



## *Jurassic rocks of the Zuni Mountains*

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## JURASSIC ROCKS OF THE ZUNI MOUNTAINS

Clay T. Smith<sup>1</sup>

The Zuni Mountains are a prominent asymmetrical anticline along the southwestern margin of the San Juan Basin. The rocks of the mountains consist of a Precambrian core flanked by sediments that range in age from Pennsylvanian(?) to Recent. During considerable intervals of geologic time the area of the Zuni Mountains was on the margin of, or was contained within regions of, major uplift, and thus were both a source for sediments and a barrier to the spread of certain formations. In late Triassic time a positive element of considerable magnitude, extending throughout most of central New Mexico and central Arizona, (called the Navajo Highland by Smith (1951) and the Mogollon Highland by Harshbarger, Repenning, and Irwin (1957)) arose which affected all of the Jurassic sedimentation in and near the Zuni Mountains.

Jurassic rocks have been recognized in the Zuni Mountains since Dutton (1885) first described the section at Fort Wingate. The almost complete lack of fossils and strikingly similar lithologies throughout the Jurassic section have resulted in widely varying interpretations and correlations. Figure 1 shows the principal nomenclature and the approximate equivalence of the various stratigraphic units which have been defined in and around the Zuni Mountains.

Dutton (1885) originally described the Jurassic rocks of the Zuni Mountains in two units, the Wingate sandstone below and the Zuni sandstone above. The Wingate sandstone included all the beds from the nodular limestone beds of the upper Chinle formation (Lower Trias of Dutton) to the limestone beds overlying the massive cliffs north of Fort Wingate, New Mexico; the upper limestone beds were later correlated with the Todilto formation by Gregory (1917). The Zuni sandstone included all the beds from the Todilto limestone at the top of the massive Wingate cliff to the capping Dakota sandstone of upper Cretaceous age.

Subsequent work by Baker, Dane, and Reeside (1936, 1947), and Harshbarger, Repenning, and Irwin (1957) has resulted in considerable revision of Dutton's original concept. Baker, Dane, and Reeside (1947) have shown that the upper cliff-forming part of Dutton's Wingate sandstone actually is the considerably younger Entrada sandstone; they recommended the abandonment of the Fort Wingate type locality for the Wingate sandstone and the substitution of the exposures in the Glen Canyon of the Colorado River as more typical of the Wingate sandstone recognized over much of the Colorado Plateau. However, Harshbarger, Repenning, and Irwin (1957) show that the lower 355 feet of Dutton's type section at Fort Wingate, New Mexico, are beds correlative with the Wingate sandstone in other parts of the Colorado Plateau and thus they restrict the Wingate sandstone to the lower 355 feet of Dutton's section. Harshbarger, Repenning, and Irwin (1957) further show that these beds now are to be considered Triassic in age, and have little relation to the overlying Jurassic sediments.

### STRATIGRAPHY

#### Entrada Sandstone

The Entrada sandstone was named by Gilluly and Reeside (1928) from exposures in the northern part of the San Rafael Swell in Utah. Eastward from the type locality two facies are recognized: A lower silty sandstone and



Figure 3.—Conglomerate of the Lukachukai member of the Wingate sandstone overlain by a narrow wedge of Entrada sandstone showing marked cross-bedding which in turn is truncated by more evenly-bedded Thoreau formation. South fork of Ruin Canyon east of Ramah, New Mexico.

mudstone unit typical of the exposures at the type locality, and an upper well-sorted, cross-bedded, medium-grained sandstone unit. Harshbarger, Repenning, and Irwin (1957) describe, in the western part of the Navajo Reservation, a lower sandstone facies below the silty sandstone and mudstone of the typical Entrada. Thus, three members of the Entrada have been recognized, the lower sandy member, the medial silty member, and the upper sandy member. In the Zuni Mountains only the medial silty member and the upper sandy member are present.

