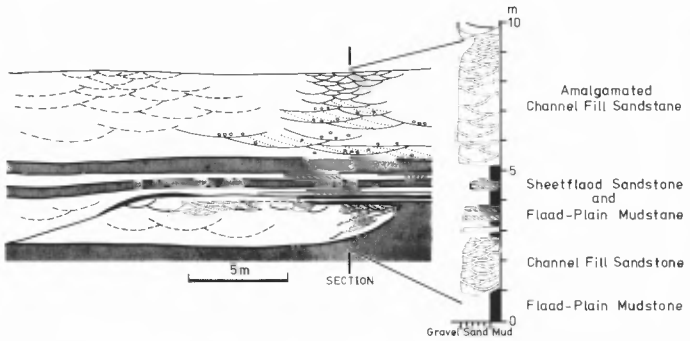


FIGURE 7. Field sketch of exposed channel margin within upper megasequence at the Mora section (interval 415–422 m in Fig. 3). Multilateral and multistoried sandstone bodies are predominantly structured by trough crossbedded, channel-fill facies. Vaguely defined sandstone sets which parallel channel margin suggest laterally accreting side bar surfaces. Lenticular mudstone drapes signify ephemeral discharge within the channel. Channel margins can be traced laterally outward into thin, tabular sandstone beds.

30–50 cm thick, and horizontally stratified facies are common in the middle to upper portions of major sandstone sequences. Rare lateral accretion sets, up to 20–30 cm in thickness, are concordant with channel margins in some gravelly sandstones.

Within the major coarse-grained sandstone facies association in the upper megasequence, two additional facies exist which are not present in channel sandstones of the lower megasequence. These include a bar-top conglomerate facies and a convolute bedding facies.

Bar-top conglomerate facies

Thin sheets of extraformational pebbles conformably overlie crude, horizontally stratified longitudinal gravel bars and are in turn abruptly overlain by finer grained sandstone. A 3–6 cm single-clast layer defines a sheet which caps an upward-fining trend in major coarse-grained sandstones. Due to a prevalence of subspherical pebble shape, no imbrication is evident.

Convolute bedding facies

Several types of soft-sediment deformation, including convolute bedding, oversteepened foresets of tabular-planar crossbeds, dewatering structures and minor synsedimentary faults exist within sandstones of the upper megasequence. These structures are most abundant in fine- to medium-grained sandstone with abrupt vertical grain-size changes. Deformed beds pass vertically into undisturbed and concordantly draping, parallel-laminated sandstone or mudstone.

Laminations contorted into dewatering structures are abundant at the FD Ranch and Pueblo sections. Dewatering structures in fine-grained sandstone are less than 20 cm in amplitude (Fig. 8). However, large-scale forms exceeding 2 m in height are present in medium- to coarse-grained sandstone at Pueblo (Fig. 9).

Interpretation of major coarse-grained sandstone-facies sequences

Similarities in textural characteristics and facies arrangement between the major coarse-grained sandstone sequences of the upper megasequence and those of the lower alluvial megasequence imply that braided fluvial processes and architectural components illustrated in Figure 6 remained constant throughout the depositional history of the Sangre de Cristo Formation. Bar-top conglomerates capping channel-sandstone sequences represent winnowed pebble-lag deposits stranded on the upper surface of mid-channel bars in response to decreased competence during the waning stages of high-energy flood events. Lenticular bar-top conglomerates typify streams with highly variable discharge (Williams, 1971).

Deformed bedding in channel sandstones at Pueblo are interpreted as dewatering structures resulting from liquefication and fluidization of metastable sands as a result of rapid deposition (Mills, 1983). Soft-sediment deformation should typify braided river deposits because of high bed-shear stresses associated with wide, shallow channels and rapid discharge and sediment-load fluctuations (Turner, 1981). Examples of deformed bedding in ancient sandy braided river deposits have been reported by Steel and Aasheim (1978) in the Hornelen Basin of Norway and by Hobday (1978) and Turner (1981) in the Karoo Basin of South Africa.

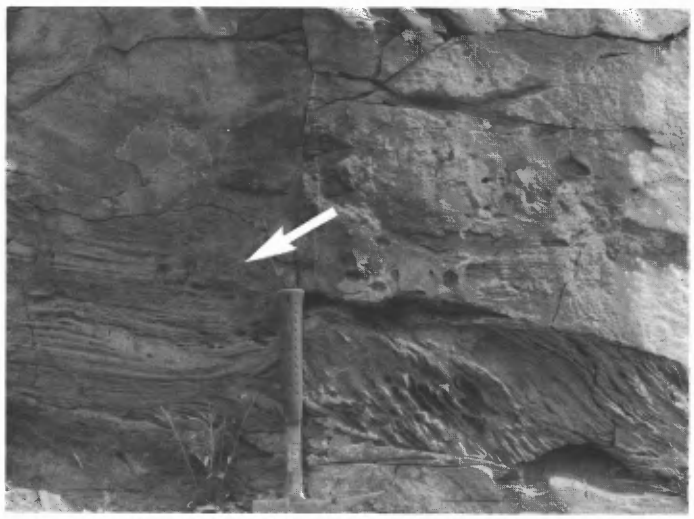


FIGURE 8. Oversteepened and deformed planar foresets in tabular crossbeds from deformed bedding facies at FD Ranch. Foresets are laterally transitional into parallel-laminated sandstones with dewatering structures (arrow). This facies sequence typifies sheetflood deposits associated with ephemeral braided alluvial systems.

Mudstone-dominated facies association

The mudstone-dominated facies association in the upper alluvial megasequence is characterized by thick beds of mudstone and thin, intercalated sandstone beds. Significant proportions of floodplain mudstones are generally absent in braided alluvial systems in which unstable channel margins and ensuing lateral migration prevent preservation of broad floodplain deposits (Miall, 1978). Thus, the origin of the mudstone-dominated facies association and its relationship to major coarse-grained braided-alluvial-channel sandstones is a key issue in resolving



FIGURE 9. Large-scale dewatering structures (deformed bedding facies) present within channel sandstones at Pueblo section (interval 23–25 m of Caldwell, 1987). Dewatering structures overlie medium-scale trough crossbeds at the base of the channel sequence.

the depositional history of the upper alluvial megasequence in the Sangre de Cristo Formation.

