Fluvial deposition and paleoenvironment of the Cutler Formation red beds, El Cobre Canyon, New Mexico

Michael A. Fracasso

New Mexico Geology, v. 9, n. 1 pp. 14-18, Print ISSN: 0196-948X, Online ISSN: 2837-6420.
https://doi.org/10.58799/NMG-v9n1.14

New Mexico Bureau of Geology & Mineral Resources
New Mexico Institute of Mining & Technology
801 Leroy Place
Socorro, NM 87801-4796

https://geoinfo.nmt.edu

This page is intentionally left blank to maintain order of facing pages.

Fluvial deposition and paleoenvironment of the Cutler Formation red beds, El Cobre Canyon, New Mexico

by *Michael A. Fracasso*, Bureau of Economic Geology, University of Texas (Austin), Austin, TX 78713–7508

Abstract

The red beds exposed at El Cobre Canyon consist of lenticular channel sandstones with U-shaped cross sections and trough crossbeds, interbedded with structureless overbank mudstones and thin crevasse-splay sandstones. Calcareous rhizoliths are abundant in the mudstones, but strongly developed paleocaliches are rare. The sediments were deposited in a single-channel low-sinuosity stream system in an upper alluvial plain, near a distal alluvial fan and braided-stream complex. Sedimentation was episodic in a semiarid climate. Ephemeral channels were the loci of sporadic, but very high, rates of sedimentation, in contrast to the much lower rates of sedimentation over most of the floodplain. Overall higher rates of basin-wide sediment aggradation were maintained by frequent shifting of channel depocenters.

Introduction

The Cutler and equivalent Abo Formations crop out sporadically in north-central New Mexico. The three most areally extensive exposures are at El Cobre Canyon near Abiquiu, the Rio Puerco drainage near Arroyo del Agua, and the Jemez River drainage near Jemez Springs (Fig. 1). These locations are widely spaced, forming the apices of a triangle with sides of 20, 40, and 50 mi. The unique vertebrate fossil faunas of these localities have been studied intensively, particularly the largely endemic fauna of unusually primitive aspect from El Cobre Canyon. The El Cobre Canyon assemblage may represent the oldest known truly terrestrial vertebrate facies-fauna (Fracasso, 1980, 1983). Unfortunately, published studies of the depositional systems represented in these localities are virtually nonexistent, with the exception of the Arroyo del Agua area (Langston, 1953; Eberth and Berman, 1983). The nature of fluvial deposition and paleoenvironment of the Cutler Formation deposits at the El Cobre Canyon locality are the subjects of this report.

Geologic setting

The Cutler–Abo sedimentary sequence is a progradational, arkosic clastic wedge shed to the west and south from the Uncompahgre uplift of the ancestral Rocky Mountains. The Maroon and Sangre de Cristo Formations are equivalents to the east of the uplift. The Uncompahgre and San Luis uplifts form a narrow belt that trends southeast through the southwestern corner of Colorado and extends a short distance into north-central New Mexico (Fig. 1; Baars, 1962, fig. 1; Baars and Stevenson, 1984, figs. 1–3). These uplifts developed as part of a regional foreland deformation in response to a late Paleozoic convergent margin located to the southeast along the Ouachita–Marathon deformed belt (Kluth and Coney, 1981). The timing of the Uncompahgre and San Luis uplifts and associated clastic sedimentation has been established by interdigitating relationships between the continental arkoses and fossiliferous marine-carbonate sequences. Such evidence demonstrates that uplift and continental sedimentation began in the late Pennsylvanian (Missourian) and waned in the early Permian (Wolfcampian–Leonardian; Baars, 1962, 1974; Baars and Stevenson, 1984; Bachman, 1975). A wide spectrum of continental, clastic depositional systems are represented in the Cutler–Abo sequence throughout this time interval, ranging from source-proximal alluvial-fan complexes (Mack and Rasmussen, 1984) to source-distal paralic environments (Mack, 1977, 1978).

Depositional environment

The stratigraphic section at El Cobre Canyon is composed predominantly of fining-upward sequences of variable thickness (Fig. 2). The basal unit of a sequence is commonly a coarse-grained arkosic sandstone with an erosional base. These units occasionally contain thin basal granitic pebble layers, and in places they grade laterally into pockets of sandy granule conglomerate, which contain intraformational clasts. The basal coarse-grained units may be either massive, trough crossbedded, or horizontally bedded on a scale of inches. These basal units are rather abruptly overlain by thicker sections of generally nonlaminated, structureless, blocky red mudstone. Thin, generally structureless sandstones are commonly interbedded with the mudstone units. The mudstones also commonly contain abundant calcareous rhizoliths and are mottled with blue-gray calcareous nodules. Discrete, thin blue-gray calcareous beds with irregular surfaces and thin lenses of fissile, dark-brown mudshale containing abundant plant fossils are rare. The overall vertical facies sequence and minor facies components are characteristic of fluival depositional systems (Allen, 1965, 1970; Visher, 1972). The basal coarse-grained units are channel deposits, and the upper fine-grained units are overbank deposits that include thick floodplain mudstones and thin crevasse-splay sandstones. The rare calcareous beds are paleocaliches, and the lenticular mudshales represent fills of abandoned channels or small backswamps.