The medial silty member of the Entrada sandstone is fine-grained, massive (3- to 4-foot beds), mottled red and white, silty sandstone. The red color is chiefly a surficial staining derived from the weathering and leaching of interlayered thin red siltstone and mudstone partings. Such partings combined with prominent vertical jointing yield the rectangular weathered blocks with rounded corners to which the name "hoodoo" or "rock baby" has so often been applied. Along the north flank of the mountains and extending eastward and westward beyond the range, the medial silty member is between 40 and 50 feet in thickness (see fig. 2 in envelope). Between Nutria Springs and Ramah it pinches out and is absent at El Morro and to the southeast (see fig. 3). The medial silty member rests on the Lukachukai member of the Wingate sandstone with slight erosional disconformity and a relief of about 6 inches. The contact with the upper sandy member is gradational; often a white bleached zone on the cliff is selected as the top of the medial silty member.

The upper sandy member of the Entrada sandstone is massive, orange-red to pale buff or white, friable, composite bedded, medium- to coarse-grained, well-sorted sandstone. Two grain sizes occur; the coarser grains are concentrated along the foreset surfaces of the cross-strata sets. In those places where planar cross-stratification sets are replaced by horizontally bedded sets some horizontally bedded strata are ripple laminated in several directions. The upper 35 feet of the upper sandy member is finer grained and limy, and locally, near the top of the unit,

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		Dutton (1885)	Baker, Dane, and Reeside (1936, 1947)		Smith (1957)	Freeman and Hilpert (1956)	Harshbarger, Repen- ning, and Irwin (1957)			
Creta- ceous	Upper	Dakota (?) sandstone	Dakota (?) sandstone		Dakota (?) sandstone	Dakota (?) sandstone	Dakota (?) sandstone			
Jurassic	Upper	Zuni  sandstone	Morrison  formation		Morrison formation	Brushy Basin member	Morrison formation	Brushy Basin member	Morrison formation	Brushy Basin member
					Prewitt member	Westwater Canyon member	Morrison formation	Westwater Canyon member		
					Chavez member	Recapture member	Morrison formation	Recapture member		
	Middle	Wingate  formation	San Rafael group	Wanakah fm	Wanakah marl	Upper member	Bluff sandstone	Cow Springs sandstone		
					Bilk Creek sandstone	Lower member		Summerville fm Upper Sandy member		
					Todilto limestone	Todilto limestone	Todilto limestone			
	Lower		Entrada sandstone	Upper Sandy member	San Rafael group	Entrada sandstone	Upper Sandy member	San Rafael group	Entrada sandstone	Upper Sandy member
Triassic	Upper	Lower  Trias	Glen Canyon group undifferentiated		Wingate formation	Lukachukai member	Not described	Wingate formation	Lukachukai member	
			Chinle formation			Rock Point member			Rock Point member	

Figure 1 - Nomenclature Chart of Jurassic Formations in Zuni Mountains



lenses of sandy limestone 1 to 3 inches thick occur. As the sandy limestone thickens and the interbedded sandstone thins, the Entrada grades into the overlying Todilto limestone. Elsewhere the limestone beds of the Todilto sharply truncate the cross-stratification of the upper sandy member of the Entrada sandstone. The upper sandy member is thickest near the west and southwest parts of the Zuni Mountains gradually thinning eastward and disappearing to the southeast (see fig. 2 in envelope). Figure 3 illustrates one of the easternmost exposures of the upper sandy member between Ramah and El Morro; about  $\frac{1}{4}$  mile east of this point the overlying Thoreau formation rests on the Wingate formation.

#### **Todilto Limestone**

The Todilto limestone was named by Gregory (1917) from exposures in Todilto Park, New Mexico. Similarities to other scattered limestone units throughout the Colorado Plateau region have led to considerable confusion concerning the stratigraphic position of the Todilto. Most recent workers are now in agreement with the correlation of Baker, Dane, and Reeside (1947) making the Todilto equivalent to the lower portion of the Curtis-Summerville sequence in the upper part of the San Rafael group.

