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THE MIDDLE JURASSIC ENTRADA SANDSTONE IN NORTHEASTERN ARIZONA AND ADJACENT AREAS

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Abstract.—In northeastern Arizona the Entrada Sandstone is about 30 m thick and consists of upper and lower sandy members and a middle silty Rehoboth Member. The Middle Jurassic Carmel and Wanakah Formations underlie and overlie the Entrada respectively. Locally, the formation directly overlies the Lower Jurassic Glen Canyon Group. The basal sandstone member and equivalent units form a narrow arcuate band stretching from west-central New Mexico through northeast Arizona and into southeastern Utah and southwestern Colorado. The overlying Rehoboth Member extends as much as 100-150 km eastward over the lower member. The upper sandy member is thicker and widespread in New Mexico and is equivalent in part to the Slick Rock Member in southwest Colorado. The stratigraphy and nomenclature of the Entrada and associated strata have been subjected to different interpretations.

INTRODUCTION

The Middle Jurassic Entrada Sandstone is widely exposed around the Carrizo Mountains (Fig. 1), an igneous intrusive complex in northeastern Arizona. It also crops out in discontinuous cliffs that trend northward to Bluff in southeastern Utah. The formation forms the middle part of the Middle Jurassic San Rafael Group and is underlain and overlain throughout most of the study area by the Carmel Formation and the Wanakah Formation respectively (Fig. 2). The Lower Jurassic Glen Canyon Group underlies, and is separated from the San Rafael Group by the J-2 unconformity. In the eastern part of the area shown in Figure 1, the Entrada is underlain by the Triassic Chinle Formation and equivalents. The Upper Jurassic Morrison Formation overlies the San Rafael Group above the J-5 unconformity (Pipiringos and O'Sullivan, 1978).

The interpretations discussed in this report are based on a stratigraphic study of the San Rafael Group from Bluff to Black Mesa in Arizona (O'Sullivan, 1978), supplemented by unpublished measured sections and geologic mapping. Details on some of the Jurassic and related rocks are from reports by Strobell (1956) and Harshbarger et al. (1957). I assisted J.D. Strobell during part of his mapping and compilation of the Carrizo Mountains area. Further details on the lithology, thickness, and stratigraphic relations are in cited references.

STRATIGRAPHY

Glen Canyon Group

The Glen Canyon Group consists of, in ascending order, Wingate Sandstone, Kayenta Formation and Navajo Sandstone. The name Wingate Sandstone is used here to apply only to the unit previously named Lukachukai Member of Wingate (Robertson and O'Sullivan, 2001, p. 65-66). The Navajo and Wingate Sandstones are crossbedded eolian deposits and the Kayenta is largely a fluviatile deposit of sandstone, siltstone, and minor shale and conglomerate. At Rock Point, about 32 km south of Mexican Water, the Wingate is 107 m thick, the Kayenta is 17 m thick, and the Navajo Sandstone is 108 m thick (Harshbarger et al., 1957, pl. 2). According to Strobell (1956), the Kayenta and Navajo thin and disappear near Horse Mesa (Fig. 2, sec. 6).