Mudstone facies

Mudstones constitute 56% of the upper alluvial megasequence. Thick mudstone deposits can be traced laterally over several 100's of meters and encase feldspathic, braided-channel-sandstone bodies. Maximum observed mudstone thicknesses are 12 m at Mora and 8 m in southern exposures of the Taos trough. At Mora, an upsection increase in thickness of mudstone units corresponds with upward-thinning and upward-fining of sandstone bodies (Fig. 3). Mudstones are massive to thinly laminated, arenaceous, often micaceous and grayish red to dark reddish brown in color (Munsell color code 10R4/2 to 10R3/4). Sporadic lenses of sandstone and gravel (<10 cm thick) are commonly intercalated with the mudstones. Rare silicified wood fragments are present within mudstones at Mora and south of Sapello. Mudstones at the FD Ranch, Los Trigos and Pueblo exhibit a variety of root traces, fossilized plant material and polygonal mudcrack imprints.

Within the mudstone facies, two varieties of calcium carbonate accumulations exist. First, horizons of concretionary limestone nodules, up to 50 cm in thickness, are most common and occur throughout the study area. Concretions vary from very light gray (Munsell N8), unconsolidated, micritic nodules (2–3 cm diameter) to medium gray (Munsell N5), well-cemented, micritic nodules up to 12 cm in diameter. Concretionary limestone nodules commonly encrust floating grains of silt to sand size. Groups of aggregated nodules which grade downward into less consolidated nodules comprise the thickest horizons.

Secondly, beds of unfossiliferous lime mudstone up to 8 m thick exist at Mora and south to Sapello. Similar thick lime-mudstone beds have also been described north of Mora near Guadalupita (Tschanz et al., 1958; Brown, 1984) and near Eagle Nest (Clark and Read, 1972). Thick lime-mudstone beds are conspicuously absent south of Las Vegas. Limestone beds can be traced laterally for several kilometers and are abruptly encased by mudstones and/or feldspathic sandstones. Limestones generally consist of cryptocrystalline calcite (micrite), although many contain abundant detrital quartz and feldspar grains up to fine gravel size. Pebble-sized micrite intraclasts exist on the upper surface of some limestone beds. Rounded micrite intraclasts are found in basal micrite-pebble conglomerates south of Sapello and in the upper 300 m of the Mora section. Intraclast conglomerate displays rare planar-crossbed foresets highlighted by sand-rich laminae (Fig. 10).

Interbedded mudstone and tabular sandstone facies

Sandstone units of variable thickness (20–100 cm) with abrupt upper and lower contacts are intercalated within thick deposits of the mudstone facies. Tabular sandstone beds can be traced laterally outward from the upper portion of exposed channel margins of major coarse-grained sandstone sequences and pinch out after several 10's to 100's of meters into mudstone. Tabular sandstones are sheet-like in geometry. Grain size is variable from fine-grained to gravelly sandstone, and beds are highly micaceous. Finer grained tabular beds south of Mora display well-developed upward-fining trends. Thin, intercalated mudstone drapes may subdivide thicker units into 20–30 cm-thick beds. Imprints of mudcracks are preserved on the basal surface of tabular sandstones. Several subfacies of the interbedded mudstone and tabular sandstone facies are defined on the basis of primary sedimentary structures. Most tabular sandstone units are parallel laminated. Internal laminations are concordant with both upper and lower boundaries of tabular sandstones. A ripple cross-laminated subfacies commonly overlies parallel laminations in finer grained units. Solitary sets of tabular-planar crossbedding, 5–25 cm thick, are laterally transitional into the parallel-laminated subfacies (Fig. 11). These planar foresets are commonly convoluted (Fig. 8).

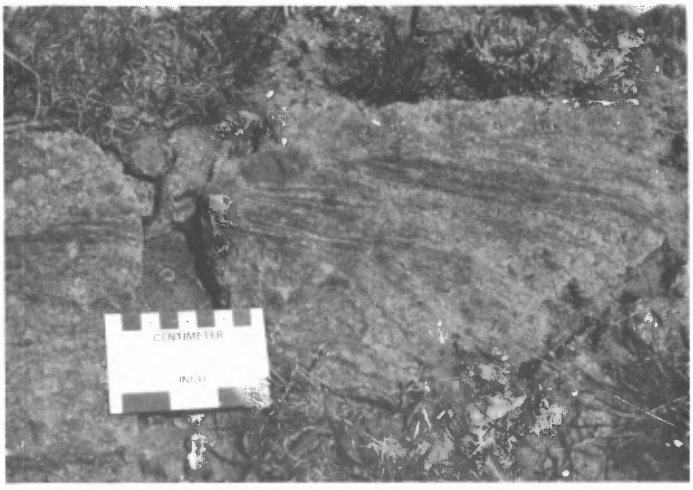


FIGURE 10. Planar foresets in micrite-pebble intraclast conglomerate at Mora section (interval 627–628 m).

Interbedded mudstone and lenticular sandstone facies

In southern exposures of the Sangre de Cristo Formation at the FD Ranch and Pueblo, discrete lenses of fine- to medium-grained sandstone are encased in grayish red to dark reddish brown mudstone. Sandstones are approximately one meter thick and 10–15 m wide. Basal contacts of the sandstones are concave upward and upper contacts are near horizontal. Internally, lenticular sandstones contain laterally juxtaposed 10–30 cm-thick sigmoidal sandstone beds. Sigmoidal beds dip at shallow angles of less than 15° and are concordant with the lower concave boundary. Beds are thickest in the upper two-thirds of depositional units and taper out against the lower and upper contacts of the lenticular sandstone units (Fig. 12). The lower tails of sigmoidal sandstone beds interfinger with mudstones which dominate in the lower and central portion of lenticular sandstone bodies. Primary sedimentary structures within sigmoidal beds include small-scale trough crossbeds at the base of the sandstone, passing upwards and laterally into form-concordant parallel-lamination and rare ripple-cross lamination.