The Todilto limestone is a very thin- to thin-bedded (1- to 6-inches) dark gray, dense, fine-grained rock. In places it contains a few fish scales and ostracod remains, but in general it is nonfossiliferous. Very thin partings ( $\frac{1}{2}$ - to 1-inch) of calcareous green-gray shale and siltstone yield a characteristic slabby weathered surface. Lenses of calcareous or gypsiferous sandstone and siltstone are interbedded with the limestone particularly near the base and top of the formation. The Todilto grades upward into the overlying Thoreau formation as the limestone layers gradually thin and interfinger with siltstone and sandstone lenses. The top of the Todilto limestone is usually placed at the top of the last continuous limestone layer. Along the north flank of the Zuni Mountains the formation ranges from 7 to 30 feet in thickness; it thins rapidly southward and is missing along the south flank of the mountains (see fig. 2 in envelope).

#### **Thoreau Formation**

The Thoreau formation was named by Smith (1954) from exposures along the north flank of the Zuni Mountains. These beds have been variously interpreted as Summerville formation, Bluff sandstone, Cow Springs sandstone, or several combinations of these units. Several facies changes along the north flank of the mountains permit local subdivisions, but on the south flank of the range the Thoreau formation is one massive sandstone unit which cannot be differentiated.

At Fort Wingate and Thoreau, New Mexico, Harshbarger, Repenning, and Irwin (1957) interpret the interval of the Thoreau sandstone as Summerville below and a tongue of the Cow Springs sandstone above. To the south they indicate an intertonguing and coalescence of these two units with massive sandstone which they refer entirely to the Cow Springs sandstone. Between Ramah and El Morro, New Mexico, the Thoreau formation is particularly well-exposed as a massive cliff between the underlying Entrada or Wingate sandstones and the overlying Dakota(?) formation. It has been mapped by Smith (1958) as all Thoreau formation although admittedly the upper portions of the exposures may contain beds equivalent to Morrison rocks on the north flank of the uplift. The degree of beveling prior to the deposition of the overlying Dakota(?)

sandstone cannot be estimated accurately, and thus the presence or absence of Morrison equivalents is not determinable.

In figure 2 (in envelope) the Thoreau formation is shown with an upper and lower member along the north flank of the mountains to facilitate correlation with the interpretations of Harshbarger, Repenning, and Irwin (1957), Silver (1948), and Freeman and Hilpert (1956). Along the south flank of the mountains no lithologic breaks are discernable and accordingly the Thoreau formation is mapped as a single unit. Figure 4 shows an alternative interpretation of the relations between the Thoreau, Summerville, Cow Springs, and Morrison formations between Haystack Butte, Thoreau, Fort Wingate, Nutria Springs, and El Morro, New Mexico.

The lower part of the Thoreau formation on the north flank of the mountains is alternating poorly sorted, thin-bedded, brown, red, and white siltstone and sandstone beds, with thin (1- to 6-inch) mudstone layers near the base; local limestone lenses and limy siltstone mark the gradation between Thoreau sandstone and the underlying Todilto limestone. The lower beds of the formation grade upward into well-sorted, medium- to fine-grained sandstone containing sparse siltstone and mudstone interbeds and partings; cross-stratified sets alternating with horizontally bedded sets are common. Southward where the Todilto limestone is missing, the sandstone is more massive throughout and contains few siltstone or mudstone partings. At Inscription Rock, near El Morro, the Thoreau formation is represented by over 200 feet of massive sandstone in which stratification is vague or absent.

Cross-stratification becomes dominant in the upper part of the Thoreau formation where sets of medium-grained, poorly sorted, cross-stratified beds from 5 to 11 feet thick alternate with even-bedded sets of similar sandstone from 2 to 5 feet thick (See fig. 5). Many of the layers contain abundant red, black, and brown chert fragments; mottled red and greenish staining and local concretionary weathering are common. On Inscription Rock the upper 3 to 5 feet of the Thoreau formation is bleached and kaolinized(?) suggesting a fossil soil horizon (See fig. 6).



**Figure 5.**—Co-sets of even- and cross-bedded units in the Thoreau formation; sets are from 3 to 8 ft. thick. One-half mile west of Chaco Canyon road, 5 miles northeast of Thoreau, New Mexico.

