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1989, pp. 231-238. https://doi.org/10.56577/FFC-40.231

in:

Southeastern Colorado Plateau, Anderson, O. J.; Lucas, S. G.; Love, D. W.; Cather, S. M.; [eds.], New Mexico Geological Society 40th Annual Fall Field Conference Guidebook, 345 p. https://doi.org/10.56577/FFC-40

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MODIFICATIONS TO MIDDLE AND UPPER JURASSIC NOMENCLATURE IN THE SOUTHEASTERN SAN JUAN BASIN, NEW MEXICO

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Abstract—Units in the southeastern San Juan Basin and Acoma sag previously known as the Bluff Sandstone and Zuni Sandstone have been reassigned to other formations. The lower part of the Bluff Sandstone is no longer recognized in this area, and instead the sandstone is correlated with the Horse Mesa Member of the Middle Jurassic Wanakah Formation. The upper part of the Bluff Sandstone, also known as the Zuni Sandstone, is not recognized as a separate formation, but rather is interpreted to be an eolian facies of the Recapture Member of the Upper Jurassic Morrison Formation.

INTRODUCTION

Recent stratigraphic studies have indicated that the Bluff Sandstone of southeastern Utah should be reinstated as the basal member of the Morrison Formation. Because a unit in the southeastern part of the San Juan Basin had previously been correlated with the Bluff, studies were undertaken to determine if this unit should also be considered as part of the Morrison Formation in that area. The Bluff Sandstone of the Laguna-Mesita area had previously been divided into two units, an upper unit that displays very large scale crossbeds and a lower unit that consists of alternating crossbedded strata and flatbedded strata. In the area south of Laguna and Mesita, along the eastern side of the Acoma sag, the same sandstone was divided into an upper unit called the Zuni Sandstone and a lower unit that retained the name Bluff Sandstone.

The present study indicates that the two-fold division of the "Bluff Sandstone" in the Laguna-Mesita and Acoma sag areas is valid. The upper unit is believed to be a time equivalent of eolian beds in the lower part of the Recapture Member of the Morrison Formation and also of the Bluff Sandstone Member of the Morrison Formation. The lower unit is correlated with the Horse Mesa Member of the Wanakah Formation and is considered to be a time equivalent of the upper part of the Cow Springs Sandstone. This paper is a condensed version of a more extensive report on the geology of the southern and southeastern San Juan Basin to be published as USGS Bulletin 1808 (Condon, in press). The Bulletin report includes the history of the Jurassic nomenclature in the southern San Juan Basin, and provides more information on the detailed lithology of the Horse Mesa Member of the Wanakah Formation in that area.

GEOLOGIC SETTING

The study area is on the southeastern side of the Colorado Plateau (Fig. 1). Jurassic rocks crop out there in an arcuate band that extends across five structural elements: the Lucero and Zuni Mountains uplifts, San Juan Basin and Acoma and Gallup sags (Fig. 1; Table 1). The Lucero uplift is a westward-tilted fault block; its present geometry is a result of Laramide and younger tectonic events (Callender and Zilinski, 1976). The uplift is at the boundary between the Colorado Plateau to the west and the Rio Grande rift to the east.

The San Juan Basin is a large, asymmetric, structural and topographic depression, the axis of which lies approximately along the Colorado-New Mexico state line, well north of the study area (Fig. 1). Strata on the northern side of the basin dip steeply southward, and those on the southern side dip gently northward. The basin is surrounded by uplifts and monoclines. The Acoma sag is a southeast-extending embayment of the San Juan Basin between the Zuni uplift to the west and the Lucero uplift to the east. The sag is an asymmetric, northward-plunging trough; its steeper flank is on the west. Jurassic rocks are exposed on both sides of the structure. The Gallup sag is a similar embayment that trends southwestward between the Zuni and Defiance uplifts.

The Zuni uplift is a northwest-trending asymmetric anticline, the steepest flank of which is on the west-southwest side. Precambrian crystalline rocks are exposed in the core of the anticline, and Paleozoic and younger rocks are exposed in concentric outcrops around its flanks.

In most of the study area, Jurassic rocks are underlain by the Triassic Chinle Formation and are overlain by the Cretaceous Dakota Sandstone. In the southernmost part of the study area and in the western part of the Gallup sag and San Juan Basin, the Rock Point Member of the Wingate Sandstone lies between the Chinle and overlying Jurassic rocks.

PREVIOUS STUDIES

The study area has a long history of geologic investigations. Some of the earliest descriptions were by Marcou (1856), Newberry (1861), Gilbert (1875) and Dutton (1885). Dutton's report is of interest because some of the nomenclature that he introduced is still in use today (Fig. 2). In particular, Dutton (1885, p. 137) described a sequence of sandstones and shales, 240–400 m thick, that he termed the "Zuni sandstones." Just east of Gallup, near Navajo Church, this sequence lay between the Wingate Sandstone and the Dakota Sandstone and included rocks that were later divided into the Wanakah Formation, Cow Springs Sandstone and Morrison Formation. The unit that Dutton named the Wingate Sandstone is now recognized as the Entrada Sandstone, of Jurassic age, in the San Juan Basin area. However, when Dutton examined similar rocks south of Gallup at Zuni Pueblo, he inadvertently placed the basal contact of the Zuni at the base of the Wingate, not at the top, as he had done at Navajo Church. The "Zuni sandstones" thus consisted of different sequences of rocks at the Gallup and Zuni lo-

TABLE 1. Locations of measured sections, San Juan Basin, Arizona and New Mexico. Locations of sections shown by number on Figure 1.

Measured section number and name	Section	Township	Range	Source
1. Todilto Park	13	20 N.	20 W.	Condon (1985a)
2. Navajo	31	20 N.	20 W.	Condon (1985a)
3. Twin Buttes Wash	30	19 N.	20 W.	Condon (1985a)
4. Pipeline Road	30	26 N.	31 E.	Condon (1985a)
5. Bowman Park	36	24 N.	30 E.	Condon (1985a)
6. Lupton East and West	3	22 N.	31 E.	Condon (1985a); Craig et al. (1959)
7. Manuelito	36	14 N.	21 W.	Condon (1985a)
8. Navajo Church	11	15 N.	17 W.	Condon (1985b)
9. Midget Mesa	7	15 N.	15 W.	Condon (1985b)
10. Pinedale Monocline/ Coolidge Quarry	33	15 N.	14 W.	Condon (1985b); A.C. Huffman Jr. and A.R. Kirk, unpubl. data (1980)
11. East Thoreau	13	14 N.	13 W.	Condon (1985b); Craig et al. (1959); J.F. Robertson, (unpubl. data 1983)
12. Haystack Mountain	13, 18, 19	13 N.	11 W.	Condon (1985b); Craig et al. (1959)
13. Quemado Road	28	10 N.	9 W.	This report
14. The Narrows	33	8 N.	10 W.	This report
15. Wilson Ranch	19	6 N.	6 W.	This report
16. Petaca Pinta	12	6 N.	7 W.	This report
17. Dripping Springs	24	8 N.	7 W.	This report
18. South Butte	2	8 N.	6 W.	This report
19. Crow Mesa	4	8 N.	5 W.	This report
20. Mesa Gigante	12	9 N.	4 W.	This report; Silver (1948); Craig et al. (1959)

