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2010, pp. 91-100. https://doi.org/10.56577/FFC-61.91

in:

Geology of the Four Corners Country, Fassett, James E.; Zeigler, Kate E.; Lueth, Virgil W., [eds.], New Mexico Geological Society 61st Annual Fall Field Conference Guidebook, 246 p. https://doi.org/10.56577/FFC-61

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CORRELATION OF THE UPPER PART OF THE MIDDLE JURASSIC SAN RAFAEL GROUP IN NORTHEAST ARIZONA, NORTHWEST NEW MEXICO, AND SOUTHEAST UTAH

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ABSTRACT—In east-central Utah, the Middle Jurassic San Rafael Group consists, in ascending order, of the Page Sandstone, Carmel Formation, Entrada Sandstone, Curtis Formation, and Summerville Formation, with a combined thickness of about 365 m. In northwestern New Mexico, the sequence, only about 80 m thick, consists of the Entrada Sandstone overlain by the Wanakah Formation the basal part of which is the distinctive Todilto Limestone Member. The San Rafael Group includes a mixture of terrestrial, marine, and marginal marine deposits. An unconformity, termed "J-3", underlies the Curtis Formation and can be traced into northwestern New Mexico where it lies near the middle of the Wanakah Formation. Previously, the Curtis Formation had been correlated with the Todilto Limestone Member. However, the Todilto lies beneath the J-3 unconformity and is separated from it by about 20 m of strata. All of the Summerville Formation is truncated by another unconformity, termed "J-5", in east-central Utah, and the formation does not extend into New Mexico and adjacent areas.

INTRODUCTION

The Middle Jurassic San Rafael Group underlies large areas of southeastern Utah and adjacent areas of Arizona, Colorado, and New Mexico (Fig.1). In the San Rafael Swell in Utah, the group consists of 5 formations, in ascending order, the Page Sandstone, Carmel Formation, Entrada Sandstone, Curtis Formation and Summerville Formation (Fig. 2). In exposures at Beclabito Dome in northwestern New Mexico, the sequence consists of the Entrada Sandstone overlain by the Wanakah Formation. The San Rafael Group thickens from 80 m at Beclabito Dome (Strobell, 1956; Condon, 1989) to 153 m in the Moab area (O'Sullivan, 1980a) and to about 365 m in the San Rafael Swell (Fig.1) (Pipiringos and O'Sullivan, 1978, pl. 1). Throughout most of the area, the strata are underlain by the Glen Canyon Group of Early Jurassic age and overlain by the Morrison Formation of Late Jurassic age.

This report changes some previous stratigraphic assumptions. For example, Anderson and Lucas (1992, p. 80) stated "…Wanakah Formation is another name for Summerville…." However, the 2 units discussed here are different and unrelated formations. The Summerville Formation is truncated in Utah 200 km north of Four Corners and does not extend into New Mexico where it is now recognized,for example ,by Kirtland and others (1995, fig. 15). The basal unit of the Wanakah Formation, the Todilto Limestone Member, thought to be equivalent to the Curtis Formation, is here shown, instead, to be older and unrelated.

STRATIGRAPHY

In this report only the uppermost parts of the San Rafael Group are discussed, including the upper part of the Entrada Sandstone and the Curtis and Summerville Formations as well as the related Wanakah Formation. Two unconformities are associated with these rocks: (1) the J-5 unconformity, which separates the Morrison Formation from underlying rocks; and (2) the J-3 unconformity, which lies within the San Rafael Group. A stratigraphic diagram (Fig. 3) shows the stratigraphic positions and distribution of the formations and some of their subdivisions. The J-3 unconformity is used as the datum to construct the diagram to emphasize the relations of units above and below the unconformity. Descriptions of all units are only briefly discussed in this report; further details are given in the reports cited.

Sources of Data

The stratigraphic diagram (Fig. 3) is drawn from several sources. The section in the San Rafael Swell (sec. 1) is from Wright and others (1979, p. 43-56). I assign their units 37-40 of the Entrada Sandstone, because of lithology, to the unit labeled "beds at Goblin Valley" (Fig. 3). Sections at Dellenbaugh Butte and at Bartlett Flat (sec. 3) are from O'Sullivan (1980a) and Caputo and Pryor (1991, fig. 3), respectively. The stratigraphic sections at Photo Gap (sec. 4) and Bluff (sec. 5) are from Carr-Crabaugh and Kocurek (1998, fig. 3), but are slightly modified for this report. The "bed at Butler Wash" of the Wanakah Formation (Fig. 3) is extended into Dry Valley to a point just north of Photo Gap, where Carr-Crabaugh and Kocurek (1998, fig. 3) recognized the Moab Tongue of the Entrada Sandstone. Section 6 at Beclabito Dome is from Condon (1989) and Strobell (1956), and sections 7 (Mexican Water), 8 (Garnet Ridge), and 9 (Red Point) are from O'Sullivan (1978).

J-3 Unconformity

An unconformity at the base of the Curtis Formation, in the San Rafael Swell, described by Gilluly (1929, p. 105-108), was later identified as the J-3 unconformity by Pipiringos and O'Sullivan (1978, p. A 23). The eastern limits of the J-3 unconformity as drawn by Pipiringos and O'Sullivan (1978) and, as now interpreted, are shown in Figure 4. The revision is based on later studies by (1) Doelling (2001, pl. 2), who extended the J-3 surface from Dellenbaugh Butte on the Green River through the Moab area and into western Colorado; and (2) Carr-Crabaugh