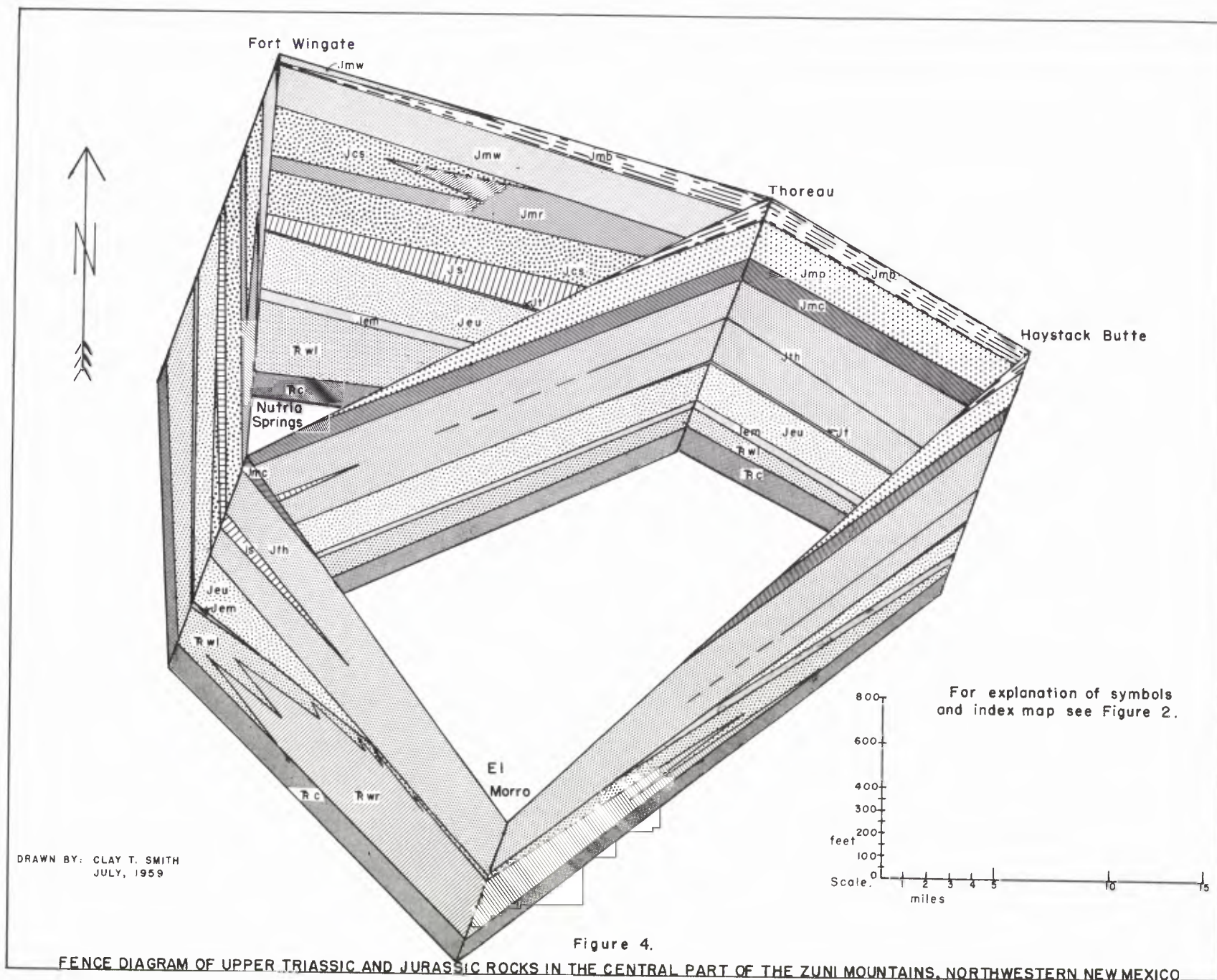


Figure 4.

FENCE DIAGRAM OF UPPER TRIASSIC AND JURASSIC ROCKS IN THE CENTRAL PART OF THE ZUNI MOUNTAINS, NORTHWESTERN NEW MEXICO





**Figure 6.**—Disconformable contact between Dakota and Thoreau formations showing bleaching of upper part of Thoreau formation. West trail to top of Inscription Rock, El Morro, New Mexico.

