

What is the Zuni Sandstone Today -- 100 Years
After Dutton? A Discussion and Review of
Jurassic Stratigraphy in West-Central New Mexico

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Introduction

The massive sequence(s) of light colored, cross bedded sandstones that underlie the Dakota Sandstone (Upper Cretaceous) in west-central New Mexico and northeastern Arizona were first described and named by Captain Clarence E. Dutton of the U. S. Army Ordinance Corps. His report entitled "Mount Taylor and the Zuni Plateau" (Dutton, 1885) contains an account of the stratigraphy and structure of those two areas and the immediately surrounding region (the Zuni Plateau is the present day Zuni uplift). In the report he described a "massive bright red sandstone" that overlies the "basal Trias sediments" (the present day Chinle Formation) in the Fort Wingate area; this unit he named "provisionally" the Wingate Sandstone.

Overlying the Wingate Dutton recognized "a series of sandstones and sandy shales wonderfully banded and variegated in color". North of Fort Wingate, New Mexico it was described as "broken up into a series of variegated beds of all conceivable colors" whereas in the Zuni Pueblo area it was described as being of "a nearly uniform creamy white color". Dutton named all these beds the Zuni Sandstones.

The type Wingate of Dutton (1885) is now recognized as the Entrada Sandstone. But the nomenclature change did not come about all at once; there were several installments. The first of these took place following a review of existing knowledge and additional field work by Baker, Dane, and Reeside (1947), who stated "this cliff forming sandstone which crops out in the cliffs north of Fort Wingate, New Mexico is thus equivalent to the sandstone that is called Entrada over most of Utah and Colorado, and has below it a thin zone of red silty sand and shale that is considered to be equivalent to the Carmel formation". Thus the type locality of the

Wingate was abandoned, but the term Wingate was retained for the basal sandstone of the Glen Canyon Group. The Glen Canyon Group was then extended into the Fort Wingate area to include the lower portion of Dutton's original Wingate Sandstone. The resulting division was, in ascending order, Glen Canyon group undivided, Carmel Formation equivalent, and Entrada Sandstone, with no thicknesses specified.

During an investigation of ground water resources of the Navajo Country, Harshbarger and others (1957) measured and interpreted the section at Fort Wingate somewhat differently. They considered the upper 303 ft of Dutton's original Wingate to be the Entrada Sandstone of Baker, Dane, and Reeside (1947), recognized an underlying 50 ft of red silty sandstone which they referred to as the "medial silty member of the Entrada" (rather than Carmel equivalent) and then designated the basal 359 ft of the section as the Lukachukai Member of the Wingate Sandstone (the Glen Canyon group of Baker, Dane, and Reeside, 1947). The type section for the Lukachukai, the upper member of the Wingate Sandstone, was the vertical cliff in the escarpment northeast of Lukachukai, Apache County, Arizona (Fig. 1).

It remained for Green (1974) to provide the final installment in the nomenclature change. His field investigations in the Gallup-Grants area of New Mexico revealed that the relationship between the medial silty member of the Entrada Sandstone and the underlying Lukachukai member of the Wingate Sandstone was a conformable one. The unconformity lay rather at the base of the Lukachukai. Thus Green reassigned the Lukachukai to the basal Entrada, named it the Iyanbito Member, and suggested the unconformity at its base represents the Triassic-Jurassic boundary. With the general acceptance of this work, there is at present, no Wingate Sandstone at Fort Wingate.

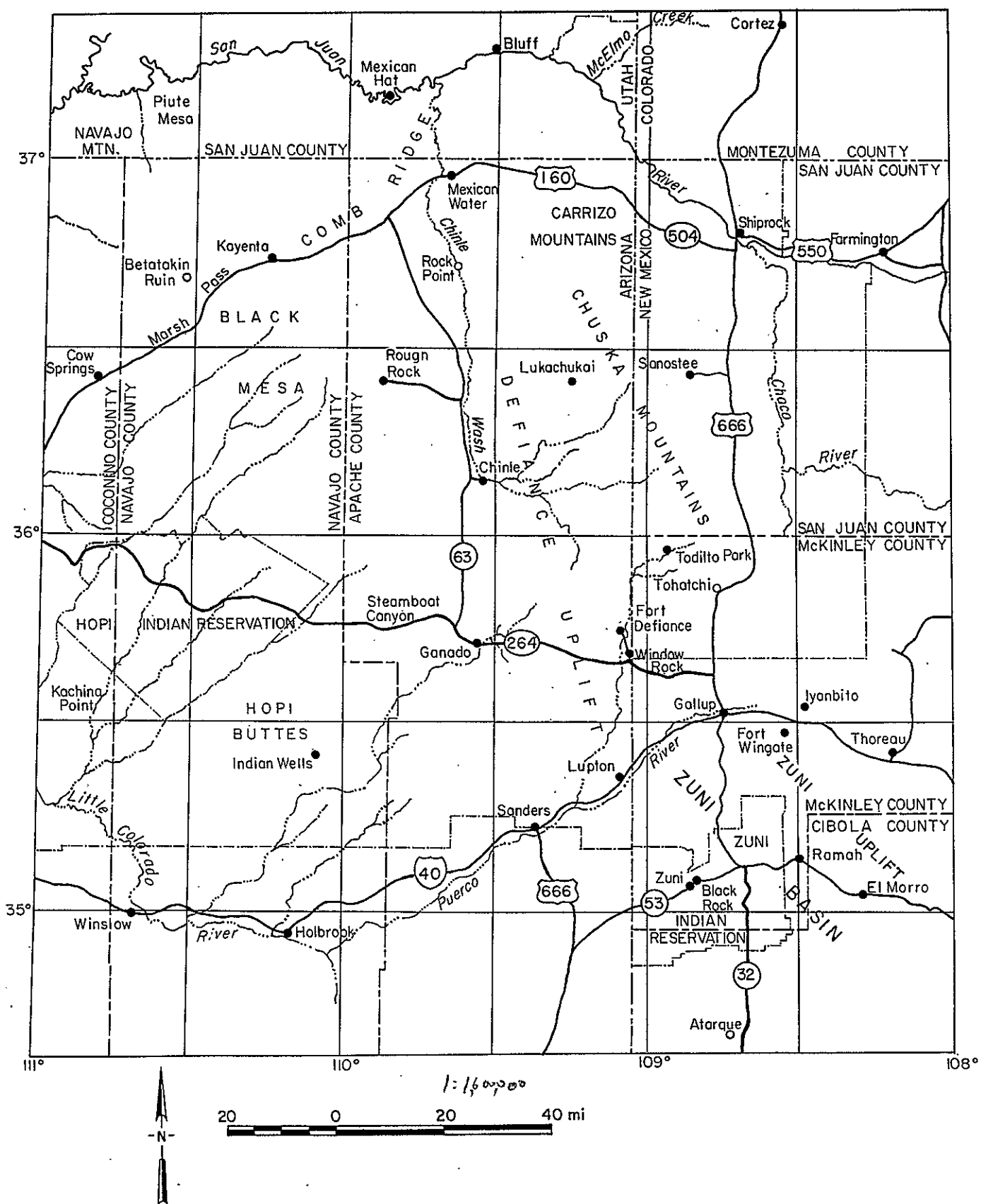


Figure 1. Index map of study area (modified from Harsharger and others, 1957)

The problems surrounding the "Zuni sandstones" of Dutton are even more confusing, and have not been resolved to the extent as those of the Wingate. The interval, or parts of it, represented by the term Zuni sandstones in its original context has been variously called the McElmo, La Plata, Navajo, White Sandstone member of the Morrison, Cow Springs, Thoreau, and Zuni. Also, at Zuni Pueblo, the lower part of Dutton's Zuni is equivalent to the present Entrada Sandstone. Some of the problems have arisen because Jurassic rocks in west-central New Mexico are isolated from equivalent rocks elsewhere on the Colorado Plateau, and lateral facies change coupled with a distinct lack of fossils have made regional correlations very difficult.

