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Adrian P. Hunt and Spencer G. Lucas

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by *Adrian P. Hunt* and *Spencer G. Lucas*, University of New Mexico, Albuquerque, NM 87131

Introduction

The nonmarine Morrison Formation, of Late Jurassic age, has an enormous outcrop area that encompasses most of the Rocky Mountain region of the western United States (Peterson, 1972, fig. 8). In New Mexico, there are extensive outcrops of the Morrison in the northern half of the state (Fig. 1). The most southerly outcrops thus far identified are in T6N in west-central New Mexico and T8N in east-central New Mexico (Dobrovolny et al., 1946; Silver, 1948; Jicha, 1958). South of T6N the Morrison was presumed to have been removed by erosion (Silver, 1948; Tonking, 1957). Thus, T6N in central New Mexico has long been considered to document the southerly extent of the entire Morrison basin of deposition. Here, we document a thin wedge of the Morrison Formation preserved in the Carthage area in T5S, extending the southern margin of the Morrison basin about 55 miles. This is particularly important in light of recent work using the southern extent of early Mesozoic sedimentary units to test ideas about the tectonics of the "Mogollon Highlands" (Bilodeau, 1986a, b).

Carthage area

The Carthage area (Fig. 2) lies on the eastern margin of the Rio Grande rift about 7 miles east of San Antonio, New Mexico, and encompasses the southern end of a southerly plunging anticlinorium (Fagrelius, 1982). Local structural complications include folding, decollement, and two trends of normal faulting (Fagrelius, 1982; Smith, 1983). The stratigraphic sequence in this area consists of a thick Pennsylvanian and Permian section (San Andres Limestone, Bursum Formation) overlain by the Triassic Moenkopi(?) and Chinle Formations (Stewart et al., 1972a, b), which in turn are overlain by a thin remnant of Morrison Formation and a thick Upper Cretaceous sequence with the Dakota Sandstone at its base (Fagrelius, 1982; Hook, 1983). The area where we have mapped and measured stratigraphic sections of the Morrison Formation includes sections 3–5 and 8–10, T5S, R2E (Fig. 2).

Previous studies

Lee (1907, p. 53) first reported on the stratigraphic sequence in the Carthage area, which includes the Morrison, referring to all of the strata as the "Red beds of the Rio Grande region." Although these strata include Permian and Triassic red beds, Lee (1907) considered them older than Permian age. Lee later examined the Carthage area in some detail and reported 200 feet of red beds unconformably overlain by the Cretaceous (Lee and Girty, 1909). Gardner (1910) subsequently published a stratigraphic section that included 1,995 feet of these "Triassic(?)" red beds below the "Dakota ? sandstone." Case (1916) confirmed the Triassic age of these red beds by collecting phytosaur fragments from them.

Darton (1922, 1928) examined the stratigraphy of the Carthage area in great detail and recognized "Dockum(?) group" sediments "in the slopes north of Carthage . . . of Chinle aspect" (Darton, 1928, p. 73). Darton (1928) described the Chinle (Dockum) sequence in some detail and noted that above the red beds and below the "Dakota(?) sandstone" there are places "4 feet or more of light-buff clay" (Darton, 1928, p. 72).

Wilpolt and Wanek (1951) published the first detailed geologic map that included the Carthage area and identified the Dakota Sandstone overlying the Dockum Formation. This nomenclature was repeated in a map and three roadlogs that subsequently encompassed the Carthage area (Budding, 1963; Foster and Luce, 1963).

In 1982, Fagrelius mapped the Carthage area in much greater detail and like Darton, recognized a thin sequence (3.7 ft) between the red beds of the Chinle and the overlying massive sandstone of the Dakota. According to Fagrelius (1982, p. 33), this thin sequence consists of "varicolored mudstone. . . [that is] shaly, gypsiferous and contains small, thin and discontinuous lenses of chert, shale, and siltstone pebble conglomerate." Although this sequence is lithologically distinct from the "typical" lower massive sandstone of the Dakota, Fagrelius (1982) included the mudstones in the Dakota. Smith (1983, p. 105) subsequently suggested that these mudstones might be "weathered Chinle, or possibly the remnant of a younger Jurassic (?) unit" or "represent Morrison-like beds" (Smith et al., 1983, p. 25), but he decided to include these beds in the Dakota (Smith, 1983). Hook (1983), in describing the Upper Cretaceous stratigraphy of the Carthage area, did not recognize this mudstone unit between the Chinle and the Dakota.