The parameters of channel sinuosity and multiplicity (Miall, 1978a) may suggest additional inferences concerning relative position along

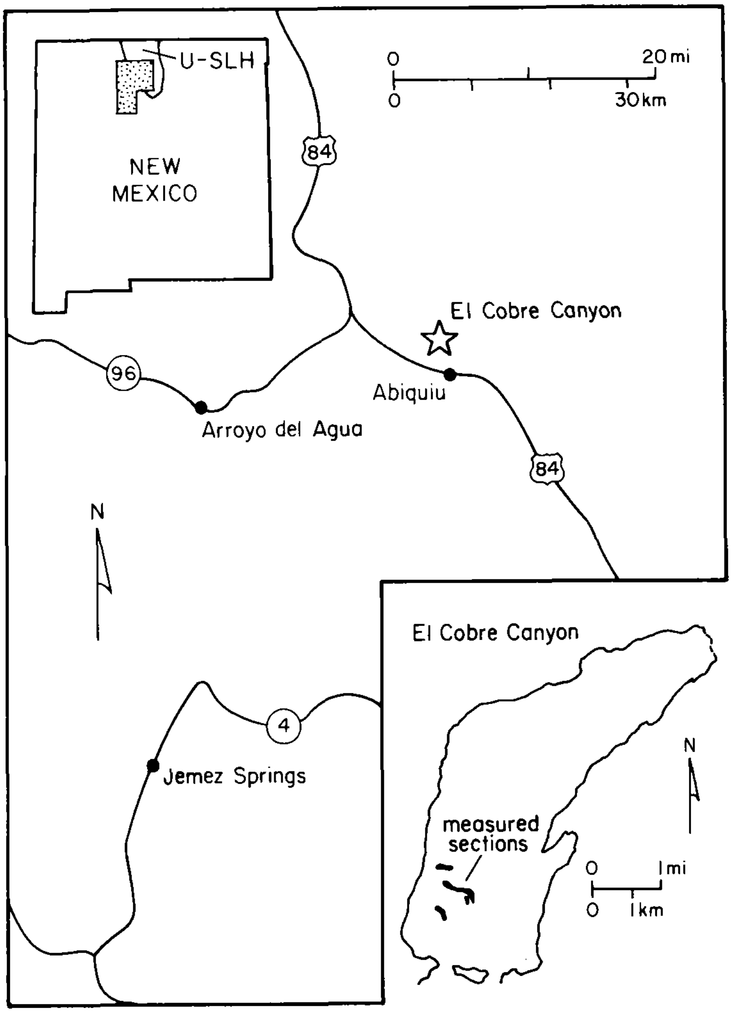
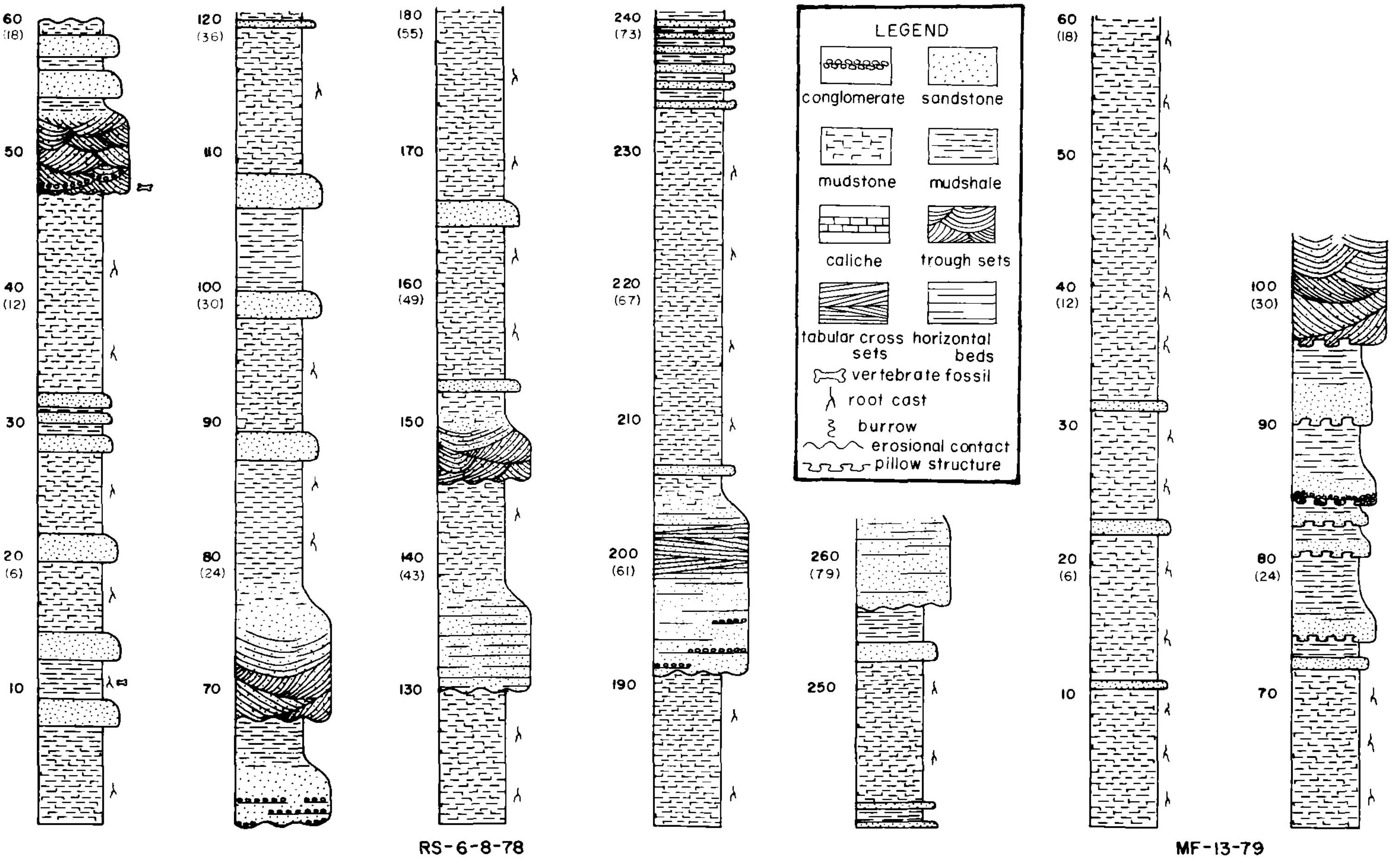