The purpose of this paper is to review the works of the various investigators in the Zuni Basin-Zuni uplift (Fig. 1) area since Dutton and to discuss the regional correlations of Jurassic rocks that were subsequently proposed. Stratigraphic data on the Jurassic section obtained during geologic mapping and coal resources investigations in the Zuni-Atarque areas is presented. The emphasis is intended to be on the uppermost of Dutton's Jura-Trias units, the "Zuni sandstones," but discussion of the lower part is frequently necessary to clarify the evolution of the nomenclature for this area.

Discussion

Gunnison Group

Following Dutton's descriptive account of the "Zuni Plateau" country in 1885, a number of investigators either visited the area or attempted correlations from their study areas into the Zuni area. Cross and Howe (1905) suggested that the Gunnison Group of southwestern Colorado, which they divided into a lower unit called the La Plata Sandstone and an upper

one named the McElmo Formation, was equivalent to Dutton's Zuni sandstones (Fig. 2). More specifically, Cross and Howe were of the opinion that the La Plata which in its type area in the La Plata Mountains was a friable, cross bedded, white or gray (locally orange to red), quartzose sandstone, correlated with Dutton's Zuni sandstone beds at Navajo Church (1½ miles north of Fort Wingate station, New Mexico). Cross and Howe also recognized a calcareous member, consisting locally of massive blue-gray limestone, in the upper half of their La Plata sandstone, with the remaining, overlying, part of the formation being "thin bedded shaly and inconspicuous." The McElmo Formation, being of a more variegated nature, was correlated with the Morrison Formation on the basis of vertebrate remains described by Riggs (1901). The Morrison Formation had been named by Cross (1894) for the nonmarine shales and sandstones so well exposed in the area about Morrison, Colorado.

In a reconnaissance survey of northwest New Mexico and northern Arizona, Darton (1910) applied Dutton's stratigraphic terms-Zuni and Wingate to "the Triassic rocks at the northern end of the Zuni uplift." One of Darton's measured sections in that locality shows the limestone beds of the present day Todilto Limestone forming the basal part of his Zuni Sandstone section. In a discussion of the Zuni Pueblo, which is south of the Todilto pinchout, Darton (1910 p. 48) stated "the Zuni Sandstone is very massive, appearing in cliffs of uniform creamy-white or pale gray color, very different from its (variegated) character on the north side of the Zuni uplift." It is appropriate to note that the north side of the uplift is where the largely eolian Zuni Sandstone (of Dutton) begins to intertongue with the Recapture Member of the Morrison and is overlain by the Westwater Canyon Member of the Morrison (Harshberger and others, 1957). Darton also observed that

Dutton's Wingate sandstone changed considerably between the Zuni Pueblo area and the area of the massive red cliffs just north of Fort Wingate. As we now know he was correlating the reddish brown, flat and thinly bedded silty sandstone of the present Rock Point Member of the Wingate Sandstone in the Zuni Pueblo area with the massive, cross bedded, present day Entrada Sandstone in the Fort Wingate area. Darton (1910) considered both the Wingate and Zuni units to be Triassic. Darton (1915, sheet 15), however, indicated a doubtful Cretaceous-Jurassic age for the upper part of the Zuni and a doubtful Jurassic age for the lower part. No reasons were stated for the division into upper and lower parts or for the age revision, but he did mention (Darton, 1910, p. 46) the "suggestion of an erosional break in the middle of the Zuni Sandstone," southeast of Gallup which is just south of the Todilto pinchout; the "break" represents the Todilto interval and thus the section below it is equivalent to the present Entrada Sandstone.

Todilto Limestone - Navajo Sandstone Terms Introduced

The next paper of significance to address the Jurassic rocks of this area was Gregory (1917). He retained Dutton's Wingate terminology for the lower more reddish part of the section, but included it as the basal unit of his La Plata Group, thereby establishing a correlation with the La Plata Sandstones (suggested by Cross and Howe) of southwestern Colorado. Gregory then introduced the terms Todilto Limestone and Navajo Sandstone for the middle and upper parts respectively of his La Plata Group. The type locality of the Todilto Limestone was designated as Todilto Park, McKinley County, New Mexico, and that of the Navajo Sandstone as simply "the Navajo Country" (see correlation chart, Fig. 2).

The presence of a thin, crystalline limestone unit (Gregory's Todilto) between two massive sandstones had been noted as early as 1875 by Gilbert, as well as by Darton (1910). Gregory (1917) saw this sequence as somewhat unique and hypothesized a correlation, through the southwestern Colorado section, to the section exposed at Navajo Mountain (30 miles east of Page, Arizona on the Arizona-Utah line) where two massive sandstones, a lower redish one and a lighter colored upper one, were separated by up to 200 ft of thin interbedded sandstone, shale, and "limestone conglomerate." Although proposed as only a "working field hypothesis" this is how and why the name Wingate was introduced to the northern Arizona-southern Utah stratigraphic section. It remains today as the basal formation of the Glen Canyon Group, even though as pointed out in the introductory remarks no Wingate Sandstone is present at the original type locality of Fort Wingate, New Mexico (that section now being recognized as the Entrada).

The thinly bedded, locally limy unit separating the two massive sandstones at Navajo Mountain was eventually recognized as being much older than the Todilto Limestone of New Mexico, aside from being of a totally different lithologic character, and was named the Kayenta Formation (Baker, Dane, and Reeside, 1936) from exposures at Kayenta, Arizona. Similarly the Navajo Sandstone, which is presently recognized north and west of Chinle, Arizona, is older than the strata overlying the Todilto in northwest New Mexico. The Todilto and the overlying Summerville and Bluff Formations would later constitute the upper part of the San Rafael Group.

Gregory (1917) further designated "all the strata in the Navajo Country between the Dakota Sandstone and the Navajo Sandstone as the McElmo Formation, breaking up the Gunnison Group of Cross and Howe (1905), but still recognizing

the correlation with the strata exposed along McElmo Creek in southwestern Colorado. To this unit he assigned a Jurassic (?) age. He acknowledged some difficulty in establishing a Navajo-McElmo break in most areas and stated that "it is not practicable to locate the contact within an error of less than 100 ft and the boundary has accordingly been mapped at the base of the lowest stratum that shows features unmistakably characteristic of the McElmo Formation." These "features" would have to be the variegated shales, argillaceous sandstones, and marls described by Cross and other early investigators. It is now clear that what Gregory (1917, p. 61) designated as the McElmo-Navajo contact at Navajo Church north of Fort Wingate (the Dutton Plateau) is the Recapture Member-Cows Spring contact of Harshbarger and others (1957, p. 68). Both Gregory and Harshbarger referred to irregularly bedded gray limestones just above the contact, which strongly supports this interpretation. Gregory also noted "one or more unconformities within the McElmo, usually at no great distance from its base." An unconformity has been recognized in the lower part of the Recapture Member in this area by recent workers, such as Green (1974).

