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Robert B. O'Sullivan and Lawrence C. Craig
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JURASSIC ROCKS OF NORTHEAST ARIZONA AND ADJACENT AREAS *

by
ROBERT B. O'SULLIVAN and LAWRENCE C. CRAIG
U.S. Geological Survey
Denver, Colorado

INTRODUCTION

Jurassic rocks are widely displayed in northeastern Arizona (fig. 1) and consist of, in ascending order, the San Rafael Group, the Cow Springs Sandstone and the Morrison Formation. The Navajo Sandstone, at present, is considered to be Jurassic and Triassic(?) in age. A recent report by Galton (1971), however, indicates that most of the Navajo is Late Triassic. For convenience, the Navajo Sandstone is not discussed herein.

This report is necessarily brief but emphasizes new findings. The work is based on studies conducted by the U.S. Geological Survey partly on behalf of the U.S. Bureau of Indian Affairs in cooperation with the Navajo Tribe and partly on behalf of the Division of Raw Materials, U.S. Atomic Energy Commission.

SAN RAFAEL GROUP

In the northeast Arizona area, the San Rafael Group comprises, in ascending order, the Carmel Formation, Entrada Sandstone, Todilto Limestone, Summerville Formation and Bluff Sandstone. The San Rafael Group is of Middle Jurassic (lower part of Carmel Formation) and Late Jurassic age. The boundary between the San Rafael Group and underlying rocks is everywhere an unconformity.

Carmel Formation

The Carmel Formation at the type locality near Mount Carmel in Kane County, Utah, contains fossiliferous marine limestone, gypsum, sandstone and shale. Eastward from the type locality the Carmel Formation thins and grades into a red nonfossiliferous shale facies in northeast Arizona and adjacent areas.

In most of the area the Carmel ranges from 0 to 280 feet in thickness (fig. 2), and consists of shale (that comprises the bulk of the formation) and minor beds of sandstone. The shale is dark reddish brown, micaceous, and at places silty and sandy. The shale occurs in beds as much as 20 feet thick but generally less than 5 feet thick and weathers to slopes. The sandstone beds are reddish orange or yellowish gray and consist of fine- to medium-grained, poorly sorted quartz grains and form ledges. The sandstone commonly is argillaceous and well cemented by calcium carbonate. The sandstone beds are about 1 to 3 feet thick, but some, especially in the upper part of the formation, are as much as 20 feet thick.

The Carmel Formation just described constitutes the red shale facies and characterizes the formation in most of the Navajo Reservation. The informal term "reservation" Carmel has been applied to this facies by many geologists. Outside of the area the "reservation" Carmel grades into a white or banded white-and-red sandstone facies northward along Comb Ridge in Utah, about 20 miles north of the San Juan River (Lewis and Campbell, 1965, p. 20-21), and southward in the southern part of Black Mesa, Ariz. (Harshbarger and others, 1957, p. 34-35).

In the Lupton, Ariz., area a 100-foot-thick sequence of reddish-orange, conspicuously crossbedded sandstone crops out below the sheer cliffs of the Entrada and Cow Springs sandstones and rests unconformably on the Glen Canyon Group. These beds are well exposed in a series of low rounded hills just north of Interstate Highway 40 and west of the westernmost promontory of Entrada and Cow Springs. In the area near Lupton these beds have been mapped with the Entrada Sandstone (Cooley and others, 1969, pl. 1, sheet 6).

From Lupton the beds dip eastward beneath younger rocks but reappear beneath the colorful Wingate cliffs east of Gallup, N. Mex. The reddish-orange, crossbedded sandstone forms low undulating hills that are best displayed south of Interstate 40 in the area about Rehoboth Mission, 5 miles east of Gallup. The beds in this area are about 140 feet thick (M. W. Green, oral commun., 1973) and lie unconformably on the Chinle Formation. In this area the beds have been mapped as the Lukachukai Member of the Wingate Sandstone (Cooley and others, 1969, pl. 1, sheet 8).

In an area 10 miles east of Gallup similar beds are described by M. W. Green (1971). In the Continental Divide quadrangle these beds are 45 to 60 feet thick and consist of reddish-orange, medium- to fine-grained, crossbedded sandstone. The upper contact is gradational with overlying beds of the Entrada Sandstone; the basal contact is unconformable on the Chinle Formation. These beds are mapped as the lower sandstone member of the Entrada Sandstone (Green, 1971).