FIGURE 1—Location map for north-central New Mexico, showing El Cobre Canyon and sites of measured sections that are discussed in the text. **U–SLH** is the paleogeographic reconstruction of the Uncompahgre–San Luis Highland (after Baars, 1962, fig. 1). Outline of El Cobre Canyon is drawn on the Cutler and Chinle Formations contact (after Smith et al., 1961, pl. 6).



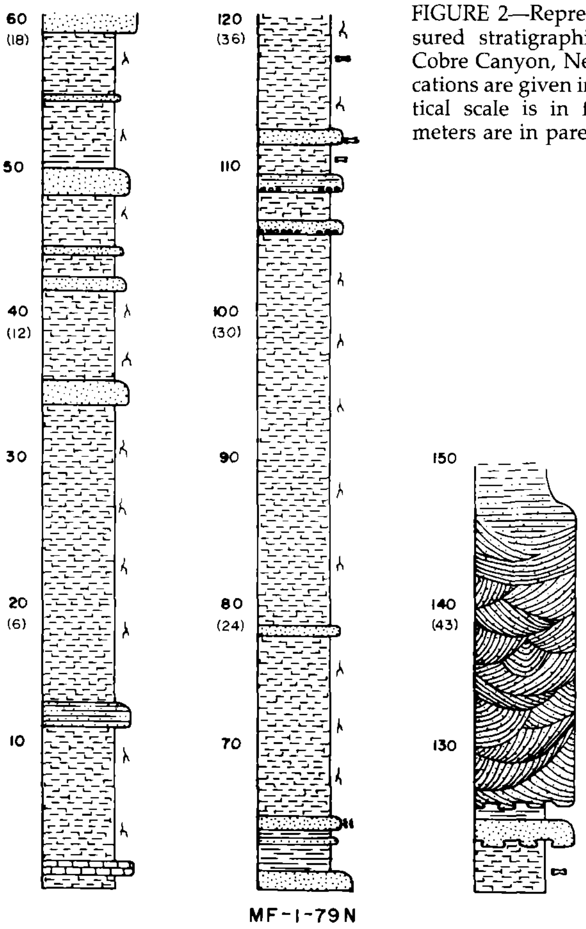


FIGURE 2—Representative measured stratigraphic sections, El Cobre Canyon, New Mexico. Locations are given in Figure 1. Vertical scale is in feet; values in meters are in parentheses.

a downstream transect through the drainage basin. An ideal progradational, terrigenous clastic wedge should display a predictable sequence of laterally-contiguous fluvial depositional systems grading away from the source. These might include: a multichannel, low-sinuosity braided-stream and alluvial-fan complex; a single-channel low-sinuosity upper alluvial-plain system; a single-channel high-sinuosity lower alluvial-plain meandering system; and a multichannel high-sinuosity delta-distributary complex. The horizontal exposures of sandstones in El Cobre Canyon are inadequate to define channel sinuosity or multiplicity, but these features may be inferred from cross-sectional profile and bedding characters. The channel sandstones are thin, averaging only 6–10 ft thick, and they are very lenticular. They are usually only 30 ft wide or less, and the original symmetric U-shaped channel outline is often evident in sections perpendicular to trend (Fig. 3). Pi cross stratification predominates, consisting of multiple sets of trough crossbeds that were probably produced by a combination of scour-and-fill and migration of curved-crest dunes during high energy, turbulent flow (Allen, 1963; Reineck and Singh, 1980).

