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THE UPPER JURASSIC MORRISON FORMATION IN THE FOUR CORNERS REGION

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Abstract—Nonmarine strata of the Morrison Formation are widespread in the Four Corners region. The Morrison Formation (Upper Jurassic)-San Rafael Group (Middle–Upper(?) Jurassic) contact is placed at a regionally traceable unconformity and sequence boundary at the base of the Salt Wash Member of the Morrison Formation. The internal stratigraphy of the Morrison is thereby simplified with only two members, the Salt Wash and the Brushy Basin, recognized for regional correlation purposes. Thus, the confusing, duplicative, and overlapping Morrison members which included Bluff, Recapture Shale, and Westwater Canyon Sandstone are no longer recognized, and the names are either abandoned or the units reassigned to the San Rafael Group. This Morrison concept and internal stratigraphy recognizes and follows useful mapping units that aid in regional correlation. The sequence boundary at the base of the Morrison records the onset of fluvial deposition and a climatic change related to northward drift of the North American continent through Jurassic time. Morrison deposition took place on riverine floodplains. A lacustrine origin for the Brushy Basin Member (ancient Lake T'oo'dichi') is not supported by several lines of evidence. Most age data suggest the Morrison Formation is of Late Jurassic age, but it still remains possible that the upper part of the formation is of Early Cretaceous age.

INTRODUCTION

The Morrison Formation (Middle? and Upper Jurassic) is a widely recognized stratigraphic unit in the Western Interior of the United States. Extending from Montana to New Mexico and from central Utah to western Oklahoma, it rivals units such as the Dakota Group and the Chinle Group in geographic extent. With the exception of areas in northern Wyoming and adjacent South Dakota and Montana, the Morrison is entirely of nonmarine origin.

As the Morrison is everywhere an unconformity-bounded unit, any basin analysis isopach data or paleogeographic interpretation must take into account the fact that thickness measurements and isopach data do not represent original accumulation of sediment. Nonetheless, the thickest sections of the Morrison occur in southwestern Colorado (near Norwood), south-central and southeastern Utah, and near the Arizona-New Mexico state line at Sanostee (Fig. 1). In these areas, the thickness of the formation may exceed 250 m, whereas elsewhere it is a more characteristic 50 to 150 m thick. In New Mexico, the Morrison is progressively beveled off southward so that the zero isopach line is near 35°20' N. latitude. Thickness, distribution, paleocurrent data, lithology, and petrology all indicate a west-