Interpretation of mudstone-dominated facies association

Mudstone facies

The mudstones represent suspension settling in low-lying areas marginal to active channel sedimentation. Thick mudstones in the upper

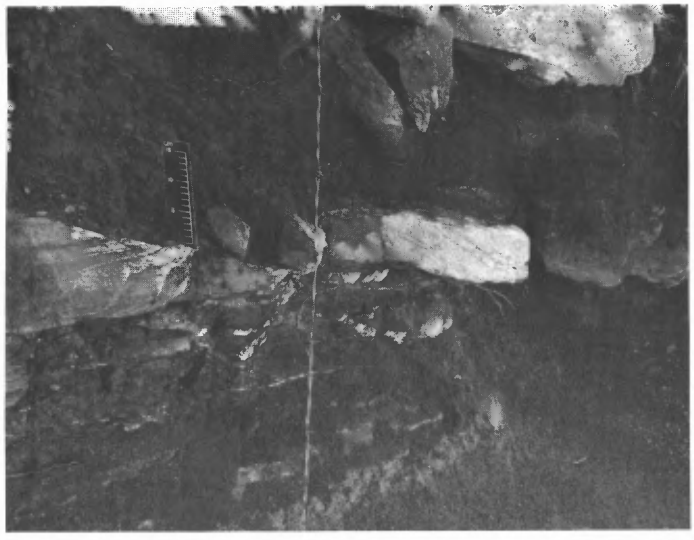


FIGURE 11. Interbedded mudstone and tabular sandstone facies from the Mora section (interval 415–417 m in Fig. 3). Tabular sheet-like sandstone exhibits transition from parallel-laminated to tabular-planar crossbedded sandstone toward the right. This facies sequence represents unconfined sheetflooding as the main channel is evacuated. The tabular sandstone beds can be traced laterally into horizontal upper surfaces of major coarse-grained channel sandstone bodies at 3.5 m mark in Figure 7.

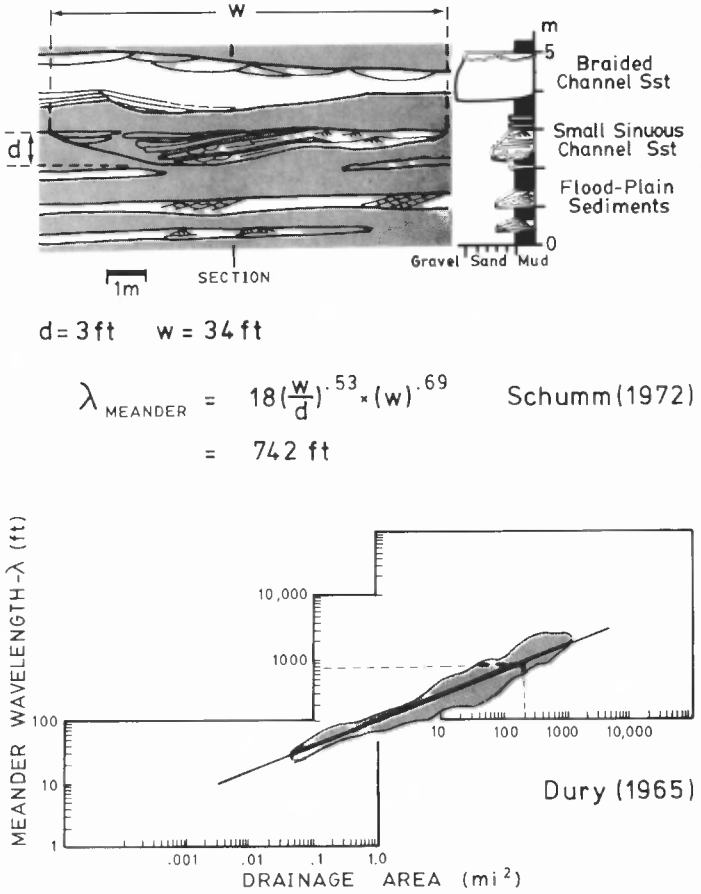


FIGURE 12. Field sketch of interbedded mudstone and lenticular sandstone facies interpreted as sinuous channel deposits at the FD Ranch section. Sigmoidal sandstone sets taper into mudstone at upper and lower contacts. Internal structures of sigmoidal sets include small-scale trough crossbeds, parallel laminations, ripple cross-laminations. Sigmoidal sets are similar to lateral accretion sets in point bar deposits of sinuous channels. Morphologic components of sinuous channels, including meander wavelength (λ) and drainage area calculated from exposures of lenticular sandstone at the FD Ranch section. Width and depth of sinuous channel are listed in feet to accommodate empirical equations by Schumm (1972).

Sangre de Cristo Formation provide evidence of well-established floodplain areas characterized by prolonged vertical accretion. Rust (1978) has suggested that thick mudstones should be expected in the deposits of ancient braided systems, providing sufficient space existed for developing widespread alluvial plains. Topographically elevated and vegetated inactive river tracts are common in modern, distal, braided river systems (Rust, 1972, 1978). Rare fragments of fossilized wood imply at least sparse vegetation on the Sangre de Cristo floodplain.

Concretionary limestone horizons closely resemble caliche (calcrete) horizons of modern semi-arid regions which develop in sandy parent material (Reeves, 1976). Isolated nodules and loose aggregates represent immature soil horizons (Gile et al., 1966). Concretionary limestones are frequently cited as evidence of prolonged subaerial exposure and low rates of floodplain aggradation (Allen, 1974; Steel, 1974; Leeder, 1975). Concretionary limestones within the Sangre de Cristo Formation are interpreted as caliche-paleosol horizons in marginal floodplain areas removed from overbank flooding in a semi-arid, or at least seasonally dry, climate. The abundance of caliche horizons, vertical root traces and mudcrack imprints in the southern exposures indicates a dry, low relief, muddy alluvial floodplain.