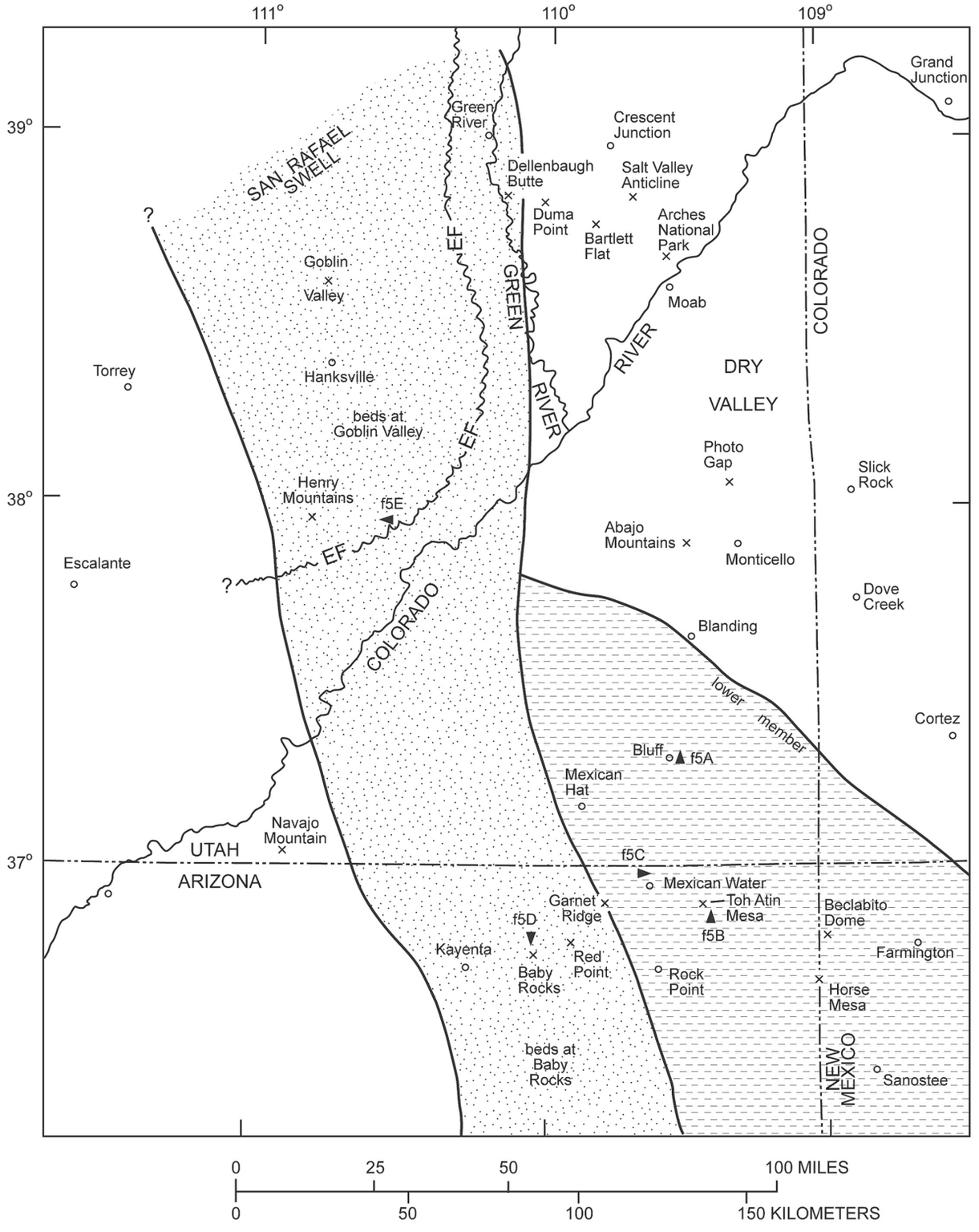


FIGURE 1. Index map of southeastern Utah and adjacent areas. Shows the distribution of rock units directly under the J-3 unconformity. Stippled area underlain by Entrada Sandstone- the beds at Goblin Valley and the beds at Baby Rocks west and east of the Colorado River, respectively. Short-dash pattern underlain by the lower member of the Wanakah Formation. Unpatterned areas underlain by "slick rock facies" of Entrada Sandstone. Locally, in southwest part of map, the "slick rock facies" of the Entrada Sandstone underlies the J-5 unconformity where the J-3 surface has been truncated (see Peterson, 1988, figs. B5, B7, B13). Triangles labeled f5A-f5E are locations of views of the J-3 shown in Figure 5. The irregular line labeled EF shows the eastern and southern limits of the "earthy facies" of the Entrada Sandstone.

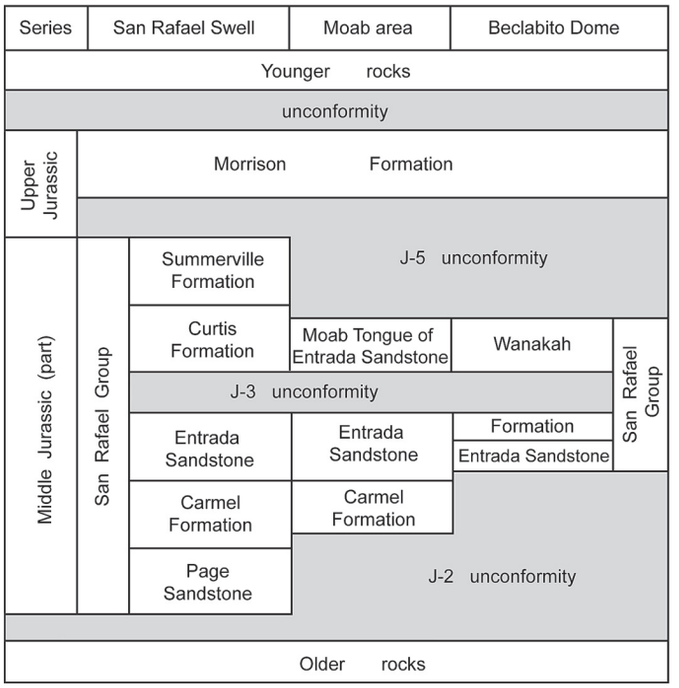


FIGURE 2 Nomenclature of Middle and Upper Jurassic rocks in the San Rafael Swell, Moab area ,and at Beclabito Dome in northwestern New Mexico. Labeled unconformities are discussed in Pipiringos and O'Sullivan (1978).

and Kocurek (1998, fig. 3) who traced J-3 from near the Moab area to Bluff on the San Juan River. In addition, I traced it into northeastern Arizona (Fig. 4). In far northwestern New Mexico at Beclabito Dome (sec. 6), the J-3 unconformity is recognized at the base of the unit termed "bed at Butler Wash". The further extent of the J-3 surface into New Mexico is uncertain. However, about 42 km southeast of Beclabito Dome the base of the bed at Butler Wash and possibly the J-3 unconformity is at a depth of 2,640 ft in the Amerada Petroleum Corp. Navajo Tract 4 No. 1 drill hole in Sec. 20, T. 27 N., R. 17 W., San Juan County, indicating that it may extend at least that far eastward (Fig. 4).