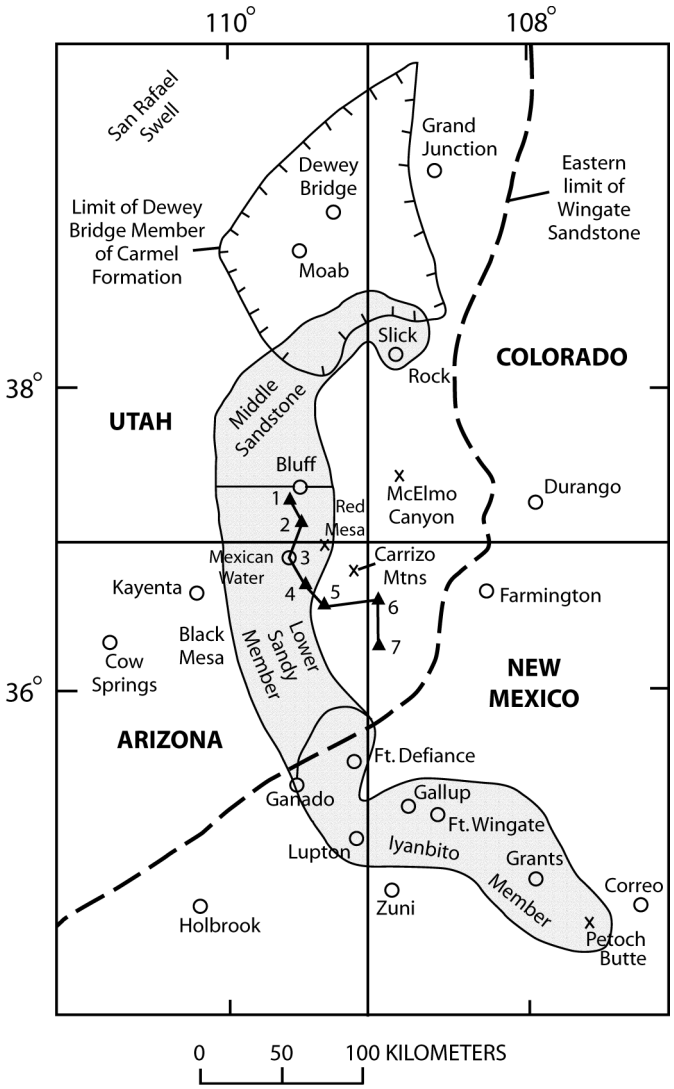

FIGURE 1. Index map of the Four-Corners area showing limits of some stratigraphic units. Eastern limit of Wingate Sandstone from Robertson and O'Sullivan (2001, p. 65-66).