The color, lithology, structure and stratigraphic position of the reddish-orange, crossbedded sandstones at Lupton, Rehoboth Mission and in the Continental Divide quadrangle (Jcr, fig. 2) are all similar. The basal contact at all localities is an unconformity and the reddish-orange sandstone underlies the medial silty member of the Entrada Sandstone (Harshbarger and others, 1957). The reddish-orange, crossbedded sandstone has been variously assigned to the Wingate or Entrada Sandstone. It is suggested here that the reddish-orange sandstone also could be assigned to the sandstone facies of the Carmel Formation.

The reddish-orange, crossbedded sandstone differs in general appearance and composition from the sandstone facies of the Carmel in the southern part of Black Mesa and along Comb Ridge, because the source areas were undoubtedly different. The sandstone facies in southern Black Mesa and along Comb Ridge were derived largely from the Navajo Sandstone whereas the reddish-orange, crossbedded sandstone was probably derived from the Rock Point Member of the Wingate. A likely

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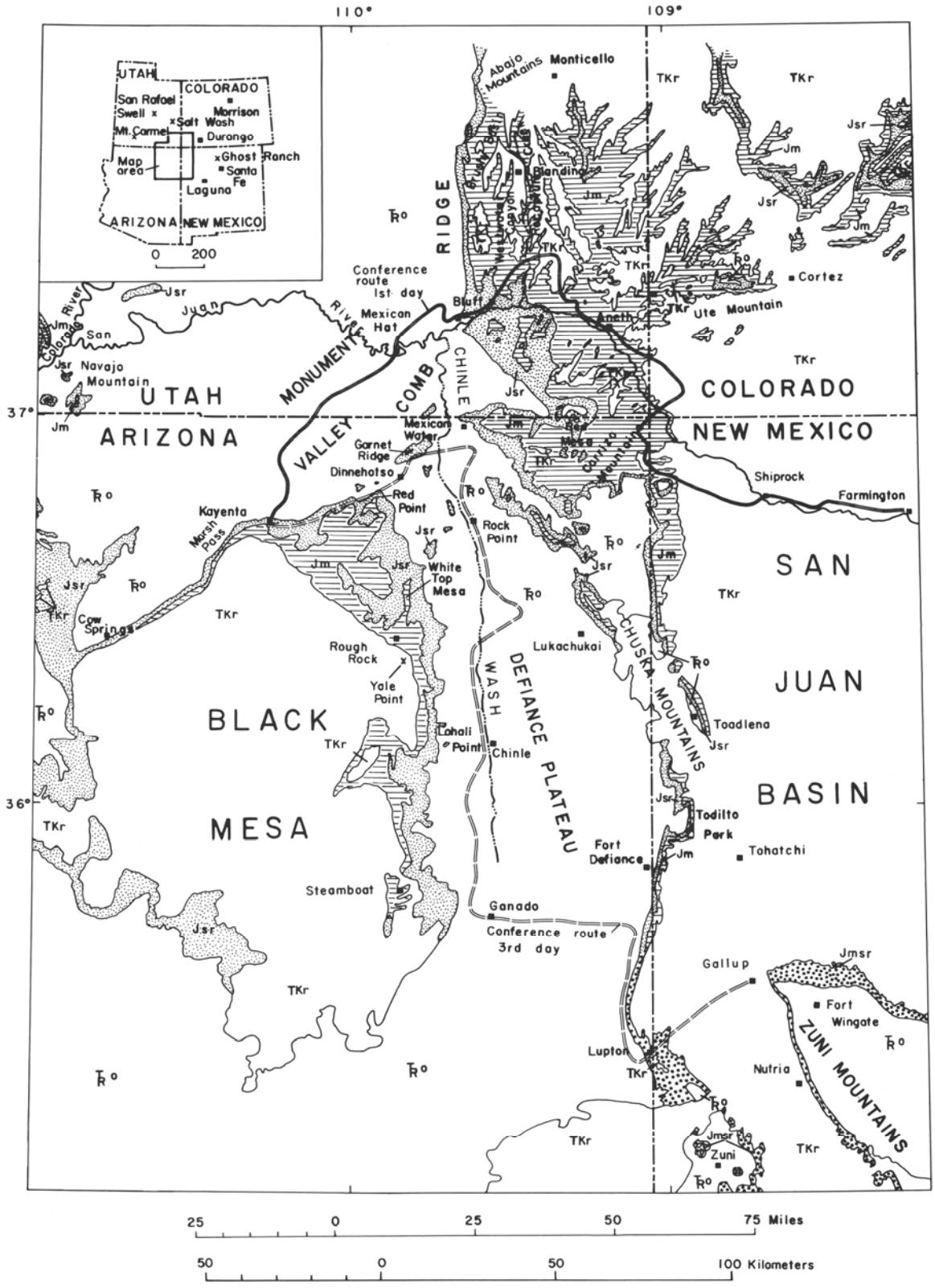

Figure 1.