The presence of unfossiliferous limestone beds in thick, nonmarine deposits favors a lacustrine or playa origin for the thick, laterally continuous limestone horizons in the upper Sangre de Cristo Formation. Similar limestone beds, in Early Permian strata in the Sacramento Mountains of southern New Mexico, have been interpreted as brackish, or possibly fresh-water, lake deposits (Delgado, 1977). In the Sangre de Cristo Formation, carbonate precipitation was periodically interrupted by overbank floods introducing variable amounts of terrigenous detritus into the shallow lakes. Periodic desiccation and reflooding led to the conglomeratic textures observed on upper surfaces of limestone beds. Subaerially exposed lake beds became desiccated and provided micrite intraclasts which, in certain instances, were reworked by alluvial processes (Fig. 10). The shallow and ephemeral nature of lake beds prevented development of upward-coarsening deltaic packages as braided streams encroached into lacustrine settings. However, these topographically low areas were probably favored channel sites during avulsion of major channel belts, thus accounting for the frequent association of braided channel sandstones above lacustrine carbonates.

Tabular sandstone sequences

Abundance of parallel-laminated subfacies within the laterally extensive tabular sandstone units signifies unconfined sheetflood events under upper flow regime conditions (McKee et al., 1967; Williams, 1971; Tunbridge, 1981). Massive tabular sandstone units abruptly capped by mudstone suggest rapidly decelerating flows, whereas upward fining units capped by ripple cross lamination imply gradually waning flows. Thin mudstone drapes with mudcrack imprints separating tabular sandstones provide a basis for interpreting multiple flood events in thicker units at Mora. Tabular crossbeds with planar foresets represent the leading edge of sandy sheetflood deposits (McKee et al., 1967; Hogg, 1982). The low abundance of intraformational clasts on basal scour surfaces, especially in view of abundant mudstone deposits, is a good indicator of nonchannelized surface-overbank flows (Tunbridge, 1981).

Tabular sandstones resemble sheet-like crevasse-splay deposits (Collinson, 1978; Bridge, 1984), but differ in that their lateral geometries suggest unconfined sheetflood deposition rather than a channelized flow at channel bank margins (Stear, 1983). Moreover, well developed levee deposits are absent in the Sangre de Cristo Formation. Since levees are a necessity for breaching of channel-belt margins in producing crevasse splays, the tabular sandstone beds are considered to be a product of wholesale channel evacuation along an extensive portion of the channel belt.

Lenticular sandstone sequences

Lenticular sandstone bodies in southern exposures of the Sangre de Cristo Formation are interpreted as channel-fill sequences based on sandstone-body geometry. The channel-fill sequences are encased in mudstones of floodplain affinity implying that channels were intimately associated with the Sangre de Cristo floodplain and not the active channel belt. Laterally juxtaposed sigmoidal sandstone beds within lenticular sandstone bodies are lateral accretion sets generated from asymmetric infilling of channels, thus implying that channels were sinuous. Interfingering of lateral accretion sets and mudstones in the lower portions of channels (Fig. 12) indicates that channels were primarily stagnant and discharge was ephemeral. Similar ephemeral sinuous channels are present on the lower Kosi alluvial fan in the Himalayan foreland in which fluvial discharge occurs during monsoonal storms (Wells and Dorr, 1987a). Maximum flow depth within the paleochannel in Figure 12 is inferred to be less than 0.9 m based on preserved sandstone thickness. Transition from small-scale trough crossbeds in the base of the channel sandstone to parallel-laminated sandstones in the upper channel-fill sequence suggests that lower flow regime dunes occupied the channel floor, whereas upper flow regime plane beds occupied the upper surfaces of lateral accretion sets. Upward transition from lower to upper flow regime conditions was in response to shallowing of channel flow along lateral accretion sets (see Allen, 1970). Paleoflow velocities were 2.6 m/s at the transition from upper to lower flow regime based on water depth of 0.7 m and with mean grain size

of 2.45ϕ (see Harms et al., 1982). High flow velocities of 2.6 m/s indicate that deposition occurred during flood events and further support the contention that discharge was unsteady within the sinuous channels.

Based on width to depth ratios of excellent exposures of paleochannels at the FD Ranch section, reconstruction of fluvial morphological characteristics such as meander wavelength and catchment area can be made on the basis of empirical relationships of Dury (1965) and Schumm (1972) (Fig. 12). Calculated size of catchment area of 200 square miles for the sinuous channels at the FD Ranch section places the drainage area well within the confines of the Sangre de Cristo floodplain (Fig. 13).

DEPOSITIONAL MODEL

The Sangre de Cristo Formation in northern New Mexico was deposited exclusively within an alluvial environment. Two separate alluvial megasequences are identified on the basis of observed facies associations. The two megasequences signify two distinctly different braided alluvial systems, both with a consistent northerly source area.

The lower conglomeratic megasequence resulted from deposition in a proximal braided alluvial environment. The braided fluvial complex consisted of a network of shallow channels and associated mid-channel longitudinal bars and lesser transverse bars. Unsteady discharge, shallow channel depths and frequent lateral switching of active channels caused selective preservation of topographically depressed channel-fill sequences, whereas elevated bar deposits were eroded and reworked. The fluvial style envisaged is similar to that of the present-day Scott outwash braidplain in Alaska (Boothroyd and Nummendal, 1978). Maximum clast diameter of 6 cm in the lower alluvial megasequence in the Sangre de Cristo Formation also compares favorably with clasts of 4–6 cm on the medial reaches of the Scott alluvial braidplain (Boothroyd and Ashley, 1975) (Fig. 14). Fluvial style, in conjunction with maximum clast size, provide a qualitative measure of stream gradient. Stream paleogradients for the lower alluvial megasequence are inferred to have been between 2–6 m/km (see Boothroyd and Ashley, 1975) (Fig. 14). Alluvial gradients of >10 m/km would have resulted in horizontally stratified conglomerate deposits due to unrestricted sheetflood sedimentation exclusively and could have supported clasts with diameters of 10–30 cm (Fig. 14). Braided fluvial systems such as the Donjek and South Saskatchewan Rivers in Canada are characterized by more steady discharge than the Scott River and, consequently, channel systems are considerably larger than those inferred for the Sangre de Cristo Formation. Stream gradients of 0.6 m/km and 0.3 m/km for the Donjek and South Saskatchewan Rivers, respectively (Rust, 1972; Cant and Walker, 1978) (Fig. 14), are an order of magnitude lower than inferred paleogradients for braided streams in the lower megasequence of the Sangre de Cristo Formation. Moreover, the South Saskatchewan River is only capable of supporting sand-sized material. Absence of fine-grained floodplain deposits in the lower alluvial megasequence implies that deposition occurred within a broad outwash braidplain, reflecting numerous coalescing braided streams supplied by a linear rather than a point source in the Cimarron uplift (see McGowen and Groat, 1971; Nilsen, 1982) (Fig. 15A).