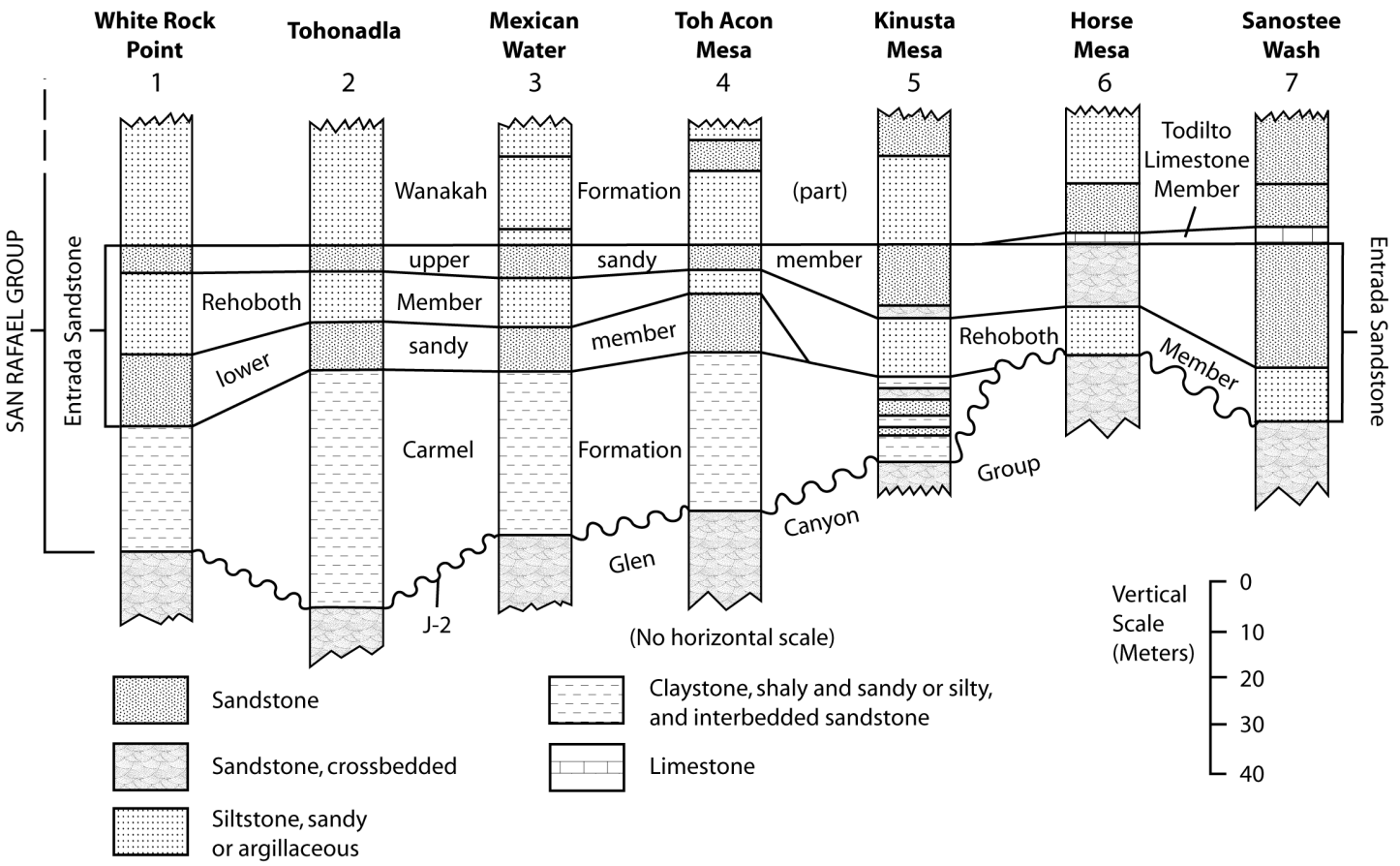

FIGURE 2. Correlation of Entrada Sandstone and related rocks from near Bluff to Sanostee Wash. Sections 3, 5, 6, 7 modified from Strobell (1956). Sections 1, 2, 4 modified in part from O'Sullivan (1978) and in part from an unpublished measured section. Location of sections shown in Figure 1.

Carmel Formation

In south-central Utah, the Carmel Formation contains fossiliferous marine limestone, gypsum, sandstone, and shale. Traced into northeastern Arizona and southeastern Utah, the formation thins and grades into a red, nonfossiliferous shale facies termed informally "reservation" Carmel by many geologists because of its characteristic lithologic expression on the Navajo Reservation.

In the Bluff-Carrizo Mountains area, the "reservation" Carmel consists of interbedded shale and sandstone. The shale is dark reddish brown, micaceous, and in places is silty and sandy. It occurs as beds generally less than 1.5 m thick, but locally are as much as 6 m thick, and weathers to slopes. The sandstone beds are reddish orange or yellowish gray, consist of fine to medium, poorly sorted quartz grains, and are argillaceous and well-cemented by calcium carbonate. The Carmel thins eastward and, at Kinusta Mesa (Fig. 2, sec. 5), contains additional sandstone beds that probably were derived from erosion of the underlying Glen Canyon Group from nearby areas. The formation ranges from 17.6 m at Kinusta Mesa (Fig. 2, sec. 5) to 50.3 m at Tohonadla (Fig. 2, sec. 2). East of Kinusta Mesa (Fig. 2, sec. 5) the Carmel laps out onto the J-2 unconformity.

Entrada Sandstone

The Entrada Sandstone overlies the Carmel Formation in most of the area; where the Carmel is absent, it rests on the Glen Canyon Group (Fig. 2) or on the Triassic Chinle Formation. In the study area, the Entrada Sandstone averages about 29 m in thickness, ranging from 22 m at Toh Acon Mesa (Fig 2, sec. 4) to 37 m at both White Rock Point (Fig. 2, sec. 1) and Sanostee Wash (Fig. 2, sec. 7).

In the Navajo country, which includes parts of northeastern Arizona, northwestern New Mexico and southeastern Utah, the Entrada Sandstone was discussed by Harshbarger et al. (1957, p. 35 and 37) as follows:

"The Entrada sandstone consists of two conspicuous facies: a red silty spheroidally weathered sandstone which is frequently referred to as the hoodoo Entrada, and a clean sandy facies which weathers into rounded massive cliffs and is often referred to as the slick-rim Entrada.... Both facies of the Entrada sandstone are present in the Navajo country.... They occur as three distinct members, two of which consist of the clean sandy facies, separated by a third consisting of the red silty facies. The upper clean sandy facies is referred to as the upper sandy member....The lower clean sandy facies is referred to ... as the lower sandy member.... The red silty facies is referred to .... as the "medial silty member" of the Entrada....The