In his discussion of the southern Rocky Mountains, Lee (1918) used Gregory's nomenclature, but assigned the McElmo to the Lower Cretaceous. Darton (1922) likewise adopted the Gregory nomenclature in the Zuni uplift area, but replaced the McElmo with the Morrison Formation to the northeast in the Chama basin, Rio Arriba County, regarding the two formations as equivalent "at least in part." He also had the Navajo Sandstone as only doubtfully present as a "chocolate brown sandstone", 150 ft thick in the Chama basin. At the present time this sandy interval is considered to be a part of the basal Morrison Formation. Budding and others (1960) described the lower

member of the Morrison in this area as an alternating sequence of pale brown, chocolate, or deep purple mudstone and white to pale gray siltstone that ranges between 300 and 400 ft in thickness and that rests on the Todilto limestone or gypsum.

San Rafael Group Defined

Gilluly and Reeside (1928) expressed some doubt about Gregory's hypothesis that the Wingate-Todilto-Navajo sequence in the northern Zuni uplift area correlated with the Wingate-thin bedded limy interval-Navajo sequence at Navajo Mountain. They did use the term Todilto with a query, however, in their stratigraphic descriptions across the San Rafael Swell in eastern Utah; but for the section above the Navajo Sandstone and below the Morrison they introduced the term San Rafael Group and assigned it an upper Jurassic age. They then divided the Group into four formations which were named Carmel, Entrada, Curtis, and Summerville in ascending order, (see correlation chart, Fig. 2). The Carmel (this formation was named in association with Gregory and Moore, who were working simultaneously on the Kaiparowits Plateau, but who did not publish until 1931) was recognized in the area as a shallow or restricted marine deposit with limy sandstones and shales, thinly bedded, in the lower part, with gypsum, anhydrite nodules, and minor salt in the upper part. The Entrada, the most prominent of the four consisted of a massive sandstone unit with two major facies, clean and well sorted to the east of the San Rafael Swell, finer grained and silty to the west. It was named for exposures at Entrada Point in the northern part of the San Rafael Swell. A massive sandstone above the Navajo Sandstone had heretofore not been recognized, and this would be of importance in later correlations into

the San Juan Basin of New Mexico. Gilluly and Reeside correlated the Entrada at the time with the Upper La Plata in the Moab, Utah area. The Curtis Formation was described as a fine grained, glauconitic sandstone usually identifiable by color alone. It had a "peculiar greenish-gray color on a fresh fracture" that weathers to a light brown. Like the Carmel, it was considered to be a shallow marine deposit and would later be established as an equivalent of the Todilto Limestone in northwest New Mexico. The Summerville consisted of even bedded red and white sandstones and maroon shales with some gypsiferous mudstone, and was named from the exposures on Summerville Point, just southeast of the head of Summerville Wash at the north end of the San Rafael Swell.

Glen Canyon Group Defined

With the growing confusion amongst the various investigators in correlating the La Plata Group westward and southwestward from Colorado into Utah and Arizona, the term Glen Canyon Group was introduced to include the massive sandstones-Wingate and Navajo-so well developed in Glen Canyon. The term first appeared in Gilluly and Reeside (1928). They, however, deferred to Gregory and Moore, who had applied the term in their work on the Kaiparowits Plateau, but who did not publish until 1931. An unpublished manuscript of Gregory and Moore was referred to by Gilluly and Reeside (1928).

In his "red beds" volume Darton (1928) recognized the Morrison Formation throughout northern New Mexico and consequently abandoned the term McElmo for use in New Mexico. The age assignment remained Cretaceous (?), and a comprehensive description of the Morrison (the type area was now more than 300 miles away) would have to await the work of Gregory (1938). The shaley, argillaceous aspect of the unit was noted at most localities, but

the sandy nature of the section north of Fort Wingate again received special mention. With respect to this area, Darton (1928, p. 38) stated that "the sandstone which had been classed as McElmo by Gregory (1917)" might represent an "overlap onto a remnant of an older sandstone." The interpretation of this is that Darton was referring to the relationship of a tongue of the Recapture Member of the Morrison to the underlying eolian sandstone (the Cow Springs Sandstone of Harshbarger and others, 1957).

Darton retained the names Wingate, Todilto, and Navajo for the units making up the section below the Morrison Formation in the area north of the Zuni uplift, but correlated the Navajo Sandstone with the basal part of the La Plata Sandstone of southwestern Colorado (Darton, 1928, p. 35). Although not explicitly stated Darton thus no longer recognized the correlation of the Todilto Limestone of New Mexico with the calcareous member in the upper part of the La Plata Group, proposed by Gregory (1917). In one sense Darton would be right as the Navajo, Carmel, Entrada Sandstone sequence in Utah would eventually be correlated with the La Plata Sandstone. He, however, as did all his contemporaries, left the Todilto too low in the section because of its position below the "supposed Navajo Sandstone" at Fort Wingate; the Todilto would ultimately be correlated with the calcareous middle member of the La Plata Group.

Darton described the Navajo Sandstone in the Zuni Pueblo and Inscription Rock (El Morro) areas, south of the Todilto pinchout, as a massive white and gray, in part red, sandstone, at places up to 475 ft in thickness, but thinning southward to not more than 120 ft at Atarque in western Cibola County. It should be noted that south of the Todilto pinchout the Navajo Sandstone of Darton, and of Gregory (1917), included in its lower portion

the equivalent of the present Entrada Sandstone. Darton reported the underlying Wingate as thinning from 280 ft thick at Zuni Pueblo to not more than 40 ft at Atarque (Darton, 1928, p. 144). He also noted that at Zuni and Atarque the Wingate was somewhat darker and less massive than in the cliffs north of Fort Wingate. As in his 1910 work, Darton (1928) continued to correlate what is presently considered the Rock Point Member of the Wingate in the Zuni-Atarque area with the sandstone forming the red cliffs north of Fort Wingate (the present Entrada Sandstone). The miscorrelation persisted because in the absence of the Todilto, color became the primary correlation tool; the lack of fossils was another detriment. Correlation of the supposed Navajo Sandstone at Fort Wingate with that of Navajo Mountain was also largely based on color as there was no "typical Todilto" present at the latter locality.

Baker, Dane, and Reeside (1936) solved some of the correlation problems by formally recognizing that the Todilto Limestone of northwest New Mexico was a younger unit than the thinly bedded, shaly, somewhat calcareous strata comprising the interval between the Wingate and Navajo Sandstone at Navajo Mountain. They proposed the name Kayenta Formation for this shaly and calcareous sandstone interval and designated a type section one mile northeast of Kayenta, Arizona. The Kayenta became the middle member of the Glen Canyon Group. The sequence of rocks overlying the Glen Canyon Group had previously been designated as the San Rafael Group (Gilluly and Reeside, 1928) consisting in ascending order of the Carmel Formation, the distinctive Entrada Sandstone, the Curtis, and the Summerville Formations. Acceptable correlations could now be made across northern Arizona and southern Utah with reference to these two groups containing seven formations, plus, locally, the overlying Morrison Formation. Correlations eastward were still problematical because

the 3000+ ft of strata in south-central Utah thinned to 300-700 ft in southwestern Colorado. Baker, Dane, and Reeside (1936) proposed that the La Plata Sandstone of southwest Colorado correlated with the Navajo-Carmel-Entrada sequence and subsequently the term La Plata would be recommended for abandonment.

