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1999, pp. 317-326. https://doi.org/10.56577/FFC-50.317

in:

Albuquerque Geology, Pazzaglia, F. J.; Lucas, S. G.; [eds.], New Mexico Geological Society 50th Annual Fall Field Conference Guidebook, 448 p. https://doi.org/10.56577/FFC-50

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CORRELATION OF JURASSIC STRATA FROM THE COLORADO PLATEAU TO THE HIGH PLAINS, ACROSS THE RIO GRANDE RIFT, NORTH-CENTRAL NEW MEXICO

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Abstract—Subsurface and outcrop sections of Jurassic strata in the Rio Grande rift of north-central New Mexico provide the basis for correlation of the Jurassic strata of the Colorado Plateau and the southern High Plains. This correlation indicates continuity of the Entrada, Todilto, Summerville, and Morrison formations across the Rio Grande rift. However, between the Jurassic section at Galisteo Dam in the rift (described here for the first time) and Romeroville section on the edge of the southern High Plains, the eastward pinchout of the following units takes place: Dewey Bridge Member of Entrada Sandstone, Tonque Arroyo Member of Todilto Formation, and Jackpile Member of Morrison Formation. Continuity of the J-2, J-3, and J-5 unconformities across the Rio Grande rift is indicated, and there is a probable regional unconformity at the Todilto-Summerville contact that may correlate to the J-4 unconformity. Jurassic depositional systems were continuous from the Colorado Plateau to the southern High Plains, so it is necessary to interpret these systems based on data gathered from both areas.

INTRODUCTION

Jurassic strata exposed in north-central New Mexico provide an important link between two extensive Jurassic outcrop belts. To the west, Jurassic strata of the southern Colorado Plateau have been studied intensively, particularly because of the uranium resources they contain (Lucas and Anderson, 1997; Anderson and Lucas, 1997). To the east, on the southern High Plains, the Jurassic strata have not received such intensive study, but are clearly genetically related to Jurassic strata on the southern Colorado Plateau (Lucas et al., 1985). Here, we detail Jurassic stratigraphy in the Rio Grande rift of north-central New Mexico (Fig. 1). Our goal is to use this detail to correlate Jurassic strata between San Ysidro on the eastern Colorado Plateau edge, and Romeroville on the western edge of the southern High Plains. This correlation has important implications for the extent and nature of Jurassic unconformities and depositional systems in the southern Western Interior. The Jurassic stratigraphic nomenclature employed here (Fig. 2) is that advocated by Lucas and Anderson (1998).

SAN YSIDRO SECTION

Anderson and Lucas (1996; also see Woodward, 1987) most recently reviewed Jurassic stratigraphy along the southeastern edge of the Colorado Plateau in the vicinity of San Ysidro. The Jurassic section here is approximately 300 m thick and is assigned to the Entrada, Todilto, Summerville, and Morrison formations (Fig. 3).

The Entrada Sandstone is about 30 m thick and consists of a lower, Dewey Bridge Member (about 13 m thick) and an upper, Slick Rock Member. The Dewey Bridge Member is mostly brown silty sandstone that is bioturbated or ripple laminated and rests disconformably on the Correo Member of the Petrified Forest Formation of the Chinle Group (Lucas and Heckert, 1996). The Slick Rock Member is about 17 m thick and mostly yellowish gray, trough-crossbedded sandstone.

The Todilto Formation sharply overlies the Entrada Sandstone and consists of up to 3 m of kerogenic limestone (Luciano Mesa Member) capped by as much as 50 m of white gypsum (Tonque Arroyo Member). The overlying Summerville Formation was previously identified as the lower portion of the Recapture Member of the Morrison Formation (e.g., Woodward, 1987). These strata, as much as 80 m thick, are mostly grayish-red siltstone, mudstone, and ripple-laminated to massive, very fine-grained sandstone and include local deposits of bedded gypsum as much as 10 m thick.

The overlying Morrison Formation consists of the Salt Wash, Brushy

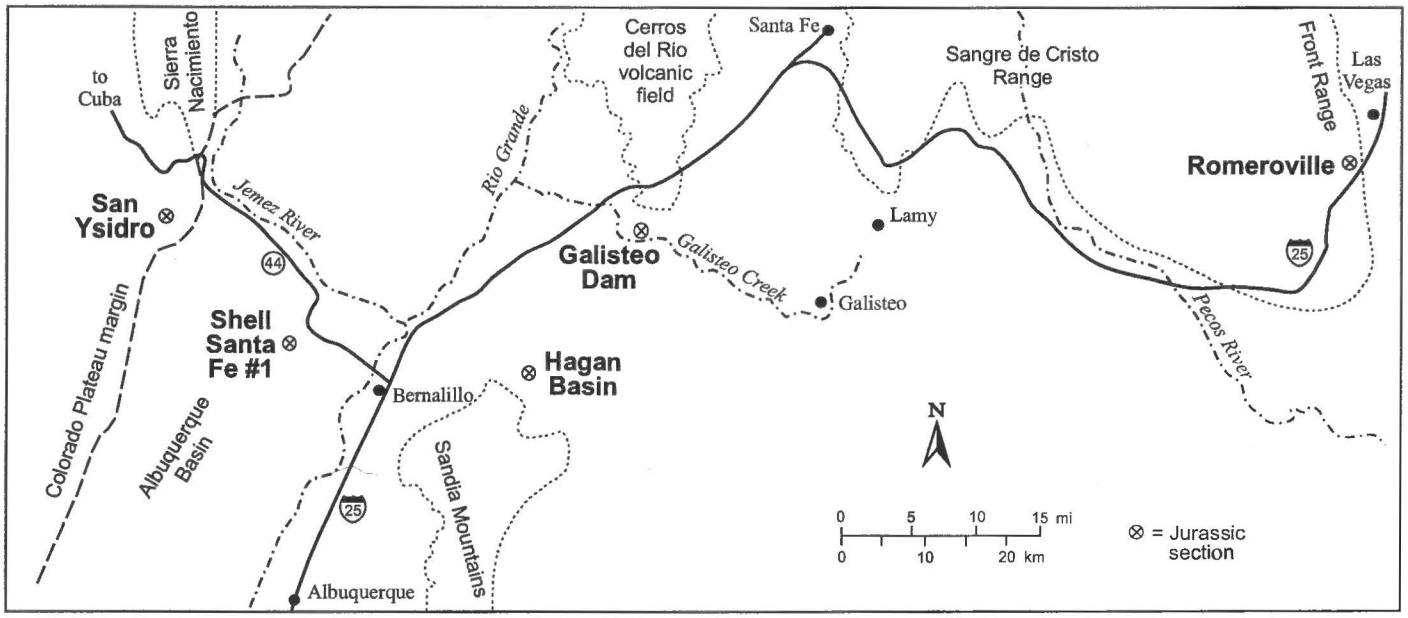


FIGURE 1. Map of north-central New Mexico, showing locations of the Jurassic sections discussed in this article.

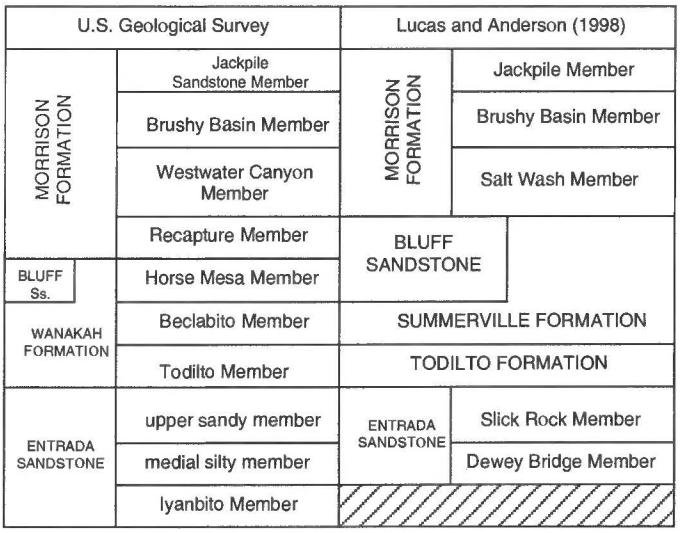


FIGURE 2. Comparison of Jurassic stratigraphic nomenclature used in northern New Mexico by workers of the U.S. Geological Survey with the nomenclature advocated by Lucas and Anderson (1998) and used here.