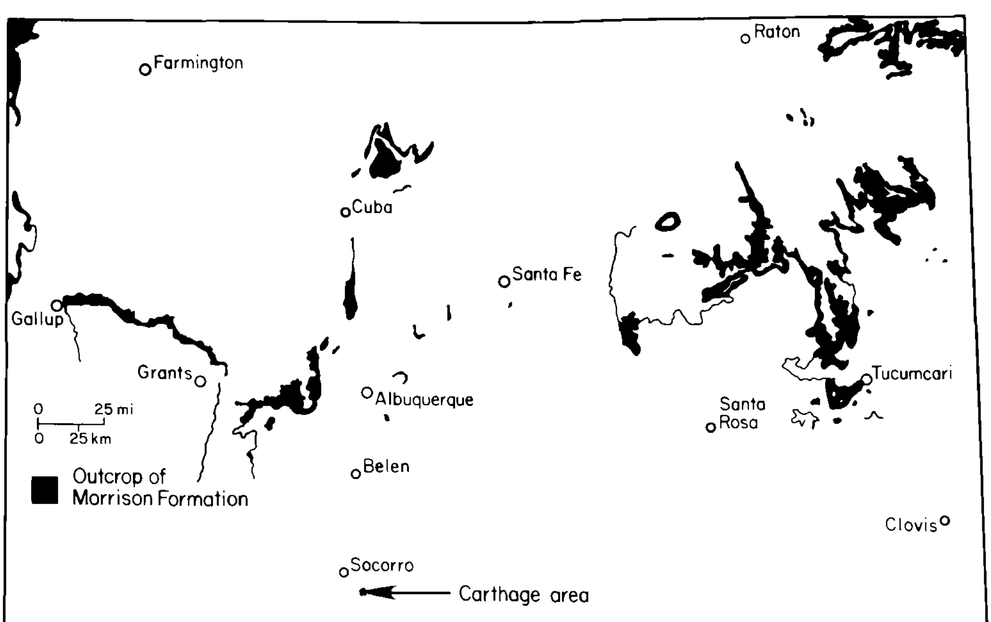

FIGURE 1—Outcrops of the Morrison Formation in New Mexico (after Dane and Bachman, 1965) and location of the Carthage area.

Stratigraphy

The Morrison Formation is thin and poorly exposed in the Carthage area and is mostly covered by debris from the Dakota Sandstone (Fig. 3). However, it is generally discernible as a very light colored interval between the grayish red (10R 4/2) of the Chinle Formation below and the lower massive sandstone of the Dakota above that is light olive gray (5Y 5/2). Darton (1928) first noted this interval and described it as about 1.2 m of light colored clay and Fagrelius (1982) measured it as 1.09 m of mudstone. However, examination of Fagrelius' section indicates that the covered interval he measured is, in reality, dominantly sandstone (Figs. 3c, d). Sandstone is also the dominant lithology in three sections that we have measured (Fig. 4; Table 1). The basal unit of the Morrison at Carthage is almost always a very light gray (N8) sandstone that lies disconformably on Chinle mudstone. The thickness of the Morrison varies from 1.09 to 3.3 m, variations probably due to an erosional topography un-

