The Middle Jurassic Summerville Formation, nothern New Mexico

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The Middle Jurassic Summerville Formation, northern New Mexico

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Abstract

We recommend continued usage of the name Summerville Formation as a stratigraphic unit in the upper San Rafael Group in northern New Mexico. Our reasons are as follows. Subsequent to recognition in 1947 of the Entrada Sandstone and overlying Todilto Formation (the lower San Rafael Group) in the southern San Juan Basin of northwestern New Mexico, field-oriented geologists generally agreed to regard the overlying rocks as the upper part of the San Rafael Group. Although fossil control was lacking, the stratigraphic sequence and position were right, and lithologies and facies were similar. Hence, until 1986, Summerville was used for these upper San Rafael Group strata in all geologic mapping, and the usage became entrenched.

In 1986, the name Wanakah Formation was introduced for the strata previously designated and mapped as Summerville in the San Juan Basin of New Mexico. The Wanakah type area is in the Ouray district of southwestern Colorado, where the strata so named had been recognized as equivalent to the Summerville Formation; the usage of Wanakah was local only. Since equivalency with Summerville can be demonstrated, no scientific purpose is served by replacing the more widespread name Summerville with the provincial term Wanakah. Of greater significance, however, is that Summerville has precedence, and that Wanakah was a stratigraphic name used in New York state at the time it was introduced in Colorado. Clearly, usage of the name Wanakah outside of New York should be discontinued.

In northeastern New Mexico, the thinly bedded strata that overlie the lower San Rafael Group have been designated as Bell Ranch Formation since 1959. Based on similarity of lithologies, depositional environments, and stratigraphic sequence and position, it is now virtually certain that the Bell Ranch is equivalent to and westward correlates with Summerville strata. We thus recommend that the name Bell Ranch be abandoned and the name Summerville retained for upper San Rafael Group strata across northern New Mexico. This simplifies the nomenclature and properly relates Middle Jurassic rocks of the High Plains to the Colorado Plateau sequence.

Other questions regarding correlation and nomenclature of Middle Jurassic units—Curtis, Pony Express beds, Bilk Creek, Bluff, Cow Springs, Junction Creek, Zuni, and Tidwell—are discussed as they relate to the Summerville Formation.

Introduction

This report discusses the Summerville Formation and associated strata of the San Rafael Group (Middle Jurassic) in northern New Mexico and adjacent areas (Fig. 1), with particular respect ☞

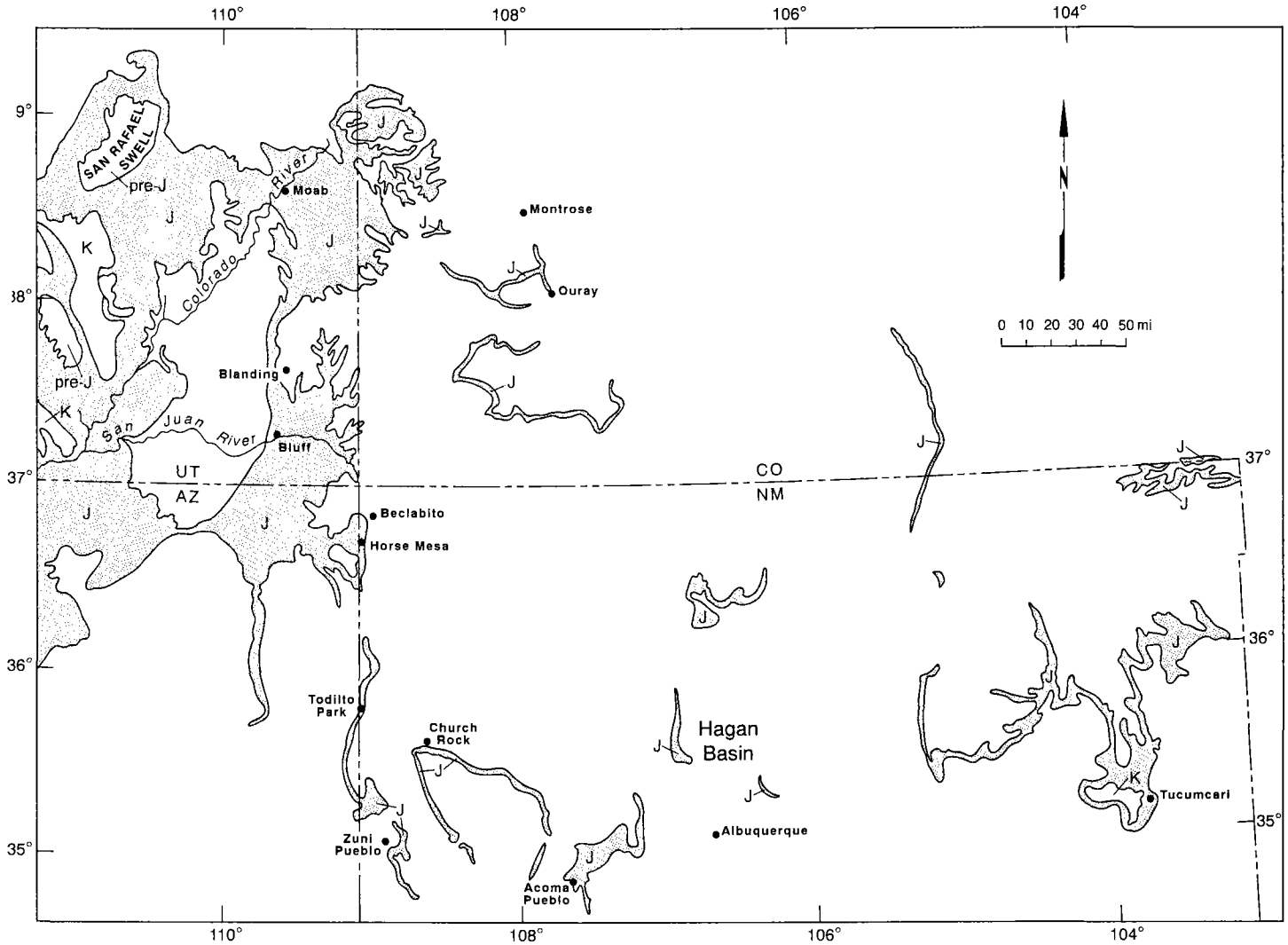


FIGURE 1—Index map of the study area showing outcrops of Middle Jurassic rocks (**J**, shaded) and some areas of pre-Jurassic (**pre-J**) and Cretaceous (**K**) rocks.

to 1) lithologies, 2) depositional environments, 3) regional correlations, and 4) the concept of a climatic change marking the transition from Middle to Late Jurassic time.

The Summerville consists of alternating fine-grained sandstone and gypsiferous siltstone or mudstone that overlies the Curtis Formation and forms the uppermost unit of the San Rafael Group in the San Rafael Swell of Utah. To the south, near Moab and La Sal Junction, the unit thins significantly across the sill or divide that separated the marine basin of Curtis deposition to the northwest from the salina-lake basin of Todilto deposition to the southeast. Still further southward near Bluff, Utah, the Summerville thickens but retains much of the lithologic character of the type area, though it is somewhat more sandy. It includes an eolian-sandstone lithosome at Bluff—the bed at Butler Wash—that has been regarded as a tongue of the Entrada Sandstone. Also at Bluff, a prominent sandstone unit overlies the Summerville, and is appropriately named Bluff Sandstone. The Bluff Sandstone has been assigned to both the San Rafael Group and to the Morrison Formation (Gregory, 1938; Craig, 1955; O'Sullivan, 1980). This conflict has arisen because the Bluff contains both eolian and fluvial facies, and because an unconformity has been perceived at the base of the Bluff by those who would have it in the Morrison Formation. In this report we treat all eolianites overlying the Summerville as essentially contemporaneous dune-field migration onto the arid, sandy plain formed during and following the northward regression of the epicontinental Curtis sea. Thus, they all have affinities to and are included in the San Rafael Group. No major unconformity, and in most instances no demonstrable unconformity, exists between the eolianites or mixed eolian-fluvial sand bodies and the underlying Summerville. These eolian-dominated units include strata that have been referred to as Bluff, Horse Mesa Member of the Wanakah, Junction Creek Sandstone (Colorado), Recapture Member of the Morrison, Zuni Sandstone, and upper part of Cow Springs Sandstone. Overlying the eolianites, or in places typical Summerville, is the fluvially dominated sequence regarded by most as the Morrison Formation. These sediments indicate increased clastic input during a Late Jurassic gradual change to more humid climates.

Southeastward from Bluff, Arizona and into New Mexico, the Summerville is present and continuous across the Four Corners platform, the San Juan Basin, and the northeastern portion of the state. Throughout much of this area the Summerville overlies and overlaps the Todilto Formation. We discuss the equivalent strata in southwestern Colorado—the Wanakah Formation—only 1) to first describe in detail a type section, 2) to demonstrate how the Wanakah Formation units, the Pony Express and the marl beds, can be correlated with the Todilto Formation and the Summerville Formation, respectively, and 3) to lend our support to previous workers who have correlated the overlying Junction Creek Sandstone westward with the Bluff Sandstone.

Previous studies

An exhaustive review of previous work on Jurassic rocks of the Colorado Plateau area is not undertaken here, as it has recently been reported on by Condon and Peterson (1986), Condon and Huffman (1988), and in other works. It is of interest to note that, following the suggestion by Baker et al. (1947) to extend the name Wanakah into New Mexico for the Todilto and overlying strata, few geologists working the Colorado Plateau or San Juan Basin have used that name. The list of authors ignoring the name Wanakah in favor of Todilto and Summerville is long and impressive and includes Harshbarger et al. (1951; 1957), Rapaport et al. (1952), Smith (1957; 1961), Moench and Puffet (1963), Schlee and Moench (1963), Moench (1964), Maxwell (1976), and Green and Pierson (1977). A significant work is Dane and Bachman (1965), who in their compilation of the New Mexico state geologic map used San Rafael Group with Todilto and Summerville Formations as component units. A correlation chart for the state of Colorado compiled by Pearl (1972) used Todilto–Summerville in place of Wanakah. The Colorado geologic map (Tweto, 1979) used both Summerville and Wanakah in the southwestern part of the state with no criteria given for distinguishing the two. The only early U.S. Geological Survey publication to recognize Wanakah was Wood et al. (1953), and curiously this was in northeastern, not northwestern New Mexico. They were thus the first to recognize the Wanakah/Summerville strata on the High Plains. Griggs and Read (1959) pointed out that since 1953, usage of the name Wanakah had been limited to the type area in southwestern Colorado, and they proceeded to introduce the name Bell Ranch Formation for strata overlying the Todilto in northeastern New Mexico.