Basin, and Jackpile members. The Salt Wash Member is as much as 36 m thick and consists mostly of pale yellow, trough-crossbedded, fine- to coarse-grained sandstone with chert-pebble conglomeratic zones (mainly in the basal part) interbedded with thinner units of siltstone and mudstone. The overlying Brushy Basin Member is as much as 80 m thick and dominated by variegated, bentonitic mudstone, and lesser, lenticular, fine- and medium-grained sandstone.

The Jackpile Member (Owen et al., 1984) is as much as 60 m thick and is mostly pale yellow to white, kaolinitic sandstone with some green mudstone interbeds. The Encinal Canyon Member of the Dakota Formation rests disconformably on the Jackpile Member at San Ysidro.

SHELL OIL SANTA FE NO. 1

From the Jurassic outcrops on the eastern edge of the Colorado Plateau near San Ysidro to Jurassic outcrops in the Rio Grande rift—in the Hagan basin and at Galisteo Dam—there is a distance of more than 50 km covered by younger strata (Fig. 1). To aid in correlation across this gap, we selected a subsurface section about midway between the Colorado Plateau edge and the Hagan basin. This is the geophysical log of the Shell Oil Santa Fe #1 well in sec. 18, T13N, R3E (Black and Hiss, 1974). Interpretation of the log of this well by Black and Hiss (1974) and by us (Fig. 3) suggest that the well penetrated the Entrada, Todilto, Summerville, and Morrison formations in the subsurface.

In the well, the Entrada rest directly on the Correo Member of the Chinle Group at a depth of about 7727 ft. Total Entrada thickness in the well is about 60 m (199 ft, from 7727 to 7528 ft). Based on the resistivity log, the lower 67 ft (20 m) of the Entrada belongs to the Dewey Bridge Member, and the upper 132 ft (40 m) belongs to the Slick Rock Member.

The Todilto Formation is 76 ft (23 m) thick in the well, being present from 7528 ft to 7452 ft. The lower 10 ft (3 m) may be the Luciano Mesa Member, but this is not certain from the log.

Black and Hiss (1974) assigned the remaining 642 ft (196 m) of Jurassic strata encountered by the well—from 7452 to 6810 ft—to the Morrison Formation and attempted no further subdivisions. We, however, feel certain that the 260-ft-thick (79 m) mudstone-dominated interval from 6910 ft to 7170 ft is the Brushy Basin Member. If the underlying 110 ft (33 m) of strata belong to the Salt Wash Member—a thickness comparable to the outcrops at San Ysidro—then the base of the Salt Wash corresponds to the base of a prominent sandstone at 7280 ft (Fig. 3). This suggests the Summerville Formation is present from 7280 ft to 7452 ft (thickness = 172 ft or 52 m). Whether or not all of the sandy strata from 6910 ft to 6810 ft include the Jackpile Member or the Morrison Formation, or include strata of the Encinal Canyon Member of the Dakota Formation, cannot be determined from the log. Nevertheless, a careful interpretation of the Jurassic section encountered by the well suggests it is very similar to the Jurassic section exposed at San Ysidro (Fig. 3).

HAGAN BASIN

Lucas et al. (1995a) recently described in detail the Jurassic section exposed in the Hagan basin (T13N, R5E). The entire Jurassic section here is as much as 440 m thick and consists of the Entrada, Todilto, Summerville, and Morrison formations. The Entrada Sandstone disconformably overlies the Upper Triassic Chinle Group and consists of the lower, Dewey Bridge Member (= medial silty member of previous usage), as much as 20 m of mostly reddish brown sandstone and siltstone, overlain by the Slick Rock Member (= upper sandy member of previous usage), as much as 29 m of mostly yellowish-gray, trough-crossbedded sandstone.

The Todilto Formation disconformably overlies the Entrada and consists of the Luciano Mesa Member, as much as 6 m of mostly dark gray kerogenic limestone, overlain by the Tonque Arroyo Member, as much as 61 m of mostly white gypsum-anhydrite. The Summerville Formation (= Recapture Member of the Morrison Formation of earlier workers) conformably(?) overlies the Tonque Arroyo Member of the Todilto Formation and is as much as 57 m of cyclically bedded, red and gray sandstone, mudstone, and siltstone. Locally, these strata include eolianite sandstones, but a regionally mappable Bluff Sandstone cannot be recognized in the Hagan basin.

The Salt Wash Member of the Morrison Formation disconformably overlies the Summerville Formation and is as much as 75 m of mostly grayish-yellow sheets of fluvial sandstone and conglomerate with some interbeds of olive and brown mudstone. The Salt Wash Member grades upward into and intertongues with the Brushy Basin Member of the Morrison Formation, as much as 128 m of mostly variegated olive, gray, and brown bentonitic mudstone/siltstone. The Jackpile Member of the Morrison Formation overlies the Brushy Basin Member and is as much as 62 m of mostly light gray and pale orange, trough-crossbedded kaolinitic sandstone. Cretaceous strata of the Dakota Formation disconformably overlie the Jackpile Member in the Hagan basin.

GALISTEO DAM

Even though the exposures of Jurassic strata along the north flank of Galisteo Creek, near what is now Galisteo Dam (T14–15N, R7E; Fig. 4), have been known for nearly a century (e.g., Johnson, 1902; Lee, 1917), the section has not been described other than in the 1:62,500-scale geologic map of Bachman (1975). Therefore, we provide here for the first time a detailed description of the Jurassic strata exposed at Galisteo Dam (Figs. 4–6).

The Jurassic section at Galisteo Dam is assigned to the Entrada, Todilto, Summerville, and Morrison formations (Fig. 5). These strata are exposed along the southern flank of the La Bajada fault zone, but towards the south, between the inactive gypsum mine and Galisteo Dam, they are structurally simple, dipping 10–23° to the northeast (see Appendix). The Entrada Sandstone at Galisteo Dam is 34 m thick and consists of the Dewey Bridge and Slick Rock members (Figs. 5, 6A). The Dewey Bridge Member is 24 m thick and rests with sharp disconformity on bentonitic, red-bed mudstones of the Petrified Forest Formation of the Chinle Group. Most of the Dewey Bridge Member is silty sandstone that is light brown, very fine grained, and bioturbated to ripple laminated. It forms a cliff and is overlain by the Slick Rock Member.

The Slick Rock Member is 10 m thick and consists of fine- to coarse-grained, very pale orange quartzarenite with large trough crossbeds. The distinctive color change in the Entrada—from light brown to pale orange—is in the upper part of the Dewey Bridge Member.