upper and lower sandy members of the Entrada sandstone range in color from moderate reddish orange ... to grayish orange pink.... The sandstone is composed mainly of medium-to-fine-grained subround to subangular quartz. Coarse well-rounded amber-colored and white quartz grains are concentrated in many places along the bedding planes. Bedding of the units ranges from thin to very thick. Most crossbedding within the units is ... small to large in scale. The variation in scale of crossbedding appears to be dependent upon the environment of deposition.... In both of the sandy members in most of the Navajo country one of the most pronounced characteristics of stratification is the abundance and persistence of parallel bedding planes. Such abundant and persistent bedding planes are not common in formations that are considered to be of eolian origin, such as the Navajo and Wingate sandstones. These bedding planes suggest that a considerable amount of the sandy facies of the Entrada may have been deposited in water. They are especially noticeable in areas where the sandy facies grades into the red silty facies without sharp intertonguing relations."

Strobell (1956) described the Entrada Sandstone as follows:

"Throughout most of the Carrizo Mountains area the Entrada consists of a lower siltstone unit and an upper sandstone unit. North and west of Red Mesa, however, additional beds of sandstone like the upper unit occur at the base.... It is concluded that the two lithologies are closely related, and they have both therefore been assigned to the Entrada sandstone. The siltstone is calcareous and sandy, moderate reddish brown to moderate reddish orange, blocky to massive, and characteristically weathers into a steep slope or forms rounded bosses and knobs called "stone babies" or "hoodoos". The stratification, mostly obscure, is parallel but wavy and may have been disturbed prior to consolidation; scattered white spots and extensive white bands as much as a foot thick that parallel some parting planes are common. The sandstone is fine- to medium-grained and commonly contains well-rounded frosted grains of quartz 0.5 to 1.0 mm in diameter. Alternating layers of intricately cross-stratified and plane-bedded sandstone are also typical. The sandstone is generally somewhat lighter reddish brown than the siltstone, and being more resistant, forms a cliff."

The descriptions by Harshbarger et al. (1957, p. 35-38) and by Strobell (1956), combined with my 1978 report (O'Sullivan, 1978) and a recent report by Robertson and O'Sullivan (2001), emphasize the three subdivisions of the Entrada recognized in the study area, which are the lower and upper sandy members and a medial silty member that is now called the Rehoboth Member. The three subdivisions are found together over an area that coincides with the distribution of the lower sandy member shown in Figure 1. The Rehoboth Member extends further eastward into New Mexico over the lower sandy member and equivalent units (Robertson and O'Sullivan, 2001, fig. 1; compare to Fig. 1 of this report). The upper sandy member and equivalents extend even further over the Rehoboth into much of northern New Mexico and adjacent areas. The successive eastward distribution of the three subdivisions, in general, reflects progressive onlap of the Entrada onto the J-2 unconformity.

The basal units of the Entrada Sandstone (lower sandy member and equivalents) are of limited distribution, forming an arcuate narrow band extending from near Correo, New Mexico, through northeast Arizona and southeast Utah, and curving into the Slick Rock area of southwest Colorado (Fig. 1). The southern segment of the band is the Iyanbito Member, the middle segment from Bluff southward towards Fort Defiance is the lower sandy member, and the equivalent segment north of Bluff is the middle sandstone. The middle sandstone was named by Witkind (1964, p. 21) and reflects its position between the Carmel Formation and the Rehoboth Member (see Fig. 6). The connection between the Iyanbito and lower sandy member has been eroded in the area north of Fort Defiance, where older rocks are exposed. In the study area, the lower sandy member averages about 11 m in thickness; where present, it ranges from 9 m at Mexican Water (Fig. 2, sec. 3) to 15 m at White Rock Point (Fig 2, sec. 1).

The name Rehoboth Member was recently introduced (Robertson and O'Sullivan, 2001) for the distinctive red hoodoo-weathering medial silty member. The name is derived from Rehoboth Mission and Hospital that lies just east of Gallup, New Mexico, and south of Interstate 40. The Rehoboth is the equivalent of the siltstone unit of Strobell (1956), the medial silty member of Harshbarger et al. (1957, p. 37) and the middle silty member as mapped in the eastern part of the Navajo Country by Cooley et al. (1969, pl. 1). In southeast Utah, it correlates with the upper red of Witkind (1964, p. 19) in the Abajo Mountains area and with the red member as used by O'Sullivan (1996). The Rehoboth Member covers a large L-shaped area within the contiguous parts of New Mexico, Arizona, Utah, and Colorado (Robertson and O'Sullivan, 2001, fig. 1).