The combination of U-shaped cross sections and pi crossbedding suggests a single-channel low-sinuosity stream complex (Moody-Stuart, 1966). Epsilon crossbedding (Allen, 1963) and sheet sandstones, which are formed by lateral accretion of high-sinuosity meandering streams, are not evident in El Cobre Canyon. The concentrated stacking of coarse-grained units (commonly gravel and pebble breccias) and near absence of fine-grained units that characterize multichannel braided streams (Miall, 1978b) and alluvial-fan complexes were not observed in El Cobre Canyon (Fig. 2). Nor is there evidence of deltaic sandstone geometry or vertical sequence of bottomset, topset, and foreset beds. Terrestrial vertebrate and plant fossils occur sporadically (Fracasso, 1980, 1983). Marine fossils are absent except for a single internal cast of the brachiopod *Anthracospirifer* (formerly *Spirifer*) *rockymontanus* reported by Williston and Case (1912). The provenance of this specimen is not known, but it was probably

☞

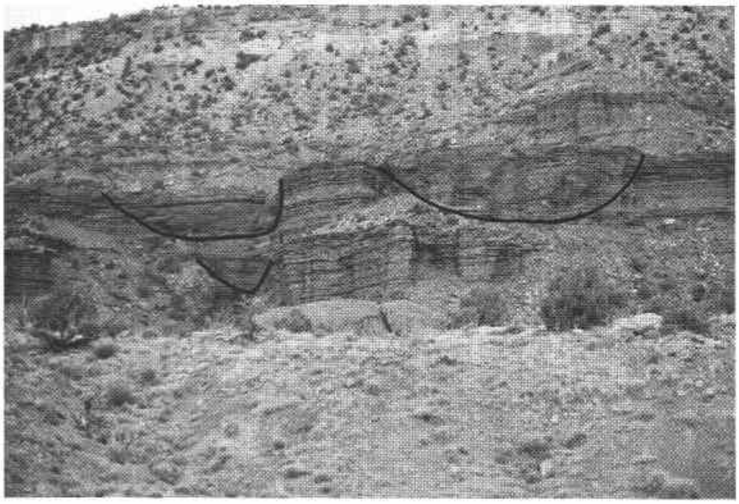


FIGURE 3—Symmetric, U-shaped channel cross sections exposed in western area of measured sections (see Fig. 1). Black lines approximate trends of channel bases; channel at right is approximately 15 ft thick; view is to the west.

FIGURE 4—Calcareous rhizoliths exposed in horizontal view by weathering. Hammer is 13 inches long.

reworked from underlying Pennsylvanian marine carbonates (Langston, 1953), which are not exposed locally. There is no other evidence to suggest a tidal channel origin or other marine influence on Cutler sediments in El Cobre Canyon.

Low-sinuosity fluvial systems that are not braided are uncommon in modern environments (Rust, 1978; Reineck and Singh, 1980; Walker and Cant, 1984), and their dynamics are therefore not well understood. The paleogeographic setting implies that the El Cobre Canyon sequence developed in the upper reaches of an alluvial plain, possibly in close proximity to a distal alluvial fan and braided-stream complex that was shed off the Uncompahgre uplift. I infer that the overall vertical facies sequence and geometry of the channel sandstones present in El Cobre Canyon represent deposition in a low-sinuosity single-channel-dominated fluvial system. The symmetric U-shaped channel outlines, overall thinness of the channel sandstones, and generally abrupt tops of the sandstones suggest that individual channels did not migrate laterally and that channel abandonment was rapid relative to rate of channel-sand aggradation. The apparent abrupt abandonment, probably by avulsion, and short-lived nature of individual channels relative to rates of lateral accretion and aggradation suggest that the channels were ephemeral. Flow in ephemeral streams is intermittent by definition, usually characterized by episodic high discharges alternating with long dry periods (Picard and High, 1973). Such episodic flow may prevail in semiarid to arid climates, in which long dry intervals are punctuated by brief high-intensity rainfalls. Channel avulsion occurs regularly in semiarid regions during major floods (Leopold, et al., 1964).

A semiarid climate is also implied by the occurrence of paleocaliche profiles in various stages of development in many of the overbank mudstone units. Isolated calcareous rhizoliths are common in the mudstone units (Fig. 4), and some are concentrated into discrete zones. A thin, micritic carbonate bed (Fig. 2, section MF–1–79N at 2 ft) is present in the lower part of the sequence at El Cobre Canyon. This bed generally possesses a sharp top and gradational bottom, displays an irregular profile, and is devoid of fossils. Thin sections prepared from this bed reveal angular blocks of micritic matrix separated by crosscutting veins of sparry calcite, which may be interpreted as ancient peds and crystallaria. Alternatively, these structures may reflect more recent deep weathering of the horizon. The isolated rhizoliths, rhizolith horizons, and micrite bed conform closely to stages in a progressive sequence of calichification described by Gile et al. (1981) and Hubert (1977, 1978) in the New Haven Arkose (Triassic). I infer that the massive micritic carbonate bed is a plugged caliche horizon. The paleoenvironmental significance of caliches is that at present they develop best in semiarid environments with low seasonal rainfall (100–400 mm; Hubert, 1977, 1978) if the sedimentation rate is very low. A terminal plugged horizon may require approximately 10,000 years to develop (Hubert, 1977, 1978), and the zone of calichification must remain close to the soil surface during that entire interval. A caliche profile may be arrested at any stage of development by a change in climate or increase in sedimentation rate, or both. In addition, Mack (1978), Mack et al. (1979), Mack and Rasmussen (1984), and Delgado (1977) have inferred semiarid to arid climates during deposition of the Cutler–Abo sequence and equivalents, based on sedimentologic parameters. Likewise, Vaughn (1969) has suggested an arid climate implied by the nature of the vertebrate fossil faunas, and both Vaughn (1969) and Mack et al. (1979) postulated an orographic effect caused by the eastern Uncompahgre highlands.