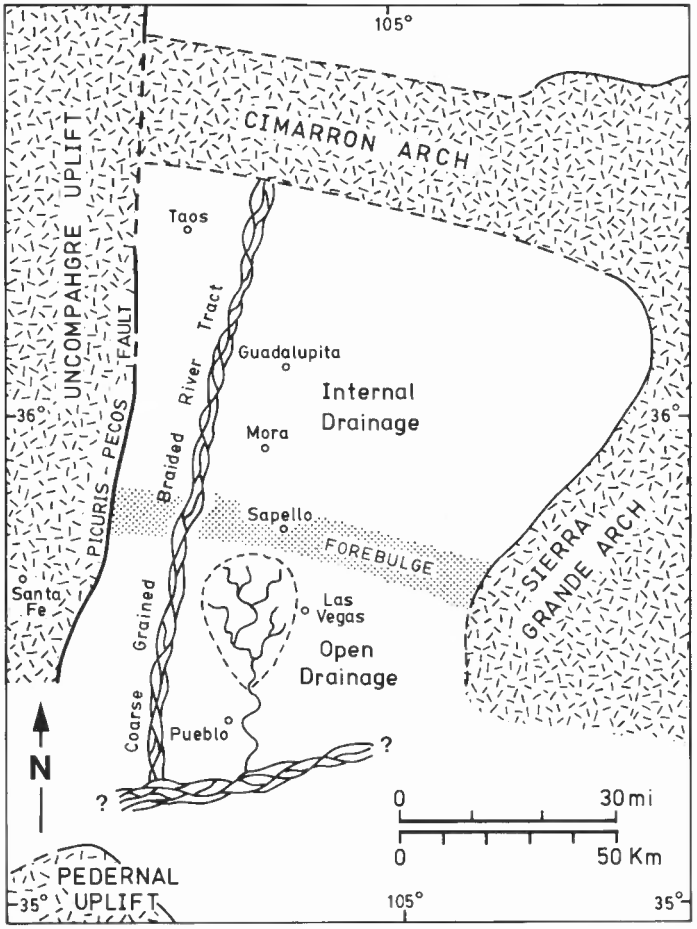


FIGURE 13. Subenvironmental domains during deposition of upper interbedded coarse-grained sandstone and mudstone megasequence. The coarse-grained braided alluvial domain received discharge from the Cimarron arch and, therefore, is dictated by allogenic processes. The mud-rich floodplain is characterized by discharge received from precipitation on the fan surface and is controlled by autogenic effects. North of the flexural bulge (forebulge indicated by stippled pattern) an internal drainage existed, whereas south of the forebulge drainage was open.

The paleoenvironmental setting of the upper interbedded sandstone and mudstone megasequence is separated into two depositional domains. These two domains included an active coarse-grained braided river tract receiving discharge from tectonic highlands within the Cimarron arch, and a mud-rich floodplain marginal to the active braided channel complex.

Braided alluvial processes in the active channel tract were similar to processes in the lower alluvial megasequence. Channels were characterized by vertical aggradation and ephemeral discharge. Well-developed channel margins can be traced laterally outwards into extensive tabular-sheetflood sandstones, implying a paucity of levee deposits in an avulsion-controlled channel network. Systematic downstream decrease in channel size is reflected by southward decrease in sandstone-body thickness and signifies a distributary rather than a contributary fluvial system. A distributary system in conjunction with a southward decrease in thickness of the upper megasequence (Fig. 2) is interpreted as deposition on a mud-rich alluvial fan rather than an alluvial plain environment (Fig. 15B).

The muddy floodplain marginal to the active braided river tract constitutes the second domain on the alluvial fan of the upper megasequence. Prevalance of paleosol horizons throughout the upper megasequence implies that extensive areas of the floodplain were subjected to significant periods of negligible sedimentation (Bown and Kraus, 1987). In the northern Taos trough, from Sapello northward to Eagle Nest, the floodplain had internal drainage where shallow ephemeral lakes existed. South of Sapello drainage was open, and small sinuous channels occupied the floodplain, becoming more numerous southward. Increasing abundance and size of sinuous channels away from the source implies that sinuous streams formed a contributary rather than distributary system. Inferred catchment areas for the sinuous channels were located south of the lacustrine belt, well within the muddy Sangre de Cristo floodplain, suggesting that these streams received discharge from the alluvial fan itself (Fig. 13). The sinuous channels were therefore controlled by autogenic rather than allogenic processes.

Sedimentologic characteristics of the modern Kosi alluvial fan, which flanks the Himalayan orogenic belt, provide the best modern analog for the dichotomy of coexisting depositional domains inferred for the upper alluvial megasequence in the Sangre de Cristo Formation. The active channel belt on the Kosi fan is a braided-river tract dominated by side and mid-channel bar deposits receiving discharge directly from