Entrada Sandstone

The Entrada Sandstone at places west of the Colorado River displays two contrasting lithologies. In the San Rafael Swell, the formation consists of red fine-grained sandstone and interbedded red mudstone, a lithology termed "earthy facies". South and east from the Swell, it grades largely into a cliff-forming crossbedded sandstone termed the "slick rock" facies (Peterson, 1988, p. 21). A line (labeled EF) separating the two facies is shown in Figure 1, derived in part from Hunt (1953, p. 71) and in part from Wright and others (1962, p. 2062). The earthy facies is considered to be of marginal to marine origin (Baker, 1946, p. 80). The slick rock facies is mostly of eolian origin.

The Entrada Sandstone varies considerably in thickness, being 314 m thick at Pine Creek (Peterson, 1988, p. 48-51) at a locality about 5 km north of Escalante, Utah, 95 m thick at the type section in the San Rafael Swell (Gilluly, 1929, p. 105), 105 m thick near Moab, 38 m thick at Bluff, and according to Strobell (1956) is only 28 m thick at Beclabito Dome. As noted earlier, only the upper part of the formation is discussed in this report.

A silty unit at the top of the Entrada Sandstone is here referred to as the "beds at Goblin Valley" west of the Colorado River, and as "the beds at Baby Rocks" in northern Arizona (Fig. 3). Both units directly underlie the J-3 unconformity, are similar lithologically, show similar weathering features, and both display contorted bedding at many localities (Fig. 5). They undoubtedly once formed a continuous north-trending unit (Fig. 1) but the connection has been eroded away by the Colorado River.

The beds at Goblin Valley at the top of the Entrada Sandstone were discussed by McKnight (1940, p. 92), who described them in outcrops extending about 10 km east of the Green River as "… a brownish-red muddy sandstone that weathers into rounded "rock baby" surfaces. The bedding is poor but appears to be largely horizontal ... This facies of the Entrada is unlike anything developed to the east." In the Green River Desert, west of the Green River (Fig. 1), Baker (1946, p. 76) recognized the unit as a "… zone of earthy sandstone 60 to 100 feet thick at the top of the formation…across the area ...." At places in the Henry Mountains, Hunt (1953, p. 71) reported that the upper beds of the Entrada have eroded very irregularly and give rise to clusters of small grotesquely shaped buttes." In Goblin Valley, a locality southeast of the San Rafael Swell (Fig. 1), the beds at Goblin Valley are eroded into a complex maze of spheroidal forms termed "hoodoos", "stone babies", or "goblins." A part of the valley has been set aside as Goblin Valley State Park because of these interesting and unique erosional features.

The beds at Baby Rocks, present only in northeastern Arizona, are massive, reddish orange, very fine-grained and silty sandstone that tends to weather to rounded forms similar to those described above. These erosional features are well displayed at Baby Rocks, a locality about 20 km east of Kayenta. According to Witkind and Thaden (1963, p. 43), sorting in the upper Entrada (beds at Baby Rocks) "… is poor …and angular polished grains of quartz average about 0.06 mm in size. All grains are stained with iron oxide. Iron oxide is the principal cementing agent." The beds, in places, show crumpled and distorted bedding that becomes more pronounced upward (Fig. 5). These structures in the Entrada and in the lower member of the Wanakah " … are believed to be due to plastic flow of water-soaked sediments downslope along the sea floor" (Harshbarger and others, 1957, p. 38) or to collapse of beds due to removal of soluble material (Witkind and Thaden, 1963, p. 44).

The Moab Tongue, of eolian origin (Wright and others, 1962, p. 2063), is the youngest part of the Entrada Sandstone. It is present over an area extending from near Duma Point southward into Dry Valley, which lies north of Monticello, Utah (Fig. 1). In the Moab-Dry Valley area, the Moab Tongue is described by Baker (1933, p. 49) as a "…single massive cross-bedded grayish-white bed 90-100 feet thick and separated from the rest of the Entrada sandstone by a definite bedding plane. The "definite bedding plane" is now recognized as the J-3 unconformity. The tongue thins abruptly near Photo Gap (Fig. 3) and the lower part continues southward and correlates with the bed at Butler Wash.