Map of northeastern Arizona and adjacent areas showing approximate outcrop distribution of Jurassic and related rocks. Jsr, San Rafael Group; Jm, Morrison Formation; Jmsr, Morrison Formation and San Rafael Group; Tkr, Tertiary and Cretaceous rocks; TRo, Triassic and older rocks. All intrusive igneous rocks are omitted. In northeast part of map Triassic and older rocks in deep canyons are locally mapped with the Jurassic. Compiled in part from Andrews and Hunt (1948); Cooley, Harshbarger, Akers and Hardt (1969); Dane and Bachman (1957); Haynes, Vogel and Wyant (1972); and Wilson, Moore and Cooper (1969). Base from U.S. Geological Survey 1:1,000,000 State base maps.

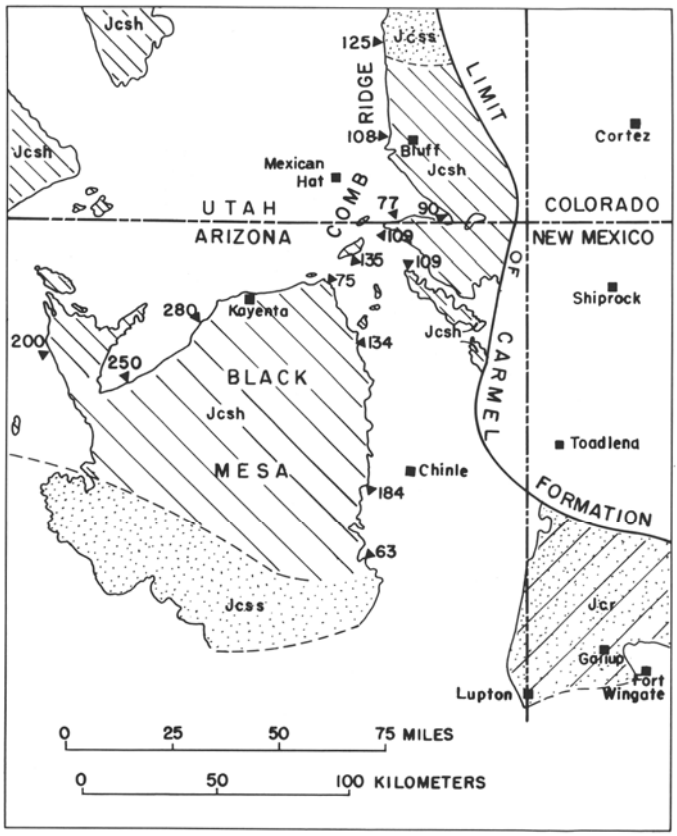

Figure 2.

Distribution, facies and thickness of Carmel Formation and related rocks: Jcss, sandstone facies; Jcsh, shale facies or "reservation" Carmel; Jcr, related reddish-orange crossbedded sandstone facies. Number at black triangle indicates thickness of Carmel Formation in feet. Thickness in Black Mesa area in part from Harshbarger, Repenning and Irwin (1957).

source area is in the vicinity of Toadlena, N. Mex., where the reddish-orange, crossbedded sandstone is absent and the medial silty member of the Entrada rests on the Rock Point Member. Although the Rock Point Member consists mostly of siltstone, in the Toadlena area it also contains ledge-forming sandstone beds 10 to 40 feet thick (Stewart and others, 1972, p. 44). Erosion and transportation southward from the Toadlena vicinity, together with the winnowing action of wind and water which removed much of the silt, resulted in deposition of the distinctive reddish-orange, crossbedded sandstone in the Lupton-Continental Divide area. The period of deposition of the reddish-orange, crossbedded sandstone might well have been contemporaneous with the deposition of the shale and sandstone facies of the Carmel elsewhere in northeast Arizona and adjacent areas.

Entrada Sandstone

The Entrada Sandstone rests conformably on the Carmel Formation. In the Four Corners area the Entrada is 80 to 165 feet thick and tends to weather to a cliff or bench above the irregular slope formed by the Carmel. In the Gallup area the Entrada is as much as 300 feet thick and forms conspicuous bold cliffs.