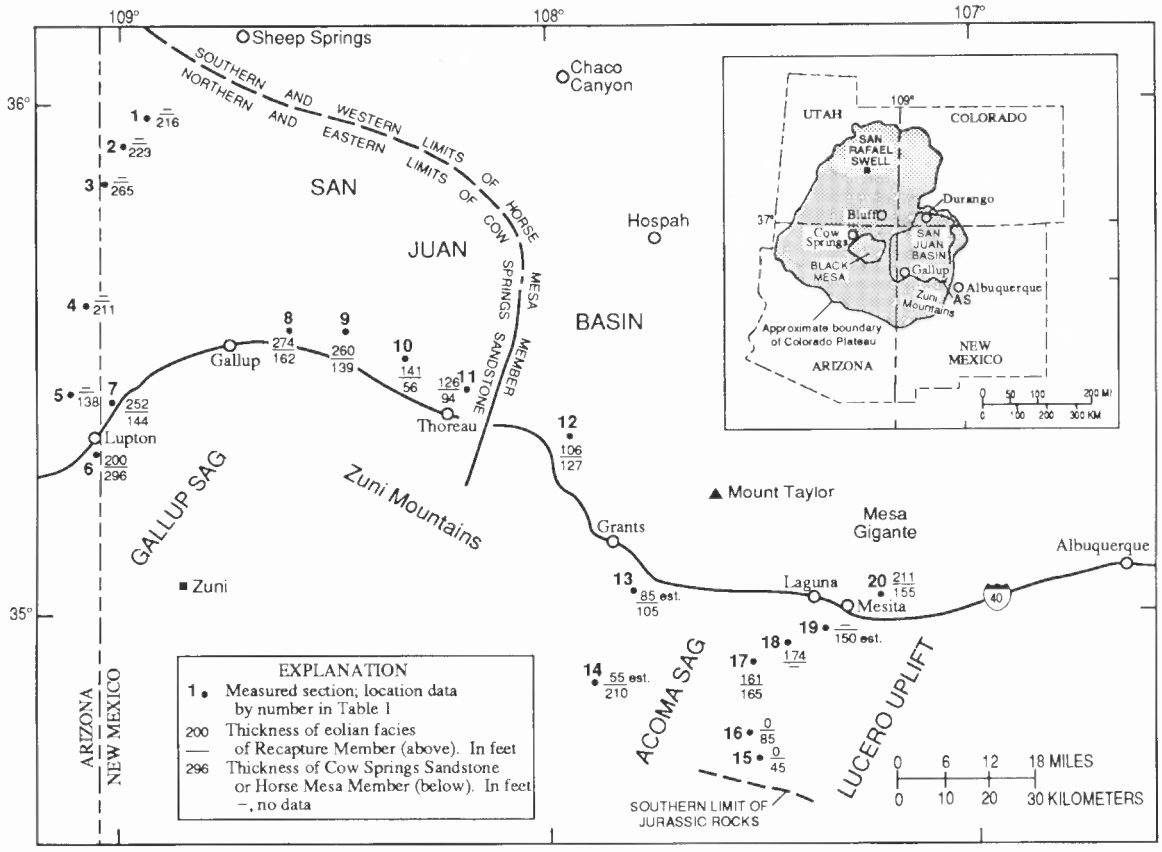


FIGURE 1. Location of measured sections and thicknesses of Recapture Member of Morrison Formation, Cow Springs Sandstone and Horse Mesa Member of Wanakah Formation, San Juan Basin area, Arizona and New Mexico. AS—Acoma sag. Detailed section location information is in Table 1.

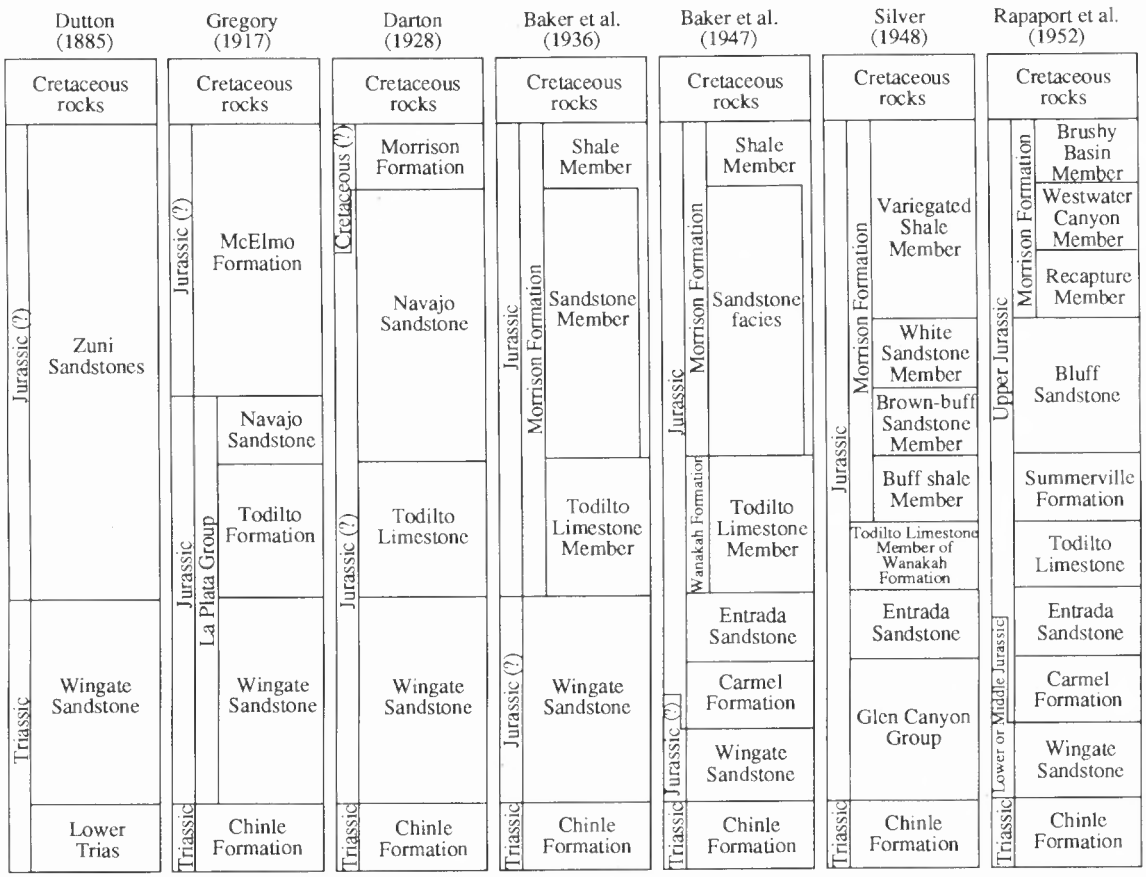


FIGURE 2. Chart showing previous and present nomenclature for the southern San Juan Basin, Gallup sag and Acoma sag.

calities. Dutton's work mainly concerned the Zuni Mountains area; his report did not cover the Laguna-Mesita area to the east.