The Luciano Mesa Member of the Todilto Formation rests with sharp disconformity (J-3 unconformity?: Lucas and Anderson, 1998) on the Slick Rock Member. It consists of paper-thin laminae of dark gray,

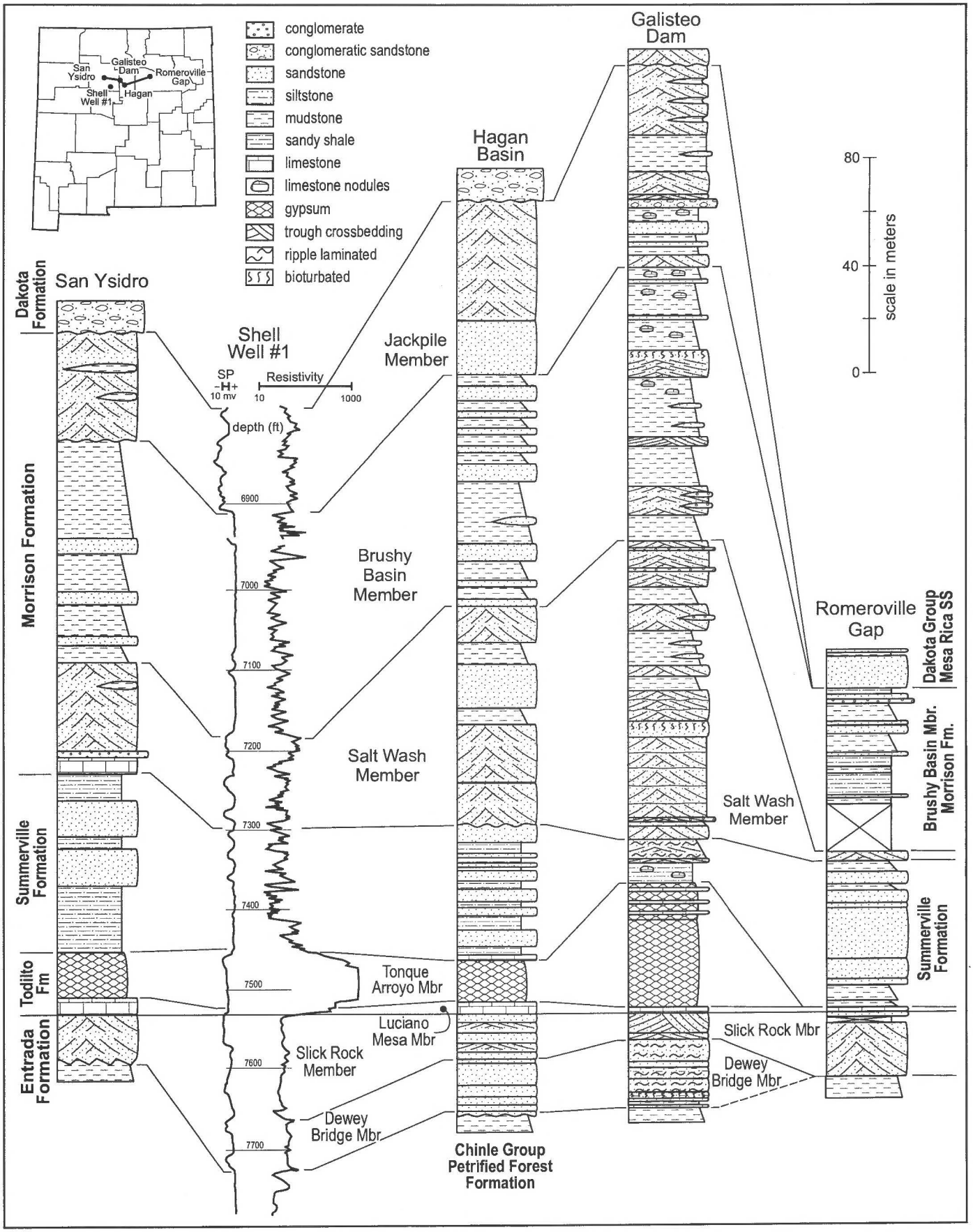


FIGURE 3. Correlation of Jurassic strata across the Rio Grande rift.

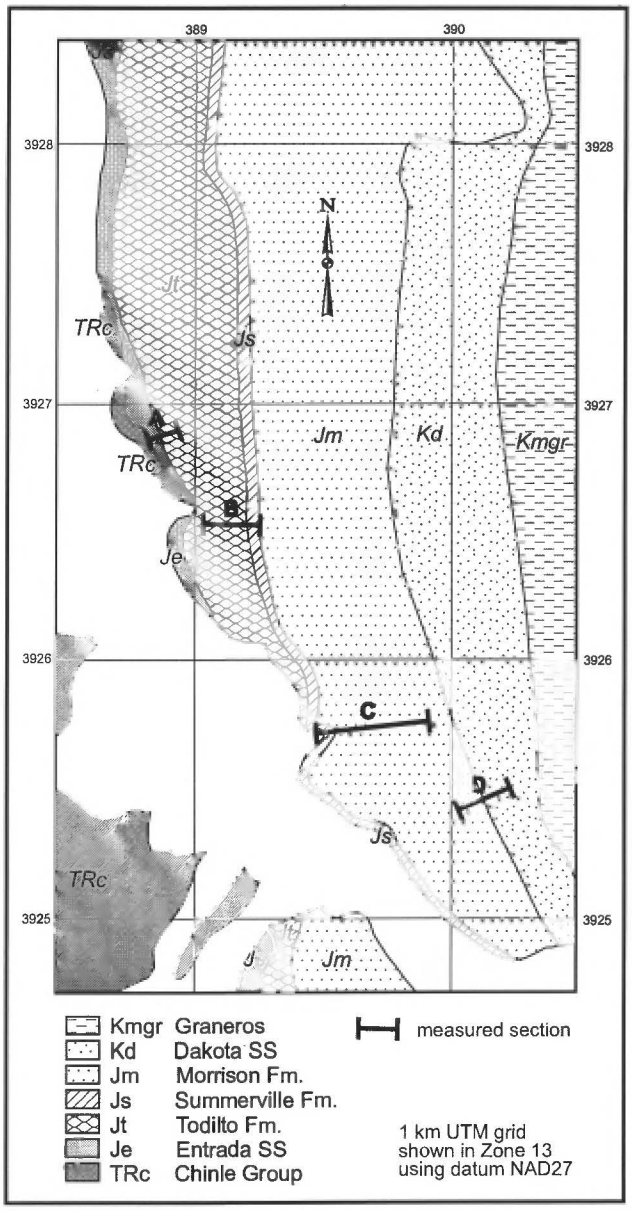


FIGURE 4. Geologic map of Jurassic strata exposed near Galisteo Dam (geology modified after Bachman, 1975), showing location of measured section (in four segments, A–D) in Figure 5.

sapropelic limestone, and is as much as 3.1 m thick. The overlying Tonque Arroyo Member consists of two units: (1) a lower bed of massive, white gypsum with chicken-wire texture about 33 m thick overlain by (2) a 13.5-m-thick cliff of thinly and repetitively bedded laminae of gypsum and nodular limestone (Fig. 6B) capped by a 0.3-m-thick interval of limestone with numerous moderate reddish brown agate nodules.

The Summerville Formation rests disconformably(?) on this "agate bed." It is 8.4 m of brownish-gray shale with limestone nodules overlain by 8.3 m of ripple-laminated brown sandstone that is a very fine-grained litharenite with numerous ripple laminations (Fig. 6C) and a few small-scale trough crossbeds.

A dramatic change in grain size (from very fine grained to pebbly rip ups), bedform (from ripple laminations to trough crossbeds), mineralogy (from litharenite to subarkose/arkose) and color (from moderate brown to very pale orange) marks the base of the Salt Wash Member of the Morrison Formation (Figs. 5, 6C–D). At Galisteo Dam, the Salt Wash Member is 113 m thick and mostly consists of laterally extensive sheets of yellow, gray, and brown arkosic sandstone and conglomerate. Green bentonitic mudstone lenses and beds appear in the upper half of the member and support the idea that the Salt Wash Member grades upward into the Brushy Basin Member.