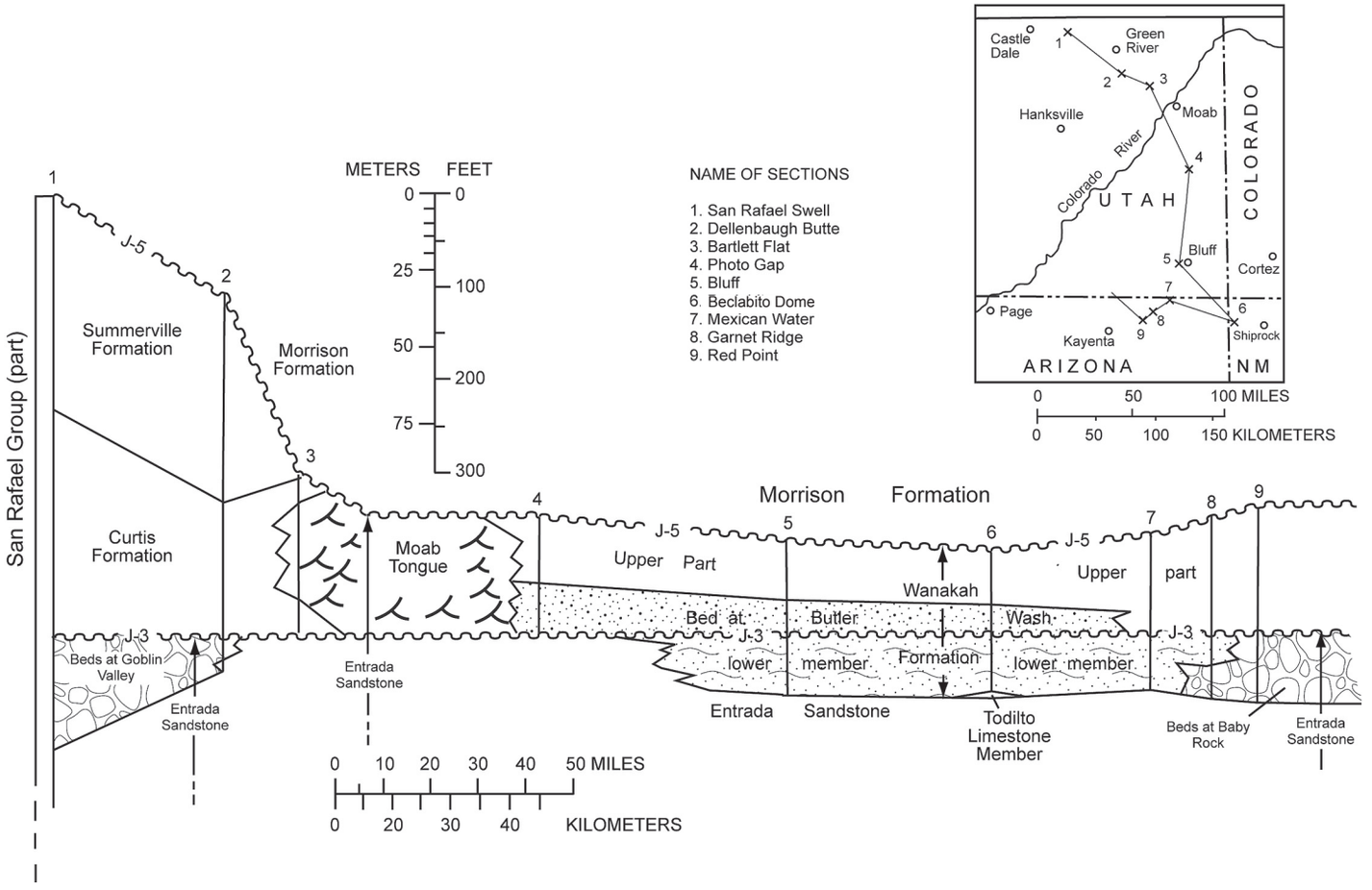


FIGURE 3. Stratigraphic diagram showing correlation of the upper part of the San Rafael Group. Location of sections discussed in text.

The Moab is presently considered a tongue that somewhere joins the underlying Entrada Sandstone. Doelling (2000) questions this assignment and states (p. 22-23) "… the Entrada is separated from the Curtis Formation by a regional unconformity … named the J-3 unconformity. I believe this unconformity continues eastward … and that the Moab Member is not a tongue of the Entrada Sandstone. I have identified this unconformity as far east as the Colorado state line…. The change from normal Curtis … lithology into the Moab Member is abrupt; from areas west of Arches, Curtis Formation rock types continue eastward under the … Moab Member into the Arches [National Park] area …". The Arches National Park lies about 5 km north of Moab. As a consequence, Doelling (2000, p. 23) assigns the Moab as a member of the Curtis Formation. Gard (1976, p. 20) also recognized the Curtis Formation beneath the Moab Tongue in the Salt Valley Anticline area about 32 km north of the town of Moab. In this report, Moab is retained as a tongue of the Entrada Sandstone because the position of the J-3 unconformity in parts of western Colorado is uncertain.

Wanakah Formation

The Wanakah Formation, possibly of marginal marine origin, is here considered to consist of 1 formal member and 3 informal units. The Todilto Limestone Member at the base of the formation is overlain by a unit termed "the lower member", and both underlie the J-3 unconformity (Fig. 3). The bed at Butler Wash and the upper part of the Wanakah Formation overlie the J-3 unconformity. The Wanakah Formation, in the study area, has a maximum thickness of 55 m at Horse Mesa, 12 km south of Beclabito Dome (Condon and Huffman, 1988, p. 11).

The Todilto Limestone Member at Beclabito Dome is near its western limits; is gray, dense, and crystalline; and is 1.21 m thick (Strobell, 1956). From there, it extends eastward across northern New Mexico for 480 km, and where it contains associated gypsum beds is as much as 32 m thick (Armstrong, 1995, p. 8). Studies by Armstrong (1995) indicate that the limestone was deposited in a large salina.

The lower member of the Wanakah Formation lies between the top of the Entrada Sandstone, or the Todilto Limestone Member where present, and the J-3 unconformity in a zone trending southeast from Blanding, Utah into New Mexico (Fig. 1). In Arizona, the lower member grades into the beds at Baby Rocks of the Entrada Sandstone (sections 7-9, Fig. 3). In New Mexico, equivalents are in the lower part of the Wanakah Formation above the Todilto Limestone Member. The lower member consists of thin-bedded reddish-brown siltstone and lesser amounts of sandstone and shale. The beds at many places are intricately contorted