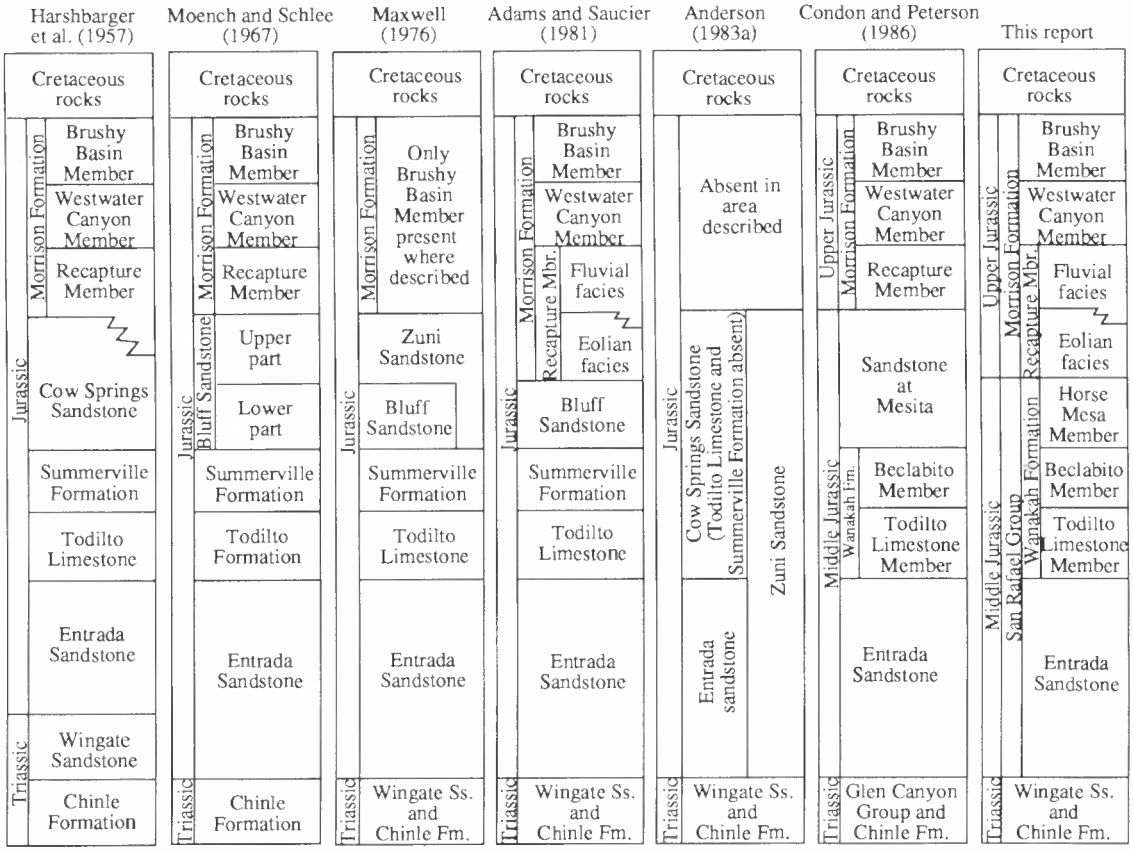
The first paper concerned specifically with the Acoma sag was by Silver (1948), who traced Jurassic strata from Mesa Gigante in the north (Fig. 1) to the southern limit of exposures of Jurassic rocks along the eastern side of the Acoma sag. Silver (1948, p. 70) made the important observation that Jurassic rocks thinned southward to a truncated edge. The thinning was caused both by onlap onto a Jurassic positive area and by subsequent erosion before deposition of overlying Cretaceous rocks (Silver, 1948, p. 81). Silver (1948) divided strata between the Chinle Formation and the Dakota Sandstone into the Wingate Sandstone (or Glen Canyon Group), the Entrada Sandstone, the Todilto Formation (now the Todilto Limestone Member of the Wanakah Formation) and the Morrison Formation. The beds included in the Morrison Formation had been mapped previously by Kelley and Wood (1946), and consisted of the buff shale member at the base, the brown-buff sandstone member, the white sandstone member and the variegated shale member at the top.

In the 1950's, stratigraphic studies concentrated mainly on the vanadium- and uranium-bearing rocks of the Colorado Plateau, including those areas discussed herein. Rapaport et al. (1952) reported on the Zuni uplift and established much of the Jurassic nomenclature subsequently used in that region. Their stratigraphy consisted of the following formations, from oldest to youngest: the Wingate Sandstone, the Carmel Formation, the Entrada Sandstone, the Todilto Limestone, the Summerville Formation, the Bluff Sandstone and the Morrison Formation. The Todilto Limestone was again recognized as a separate formation, as originally defined by Gregory (1917). The Todilto was correlated with equivalent limestone beds in the Wanakah Formation of Colorado. The names Summerville Formation and Bluff Sandstone were introduced for the first time into west-central New Mexico from southeastern Utah. Figure 2 compares the nomenclature of Rapaport et al. (1952) to that of Silver and previous workers.

Moench and Schlee (1967, p. 15–17) mapped extensively in the Laguna-Mesita area and divided the Bluff Sandstone into distinct lower and upper parts. The lower part is pale-reddish-brown to pale-orange, very fine- to medium-grained, fairly well sorted sandstone. Alternating thin to very thick, flatbedded and crossbedded sandstone strata characterize the unit. Crossbedding in the lower part is mostly small to medium scale. Transport directions, as indicated by crossbed dip directions, are scattered fairly evenly between northeast and southeast quadrants. The mean of 81 measurements of transport direction was calculated as S87°E (Moench and Schlee, 1967, p. 15). The lower part of the Bluff Sandstone intertongues with the underlying Summerville Formation (now Wanakah Formation) and is overlain gradationally by the upper part of the Bluff.

The upper part of the Bluff Sandstone of Moench and Schlee (1967) is yellowish-gray, grayish-yellow and grayish-yellow-green, fine- to medium-grained, very well sorted sandstone. Spectacular large to very large scale crossbed sets are characteristic of the upper part. The sets dip consistently northeastward; the average of 63 dip readings was calculated as N78°E (Moench and Schlee, 1967, p. 16). Because of its large-scale, high-angle crossbeds, this part of the Bluff Sandstone is believed to have an eolian origin (Moench and Schlee, 1967). The upper part intertongues with the overlying Recapture Member of the Morrison Formation.

Maxwell (1976, 1982) also conducted field studies in the Acoma sag. Although his use of Jurassic nomenclature was essentially the same as that of Moench and Schlee (1967), he defined the Bluff Sandstone differently. In Maxwell's usage, the lower part of the Bluff Sandstone of Moench and Schlee (1967) was termed the Bluff Sandstone, but the upper part was named the Zuni Sandstone (Fig. 2). Maxwell's (1976, p. 98) descriptions of the Bluff and Zuni sandstones correspond well with the descriptions of the upper and lower Bluff Sandstone by Moench and Schlee. Maxwell believed that the Bluff and Zuni sandstones merged southward and became indistinguishable. Where only one unit was



recognized, the whole unit was termed the Zuni Sandstone. As shown on Figure 2, Maxwell's use of the name Zuni Sandstone is a restriction of Dutton's (1885) definition.