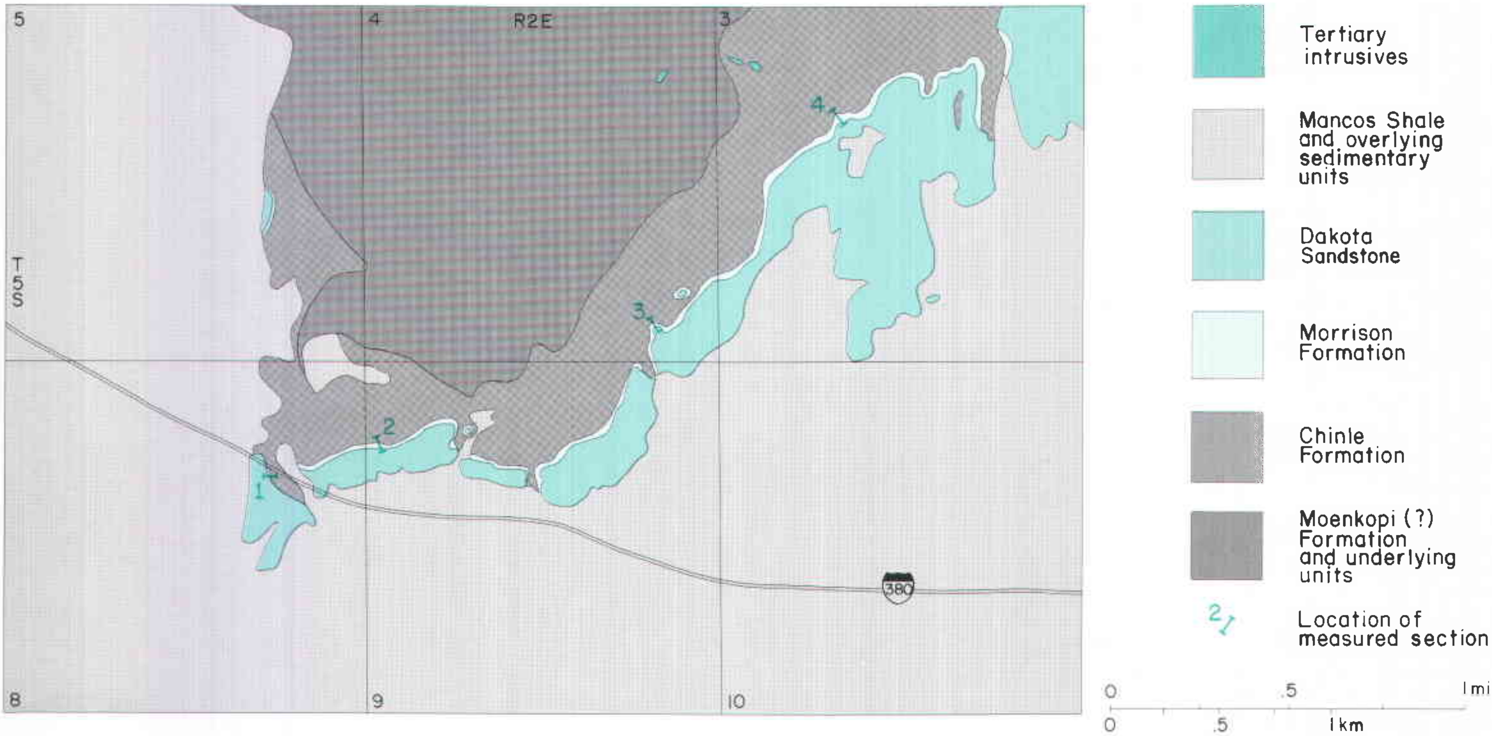

FIGURE 2—Simplified geologic map of part of the Carthage area (after Fagrelius, 1982) showing outcrops of the Morrison Formation and location of measured sections. Width of Morrison outcrop is exaggerated for clarity.

derlying the Dakota. The basal Dakota Sandstone is coarse grained and always has a scoured base. Local scouring of the Dakota into the Morrison can be seen in the roadcut of NM–380 at our stratigraphic section 1 (Figs. 2, 3a, 3b). The relief on the erosion surface is about 40 cm at this outcrop.

Lithology

The Morrison consists of a sequence of fine- to medium-grained sandstone and thin intervals of mudstone. The sandstones are very light in color ranging from white (N8) to pale greenish yellow (10Y 8/2) and contain abundant kaolinitic matrix. Composition ranges from sub-quartzose arenite to sublithic arenite with the most common lithology being subarkose. That sandstones have received a large input of volcanic ash is suggested by common euhedral micas.

Mudstones are variegated in color, ranging from light greenish gray (5GY 8/1) to grayish red-purple (5RP 4/2). All mudstones are rich in kaolinite and one bed contains euhedral micas and zircons and may represent a weathered air-fall ash.

Why is this unit the Morrison Formation?

Three lines of evidence suggest that the rocks described here should be assigned to the Morrison Formation: stratigraphic, geographic, and lithologic.

The Morrison strata in the Carthage area are immediately below the Dakota unconformity (K1 unconformity of Pipiringos and O'Sullivan, 1978) and above the Upper Triassic red bed sequence of the Chinle Formation. The only rocks found within this interval in New Mexico are the Late Triassic(?) Wingate Sandstone and Middle Jurassic Entrada Sandstone of eolian origin, the upper San Rafael Group (Wanakah Formation) sediments of broadly lacustrine origin (Condon and Peterson, 1986), the Morrison Formation, and the Lower Cretaceous nonmarine sequences of the Chama Basin, northeastern and southwestern New Mexico (Aubrey, 1986; Kues et al., 1985; Mack et al., 1986).