More recently Condon and Peterson (1986) and Condon and Huffman (1988) "reinstated" the name Wanakah Formation, which they asserted "replaces the name Summerville Formation" throughout northwestern New Mexico. They alleged this change in nomenclature was necessary because of stratigraphic reports (O'Sullivan, 1980; O'Sullivan and Pierce, 1983) indicating that all the Summerville Formation was cut out by an unconformity in southeastern Utah. But, in actuality, the Summerville is not cut out, although when O'Sullivan (1980; 1981) realized this he had already decided to use the name Wanakah for these strata; this is documented by personal correspondence (1986) as well as the regional cross sections (Fig. 2). In essence, the Summerville is continuous throughout the area and can be recognized in northwestern New Mexico on the basis of lithology, sequence, and stratigraphic position. Condon and Huffman (1988) also 1) reduced the Todilto Formation to a member-rank unit at the base of the newly established Wanakah Formation, 2) introduced the name Beclabito Member for the overlying Summerville, and 3) replaced the name Bluff Sandstone with Horse Mesa Member, which forms the upper part of their Wanakah Formation. They then established a reference section in New Mexico using member names not used in the type area, and without benefit of an accompanying stratigraphic section from the type area.

Statement of problem

The Summerville Formation overlies the Curtis in the type area and demonstrably overlies the Todilto in northern New Mexico. In both areas the Summerville has been described as a thinly bedded unit consisting of arid coastal plain or sabkha, supratidal or hypersaline marine, wave-dominated deltaic (McKnight, 1940), and lacustrine deposits. These sediments were thus regressive and prograded across facies deposited during a high sea-level stand that was synchronous in the Curtis and Todilto depositional basins. In the southern San Juan Basin and adjacent northeastern Arizona, the Summerville grades southward and southwestward into an eolian sandpile that has been called the Cow Springs Sandstone.

Our interpretation of this physical stratigraphic sequence is that the onset of regressive conditions in the Todilto salina basin and the Curtis Seaway was synchronous and initiated by relative sea-level fall. Ensuing depositional environments in both basins were similar, with eolian processes dominating along the southwest margin of the integrated basin. It is therefore in the interest of regional correlations to perpetuate the name Summerville Formation for these strata in both areas.

The Wanakah Formation is another name for Summerville and associated strata in southwestern Colorado. Recently, Wanakah Formation has been proposed as a more appropriate name for Summerville strata in southeastern Utah, and Beclabito Member of the Wanakah in northwestern New Mexico (Condon and Peterson, 1986; Condon and Huffman, 1988; Condon, 1989). The reasons given by those authors were 1) an earlier U.S. Geological Survey report that had (mistakenly) concluded that Summerville strata were missing in southeastern Utah; 2) when the Summerville error was discovered, the name Wanakah had already been installed for the missing strata and thus the name had to be recognized in all areas to the south and east; and 3) Baker et al. (1947) had "recognized" the Wanakah in New Mexico.

We question the logic and procedure followed in the proposed name change and consider the stated reasons trivial because they

were based on an error in judgment, in this case a double error, since introducing the name Wanakah was done prematurely and before full disclosure of all the stratigraphic data in southeastern Utah. In reference to 3) above, the Baker et al. paper consisted of interim recommendations; Baker et al. merely stated that "it seems desirable to extend into New Mexico" use of the name Wanakah because the upper contact of the San Rafael Group was "not yet definitely known." This is not synonymous with recognizing strata that correlate with Wanakah, particularly so because no detailed stratigraphic studies or sections were presented.

A further objection to the use of the name Wanakah for these strata in New Mexico is that it relegates the Todilto to a member-rank unit at the base of the Wanakah Formation. While we are not preoccupied with rank, we do recognize and accept the concept of formation. The Todilto, which has two mappable facies, locally exceeds 150 ft (45.7 m) in thickness, and extends over an area of 33,000 mi^2 (86,000 km^2), not only meets all the contemporary criteria for a formation-rank unit, but has been recognized as such since the name was introduced by Gregory (1917).

Our usage of Todilto Formation would extend into southwestern Colorado to include the Pony Express beds at the base of the Wanakah. The overlying strata of the Wanakah are herein assigned to the Summerville Formation, which has precedence; Wanakah is abandoned in recognition of the fact that it is an occupied name in the state of New York.

The Zuni Sandstone, long an undefined or poorly defined term, is retained for use in New Mexico and applied to strata formerly designated as Cow Springs Sandstone. In the Acoma–Mesa Gigante area of the southeastern San Juan Basin the upper part of the Bluff Sandstone with contrasting bedforms has been mapped as the Zuni Sandstone (Maxwell, 1976). Inasmuch as this upper unit can be traced southward into the main Zuni, the entrenched local usage of Zuni is herein considered valid and is given the name Acoma Tongue of the Zuni Sandstone.

Stratigraphy and depositional setting

At the type area in eastern Utah the Summerville Formation forms the uppermost unit of the San Rafael Group. The remainder of the group in descending order consists of the Curtis Formation, the Entrada Sandstone, and the Carmel Formation.

In extreme southeastern Utah and northwestern New Mexico the Carmel is not present and thus the Entrada rests unconformably (the J-2 unconformity, Pipiringos and O'Sullivan, 1978) on Triassic rocks (Chinle Group) in those areas. The Curtis Formation likewise pinches out to the southeast due to pre-Summerville erosion or nondeposition and thus from the Moab area southward to the Four Corners area the Summerville rests paraconformably on the Entrada Sandstone. Southeastward into northern New Mexico the Todilto Formation is present between the Entrada and the Summerville. The Todilto is therefore homotaxial to, and as we shall argue, correlative with, the Curtis Formation. Our concept of the regional correlation of the San Rafael Group is shown in Fig. 2.

In southeastern Utah, a low sill or divide on an arid landscape of no relief other than dunes separated the basin of Curtis deposition from the salina basin to the southeast in which the Todilto was deposited. The Moab Tongue of the Entrada accumulated across a portion of this divide, and local eolian deposition thus persisted throughout Todilto and well into Summerville time. Similar eolian deposition in post-Entrada time is represented by the bed at Butler Wash. This informal sandstone unit within the Summerville Formation is 30–70 ft (9–23 m) thick. It extends southward into the Four Corners area, and northward it merges with the main body of the Entrada near Blanding.

Establishing the correlation of the Curtis and Todilto Formations, which was doubted by Pipiringos and O'Sullivan (1978), is of importance in correlating the younger sediments that prograded out across their respective basins to form the Summerville strata. The Curtis Formation is composed largely of grayish-green, glauconitic, flat and crossbedded sandstone, with thin beds of mudstone, minor, thinly bedded, dense gray limestone, and one gypsum bed (Peterson, 1988). Based on the presence of marine invertebrate fossils and glauconite, a marine origin is indicated; lithology and depositional setting further identify this unit as shallow marine, likely hypersaline marine toward the end of deposition. The Curtis represents a highstand facies tract associated with maximum inundation of the region during Middle Jurassic (Callovian) time.

Related to and indirectly sustained by the Curtis Sea was the paralic salina in which the Todilto Formation accumulated. Hypersaline conditions are indicated by the scarcity and low diversity of fossils in the limestone member and the presence of a thick gypsum facies in the central basin. The possibility of brief periods of direct marine influence cannot be discounted based on the presence of dasyclad algae in the limestone (Armstrong et al., in press). This interpretation has also found support in the work of Ridgley (1989), who postulated a connection between the Todilto basin and the Curtis seaway. A connection is suggested by the northward-extending tongue of the Todilto Formation reaching the latitude of Montrose, Colorado (Fig. 1). No detail of the stratigraphic relationship of the northern terminus of the Todilto (called Pony Express beds in southwestern Colorado) with marine Jurassic rocks to the north was provided by Ridgley (1989), and the evidence for a seaway link thus is inconclusive at this point. The sulfur-isotope data presented by Ridgley and Goldhaber (1983) were used to support their case for a direct seaway connection. We contend that the isotope data merely confirm the proximity of marine waters to the Todilto basin. These marine waters could then move as shallow ground water into the Todilto basin with little change in isotopic composition. The isotope data do more to strengthen the case for synchronous Curtis–Todilto deposition than they do to support direct marine influence.

Without a direct seaway connection the high evaporative rates prevalent at the time would have necessitated replenishment via ground-water movement. Continuous transfer of marine waters through a divide perhaps as much as 25 mi (40 km) in width is the most plausible explanation. Hydraulic conductivity of the eolian sand (Entrada) that formed the shallow brine aquifer spanning the divide would have been sufficient and adequate to supply the water. Runoff would have been another source of water and dissolved solids in the system, although climates were very arid. It is further possible that eolian transport of gypsum southeastward from the margins of the Curtis Seaway selectively enriched the Todilto salina in sulfate. Paleowind studies by Poole (1962) do not, however, lend great support to this interpretation; the study did nevertheless indicate a strong northerly wind pattern during deposition of the Cow Springs Sandstone, which is in part correlative with the Todilto.

Regardless of how the Todilto salina basin and its carbonate-evaporite sequence are interpreted, contemporaneity with the Curtis Seaway is well supported by the physical stratigraphy and hydrologic concepts in terms of the constraining effects of arid climates on runoff. Thus the fall of relative sea level (or increased clastic supply) following the Curtis–Todilto highstand initiated simultaneous progradation in both basins as basal Summerville strata were deposited.