The first laterally extensive, thick (9–10 m) bed of variegated green and brown bentonitic mudstone is chosen by us as the base of the Brushy Basin Member, which is nearly 82 m thick. This type of mudstone is the dominant lithology of the Brushy Basin Member, which forms a gentle slope between the cliff- or cuesta-forming Salt Wash and Jackpile members. Brushy Basin sandstones form thin ledges in that slope and are mostly dark brown, massive, lithic subarkoses.

The Jackpile Member is 77 m thick at Galisteo Dam. It is mostly yellowish gray and very pale orange, trough-crossbedded, kaolinitic, subarkosic sandstone with some interbeds of green sandy mudstone. The base of the Dakota Sandstone (Oak Canyon Member; no Encinal Canyon Member is present at Galisteo Dam: Lucas et al., 1998) is a prominent disconformity at which clayey, carbonaceous litharenite of the Dakota rests directly on kaolinitic subarkose of the Jackpile (Figs. 5, 6F).

ROMEROVILLE

The Jurassic section exposed at Romeroville Gap in San Miguel County (T15N, R16E) was most recently described by Lucas et al. (1995b). However, based on recent work we reinterpret part of this section by assigning some of the strata Lucas et al. (1995b) termed Salt Wash to the Summerville Formation (Fig. 7). Here, the Jurassic section is approximately 185 m thick and assigned to the Entrada, Todilto, Summerville, and Morrison formations.

At Romeroville Gap, the base of the Entrada Sandstone is not exposed (only about 2–3 m of Entrada are exposed), but nearby sections suggest an Entrada section about 20 m thick that rests with sharp disconformity on the Redonda Formation of the Chinle Group (Lucas et al., 1985). Entrada strata are yellowish gray, trough-crossbedded quartzarenites of the Slick Rock Member; no Dewey Bridge strata are present at Romeroville, or elsewhere on the southern High Plains (Lucas and Anderson, 1998).

The Todilto Formation at Romeroville consists only of the Luciano Mesa Member, about 5 m of laminar and "crinkly," gray, kerogenic limestone. The lower 15 m of Summerville Formation above the Todilto consist mostly of variegated green and red shale and siltstone beds with nodular chalcedony and two thin, kaolinitic, volcanic ash beds.

The upper Summerville at Romeroville is an interval 50 m thick of pale red (5R6/2) to grayish red (10R4/2), fine-grained sandstone with two prominent beds of maroon siltstone and very fine-grained sandstone, 35 m and 46 m above its base, respectively (Fig. 7). The sandstones are massive to ripple laminated with some trough crossbeds. This sandstone interval may be homotaxial with the Bluff Sandstone (uppermost San Rafael Group) of west-central New Mexico.

Previous workers (see Lucas et al., 1995b and references cited therein) assigned these sandstones to the Morrison Formation. However, we place the base of the Morrison Formation at a change to coarser, pebbly, trough-crossbedded sandstone that characterizes a 5-m-thick interval assigned here to the Salt Wash Member (Fig. 7). Clay clasts, a color change to yellowish brown and bioturbation characterize the Salt Wash sandstone at Romeroville. We thus believe the magnetostratigraphic correlation of the thick Summerville sandstone section at Romeroville with Salt Wash strata on the Colorado Plateau presented by Steiner et al. (1994) needs to be re-evaluated.

Bentonitic mudstones that are variegated brown, green and gray dominate the overlying Brushy Basin Member, which is 80 m thick. The Lower Cretaceous (Upper Albian) Mesa Rica Sandstone of the Dakota Group rests disconformably on the Brushy Basin Member at Romeroville.

CORRELATION

Correlation of Jurassic strata across the northern Rio Grande rift (Fig. 3) is a straightforward one based on lithostratigraphy. Other than the

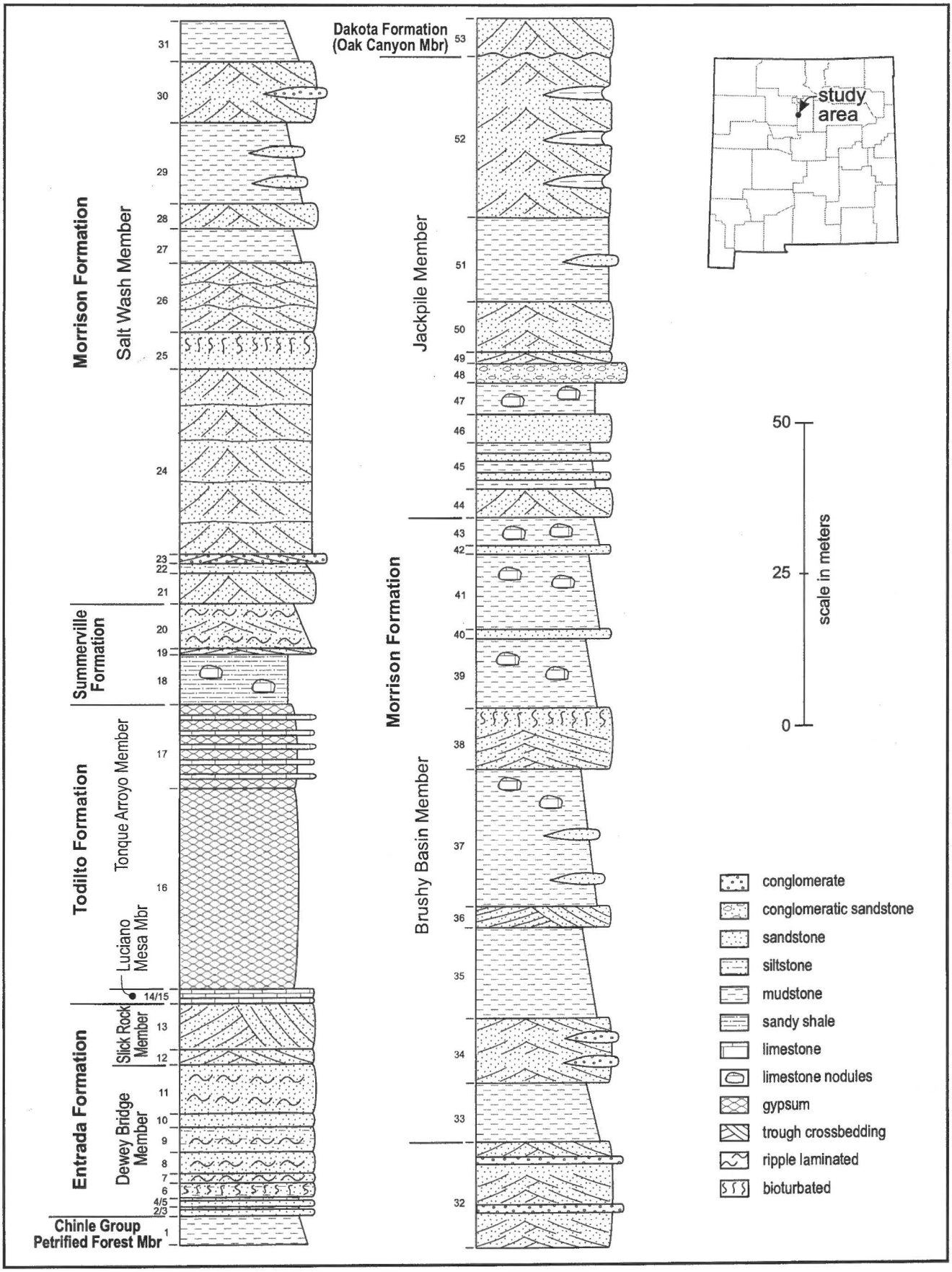


FIGURE 5. The Jurassic section at Galisteo Dam. See Appendix for description of numbered lithologic units.