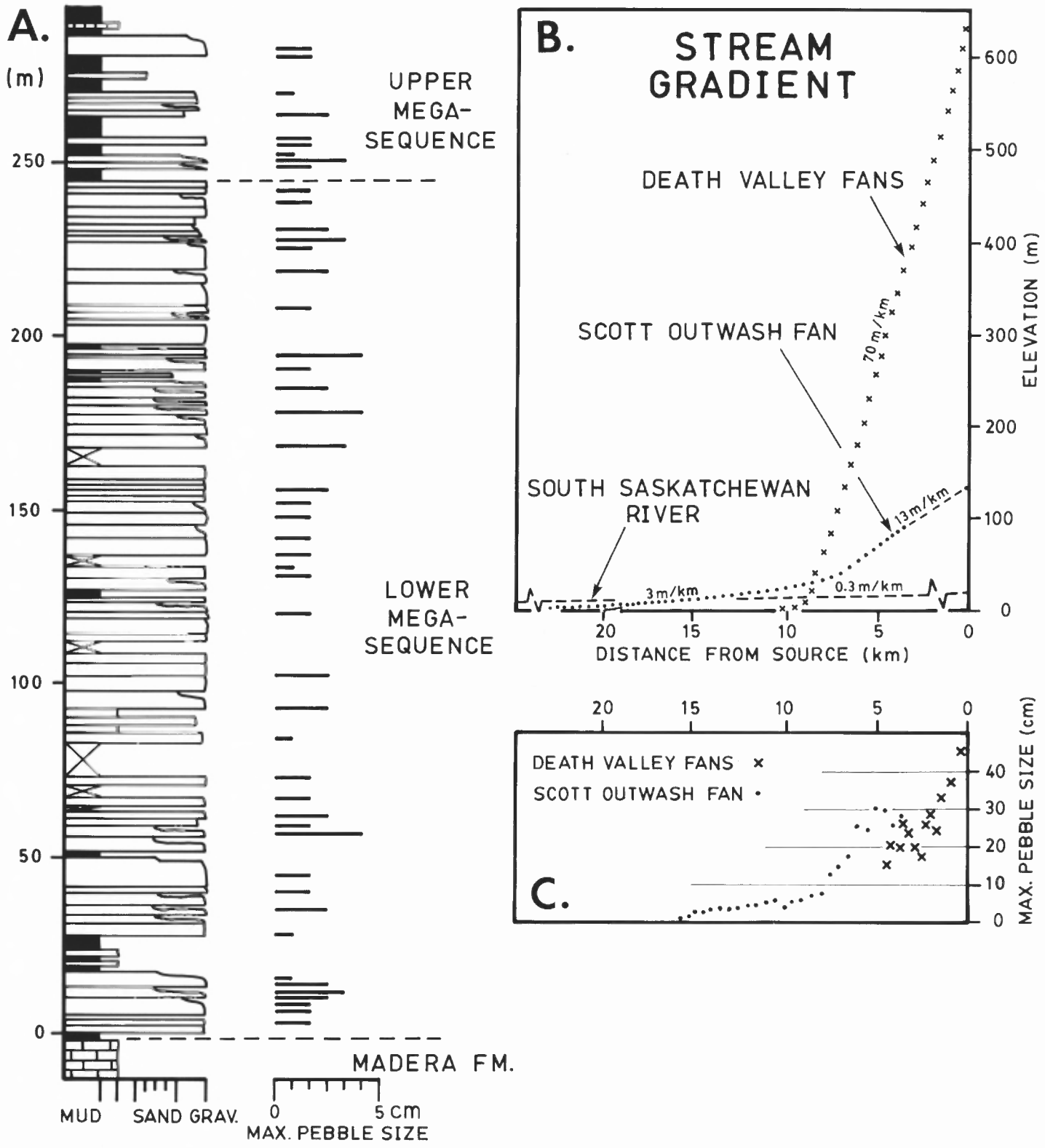


FIGURE 14. A, Vertical succession of amalgamated conglomerate units and maximum clast size within the lower alluvial megasequence at Mora. Depositional style and maximum clast size are both sensitive to alluvial gradients and proximity to source area. For reference, in B are stream gradients of selected modern alluvial fans. The Death Valley fans and Scott outwash braidplain have alluvial gradients of ~3 m/km and are characterized by shallow wide channels separated by longitudinal bars. C, Maximum pebble size within the Death Valley alluvial fans and the Scott outwash braidplain. Both inferred alluvial processes and maximum clast size for the lower megasequence in the Sangre de Cristo Formation are consistent with the medial reaches of the Scott River. The South Saskatchewan River in Canada has deep and relatively stable channels. This modern river contains only sand-sized particles and alluvial gradients are an order of magnitude less than those of the Scott River. The lack of a progressive change in maximum clast size, thickness of depositional units, and the uniformity of inferred depositional processes up through the lower alluvial megasequence at Mora implies that this megasequence is aggradational.

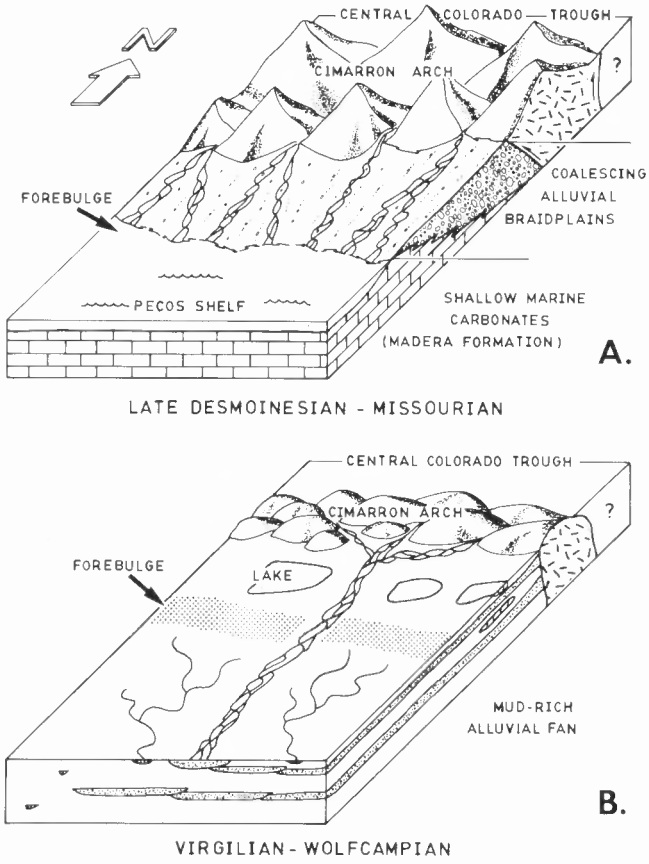


FIGURE 15. Schematic representation of depositional model proposed for Sangre de Cristo Formation. A, Lower amalgamated conglomerate megasequence represents prograding and aggrading sand/gravel-rich coalescing proximal alluvial braidplain deposits. B, Upper interbedded sandstone and mudstone alluvial megasequence represents mud-rich fan sediments in which an active braided channel belt migrated across a broad low gradient, muddy floodplain during deposition.

the Himalayan orogen. The active channel belt is a minor geomorphic component relative to a broad, low gradient, muddy floodplain and has episodically swept across the fan surface from east to west (Gole and Chitale, 1966). Meander scars and sinuous channels filled by fine-grained sand and mud are prominent on the distal Kosi fan (Wells and Dorr, 1987b). The fan is probably comprised of stacked channel belts up to 15 km wide and 2 m in height, with intervening muddy intervals (Wells and Dorr, 1987a). Pronounced lateral migration of the braided-channel tract presumably produced thin, amalgamated sheet-like and channelized sandstones encased in mud-rich floodplain deposits similar to those documented in the upper alluvial megasequence of the Sangre de Cristo Formation.