Summerville Formation

Named by Gilluly and Reeside (1928) for exposures at Summerville Point in the northern San Rafael Swell, the Summerville Formation consists of reddish-brown, thinly bedded sandstone with interbedded gypsiferous siltstone, sandy siltstone, or mudstone. Lithologies may vary somewhat, specifically mudstones are not everywhere present, the sequence is not everywhere gypsiferous, and coarser-grained conglomerate facies are present near the depositional basin margins on the south and southwest. Bedded gypsum is generally not present in the San Juan Basin. The flat, thin bedding, however, is a characteristic from the type area to the southern San Juan Basin and eastward into the High Plains of east-central New Mexico (Fig. 2B). ☞

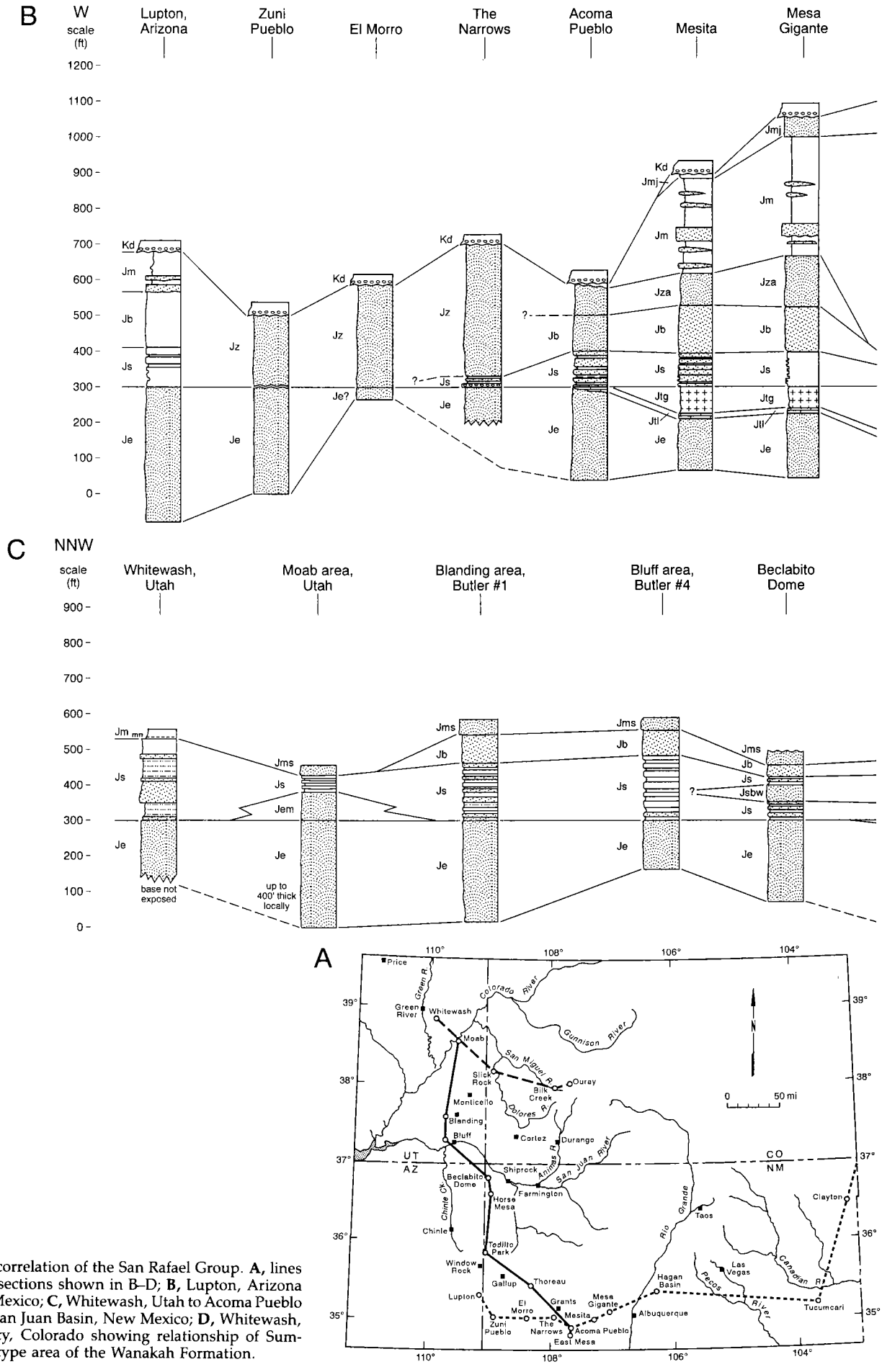
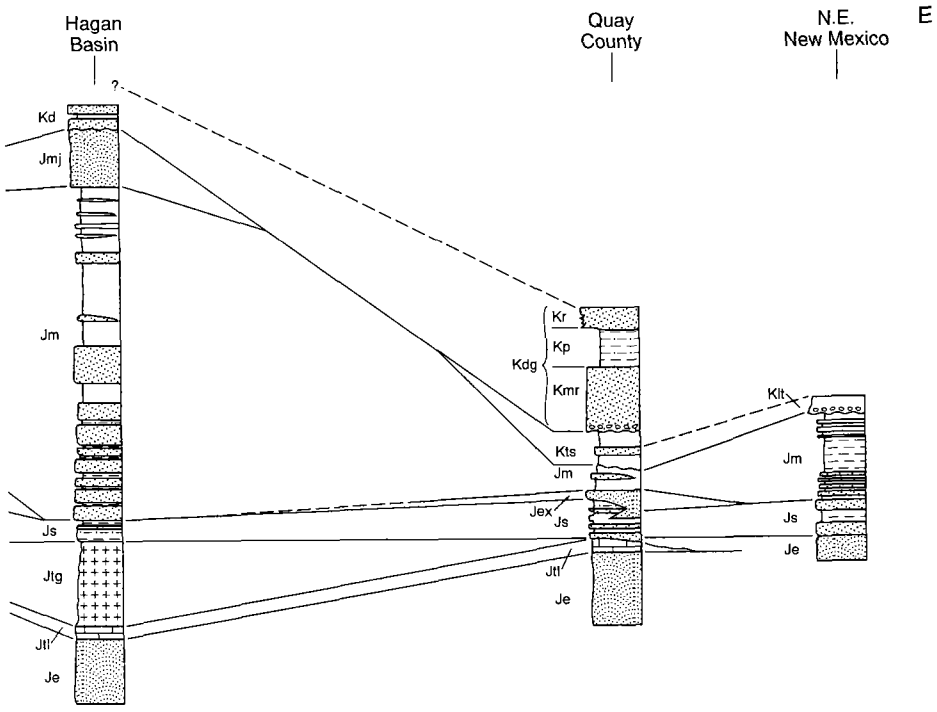
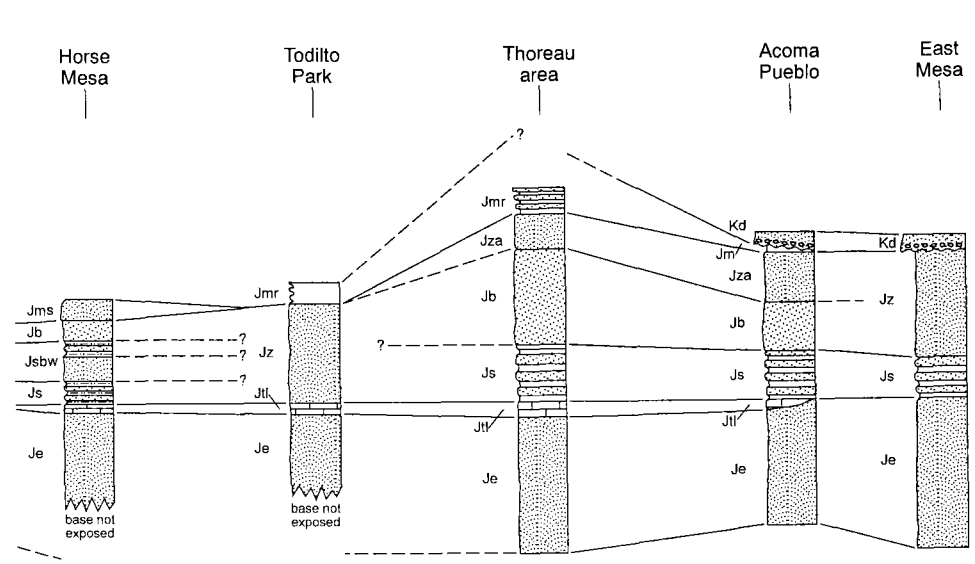


FIGURE 2—Regional correlation of the San Rafael Group. **A,** lines of stratigraphic cross sections shown in B–D; **B,** Lupton, Arizona to northeastern New Mexico; **C,** Whitewash, Utah to Acoma Pueblo area in southeastern San Juan Basin, New Mexico; **D,** Whitewash, Utah to Ouray County, Colorado showing relationship of Summerville strata to the type area of the Wanakah Formation.

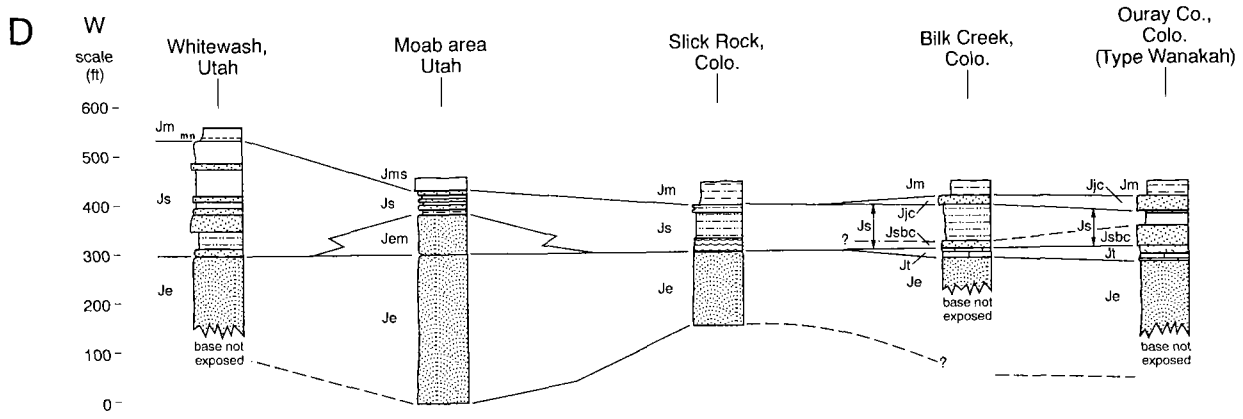


Kd – Dakota Fm.
Kdg – Dakota Gp.
Kr – Romeroville Ss.
Kp – Pajarito Fm.
Kmr – Mesa Rica Ss.
Kts – Tucumcari Sh.
Klt – Lytle Ss.
Jm – Morrison Fm.
Jmj – Jackpile Mbr., Morrison Fm.
Jz – AcomaTongue, Zuni Ss.
Jza – Zuni Ss.
Jb – Bluff Ss.
Js – Summerville Fm.
Jtl – limestone mbr., Todilto Fm.
Jtg – gypsum mbr., Todilto Fm.
Jex – Exeter Mbr., Entrada Ss.
Je – Entrada Ss.



Kd – Dakota Fm.
Jm – Morrison Fm.
Jmr – Recapture Mbr., Morrison Fm.
Jms – Salt Wash Mbr., Morrison Fm.
Jb – Bluff Ss.
Js – Summerville Fm.
Jsbw – bed at Butler Wash, Summerville Fm.
Jz – Zuni Ss.
Jza – Acoma Tongue of Zuni Ss.
Jtl – limestone mbr., Todilto Fm.
Je – Entrada Ss.
Jem – Moab Tongue, Entrada Ss.
mn – manganese bed at base of Morrison Fm.

sandstone
crossbedded sandstone
limestone
silty sandstone
sandy siltstone
shale



Jm – Morrison Fm.
Jms – Salt Wash Mbr., Morrison Fm.
Jjc – Junction Creek Ss.
Js – Summerville Fm.
Jsbc – Bilk Creek Ss. bed, Summerville Fm.
Jt – Todilto Fm.
Je – Entrada Ss.
Jem – Moab Tongue, Entrada Ss.
mn – manganese bed at base of Morrison Fm.