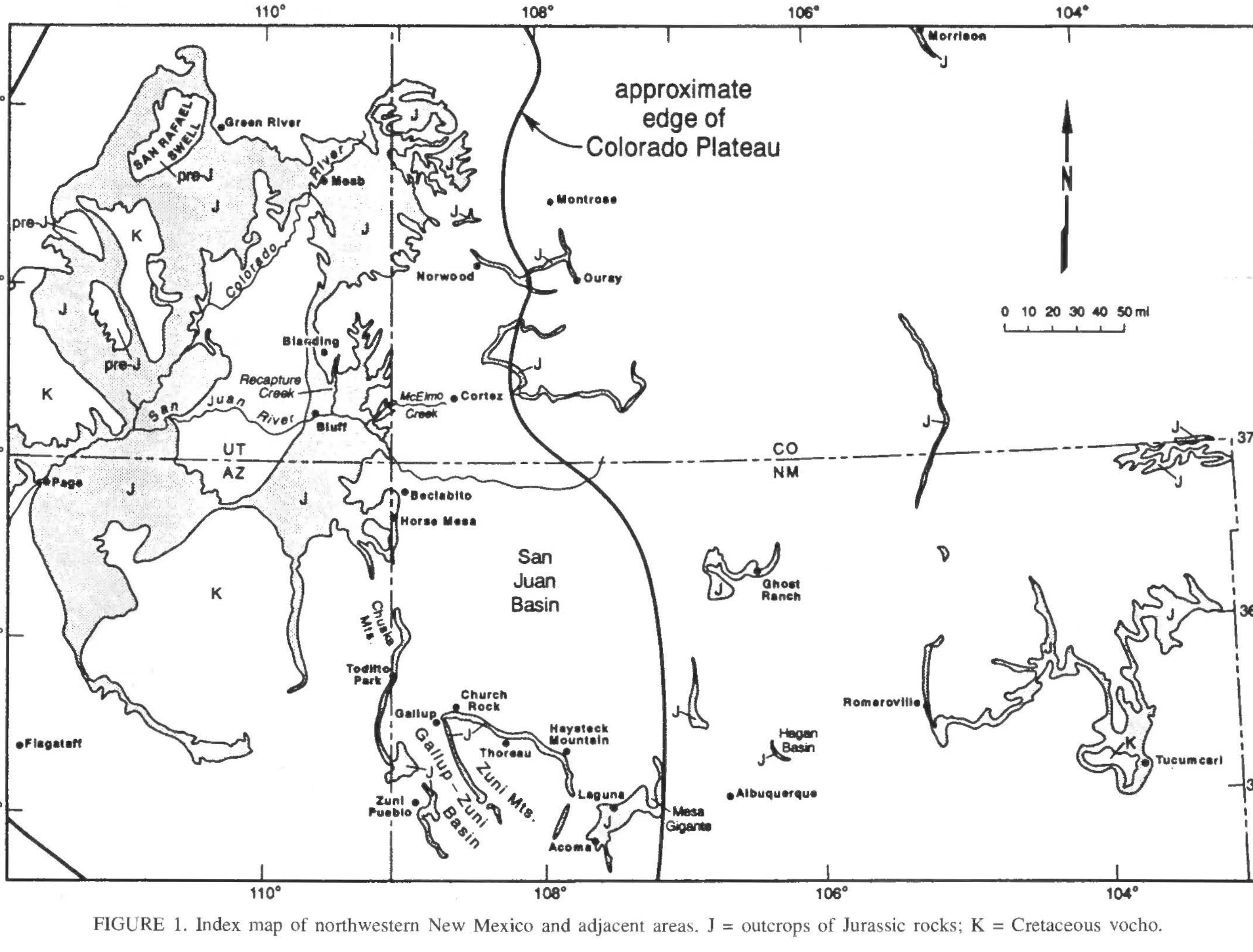

FIGURE 1. Index map of northwestern New Mexico and adjacent areas. J = outcrops of Jurassic rocks; K = Cretaceous vocho.

ern source area (Craig et al., 1955; Saucier, 1967) and to a lesser extent a southwestern source area, commonly refered to as the Mogollon highlands, a persistent positive area along the southwestern margin of the depositional basin.

The internal stratigraphy of the Morrison Formation, while locally complex, is not so on a regional scale, and the unit is not well served by the burden of formal member names that have been bestowed upon it (Fig. 2). The lower part is dominated by fine- to coarse-grained, crossbedded, conglomeratic sandstone, interbedded with red-brown mudstone and siltstone, known since Gilluly and Reeside (1928) as the Salt Wash Member. Maximum thickness of more than 180 m is reached in depocenters north of Page, Arizona, near Sanostee, New Mexico, and at Norwood, Colorado (Fig. 1). Paleotransport direction was to the east and southeast and to a lesser extent to the northeast. The unit thins down-depositional dip, a trend that is independent of the overall southward thinning of the formation.

The Salt Wash Member has an intertonguing relationship with the overlying claystone-dominated Brushy Basin Member. Much of this claystone is smectitic and was derived from volcanic ash, both primary ash falls and fluvially reworked ash. Thickness of the Brushy Basin varies considerably, as the top is everywhere an unconformity overlain by either Cretaceous rocks or by a surface of modern erosion. In Utah it ranges from 0 to 180 m thick (Craig et al., 1955); in New Mexico it ranges from 0 to 115 m (Freeman and Hilpert, 1956).

Here, we present a review of Morrison Formation stratigraphy, deposition and age, with special emphasis on the Four Corners region.