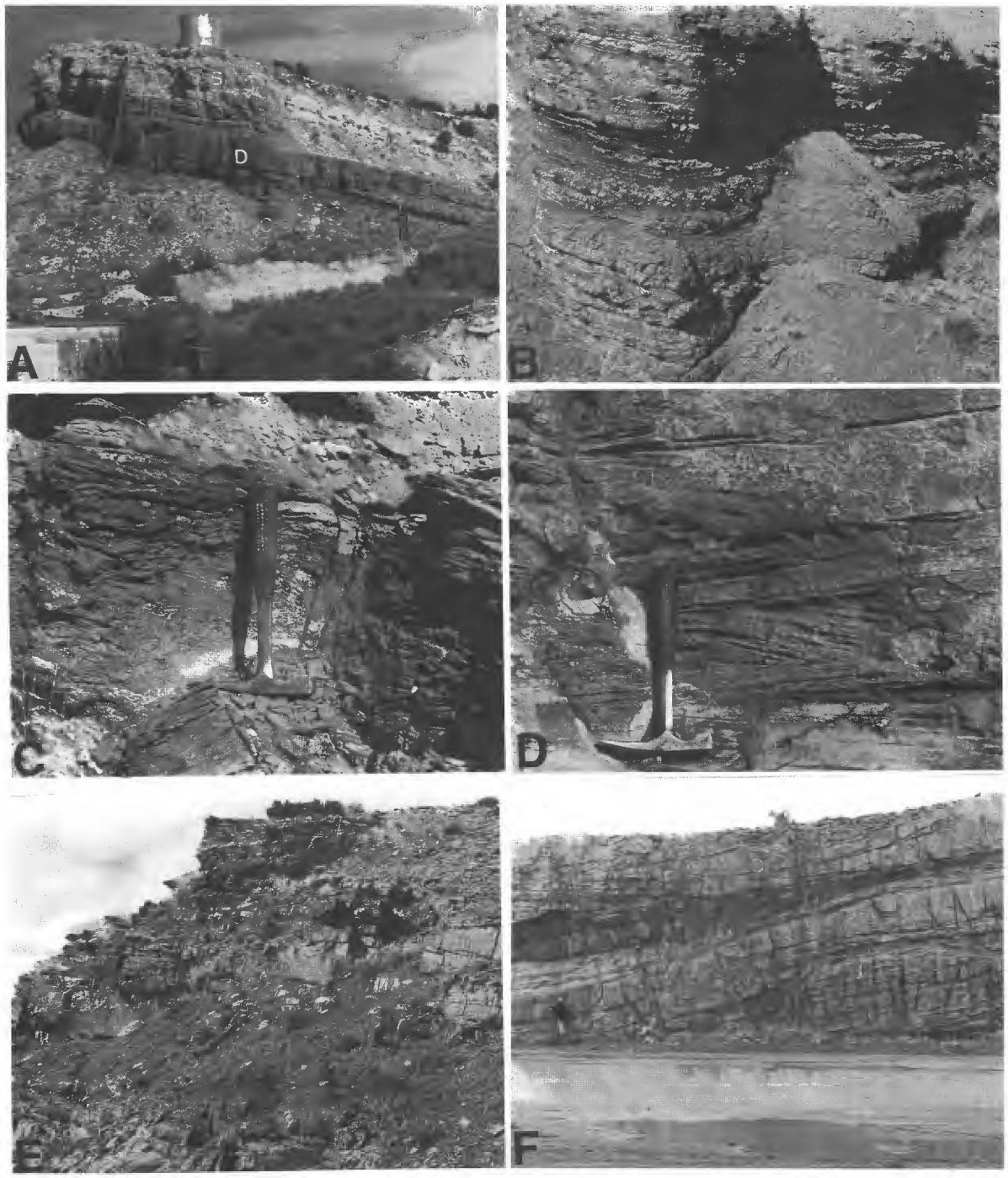


FIGURE 6. Photographs of selected Jurassic strata at Galisteo Dam. **A**, Slope of mudstones of Petrified Forest Formation of Chinle Group (C) overlain by cliff composed of Dewey Bridge (D) and Slick Rock (S) members of Entrada Sandstone. **B**, Thinly bedded gypsum and carbonate in upper part of Tonque Arroyo Member of Todilto Formation. C, Ripple-laminated, fine-grained sandstone of Summerville Formation. **D**, Crossbedded and pebbly sandstone of Salt Wash Member of Morrison Formation. **E**, Typical ledgy sandstones of Salt Wash Member of Morrison Formation split by thin mudstone slopes. **F**, Contact of Oak Canyon Member of Dakota Sandstone (O) on Jackpile Member of Morrison Formation (J) at the Galisteo Dam spillway.

eastern pinchout of the Dewey Bridge Member of the Entrada Sandstone, the Tonque Arroyo Member of the Todilto Formation and the Jackpile Member of the Morrison Formation—these units are not present at Romeroville—all Jurassic formations and members are present at all the sections studied (Fig. 8). Thickness variation of the units in part reflects unconformities or facies changes and is discussed below. Little paleontological control of the correlation is available, there are no radioisotopic ages from the sections, and magnetostratigraphy is only available for the Romeroville section (Steiner et al., 1994). Nevertheless, these few data support the correlation presented here and provide the basis for the age determinations indicated (Fig. 8).

IMPLICATIONS

The correlation presented here of Jurassic strata across the northern Rio Grande rift impacts our understanding of the nature and extent of regional Jurassic unconformities, and of deposition in the Jurassic paleobasin.

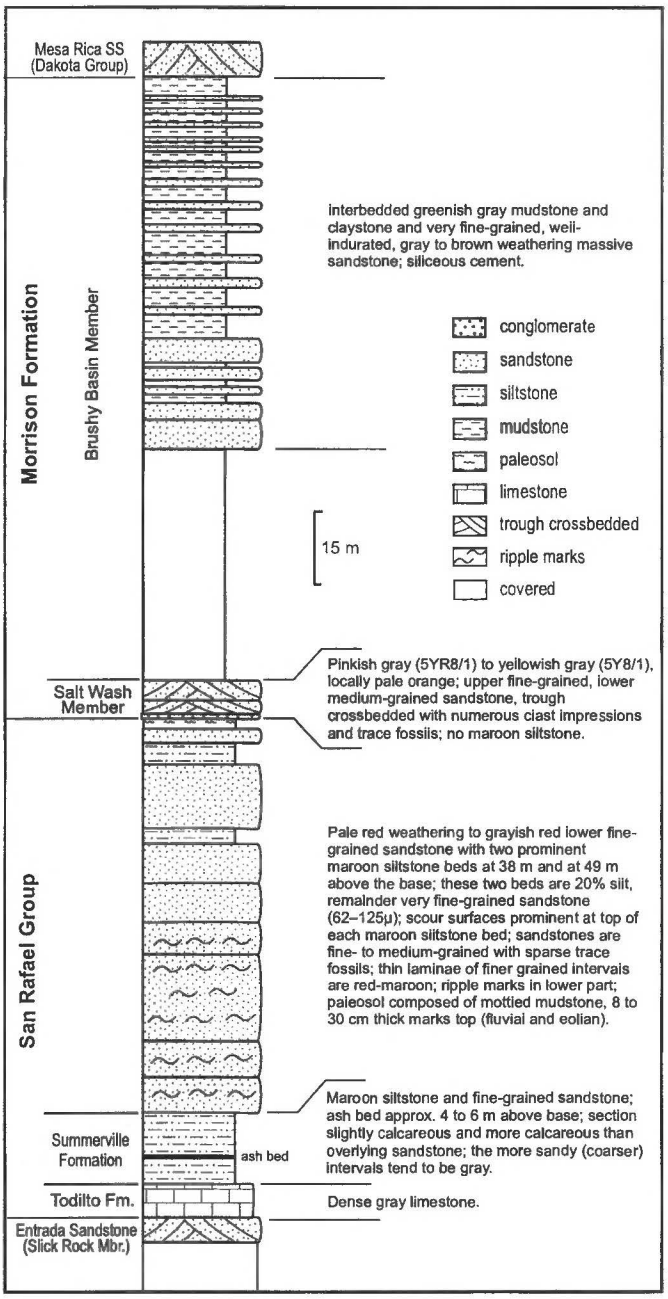


FIGURE 7. The Jurassic section exposed at Romeroville Gap.