Differences in relative rates of sedimentation between facies also corroborate the low-sinuosity, ephemeral, single-channel depositional model. Sedimentary structures, especially evidence of bioturbation, are good indicators of relative differences in sedimentation rate between facies. Organisms exist in most sedimentary environments and through their activities tend to obliterate small-scale primary sedimentary structures and textures. Therefore, bioturbation effectively homogenizes the stratigraphic sequence unless the rate of sedimentation is high enough to inhibit organic activity or bury the primary structures below the zone of activity, or both.

Both in-channel and overbank sedimentation are episodic in seasonal climates. Even so, at a gross scale, rates of in-channel sedimentation are much higher than overbank sedimentation when considered over short time intervals. Thus, primary sedimentary structures and textures are generally well preserved in the channel sandstones. The generally slower rate of accumulation of overbank deposits, and, hence, lower preservation potential of primary structures and textures, is partly dependent on the frequency of flood breaches of nearby channels. This, in turn, is a function of the duration of channel occupancy or of the rate of channel avulsion and traverse across the alluvial plain, or both.

One of the most striking features of the overbank units is the rarity of small-scale primary structures and textures. The mudstones are generally massive and show no trace of fissility. Thin crevasse-splay sandstones, less than 3 ft thick, are common in the mudstone units and sometimes exhibit subtle graded bedding. Horizontal laminations, cross laminations, and convoluted laminations that are typical of crevasse-splay deposits are rarely found (Fig. 5). Rhizoliths, however, are abundantly dispersed throughout the mudstone units and individual thick rhizoliths occasionally crosscut the thin, intercalated sandstones. I propose that extensive bioturbation, primarily phytoturbation by extensive root systems, has homogenized the overbank sequence over wide areas characterized by episodic, relatively low rates of sedimentation. Channels were neither occupied long enough nor provided enough suspended sediment load to the adjacent floodplain during seasonal floods to inhibit or balance the processes of bioturbation that occurred between floods. Fryberger

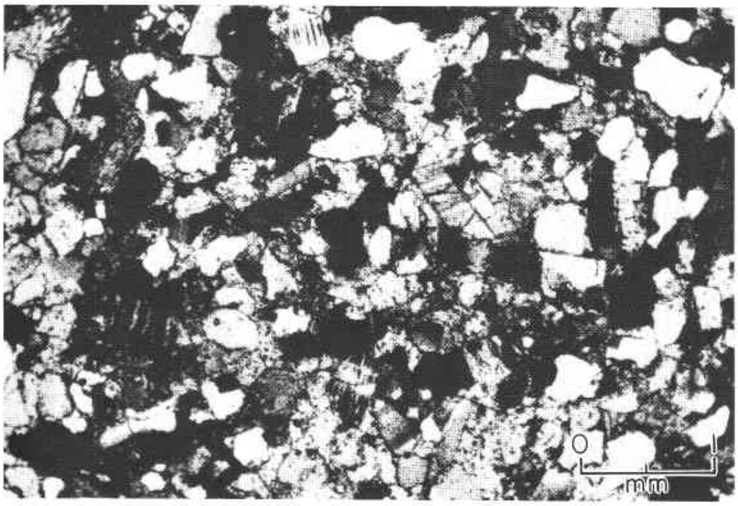


FIGURE 5—Photomicrograph of poorly sorted, structureless crevasse-splay sandstone. Locally low sedimentation rate has allowed bioturbation to obliterate primary sedimentary structures.

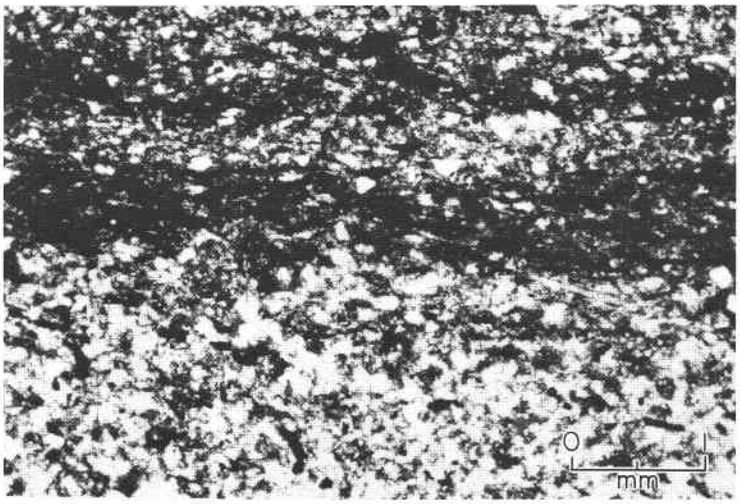


FIGURE 7—Photomicrograph of well-sorted, laminated crevasse-splay sandstone. Locally high sedimentation rate caused rapid burial below the zone of bioturbation and allowed preservation of primary structures.