Saucier (1967) and Adams and Saucier (1981) also conducted stratigraphic studies of Jurassic rocks of the Zuni uplift. Although their work was mainly to the west of the Mesita area, near Gallup, their observations add an important dimension to an understanding of Jurassic rocks in the study area. Adams and Saucier (1981, p. 22) reported that the Recapture Member of the Morrison Formation is composed of three facies. One facies consists of fine-grained, lenticular sandstone beds that were deposited by small meandering streams. Another facies, deposited in small playa lakes, is composed of fine-grained, thin-bedded sandstone beds interbedded with siltstone and mudstone beds. The third facies, which in places comprises almost the entire Recapture Member, consists of pale-red to grayish-yellow, very fine- to fine-grained sandstone. The distinguishing feature of this third facies is the presence of very large scale crossbed sets, as thick as 24 m, that have consistent crossbed dip directions to the east. This facies was interpreted as eolian in origin (Saucier, 1967). The underlying Cow Springs Sandstone or "Bluff Sandstone" was recognized by Adams and Saucier as a separate, older eolian sandstone.

Saucier's (1967) and Adams and Saucier's (1981) interpretation of the Recapture is important to the present study because of the apparent equivalence of the eolian beds of the Recapture near Gallup to the upper part of the Bluff Sandstone of Moench and Schlee (1967) and to the Zuni Sandstone of Maxwell (1976, 1982) in the Acoma sag area. The units occupy the same stratigraphic position, have the same lithology and distinctive very large scale crossbedding and display northeast transport directions. Beds with the same characteristics can be traced in nearly continuous outcrops from the Gallup area to the west side of the Acoma sag (Condon, 1985b).

Anderson (1983a, b) reviewed and summarized past use of the name Zuni Sandstone in New Mexico, including the area of this report. He noted that although some workers following Dutton (1885) had applied the name Zuni Sandstone, their usage of the term only added more complexity to the already ill-defined formation. Anderson (1983a, b) recommended that the name Zuni Sandstone be retained, but restricted in areal extent. The area would include primarily the southern part of the Gallup sag. Anderson also advocated a clarification of which strata the Zuni Sandstone should include. In Anderson's usage the Zuni is equivalent to only the undivided Entrada and Cow Springs sandstones where other intervening stratigraphic units, such as the Todilto Limestone or the Summerville Formation (now Wanakah Formation), are absent. Anderson's Zuni Sandstone is therefore the same as Dutton's Zuni in the Zuni Pueblo area but is different from both Dutton's (1885) and Maxwell's (1976, 1982) Zuni in other areas. Anderson's usage is adopted in this report, and the name Zuni Sandstone is restricted to the Zuni Pueblo area. The unit consists of rocks equivalent to the undifferentiated Cow Springs and Entrada sandstones in the areas where those units are indistinguishable.

Studies in southeastern Utah have influenced recent nomenclature changes in northwestern New Mexico. O'Sullivan (1980) found that the correlation of the Summerville Formation from east-central Utah to southeastern Utah by Baker et al. (1936) was incorrect. As a consequence, the name Wanakah Formation was extended from southwestern Colorado into southeastern Utah to replace the name Summerville. O'Sullivan (1980) established that the Wanakah was largely older than the Summerville Formation. Additionally, O'Sullivan (1980) determined that Gregory's (1938) original inclusion of the Bluff Sandstone as a member of the Morrison Formation was merited because the Bluff lay above the regional J-5 unconformity at the base of the Morrison. The rank of the Bluff Sandstone was changed by O'Sullivan (1980), and it is now considered as the basal member of the Upper Jurassic Morrison Formation and is not equivalent to any part of the Middle Jurassic Cow Springs Sandstone.

Subsequently, Condon and Huffman (1988) extended the name Wanakah Formation to Arizona and New Mexico to replace the Summerville Formation in those areas. In New Mexico the Wanakah consists of the Todilto Limestone Member at the base, the Beclabito Member and the Horse Mesa Member at the top. The Beclabito is the same lithostratigraphic unit as the unit previously called Summerville, and the Horse Mesa Member replaces the Bluff Sandstone in the northwestern San Juan Basin.

In a summary of Jurassic stratigraphy of the San Juan Basin, Condon and Peterson (1986) discussed the rocks of the Acoma sag area. They recognized the problem with using the name Bluff Sandstone in this area, but studies to resolve the problem had not been completed. Condon and Peterson (1986) used the informal term "sandstone at Mesita" to refer to the Bluff Sandstone of Moench and Schlee (1967) and to the Bluff and Zuni sandstones of Maxwell (1976). The name "sandstone at Mesita" was only an informal interim term and is no longer used.

Following these extensive changes in nomenclature, the question arose: What was the "Bluff Sandstone" in the southeastern San Juan Basin? Should it be considered a member of the Morrison Formation, as is the Bluff Sandstone near Bluff, Utah, or was it unrelated to the Bluff Sandstone Member? Moench and Schlee (1967) had reported that the upper unit of the "Bluff" intertongued with the Recapture Member of the Morrison in the Mesita area. However, they also reported that the lower unit of the "Bluff" intertongued with the underlying Summerville Formation (Beclabito Member of Wanakah Formation of present usage). The work undertaken to answer these questions resulted in the decision that the "Bluff Sandstone" of the Laguna-Mesita area could, and should, be divided into two separate units. The next section describes these and associated units.

STRATIGRAPHY

Todilto Limestone and Beclabito members of the Wanakah Formation

In the study area, the Wanakah Formation consists of three members: the basal Todilto Limestone Member, the Beclabito Member and the Horse Mesa Member. The Todilto is composed of medium- to dark-gray, carbonaceous, thinly laminated to thin-bedded limestone and gypsum. In a typical exposure at Mesita, the limestone is about 5 m thick. The Todilto gradationally overlies the Entrada Sandstone, and at the contact a few thin beds of calcareous sandstone or siltstone are commonly interbedded with limestone. At Mesita, about 33 m of white, crudely bedded gypsum having a "chickenwire" texture overlie the limestone. The gypsum pinches out a short distance southwest of Mesita (Moench and Schlee, 1967). The limestone thins and also pinches out southwest of Mesita (Maxwell, 1976). The Todilto is interpreted to have been deposited in a restricted marine embayment (Ridgley and Goldhaber, 1983; Ridgley, 1984) or in a landlocked salina (Lucas et al., 1985).

The Beclabito Member of the Wanakah is the same as the buff shale member of the Morrison of Silver (1948). It is composed of reddish-brown to white, silty sandstone, sandy siltstone and claystone. The lithologies are interbedded and commonly form a steep slope or a series of ledges above the Todilto Limestone Member (Fig. 3); the Beclabito ranges in thickness from a truncated edge in the south to about 38 m at Mesita. Although the Beclabito is generally very fine to fine-grained, it becomes coarser grained to the south, and the basal beds grade southward into a chert-pebble conglomerate. Bedding is very thin to very thick, and individual beds have ripple cross-laminations, small-scale crossbedding and irregular, subhorizontal, wavy laminations or flatbedding. Beds of the Beclabito are relatively thin but laterally extensive; exposures of the unit have a horizontally ruled appearance. Contorted bedding is common locally and may be the result of loading of unconsolidated sediment by overlying sand. Locally near Mesita, large breccia pipes disturb bedding in the Beclabito Member.