Geographically, the choice of these units can be narrowed by considering the formations that occur in central New Mexico in the southeastern San Juan Basin, the Tijeras Basin, and the Hagan Basin. In these areas, only the Entrada, Wanakah, and Morrison Formations occur in the appropriate stratigraphic position (Kelley and Northrop, 1975; Condon and Peterson, 1986).

Lithologically, the Wanakah and Entrada Formations can be dismissed from consideration. The Wanakah (Condon and Peterson, 1986) is characterized by limestone, gypsum, and red gypsiferous mudstones, all of which are absent from the Carthage section. Fagrelius (1982, p. 33) reported gypsum in Morrison mudstones, but we are unable to verify his observations. The Entrada is a quartzose sandstone with minor siltstone of dominantly eolian origin. In contrast, the Carthage sequence is characterized by very poorly sorted sandstones with a high clay matrix content.

Petrographically, the Morrison sandstones at Carthage contain fewer lithic fragments than beds in the upper Chinle Formation and more feldspar than is found in the overlying Dakota Sandstone. Morrison sandstones are fine to medium grained in contrast to the coarse grain size of the lower Dakota and the fine grain size of the upper Chinle. Kaolinitic clay matrix is common in the Morrison sandstones in contrast with the underlying and overlying units. This lithologic evidence seems to preclude the Morrison beds at Carthage from being "weathered Chinle" (Smith, 1983). Morrison mudstones tend to be moderately sorted with common silt and fine-sand-sized clastic material. The Morrison sandstones from Carthage are very similar to those from the Morrison Formation in Sandoval County studied by Flesch and Wilson (1974) because they are dominantly medium grained, have high clay matrix content, and they are generally subarkosic in composition. In conclusion, both negative and positive evidence suggests that these rocks should indeed be assigned to the Morrison Formation.

The Morrison basin edge in central New Mexico

The thinning and disappearance of the Morrison Formation in western New Mexico was studied in detail by Silver (1948), who documented both a depositional and erosional thinning of the Morrison southward. The southernmost Morrison in the area Silver studied (sec. 25, T6N, R7W) consists of a thin-bedded platy sandstone equivalent to the lower Recapture Shale of the Morrison and the Wanakah Formations (buff shale member of Silver, 1948) and an overlying white sandstone representing a remnant of the medial Westwater Canyon Member of the Morrison Formation (white sandstone member of Silver, 1948). Both of these units are much thinner than their lateral equivalents in the San Juan Basin (Silver, 1948, fig. 2). Before disappearing, the Morrison overlaps the underlying Entrada Sandstone (sec. 19, T6N, R6W) so that it rests directly on the ☞