Thickness is also similar from the type area southward into the San Juan Basin, as both areas were very shallow epicontinental basins during the Middle Jurassic. Maximum thickness may be as much as 300 ft (91 m) in Utah but is generally less and in the type area is 163 ft (50 m) (Gilluly and Reeside, 1928). In the San Juan Basin thicknesses vary from 90 to 150 ft (27.5 to 46 m) in the southern portion to more than 200 ft (61 m) at Todilto Park on the Arizona–New Mexico state line (Harshbarger et al., 1957). Thicknesses are vastly reduced in the area that formed the divide between Todilto and Curtis deposition. Here the Summerville may be as thin as 4–5 ft (1.2–1.5 m) (O'Sullivan, 1980) and rests on the Moab Tongue of the Entrada. Even in those areas where it is thinnest, the thinly bedded aspect identifies it as Summerville strata.

Intraformational deformation and slumping are additional characteristics of the Summerville. In northeastern Arizona this slumping was thought by Harshbarger et al. (1957) to represent soft-sediment deformation of water-saturated strata on a gently sloping sea floor. Inasmuch as the Summerville is nonmarine in this area, we do not agree entirely with their interpretation. The soft-sediment deformation is uncontested; however, the deforming mechanism probably relates to dewatering and local variation in confining pressure. In the San Juan Basin an additional feature of the Summerville is the sandstone pipes up to 100 ft (30 m) or more in diameter. It has been suggested (Moench and Schlee, 1967) that the pipes formed during deposition of the uppermost part of the formation by the foundering of sand into spring vents as compaction and dewatering proceeded. Locally the removal of underlying gypsum may have been a factor in pipe formation; however, many of the pipes do not extend downward to the Todilto and thus are unrelated to dissolution and removal of gypsum.

In east-central New Mexico strata equivalent to the Summerville have been recognized since the 1950s. These strata overlie and overlap the Todilto Formation and range in thickness from 0 to 66 ft (0–20 m) (Lucas et al., 1985). The thinly bedded, ribbed-outcrop aspect is well displayed and lithologies are similar to lithologies of the Summerville in the type area on the Colorado Plateau. Griggs and Read (1959) recognized the equivalence of these High Plains strata to the Wanakah Formation, a name they stated was used for Summerville strata in southwestern Colorado. However, since the name Wanakah had not been used outside of Colorado since 1953, Griggs and Read (1959) introduced the name Bell Ranch Formation for these strata in east-central New Mexico. We agree with Griggs and Read in the correlation Summerville = Wanakah = Bell Ranch. Thus in the interest of clarification of regional stratigraphy and correlations the nomenclature ought to be simplified. We therefore recommend that the name Bell Ranch Formation be abandoned in eastern New Mexico and instead the name Summerville be used for these strata. The name Summerville thus is applied across the entire northern half of New Mexico, recognizing the correlation of these High Plains strata with the type Summerville.

A nonmarine origin for the Summerville is indicated by the nearly complete lack of fossils, the gypsiferous character of the sediments, and also by the assumption that the dewatering phenomena noted above could only occur subaerially. Nonetheless, some type of quiet-water or intermittent quiet-water deposition is strongly indicated by the great lateral continuity of individual strata, the localized presence of ripple marks, and the nodular and bedded gypsum. These features along with the near absence of channel-form structures indicate deposition in broad, shallow temporary lakes and tidal flats on an arid coastal plain of very low relief. High water tables related to the nearby seaway characterized the entire area and evaporative pumping contributed to the gypsum content of the sediments. During prolonged drought eolian-sand sheets and dune fields encroached upon the lake beds to be later worked into thin strata by wave action, as brackish to saline lakes formed and waned. Much of the finer material and salt was perhaps deflated by the prevailing winds. Sand predominated, the shrinkage factor was low, and therefore mudcracks were not formed.

The general lack of fluvial facies in the fine-grained Summerville suggests that a significant portion of the sediment was introduced as eolian material. Fluvial deposits in the form of coarser-grained lenticular sandstone and conglomeratic sandstone exist within the Acoma Sag in the extreme southern San Juan Basin south of Acoma Pueblo (Maxwell, 1979). Further to the northwest, along the southwestern margin of the basin of Summerville deposition, fluvial facies consisting of pebbly conglomeratic-sandstone beds containing clay clasts have been noted by Peterson (1988), who assigned them to a new unit called the Romana Sandstone. The usage of Romana is restricted to the Kaiparowits basin where it is considered to be correlative with the Summerville. Bedform and lithology are sufficiently different in the Romana Sandstone to warrant recognition as a separate stratigraphic unit, albeit a member or tongue of the Summerville would have served.

Wanakah Formation

The name Wanakah was first applied to a lithostratigraphic unit in the contiguous United States by Grabau (1917, p. 338, footnote), who introduced the name "Wanakah shales" for the lower part of the Devonian Hamilton Formation in western New York. Cooper (1930, p. 225) subsequently designated a type section ("the Wanakah and Lakewood Beach cliffs, Lake Erie") of what he termed the "Wanakah Member" of the Ludlowville Formation of the Hamilton Group. The Middle Devonian Wanakah Member is a well recognized stratigraphic unit in western New York. For example, on the "Geologic Map of New York" published by the New York State Museum of Science/New York Geological Survey, the Wanakah Member is recognized on the Finger Lakes Sheet (Rickard and Fisher, 1970a) and Niagara Sheet (Rickard and Fisher, 1970b). Burbank's (1930) use of the name Wanakah thus is preoccupied by Grabau's (1917). According to the accepted rules of stratigraphic procedure (NACSN, 1983, p. 852–853, Article 7(b)), the name Wanakah should not be used for a Jurassic lithostratigraphic unit in Colorado since it is being used in New York for a Devonian unit named 13 years earlier (Lucas et al., 1985; Lucas, 1988).

Burbank (1930, p. 172) introduced the name Wanakah Member of the Morrison Formation for strata exposed in the Ouray mining district of southwestern Colorado named for its exposure in the Wanakah mine near Ouray. Eckel (1949) subsequently raised Wanakah to formation rank, and it currently is recognized as a formation in Colorado, New Mexico, and Utah by workers of the U.S. Geological Survey (e.g. Condon and Peterson, 1986; Condon, 1989) despite the fact that no type section of the Wanakah Formation has been established or described. It is of interest to note that Goldman and Spencer (1941) recognized the Summerville and Wanakah as "being equivalent to each other."

The only surface section of the Wanakah described that approximates a type section is one measured "on the east side of the Uncompahgre Valley 6 miles north of Ouray" (Burbank, 1930, p. 174). We measured a section of Burbank's (1930) Wanakah Member approximately 6 miles north–northwest of Ouray, just east of the Uncompaghre River in the NW1/4 NW1/4 sec. 35, T4SN, R8W, Ouray County, Colorado (Table 1). We consider this section (Fig. 3) to be the type section (principal reference section or lectostratotype of some authors) of the Wanakah (Formation).

At its type section the Wanakah Formation is 85 ft (25.7 m) thick, including a basal 12 ft (3.6 m) thick interval of limestone and limestone breccia (Fig. 4). This interval, named the "Pony Express Beds" by Burbank (1930), rests directly on the Entrada Sandstone and clearly is the Todilto Limestone of Gregory (1916). We thus follow earlier authors and abandon the superfluous term Pony Express Beds.

Above the limestone breccia north of Ouray are 43.5 ft (13.2 m) of silty, gypsiferous sandstone that are equivalent to the Bilk Creek Sandstone of Goldman and Spencer (1941). The remainder of the type Wanakah section is 29.4 ft (8.9 m) of gypsiferous

TABLE 1—Measured type section of the Wanakah Formation, NW¼ NW¼ sec. 35 T45N R8W, Ouray County, Colorado.

Unit	Lithology	Thickness (m)
Morrison Formation:		
12	Sandstone; grayish-orange pink (10 R 6/2); fine-grained, subrounded, well-sorted, quartzose, calcareous; trough-crossbedded; forms a ledgy cliff.	not measured
11	Mudstone; brownish-gray (5 YR 4/1) and grayish red-purple (5 RP 4/2); silty and smectitic; deeply weathered, partially covered slope.	12.1
Junction Creek Sandstone:		
10	Sandstone; yellowish-gray (5 Y 7/2 and 5 Y 8/1); very fine to medium-grained, subrounded, moderately sorted, quartzose, very calcareous; laminar, in flaggy weathering beds 0.3–0.6 m thick.	3.3
9	Sandstone; pale-red (10 R 6/2) and very pale orange (10 R/YR 8/2); fine- to medium-grained, subrounded, moderately sorted, quartzose, slightly calcareous; laminar bedding; forms a prominent ledge.	3.0
"Wanakah Formation" (type section):		
8	Muddy and sandy siltstone; grayish-orange (10 YR 7/4) and moderate yellowish-brown (10 YR 5/4); slightly calcareous; massive; laterally gives way to massive medium-gray (N5), kerogenic, micritic limestone.	0.8
7	Siltstone; same color and lithologies as unit 6 but better cemented and thus forms a more resistant cliff than 6.	5.1
6	Siltstone and sandy siltstone; siltstone is pale red (5 R 6/2) to grayish red (10 R 4/2), slightly calcareous and gypsiferous; sandy siltstone contains very fine grained quartzose sand and is pale yellowish brown (10 YR 6/2), very calcareous and gypsiferous; unit contains fist-sized gypsum rosettes that are mottled pale yellowish orange (10 YR 8/6), very pale orange (10 YR 8/2) and moderate reddish orange (10 R 6/6); bedding is laminar and small-scale troughs.	3.0
5	Silty sandstone; mostly light olive-gray (5 Y 6/1) but mottled grayish-orange (10 YR 7/4); very fine grained, subangular, well-sorted, gypsiferous, calcareous; small trough crossbeds and much bioturbation; partly covered by slope debris; this is the "Bilk Creek Sandstone" of Goldman and Spencer.	13.2
"Pony Express Beds":		
4	Limestone breccia in gypsiferous matrix; angular limestone fragments of unit 3 lithology and color up to 2 cm in diameter in light olive-gray (5 Y 6/1) very calcareous gypsiferous matrix; forms a ledge.	2.8
3	Limestone; dusky yellowish-brown (10 YR 2/2) and medium-dark gray (N4); micrite; laminar and wavy laminar (crinkly).	0.8
Entrada Sandstone:		
2	Sandstone; pale yellowish-brown (10 YR 6/2); very fine grained, subrounded, well-sorted, quartzose, very calcareous, trace micas, laminar.	0.4
1	Sandstone; dusky yellowish-brown (10 YR 2/2); very fine grained, subrounded, well-sorted, quartzose, calcareous, trough-crossbedded.	not measured