The Beclabito is interpreted as mainly marginal-marine and sabkha desposits that grade southward into fluvial deposits. Fluvial deposits are represented by chert-pebble conglomerate at the Wilson Ranch and The Narrows locations (Fig. 1). At The Narrows, the conglomerate sequence is as thick as 3 m and is interbedded with crossbedded sandstone. Most of the Beclabito was deposited on a low-lying area that

FIGURE 3. Horse Mesa and Beclabito members of Wanakah Formation near Mesita, New Mexico. Massive Horse Mesa Member (about 46 m thick) forms cliff. Beclabito Member of Wanakah Formation forms interbedded sequence in lower part of photograph. View is to west.

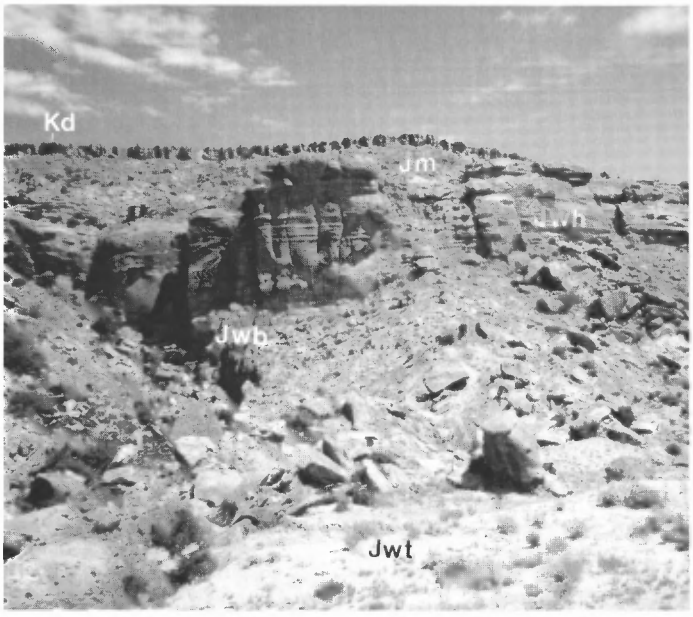


FIGURE 4. Principal reference section of Horse Mesa Member of Wanakah Formation at Mesa Gigante (47 m thick). Kd, Dakota Sandstone; Jm, Morrison Formation; Jwh, Horse Mesa Member of Wanakah Formation; Jwb, Beclabito Member of Wanakah; Jwt, Todilto Limestone Member of Wanakah. View is to north. Section shown is location 20 in Figure 1; detailed location information is in Table 1.

was transitional between highlands to the south and the Todilto sea to the north. The very fine-grained texture and lateral continuity of beds suggest deposition in a low-energy environment. A few beds of the Beclabito are composed of very well sorted, fine-grained sandstones that exhibit high-angle crossbedding characteristic of eolian dunes. These beds indicate deposition in an environment that was periodically subaerially exposed. If, however, the interpretation of the Todilto Limestone as a landlocked salina (Lucas et al., 1985) is correct, then the Beclabito would be interpreted as marginal lacustrine. In either case, the unit was deposited mainly on low-lying areas marginal to a body of water.

Horse Mesa Member of the Wanakah Formation

The Horse Mesa Member of the Wanakah Formation is a massive sandstone at the top of the Wanakah in the Acoma sag area (Fig. 1). It was called the brown-buff sandstone member of the Morrison by Silver (1948). The member is typically exposed near the village of Mesita. A reference section of the Horse Mesa Member in the southeast San Juan Basin was established by Condon (in press) on the south side of Mesa Gigante, 9.6 km east-northeast of Mesita, in SE¼ sec. 12, T9N, R4W. In this area, the Horse Mesa almost everywhere forms a vertical cliff; one locality that could be climbed and measured is the reference section (Fig. 4).

The Horse Mesa Member conformably overlies the Beclabito Member of the Wanakah Formation. In most of the exposures examined, the contact is gradational and is placed at the change from interbedded sandy siltstone and silty sandstone to massive sandstone. At one location (Crow Mesa, Fig. 1), the contact is sharp and irregular.

At the reference section, the Horse Mesa is 47-m-thick, cliff-forming, reddish-brown, light-orange, yellowish-gray and white, very to fine to coarse-grained sandstone (Fig. 4). The sandstone is moderately sorted, and grains are subangular to rounded. The Horse Mesa is mainly clean, quartzose sandstone, but coarse grains of white chert are a characteristic accessory mineral. At the reference section, the top of the Horse Mesa consists of about 3 m of massive silty sandstone that contains irregular calcareous concretions. The thickness of the Horse Mesa in the eastern Acoma sag ranges from 0 to 64 m and averages about 46 m. The member is truncated by the overlying Dakota Sandstone in the southern part of the study area.

Bedding within the Horse Mesa Member is thin to very thick; sedimentary structures include subhorizontal, wavy, nonparallel laminations (flatbeds) interbedded with small to very large scale, high-angle crossbed sets. The size and number of crossbed sets increases up section; individual laminae in the sets are inversely graded. Some flatbedded sandstone strata exhibit dish structures and dissipation structures, which indicate fluid movement at the time of, or shortly after, deposition. The bases of both flatbed and crossbed sets commonly are loaded into underlying strata.

The Horse Mesa Member was deposited mainly in an eolian environment that included dunes and interdunes or sand sheets and minor small fluvial channels. Eolian dunes are indicated by well-sorted sandstones that exhibit high-angle crossbeds, individual laminae of which are inversely graded. Crossbedding measurements indicate that eolian transport was generally to the northeast and southeast; a calculated vector resultant of 84 readings indicates wind directions oriented N73°E.

Interdune or sand-sheet deposits are represented by numerous flatbedded strata. The flatbedded sets are composed of bimodally sorted sandstone having irregular adhesion ripples, dissipation structures and contorted beds, all of which are considered to be indicators of interdune deposits (Ahlbrandt and Fryberger, 1982). The laterally extensive nature of both crossbedded and flatbedded sets suggests that drier periods alternated with more moist periods throughout the area. The interdune or sand-sheet deposits commonly have stringers of coarse white chert grains, which may be lag deposits.

Near Dripping Springs (Fig. 1), beds at the base of the Horse Mesa Member have features that indicate deposition in fluvial channels. These features include coarse to very coarse, poorly sorted sandstone, small- to medium-scale crossbeds, scoured bases and abundant clay clasts. These small channels were not noted in areas to the north of Dripping Springs and may represent fluvial runoff from highlands to the south.

The Horse Mesa is considered to be a temporal equivalent of the upper part of the Cow Springs Sandstone because of its stratigraphic position above the Beclabito Member of the Wanakah. The Cow Springs is recognized as extending to just east of Thoreau (Fig. 1); the Horse Mesa extends westward to about Thoreau. The original extent of the Horse Mesa Member to the northeast, east, and southeast of the Mesita area is unknown because of later erosion, which has removed the unit, or because the unit is deeply buried in the Rio Grande rift. The Horse Mesa Member is coarser grained than the Cow Springs Sandstone; this difference in grain size is interpreted to indicate slightly different source areas. Similarity of sedimentary structures of the two units, consisting

of relatively thin but widespread, alternating crossbed and flatbed sets, indicates that they were deposited under similar conditions. Transport directions of the Cow Springs Sandstone also indicate somewhat different source areas for the two units.