The Entrada Sandstone is reddish-orange to moderate red dish-brown with small white or light-greenish-gray spots and is streaked with white beds or bands parallel to bedding planes. The sandstone is composed of very fine to fine-grained, sub-rounded to subangular quartz. Here and there are scattered medium to coarse grains of white chert and clear or frosted well-rounded quartz. Sandstone beds are massive and parallel and some small-scale crossbedded units are present at most localities. Large-scale crossbedding in the Entrada is best developed in the Fort Defiance-Gallup area.

The Entrada also includes hard, well-cemented beds that tend to weather into rounded spheroidal forms called stone babies, pillows, or hoodoos. Hoodoo beds, though commonly a moderate reddish-orange, are locally a distinct bright red. The calcareous hoodoo beds are composed of very fine-grained sandstone that contains a considerable amount of silt and clay. Locally there are widely scattered small amounts of fine to coarse quartz and chert grains.

A threefold division (O'Sullivan, 1965, p. 73-76) of the Entrada Sandstone can be traced from Bluff, Utah, to Mexican Water, Ariz. (fig. 3). The same threefold division is recognized in the lower part of the Entrada Sandstone from Garnet Ridge to Lohali Point. At Bluff the threefold division of the Entrada consists of a lower sandstone 48 feet thick, a middle hoodoo unit 55 feet thick and an upper sandstone 19 feet thick. At Red Point the lower part of the Entrada consists of a 27-foot thick lower sandstone, a 7-foot-thick middle hoodoo unit and a 42-foot thick upper sandstone.

The recognition of a threefold Entrada throughout the line of outcrops from Bluff to Lohali Point (fig. 3) differs from the interpretation by Harshbarger, Repenning and Irwin (1957). Their Entrada Sandstone consisted of upper and lower sandy members separated by a medial silty member and they further stated that all three members were present only in the vicinity of Mexican Water (Harshbarger and others, 1957, p. 35-38).

From Garnet Ridge to Lohali Point the threefold Entrada is overlain by a sequence of hoodoo beds referred to as the "beds at Baby Rocks." These beds range in thickness from 100 feet at White Top Mesa to 50 feet at Lohali Point (fig. 3).

The massive "beds at Baby Rocks" show crumpled and distorted bedding that becomes more pronounced upward. The structures displayed by the "beds at Baby Rocks," and similar ones in the Summerville Formation elsewhere, are attributed to submarine downslope flowage of water-soaked sediments (Harshbarger and others, 1957, p. 38), or to collapse of beds due to removal of soluble material (Witkind and Thaden, 1963, p. 44).

Previously, the "beds at Baby Rocks" had been assigned to the medial silty member by Harshbarger, Repenning and Irwin (1957, p. 37). As discussed above, the medial silty member is correlated with the middle hoodoo bed of the threefold Entrada that everywhere underlies the "beds at Baby Rocks" (fig. 3). Thus the "beds at Baby Rocks" are here considered to be a younger unit.

Todilto Limestone

The Todilto Limestone underlies an area of approximately 35,000 square miles principally in New Mexico and Colorado. It consists of a widespread lower limestone generally 7-8 feet thick, and an upper gypsum member generally 70-100 feet thick deposited near the center of the basin in which the Todilto accumulated (Anderson and Kirkland, 1960, p. 37). The Todilto Limestone is present locally along the Arizona-