HISTORY OF MORRISON FORMATION STUDIES

The Morrison Formation was named and described by Cross (1894) in the Pikes Peak Folio, and by Eldridge (1896) in the type area near Morrison, Colorado, along the Front Range. It was recognized by them as consisting of as much as 136 m of sandstone and shale of a variety of colors. Lee (1920) restricted the original definition, recognizing the upper 80 m as more properly belonging to the "Dakota group" and the lower 5.2 m as belonging to the Sundance Formation. The remaining approximately 48.5 m was a

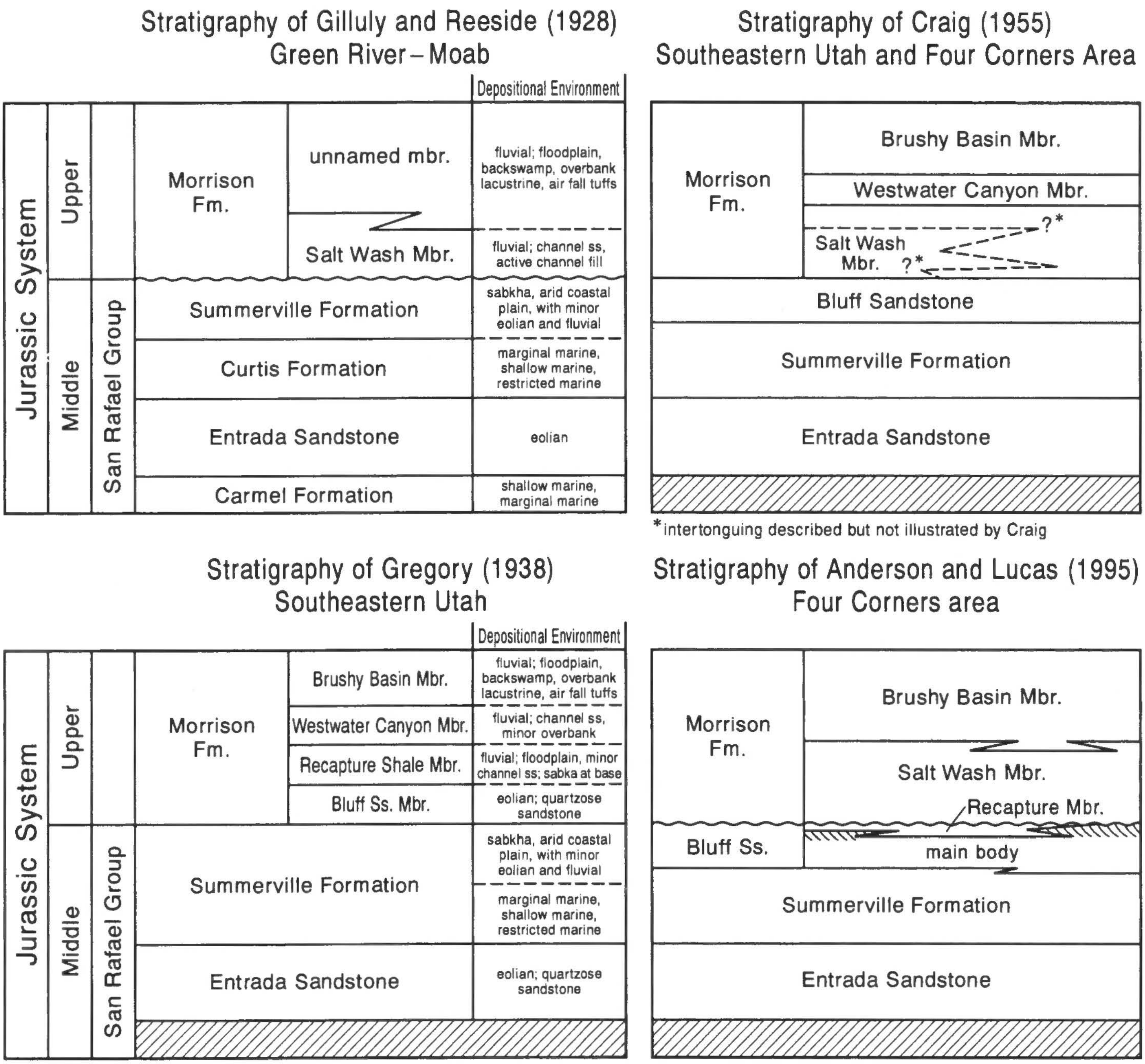

FIGURE 2. Comparison of Morrison stratigraphic nomenclature proposed by various workers.

more homogeneous unit, predominantly "shale" (claystone), and became generally accepted as the Morrison Formation in that area.