Jurassic unconformities

Pipiringos and O'Sullivan (1978) proposed a scheme of regional unconformities for Jurassic strata in the Western Interior. In New Mexico, the base of the Jurassic section is their J-2 unconformity, a profound hiatus between the Middle Jurassic Entrada Sandstone and underlying Upper Triassic strata of the Chinle Group (Lucas and Anderson, 1998). Pipiringos and O'Sullivan (1978) depicted this as a regional (from Arizona to New Mexico), eastward stepping-down of the Entrada onto older units as the Lower Jurassic Glen Canyon Group pinches out from west to east.

However, the correlation presented here (Fig. 3) demonstrates that the J-2 unconformity is actually more complicated with respect to the Chinle Group. Thus, in west-central and in east-central New Mexico, the Entrada overlies the youngest Chinle Group strata—the Rock Point and Redonda formations, respectively. However, in north-central New Mexico, the Entrada rests on older Chinle strata, the Petrified Forest Formation. Given the relative continuity and constancy of Entrada lithofacies and thicknesses from west-central through north-central New Mexico, it seems most likely that there is an area of uppermost Chinle nondeposition or pre-Entrada erosion in north-central New Mexico. This explains why Entrada strata here rest on older Chinle strata than they do to the west and the east.

The J-3 unconformity of Pipiringos and O'Sullivan (1978) is the basal transgressive unconformity that separates the Entrada Sandstone eolian deposits from the overlying marine Curtis Formation in Utah. Lucas and Anderson (1998) correlate the Curtis with the Todilto, and suggested that the Todilto base—characterized by local stratigraphic relief, rip-up clasts and floating pebbles as well as sharp lithologic contrast (kerogenic limestone on eolianite sandstone)—is the J-3 unconformity. Data from north-central New Mexico presented here do not contradict this suggestion. However, the temporal magnitude of the J-3 unconformity remains poorly constrained. We suspect it is a relatively short interval within Callovian time.

It seems likely that there is an unconformity between the Summerville Formation and underlying Todilto Formation across northern New Mexico. Evidence of this unconformity consists of: (1) sharp lithologic contrast, implying a major lithofacies change, between Summerville clastics and underlying Todilto gypsum or limestone; (2) the absence of the Todilto upper member (Tonque Arroyo Member) outside of the limits of the Todilto evaporitic basin and the absence of the lower member (Luciano Mesa Member) outside of the Todilto depositional basin, so that the Summerville rests on units of different ages across its basin of deposition; and (3) the age difference between the Todilto (middle Callovian) and Summerville (Oxfordian). Nevertheless, we are not certain if this probable Todilto-Summerville regional unconformity is the J-4 unconformity of Pipiringos and O'Sullivan (1978), which is the erosion surface allegedly underlying the Redwater Shale Member of the Sundance Formation in South Dakota, Wyoming, northeast Utah, and northwest Colorado. According to Pipiringos and O'Sullivan (1978), the J-4 surface truncates the Summerville Formation, but we are not convinced of this, particularly given the near age equivalence of the Summerville and Redwater Shale. There is evidence of a Todilto–Summerville unconformity in northern New Mexico, but the full extent, nature and duration of this break need further study.

The base of the Salt Wash Member of the Morrison Formation is the J-5 unconformity (Anderson and Lucas, 1995; Lucas and Anderson, 1998). The great thickness changes in the Salt Wash Member evident across northern New Mexico (Figs. 2, 7) may reflect paleotopography that developed during the hiatus preceding Morrison deposition. The general eastward thinning is consistent with distal thinning in the Morrison depositional system.

Jurassic strata in northern New Mexico are overlain by Cretaceous strata at what Pipiringos and O'Sullivan termed the K unconformity. These are strata of the Dakota Group of late Albian or earliest Cenomanian age.

Jurassic deposition

Reconstructions of Jurassic depositional systems in the southern Western Interior have largely been confined to the Colorado Plateau (e.g., Condon and Peterson, 1986). These studies ignore the Jurassic strata on the southern High Plains, and therefore do not consider the southern or the eastern edge of the Jurassic paleobasin, which is off of the Colorado Plateau. However, the correlation presented here documents the continuity of most of the Jurassic depositional systems from the Colorado Plateau eastward onto the southern High Plains. Some important inferences include:

1. The Dewey Bridge Member of the Entrada continues eastward into the Rio Grande rift but is absent on the southern High Plains. The Dewey Bridge is generally interpreted as water reworked eolianites or water deposited sandstones that reflect the transgression of the Carmel seaway in Utah (Wright et al., 1962). This means north-central New Mexico is the southeasternmost record of water-laid deposits related to the Carmel transgression.

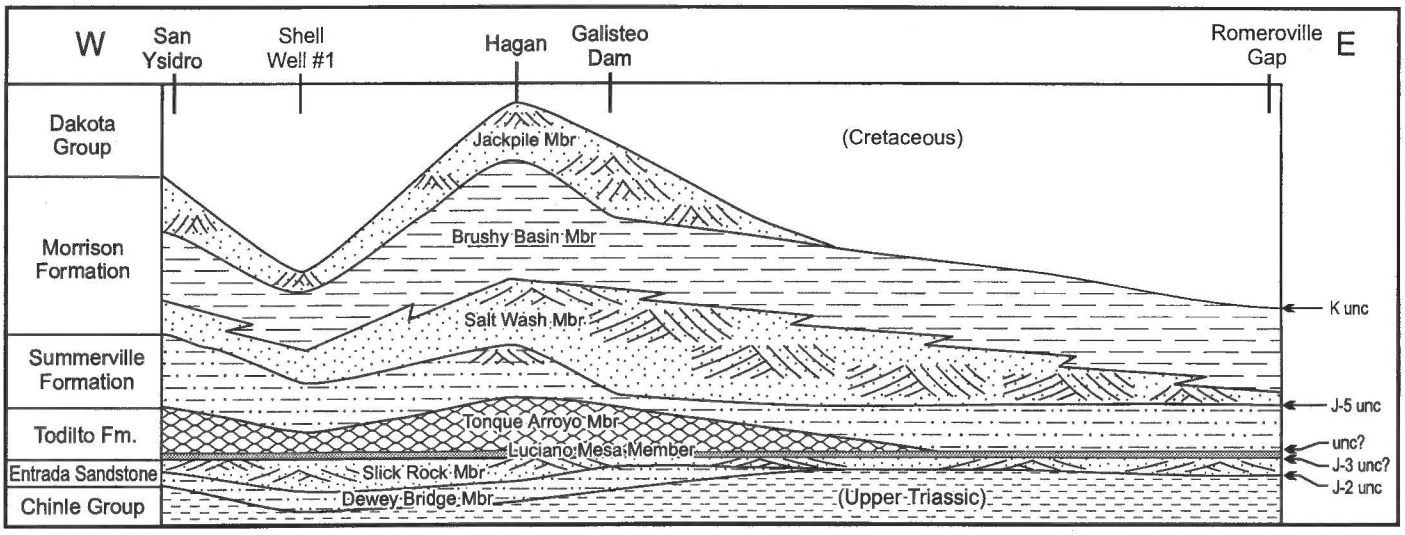


FIGURE 8. Restored cross section of Jurassic strata across northern New Mexico.