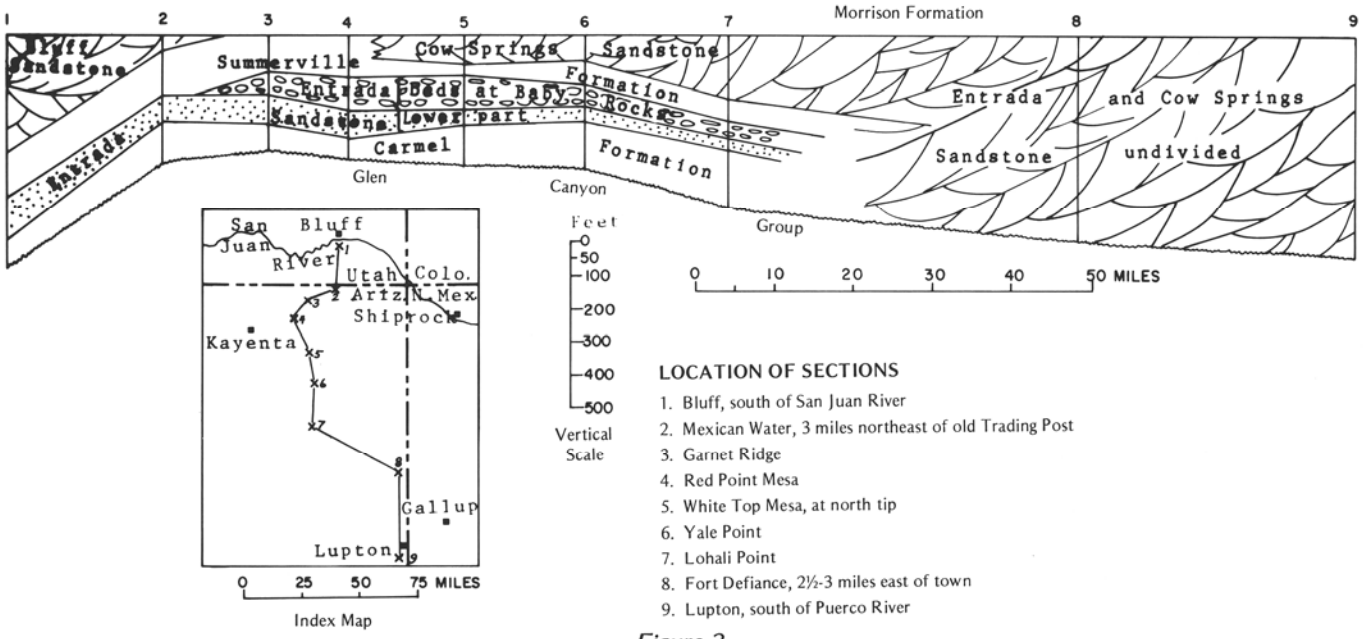

Figure 3.

Stratigraphic diagram showing correlation of San Rafael Group and Cow Springs Sandstone from Bluff, Utah, to Lupton, Ariz.

New Mexico state line on the east side of the Carrizo Mountains and extends no more than 14 miles into Arizona in the northern part of the Chuska Mountains. It is absent in the stratigraphic sequence along the line of sections shown on Figure 3. The route of this field conference therefore lies near the western limits of the Todilto Limestone.

At Todilto Park both the upper and lower contacts of the Todilto Limestone are sharp (Harshbarger and others, 1957, p. 38). Away from the type locality the contacts with the overlying Summerville Formation and underlying Entrada Sandstone are gradational at most places. The limestone that is most conspicuous along the western limits of the formation is light gray, dense and crystalline and thinly laminated. Fresh exposures of the Todilto have a petroliferous odor at most localities.

The Todilto Limestone is now considered to represent deposition in a large saline lake that was probably not connected with a sea. The varve study by Anderson and Kirkland (1960) indicates that the Todilto was deposited in a period of 20,000 years.

Summerville Formation

Above the Entrada Sandstone or the Todilto Limestone where present, is the crinkled and banded Summerville Formation. The Summerville in the Four Corners area is generally well exposed in steep slopes or cliffs.

The Summerville is dominantly silty from Bluff to a line running roughly through Red Point (south of Dinnehotso, Ariz.) to Toadlena, N. Mex. In the area just defined the Summerville is 50 to 160 feet thick and consists of interbedded silty sandstone, shaly siltstone and thin minor shale beds. The sandstone beds are tan, grayish orange, or buff and individually range in thickness from 1 to 8 feet. The very fine- to fine-grained and silty sandstone beds locally contain a scattering of medium grains and generally are parallel or irregularly bedded but locally are crossbedded. The reddish-brown shale and siltstone beds occur mainly as thin grooves between the hard calcareous sandstone beds.

From Bluff to the Carrizo Mountains area the lower 70 to 85 feet of the Summerville is intricately contorted or crinkled as a result of intraformational deformation. The upper part of the formation is evenly bedded except near Bluff where the entire formation is contorted. The contorted zone of the Summerville may be equivalent to that part of the Entrada Sandstone which constitutes the "beds at Baby Rocks" in the Garnet Ridge-Lohali Point area.