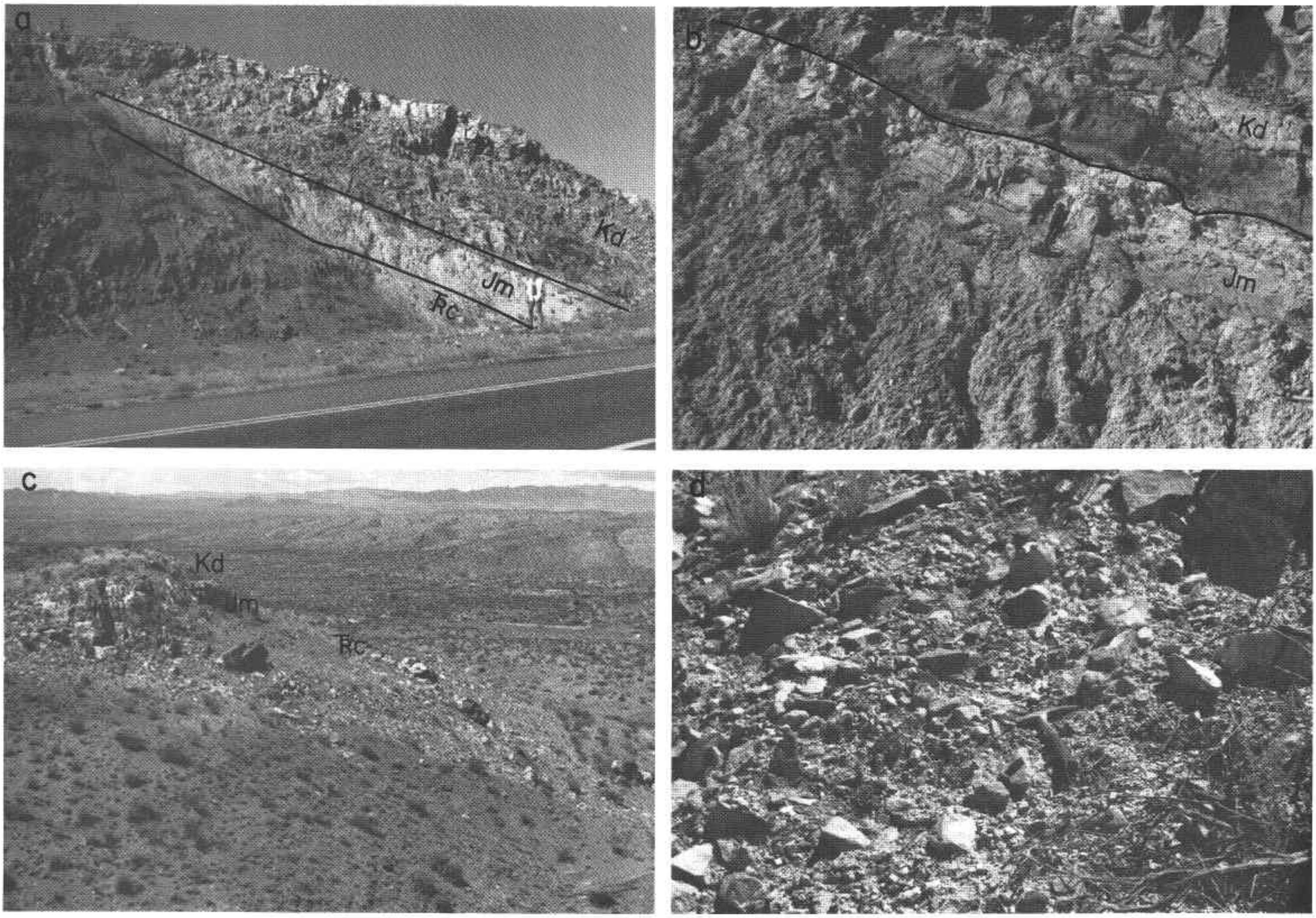

FIGURE 3—Outcrops of the Morrison Formation in the Carthage area. **a**, overview of sec. 1 (see Fig. 4 and Table 1); note that the Morrison thins to the southeast due to faulting; woman for scale. **b**, Close-up of sec. 1 showing units 5, 6, and 7. **c**, Overview of sec. 4 (see Fig. 4 and Table 1); hammer for scale. **d**, Close-up of sec. 4; hammer for scale. **Jm** = Morrison Formation, **Kd** = Dakota Formation, **TRC** = Chinle Formation.

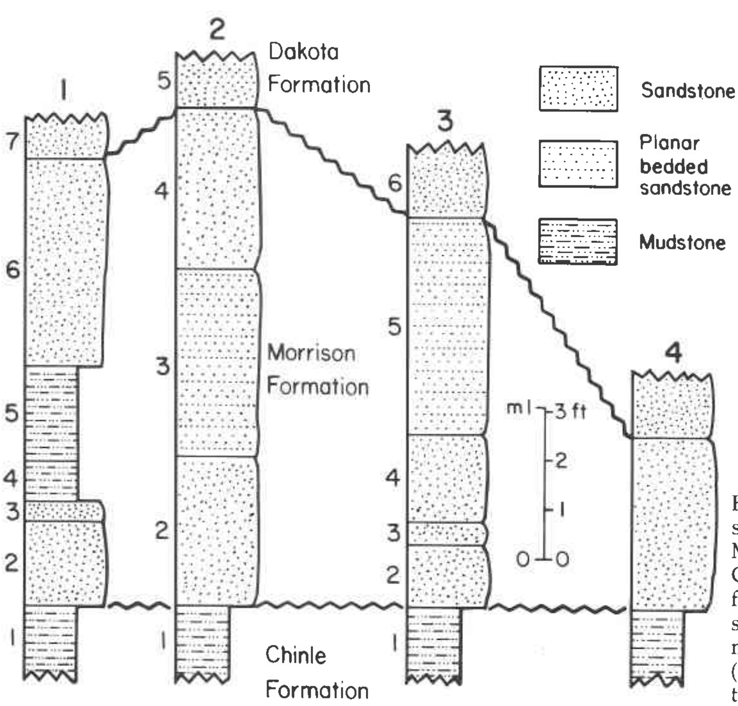

FIGURE 4—Measured stratigraphic sections of the Morrison Formation in the Carthage area. See Table 1 for lithologic description of secs. 1, 2, and 3. Sec. 4 is modified from Fagrelius (1982). See Fig. 2 for location of measured sections.