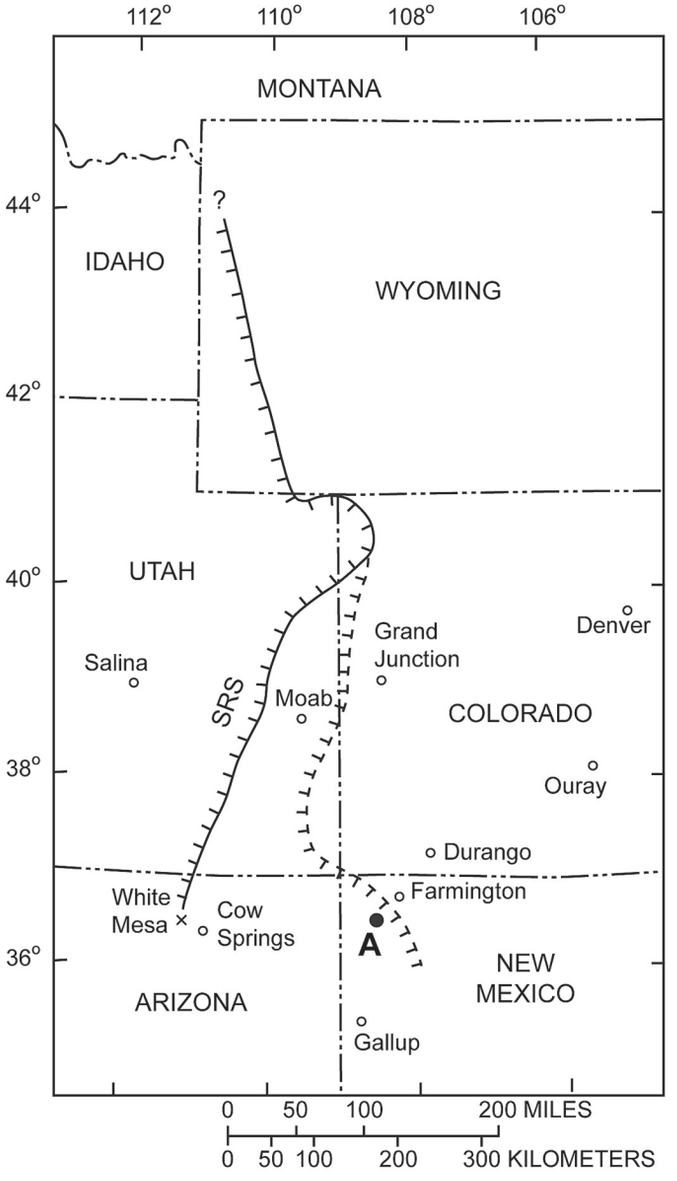


FIGURE 4 Eastern limits of J-3 unconformity. Solid hachured line is eastern extent from Pipiringos and O'Sullivan (1978). Dashed hachured line is new limits discussed in this study. Locality "A" in New Mexico marks the Amerada Petroleum Corp. drill hole discussed in the text. San Rafael Swell (SRS).

or crinkled as a result of intraformational deformation, similar to that in the beds at Baby Rocks and the beds at Goblin Valley of the Entrada Sandstone.

The bed at Butler Wash extends from southern Dry Valley, Utah to northwestern New Mexico and northeastern Arizona (Fig. 3). The unit is mostly gray and brown fine- to very fine-grained sandstone. Bedding is generally flat, but crossbeds are present at many places; the crossbeds are of eolian origin (Condon, 1989). Locally, the unit contains thin, reddish-brown siltstone beds. The base of the bed at Butler Wash is the J-3 unconformity (Carr-Crabaugh and Kocurek, 1998, fig. 3).

The bed at Butler Wash has undergone different interpretations. I had previously thought (O'Sullivan, 1980b) that the bed joined the main body of the Entrada Sandstone northwest of Blanding, Utah. In the southern part of the Abajo Mountains, Witkind (1964, p. 23) noted that the base of his Moab Sandstone Member [the bed at Butler Wash of this report] is "… a definite bedding plane… traced southward, red beds appear below it…" The "definite bedding plane" is the J-3 unconformity and the red beds are the lower member of the Wanakah Formation. The J-3 unconformity was traced throughout the Abajo Mountains and equivalents of the bed at Butler Wash were observed to join the Moab Tongue in Dry Valley by Carr-Crabaugh and Kocurek, (1998, p. 221 and fig. 3). At Bluff, Cadigan (1952, p. 25, 32) assigned the bed to the Moab Tongue and in northwestern New Mexico, it was included within the type Beclabito Member of the Wanakah Formation by Condon and Huffman, (1988, p. 11)

The upper part of the Wanakah Formation is a slope-forming sequence of red siltstone and thin, red and gray sandstone with minor thin red claystone beds. It is overlain locally by the Horse Mesa Member, which can be recognized from Beclabito northward through Bluff and into Dry Valley (Fig. 1). The member, as much as 18 m thick, consists of gray and reddish-tan, fine-grained, flat-bedded, and crossbedded sandstone. At most exposures, it forms a cliff or ledge. According to Condon and Huffman (1988, p. 7, 11), the Horse Mesa Member was deposited in eolian dune, interdune, and sabkha environments.

Curtis Formation

The Curtis Formation overlies the Entrada Sandstone along the J-3 unconformity in and near the San Rafael Swell (Fig. 3). The formation consists principally of gray to greenish-gray, fine- to very fine-grained sandstone and interbedded green siltstone. Conglomeratic sandstone beds are present, generally concentrated at or near the base of the formation and locally filling depressions cut into the top of the Entrada along the unconformity. Gypsum and sandy limestone in thin beds constitute a minor lithology. Fossils indicate that the Curtis Formation in the San Rafael Swell is of marine origin. East and south of the Swell the Curtis is of marginal marine origin (Baker, 1946 p 84).

The gray Curtis Formation becomes red east of Dellenbaugh Butte on the Green River (Fig. 1). As described by McKnight (1940, p. 98): "All the Curtis sections east of the Green River show some red coloration, which gradually increases in amount to the east until the red color predominates, where upon the Curtis loses its identity and becomes lower Summerville." McKnight (1940, pl. 1) did not recognize the Curtis Formation about 10 km east of Dellenbaugh Butte. I previously (O'Sullivan, 1980a) referred to these laterally equivalent Curtis red beds as the "lower Summerville of McKnight (1940)." Similarly, Blakey (1989, p. 390) noted: "Between the Green and Colorado Rivers, the Curtis rapidly grades laterally first into red beds and then into eolian deposits of the Moab Tongue of the Entrada Sandstone…" Caputo and Pryor (1991, fig. 3) also recognized a redbed facies of the Curtis Formation east of Dellenbaugh Butte that is replaced eastward by the Moab Tongue. The Moab Tongue wedges into the Curtis Formation about 15 km east of Dellenbaugh Butte (see