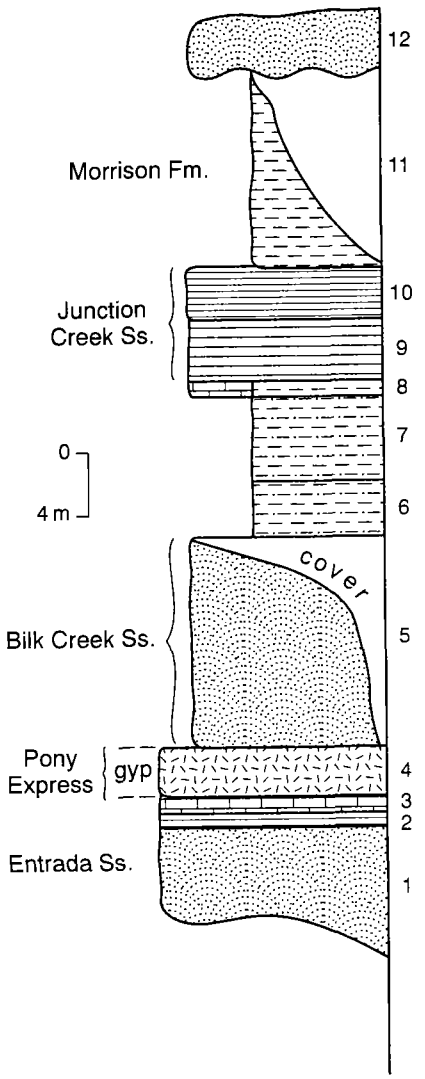


FIGURE 3—Measured section at the type Wanakah location, NW¼NW ¼ sec. 35 T45N R8W, Ouray County, Colorado; strata dip 23° N30°W.

siltstones with thin interbedded limestone near their top overlain by quartzose, laminar sandstone, the Junction Creek Sandstone of Goldman and Spencer (1941). Strata included in the Morrison Formation (Salt Wash Member) overlie the Junction Creek Sandstone north of Ouray.

Eolianites overlying Summerville Formation

Junction Creek Sandstone

The Junction Creek Sandstone is a massive, whitish, crossbedded sandstone that has a lithology and bedform similar to that of the much older Entrada Sandstone (Figs. 2D and 4F). It is a dominantly eolian unit that attains thicknesses of 300–500 ft (91–152 m). The Junction Creek is correlative with the Bluff Sandstone southwestward into Utah (Goldman and Spencer, 1941; Craig, 1955; Poole, 1962; Ekren and Houser, 1965). The Bluff, also dominantly eolian, conformably overlies the Summerville in the type area of southeastern Utah (Harshbarger et al., 1957; Craig, 1955); the Junction Creek conformably overlies the Wanakah Formation (now Summerville) in southwestern Colorado.

The significance of the Junction Creek Sandstone is that Goldman and Spencer (1941), who named the unit, recognized it as the upper part of the San Rafael Group and also realized the regional correlations. They specifically discussed the correlations ☞

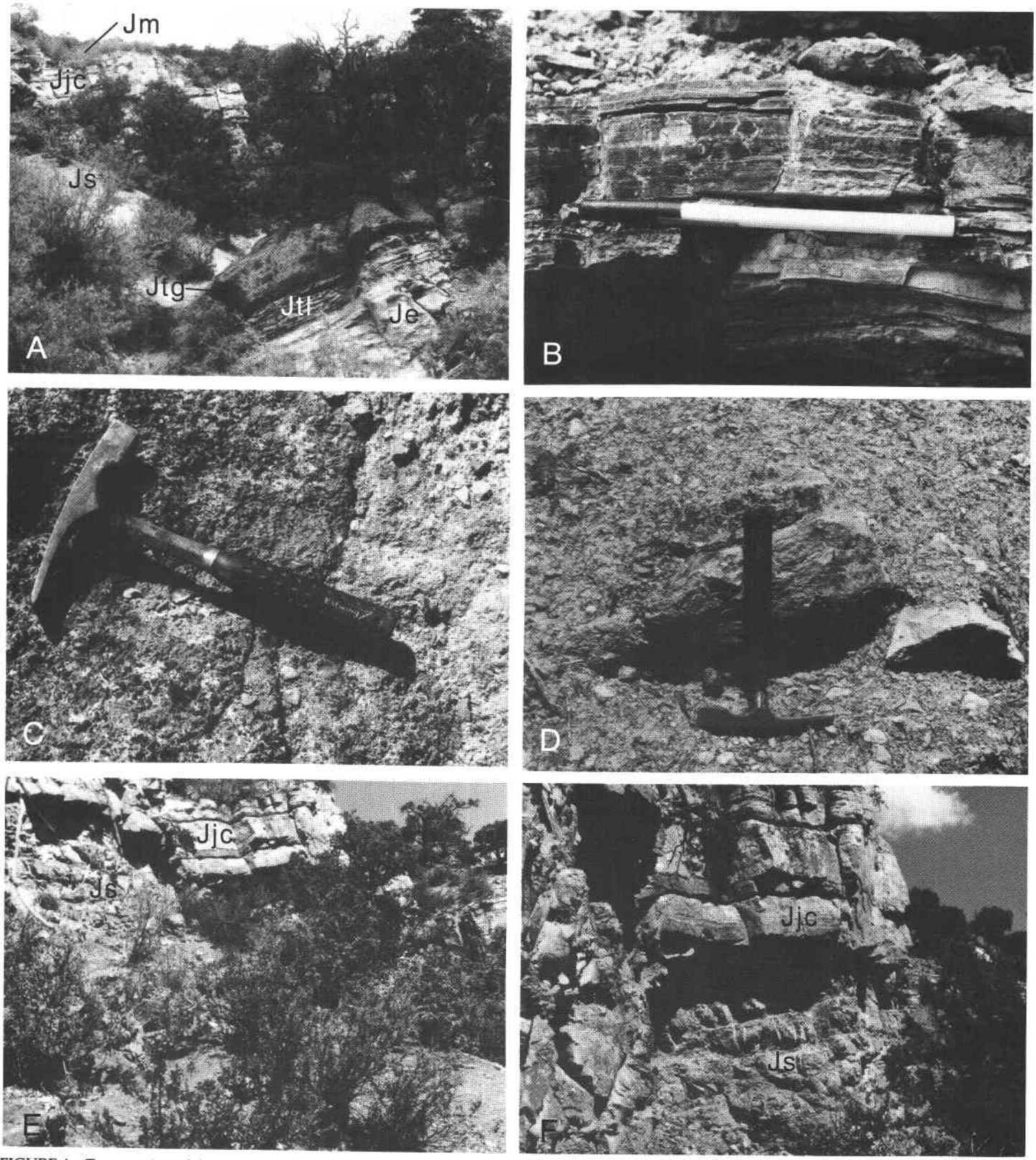


FIGURE 4—Type section of the Wanakah Formation north of Ouray, Colorado. **A,** Overview of type section, showing Entrada Sandstone (**Je**) overlain by limestone (**Jtl**) and gypsum (**Jtg**) of the Todilto Formation. Burbank (1930) named these strata the "Pony Express beds" at the base of the Wanakah. Gypsiferous sandstone and siltstones (**Js**) overlie the Todilto and comprise the major portion of the type Wanakah, here considered strata of the Summerville Formation. The Junction Creek Sandstone (**Jjc**) overlies the type Wanakah and is in turn overlain by the Morrison Formation (**Jm**). **B,** Laminar limestone (Table 1, unit 3) at type Wanakah section, a unit of the Todilto Formation. **C,** Limestone breccia in a gypsum matrix (unit 4) at Wanakah section, a unit of the Todilto Formation. **D,** Ripple-laminated sandstone (unit 5) at type Wanakah section, a unit of the Summerville Formation. **E–F,** long view (**E**) and close-up (**F**) of gypsiferous siltstones (units 6–8) of Summerville Formation (upper beds of type Wanakah) overlain by quartzose laminar sandstones (units 9–10) of the Junction Creek Sandstone (**Jjc**).

with the Utah section, the Four Corners area, and even correlations of the Wanakah or post-Entrada units into the Dry Cimarron River valley in the northeastern corner of New Mexico. They noted the similarities of the Pony Express beds to the Todilto, the Wanakah units—Bilk Creek Sandstone and the marl beds—to the Summerville, and, as stated, the Junction Creek—Bluff Sandstone correlation. Griggs and Read (1959) were aware of the eastward regional extent of the Entrada and Summerville on the basis of physical stratigraphy. They, however, chose to introduce the name Bell Ranch Formation for Summerville strata in east-central New Mexico. No eolianite such as the Junction Creek Sandstone is systematically present at the top of the San Rafael Group (above the Bell Ranch Formation—now Summerville) in these eastern locations on the High Plains. However, an upper member of the Entrada Sandstone is locally well developed and apparently occupies the stratigraphic interval of the Todilto Formation and a part of the overlying Summerville. This upper eolianite, called Exeter Member of the Entrada Sandstone, is analogous to and homotaxial with the Moab Tongue of the Entrada; both occupy stratigraphic levels below the Bluff Sandstone and are therefore older than that unit.

Source area for the Junction Creek Sandstone lay to the west and southwest based on paleowind studies by Poole (1962) who reported eastward and northeastward transport direction. Eolian-sand bodies tend to thicken downwind, being thickest at their downwind limit (Poole, 1962). The Junction Creek is at its thickest in the La Plata mining district in southwestern Colorado, reported by Eckel (1949) to be 200–500 ft (61–152 m) thick. The eolianites thus are locally well developed, well defined units of sufficient extent and thickness to merit separate stratigraphic names. Consequently, we recognize Junction Creek Sandstone as one of several homotaxial eolian units that overlie a regionally extensive Summerville.

Since the earlier work pertaining to upper San Rafael Group lithologies and correlation (Goldman and Spencer, 1941; Eckel, 1949; Griggs and Read, 1959) and the relationship to the overlying Morrison Formation (Craig, 1955), there has been a great deal of effort on the part of U. S. Geological Survey investigators to disprove those original findings and provisional correlations, most of which we feel were valid. Specific attempts have been made to find a way to get the eolianites into the Morrison Formation. A "horizontal parting surface" within the Junction Creek Sandstone was noted by Ekren and Houser (1965), who very observantly placed the entire formation within and at the top of the San Rafael Group. Condon and Huffman (1988), however, have elevated the status of this "horizontal parting surface" to that of the basal contact of the Morrison Formation and by inference to a regional unconformity. Lithologies above and below the parting surface are similar, as is bedform. We contend that there is little, if any, scientific basis for the stratigraphic division or assignment proposed by Condon and Huffman. Rather it is a contrivance to reconcile a problem created when O'Sullivan (1980) reassigned the Bluff Sandstone to the Morrison Formation, and in doing so envisioned an unconformity (the J–5) at the base. There had been a prior general agreement based on observable criteria and stratigraphic position that the Bluff and Junction Creek were correlative. Thus, with the Bluff included in the Morrison a means to reassign the Junction Creek Sandstone, or part of it, to the Morrison became necessary, and the "horizontal parting surface" was selected for that purpose. Placement of the basal Morrison Formation contact within the Junction Creek Sandstone created other minor problems for Condon and Huffman (1988). The upper Junction Creek was Morrison, the lower Junction Creek was "pre-Morrison," and they concluded that this rendered the Junction Creek both Middle and Late Jurassic in age. All these age assignments were without benefit of any fossil control and with no radiometric dates. The result was that Junction Creek could no longer be included in the San Rafael Group, which is entirely of Middle Jurassic age.