Chinle Formation (Silver, 1948), the same situation found at Carthage. However, in T6N Maxwell (1979) mapped a "Bluff" sandstone overlying the Entrada Sandstone south of the disappearance of the Morrison Formation.

Farther east, the Morrison (and Wanakah(?) equivalent) occurs as far south as sec. 20, T6N, R6W where it is also represented by a white sandstone underlain in this area by interbedded sandstone and siltstone. These units thin to the south (Jicha, 1958). In this area it is not apparent, because of erosion, whether the Morrison overlaps the Entrada or not. In both areas it is evident that the Morrison becomes more lithologically homogeneous and sandy as it thins (Silver, 1948; Jicha, 1958). This is consistent with the thin sandy Morrison found at Carthage. Directly north of Carthage the Morrison is next well exposed in the Tijeras Basin. In geophysical logs (e.g., Southern Production Company Tijeras Canyon Unit No. 3, sec. 12, T10N, R5E) the Recapture, Westwater Canyon, Brushy Basin, and Jackpile Members can be recognized. There is no indication of any Morrison Formation between the southern Sandia Mountains and Carthage or farther south than Carthage. This suggests that locally in the

Carthage area, the Morrison was preserved from erosion either by being deposited in a topographic low or by a local downwarp before deposition of the Dakota (cf. preservation of the Jackpile Sandstone; Aubrey, 1986).

Although the bentonitic nature of the mudstones at Carthage might suggest a correlation with the upper part of the Morrison Formation (Hunt, 1986), it is likely from regional relationships that it represents a compressed basin margin sequence of the lower Morrison (cf. Silver, 1948). Multiple unconformities within the Jurassic sequence at Acoma (Maxwell, 1976), a high degree of homogeneity of lithologies in the Morrison Formation near its pinchout (Silver, 1948; Jicha, 1958), and the angularity between the most southerly Morrison Formation and the overlying Dakota Sandstone (Silver, 1948) suggest that the Morrison truncation in central New Mexico has components of both depositional thinning and tectonism. Although the most southerly preserved Morrison Formation outcrops are probably near the basin edge, as suggested by lithologic evidence, a component of uplift and erosion probably dictated the actual preservation of the basin-margin facies.

The absence of high-energy (large grainsize) deposits in the Morrison Formation of the Carthage area indicates that probably there were no "Mogollon Highlands" in New Mexico during the Late Jurassic. Bilodeau (1986a, b) used the geographic distribution of the Early Jurassic Navajo Sandstone to show that the "Mogollon Highlands" were not a topographic high in Arizona during the Jurassic. Many previous workers (e.g., Kelley, 1967; Saucier, 1976) have assumed that the "Mogollon Highlands" were an important source for the Morrison Formation in New Mexico. However, the evidence from the outcrops at Carthage suggests that the "Mogollon Highlands" were either nonexistent in New Mexico or were restricted to the extreme western part of the state.

Conclusions

The outcrop of the Morrison Formation is extended southward to T5S, where it is represented by a sequence from 1.09 to 3.3 m thick. The dominant lithology is kaolinitic sandstone with minor variegated mudstone. Based on stratigraphic position, geographic location, and lithology this sequence can be assigned to the Morrison Formation. This outlier probably has been preserved in a structural low. Based on regional considerations this outcrop lies near the edge of the Morrison basin of deposition, although uplift and erosion have affected the preservation of basin-margin sediments.

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TABLE 1—Section 1 measured in the NE1/4 sec. 8, T5S, R2E; section 2 measured in the NW1/4 sec. 9, T5S, R2E; and section 3 measured in the SE1/4 sec. 4, T5S, R2E. See Fig. 2 for exact locations. Colors follow Goddard et al. (1979).