The Summerville Formation becomes increasingly sandy as it grades southward into the Cow Springs Sandstone. This progressive lateral change is most obvious in the area lying south of the line through Red Point and Toadlena where the sandy sequence is 50 to 250 feet thick and is reddish-brown or banded reddish-brown and white. The sandstone is fine-grained, well sorted and consists mostly of amber-stained and clear quartz. Bedding characteristically is flat and even but at places shows some small-scale crossbedding. The banded beds of the Summerville are present at least as far south as Lohali Point (fig. 3). On the east side of the Defiance Plateau, the Summerville Formation cannot be recognized near Fort Defiance; its stratigraphic position is occupied by the Cow Springs Sandstone.

Bluff Sandstone

The uppermost formation of the San Rafael Group in the northeast Arizona area is the Bluff Sandstone. The Bluff Sandstone weathers tan to very light gray and is a fine- to very fine-grained, well-sorted sandstone cemented mainly by calcium carbonate. The sandstone commonly contains well-rounded medium to coarse grains either disseminated through the beds or concentrated along laminae.

The Bluff Sandstone consists of four informal members which are referred to as A, B, C and D, in ascending order (Craig and Cadigan, 1958). Member A consists of alternating crossbedded and flat-bedded strata separated by parallel bedding planes and was formed by reworking of dune sands by water. Members B and C are characterized respectively by large-scale and smaller scale crossbeds of eolian origin. Member D is mainly a structureless unit deposited in water.

The Bluff Sandstone is 338 feet thick at Bluff and thins rapidly both to the north and to the south (fig. 3). Most of the loss in thickness is the result of internal thinning. Therefore, the Bluff Sandstone in the Carrizo Mountains is 25 to 50 feet thick and contains beds equivalent only to member A.

In most places the contact between the Bluff Sandstone and the overlying Morrison is a conspicuous erosion surface that may be a widespread disconformity. At places members C and D are both missing and the erosion surface rests on member B. At other localities mudstone of the Morrison Formation overlies member D and the sequence appears conformable. The basal contact of the Morrison Formation marks a change in lithology and bedding structures, and may represent a long time span.

Cow Springs Sandstone

The Cow Springs Sandstone is a crossbedded sandstone that intertongues with both the Summerville Formation and the Morrison Formation and for this reason is treated as a separate formation. At the type locality on the west side of Black Mesa the Cow Springs is 340 feet thick. The Cow Springs usually weathers to smooth rounded slopes but where protected by the Cretaceous Dakota Sandstone it forms a vertical cliff.

The Cow Springs is a fine-grained sandstone made up of subangular to rounded well-sorted grains of quartz and a minor amount of feldspar. The sandstone generally is light green, due to the grayish-green calcium carbonate cement. At most places the Cow Springs is characterized by high-angle, large-scale crossbeds of eolian origin. Flat bedding is locally present, particularly where the Cow Springs grades into the Summerville or Morrison Formation.

On the east side of the Defiance Plateau from Fort Defiance to Lupton, the Cow Springs combines with underlying sandstone equivalents of the San Rafael Group to form a body of sandstone as much as 675 feet thick (fig. 3). The sandstone in this area is a moderate orange, pink, white, light greenish gray and pale reddish brown. It consists mostly of very fine- to medium-grained, well-sorted, subangular to rounded grains of frosted clear and amber-stained quartz. The sandstone is characterized by large-scale crossbeds but flat bedding is present at many places.

It is difficult to distinguish the Entrada from the Cow Springs Sandstone, inasmuch as the distinctive Todilto Limestone is absent and the Summerville Formation cannot be recognized. The Entrada and Cow Springs sandstones are exposed in a rounded cliff-face that is marked by several horizontal bedding planes, some of which form noticeable grooves. The lowest conspicuous groove (or nick) at places contains a thin bed of grayish-red claystone and may represent the horizon of the Todilto Limestone.

Morrison Formation

The Morrison Formation is generally accepted as Late Jurassic in age although the exact age of its upper limits is questionable (Imlay, 1952, p. 953). In the Four Corners area the Morrison Formation is divided into four members (Stokes, 1944; Craig and others, 1955), in ascending order: the Salt Wash, Recapture, Westwater Canyon and Brushy Basin. The interrelation of the members and a generalized idea of their distribution are shown in Figure 4. The petrology of the Morrison was described in detail by Cadigan (1967).