Along the north flank of the mountains the Thoreau formation is nearly 400 feet thick, while along the south flank it averages between 250 and 300 feet. Figure 2 shows that thickness variations are attributed best to facies changes than to any particular differences in depositional accumulation. It is not clear how far to the south the basin may have extended as pre-Dakota(?) erosion has removed all of the Jurassic rocks to the south, if they were deposited at all.

#### **Morrison Formation**

The Morrison formation is well exposed along the north flank of the Zuni Mountains but apparently is absent along the south flank because of pre-Dakota(?) erosion. The Morrison formation originally was defined by Eldridge (Emmons, Cross, and Eldridge, 1896) from rocks near Morrison, Colorado, which have since been shown to include lower Cretaceous beds. Waldschmidt and Leroy (1944) described a new type section, which is much better exposed than the earlier localities, but subdivision into members, so common farther west, is not possible. In the Colorado Plateau region Craig (Craig and others, 1955) grouped the various units assigned to the Morrison formation into four members showing considerable facies variation, but reasonably consistent throughout. However, considerable confusion still exists, even among U. S. Geological Survey personnel, as to where boundaries between members should be drawn. For example, at Laguna, New Mexico, Craig's (Craig and others, 1955, p. 155, fig. 29) isopach map of the Brushy Basin member of the Morrison formation indicates 50 feet of Brushy Basin; Freeman and Hilpert (1956, p. 320-321) report a measured section of the Brushy Basin member 372.3 feet thick at the same locality. Three subdivisions of the Morrison formation are recognized readily along the north flank of the Zuni Mountains and Harshbarger, Repenning, and Irwin, (1957) distinguish a fourth unit near Fort Wingate. Because of the confusion noted above, local names defined by Smith (1954) are used herein, and figure 2 indicates the probable correlations.

The lowest member of the Morrison formation is the Chavez member (Smith, 1954) of alternating greenish silt-

stone, purplish to reddish, sandy mudstone, and white to buff, coarse-grained, conglomeratic sandstone. The sandstone layers are cross-bedded exhibiting either planar or trough cross-stratification on a small to medium scale. The sandstone beds are from 3 to 6 feet thick, siltstones from 1 to 3 feet thick, and mudstone intervals from 3 inches to 2 feet thick. Chert and chalky clay (derived from feldspar?) particles are common particularly in the upper part of the member.

The Chavez member rests disconformably on the Thoreau formation with local relief of as much as 2 to 5 feet. Individual beds in the Chavez member vary in thickness and the upper part of the member intertongues with and is scoured by the overlying Prewitt member (Smith, 1954), so that thicknesses ranging from less than 100 feet to over 200 feet have been measured at various points. The average thickness over most of the north flank of the mountains is between 150 and 200 feet.

Lithologically the Chavez member resembles the Recapture member of the Morrison formation in exposures northwest of Todilto Park, New Mexico. However, it also is similar to the Salt Wash member particularly where the Salt Wash intertongues with the Recapture. The Chavez member occupies approximately the same stratigraphic position as these units and probably is equivalent to one or both of them, wholly or in part. The variations exhibited by figure 2 and those visible in outcrop along the north flank of the mountains make arbitrary correlations somewhat illogical until more detailed information and mapping is available.

The Prewitt member of the Morrison formation (Smith, 1954) locally overlies the Chavez member along a scour surface with as much as 4 to 5 feet of relief. In other places the two members intertongue and selection of a basal contact for the Prewitt member is arbitrary. The Prewitt member is a brown-weathering, massive, coarse-grained, light pinkish-red, conglomeratic sandstone. Tabular or wedge-shaped, planar or trough cross-stratification is common. Poor sorting and coarseness, the occurrence of small (5 millimeter) green mud balls, and the bedding suggest a nearby sedimentary source. Purplish siltstone layers very similar to beds in the underlying Chavez member occur in the lower and central portions of the exposures. Above the central siltstone layer the sandstone is much coarser with the coarsest material concentrated along the foreset planes of the cross-stratification.