Correlations southward into New Mexico remained a problem because for considerable distances the Glen Canyon Group and San Rafael Group are covered and when they reappear some formations are missing and others have undergone facies change. Baker, Dane, and Reeside (1936) dispensed with the San Rafael Group entirely in northwest New Mexico and reduced the Todilto and Navajo to members of the lower part of the Morrison Formation. In support of this they stated that "the sum of the evidence in hand shows that both the Kayenta and the Navajo Formations, and indeed the whole San Rafael Group, thin out southeastward and scarcely enter New Mexico." They also stated (1936, p. 17) "the massive sandstone that rests upon the Wingate (present Entrada) at Zuni and Lupton and upon the Todilto Limestone at Todilto Park has been designated as the 'Navajo' by earlier workers. The regional data now in hand as well as the lithologic characters of the sandstone itself seem to the writers to show definitely that the unit is part of the Morrison Formation." (They had recognized that the Morrison graded southward into an eolian sand facies). The inclusion of the Todilto in the Morrison was somewhat less defensible but they stated that such diverse lithologies, though less well developed, could be found elsewhere in Morrison age rocks. Their definition of the Morrison included "all the Jurassic continental sediments deposited subsequent to the deposition of the San Rafael Group". Thus they strongly recommended the abandonment of the name Zuni Sandstone!

For the massive reddish brown sandstone underlying the Todilto Member of the Morrison, Baker, Dane, and Reeside retained the name Wingate Sandstone. It stood as the sole representative of the Glen Canyon Group in New Mexico and was given a doubtful Jurassic age. Even though it did not solve all the correlation problems, nor provide an adequate treatment of the Morrison Formation in west-central New Mexico, theirs was a significant paper. The inclusion of the "Navajo" in the lower Morrison had the beneficial effect of removing the Navajo name from northwest New Mexico and prompting the idea that the type Todilto lies above the type Navajo. The nomenclature chart (Baker, Dane, and Reeside, 1936, table 8) provided an excellent summary of the stratigraphic terms of the various authors to date. It is included herein as part of Fig. 2.

Gregory (1938) reiterated that there were no particular difficulties in correlating Jurassic strata from southeastern Utah westward, but stated that "correlations southward have led to unlike conclusions." He regarded the stratigraphic reassignment of the Todilto to a younger position as "necessarily tentative." He did, however, recognize the Kayenta Formation to the west, but correlated it with the Todilto Limestone of New Mexico and with the calcareous member of the La Plata Group in southwestern Colorado. Gregory stated that "the great sandstone beds of the tentative Jurassic-Wingate, Navajo, Entrada, and La Plata-are so alike in range of composition, structure, color, and weathering that hand specimens are practically indistinguishable, and outcrops in the field can be recognized with certainty only where the whole series is present." He thus hung his correlations on the limestones or calcareous members; the Todilto-La Plata correlation would stand, but not the Todilto-Kayenta.

Gregory also recognized some correlation of the La Plata Sandstone with the Wingate (present Entrada) of New Mexico, as they both lay between the Chinle and the Morrison. He assigned the Entrada Sandstone and Morrison Formations an upper Jurassic age and the Glen Canyon Group a Jurassic (?) age, but with the comment that paleontologic evidence may ultimately result in an older age assignment for the Glen Canyon.

Morrison Formation Subdivided

Gregory's greatest contribution in the 1938 paper was a description of the Morrison Formation in the San Juan Country of southwestern Utah, and the division of the formation into four, widely recognized members. These were in ascending order the Bluff Sandstone, Recapture Shale, Westwater Canyon Sandstone, and the Brushy Basin Shale. The Bluff was named from exposures at the town of Bluff, Utah, on the San Juan River, and the other members took their names from drainage features northward from Bluff toward the Abajo Mountains. The Bluff Sandstone Member would later be considered as a formation of the San Rafael Group (Craig, and others 1955).

Additional field studies by Baker, Dane, and Reeside and consultations with C. B. Read of the U. S. Geological Survey resulted in the publication of a revised correlation of Jurassic formations (Baker, Dane, and Reeside, 1947) in which the Entrada Sandstone was recognized in the Fort Wingate, New Mexico area. They concluded that "the cliff forming sandstone which crops out in the cliffs north of Fort Wingate is thus equivalent to the sandstone that is called Entrada over most of Utah and Colorado." They also considered the silty, flat bedded, sandstone and shale zone underlying the Entrada to be equivalent to the Carmel Formation. Unfortunately no thicknesses were specified for these new (to this area) stratigraphic units.

Although it would later be determined that the Carmel did not extend this far southward, the recognition of the Entrada-Todilto sequence at Fort Wingate established the correlation with the San Rafael Group in southeastern Utah. The possibility of the Entrada extending southward beyond the Todilto pinchout and into the Zuni Pueblo area was not discussed, however.

The limestone and gypsum beds of the Todilto were acknowledged as being evaporite deposits related to a restricted portion of the Upper Jurassic sea and were subsequently excluded from the Morrison Formation. Baker, Dane, and Reeside (1947) did not recognize an overlying Summerville-Bluff sequence and as a result ran into difficulty in attempting to place an upper limit on the San Rafael Group. However, the Bluff Sandstone at the type locality in Utah had been described (Gregory, 1938) as a white-light brown, massive, cross bedded sandstone, that ranges from 200 to 350 ft thick. A very similar sandstone unit nearly 200 ft thick occurs above the Todilto in the Fort Wingate section (Harshbarger and others, 1957) and perhaps could have been designated as the Bluff Sandstone by Baker, Dane, and Reeside (1947) as a tentative correlation. They instead chose to refer to the sand as "most probably a facies of the Morrison Formation" and proposed that the Todilto limestone and gypsum beds be made members of the Wanakah Formation of the San Juan Mountain region in southwestern Colorado. The term Wanakah never gained widespread usage in New Mexico, although it would later be generally accepted that the Pony Express beds at the base of the Wanakah were equivalent to the Todilto Limestone.

In a discussion of the areal extent of the "Todilto limestone unit" Baker, Dane, and Reeside (1947, p. 1668) stated that the Todilto might now be regarded as a representative of the Curtis, or perhaps the Summerville,

and that they had recognized it at Kayenta, Cow Springs, and Tuba City, Arizona. It remains uncertain as to what facies of the Todilto they were referring, because no limestone occurs in the section above the Entrada at these localities. The Todilto has not been recognized by subsequent workers in those areas.

Silver (1948) described a section at the west end of Mesa Gigante, 30 miles west of Albuquerque, in an area where Darton (1928) had measured a section. Silver used the name Wingate for the Entrada part of the section, but acknowledged in a foot note that it had been considered by Baker, Dane, and Reeside (1947) to be Entrada Sandstone. He recognized about 100 ft of Todilto in the section (mostly gypsum) and broke the overlying Morrison Formation into four members after Kelley and Wood (1946). These four members in ascending order were the Bluff shale, Brown-Buff sandstone, White sandstone, and the Variegated shale member. No attempt was made to correlate these members with those named and described by Gregory (1938) in southeast Utah, but later work would demonstrate the Buff shale was the local representative of the Summerville Formation, with the Brown-buff sandstone being the equivalent of the Bluff Sandstone, together forming the upper part of the San Rafael Group. The White Sandstone was later designated as the Zuni Sandstone (Maxwell, 1976), or Cow Springs Sandstone further west in the Grants-Gallup area; most importantly the unit was recognized as an eolian sandstone present along the southern margin of the basin of Morrison deposition. The Variegated shale member, which Silver described as grading southward into sandstone would later be considered equivalent to the Brushy Basin Member of the Morrison.