The age of the Horse Mesa Member is Middle Jurassic based on its correlation to the Middle Jurassic Cow Springs Sandstone. No fossils were found in the Horse Mesa that would allow a more definitive age assignment. The Horse Mesa is considered to be part of the San Rafael Group, which consists of the Entrada Sandstone and the Wanakah Formation in the Acoma sag area.

Two alternatives to extending recognition of the Horse Mesa Member of the Wanakah Formation to the Acoma sag have been suggested by O. J. Anderson and S. G. Lucas (written commun., 1988). The first alternative is to extend the name Cow Springs Sandstone eastward to replace the Bluff. The second alternative is to introduce an entirely new, local name to replace the Bluff. However, the assertion that the names of rock stratigraphic units should reflect local manifestations of the rocks can only lead to a confusing glut of names in the literature. The problems created by this approach are illustrated by the arbitrary change in nomenclature from the Todilto Limestone Member of the Wanakah (recognized in New Mexico) to the Pony Express Limestone Member of the Wanakah (recognized in Colorado). The rock stratigraphic unit in this case is the same; the difference in names reflects only local usage. Conversely, the names Dakota Sandstone, Entrada Sandstone and Leadville Limestone are accepted and used in the San Juan Basin, although the units were named at localities far from the area. The purpose of stratigraphic studies is to discern and demonstrate similarities between rock units in sometimes widely scattered localities and to reflect these similarities in the nomenclature. Both the names Cow Springs Sandstone and Horse Mesa Member of the Wanakah are already used in the San Juan Basin; thus, it is felt that these names have priority and can be applied to the Acoma sag area.

The next question is: Which name is more appropriate for the unit in the southeastern San Juan Basin—the Cow Springs Sandstone or the Horse Mesa Member of the Wanakah? The author believes that Horse Mesa is the more appropriate name because of similarities or differences in lithology, crossbedding dip vectors, stratigraphic position and geophysical-log characteristics between the Cow Springs Sandstone, the Horse Mesa Member and the sandstone in question in the Acoma sag. These similarities or differences are summarized below.

The lithology of the Cow Springs Sandstone is quite similar to that of the underlying Entrada Sandstone. Both sandstones consist of very fine- to fine-grained, very well sorted, subangular grains of quartz and minor amounts of varicolored accessory minerals. The Horse Mesa Member and the sandstone in the southeastern part of the basin are composed of very fine- to coarse-grained, moderately sorted, subangular to rounded quartz grains and varicolored accessory minerals. A distinctive feature of the Horse Mesa is the presence of coarse accessory grains of white chert; the white chert grains are also present in the sandstone in the southeastern San Juan Basin. Thus, the sandstone in the southeastern San Juan Basin is petrologically much closer to the Horse Mesa Member than it is to the Cow Springs Sandstone.

The vector resultant of 143 crossbed readings in the Cow Springs Sandstone is N64°E with spherical variance (S_v) equal to 0.0146. The resultant of 84 readings in the sandstone unit in the southeastern San Juan Basin is N73°E ($S_v = 0.0104$). Crossbed dip directions in the Cow Springs are widely scattered and include significant numbers of readings to the northwest and some to the southwest; dip directions in the sandstone in the southeastern San Juan Basin are clustered rather tightly in an easterly direction. Rose diagrams of crossbed dip directions show significant differences between the two units (Condon, in press), and indicate possible differences in source area.

Although the Cow Springs Sandstone and the Horse Mesa in part may be time equivalent, they can be distinguished as different units on outcrops where both occur together. At the type section of the Cow Springs Sandstone in Arizona and at Lupton (Fig. 1), the Cow Springs rests directly on the Entrada Sandstone with no intervening Wanakah Formation. At the Jurassic exposures east of Lupton, near Gallup, 1 m of Todilto Limestone Member and 17.8 m of the Beclabito Member of the Wanakah Formation are overlain by 49.2 m of Cow Springs Sandstone (Condon, 1985b). The lithology of the Cow Springs at Gallup is identical to that of the Cow Springs at Lupton, and differs from the lithology of the Horse Mesa Member of the Wanakah.

The Cow Springs can be traced eastward from Gallup in nearly continuous exposures to the Thoreau area (Condon, 1985b). At the East Thoreau measured section (Table 1), 6.2 m of Todilto Limestone Member are present above the Entrada, and are overlain by 35.2 m of Beclabito Member, 26.9 m of Cow Springs Sandstone and 1.7 m of a unit that was described as "sandstone at Mesita" (Condon, 1985b). Southeast of Thoreau, at Haystack Mountain (Table 1) the Todilto is 2.5 m thick, the Beclabito is 51 m thick and the "sandstone at Mesita," which was not assigned to a formation, is 38.5 m thick.

An interesting aspect of this last outcrop is that although the Cow Springs Sandstone was not identified, several white sandstone beds within the upper part of the Beclabito Member have lithologies similar to the Cow Springs. In this author's opinion, these sandstone beds represent the eastern distal margins of the Cow Springs erg on the southern side of the San Juan Basin. These sandstone tongues are distinct from the overlying "sandstone at Mesita" at the Haystack Mountain locality. The unit identified as "sandstone at Mesita" at Haystack Mountain by Condon (1985b) is the stratigraphic unit described as the Horse Mesa Member of the Wanakah Formation in the southeastern San Juan Basin in this report.

The Horse Mesa Member of the Wanakah can be identified in many geophysical logs in the area of its type section. The unit can be traced in the subsurface throughout much of southeastern Utah, northeastern Arizona, southwestern Colorado and northwestern New Mexico (S. M. Condon and A. C. Huffman, Jr., unpubl. data). Although drill-hole data are widely scattered in the southeastern San Juan Basin, the Horse Mesa can be traced into that area from its type section. The Horse Mesa has a distinctive geophysical log response that is different from the log response of the Cow Springs Sandstone.

Any of the features of the sandstone in the southeastern San Juan Basin discussed above, judged alone, might not be sufficient to decide whether that unit should be regarded as a correlative of the Cow Springs Sandstone or of the Horse Mesa Member. However, considered together the unit definitely has a closer likeness to the Horse Mesa than to the Cow Springs. Since a new name would only further complicate the Jurassic nomenclature of this area, the name Horse Mesa Member is applied to the unit.

Eolian facies of the Recapture Member of the Morrison Formation

Near Gallup, an eolian sandstone in the Recapture Member of the Morrison Formation overlies the Cow Springs Sandstone (Saucier, 1967; Adams and Saucier, 1981; Condon and Huffman, 1984; Condon, 1985b; Condon and Peterson, 1986). This sandstone is characterized by very large scale, high-angle eolian crossbed sets that are interbedded with and grade laterally into flatbedded interdune deposits. In the Acoma sag, a sandstone displaying the same features overlies the Horse Mesa Member of the Wanakah (Fig. 5). The unit was called the white sandstone member of the Morrison by Silver (1948). This sandstone was measured in detail at Mesa Gigante, South Butte and Dripping Springs (Fig. 1; Condon, in press).