TECTONIC IMPLICATIONS

The coarse-grained nature and immature composition of braided alluvial sediments in the Sangre de Cristo Formation imply that the Taos trough was tectonically active at the time of sedimentation. The consistent southward orientation of paleocurrent indicators in a spatial (Fig. 1) as well as a temporal sense (Fig. 3) indicates a northerly source terrain located in the Cimarron arch region.

The nature of faulting responsible for uplift in the Cimarron arch is unclear. Soegaard et al. (1986) and Soegaard (1990) have shown that the early history of the Taos trough, during deposition of the Sandia Formation between Morrowan and early Desmoinesian time, was characterized by eastward thrusting along the north-south-trending Picuris-Pecos fault. This thrusting was in response to westward compression in the Ouachita foldbelt at that time (Kluth and Coney, 1981) (Fig. 16). By late Desmoinesian to Wolfcampian time, when the Sangre de Cristo orogenic clastic sediments were deposited, convergence in the Ouachita-Marathon foldbelt had shifted to the Marathon region, and shortening had become north-south oriented (Ross, 1986; Armin, 1987; McConnell, 1989). The northward compression would imply that the east-west-trending northerly boundary of the Taos trough would become a convergent margin and that the frontal zone was located along the southern boundary of the Cimarron uplift (Fig. 16).

A convergent-basin-margin fault for the Taos trough from late Desmoinesian to Wolfcampian time has stratigraphic implications for the basin fill and can be constrained by the depositional history of the Sangre de Cristo Formation. During early faulting, coalescing alluvial braidplain deposits in the lower megasequence signify a linear rather than a point source which typifies active uplift in the source region (Stow, 1985). Lack of variability in fluvial processes and maximum clast size up through the lower alluvial megasequence, between Guadalupita and Sapello, indicates that coalescing braidplain deposits were aggradational (see Heward, 1978) (Fig. 14). Moreover, southward younging of the Madera-Sangre de Cristo contact (Fig. 2) indicates progradation of the early coalescing alluvial braidplains. Simultaneous aggradation and southward progradation imply that the braidplains expanded southward and that sedimentation rates matched tectonic uplift rates in the Cimarron arch.

The lack of a deepening phase prior to deposition of the lower alluvial megasequence is generally inconsistent with tectonic load-induced subsidence implied by a convergent basin-margin fault (Beaumont, 1981). However, Stockmal et al. (1986) have shown that subsidence rate is inversely proportional to the attitude of basin-margin faults in foreland basins. Thus, faulting along the southern boundary of the Cimarron arch uplift may have been characterized by a relatively steep reverse fault rather than low-angle thrusts.

Alternatively, the lack of an early deepening phase may be attributed to high sedimentation rates from the onset of foreland basin formation. For example, in the southern Andean foreland in western Argentina, high sedimentation rates of 0.2–0.9 m/10^3 years in Neogene times resulted in alluvial sedimentation exclusively (Johnson et al., 1986).

The mudstone-dominated upper alluvial megasequence signifies stabilization of the Sangre de Cristo fan surface following cessation of uplift and diminution of the Cimarron arch. The active braided river tract inferred for the upper alluvial megasequence (Figs. 13 and 15B) and its modern analogue, the Kosi river, received discharge from a point source which typifies a tectonically more evolved provenance (Stow, 1985). A point source enabled stabilization of the mud-rich floodplain adjacent to the active channel tract and is manifested by an abundance of paleosol horizons (Fig. 3). Internal drainage on the proximal northerly portion of the fan is a result of higher subsidence rates adjacent to the tectonic highlands in conjunction with formation of a felxural bulge in the vicinity of Sapello (Fig. 13). South of the forebulge, on the distal portion of the fan, drainage was open as manifested by southward-flowing sinuous channels on the fan surface.

Southward expansion of the Sangre de Cristo foreland basin and development of a sub-basin with open drainage south of the forebulge is predicted by increasing the sediment flux *within* the basin (i.e., increasing river capacity) (see Flemings and Jordan, 1989). The increased capacity of rivers is a consequence of an increased drainage area within the tectonically inactive Cimarron arch in the latter part of the depositional history of the Sangre de Cristo Formation.

Overall upward-fining and thinning of beds within the upper facies association indicates the upper alluvial megasequence is retrogradational (Caldwell, 1987; Fig. 3). Retrogradation occurred in response to diminution of the Cimarron arch (see Heward, 1978), which also supports the contention that active uplift ceased following deposition of the lower alluvial megasequence.

CONCLUSIONS

A detailed sedimentary facies analysis has shown that the Sangre de Cristo Formation was deposited exclusively within an alluvial environment. Depositional processes were primarily controlled by extrabasinal mechanisms related to development of the ancestral Rocky Mountains.