Part of the stratigraphic interval occupied by the Westwater Canyon member of the Morrison formation in southeast Utah probably coincides with the position of the Prewitt member along the north flank of the Zuni Mountains. However, the nature of the Prewitt sediments suggests a local source and makes exact correlation doubtful. If Freeman and Hilpert (1956) are correct in their interpretation of the section at Laguna, New Mexico, then all of the Prewitt and much of the Chavez must be equivalent to the Brushy Basin member. In contrast to the other units of the Morrison formation to the north and west, no commercial uranium mineralization has ever been found in the Prewitt member as defined by Smith (1954) and very little in the Chavez member despite the large reserves now known in the Grants and Laguna areas. Such relations must have significance when these various units are correlated.

The uppermost member of the Morrison formation along the north flank of the Zuni Mountains is the Brushy Basin member. The Brushy Basin member was defined by Gregory (1938) and is the only unit in the Colorado

Plateau region which resembles closely the type Morrison formation of eastern Colorado. Pre-Dakota(?) erosion has removed much of the Morrison formation to the south and west of the Zuni Mountains, but the rapid facies changes from siltstone and mudstone to sandstone which take place in the Brushy Basin member along the north flank of the mountains suggest that the limits of deposition could not have been far south of the present southern flank of the mountains.

A sharp lithologic change marks the contact between the Brushy Basin member and the underlying Prewitt member. Typically, the Brushy Basin member is a variegated green, gray, and yellow, thin-bedded, calcareous siltstone and mudstone interval, locally containing lenses of coarse sandstone and conglomerate. Where carbonaceous or asphaltic material is present uranium mineralization is common. Abrupt facies changes, from mudstone and siltstone beds to soft, friable, silty sandstone with conglomerate lenses, occur along the strike of the beds. In all cases the Brushy Basin member is characterized by soft, readily weathered, fine-grained material which contrasts sharply with the hard, well-cemented, conglomeratic beds of the underlying Prewitt member. The Brushy Basin member averages about 100 feet in thickness along the north flank of the mountains. The sandy facies usually are somewhat thicker and the mud facies a little thinner. The member thickens to the east and north where it merges with the undifferentiated Morrison of the type locality and can no longer be distinguished as a mappable unit.

The Morrison formation varies in thickness from 0 feet, along an arcuate line roughly paralleling the present mountain trend between Zuni Pueblo and Acoma, to over 500 feet in the Ambrosia Lake area. The variations in thickness are due to differences in original deposition combined with irregular pre-Dakota(?) erosion. It is obvious from a study of figure 2 that tilting to the northeast took place before the deposition of the overlying Dakota(?) formation, but angularity between the Morrison and the overlying beds cannot be observed in individual outcrops. Locally, a few feet of relief may be present at the contact.

### STRUCTURE

The Jurassic rocks of the Zuni Mountains outline the elongate, asymmetrical dome which constitutes the present structural pattern of the uplift. Locally, minor folds and faults are superposed on the broad dome but no marked divergences occur. Dips along the northern, eastern, and southern flanks are low, rarely exceeding 5 degrees; however, along the western and southwestern margins vertical and overturned dips reflect the marked asymmetry of the mountain block. In the area between Gallup and Nutria Springs, New Mexico, reverse faulting accompanies the steep dips and the Jurassic and older rocks have been forced upward and southwestward over the Cretaceous beds of the adjacent Zuni Basin.

Figure 2 demonstrates a northeastward tilting associated with a post-Entrada, pre-Thoreau erosion interval. The tilting affected only the southeastern part of the mountains and apparently deposition was continuous along the north flank during this interval. The lack of definitive contacts in the thick sandstones to the west and south of the mountains prevents proper evaluation of this pre-Thoreau structure. Harshbarger, Repenning, and Irwin (1957, p. 51) state: "The Cow Springs sandstone represents the fourth major period of eolian deposition in Late Triassic and Jurassic time in the Navajo country . . . . The Cow Springs sandstone seems to have been deposited on the

flanks of the elevated Mogollon Highland. As this highland was south of the areas of San Rafael and Morrison deposition, dunes probably persisted from the time of Navajo deposition to the close of the Jurassic period in this region. Although the relationships cannot be observed, owing to the removal of the strata by pre-Dakota(?) erosion, the Navajo sandstone, the eolian facies of the Entrada, and the Cow Springs at one time may have formed one continuous deposit of crossbedded sandstone south of the Navajo country." A similar tilting on a much grander scale is associated with the pre-Dakota(?) erosion interval, although deposition may have been nearly continuous in areas far to the northeast.