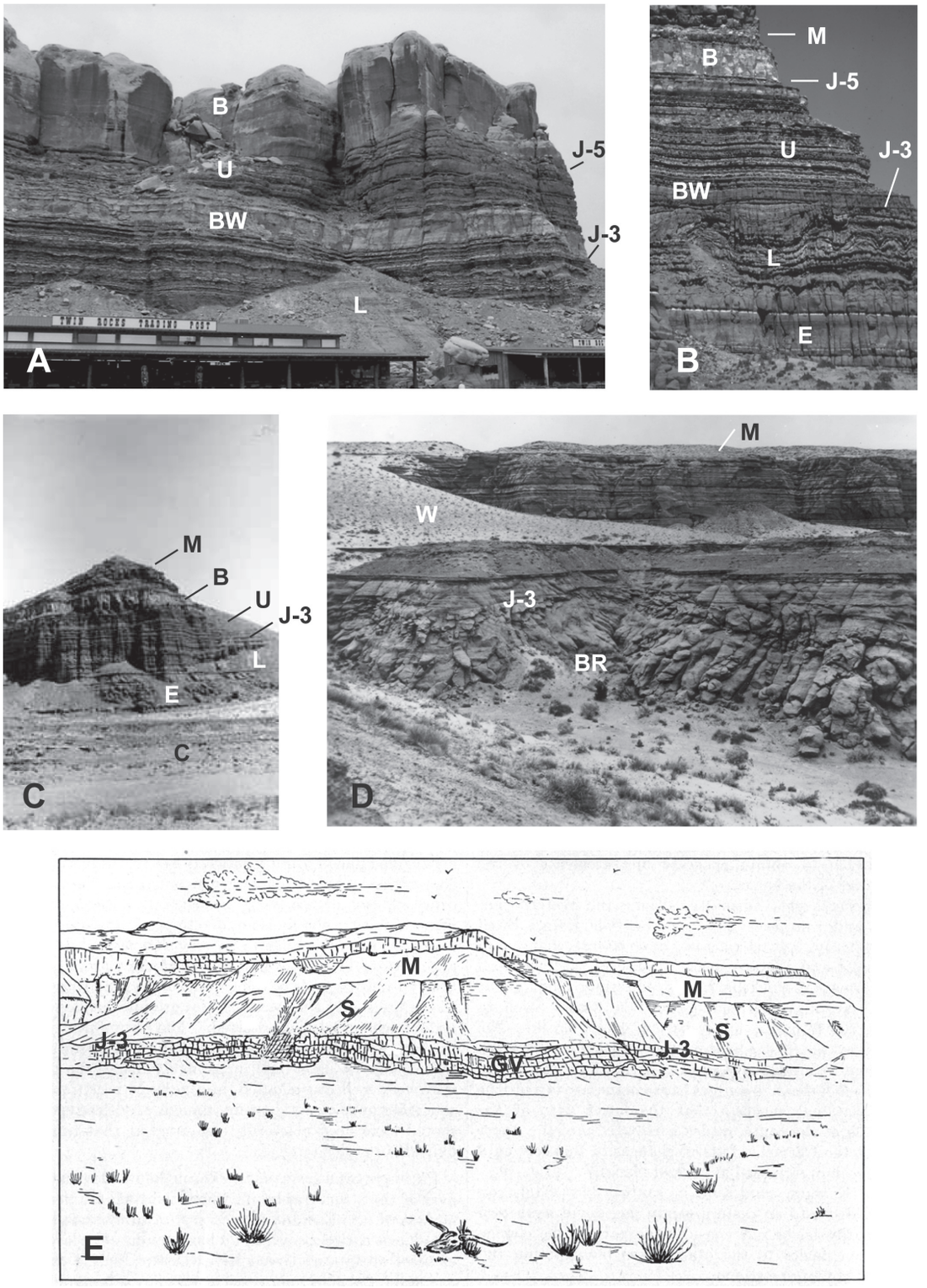


FIGURE 5. Views of the J-3 unconformity and associated rocks. Location of views is shown on the Index Map (Fig. 1). A. Section at Bluff, Utah, Photograph by Jacques F. Robertson; B. Toh Atin Mesa, Arizona, from Condon and Huffman (1988.p. 8, fig. A4A); C. Mexican Water, approximately 4 km northeast of Trading Post at Mexican Water, Arizona; D. Baby Rocks, approximately 22 km northeast of Kayenta, Arizona, from Witkind and Thaden (1963, fig. 6); E. Henry Mountains. Utah, from Hunt (1953, fig. 16), about in Sec. 20, T. 32 S.,R. 12 E. Bluff Sandstone Member (B) of the Morrison Formation (Bluff may include older beds, see Peterson and Turner, 2010); beds at Baby Rocks of the Entrada Sandstone (BR); bed at Butler Wash of the Wanakah Formation (BW); Carmel Formation (C); Entrada Sandstone (E); beds at Goblin Valley of the Entrada Sandstone (GV); lower member of the Wanakah Formation (L); Morrison Formation (M); upper part of the Wanakah Formation (U); Wanakah Formation (W).

sec. 3, Fig. 3), then thickens eastward into Dry Valley to replace all of the Curtis Formation.

West of the Colorado River in Utah, the Curtis Formation thins southward from the San Rafael Swell. It was mapped to a southern limit in the northern part of the Henry Mountains by Hunt (1953, pl. 1), and is absent over large areas of south-central Utah and adjacent parts of Arizona, probably because of erosion associated with the J-3 or J-5 unconformities (Peterson, 1988, fig. B2).

Summerville Formation

The Summerville Formation, of marginal marine origin, conformably overlies the Curtis Formation (Fig. 3). Where the Curtis Formation is absent west of the Colorado River and south of the Henry Mountains, the Summerville lies unconformably on the Entrada Sandstone (Peterson, 1988, fig. B13). The Summerville consists of thin-bedded red siltstone and minor sandstone and shale. Gypsum is present in the upper part in thin beds and as nodules, and also fills seams that cut across bedding. A characteristic feature of the formation, described by many geologists, is the thin, even bedding. Near the type locality in the northern part of the San Rafael Swell, Gilluly (1929, p. 109) stated that "… the bedding is very even and continuous…" In the Green River Desert, east of the Swell, Baker (1946) noted (p. 84) that the Summerville is "… in very thin regular beds" and also took note (p. 86) of the "… the thin regular bedding of the Summerville…"

The Summerville Formation is completely truncated by the J-5 unconformity between the towns of Green River and Moab. From Dellenbaugh Butte on the Green River to a point about 6.5 km to the east, about 60 m of the Summerville Formation is cut out beneath the J-5 unconformity (see O'Sullivan, 1980a), in which case the truncation surface slopes about one-half degree per 1.6 km. The thinning of the Summerville can be followed about 30 km east of the Green River into Bartlett Flat, where it is completely beveled out along the J-5 unconformity (sec. 3, Fig. 3); (Caputo and Pryor, 1991, fig. 3). Blakey (1989, fig. 10) similarly terminates the Summerville Formation in the same general area. An outcrop about 8 km northeast of Dellenbaugh Butte clearly shows (Fig. 6) an angular relation between the Summerville Formation and the J-5 unconformity. The outcrop is along Salt Wash in an area where Lupton (1914, p. 127) named the Salt Wash Member that is now assigned to the Morrison Formation.