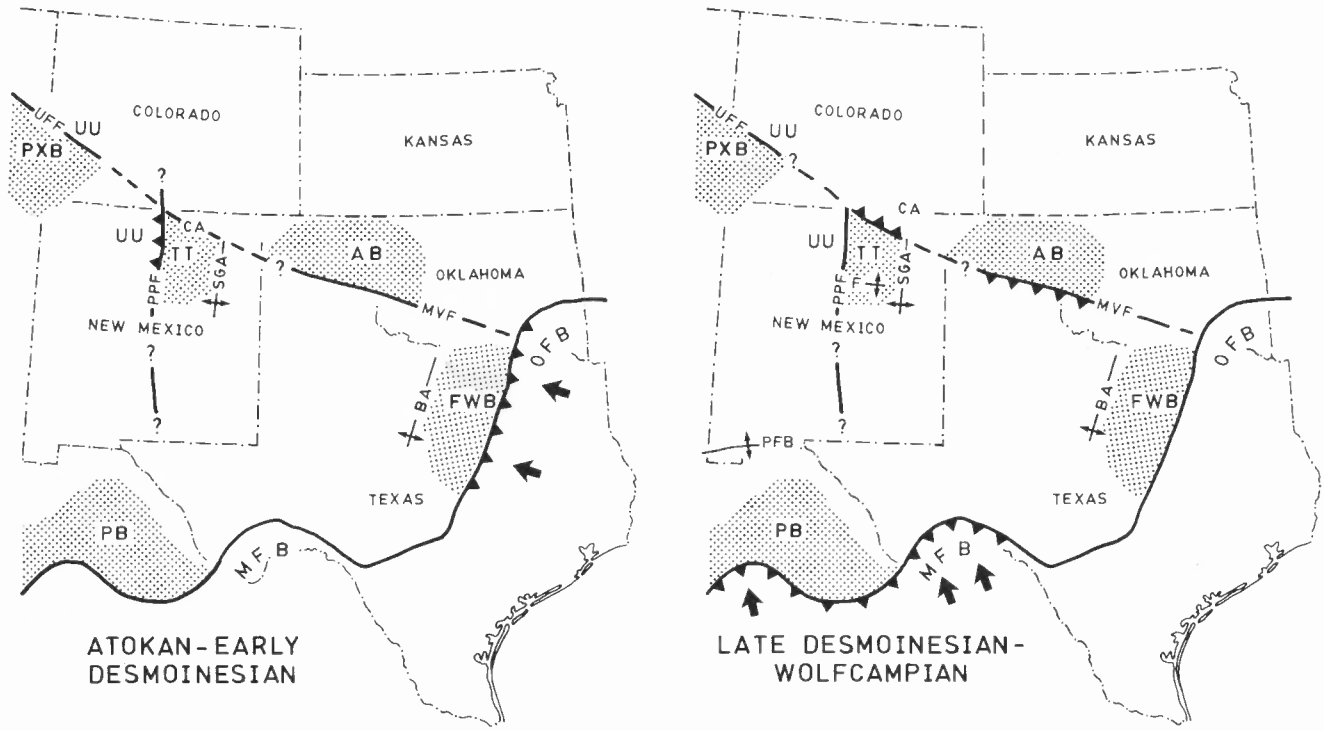


FIGURE 16. Relationship between timing and deformation in the Ouachita-Marathon fold belt and Taos trough in the ancestral Rocky Mountains. (TT) Taos trough; (AB) Anadarko basin; (FWB) Fort Worth basin; (PXB) Paradox basin; (PB) Pedregosa basin; (OFB) Ouachita fold belt; (MFB) Marathon fold belt; (UU) Uncompahgre uplift; (CA) Cimarron arch; (SGA) Sierra Grande arch; (MVF) Mountain View fault; (PPF) Picuris-Pecos fault; (UFF) Uncompahgre Frontal fault; (BA) Bend arch; (F) Sangre de Cristo forebulge; (PFB) Pedregosa forebulge. Extension of Mountain View fault from Anadarko basin through Cimarron arch and into Uncompahgre uplift in southwestern Colorado (Wichita megashear) is fault; (PPF) Picuris-Pecos fault; (UFF) Uncompahgre Frontal fault; (BA) Bend arch; (F) Sangre de Cristo forebulge; (PFB) Pedregosa forebulge. Extension of Mountain View fault from Anadarko basin through Cimarron arch and into Uncompahgre uplift in southwestern Colorado (Wichita megashear) is after Budnik (1986). Atokan-early Desmoinesian eastward compression in Ouachita fold belt and formation of Fort Worth basin and Taos trough inferred from Brown et al. (1973) and Soegaard (1990) respectively. Late Desmoinesian-Wolfcampian northward compression in Marathon foldbelt and south of Pedregosa basin after Ross (1986) and Armin (1987) respectively. Late Desmoinesian convergence along Mountain View fault at southern margin of Anadarko basin after McConnell (1989).

Two alluvial megasequences are identified in the Sangre de Cristo Formation and reflect a temporal change in depositional style. A lower alluvial megasequence is confined to the northern portion of the basin and resulted from deposition on a broad alluvial plain characterized by laterally migrating shallow channels in which discharge was unsteady. The alluvial system consisted of coarse detritus derived from the Cimarron arch to the north, and alluvial gradients were relatively steep. Concomitant aggradation and southward progradation within the lower alluvial megasequence occurred in response to continuous uplift in the Cimarron source region at a rate which equalled sedimentation rates.

Deposition within the upper alluvial megasequence occurred on a large, mud-rich alluvial fan in which shallow braided streams flowed within a well developed marginal floodplain. The atypical association of braided alluvial sediments and thick floodplain deposits was related to allogenic controls on sedimentation. Coarse-grained braided channels were sourced in the uplifted tectonic highlands to the north and, therefore, were allogenic in origin. Deposition on the floodplain was characterized by autogenic processes. On the northern portion of the fan an internal drainage system prevailed and lacustrine sedimentation occurred. On the southern portion of the fan drainage was open and sinuous channels received discharge from the fan surface itself and flowed southwards. A modern geomorphic analogue to the upper facies association is the Kosi alluvial fan in the Himalayan foreland.

The Sangre de Cristo Formation signifies a foreland basin fill. Uplift associated with deposition of this alluvial succession was in response to convergent margin faulting along the northern margin of the Taos trough. Late Desmoinesian-Wolfcampian north-south compression in the Taos trough is related to convergence in the Marathon foldbelt at that time.

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Prior to the arrival of the automobile (in about 1910 for most of New Mexico) the local blacksmith's shop, and adjacent livery stable, was the equivalent of the corner garage. Messrs. Lail and Wilkins not only provided blacksmithing services at their Cimarron shop, but were apparently one of New Mexico's earliest John Deere dealers, a brand of farm implements still with us today. Photo courtesy of Philmont Scout Ranch.