However, in their correlations of the Junction Creek southward into New Mexico, Condon and Huffman (1988) tentatively recognized the equivalency of their lower Junction Creek and the Horse Mesa Member of the Wanakah (our Bluff Sandstone). They did include the Horse Mesa Member (Bluff) in the San Rafael Group, and we thus think their lower Junction Creek would by inference also be included in that group. This supports our case because we regard the entire Junction Creek as one formation and include it as the uppermost unit of the San Rafael Group (with perhaps even more Summerville above it locally; see Goldman and Spencer, 1941, p. 1766.). Thus the Junction Creek, Horse Mesa Member, and Bluff Sandstone all are homotaxial sand bodies and are likely correlative, but this lacks a definite proof. We regard the name Horse Mesa as superfluous.

The following quote from Goldman and Spencer (1941) summarizes our concept of Junction Creek Sandstone:

> Any correlation of the beds overlying the Entrada sandstone in southwestern Colorado with those in Utah must, in our opinion, be based on recognition of the fact that the Junction Creek sandstone, by its purity, its eolian type of crossbedding, the uniform size and relative roundness of its grains, and the great thicknesses it attains, is of the type of the pre-Morrison sandstones of the east-central Utah section, the Wingate, Navajo and Entrada, and not of the type of the sandstones in the Morrison Formation. If this fact is accepted a very plausible correlation can be made, of the beds between the Entrada and the Junction Creek sandstone, with the pre-Morrison beds of east-central Utah.

Bluff Sandstone

Overlying the Summerville Formation through most of the San Juan Basin is a cliff-forming unit of similar lithology but with more sandstone and thicker beds than the underlying section. It is largely eolian, but fluvial facies are locally common and predominate. This unit, named the Bluff Sandstone Member of the Morrison Formation by Gregory (1938) and subsequently assigned to the San Rafael Group by Craig (1955), consists of a well-cemented sandstone of variable thickness, best developed near Bluff, Utah, from which it takes its name. The thickness near Bluff is as much as 300 ft, but decreases to approximately 30 ft in the Horse Mesa area of northwestern New Mexico. The unit extends southward in the subsurface and eventually merges with the Bluff and Zuni Sandstones in the southwestern and southern San Juan Basin. In the southeastern San Juan Basin the Bluff is delineated from the Summerville on the basis of bed form and bed thickness, and is shown with an overlying tongue of the Zuni Sandstone (Fig. 2C). The Bluff has been recognized as a medium- to thick-bedded sandstone of eolian and fluvial origin conformably overlying distinctive, thinly bedded Summerville strata. An upper part of the Bluff, commonly lighter in color and with thick sets of high-angle crossbedded strata, has been mapped (Maxwell, 1976, 1979) and recognized as a northward-extending tongue of the Zuni. We show it as a separate unit in our cross sections (Fig. 2B, C) and refer to it as the Acoma Tongue of the Zuni. Southward and southwestward the Bluff and Summerville lose their identity and become one eolian-sand sequence that is called Zuni Sandstone, the preferred name in New Mexico. The Zuni is well exposed at Zuni Pueblo and thus a local name is justified; however, it is the same unit that Harshbarger et al. (1957) and Condon and Peterson (1986) called the Cow Springs Sandstone.

The Bluff–Summerville contact is not everywhere apparent or readily picked. Harshbarger et al. (1957) stated that this contact is arbitrary in areas, suggesting that the transition from arid coastal-plain sabkha and eolian deposition to dominantly eolian and fluviatile deposition was unbroken and gradual. The contact is essentially based on bed form; the thinly bedded Summerville contrasts with the much thicker bed sets and large-scale crossbeds that typically occur in the overlying Bluff Sandstone.

Bluff–Zuni Sandstone–Morrison Formation relationships

We do not afford as much significance to the bedform break between the Bluff Sandstone and the overlying tongue of the Zuni

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in the southern San Juan Basin as did Condon and Peterson (1986) or Condon (1989). The former favored an interpretation of the relationship between the two units as "an unrecognized time boundary" and that the lower part was the San Rafael Group, whereas the upper, more crossbedded portion was the Morrison Formation. Their only reason was that other workers had reported the upper, crossbedded sandstone to intertongue with the Morrison Formation, and thus it had to be the Morrison. We regard the crossbedded sandstone as a facies of the San Rafael Group. Condon (1989) was more definitive. Although conceding that in most places the break between the upper and lower sandstones was gradational and based on the presence of eolian crossbedding, Condon nevertheless saw it as a formational contact between his Wanakah Formation and an "eolian facies of the Recapture Member of the Morrison Formation." This "contact" was of importance to Condon because it had been described as an unconformity (the J–5) by O'Sullivan (1980) in areas to the northwest of the San Juan Basin; all strata above the J–5 by definition belonged in the Morrison Formation. The subdivision of the Bluff and repositioning of the base of the Morrison Formation is analogous to what was done with the Junction Creek Sandstone described above. We contend that a formation contact ought to be physically observable at the point where it is picked and not based on interpretative information such as "unrecognized time boundaries" projected in from several hundred miles away. Condon (1989) was perhaps describing his Wanakah–Morrison contact as a correlative conformity, correlative with what was perceived as the J–5 unconformity at the base of the Morrison at Bluff, Utah. Our contention is that lithologies and bedform of the "eolian facies of the Morrison" suggest it more properly belongs with the Bluff Sandstone, or a tongue of the Zuni Sandstone. Moreover, by definition, a formation is a lithostratigraphic unit, not a chronostratigraphic unit. Accordingly, we name and map lithostratigraphic units, not chronostratigraphic units. With these stratigraphic concepts in mind, we can readily see that Condon has tried to project in and recognize chronostratigraphic units. As the Bluff supposedly intertongues with the Morrison, it is obvious that the base of the Morrison is not everywhere of the same age or, conversely, that eolian deposition persisted locally into the Late Jurassic.

The basal Morrison Formation contact in the Mesa Gigante area is more properly placed at the base of the fluvial section that overlies the eolian facies. This fits much better conceptually as well, because Morrison climates were decidedly more humid than those that prevailed during San Rafael Group deposition. The climatic change, in part related to continued northward drift of the North American plate, was gradual, however, and this is shown in the sedimentary units westward from Mesa Gigante. In the Thoreau–Church Rock area, interbedding of fluvial and eolian facies creates even greater difficulty in placing the basal Morrison contact. We agree with Robertson (1990), nonetheless, in being reluctant to place the stratigraphically highest eolian sandstone in the Recapture Member of the Morrison.

Paleotransport direction during deposition of the Bluff determined from eolian facies in the Horse Mesa area was to the southeast and northeast (Condon, 1989). Thus, the source area may well have been in part the vast plain left exposed by the retreat of the Curtis–Summerville sea. An additional sand source must have been present to the southwest, however, supplying sediment to the Cow Springs eolian system in Arizona. Poole (1962) reported generally eastward transport direction in the type area of the Bluff. This is consistent with transport direction observed in the Junction Creek Sandstone with which the Bluff has been correlated.

Zuni–Cow Springs Sandstone relationship

The name Zuni Sandstone is retained for use in New Mexico. Our usage of Zuni differs slightly from that suggested in a preliminary report by Anderson (1983) by excluding the lower part of the Zuni in the type area at Zuni Pueblo. This lower part, totaling some 280 ft (85 m) of crossbedded sandstone, is recognized as the Entrada Sandstone. Only the upper 200 ft (61 m) are assigned to the Zuni. The reason given by Anderson (1983) for the initial inclusion of the Entrada is that the break, or "Todilto notch," between the upper and lower parts is not everywhere present; where it is not present no basis exists for subdividing the sandpile. While this remains true, we now prefer to call the undivided section Zuni–Entrada Sandstone and reserve the name Zuni only for the upper part, the post-Todilto portion above the notch.

The Zuni Sandstone is well exposed in the Zuni Pueblo area, which is in the type area of the "Zuni sandstones" of Dutton (1885). The Cow Springs Sandstone, named by Harshbarger et al. (1957) for exposures on the north side of the Black Mesa in Arizona, was projected into western New Mexico by those authors. We, however, object to usage of Cow Springs in New Mexico, because Peterson (1988) has indicated that in the type area the Cow Springs is a member of the Entrada Sandstone. Peterson (1988) correlated the Cow Springs Sandstone eastward as a pre-Todilto unit beneath the J–3 unconformity of Pipiringos and O'Sullivan (1978). This indicates that the type Cow Springs is older than the Cow Springs strata projected into New Mexico. Although it is doubtful that the pre-Todilto age of the Cow Springs can ever be demonstrated, we accept it because so defined it should not be applied to the Zuni Sandstone that is demonstrably post-Todilto. Also a local name is highly appropriate for this unit; it is well exposed at Zuni Pueblo and usage of the name dates from 1885. In compiling the geologic map of New Mexico, Carle H. Dane (1956 memo) and Dane and Bachman (1965) very clearly expressed their preference for the name Zuni.

The Acoma Tongue of the Zuni is recognized as an eolian facies extending northeastward from the main Zuni (Fig. 2B). The main body of the Zuni Sandstone is developed as the Summerville Formation and Bluff Sandstone lose their identities southward and grade into a thick, crossbedded sandstone sequence of undoubted eolian origin. This relationship can be traced out in the southern San Juan Basin (Maxwell, 1976, 1979; Moore, 1990) and thus lends validity to the extensive use of the name Zuni Sandstone in the area by geologic mappers and explorationists during the past 20 years.

The type area of the Acoma Tongue is the east side of Seama Mesa in sec. 19 T9N R6W and in secs. 24, 25, 34, and 35 T9N R7W on the Acoma Pueblo quadrangle. The Acoma Tongue consists of as much as 300 ft (91 m) of fine-to medium-grained, well-sorted quartzose sandstone. Large-scale eolian crossbedding along with the light color are distinguishing characteristics. It is sharply overlain by the coarser-grained, darker-colored Dakota Sandstone at the K-1 unconformity. We, however, defer to the local investigator the decision to recognize, or not recognize, the Acoma Tongue as a separate unit on the basis of bedform alone. In his map of the Acoma Pueblo quadrangle, Maxwell (1976) used a dashed line everywhere for the Bluff–Zuni contact.