Cow Springs Sandstone

Working in the Navajo Country Harshbarger and others (1951) described a grayish-white, massive sandstone, with large scale cross bedding features, capped by the Dakota Sandstone, from an exposure 4 miles east of Cow Springs, Arizona (Fig. 1). They proposed the name Cow Springs Sandstone for the unit and designated this site as the type locality.

At the type locality the Cow Springs is 342 ft thick (Harshbarger and others, 1951) and is unconformably overlain by the darker colored Dakota Sandstone. It may be distinguished from the underlying Entrada Sandstone on the basis of color, topographic expression, grain size, and fines content. The Entrada, at least in the upper part is a cleaner, slightly coarser grained sandstone that forms a bench below the lighter colored cliff forming to steep slope forming-Cow Springs Sandstone. Harshbarger and others (1951) traced the unit southeastward to Steamboat, Arizona where it thickened to 420 ft and then correlated it 60 miles further southeastward with the 240 ft thick white-to very light gray sandstone lying between the Entrada and Dakota Sandstones at Lupton, Arizona. Southward from this point toward Black Rock, New Mexico, (immediately east of Zuni Pueblo) they found the contact between the Cow Springs and Entrada to become "practically unidentifiable."

Harshbarger and others (1951) also recognized that several upper Jurassic units graded southward and southwesterly into their Cow Springs Sandstone. Included among these were the Summerville Formation and Bluff Sandstone of the San Rafael Group and the Recapture Member of the Morrison. In a more definitive work, Harshbarger and others (1957) described the southward gradation or intertonguing more specifically, noting that in the southwestern part of their area (the Navajo country) the entire interval between the

Entrada and the Dakota is composed of the Cow Springs, whereas northeastward in the area north of Gallup the Summerville, Bluff, and lower members of the Morrison Formation intertongue with and replace the Cow Springs. These relationships may be seen along the Arizona-New Mexico state line northward from Lupton to Todilto Park (Fig. 1), and in the area north of Fort Wingate (Harshbarger and others, 1957, p. 50, 68). The lithologic and stratigraphic relationships both suggest that the eolian Cow Springs Sandstone accumulated along the southern and southwest margin of the basin of deposition of the Upper San Rafael Group and the Morrison Formation and is equivalent in part to these formations. The main mass of the Cow Springs thus lies along a northwest-southeast trending axis.

Eastward from Zuni-Black Rock, Harshbarger's Cow Springs interval can be recognized along the south flank of the Zuni Uplift at El Morro, at which point it is still bounded by the Entrada and the Dakota Sandstones although the lower contact would be difficult to place. Further eastward and on the other side of the Zuni Uplift Moench (1963) mapped a similar unit on the Laguna Quadrangle as the Bluff Sandstone, overlying the Summerville and overlain by the Recapture Member of the Morrison Formation.

Smith (1954) had designated the section overlying the Todilto Limestone on the Thoreau Quadrangle (30 miles northwest of Grants, N.M.) as the Thoreau Formation. The lower part of the Thoreau was reddish brown, flat bedded, and silty and would later be considered equivalent to the Summerville by other authors. The upper part was a lighter colored, cross bedded, massive sandstone that would be variously referred to as Bluff, Cow Springs, or Zuni by later workers. Smith (1959) extended his Upper Thoreau Formation southward to include the section at Inscription Rock (El Morro), on the south side of the Zuni Uplift.

In the Haystack Mountain area, 15 miles northwest of Grants, McKinley Co. New Mexico, Thaden and Ostling (1967) recognized two sandstone units between the Summerville and the Morrison Formations. The lower cross bedded, "white and pale orange unit" they mapped as the Bluff Sandstone. The upper "moderate-orange-brown, fine grained, cross bedded eolian sandstone" they mapped as a tongue of the Cow Springs Sandstone. They distinguished the two on the basis of a slight color contrast, more distinctly eolian features in the upper one, and on the fact that the Cow Springs wedged out in the north-central part of their quadrangle map leaving the Recapture shale resting on the Bluff Sandstone.

All of these authors whose works dealt with Jurassic rocks of west-central New Mexico had since Baker, Dane, and Reeside (1947) a number of options open to them. They could (1) correlate strata above the Todilto (or above the Entrada further south) with the Summerville and/or Bluff Formations of the San Rafael Group, or with the lower members of the Morrison, as was being done on the western side of the San Juan Basin; (2) for the light colored, eolian sandstones that developed southward at the expense of the Upper San Rafael Group and lower Morrison Formation they could use existing or previously used names like White sandstone member, Cow Springs sandstone, or Zuni sandstone, or (3) introduce a new name. Because it is extremely difficult or impossible to correlate the eolian facies northward into a recognizable formation in the San Rafael Group, option number 2 emerged as the choice of most authors. The name Zuni, however, had been abandoned earlier (Baker, Dane, and Reeside, 1936); even if it were to be used a redefinition would have been in order as Dutton's original usage of the term included the Todilto, Summerville, Bluff and Morrison Formations, and the thickness ranged up to 1300 ft. Thus, authors tended to avoid the name.

No redefinition of the Zuni was forthcoming but in 1957, Harshbarger and others, working southeastward from the Navajo Country recognized in the Lupton-Zuni areas the unit they had been calling Cow Springs Sandstone on Black Mesa. It had similar color, grain size, cross bedding, and topographic expression and occupied the same stratigraphic position. They accordingly designated a 440 ft section 2 miles east of Zuni Pueblo as the Cow Springs Sandstone, and acknowledged that "in some areas the Cow Springs Sandstone is roughly equivalent to the Zuni Sandstone as defined by Dutton (1885, p. 137)." The Zuni section turned out to be one of the thicker sections measured and the authors went on to state that "elsewhere the formation is either transitional into units with which it intertongues or pre-Dakota erosion has removed an appreciable thickness of it." They also noted that south of Lupton, which is south of the Todilto pinchout, and on into New Mexico it becomes increasingly difficult to differentiate the Entrada and the Cow Springs. They did not discuss the rocks below the Cow Springs at the measured section east of Zuni, but Stewart, Poole, and Wilson (1972) working in the same locality estimated 300 ft of Entrada consisting of light brown and very pale orange, very fine to fine grained sandstone. Stewart and others also estimated another 400 ft of undescribed section above the Entrada (presumably the Cow Springs) and measured 199 ft of the Rock Point Member of the Wingate Sandstone below the Entrada. Inasmuch as it is difficult to get 900 ft of section exposed at their measured locality, the Cow Springs estimate is probably somewhat high. Stricker (personal communication, 1982) has estimated the entire interval from the top of the Rock Point Member to the base of the Dakota to be about 500 ft and the present author concurs with this. A medial color change that commonly occurs at a notch (depositional

break) that is not everywhere traceable (the Summerville-Todilto notch of some investigators) has led to the idea of the Entrada-Cow Springs break at this point.