### SEDIMENTATIONAL HISTORY

The medial silty member of the Entrada sandstone is the earliest Jurassic formation in the Zuni Mountains. Harshbarger, Repenning, and Irwin (1957) consider this member to be marine although no evidence exists in the Zuni Mountains area for this conclusion. The alternation of even bedded sands and silts in this member suggests a tidal flat environment along a relatively uniform coast line. The depositional margin of the basin could not have been far south of the present structural axis of the mountains. Indeed, the mountains may have been a low ridge extending northward from the Mogollon or Navajo highland, which was the source of the sediments.

The upper sandy member of the Entrada sandstone contains beds indicative of eolian, fluvial, and shallow marine environments. The gradation between the medial silty member and the upper sandy member suggests that as the sea began to retreat, sand dunes moved northward over the exposed flats. Streams flowing northward from the highland to the south added sand and reworked the material piled up as dunes. Gentle tilting to the northeast produced a new basin in which the Todilto limestone and gypsum was deposited.

The Todilto exhibits such remarkable uniformity over such a broad area that it must have been deposited in a restricted basin which contained toxic waters but had sufficient circulation to the open sea or the addition of enough fresh water from streams to prevent desiccation and precipitation of halite. The excellent preservation of the few fossils found in the Todilto indicates an absence of scavengers. It seems probable that the edge of the Todilto basin did not extend south of the mountains and that the pinch out of the formation to the south represents the depositional edge. During Todilto deposition the mountains may have been a low northern expression of the highland area farther south.

At the close of Todilto time sand dunes and fluvial sand deposits began to spread across the edges of the basin, probably because of a slight rejuvenation of the highland area. At least enough tilting occurred so that the Thoreau formation truncates the underlying upper sandy member of the Entrada. Erosion has removed evidence which might have determined the southern extent of this truncation. Although the lower part of the Thoreau formation contains silt and mudstone indicative of quiet-water deposition, the upper parts of the formation are nearly all eolian and cannot be readily distinguished from the Cow Springs sandstone farther west. Harshbarger, Repenning, and Irwin (1957) suggest that the Curtis-Summerville sequence in southeastern Utah represents a continuous depositional interval during a marine transgression and regression. Under those conditions the Thoreau formation would represent the last stages of the regression followed



by deposition of coastal sand dunes. Following the deposition of the Thoreau formation the marine environments disappeared.

The Morrison formation is completely terrestrial and made up of fluvial sandstones and channel fillings alternating with mudstones and siltstones representing quiet-water deposition. The Chavez member apparently was deposited by several braided streams whose source area lay only a short distance to the south of the Zuni Mountains, but in which there were no major trunk drainages to concentrate channel sandstones. The Prewitt member represents a coarse alluvial-fan deposit probably reflecting a rather marked rejuvenation of the Mogollon or Navajo highland and the development of a major drainage channel extending approximately across the central part of the

mountains. The Brushy Basin member reflects the gradual reduction of the Mogollon or Navajo highland so that very little coarse-grained material was available for deposition. Many of the mudstones in the Brushy Basin member contain bentonitic clays that suggest a part of the unit was derived from volcanic ash falls. The presence farther north of more abundant fossil remains, both animals and plants, is indicative of a more moist climate and thus may explain the lack of sand-dune deposits in the later Jurassic rocks.

Following the deposition of the Morrison formation the entire area was tilted to the northeast and subjected to a long period of erosion. The actual southern limit of deposition of the Jurassic rocks was destroyed and finally the area was inundated by the advancing sea of late Cretaceous time.

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