Correlation and discussion

During the 1980s, two arguments were presented by workers at the U.S. Geological Survey to support use of the name Wanakah Formation in place of Summerville in southeastern Utah and northwestern New Mexico. First, O'Sullivan (1980) claimed that the Summerville Formation pinched out beneath the J–5 unconformity near Moab, Utah, and was not present southeast of the pinchout. Subsequently, O'Sullivan (1981) himself corrected this conclusion and recognized Summerville strata southeast of Moab as the "Wanakah Formation." Nomenclature aside, O'Sullivan demonstrated that although the Summerville thins significantly southeast of Moab, it can be traced throughout the Four Corners area and southeastward into the San Juan Basin.

We further note that identification of the Tidwell Member of the Morrison Formation by Peterson (1988) removed strata long and, we believe, correctly included in the Summerville Formation (e.g., McKnight, 1940) from that unit. This contributed to the apparent thinning of the Summerville locally in southeastern Utah.

The second argument focused on correlation of the Wanakah, Summerville, and Curtis Formations. In the Blanding area of southeastern Utah, O'Sullivan (1980) applied the informal name "Bed at Black Steer Knoll" to a locally persistent sandstone ledge in the upper part of the Wanakah (Summerville) Formation. He then identified this bed as far east as Slick Rock, Colorado and as far north as White Wash, northwest of Moab (Fig. 2C). At the White Wash locality, O'Sullivan (1980) claimed that the "Bed at Black Steer Knoll" was correlative with the upper Curtis Formation and thus beneath the Summerville Formation. Condon and Peterson (1986, p. 15) thus concluded that "a marker bed [the Bed at Black Steer Knoll] in the upper part of the Wanakah is also present in the upper part of the Curtis Formation of the San Rafael Swell area which indicates that the Wanakah is older than the Summerville."

We, however, question O'Sullivan's (1980) identification of the "Bed at Black Steer Knoll" at localities such as White Wash, Utah, and Slick Rock, Colorado, (Fig. 5) that are a long distance from Black Steer Knoll west of Blanding and between which the San Rafael Group strata cannot be directly traced. Furthermore, at these localities the lithology, thickness, and exact stratigraphic position of the "Bed at Black Steer Knoll" differ (Fig. 6), thus making it difficult to accept O'Sullivan's correlations. In the Black Steer Knoll area the "Bed at Black Steer Knoll" is very gypsiferous and massive (Fig. 5C), and is in the middle of the Summerville when the Tidwell Member is, as it indeed should be, included in the Summerville. At White Wash, the unit identified by O'Sullivan as the "Bed at Black Steer Knoll" is a calcareous ripple-laminated sandstone near the top of the Summerville Formation (Fig. 5A). It is not at the top of the Curtis Formation; no Curtis Formation strata are present at White Wash (McKnight, 1940). Finally, at Slick Rock, Colorado, gypsiferous crossbedded sandstone at the top of the Summerville Formation (Fig. 5D) was identified by O'Sullivan as the "Bed at Black Steer Knoll." Clearly, O'Sullivan's identification of different lithologies at different stratigraphic levels over a relatively large geographic area as the "Bed at Black Steer Knoll" is difficult to accept.

Since the Summerville Formation is so readily correlated on the basis of lithology and physical stratigraphy, we are puzzled by recent attempts to restrict usage of the name. Given that the ultimate goals of detailed stratigraphic studies are regional correlations, paleogeographic reconstructions, and conceptual depositional models, it is paramount that stratigraphers strive to recognize regionally interrelated genetic units.

Formation contacts cannot always be drawn at boundaries between genetic units, nor does definition demand this. Contacts must, nevertheless, be placed at lithostratigraphic breaks, not at "unrecognized time boundaries" or chronostratigraphic breaks; this is simply in accordance with the basic definition of a formation. For purposes of discussion we can recognize and correlate chronostratigraphic units, conceivably worldwide, but by definition we map formations.

Sufficient stratigraphic information exists to permit accurate regional correlations of the San Rafael Group strata (Fig. 2B–D) and to relate component formations and facies to depositional settings. Paleotransport directions and paleohydrologic considerations allow an accurate paleogeographic model of the Middle Jurassic in the Southwest. In post-Carmel time it consisted in turn of 1) an extensive eolian erg represented by the Entrada Sandstone that contains indicators of southward paleotransport of sand in migrating dunes. 2) Encroachment into southern Utah of a shallow epicontinental seaway in which the fine-grained, glauconitic Curtis Formation was deposited. An associated highstand depositional system developed as a salina lake or a paralic salina to the southeast in what is now northern New Mexico; in this salina the Todilto Formation accumulated. Peripheral to the water masses were an arid coastal plain-sabkha and shallow temporary lacustrine environments in which wave-dominated deltas prevailed and in which the basal Summerville strata were laid down. Farther away from the water masses, especially to the south and southwest, eolian deposition persisted and resulted in a sandpile called the Zuni Sandstone (previously Cow Springs). 3) Northward withdrawal of the Curtis Sea and the related disappearance of the Todilto salina initiated progradation of arid coastal plain-sabkha depositional systems that laid down the bulk of Summerville strata. 4) Eolianite depocenters, thickest in their downwind direction, developed as penecontemporaneous sandpiles on the Summerville strata as the San Rafael Group deposition came to an end. The cessation of eolianite, sabkha, and salina-lake deposition was the direct result of progressively more humid climates during latest Middle and earliest Late Jurassic times. The humid climates initiated fluvial deposition as represented by the lower members of the Morrison Formation culminating in the Brushy Basin Member.

Sedimentary rocks are now being described in terms of sequence stratigraphy, which defines a sequence as an unconformity-bounded succession of genetically related strata. As a result of the nearly complete lack of fossils, unconformities have become an increasingly popular tool with Middle Jurassic stratigraphers. A study of the Jurassic unconformities by Pipiringos and O'Sullivan (1978) resulted in the identification of six regionally significant unconformities labeled J–0 through J–5.

The oldest unconformity pertaining to the San Rafael Group strata is the J–2. It represents a hiatus between the Entrada (or the Carmel where present) and underlying strata. This unconformity is widespread, coextensive in fact with the San Rafael Group, and is easily recognized. The J–3 is recognized at the base of the Curtis Formation and may represent some minor reworking of sediment associated with the transgression of the shallow Curtis Seaway. It is also recognized at the base of the correlative Todilto Formation to the southeast (Maxwell, 1976; 1982; 1986). The J–4 is of limited applicability here, being present in the northern San Rafael Swell where it represents a break between the upper and lower Curtis or locally between the Summerville and the Redwater Shale Member of the Sundance Formation (Pipiringos and O'Sullivan, 1978).

Forming the top of the San Rafael Group is the J–5 unconformity, which is generally regarded as regional in scope. The problem is that not all workers have recognized it nor placed it at the same horizon. No attempt is made here to resolve this problem except to state that conceptually the contact between the San Rafael Group and the Morrison Formation should be placed at the break between the quartzose eolianites or thinly bedded sabkha-type gypsiferous sandstones and the overlying coarser-grained fluvial sandstones of more lithic composition. As such it may not be an isochronous surface and perhaps would not fit the definition of a sequence boundary. It is mentioned here briefly only because in the more northwestern extent the Morrison directly overlies the Summerville Formation.

Correlation of the Bluff Sandstone

Condon and Huffman (1988) questioned correlation of the Bluff Sandstone from the type area at Bluff, Utah (Fig. 5E) to Horse Mesa, New Mexico (Fig. 2C). This is the direct result of stratigraphic reassignment by O'Sullivan (1980) of the type Bluff Sandstone to the basal member of the Morrison Formation. Because the 30-ft-thick (10-m-thick) eolian section at Horse Mesa has been recognized as part of the San Rafael Group and as correlative with the Bluff Sandstone, reassignment of the type Bluff necessitated a new name—the Horse Mesa Member of the Wanakah Formation—for the section at Horse Mesa. To support this new name, Condon and Huffman (1988) stated that some contorted bedding and fold structures in the "Horse Mesa Member" at Tsitah Wash, on the west side of the Carrizo Mountains, Arizona, are truncated by the younger Bluff Sandstone. We believe the contorted bedding in the "Horse Mesa Member" is due to soft-sediment deformation, dewatering or piping in the underlying Summerville, or some large-scale, primary-bedding feature. The deformation thus is syndepositional and not related to tectonic deformation; therefore, little basis for an unconformity exists. Horse Mesa and Tsitah Wash are 23 mi (37 km) apart, and the ☞