Salt Wash Member

In the area of the field conference the Salt Wash Member ranges in thickness from a featheredge to about 220 feet on the east side of the Carrizo Mountains (Strobel', 1956). To the south the member pinches out at the bottom of the Morrison mostly by grading into and intertonguing with the Recapture Member, but south of Marsh Pass it may grade into the Cow Springs Sandstone. This pinchout is along a line that extends just south of Marsh Pass, north of Rough Rock, Ariz. and north of Toadlena, N. Mex. To the north, near Blanding, Utah, the Salt Wash Member replaces the Recapture (fig. 4) and constitutes the lower half of the Morrison Formation over a large part of eastern Utah and western Colorado.

The Salt Wash Member consists of alternating very pale orange, very fine to medium-grained, relatively well-cemented crossbedded sandstone and pale-reddish-brown, silty to sandy mudstone. The sandstone forms strata composed of many lensing beds which generally have a slightly irregular to sharply channeled scour surface at the base. The sandstone strata form cliffs, ledge slopes and broad benches.

Recapture Member

The Recapture Member attains a maximum thickness of more than 600 feet near Yale Point on Black Mesa. The member thins rapidly to the south and west and is interpreted to pass laterally into the Cow Springs Sandstone (Harshbarger and others, 1957, p. 53).

The Recapture Member consists of interstratified pinkish-gray to light-brown, fine- to medium-grained sandstone and pale-red to very dusky red, silty to sandy mudstone. The sandstone is locally conglomeratic and contains granules and pebbles of quartz, feldspar, granite and black and gray chert disseminated in the sand matrix or concentrated in stringers and layers. The sandstone, as well as the mudstone, is quite friable and the member is generally eroded to form a steep color-banded slope beneath the cliff formed by the Westwater Canyon Member and above the bench formed by the Salt Wash Member, where the Salt Wash is present. The sedimentary structures are generally poorly displayed but where they can be discerned the sandstones are lenticular, cross-laminated, scour-fill beds similar to the sandstones of the Salt Wash Member.

Westwater Canyon Member

The Westwater Canyon Member attains a maximum thickness of more than 300 feet near the New Mexico-Arizona state line in the Todilto Park area. It thins rapidly to the south to a northwest-trending featheredge that passes near Cow Springs Trading Post, Ariz., and south of Zuni, N. Mex. This thinning is interpreted as the result mainly of post-Morrison and pre-Dakota erosion, but, in part, the member may pass laterally into the Cow Springs Sandstone (Harshbarger and others, 1957, p. 53). To the northwest, northeast and east the member thins gradually and tongues and grades into the lower part of the Brushy Basin Member reaching a limit of recognition that passes north of Blanding and southwest of Cortez, Colo.

The Westwater Canyon Member consists of sandstone and minor amounts of mudstone. The sandstone is mostly yellowish gray to light brown, fine- to coarse-grained and locally contains stringers and layers of pebbles of quartz, feldspar, granite, quartzite and minor gray and black chert. The sand-