The sandstone above the Horse Mesa Member is yellowish gray, grayish red and greenish gray, fine to medium grained and well sorted. Grains are subangular to rounded. At the South Butte section (Fig. 1), a few beds of dark-reddish-brown mudstone are present at the base and at the top of the unit. Bedding is thick to very thick, and sedimentary structures consist of very large scale, high-angle crossbed sets and minor flatbedded intervals. In some areas, thick, massive intervals have no discernible sedimentary structures.

Large crossbed sets are the distinctive feature of this sandstone. Single set thicknesses of 18 m, 35 m and 20 m were measured at Mesa Gigante, South Butte and Dripping Springs, respectively. Individual crossbed laminae are inversely graded; at South Butte, the laminae are from 1.3

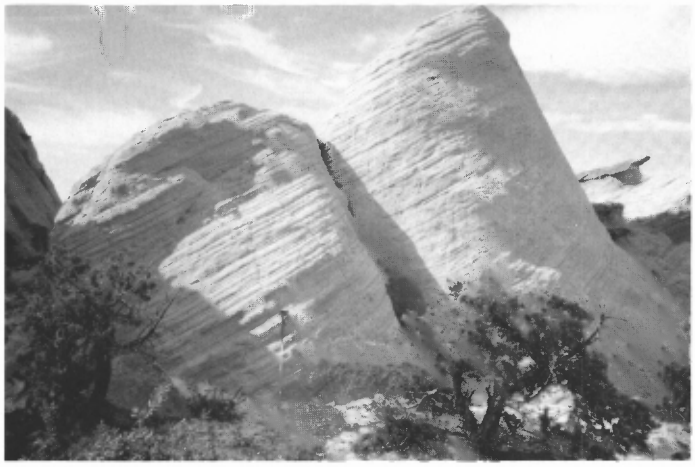


FIGURE 5. Very large scale crossbeds in eolian facies of Recapture Member of Morrison Formation at South Butte, New Mexico. Jacob staff is 1.5 m tall. View is to south.

to 15.2 cm thick. The laminae pinch out both parallel and perpendicular to the dip of bedding and represent avalanche deposits or sand flows that developed on the lee slopes of eolian dunes (Ahlbrandt and Fryberger, 1982). The transport direction of this eolian sandstone is N63°E ($S_v = 0.0015$). An abrupt, local facies change from eolian dunes to interdunes distinguishes this sandstone from the underlying Horse Mesa Member. In contrast, the Horse Mesa has thin, tabular and widespread crossbedded and flatbedded strata, without the lateral facies changes of the Morrison sandstone.

The Morrison eolian sandstone is more than 64 m thick at Mesa Gigante and thins to about 17 m to the west-southwest at The Narrows. The observed thinning is due to depositional thinning, erosion prior to deposition of the overlying Dakota Sandstone or scour at the base of the Dakota. The sandstone is truncated southward in outcrops on the east side of the Acoma sag between the Dripping Springs and Petaca Pinta sections (Fig. 1).

The contact of the eolian sandstone beds of the Recapture with the underlying Horse Mesa Member is locally sharp, but appears gradational at other places. This contact is important because it has been described as an unconformity in areas to the northwest of the San Juan Basin (Pipiringos and O'Sullivan, 1978). At Mesa Gigante, a 3-m-thick, silty sandstone occurs at the top of the Horse Mesa Member. This sandstone displays many features considered characteristic of a paleosol, such as destruction of primary sedimentary structures, bioturbation and mottling and carbonate nodules (Blodgett, 1988). The paleosol is overlain sharply by well-sorted, clean, eolian sandstone of the Recapture Member. In other areas, the lithology on either side of the contact is not as sharply defined, and the contact is placed at the base of the very large-scale crossbed sets. The contact is also marked by a change in color from the common reds and browns of the Horse Mesa Member to the more pastel yellows and greens of the overlying eolian sandstone. With the exception of the Mesa Gigante section, the contact appears to be more gradational than unconformable in the Acoma sag area.

The contact between the eolian facies and the fluvial facies of the Recapture Member is conformable. In some places the eolian and fluvial strata are interbedded (Condon, 1985a, b). This interbedding of facies is most pronounced in the Lupton, Navajo Church and Midget Mesa areas (Fig. 1; Condon and Peterson, 1986) but has been observed as far east as Laguna (Huffman et al., 1984) and Mesa Gigante (Moench and Schlee, 1967). In the Acoma sag, the fluvial beds of the Recapture Member and the Westwater Canyon and Brushy Basin Members of the Morrison thin and pinch out depositionally and(or) were removed by pre-Dakota erosion in a southward direction.

The white sandstone member of Silver (1948), the upper part of the Bluff Sandstone of Moench and Schlee (1967) and the Zuni Sandstone of Maxwell (1976) are an eolian facies of the Recapture member of the Morrison Formation. The Zuni Sandstone of Anderson (1983a) is an older unit, the top of which can be no younger than the Horse Mesa Member. The eolian sandstone is also present in the southwestern and south-central parts of the San Juan Basin, where it is called the white sandstone tongue of the Cow Springs Sandstone by Harshbarger et al. (1957). Transport directions of the eolian sandstone of the Recapture in the southern and southwestern parts of the basin and in the Acoma sag are to the northeast. The vector resultant of 68 readings is N62°E ($S_v = 0.0042$). Eolian beds in the Recapture have also been observed north of Lupton, along the west side of the San Juan Basin, and northwest of Lupton in northeastern Arizona, along the east side of Black Mesa.

The eolian sandstone of the Recapture Member is considered to be a temporal equivalent of the Bluff Sandstone Member of the Morrison Formation of Utah and of most of the Junction Creek Sandstone of southwestern Colorado, although a physical connection has not been demonstrated. Each of these units is characterized by very large scale, high-angle eolian crossbeds that show consistent transport directions to the northeast.

SUMMARY

In the southeastern San Juan Basin and Acoma sag area, the lower and upper parts of the Bluff Sandstone of Moench and Schlee (1967) or the Bluff and Zuni sandstones of Maxwell (1976) are composed of two distinct sandstone bodies that differ in color, grain size, sorting, sedimentary structures and facies distribution. The lower sandstone body is now correlated with the Horse Mesa Member of the Wanakah Formation, and the name Bluff Sandstone is no longer used. The upper sandstone body is recognized as part of the Recapture Member of the Morrison Formation and is equivalent to similar beds in the Recapture west of the Acoma sag; the name Zuni Sandstone is no longer used.

ACKNOWLEDGMENTS

The comments of S. Craigg, C. Schenk, O. Anderson and S. Lucas are gratefully acknowledged. Thanks are extended to the people of the Laguna Pueblo for allowing me to conduct geological studies on their land.

REFERENCES

Adams, S. S. and Saucier, A. E., 1981, Geology and recognition criteria for uraniferous humate deposits, Grants uranium region, New Mexico: U.S. Department of Energy, Report GJBX-2(81), 226 p.

Ahlbrandt, T. S. and Fryberger, S. G., 1982, Eolian deposits; *in* Scholle, P. A. and Spearing, D., eds., Sandstone depositional environments: American Association of Petroleum Geologists, Memoir 31, p. 11–47.

Anderson, O. J., 1983a, Preliminary report on redefinition of Zuni Sandstone, west-central New Mexico: New Mexico Geology, v. 5, p. 56–59.