2. The Todilto salina basin continued across the rift, but its evaporitic phase, which produced anhydrite, left no extensive deposits on the southern High Plains. This has long been known (e.g., Anderson and Kirkland, 1960), largely because the Todilto Formation is one of the few Jurassic formations whose entire depositional system has been reconstructed (also see Kirkland et al., 1995; Lucas and Anderson, 1996).

3. Summerville deposition continued from the Colorado Plateau onto the High Plains. Anderson and Lucas (1992) first advocated continuity of the Summerville Formation across northern New Mexico based on the presence of Summerville strata at all northern New Mexico outcrops (also see Lucas and Anderson, 1998). Previously, a parochial stratigraphy assigned Summerville strata in northern New Mexico to the Summerville, Bell Ranch, and Ralston Creek formations and to the "Recapture Member" of the Morrison Formation (see Lucas and Anderson, 1997, for references), thereby confusing a relatively straightforward correlation of similar lithotypes in the same stratigraphic position.

4. Morrison facies continued eastward with little change. The Jackpile Member was deposited by an eastward flowing braided stream complex (e.g., Flesch, 1974). It is not present on the southern High Plains, but whether that absence is due to eastward distal pinchout or to its removal at the K unconformity eastward is not clear from available data.

5. The continuous but eastward thinning Salt Wash Member in northern New Mexico well fits the depositional model proposed by Anderson and Lucas (1997). Thus, Salt Wash rivers flowed generally from west to east across the Morrison depositional basin. Clastic input to and subsidence of the basin was highly asymmetrical, with the greatest accumulations of Salt Wash Member in the western part of the basin.

6. Continuity of the Brushy Basin Member off of the Colorado Plateau onto the High Plains has particular significance for interpretation of depositional systems. Turner and Fishman (1991) argued that Brushy Basin Member deposition took place in a large lake centered in the Four Corners area with a maximum northwest–southeast dimension of 500 km. However, Brushy Basin Member outcrops off the Colorado Plateau were not included in this lake system, which was termed "Lake T'oo'dichi'" by Turner and Fishman (1991). Clearly, the lake was either much larger than Turner and Fishman (1991) envisioned, or another model of Brushy Basin Member deposition needs to be proposed.

ACKNOWLEDGMENTS

Doug Bailey, of the Albuquerque District Army Corps of Engineers, facilitated access to the outcrops at Galisteo Dam. Bruce Black and Charles Maxwell provided helpful reviews of the manuscript.

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APPENDIX—MEASURED SECTION

Measured section of Jurassic strata at Galisteo Dam

Strata dip from 10–23° to N40–60°E. Section measured 26 October 1998 in four segments in UTM Zone 13, using datum NAD27. Segment A starts at UTM 388842E, 3926866N and ends at 388857E, 3927063N; segment B starts at UTM 389032E, 3926530N and ends at 389254E, 3926526N; segment C starts at UTM 389473E, 3925719N and ends at 389911E, 3925764N; segment D starts at UTM 390027E, 3925423N and ends at 390229E, 3925508E.

Unit	Lithology	Thickness (m)
Dakota Formation:		
Oak Canyon Member:		
53	Clayey sandstone; carbonaceous with chips and pellets of mudstone. Sandstone is very fine- to medium-grained, poorly sorted, subangular, litharenite; brownish black (5YR2/1).	not measured
K unconformity		
Morrison Formation:		
Jackpile Member:		
52	Sandstone and sandy mudstone. Sandstone is fine- to medium-grained, subrounded, kaolinitic subarkose; yellowish gray (5Y8/1) and dark yellowish orange (10YR6/6); not calcareous. Mudstone is yellowish gray (5Y7/2); not calcareous.	27.0
51	Sandstone and sandy mudstone. Sandstone is fine-grained, well-sorted, kaolinitic subarkose; very pale orange (10YR8/2) with grayish orange (10YR7/4) mottles; not calcareous. Sandy mudstone is grayish yellow green (5GY7/2) and greenish gray (5G6/1); not calcareous.	13.9
50	Sandstone; very fine- to medium-grained, subrounded, moderately sorted, kaolinitic arkose; very pale orange (10YR8/2); calcareous; trough crossbedded.	8.0
49	Sandstone with mudstone lenses. Sandstone is very fine- to fine-grained, subrounded, moderately sorted, kaolinitic litharenite; grayish orange (10YR7/4); slightly calareous; laminar to trough crossbedded. Mudstone is moderate pink (5R7/4) to moderate red (5R5/4); very calcareous.	1.8
48	Conglomeratic sandstone and conglomerate. Sandstone is fine-grained, subrounded, well-sorted, ferruginous subarkose; light brown (5YR5/6); not calcareous. Conglomerate is matrix supported; matrix is dark yellowish orange (10YR6/6); clasts are mudstone and lithic pebbles up to 20 mm in diameter; green, black, and gray; not calcareous.	3.6
47	Slightly sandy shale and silty shale with limestone nodules. Sandy shale is light olive gray (5Y5/2); not calcareous. Silty shale is moderate yellow (5Y7/6) to grayish yellow (5Y8/4); not calcareous. Limestone nodules are medium light gray (N6) when fresh, weather to light brown (5YR6/4); calcareous.	5.0
46	Sandstone and conglomerate. Sandstone is very fine-grained, subrounded, well-sorted, kaolinitic arkose; very pale orange (10YR8/2) with spots of grayish orange (10YR7/4) and light greenish gray (5GY8/1); not calcareous. Conglomerate is matrix supported; matrix is very pale orange (10YR8/2) to pale yellowish brown (10YR6/2), not calcareous; clasts are siliceous, mostly chert and quartzite with some lithics, up to 15 mm in diameter and gray, black and brown.	4.5
45	Sandstone and mudstone. Sandstone is pebbly and bioturbated, same lithology and color as unit 44. Mudstone is same lithology and color as unit 39. Forms a slope.	7.5
Top of segment C; offset to bottom of segment D; dip changes to 14° to N50°E.		
44	Sandstone; fine- and coarse-grained. Fine parts are very fine-grained, subrounded, kaolinitic subarkose; yellowish gray (5Y8/1); slightly calcareous. Coarse parts are medium- to very coarse-grained, kaolinitic subarkose; very pale orange (10YR8/2) to pale yellowish brown (10YR6/2); calcareous.	5.6
Morrison Formation:		
Brushy Basin Member:		
43	Mudstone; same lithology and color as unit 39.	4.8
42	Sandstone; same lithology and color as unit 40. Forms a bench.	1.1
41	Mudstone; same lithology and color as unit 39.	12.2
40	Sandstone; very fine-grained, subrounded, well-sorted, ferruginous litharenite; grayish orange pink (5YR7/2); slightly calcareous. Forms a massive bench along more than 50 m of strike.	1.1
39	Mudstone with limestone concretions. Mudstone is sandy, bentonitic; light olive gray (5Y6/1); slightly calcareous. Limestone concretions are moderate brown (5YR4/4); calcareous. Forms a slope.	12.0
38	Sandstone; medium- to coarse-grained, subrounded, moderately sorted, ferruginous, lithic subarkose; dark yellowish orange (10YR6/6) when fresh, weathers to moderate yellowish brown (10YR5/4); slightly calcareous; multi-storied trough crossbeds; very bioturbated near top.	10.0
37	Silty mudstone and sandy limestone. Mudstone is greenish gray (5GY6/1), pale brown (5YR5/2) and light brown (5YR6/4); not calcareous. Limestone is light gray (N7); calcareous. Forms a strike valley.	23.2
36	Sandstone; very fine-grained, moderately sorted, ferruginous litharenite; white (N9) with mottles of moderate brown (5YR4/4); some parts are pale brown (5YR5/2); calcareous; trough to planar crossbeds; forms a cuesta.	3.3
35	Mudstone; same lithology and color as unit 33; forms a slope; much cover.	14.7
34	Sandstone and conglomerate; same lithology and color as unit 32; forms a cuesta.	10.7
33	Mudstone; bentonitic, variegated greenish gray (5GY6/1) and pale brown (5YR5/2); not calcareous; forms slope; much cover.	9.5