Morrison Formation

The Upper Jurassic Morrison Formation, deposited in fluvial, flood plain, lacustrine, and eolian environments, is separated from the underlying San Rafael Group by the J-5 unconformity, which is subject to change (Peterson and Turner, 2010, this volume). The basal part of the formation includes the eolian Bluff Sandstone Member (Fig. 5, A, B, C) in the Four Corners area, whereas north of Blanding (Fig. 1) the Tidwell Member (Bernier and Chan, 2006) originating as a flood-plain deposit, and the overlying Salt Wash Member of fluvial origin are at the base. Formation thicknesses are 243 m near Bluff (Peterson, 1999, written commun.), 229-243 m in Dry Valley (Weir and others, 1994), and 155 m near Dellenbaugh Butte (Craig, 1959, section no. 64).

DISCUSSION AND CONCLUSIONS

Studies primarily by Blakey (1989), Caputo and Pryor (1991), Carr-Crabaugh and Kocurek (1998), Doelling (2000, 2001), and Peterson (1994) have clarified some complex Jurassic stratigraphic problems. These include (1) the stratigraphic position and correlation of the Todilto Limestone Member of the Wanakah Formation, (2) the limits of the Summerville Formation, and (3) the use of the name Wanakah Formation instead of Summerville Formation in the Four Corners area.

The Todilto Limestone Member of the Wanakah Formation was miscorrelated with the Curtis Formation by some workers, including Berman and others (1980, fig. 1 and p. 117), Brenner (1983, fig. 4),and Lucas and Heckert (2003) who stated (p. 295) "…we continue to advocate a Todilto-Curtis correlation."

Others, however questioned this correlation; Peterson (1994, fig. 3), for example, showed the Todilto Limestone Member as older then the Curtis Formation, stating further (p. 248) "…the Todilto Limestone Member of northwestern New Mexico and its correlative, the Pony Express Limestone Member of the Wanakah in southwestern Colorado, correlate with the lower beds of the middle member of the Entrada in south-central Utah." Carr-Crabaugh and Kocurek (1998, p. 221) also noted that "…the flooding of the Todilto Basin … and the J-3 surface were not coincident," and Dickinson and Gehrels (2009, p. 416) stated that the "… Todilto Formation, which may be slightly older than the Curtis Formation (Peterson, 1994) was deposited in an evaporative salina.…" Peterson (1994), however, made no mention of the

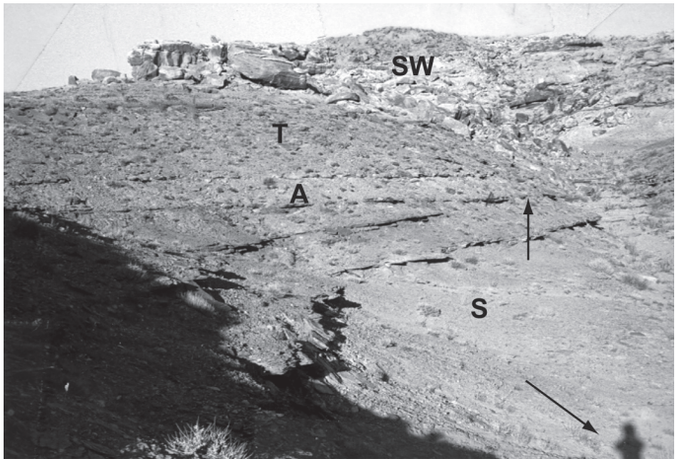


FIGURE 6. View northward of truncation of Summerville Formation (S). Locality is about 8 km northeast of Dellenbaugh Butte in Sec. 34, T. 22 S., R. 17 E. Arrow points to the J-5 unconformity at the base of bed A (A) , a marker sandstone bed; Tidwell Member (T) of Morrison Formation about 14 m thick; Salt Wash Member (SW) of Morrison Formation Unconformity removes about 2 m of strata in a lateral distance of 25 m. In lower right corner, arrow points to partial shadow of photographer to give an approximate scale.

magnitude of the unconformity; only that the J-3 surface separates the Curtis from the Todilto Limestone Member. The diagram in Figure 3 is my interpretation of the stratigraphic relations of the Todilto Limestone Member, showing it to be in the basal part of the Wanakah Formation, well below the J-3 unconformity that is also the base of the Curtis Formation in the San Rafael Swell.

In further clarification, miscorrelation of the Todilto Limestone Member of the Wanakah Formation apparently was due to (1) failure to recognize regional differences in the position of the top of the Entrada Sandstone and (2) uncertainty as to the source of the marine waters in which the Todilto Limestone Member was deposited.

Some workers envisioned the top of the Entrada Sandstone, to be a level plane over large areas, for example from Beclabito Dome to near Dellenbaugh Butte (Lucas and Anderson, 1997, fig. 10c) and from near Bluff to the Moab area (Craig and Shawe, 1975, fig. 3), covering distances of 125-230 km. The intertonguing between the lower member of the Wanakah Formation and Entrada Sandstone (Carr-Crabaugh and Kocurek, 1998, fig. 3) was not recognized, nor was the top of the Entrada Sandstone seen to be at stratigraphically different levels in the San Rafael Swell compared to the Four Corners area (Fig. 3). In the Swell, the top of the Entrada Sandstone coincides with the J-3 unconformity and is directly overlain by the Curtis Formation. At Bluff, the top of the Entrada is separated from the J-3 unconformity which is at the base of the bed at Butler Wash, by about 20 m of strata. At Beclabito Dome, where the Todilto Limestone Member of the Wanakah Formation rests directly on the Entrada Sandstone, about 20 m of strata also intervenes between that member and the bed at Butler Wash. These stratigraphic relations obviate a correlation of the Curtis Formation and the Todilto Limestone Member.