The Rehoboth Member overlies the lower sandy member in some of the study area and in the eastern part of the Carrizo Mountains area it overlies the Carmel Formation or Glen Canyon Group (Fig. 2). East of the pinchouts of the Carmel and Glen Canyon Group, the Rehoboth overlies the Triassic Chinle Formation. The Rehoboth Member averages about 11 m in thickness, and where present, ranges from 4.5 m thick at Toh Acon Mesa (Fig. 2, sec. 4) to 17 m at White Rock Point (Fig. 2, sec. 1).

The upper sandy member is similar lithologically to the lower sandy member and tends to form a smooth ledge above the Rehoboth Member. In the study area, the member averages about 11 m in thickness, ranging from 4.5 m at Tohonadla (Fig. 2, sec. 2) to 26 m at Sanostee Wash (Fig. 2, sec. 7); it thickens easterly and is 60-70 m thick in the Gallup area.

Wanakah Formation

The Middle Jurassic Wanakah Formation overlies the Entrada Sandstone throughout the Bluff-Carrizo Mountains area. It is largely a redbed sequence of sandstone and siltstone in beds generally less than 1 m thick. The Todilto Limestone Member, at the base of the formation in the eastern part of the study area, is 0.6 m thick at Horse Mesa (Fig. 2, sec. 6) and 3.3 m thick at Sanostee Wash (Strobell, 1956). The Wanakah in the study area averages about 48 m in thickness, ranging from 39 m at Kinusta Mesa (Fig. 2, sec. 5) to 53 m at Sanostee Wash (Fig. 2, sec. 7). Only the lower part of the formation is shown in Figure 2.

OTHER INTERPRETATIONS

The Iyanbito Member of the Entrada Sandstone, herein considered an equivalent of the lower sandy member in areas southeast of Ft. Defiance (Fig 1), is treated by Lucas et al., (2001, p. 225) as "....nothing more than outcrops of the Wingate Sandstone in west-central New Mexico and adjacent Arizona...." However, the eastern limit of the Wingate Sandstone lies along a northeast- to north-trending line generally west of the area underlain by the Iyanbito (Fig. 1). This line also roughly parallels the eastern limit of the overlying Kayenta Formation and Navajo Sandstone (see Robertson and O'Sullivan, 2001, fig. 1). If the Iyanbito Member was part of the Wingate, then the eastern limit of that formation would swerve southeast from the Fort Defiance area toward Petoch Butte, forming an anomalous distribution pattern not followed by any other directly underlying or overlying unit. In addition, Hackman and Olson (1977), who mapped the Gallup 1° x 2° quadrangle, described the eastern limit of the Wingate Sandstone as lying several miles west of Ganado, Arizona, over 80 km northwest of Gallup (as shown in Fig. 1), whereas the Iyanbito Member was mapped with the Entrada east of Gallup. Baars (2000, p. 144) stated "....there is no Wingate Sandstone at the type section at Ft. Wingate east of Gallup....."

The term "Dewey Bridge Member" of the Entrada Sandstone was incorrectly introduced into the Gallup area by Lucas et al. (1998, p. 54-55) in place of the medial silty member (now Rehoboth Member). The Dewey Bridge Member is now assigned to the Carmel Formation (O'Sullivan, 2000) and is removed from the Entrada Sandstone. I recognize the Dewey Bridge Member only in an area of about 14,500 km^2 in east-central Utah and adjacent parts of Colorado (Fig. 1). The member derives its name from Dewey Bridge, a locality on the Colorado River about 32 km northeast of Moab. The Dewey Bridge Member is lithologically like the Rehoboth Member but the two members are separated by the middle sandstone.