Unit	Lithology	Thickness (m)
Morrison Formation:		
Salt Wash Member:		
32	Sandstone and conglomerate. Sandstone is fine- to medium-grained, subrounded, arkose with some kaolinite and some ferruginous lenses; very pale orange (10YR8/2) with mottles of light brown (5YR6/4); calcareous; multi-storied trough crossbeds. Conglomerate is clast supported; matrix is light brownish gray (5YR6/1); clasts are limestone up to 1.5 cm in diameter; conglomerate usually at base of sandstone troughs.	17.4
31	Silty mudstone; same lithology and color as unit 29.	6.4
30	Sandstone with mudstone lenses. Sandstone is very fine- to fine-grained, subangular, moderately sorted, arkose; pinkish gray (5YR8/1) with speckles of light brown (5YR5/6); pebbly lenses; trough crossbeds; forms a cliff. Mudstone is light olive gray (5Y6/1); calcareous.	9.5
Dip changes to 15°.		
29	Silty mudstone with sandstone lenses. Mudstone is bentonitic; grayish red (10R4/2) with some green and purple mottles; calcareous; forms a slope. Sandstone lenses are 0.2–0.3-m-thick; very fine-grained, muddy, micaceous litharenite; pale yellowish brown (10YR6/2); calcareous; trough crossbeds; forms small benches.	13.5
28	Sandstone; very fine- to fine-grained, subrounded, well-sorted, arkose; very pale orange (10YR8/2) and grayish orange (10YR7/4); not calcareous; planar crossbeds and some ripple laminations; forms a bench.	3.9
27	Silty mudstone; same lithology and colors as unit 29.	5.8
26	Sandstone with pebbly lenses. Sandstone is fine-grained, subangular, well-sorted, arkose; very pale orange (10YR8/2) and grayish orange (10YR7/4) when fresh, weathers moderate brown (5YR4/4); calcareous; multi-storied trough crossbeds; forms a bench. Pebbly lenses of same lithology and color as unit 23.	11.5
25	Sandstone; same lithology as unit 26; pale yellowish brown (10YR6/2); poorly indurated; calcareous; laminar; bioturbated; forms a slope.	5.7
24	Sandstone with pebbly and silty lenses. Sandstone is very fine-grained, subangular, well-sorted, lithic subarkose; pinkish gray (5YR8/1); not calcareous; multi-storied trough crossbeds; forms a large cuesta. Pebbly lenses same lithology and color as unit 23. Silty lenses same lithology and color as unit 22.	30.7
23	Sandstone and conglomerate; trough crossbedded. Sandstone is fine- to medium-grained, subrounded, moderately sorted, ferruginous arkose; very pale orange (10YR8/2) and moderate yellowish brown (10YR5/4); calcareous. Conglomerate is clast supported; clasts are limestone up to 1 cm in diameter, light brownish gray (5YR6/1).	1.6
22	Muddy sandstone to sandy mudstone; very fine-grained, subangular, litharenite; grayish brown (5YR3/2); calcareous; laminar; forms a slope.	2.4
Top of segment B; offset to bottom of segment C; dip changes to 23° to N60°E.		
21	Sandstone; very fine-grained, subrounded, well-sorted, lithic subarkose; grayish orange pink (5YR7/2) and moderate brown (5YR4/4); calcareous; trough crossbeds; contains pebbly rip ups of unit 20; forms a ledge.	4.6
Summerville Formation:		
20	Silty sandstone; very fine-grained, subangular, litharenite; grayish brown (5YR3/2); slightly calcareous; ripple laminated, some trough crossbeds; forms a slope.	7.1
19	Silty sandstone; very fine-grained, subangular, litharenite; moderate brown (5YR3/4); calcareous; trough crossbeds and ripple laminations; forms a ledge.	1.2
18	Shale with some limestone nodules. Shale is slightly sandy; brownish gray (5YR4/1) with green mottles; very calcareous; forms slope.	8.4
Todilto Formation:		
Tonque Arroyo Member:		
17	Gypsum, limestone and nodular agate; all thinly parallel bedded; forms a cliff. Gypsum is grayish pink (5R8/2). Limestone is gypsiferous micrite; pale yellowish brown (10YR6/2). Agate is 0.3-m-thick bed at top of unit; moderate reddish brown (10R4/6).	13.5
16	Gypsum; chicken wire texture; white (N9) with calcareous lines of dark gray (N3).	33.0
Todilto Formation:		
Luciano Mesa Member:		
Top of segment A; offset to bottom of segment B.		
15	Limestone; sapropelic; very thinly laminated; dark gray (N3); calcareous.	1.8
14	Limestone; not as organic rich as unit 15; thinly laminated; dark yellowish brown (10YR4/2); calcareous.	1.3
Entrada Formation:		
Slick Rock Member:		
13	Sandstone; fine- to medium-grained, subrounded, moderately sorted, quartzarenite; pale yellowish orange (10YR8/6) and very pale orange (10YR8/2); not calcareous; trough crossbeds.	6.8
12	Sandstone; mostly fine-grained with some coarse grains near top; trough crossbeds with big foresets; sharp basal contact with nearly planar surface; forms cliff. Main sandstone is fine-grained, subrounded, well-sorted, lithic quartzarenite; very pale orange (10YR8/2); slightly calcareous. Top sandstone is coarse-grained, subrounded, well-sorted, lithic quartzarenite; grayish orange (10YR7/4) to very pale orange (10YR8/2); not calcareous.	3.4
Entrada Formation:		
Dewey Bridge Member:		
11	Silty sandstone; very fine-grained, subrounded, quartzose; very pale orange (10YR8/2) to pale yellowish brown (10YR6/2); not calcareous; ripple laminated; forms ledges.	8.1
10	Silty sandstone; very fine-grained, quartzose; grayish orange pink (5YR7/2) with mottles of yellowish gray (5YR8/1); not calcareous.	2.6
9	Silty sandstone; very fine-grained, quartzose; light brown (5YR5/6); calcareous; ripple laminated and flaggy as a slope; massive as a cliff.	4.2
8	Silty sandstone with gypsum nodules. Sandstone is very fine-grained, quartzose; light brown (5YR5/6); not calcareous. Gypsum nodules at top of unit are up to 2 cm in diameter in ~ 0.1-m-thick bed; pinkish gray (5YR8/1).	2.5
7	Silty sandstone; very fine-grained, quartzose; light brown (5YR5/6); slightly calcareous; massive to ripple laminated; weathers rounded.	2.1
6	Clayey sandstone; very fine- to fine-grained, subrounded, quartzose; light brown (5YR5/6) with pinkish gray (5YR8/1) mottles; calcareous; bioturbated.	2.7
5	Mudstone; moderate brown (5YR4/4); not calcareous.	0.1
4	Muddy sandstone; very fine-grained, litharenite; light brown (5YR5/6); very calcareous; bioturbated; weathers rounded.	1.0
3	Sandy mudstone to muddy sandstone; light brown (5YR5/6) with pinkish gray (5YR5/6) mottles.	0.1
2	Sandstone; very fine-grained, subrounded, well-sorted, litharenite; light brown (5YR5/6); slightly calcareous; massive with faint trough crossbeds; forms a ledge.	1.0
Chinle Group:		
Petrified Forest Formation:		
1	Mudstone; bentonitic, pale reddish brown (10R5/4); calcareous; blocky; forms a slope.	not measured