At the type locality of the Cow Springs Sandstone, however, there is no uncertainty about the base of the unit. The present author noted a 28 ft thick grayish red (10 R 4/2) to pale reddish brown (10 R 5/4), flat bedded, sandy siltstone between the Entrada and the Cow Springs. Lithologically it does not fit with either the underlying or overlying sandstones, but Harshbarger and others (1957) reported the interval as only 23 ft thick and placed it at the base of the Cow Springs as a gradational unit between the two sandstones. It is not, however, gradational in color or grain size and should perhaps be considered equivalent to the Summerville Formation. The Summerville which grades southward into the Cow Springs, is 108 ft thick at Marsh Pass 30 miles northeast of the Cow Springs type locality (Harshbarger and others, 1957). This interpretation would further strengthen the case for two sandstones of distinctly different ages; an upper light colored, eolian sandstone and a lower, distinctly older, commonly pale reddish brown-moderate reddish brown, largely eolian sandstone. This relationship of the two sandstones has been questioned by Peterson (1974) who would interpret the upper lighter colored sandstone as "a thick bleached zone in the upper part of the Entrada." Such an interpretation would seem unlikely in view of the Summerville-like sediments between the two sandstones at the type locality and also because in the Zuni area the lighter, bleached color is a characteristic of the lower sand not the upper. These colors, however, are often only superficial.

In 1956 word reached C. H. Dane of the impending U. S. Geological Survey publication by Harshbarger and others in which the Cow Springs Sandstone would be recognized as far east as the Zuni-Black Rock area. Dane responded with the following memorandum reprinted here with permission of the U. S. Geological Survey.

March 8, 1956

TO: Geologic Names Committee

FROM: Carle H. Dane

SUBJECT: Reinstatement of Zuni Sandstone

All the strata between the Wingate (now Entrada) and Dakota sandstones were mapped by Dutton (1885, Mt. Taylor and the Zuni Plateau, (USGS 6th Ann. Rept. p. 137). The basal 2 to 25 feet above the Wingate (now Entrada), where it was thin bedded limestone, was called by Gregory the Todilto formation and the overlying lower part of the sandstone unit was erroneously called Navajo by Gregory (1917, Geology of the Navajo country). The Todilto is not present in the western and southern parts of the Gallup-Zuni Basin. Baker, Dane, and Reeside (1936) recognized Gregory's miscorrelation of Dutton's Zuni sandstone with the Navajo and correctly assigned the bulk of the Zuni to their Morrison formation as a sandstone facies of the formation (see Figure 14, p. 51, Professional Paper 183), but they included the Todilto limestone as a member of the Morrison. The history is rather fully documented on pp. 43-44 of the Baker, Dane and Reeside report. The comparable sandstone facies in the Black Mesa area of Arizona was later called Cow Springs sandstone by Harshbarger. Subsequently it became clear that the Baker, Dane, Reeside report "Morrison sandstone facies" included equivalents of

the upper part of the San Rafael group of which certainly the Todilto limestone, the Summerville, and the Bluff sandstone (if that is now included in the San Rafael group, and I believe it is) are representatives. Therefore, it is clear that the only proper procedure is to restore Zuni sandstone in Dutton's original usage. If the stratigraphic relationships had been fully understood, it would have been highly appropriate for Harshbarger to use Zuni for what he termed Cow Springs sandstone in the Black Mesa area. In my opinion, this should have been done but there are, of course, arguments in favor of a local Arizona name. Once it was done, however, there was no good reason why Cow Springs should have been permitted to jump east of the Defiance uplift into the Arizona-New Mexico border area; and there is certainly no justification for crow-hopping Cow Springs into the Acoma Basin farther east. (I might add that the thought of replacing an elegant name like Zuni by the tawdry commonplace Cow Springs curdles my gizzard. Imagine the Enchanted Mesa, the fabulous El Morro, "Acoma, the Sky City", and all the other beautiful rocks of the Land of Enchantment composed of the Cow Springs sandstone, Heaven forbid) On the New Mexico Geologic Map, I propose to use Zuni sandstone in the Gallup-Zuni and Acoma basins. The abandonment of the name was based on a misunderstanding of correlation. It should be restored.

Carle H. Dane

The memorandum, which was never circulated, indicated that Dane accepted the correlation proposed by Harshbarger and found only the name Cow Springs objectionable. From Harshbarger's and others point of view, however, there was no legitimate reason to revive an abandoned name and "back correlate"

that name (undefined) 120 miles to the original type section that he had named and described in 1951. It is unfortunate that a name with no geographic connotation (such as the White Cliffs Sandstone) was not available to lessen the objection to Harshbarger's work.

As per his memo, Dane did restore the name Zuni for use in the Zuni-Acoma Basin, but an official notification of the restoration was not circulated by the U. S. Geological Survey. Official notification came ostensibly through Keroher (1966) who updated the lexicon of geologic names. The lexicon, however, contained no definition or redefinition of the Zuni Sandstone, nor did the New Mexico state geologic map (Dane and Bachman, 1965). It appears the name Zuni was being used in a different sense than that of Dutton (1885), but without a redefinition or a type section.

Following the publication of the state geological map in 1965 and the lexicon in 1966, various investigators began referring to the Zuni as the equivalent of one of their mapped units. One of the earliest such usages was by Thaden, Merrin and Raup (1967) and Thaden, Santos, and Raup (1967) who mapped a 300-340 ft thick fine grained cross-bedded sandstone between the Summerville Formation and the Recapture Member as the yellow sandstone in the Grants, New Mexico area. They stated that the yellow sandstone interval had been called Bluff or Zuni by some workers and that it may be a tongue of the Cow Springs Sandstone. Diagrammatically they indicated as intertonguing relationship between the Bluff and the yellow sandstone, with a tongue of the Cow Springs coming in from the west, and all units overlain by the Recapture Member. The Bluff and the yellow sandstone interval can be traced all the way, with minor color changes, to the Fort Wingate-Gallup area where Harshbarger and others (1957) described the section as Cow Springs overlain by and inter-

tonguing with the Recapture Member. Other mapping in the Grants area by Thaden and others (1967) has already been discussed.

Hackman and Olson (1977) compiled the geology of the Gallup 10 x 20 quadrangle in which they used the term Cow Springs-Entrada (after Harshbarger and others). Further northward they lumped the Cow Springs-Summerville as a unit. Green and Pierson (1977) used the terms Cow Springs and Bluff in their San Juan Basin nomenclature chart and stated that where the two are recognized separately, the contact between them is considered to be intertonguing and arbitrary. Green (1975) had earlier discussed paleodepositional units in upper Jurassic rocks of the Southern San Juan Basin and included the Bluff in his Cow Springs Sandstone with an unconformity in the upper part. Lupe (1981) described the relationship of the lower part of the Morrison to the Bluff and Cow Springs as a lateral facies change; he considered the Recapture Shale Member of the Morrison to have gone from a fluvial to an eolian facies southward.

Mapping by Anderson (1982) in the Atarque area initially recognized the Cow Springs Sandstone, but this had to be revised with the realization that the Cow Springs Sandstone did not include the lower, Entrada part, of the section which is now considered to be present in the area; the unit is now recognized as the redefined Zuni Sandstone.