Lucas et al. (2001, fig. 1) also showed their "Dewey Bridge Member" grading into the Carmel Formation in the vicinity of Mexican Water (Fig. 3). This implies that the hoodoo-weathering Rehoboth Member (their "Dewey Bridge") is an equivalent of the Carmel Formation. Harshbarger et al. (1957, p. 34-35) discussed this possible relation as follows (bracketed notations have been added):

"In eastern Utah and western Colorado [the Moab area] the red silty facies of the Carmel is massive and shows little tendency to weather differentially along bedding planes (Baker, 1933). In this area it weathers into rounded forms often described as hoodoos [this describes the Dewey Bridge Member in the Moab area]. This lithology is similar to the silty facies of the overlying Entrada sandstone. Similar facies occur in a unit beneath the sandy facies of the Entrada along the Arizona-New Mexico State line and eastward into New Mexico. In the Fort Wingate area this unit [the Rehoboth Member] has been considered correlative with the Carmel Formation (Baker and others, 1947, p. 1666), presumably because of the resemblance of the hoodoo weathering to that of the Carmel in the Colorado-Utah State line area [that is, to the Dewey Bridge Member in the Moab area]. However, geologic mapping from Bluff, Utah, across the northeastern corner of Arizona and along the east flank of the Defiance uplift has shown no tendency in the red silty facies of the Carmel [the "reservation" Carmel] to develop into massive hoodoo type of rock, as it apparently does eastward across Utah into Colorado. In addition, the red silty, hoodoo-weathering facies of the Entrada [the Rehoboth Member] has been recognized throughout this area and in New Mexico. Consequently, the silty unit [the Rehoboth] present at Fort Wingate is herein treated as a facies of the Entrada."

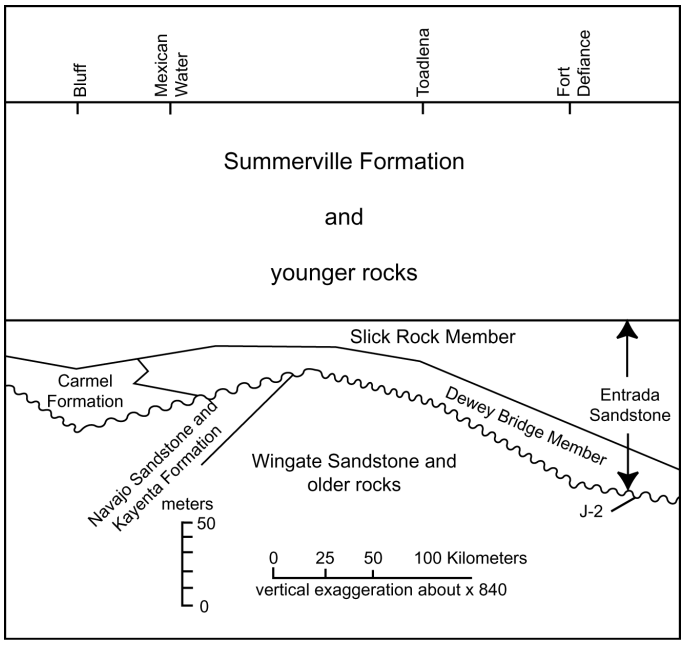

FIGURE 3. Correlation of some Jurassic rocks from Bluff to Fort Defiance; modified in part from Lucas et al. (2001, fig. 1B). Correlation used in the present report is shown in Figure 2.

Lucas et al. (2001, p. 227) further stated "Thus, in west-central New Mexico the "Rehoboth Member" is the lowest stratigraphic interval of the Entrada Sandstone and is largely equivalent to the Carmel...." However, at Mexican Water (Fig. 2, sec. 3) the Rehoboth Member is separated from the Carmel by the lower sandy member, and at Red Mesa (Fig. 4), 26 km northeast of Mexican Water, the Rehoboth Member also overlies the Carmel Formation as it does near Bluff (Fig. 5). Therefore, the Rehoboth and Carmel cannot be correlative.