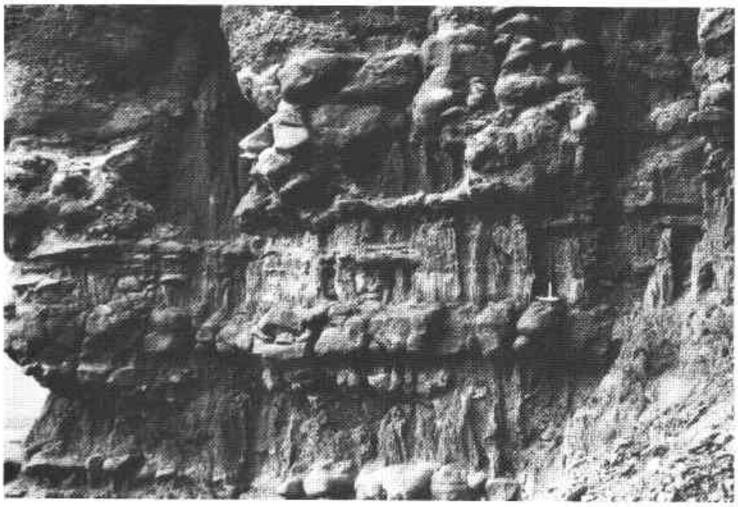


FIGURE 6—A sequence of thin sandstones with load-casted and pillowed bases, interbedded with mudstones, provides evidence for a high rate of overbank sedimentation, possibly within a single season. This succession is located in measured section MF–13–79 (see Fig. 2). Hammer is 13 inches long.

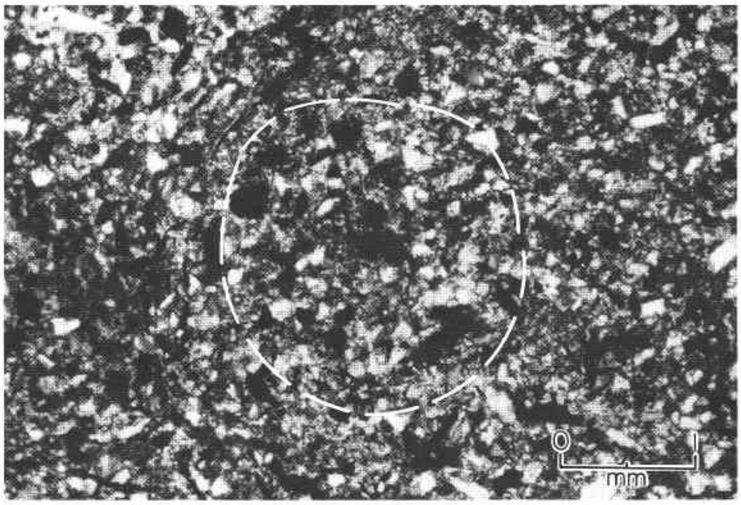


FIGURE 8—Photomicrograph of poorly sorted, laminated crevasse-splay sandstone. Laminae are locally disrupted by crosscutting burrows. Dashed black line highlights the trend of concentric annuli produced by burrowing in nonindurated sediment.

et al. (1983) have noted the efficacy of bioturbation in the destruction of primary structures of Recent continental sand-sea sediments in environments as seemingly inimical as the arid Arabian Gulf area.

Small-scale primary structures and textures are rarely preserved in the mudstones, and when present they are nearly always in close proximity to large channels. This preservation indicates high local rates of overbank sedimentation during the short time spans that the adjacent channels were occupied. One example is illustrated in Figure 6, encompassing the interval between 72 and 100 ft in section MF–13–79 (Fig. 2). The underlying thick mudstone is typically massive and contains abundant rhizoliths. The overlying interval comprises a tightly intercalated succession of thin sandstone and mudshale beds, truncated above by the erosional base of a thick channel sandstone. The thin mudshales are fissile, and the bases of the overlying thin sandstones are load-casted. These features indicate soft sediment deformation during pulses of rapid sedimentation; the sandstones were deposited before the underlying mudshales had dewatered. The thin sandstones reveal horizontal lamination on a very fine scale when viewed in thin section (Fig. 7). Even so, rounded burrows several millimeters in diameter that display internal concentric shear-zone annuli have begun to disrupt the primary lamination (Fig. 8). The burrows weather differentially and are visible in outcrop as well as in thin section. They are randomly oriented and cross the laminae at various angles. No rhizoliths are present in this interval.

I interpret this thin sedimentary packet as having originated when a major channel developed near the site and shed a large volume of sediment over the floodplain in its immediate vicinity during several floods. The flood episodes represented in this sequence probably occurred in a single season, possibly within the span of a few weeks. The thin crevasse-splay sandstones represent the initial influxes of sediment during high-energy waxing phases of floods. Each was deposited over a still wet mudshale that had been deposited from suspension during the low-energy waning phase of the preceding flood. Given a semiarid climate, the thin sandstone–mudshale couplets of each flood cycle would probably have dewatered before deposition of the next cycle if only one flood occurred per season, and soft sediment deformation would not have occurred. The annular shear zones that characterize burrows in cross section also indicate that burrowing had begun while the sediment was still wet. Yet there was not enough time for bioturbation to completely homogenize the sequence before deposition of the next unit. Deposition was rapid enough to preclude plant growth because root casts are absent from this interval.