Anderson, O. J., 1983b, What is the Zuni Sandstone today—100 years after Dutton? A discussion and review of Jurassic stratigraphy in west-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Report 174, 34 p.

Baker, A. A., Dane, C. H. and Reeside, J. B., Jr., 1936, Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: U.S. Geological Survey, Professional Paper 183, 66 p.

Baker, A. A., Dane, C. H. and Reeside, J. B., Jr., 1947, Revised correlation of Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: American Association of Petroleum Geologists Bulletin, v. 31, p. 1664–1668.

Blodgett, R. H., 1988, Calcareous paleosols in the Triassic Dolores Formation, southwestern Colorado; *in* Reinhardt, J. and Sigleo, W. R., eds., Paleosols and weathering through geologic time—principles and applications: Geological Society of America, Special Paper 216, p. 103–121.

Callender, J. F. and Zilinski, R. E., 1976, Kinematics of Tertiary and Quaternary deformation along the eastern edge of the Lucero uplift, central New Mexico: New Mexico Geological Society, Special Publication 6, p. 53–61.

Condon, S. M., 1985a, Lithologic descriptions of selected intervals of Jurassic rocks in southeastern Utah, northeastern Arizona, and northwestern New Mexico: U.S. Geological Survey, Open-file Report 85-223, 100 p.

Condon, S. M., 1985b, Lithologic descriptions of selected Middle and Upper Jurassic rocks from Gallup to Laguna in northwest New Mexico: U.S. Geological Survey, Open-file Report 85-126, 68 p.

Condon, S. M., in press, Revisions of Middle Jurassic nomenclature in the

southeastern San Juan Basin, New Mexico: U.S. Geological Survey, Bulletin 1808.

Condon, S. M. and Huffman, A. C., Jr., 1984, Stratigraphy and depositional environments of Jurassic rocks, San Juan Basin, New Mexico, with emphasis on the south and west sides; *in* Brew, D. C., ed., Field trip guidebook: Rocky Mountain Section, Geological Society of America, 37th Annual Meeting, p. 93–107.

Condon, S. M. and Huffman, A. C., Jr., 1988, Revisions in nomenclature of the Middle Jurassic Wanakah Formation, northwest New Mexico and northeast Arizona: U.S. Geological Survey, Bulletin 1633-A, p. 3–11.

Condon, S. M. and Peterson, F., 1986, Stratigraphy of Middle and Upper Jurassic rocks of the San Juan Basin—historical perspective, current ideas, and remaining problems; *in* Turner-Peterson, C. E., Santos, E. S. and Fishman, N. S., eds., A basin analysis case study; the Morrison Formation, Grants uranium region, New Mexico: American Association of Petroleum Geologists, Studies in Geology no. 22, p. 7–26.

Craig, L. C., Holmes, C. N., Freeman, V. L., Mullens, T. E. et al., 1959, Measured sections of the Morrison and adjacent formations: U.S. Geological Survey, Open-file Report 59-485, 700 p.

Darton, N. H., 1928, "Red beds" and associated formations in New Mexico, with an outline of the geology of the state: U.S. Geological Survey, Bulletin 794, 356 p.

Dutton, C. E., 1885, Mount Taylor and the Zuni Plateau; *in* Powell, J. W., Sixth annual report of the United States Geological Survey, 1884–85, p. 105–198.

Gilbert, G. K., 1875, The geology of portions of New Mexico and Arizona examined in 1873: U.S. Geographic and Geological Surveys, West 100th Meridian Report, v. 3, pt. 5, p. 503–567.

Gregory, H. E., 1917, Geology of the Navajo country: U.S. Geological Survey, Professional Paper 93, 161 p.

Gregory, H. E., 1938, The San Juan country: U.S. Geological Survey, Professional Paper 188, 123 p.

Harshbarger, J. W., Repenning, C. A. and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country: U.S. Geological Survey, Professional Paper 291, 74 p.

Huffman, A. C., Condon, S. M. and Thaden, R. E., 1984, Jurassic stratigraphy and depositional environments, southern and western San Juan Basin; *in* Brew, D. C., ed., Field trip guidebook: Rocky Mountain Section, Geological Society of America, 37th Annual Meeting, p. 93–107.

Kelley, V. C., 1963, Tectonic setting: New Mexico Bureau of Mines and Mineral Resources, Memoir 15, p. 19–20.

Kelley, V. C. and Wood, G. H., Jr., 1946, Lucero uplift, Valencia, Socorro, and Bernalillo counties, New Mexico: U.S. Geological Survey, Oil and Gas Preliminary Map 47.

Lucas, S. G., Kietzke, K. K. and Hunt, A. P., 1985, The Jurassic System in east-central New Mexico: New Mexico Geological Society, Guidebook 36, p. 213–242.

Marcou, J., 1856, Resumé of a geological reconnaissance extending from Napoleon, at the junction of the Arkansas with the Mississippi, to the Pueblo de Los Angeles in California: U.S. Pacific Railroad Exploration [Whipple], v. 3, pt. 4, p. 165–171.

Maxwell, C. H., 1976, Stratigraphy and structure of the Acoma region, New Mexico: New Mexico Geological Society, Special Publication 6, p. 95–101.

Maxwell, C. H., 1982, Mesozoic stratigraphy of the Laguna-Grants region: New Mexico Geological Society, Guidebook 33, p. 261–266.

Moench, R. H. and Schlee, J. S., 1967, Geology and uranium deposits of the Laguna district, New Mexico: U.S. Geological Survey, Professional Paper 519, 117 p.

Newberry, J. S., 1861, Geological report; *in* Ives, J. C., Report upon the Colorado River of the West, explored in 1857 and 1858: U.S. 36th Congress, 1st Session, Senate Executive Document 77–House Executive Document 90, pt. 3, 154 p.

O'Sullivan, R. B., 1980, Stratigraphic sections of Middle Jurassic San Rafael Group from Wilson Arch to Bluff in southeastern Utah: U.S. Geological Survey, Oil and Gas Investigations Chart OC-102.

Pipiringos, G. N. and O'Sullivan, R. B., 1978, Principal unconformities in Triassic and Jurassic rocks, Western Interior United States; a preliminary survey: U.S. Geological Survey, Professional Paper 1035-A, 29 p.

Rapaport, I., Hadfield, J. P. and Olsen, R. H., 1952, Jurassic rocks of the Zuni uplift, New Mexico: U.S. Atomic Energy Commission, RMO-642, 49 p.

Ridgley, J. L., 1984, Paleogeography and facies distribution of the Todilto Limestone and Pony Express Limestone Member of the Wanakah Formation, Colorado and New Mexico: Geological Society of America, Abstracts with Programs, v. 16, p. 252.

Ridgley, J. L. and Goldhaber, M., 1983, Isotopic evidence for a marine origin of the Todilto Limestone, north-central New Mexico: Geological Society of America, Abstracts with Programs, v. 15, p. 414.

Saucier, A. E., 1967, The Morrison Formation in the Gallup region: New Mexico Geological Society, Guidebook 18, p. 138–144.

Silver, C., 1948, Jurassic overlap in western New Mexico: American Association of Petroleum Geologists Bulletin, v. 32, p. 68–81.