Lucas et al. (Fig. 3) considered all of the upper part of their Entrada Sandstone to be equivalent only to the Slick Rock Member. In contrast, I recognize a three-fold subdivision of the Entrada at Mexican Water (Fig. 2, sec. 3), at White Rock Point (Fig. 2, sec. 1), and in some adjacent sections (Fig. 2). Further, I recognize only the thin upper sandy member of the Entrada as an equivalent of the Slick Rock Member (Fig. 6). The type locality of the Slick Rock Member is at the town of Slick Rock, Colorado, about 100 km northeast of Bluff, where it is 31.4 m thick (Wright et al., 1962, p. 2069), consists of crossbedded eolian sandstones alternating with flat-bedded interdune strata, and is underlain by the Rehoboth Member. The latter has been traced as the medial silty member of Harshbarger et al. (1957), from Mexican Water

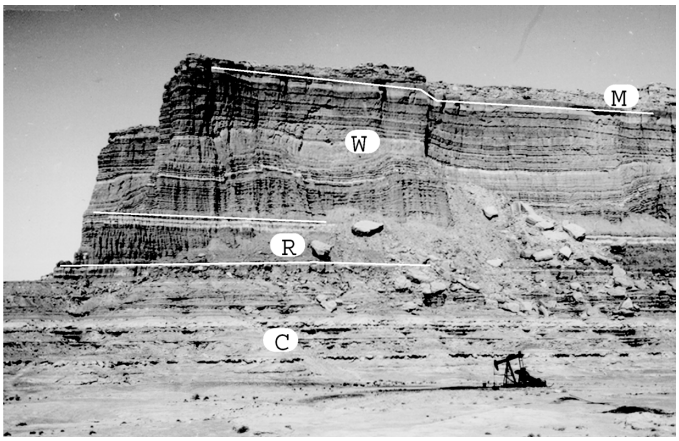

FIGURE 4. View west of Red Mesa in Sec. 4, T.41N., R.28E., Apache County, Arizona. Carmel Formation (C) 29 m thick. Entrada Sandstone includes Rehoboth Member (R) 20 m thick; upper and lower sandy members make thin white bands at top and base of Rehoboth. Wanakah Formation (W) and Morrison Formation (M) cap the mesa.

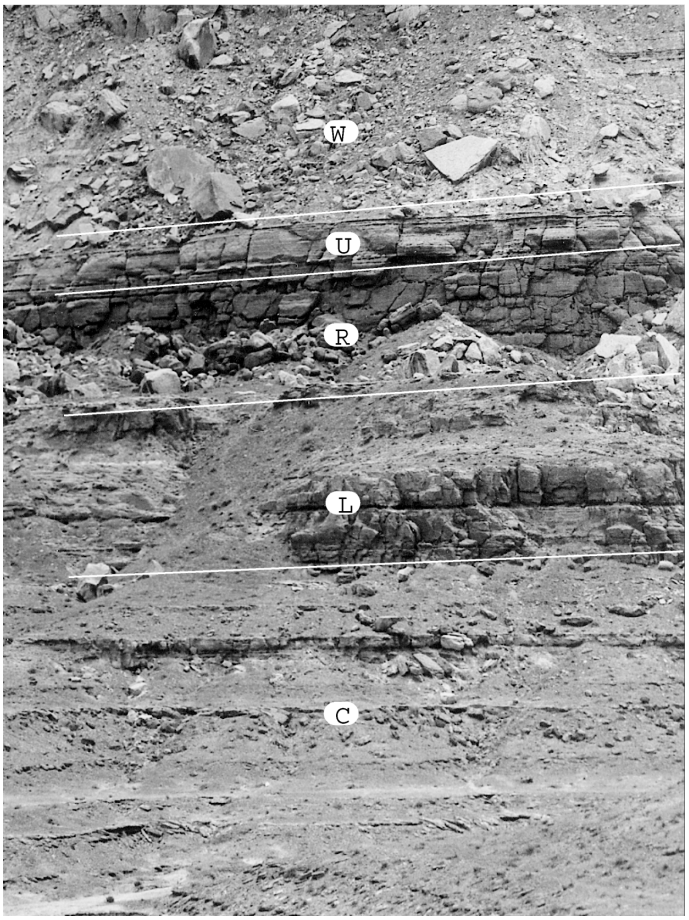

FIGURE 5. View of some Jurassic rocks south of San Juan River about 4 km southwest of Bluff and near White Rock Point, Carmel Formation (C). Overlying Entrada Sandstone includes: (L) lower sandy member (middle sandstone north of San Juan River); (R) Rehoboth Member; (U) upper sandy member (salmon sandstone north of San Juan River). Wanakah Formation (W). Rehoboth is about 17 m thick. The Carmel, Entrada and Wanakah Formations have the same stratigraphic arrangement at Mexican Water.