In addition, the Curtis sea was erroneously thought to have been the water body (Fig. 7) in which the Todilto Limestone Member was deposited. However, the stratigraphic relations (Fig 3) also preclude such an interpretation inasmuch as an unconformity and 20 m of strata separate the Todilto Limestone Member and the bed at Butler Wash, an equivalent of the Curtis Formation. The source of the marine waters may lie north of the San Rafael Swell in a sea associated with the Middle Jurassic Preuss Sandstone, an equivalent of the Entrada Sandstone (Imlay, 1980, p. 74, 89) that unconformably underlies the Curtis Formation. Hunt (1953, p. 72) believed that the earthy facies of the Entrada Sandstone, including the beds at Goblin Valley, "… probably … was deposited in shallow water … marginal to the sea that lay to the north." The linear north- south distribution of the beds at Goblin Valley and the beds at Baby Rocks (possibly a tongue of the Preuss Sandstone) indicate a trough (Fig. 1) that might have conveyed marine waters from north of the San Rafael Swell southward into the Todilto Basin in New Mexico and adjacent areas. Harshbarger and others (1957, fig. 31) also postulated a connection, in the Four Corners area, of marine waters to the north with the Todilto Basin in New Mexico. However, they erred in believing the waters were from the Summerville Sea inasmuch as the Summerville Formation is absent in the Four Corners area.

The Summerville Formation is beveled out in the Bartlett Flat area about 25 km northwest of Moab (Fig. 1). It has, however, been recognized over large areas of southeastern Utah and New Mexico and adjacent areas. For example, Baker (1933, pl. 1) mapped a thin "Summerville formation" between the Moab Tongue of the Entrada Sandstone and the Salt Wash Member of the Morrison Formation in the Moab-Dry Valley area, describing his (p. 51-52) "Summerville formation" as composed of "… red sandy mudstone, fine-grained sandstone, and shale in which large chert nodules are embedded. The chert is peculiar to this formation and serves to distinguish it from all other formations that crop out in the Moab area." To the contrary, the chert is a common feature in the Tidwell Member of the Morrison Formation (Peterson and Turner-Peterson, 1987, p. 4-6; and Bernier and Chan, 2006, p. 325). The strata mapped by Baker (1933) as "Summerville formation" are now identified as the Tidwell Member (see O'Sullivan, 1991). In parts of Dry Valley, Bernier and Chan (2006, p. 324) also described the same strata as the Tidwell Member of the Morrison Formation.

South of Dry Valley, in the Monticello-Bluff area (Fig. 1), the strata between the Entrada Sandstone and the Bluff Sandstone Member of the Morrison Formation were placed by Gregory (1938, p. 57, 58), with a degree of uncertainty, in the "Summerville (?) formation," but he noted that "…strata in the position of beds reasonably assigned to the Summerville are little like those at the type locality…". I agree that, at least in part, the strata in this area are unlike the type Summerville Formation, because they correlate with older formations (Fig. 3). The same beds can be traced from southeastern Utah into northwestern New Mexico where they are also termed "Summerville Formation" on the state

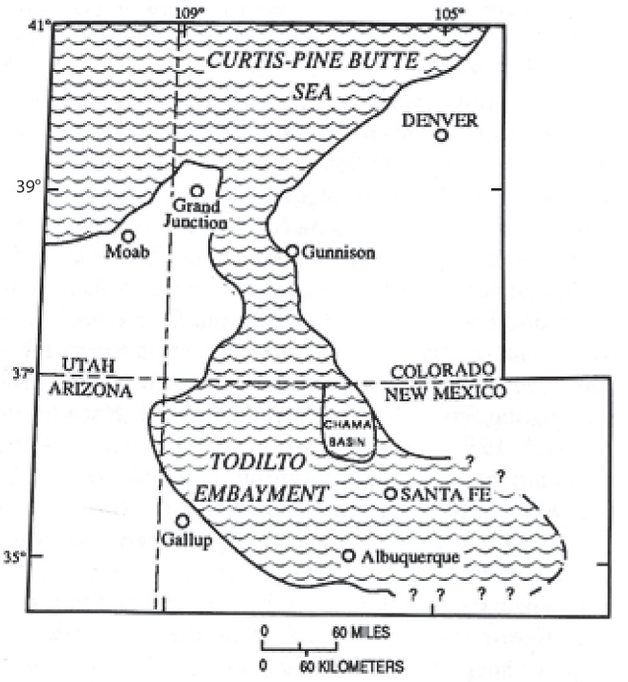


FIGURE 7. Paleogeographic map showing supposed (incorrect) connection of Curtis sea with Todilto embayment. From Ridgely (1989, fig. 9). Similar maps are in reports by Armstrong (1995, fig. 3), Kirtland and others (1995, figs. 12, 14), and Lucas and Anderson (2000, fig. 4).

geologic map (New Mexico Bureau of Geology and Mineral Resources, 2003). Near Ouray, Colorado these strata were originally defined by Burbank (1930, p. 174) as the Wanakah Member of the Morrison Formation, but they are now recognized as the Wanakah Formation.

Changes in the arrangement of units now included in the Wanakah Formation are described elsewhere (O'Sullivan, 1992). There are, however, objections to the use of the name "Wanakah," particularly in New Mexico. Armstrong (1995, p. 5) noted that the "…New Mexico Bureau of Mines and Mineral resources … recognizes that the name Wanakah is preoccupied (in the state of New York) and therefore, unavailable as a stratigraphic name …" The last sentence refers to the North American Stratigraphic Code (1983) that discourages the use of the same name for different units. The first such code was released in 1933, 3 years after Burbank (1930) named the Wanakah Formation. He was aware of the duplication of names and in a footnote (Burbank, 1930, p. 172) stated: "The name Wanakah has been used for certain Middle Devonian shales in New York …, but in view of the wide geographic and geologic separation it is believed that there will not be confusion by the use of the same name for the two units." Burbank's reasoning seems appropriate, and continued use of the name Wanakah Formation is highly preferable to the use of "Summerville Formation," which is absent in the Four Corners area.

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