☞

I suggest that this sequence was preserved by a depositional capping event. A large channel, represented by the erosional base of the thick channel sand appearing at 100 ft in section MF–13–79 (Fig. 2), migrated directly over the sequence and effectively buried the underlying succession below the zone of bioturbation and alteration by surficial physical processes. This type of depositional capping event also may explain the common association of vertebrate fossils preserved in the mudstones immediately beneath channel sandstones, which also occur commonly as channel-lag concentrations in basal granule conglomerate pockets. Most thick mudstones were deposited slowly, were subject to long-term surface exposure and intense bioturbation, and are thus structureless and devoid of fossils except for rhizoliths.

Summary

The El Cobre Canyon fluvial red beds accumulated in a single-channel low-sinuosity stream depositional system located in the upper reaches of an alluvial plain, distal to an alluvial-fan complex fronting the Uncompahgre uplift. Channels were ephemeral, occupied for few flood events before abandonment by avulsion. Channels were the loci of episodic sediment dispersal over the floodplain. They were flanked by narrow zones that intermittently received large volumes of sediment during the short time spans of sporadic floods. The overall rate of alluvial-plain sedimentation was much lower, and net sediment aggradation in the basin resulted from frequent shifting of channel depocenters across the floodplain, averaged over long time intervals. Paleocaliches arrested at various stages of development provide additional evidence of infrequent, episodic sedimentation in a semiarid climate.

It is uncertain to what extent this depositional framework pertains to the other significant Cutler–Abo exposures in north-central New Mexico. Eberth and Berman (1983) noted the existence of broad lateral-accretion channels as well as U-shaped channels in the Arroyo del Agua area. This suggests a single-channel stream complex, transitional between low- to high-sinuosity channels, situated lower in the alluvial plain than El Cobre Canyon. Eberth and Berman (1983) suggested a midfan location, but the large proportion of fine-grained overbank sediments at El Cobre Canyon and Arroyo del Agua implies that both localities were somewhat distal to an alluvial-fan complex. Cursory inspection of the Jemez Springs area suggests a paralic, single-channel high-sinuosity meandering stream complex, but more study is required to corroborate this.

ACKNOWLEDGMENTS—I thank J. D. Archibald, J. H. Ostrom, K. S. Thomson, and K. M. Waage of Yale University; J. R. DuBar of the University of Texas, Bureau of Economic Geology; D. L. Wolberg and R. F. Broadhead of the New Mexico Bureau of Mines and Mineral Resources; and G. H. Mack of New Mexico State University for reviewing various drafts of this paper. S. Lucas and P. Reser provided valuable assistance in the field. Fieldwork was supported in part by grants from Sigma Xi, Geological Society of America, and Yale University. The manuscript was originally typed by V. C. Zeikus; word processing was by L. L. Farnam, under the supervision of L. C. Harrell. J. A. Morgan provided photographic reproductions, under the supervision of R. L. Dillon. Joel Lardon and Cherie Pelletier provided assistance in drafting the figures.

References

Allen, J. R. L., 1963, The classification of cross-stratified units with notes on their origin: Sedimentology, v. 2, pp. 93–114.

Allen, J. R. L., 1965, Fining-upwards cycles in alluvial successions: Geological Journal, v. 4, pp. 229–246.

Allen, J. R. L., 1970, Studies in fluviatile sedimentation—a comparison of fining-upwards cyclothems, with special reference to coarse-member composition and interpretation: Journal of Sedimentary Petrology, v. 40, pp. 298–323.

Baars, D. L., 1962, Permian System of Colorado Plateau: American Association of Petroleum Geologists Bulletin, v. 46, pp. 149–218.

Baars, D. L., 1974, Permian rocks of north-central New Mexico: New Mexico Geological Society, Guidebook to 25th Field Conference, pp. 167–169.

Baars, D. L., and Stevenson, G. M., 1984, The San Luis uplift, Colorado and New Mexico—an enigma of the ancestral Rockies: The Mountain Geologist, v. 21, pp. 57–67.

Bachman, G. O., 1975, Paleotectonic investigations of the Pennsylvanian System in the United States, pt. I—Introduction and regional analyses of the Pennsylvanian System, New Mexico: U.S. Geological Survey, Professional Paper 853L, pp. 233–243.

Delgado, D. J., 1977, Paleocaliche textures from Wolfcampian strata of the Sacramento Mountains, New Mexico; *in* Pray, L. C., Wilson, J. L., and Toomey, D. F. (eds.), Geology of the Sacramento Mountains, Otero County, New Mexico: West Texas Geological Society, Field Trip Guidebook, 1977, pp. 102–108.

Eberth, D. A., and Berman, D. S., 1983, Sedimentology and paleontology of lower Permian fluvial redbeds of north-central New Mexico—preliminary report: New Mexico Geology, v. 5, no. 2, pp. 21–25.

Fracasso, M. A., 1980, Age of the Permo–Carboniferous Cutler Formation vertebrate fauna from El Cobre Canyon, New Mexico: Journal of Paleontology, v. 54, pp. 1237–1244.