Unit	Description	Thickness (m)
Section 1		
	Dakota Sandstone	
7	Sandstone, light olive gray (5Y 5/2), coarse grained (1.0–0.5 phi), quartz arenite, heavily bioturbated, planar and trough cross-beds, scoured base	6.0
	Morrison Formation	
6	Sandstone, very light gray (N8), medium grained (2.0–1.5 phi), sub-quartz arenite, kaolinitic matrix, subhedral black and white micas, large component of volcanic ash	1.4
5	Mudstone, light greenish gray (5GY 8/1), mottled grayish red-purple (5RP 4/2), kaolinitic, altered volcanic ash(?)	0.6
4	Mudstone, light pale greenish yellow (10Y 8/2), kaolinitic, white mica common, altered volcanic ash(?)	0.25
3	Sandstone, grayish yellow (5Y 8/4), fine grained (3.0–2.5 phi), abundant kaolinitic matrix, subarkose, subhedral biotite	0.15
2	Sandstone, pale greenish (10Y 8/2), medium to fine grained (2.0–2.5 phi), abundant kaolinitic matrix, subhedral mica, sub-quartz arenite, base ferruginized, moderate orange-pink (10R 7/4), weathers blackish red (5R 2/2)	0.55
	Chinle Formation	
1	Mudstone and siltstone, mottled, siltstone grayish red (10R 4/2), poorly sorted with fine sand grains common locally; mudstone pale greenish yellow (10Y 8/2) with mica common	0.75
Section 2		
	Dakota Sandstone	
5	Sandstone, light olive gray (5Y 5/2), coarse grained (1.0–0.5 phi), quartz arenite, heavily bioturbated, planar and trough cross-beds, scoured base	4.5+
	Morrison Formation	
4	Sandstone, white (N9), fine grained (3.0–2.5 phi), abundant kaolinitic matrix, biotite common, sub-quartz arenite, pale red-purple streaks (5RP 6/2; iron bleeding from Dakota Sandstone), basal 5 cm contains abundant mudstone clasts up to 2 cm long and flattened, light greenish gray (5GY 8/1), channel-form sandbody (<2 m wide) trends 20–200°	1.1
3	Sandstone, white (N9), medium grained (1.0–1.5 phi), abundant kaolinitic matrix, euhedral micas, sub-quartz arenite, flat bedded	1.25
2	Sandstone, white (N9) grades(?) laterally to mudstone, light greenish gray (5GY 8/1), sandstone has abundant kaolinitic matrix, medium grained (1.5–1.0 phi), mica common, sub-quartz arenite	0.95
	Chinle Formation	
1	Mudstone, grayish red (10R 4/2), mottled pale greenish yellow (10Y 8/2)	1.0+
Section 3		
	Dakota Sandstone	
6	Sandstone, light olive gray (5Y 5/2), coarse-grained (1.0–0.5 phi), quartz arenite, heavily bioturbated, planar and trough cross-beds, scoured base	8.0+
	Morrison Formation	
5	Sandstone, white (N9), fines up to mudstone, pale greenish yellow (10Y 8/2), sandstone is fine grained (3.5–3.0 phi) with abundant kaolinitic matrix, flat-bedded sublithic arenite, top 30 cm locally stained pale pink (5RP 8/2)	1.3
4	Sandstone, very light gray (N8), fine-grained (2.5–2.0 phi), abundant kaolinitic matrix, subarkose, streaks of pale red-purple (5RP 6/2; iron bleeding from Dakota Sandstone)	0.55
3	Sandstone, very light gray (N8), very fine grained (3.5–3.0 phi), abundant kaolinitic matrix, common euhedral micas, subarkose, volcanic ash diluted with minor clastic input	0.15
2	Sandstone, very light gray (N8), fine grained (2.5–2.0 phi), abundant kaolinitic matrix, subarkose	0.4
	Chinle Formation	
1	Mudstone, grayish red (10R 4/2), mottled pale greenish yellow (10Y 8/2)	1.0+

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MINING REGISTRATIONS

(February 12, 1987, through April 23, 1987)

Bureau of Mine Inspection   Energy & Minerals Dept.   2825–E Broadbent Pkwy. NE   Albuquerque, NM 87107