Maxwell (1976) working in the area east of Grants was one of the earliest to map the reinstated-undefined Zuni Sandstone following publication of the state geologic map (1965). Maxwell was able to distinguish a light colored eolian cross bedded sandstone from the underlying Bluff Sandstone in the northern half of the Acoma Pueblo Quadrangle; this upper sandstone he designated the Zuni. He considered the Bluff to be a fluviatile deposit

at this locality and the presence of numerous sandstone pipes within it helps distinguish it from the Zuni (of Maxwell). He noted that the Zuni is unconformably overlain by the Brushy Basin Member with a fossil soil zone at the contact. Thus the Brushy Basin does not grade southward into eolian sandstone at this locality, as has been described at other localities (Silver, 1948) but rather has cut out part of and therefore is younger than the underlying eolian sandstone. This is consistent with the observation by most workers that only the lower members of the Morrison intertongue with the eolian facies southward. By Brushy Basin time mostly shale was being deposited and the sand supply for the eolian deposits to the south was interrupted. The Brushy Basin shale overlapped the Zuni (of Maxwell) as Morrison deposition came to a close. A short distance to the south of Maxwell's area the Brushy Basin member has been beveled off by pre-Dakota erosion of gently northward dipping strata and the Dakota Sandstone rests on the Zuni Sandstone of Maxwell (see also Maxwell, 1982).

Zuni Sandstone Redefined

The necessity of a redefinition of Zuni Sandstone can be explained as follows. In its southern and southwesternmost areas the eolian Cow Springs Sandstone extends beyond the pinchout of the easily recognizable restricted marine and fluvial facies (Todilto and Summerville Formations) of the upper part of the San Rafael Group, and rests on the eolian Entrada Sandstone. In these areas, which include Zuni Pueblo, it is somewhat difficult to distinguish the two eolian units, but there is commonly the color change and the notch. The "Zuni sandstones" of Dutton (and the Navajo Sandstone of Gregory, 1917) did not distinguish the two; Harshbarger and others (1951) (1957) did distinguish the two, although with difficulty, and called only the upper one the Cow

Springs Sandstone. The point is here made that Dutton's Zuni and Harshbarger's and others (1951) Cow Springs are not equivalent units at Zuni Pueblo (or elsewhere) and that Harshbarger, being the first to recognize and describe the interval with respect to the modern stratigraphic framework has nomenclatorial priority. Whether or not it is practical for the field geologist to everywhere distinguish these two eolian units is doubtful, but they have nevertheless been traced into the Zuni area.

The present author is recommending the following: while it is recognized that the in-field distinction between the two largely eolian units-the Entrada and Cow Springs-will be difficult and not always practical, the name Zuni Sandstone shall be applied to the undivided equivalents of the Entrada Sandstone and the Cow Springs Sandstone south of the Summerville-Todilto pinchouts in the Gallup Sag-Zuni Basin area and eastward as appropriate into the Acoma Basin, (see correlation chart, Fig. 2). This usage corresponds to the original use of the term "Zuni sandstones" in this area only. Northward and eastward the Cow Springs Sandstone rests on younger San Rafael formations, the Summerville and the Bluff, and is more easily distinguished from them. Although there are problems locally in recognizing the Bluff and Cow Springs as separate units, this does not justify usage of the term Zuni outside the specified area. In the San Juan Basin and the Acoma Sag the usage of the name Cow Springs Sandstone ought to continue in the sense of Thaden and others (1966,67), Green (1975), Green and Pierson (1977) and Lupe (1981).

The type locality of the redefined Zuni Sandstone is Taaiyalone Mesa (Dowa Yalanne on the Zuni 7½' sheet) in sec. 36 T. 10 N., R. 19 W. and sec. 1 T. 9 N., R. 19 W. (Fig. 3). Here the Zuni is 490 ft thick with the "notch" about two thirds of the way up from the base. Five miles northeastward

a yellowish gray to pale-olive gray poorly sorted sandstone begins to appear near the top of this section. It is thought by the present author that Harshbarger and others (1957) recognized this as the southernmost extent of the Westwater Canyon Member of the Morrison Formation. Overlying the Westwater Canyon is a conspicuous bleached zone 20 to 25 ft. thick extending downward from the unconformity at the base of the Dakota Sandstone. The bleached zone is widespread and appears to be a Tongue of the Zuni Sandstone that has been thoroughly cemented and indurated with silica probably emplaced by capillary waters prior to deposition of the Dakota Sandstone. Maxwell (personal communication) has found that barite and kaolinite are commonly present in addition to the silica, and that the origin of the zone is associated with organic rich waters percolating downward from the Dakota sandstone.

A stratigraphic cross section from the type locality of the Zuni sandstone south toward Los Pilares (Atarque area) shows the pronounced, though nonuniform, southward thinning (Fig. 4). This is due to both depositional thinning and to pre-Dakota beveling.

Summary

Maxwell's usage of the Zuni Sandstone followed that of Dane and Bachman (1965) and is not consistent with the usage of Dutton (1885). Dutton's Zuni sandstone was stratigraphically most restricted in the Zuni Pueblo area, where it was demonstrated by Harshbarger and others (1957) and Stewart, Poole, and Wilson (1972) to be made up of the Entrada Sandstone and the Cow Springs Sandstone, recognizable as two separate units only with difficulty. The usage of Zuni by Dane and Bachman (1965) on the state geologic map remains undefined. The usage recommended in this paper corresponds with Dutton's

usage only in the Zuni Pueblo area; here the Zuni is defined as encompassing the undivided equivalents of the Entrada Sandstone and the Cow Springs Sandstone and is recognized only in the Gallup Sag-Zuni Basin area south of the pinchouts of the Todilto and Summerville Formations and eastward as appropriate into the Acoma Basin. At all other localities the upper part of the Zuni interval would be recognized as Cow Springs, the lower part as Entrada. Maxwell's Zuni Sandstone is equivalent to only the upper part of the redefined Zuni Sandstone, and thus is equivalent to the Cow Springs Sandstone.

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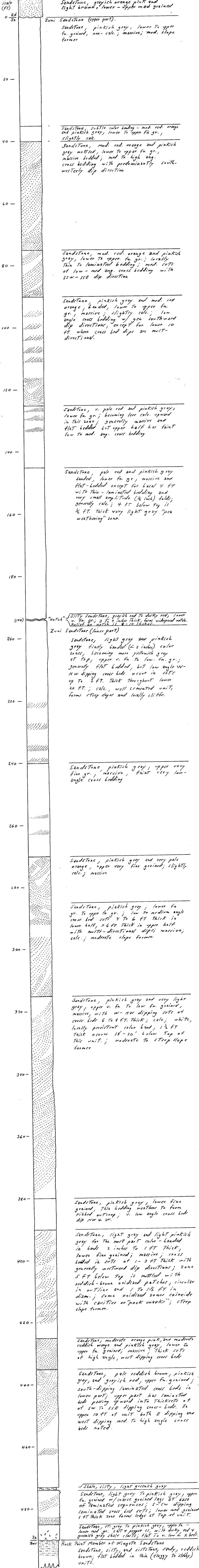
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Figure 2. Evolution and correlation of Jurassic nomenclature