Fracasso, M. A., 1983, Cranial osteology, functional morphology, systematics and paleoenvironment of *Limnoscelis paludis* Williston: Unpublished Ph.D. dissertation, Yale University, 624 pp.

Fryberger, S. G., Al-Sari, A. M., and Clisham, T. J., 1983, Eolian dune, interdune, sandsheet, and siliciclastic Sabkha sediments of an offshore prograding sand sea, Dharan area, Saudi Arabia: American Association of Petroleum Geologists Bulletin, v. 67, pp. 280–312.

Gile, L. H., Hawley, J. W., and Grossman, R. B., 1981, Soils and geomorphology in the Basin and Range area of southern New Mexico—guidebook to the Desert Project: New Mexico Bureau of Mines and Mineral Resources, Memoir 39, 222 pp.

Hubert, J. F., 1977, Paleosol caliche in the New Haven Arkose, Connecticut—record of semiaridity in Late Triassic–Early Jurassic time: Geology, v. 5, pp. 302–304.

Hubert, J. F., 1978, Paleosol caliche in the New Haven Arkose, Newark Group, Connecticut: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 24, pp. 151–168.

Kluth, C. F., and Coney, P. J., 1981, Plate tectonics of the ancestral Rocky Mountains: Geology, v. 9, pp. 10–15.

Langston, W., Jr., 1953, Permian amphibians from New Mexico: University of California (Berkeley), Publications in Geological Science, v. 29, pp. 349–416.

Leopold, L. B., Wolman, M. G., and Miller, J. P., 1964, Fluvial processes in geomorphology: W. H. Freeman and Co., San Francisco, pp. xiii, 522.

Mack, G. H., 1977, Depositional environments of the Cutler–Cedar Mesa facies transition (Permian) near Moab, Utah: The Mountain Geologist, v. 4, pp. 53–68.

Mack, G. H., 1978, The survivability of labile light-mineral grains in fluvial, aeolian and littoral marine environments—the Permian Cutler and Cedar Mesa Formations, Moab, Utah: Sedimentology, v. 25, pp. 587–604.

Mack, G. H., and Rasmussen, K. A., 1984, Alluvial-fan sedimentation of the Cutler Formation (Permo–Pennsylvanian) near Gateway, Colorado: Geological Society of America Bulletin, v. 95, pp. 109–116.

Mack, G. H., Suttner, L. J., and Jennings, J. R., 1979, Permo–Pennsylvanian climatic trends in the ancestral Rocky Mountains: Four Corners Geological Society, Guidebook to 9th Field Conference, pp. 7–12.

Miall, A. D. (ed.), 1978a, Fluvial sedimentology: Canadian Society of Petroleum Geologists, Calgary, Memoir 5, pp. xii, 859.

Miall, A. D., 1978b, Lithofacies types and vertical profile models in braided river deposits—summary; *in* Miall, A. D. (ed.), Fluvial sedimentology: Canadian Society of Petroleum Geologists, Calgary, Memoir 5, pp. 597–604.

Moody-Stuart, M., 1966, High- and low-sinuosity stream deposits, with examples from the Devonian of Spitsbergen: Journal of Sedimentary Petrology, v. 36, no. 4, pp. 1102–1117.

Picard, M. D., and High, L. R., Jr., 1973, Sedimentary structures of ephemeral streams: Elsevier Scientific Publishing Co., New York, pp. xvi, 223.

Reineck, H. E., and Singh, I. B., 1980, Depositional sedimentary environments: Springer-Verlag, New York, 2nd edition, pp. xix, 549.

Rust, B. R., 1978, A classification of alluvial channel systems; *in* Miall, A. D. (ed.), Fluvial sedimentology: Canadian Society of Petroleum Geologists, Calgary, Memoir 5, pp. 187–198.

Smith, C. T., Budding, A. J., and Pitrat, C. W., 1961, Geology of the southeastern part of the Chama Basin: New Mexico Bureau of Mines and Mineral Resources, Bulletin 75, 57 pp.

Vaughn, P. P., 1969, Early Permian vertebrates from southern New Mexico and their paleozoogeographic significance: Los Angeles County Museum, Contribution to Science, no. 166, pp. 1–22.

Visher, G. S., 1972, Physical characteristics of fluvial deposits; *in* Rigby, J. K., and Hamblin, W. K. (eds.), Recognition of ancient sedimentary environments: Society of Economic Paleontologists and Mineralogists, Special Publication 16, Tulsa, pp. 84–97.

Walker, R. G., and Cant, D. J., 1984, Sandy fluvial systems; *in* Walker, R. G. (ed.), Facies models: Geoscience Canada, Reprint Series I, Geological Association of Canada, Toronto, pp. 71–89.

Williston, S. W., and Case, E. C., 1912, The Permo–Carboniferous of northern New Mexico: Journal of Geology, v. 20, pp. 1–12. □

Addition

Richard Lozinsky and John Hawley wish to acknowledge the valuable review comments provided by Christina Balk and Charles H. Maxwell for their article "The Palomas Formation of south-central New Mexico—a formal definition" (*New Mexico Geology*, v. 8, no. 4, pp. 73–78, 82).