north to the Bluff area, thence, as the red member of O'Sullivan (1996), east to McElmo Canyon and north to Slick Rock, Colorado (O'Sullivan, 1997, 1995a, 1995b). At White Rock Point (Fig. 2, sec. 1) the upper sandy member of the Entrada is only 5.9 m thick and grades into the Slick Rock Member east of Bluff near the Colorado-Utah State line (O'Sullivan, 1997). At exposures in McElmo Canyon, the Slick Rock Member is 21-24 m thick (Ekren and Houser, 1965, p. 8) and thickens northward to the type locality. Because some of the overlying Wanakah grades into and has been replaced by the Slick Rock Member (Fig. 6), the latter is much thicker than the upper sandy member.

The name "Summerville Formation", rather than Wanakah Formation, has previously been used for strata above the Entrada Sandstone in the Carrizo Mountains area. Strobell (1956) thought that "The name Wanakah has been applied in southwestern Colorado to a varying stratigraphic interval (Burbank, 1930; Goldman and Spencer, 1941; Read et al., 1949). Because of this confusion and because the exposures are in different areas 40 or 50 miles apart, extension of the term Wanakah to Arizona seems inexpedient." Instead, Strobell (1956) assumed that the beds above the Entrada "correlated with the Summerville formation of Utah".

Similarly, Lucas et al. (2001) used the term "Summerville" for beds above the Entrada. The Middle Jurassic Summerville Formation at the type locality in the San Rafael Swell, about 110 km northwest of Moab, is separated from the Entrada Sandstone by the Middle Jurassic Curtis Formation – a marine sandstone about 61 m thick. The Wanakah Formation, however, was defined by Burbank (1930, p. 171-177) as beds directly overlying the Entrada Sandstone. The Todilto Limestone Member at the base of the Wanakah was considered by Anderson and Lucas (1992, p. 81) to be a homotaxial correlative of the Curtis Formation and the

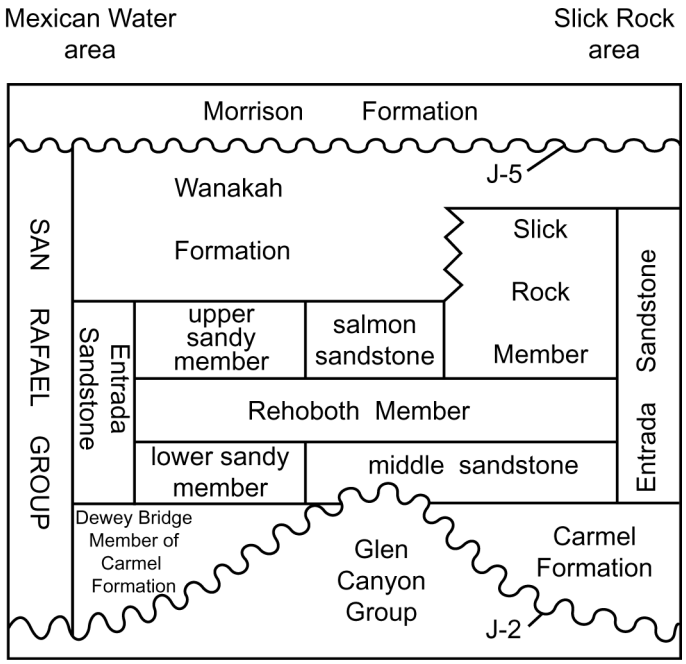

FIGURE 6. Schematic diagram from the Mexican Water area to the Slick Rock area showing general stratigraphic relations of the Entrada Sandstone and related formations. Not to scale.

beds overlying the Todilto were thought to be equivalent to the Summerville Formation. On the other hand, Peterson (1994, p. 248-249) believed that the Todilto Limestone Member correlates with the upper part of the Entrada Sandstone in south-central Utah and not with the Curtis Formation. However the stratigraphic relations are resolved, the beds above the Entrada are unequivocally Wanakah by definition and are so used in the present study.

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