Current Divisions of Southern San Juan Basin New Mexico (USGS.)		Dutton, C.E., 1885 Zuni Pueblo, New Mexico	Cross, W., and Howe, E., 1905 Red Beds paper	Darton, N.H., 1910 Reconnaissance of Northwestern New Mexico	Darton, N.H., 1915 Santa Fe Railroad guidebook	Gregory, H.E., 1917 Navajo Country	Lee, W.T., 1918 Mesozoic physiography	Darton, N.H., 1922 Geologic Structure of New Mexico	Darton, N.H., 1928 "Red Beds" of New Mexico	Gilluly, J., and Reeside, J.B., 1928 San Rafael Swell Utah	Baker, Dane, and Reeside, 1936 Correlation of Jurassic Rocks	Gregory, H.E., 1938 Southeastern Utah	Baker, Dane, and Reeside, 1947 Revised Correlation, Fort Wingate section	Harshbarger, Repenning, and Irwin, 1957 Fort Wingate section	Green, M.W., 1974	This paper 1983 Zuni Pueblo, New Mexico																																																																																																																																																																																																																																																							
Cret.	Dakota Ss.	Cretaceous	(not described)	Cretaceous	Cretaceous	Cretaceous	Upper Cretaceous	Cretaceous	Cretaceous		Dakota Ss.	Cretaceous	(not described)	Cretaceous	Cret.	Dakota Ss.	(not described)	Cret.	Dakota Ss.																																																																																																																																																																																																																																																				
Jurassic	Morrison Fm. Brushy Basin Mbr. Westwater Canyon.	Zuni sandstones	Jurassic	Zuni sandstone	Jur. or Cret.	shale	Jurassic (?)	Mc Elmo formation	L. Cretaceous	Mc Elmo formation	Cretaceous (?)	Mc Elmo or Morrison formation	Cretaceous (?)	Morrison formation	Jurassic	Morrison fm.	Shale member	Jurassic	Morrison fm.	Brushy Basin Westwater Canyon mbr. Recapture shale mbr. Bluff sandstone mbr.	Morrison fm.	shale member	Jurassic	Morrison Formation	(not described)	Jurassic	Morrison Formation	(not described)	Jurassic	Dakota Ss.	(absent)																																																																																																																																																																																																																																								
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* San Rafael Group
not recognized in
New Mexico at
the time

Figure 3. Measured section at Type locality of Zuni Sandstone; $5\frac{1}{2}$ NW $\frac{1}{4}$ sec 36 T 10 N R 19 W. measured by G. D. Stricker (USGS) and O. J. Anderson (NMBMMR), 1983.



Los Pílares, SW 1/4 NW 1/4 sec. 14, T6N, R18W
(Fence Lake quadrangle). The Dakota Sandstone
is shown as a composite section for the area.

E 1/2 NW 1/4 sec. 18, T7N, R18W
(Atarque Lake quadrangle)

SW 1/4 NW 1/4 sec. 6, T7N, R18W
Cibola Co., New Mexico (Atarque
Lake quadrangle)

E 1/2 NE 1/4 sec. 24, T8N, R19W
(Plumasano Basin quadrangle)

NE 1/4 SW 1/4 sec. 12, T8N, R19W
(Plumasano Basin quadrangle)

E 1/2 sec. 11, T8N, R19W
(Plumasano Basin quadrangle)

Zuni Pueblo area, type locality of the
Zuni Sandstone in SW 1/4 NW 1/4 sec. 36,
T10N, R19W (Zuni quadrangle)

Scale (ft.)
100

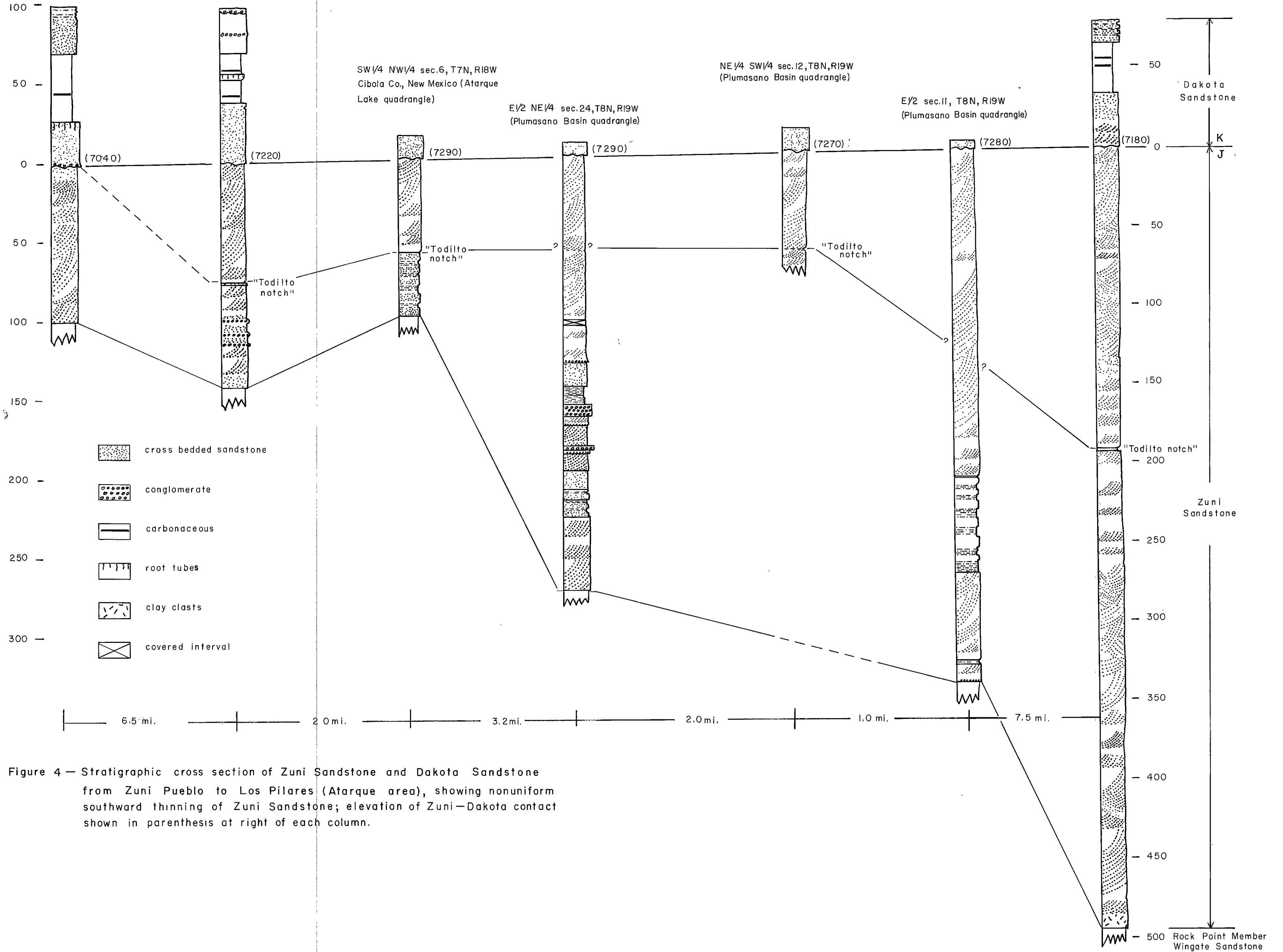


Figure 4 — Stratigraphic cross section of Zuni Sandstone and Dakota Sandstone from Zuni Pueblo to Los Pílares (Atarque area), showing nonuniform southward thinning of Zuni Sandstone; elevation of Zuni-Dakota contact shown in parenthesis at right of each column.