Date and operation	Operators and owners	Location
2–12–87 silver, copper	Operator—Emerald Entry of Hopeful Claims, Bullard Peak Mining, Ltd., P.O. Bin R, Tyrone, NM 88065; Gen. Mgr.—Don Snodgrass, 2507 Carol NE, Albuquerque, NM 87112, phone: 884–6515; Person in charge—Louis Osmer, Jr., company address, phone: 538–2195; Gen. Supt.—John Miller, 410 Old Taos Hwy., Santa Fe, NM, phone: 988–2845. Property owner—Mile High Development Co., 2507 Carol NE, Albuquerque, NM 87112.	Grant County; federal land; secs. 13, 18, T18S, Rgs. 16W, 17W; directions to mine: 14 mi west on NM–180 from Silver City turn left on FS RD 118, go 1.5 mi and turn right on RS RD 810, go approx. 4 mi, follow goat canyon to mine.
2–12–87 gold, silver mill	Operator—Westar–Federal Venture Mill, Westar Federal Venture, P.O. Drawer D, Lordsburg, NM 88045; Supt.—E. A. Walker, same address; Gen. Mgr.—Robert D. Lowery, same address; Other official—Jack Losse, V.P. Federal Resources Corp., P.O. Box 806, Salt Lake City, UT 84110. Property owner—Federal Resources Corp., P.O. Box 806, Salt Lake City, UT 84110.	Hidalgo County; private land; secs. 14, 23, T23S, R19W; 500 tons/day, no custom milling; directions to mill: south on NM–494.
2–12–87 gold, silver	Operator—Bonney–85, Westar–Federal Venture, P.O. Drawer D, Lordsburg, NM 88045; Gen. Mgr.—Robert D. Lowery, same address, phone: 542–9152; Person in charge—E. A. Walker, same address and phone; Other officials—Daniel Demers, Pres.–Westar Corp.; Jack Losse, V.P.–Federal Resources, 333 Rancho Dr., Ste. 616, Las Vegas, NM 89106. Property owner—Federal Resources Corp., P.O. Box 806, Salt Lake City, UT 84110.	Hidalgo County; private land; secs. 11–14, T23S, R19W; directions to mine: south on NM–494, Lordsburg, NM.
2–26–87 scoria	Operator—San Antonio Mtn. Pit, 117 White Pine, Alamosa, CO 81101; Gen. Mgr.—Butch Southway, same address, phone: 589–5105; Person in charge—Albert Deltevera, 1731 West 7th, Alamosa, CO, phone: 589–3138; Other official: Dave McCarroll, Crusher Foreman.	Rio Arriba County; federal land; directions to pit: approx. 20 mi north of Tres Piedras on NM–285, turn left near San Antonio Peak.
3–27–87 iron, gold, silver	Operator—Peru Hill Mill, National Supply/Cardiff Resources, 5959 Gateway W., #552, El Paso, TX 79925; Gen. Mgr.—Jorge Ganem, company address. Property owner—Cardiff Resources, 1019 Waterwood Parkway, Ste. B, Edmond, OK 73034.	Luna County; private land; sec. 18, T23S, R9W; custom milling; capacity of mill: 500 tpd; directions to mill: 6 mi north of Deming—W 2nd St. north S70 7E road 394.
3–27–87 gold, silver mill	Operator—Minos Amigos Mill, Gold Hill Minerals, P.O. Box 268, Lordsburg, NM 88045–0268; Gen. Mgr.—Arvil Higginbotham, same address, phone 542–9781. Property owner—Ira and Larry Holliday, W–D Ranch.	Hidalgo County; private land; sec. 31, T21S, R16W; no custom milling; capacity of mill: 40–50 tpd; directions to mill: go north from Lordsburg on NM–90 for 10.5 mi, then east 4.5 mi on Diet Road to W–D Ranch.
3–27–87 gold, silver	Operator—Spanish Pit, Gold Hill Minerals, P.O. Box 268, Lordsburg, NM 88045–0268; Gen. Mgr.—Arvil Higginbotham, same address, phone: 542–9781. Property owner—Ira and Larry Holliday, W–D Ranch.	Hidalgo County; federal land; sec. 1, T22S, R17W; directions to mine: go north from Lordsburg on NM–90 for 10.5 mi, then east 4.5 mi on Diet Road to W–D Ranch.
4–13–87 gold, silver	Operator—Grand New Mexico Mines, North Sierra Mining Co., P.O. Box 1566, T or C, NM 87901; Gen. Mgr.—Edward C. Rudder, Broadway St., Winston, NM 87943, phone: 894–3446; Gen. Supt.—Richard Johnson, same as Gen. Mgr. Property owner—Goldfield Corp., P.O. Box 1899, Melbourne, FL 32901	Sierra County; private land; secs. 2, 3, 28, 34, 35, Tps 9S, 10S, R9W; directions to pit: about 12 mi north of Winston on paved hwy; working area about 1 mi north of paved hwy.
4–22–87 gold	Operator—Virtue, Southwest Exploration, P.O. Box 99, Pinos Altos, NM 88053; Person in charge—David Aker, 201 N. Cleveland St., Central, NM 88026; Pres.—Daniel Maxwell, company address. Property owner—Phelps Dodge Corp., Tyrone Branch, Tyrone, NM 88065.	Grant County; private land; sec. 3, T19S, R15W; directions to mine: 3 mi northwest of NM–90 on Mangas Valley Rd.