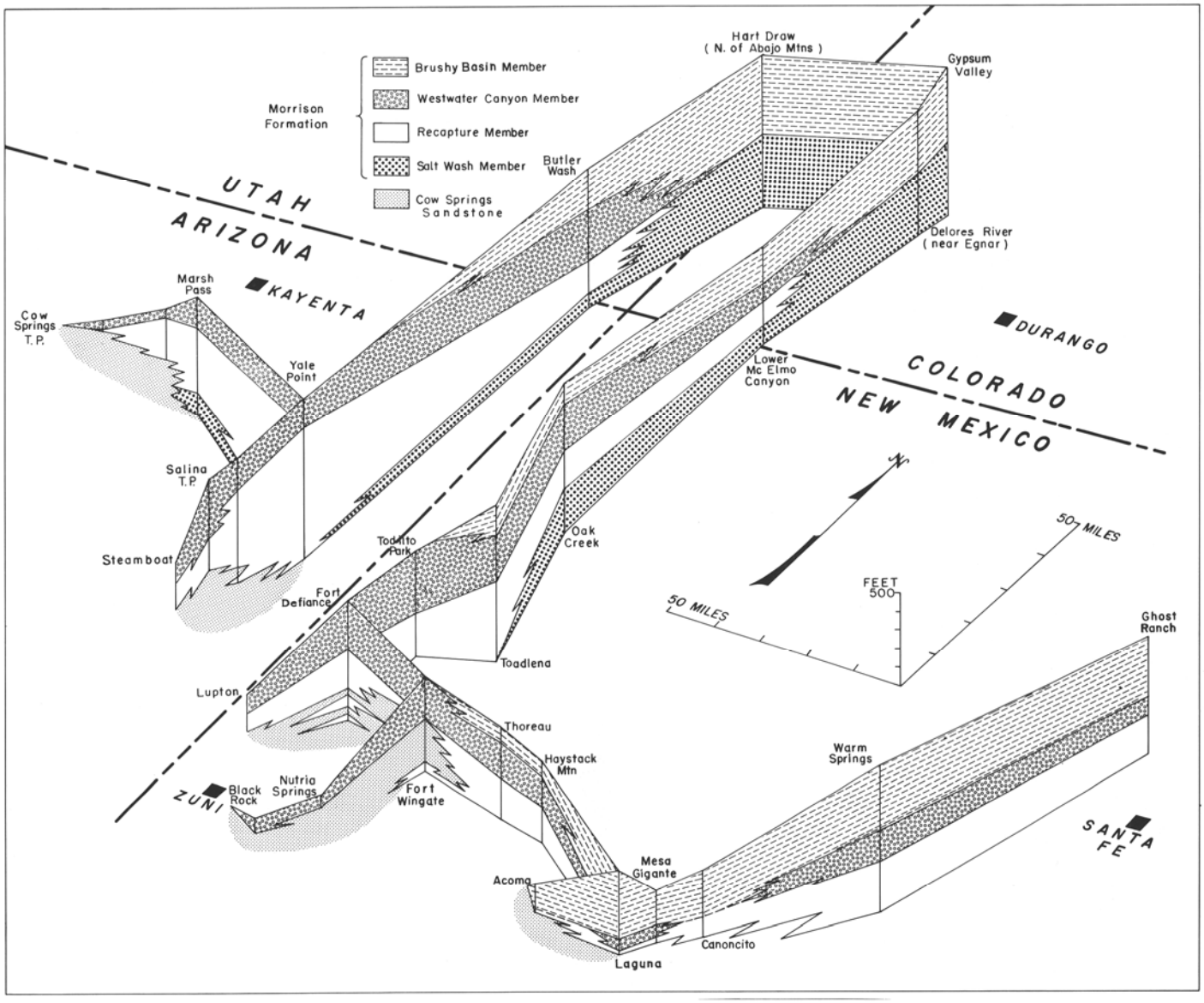

Figure 4.

Fence diagram of Morrison Formation in parts of Arizona, New Mexico and adjacent areas. Datum is top of fence. Sections at Black Rock and Nutria Springs from Harshbarger, Repenning and Irwin (1957, pl. 3); sections at Acoma and Canoncito from Freeman and Hilpert (1956, p. 322, 328). Remainder measured by Craig and others (1959).

stone beds are lensing and cross-laminated and show slightly irregular to deeply channeled scour surfaces at their base. The thin mudstone units are dominantly light-greenish-gray, locally grayish red, and are variably silty and sandy. Although quite friable, the sandstones of the Westwater Canyon Member are more resistant than those of the Recapture Member, and the Westwater Canyon forms nearly vertical cliffs, or very steep, ledgy slopes.

Brushy Basin Member

The Brushy Basin Member thins southwestward from a maximum of about 250 feet near the Four Corners to a northwest-trending featheredge that passes north of Black Mesa to near Todilto Park and east of Gallup. The southward pinchout of the member is largely the result of post-Morrison and pre-Dakota erosion. To the north the member thickens gradually; north of Blanding the Brushy Basin thickens abruptly to 300 feet or more where the Westwater Canyon grades and tongues out into the lower part of the Brushy Basin.

In the area of the field conference the Brushy Basin consists of variegated, silty and sandy mudstone, dominantly grayish green but with minor grayish-red and pinkish colors. It is composed of bentonitic clay, dominantly montmorillonite, in contrast to the lower members which contain mainly nonswelling clays, mostly chlorite, illite and kaolinite (Keller, 1962, p. 32-39).

Overlying Beds

The Morrison Formation in the Four Corners area is overlain by the Lower Cretaceous Burro Canyon Formation. The Burro Canyon thins irregularly southward from the vicinity of Aneth, Utah, and is missing from the section, probably as a

result of pre-Dakota erosion, south of a northwest-trending line through the Carrizo Mountains. Southwest of this line the Dakota Sandstone (Lower(?) Cretaceous and Upper Cretaceous) rests directly on the Morrison Formation.

The entire Morrison Formation is missing from the section south of Zuni, N. Mex., as a result of (1) pre-Dakota erosion cutting progressively lower in the section to the south and (2) a southward facies change in which Morrison beds pass laterally into beds indistinguishable from the Cow Springs Sandstone.

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