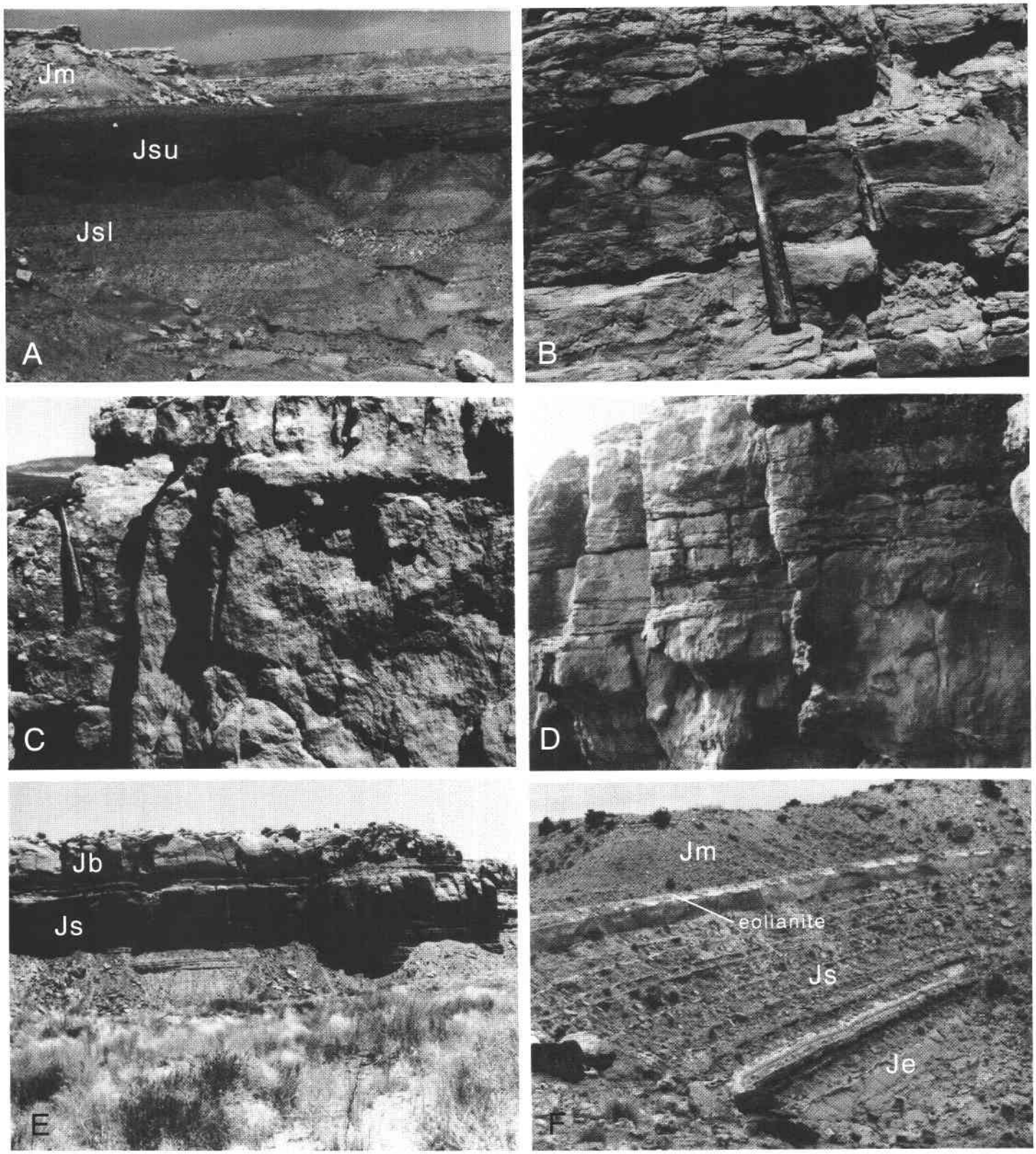

FIGURE 5—**A,** Part of the Jurassic section exposed at White Wash, NE¼ NW¼ sec. 14 T23S R17E, Grand County, Utah, showing lower (**Jsl**) and upper (**Jsu**) Summerville Formation overlain by Morrison Formation (**Jm**). **B,** Close-up of sandstone interval at White Wash identified by O'Sullivan (1980) as the "Bed at Black Steer Knoll." **C,** Close-up of "Bed at Black Steer Knoll" near Black Steer Knoll, SW¼ NW¼ sec. 21 T35S R21E, San Juan County, Utah. Note gypsiferous nodules weathering out, especially around the rock hammer. **D,** Close-up of the sandstone interval near Slick Rock, Colorado (NE¼ NE¼ sec. 36 T44N R19W, San Miguel County) identified by O"Sullivan as the "Bed at Black Steer Knoll." Thickness of outcrop in photo is 10 ft. **E,** Summerville Formation (**Js**) overlain by Bluff Sandstone (**Jb**) near Bluff, Utah, sec. 20 T40S R21E, San Juan County. **F,** Entrada Sandstone (**Je**) overlain by type Bell Ranch Formation (**Js**) overlain in turn by Morrison Formation (**Jm**) at Carpenter Mesa, SW¼ NE¼ sec. 22 T16N R30E, Quay County, New Mexico. The uppermost sandstone bed in the Bell Ranch is an eolianite homotaxial to the Bluff Sandstone on the Colorado Plateau.

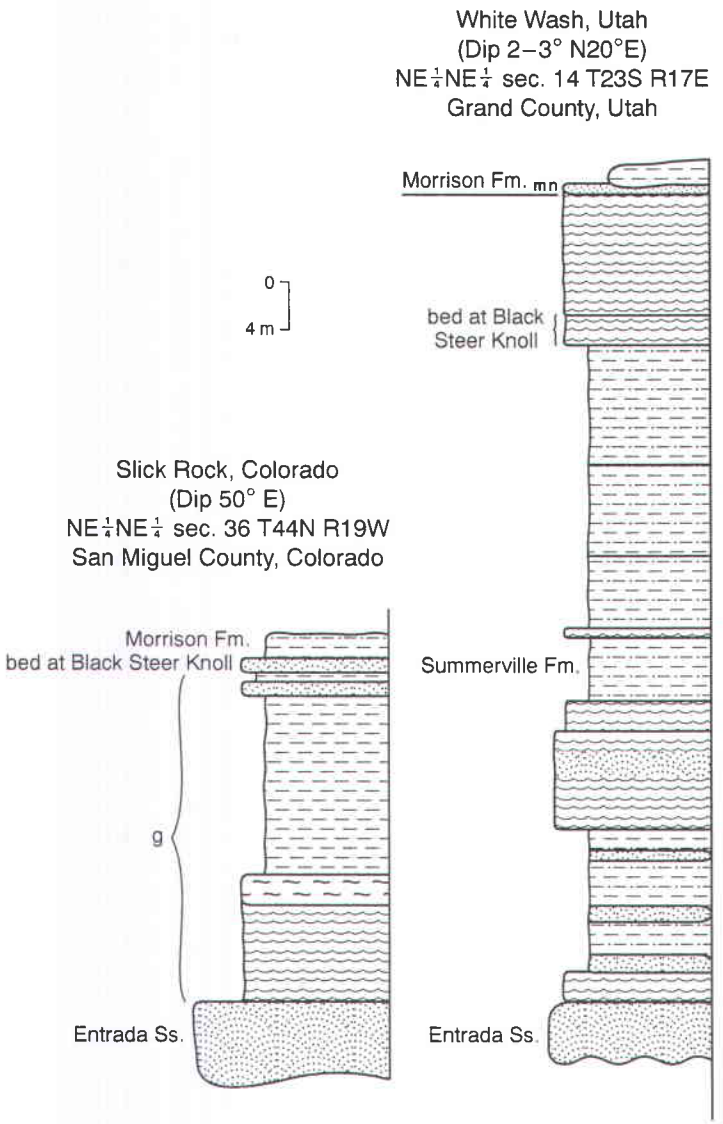

FIGURE 6—Stratigraphic sections at Whitewash, Utah and Slick Rock, Colorado showing position and thickness contrasts of the "bed at Black Steer Knoll." **g,** gypsiferous; **mn,** manganese bed.

Bluff Sandstone merely thickens and develops an upper facies westward into Arizona, where it exhibits internal deformation features common in gypsiferous sediments.

The "unconformity" or "truncation" described by Condon and Huffman is chronologically insignificant. It is apparently another contrivance and argument put forth to defend placing the Bluff in the Morrison Formation. Regardless of whether or not the Horse Mesa Member can eventually be established as older than the type Bluff, they are here both considered to be part of the San Rafael Group. On the basis of lithology, bedform, and stratigraphic position they appear correlative. We therefore regard the name Horse Mesa Member as superfluous. Should an age difference ever be established, the option would be to regard the thinned Horse Mesa section as a tongue of the Bluff.

The Bluff Sandstone was observed by O'Sullivan (1980) to pinch out into the Morrison Formation. We have not visited the location where the pinchout occurs, but if it indeed does so, it is simply an example of formations intertonguing. A preconceived J–5 unconformity should not be sought at the San Rafael Group–Morrison contact. This contact must be based on lithology, which then dictates placement of the Bluff Sandstone in the San Rafael Group (Craig, 1955; Ekren and Houser, 1965; Goldman and Spencer, 1941). The Salt Wash Member of the Morrison overlies the San Rafael Group at a commonly, but not universally, channel-scoured surface. Ekren and Houser (1965) reported that in southwestern Colorado fluvial sandstone of the Salt Wash Member has been deposited in channels scoured into the Junction Creek Sandstone. This is the J–5 unconformity.

Summary

Our correlations of Middle Jurassic strata are summarized by the cross sections (Fig. 2B–D). The thinly bedded strata overlying the Curtis Formation in the San Rafael Swell of Utah were given the name Summerville Formation by Gilluly and Reeside (1928). The Summerville can be physically traced into southeastern Utah and correlated into adjacent southwestern Colorado and New Mexico on the basis of lithology, bedform, and stratigraphic position. Thus the name Wanakah Formation applied to these strata in southwestern Colorado by Burbank (1930), but never widely used, is abandoned in favor of the widely used name Summerville. The Pony Express (limestone and gypsum) beds at the base of the Wanakah are correlative with the Todilto Formation, and thus the name Pony Express beds is also abandoned.

Attempts to rejuvenate and expand the use of the name Wanakah Formation in New Mexico in place of the entrenched name Summerville Formation (Condon and Peterson, 1986; Condon and Huffman, 1988; and Condon, 1989) are without merit and tend to stifle or inhibit regional correlations. Most importantly, Summerville has precedence, and the name Wanakah is occupied in New York State. Therefore, the name Wanakah should not be used to designate strata in Colorado.

In northeastern New Mexico the strata overlying and overlapping the Todilto Formation have been since 1959 referred to as the Bell Ranch Formation (Fig. 5F). The Bell Ranch is demonstrably equivalent to the Summerville strata to the west, and thus is abandoned in favor of Summerville.

The gypsiferous, thinly bedded Tidwell Member of the Morrison Formation is not recognized. Genetically and lithologically, these strata are properly included with the Summerville strata.

Eolianites overlying the Summerville and/or forming the top of the San Rafael Group are homotaxial and very likely correlative. These include the Junction Creek Sandstone, the Bluff Sandstone, and the Acoma Tongue of the Zuni Sandstone in the southeastern San Juan Basin. The Horse Mesa Member of the Wanakah, named for exposures in extreme northwestern New Mexico, does not demonstrably differ from the Bluff Sandstone in age or lithology. Horse Mesa thus is a superfluous name.

The Bluff Sandstone and Summerville Formation grade southward and southwestward into an undifferentiated eolian sandstone. In west-central New Mexico and in the southern San Juan Basin this eolian unit has been called the Cow Springs Sandstone, named for exposures near Cow Springs at the north end of Black Mesa, Arizona. The Cow Springs Sandstone, however, is considered by Peterson (1988) to be a pre-Todilto unit in Arizona, and as such is merely the upper part of the Entrada. We note that the unit called Cow Springs in west-central New Mexico is a post-Todilto unit and consequently, we use the local name Zuni Sandstone, for exposures near Zuni Pueblo, in place of Cow Springs. Usage of the name Zuni for these strata dates from Dutton (1885).

In the Laguna, Acoma, and Mesa Gigante areas a northerly extending uppermost unit of the main Zuni Sandstone was previously called the upper Bluff or assigned to the Recapture Member of the Morrison Formation. This highly crossbedded unit, recognized by Maxwell (1976) largely on the basis of bedform, is herein designated the Acoma Tongue of the Zuni Sandstone for those who wish to differentiate it from the underlying Bluff.

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