Recognition of the Morrison Formation in areas west of the southern Rocky Mountains, particularly in Utah, came with the work of Gilluly and Reeside (1928; Fig. 2). They first defined the San Rafael Group (Middle Jurassic) from exposures in the San Rafael Swell (east-central Utah), and identified the top of this new unit on the basis of sharp lithologic contrast, further marked by a regional unconformity. The strata above this unconformity were recognized as the Morrison Formation, which they stated as ranging in thickness from 126 m to 256 m in the area. The crossbedded, conglomeratic sandstone at the base was designated the Salt Wash Member, utilizing the name that Lupton (1914) had earlier used for these strata. The upper part of the Morrison, which is claystone dominated and intertongued with the Salt Wash, was not given a formal name at that time.

Gregory (1938) described the Morrison in southeastern Utah, extending that unit considerably southward from the San Rafael Swell. He also introduced the member names for the formation that eventually gained widespread usage, ultimately finding their way into the San Juan Basin of northwestern New Mexico (Fig. 2). For the crossbedded sandstone unit which "appears to lie in the position of the Salt Wash Member" Gregory tentatively applied the term Westwater Canyon Sandstone Member of the Morrison Formation. The overlying, slope-forming claystone and sandstone unit was designated the Brushy Basin Shale Member. This portion of Gregory's work was consistent with the excellent observations presented by Gilluly and Reeside ten years earlier.

Southward, Gregory extended the Morrison Formation downward from the base of his Westwater Canyon Member. In most areas the immediately underlying unit (Recapture Shale Member of Gregory) consists of sandstone and siltstone in thin, parallel beds, with subordinate mudstone; it is generally a redbed sequence, but commonly mottled or bleached. A problem with this member designation was that the type locality included the Westwater Canyon Sandstone Member (Stokes, 1944; Anderson and Lucas, 1995). This accounts for the difficulty many investigators have had in explaining lateral relationships among the Recapture, Westwater Canyon, and Salt Wash Members (e.g., Peterson and Turner-Peterson, 1987). Gregory's Recapture Shale Member also intertongues with the underlying sandstone, which is a prominent, cliff-forming eolianite in the Recapture Creek area (Fig. 3). Gregory had little choice but to include the sandstone, which he formally named the Bluff Sandstone Member, in his expanded Morrison Formation. A more detailed discussion of Gregory's work is described later in this paper.

In a detailed account of Morrison Formation stratigraphy of the Colorado Plateau region, Craig et al. (1955) recognized most of Gregory's (1938) Morrison members (Fig. 2). They differed with the earlier work only in that they chose to include the Bluff Sandstone in the San Rafael Group on the basis of "bedding and lithologic characteristics." Craig et al. further pointed out that the Bluff is gradational laterally and vertically with the Summerville Formation and locally is intertongued with that unit. Thus the matter of the basal contact of the Morrison becomes very problematic if (Gregory, 1938) the Bluff is included with Morrison Formation strata. The Morrison was at risk of becoming trivialized by the inclusion of progressively older, intertonguing units within the distinctive San Rafael Group.

Condon (1985) and Condon and Peterson (1986) contended that some type of chronostratigraphic contact lies within the Bluff Sandstone and that it could be an "unrecognized time boundary" representing the base of the Morrison Formation. The disadvantage of this view is that it is not based on lithostratigraphy and that such an unrecognized boundary is not mappable and does not result in the placement of formation contacts at positions of maximum lithologic contrast. The advantage or purpose of this perspective is presumably that it seeks to validate the work of Gregory (1938) and thus provide continuity to the nomenclature, although in doing so some of the observations of Craig et al. (1955) are unavoidably ignored.

Recently Anderson and Lucas (1995) presented their interpretations of Morrison-San Rafael Group relationships (Fig. 2), following field studies that included visits to most of Gregory's (1938) sites. They concluded that the Salt Wash Member and the basal unconformity associated with it define the base of the Morrison Formation throughout most of the area of its western distribution, and that the name Westwater Canyon Member, introduced by Gregory (1938), is a junior synonym for strata previously designated as Salt Wash Member. Consequently, Anderson and Lucas recommended that the name Westwater Canyon Member be abandoned. More-

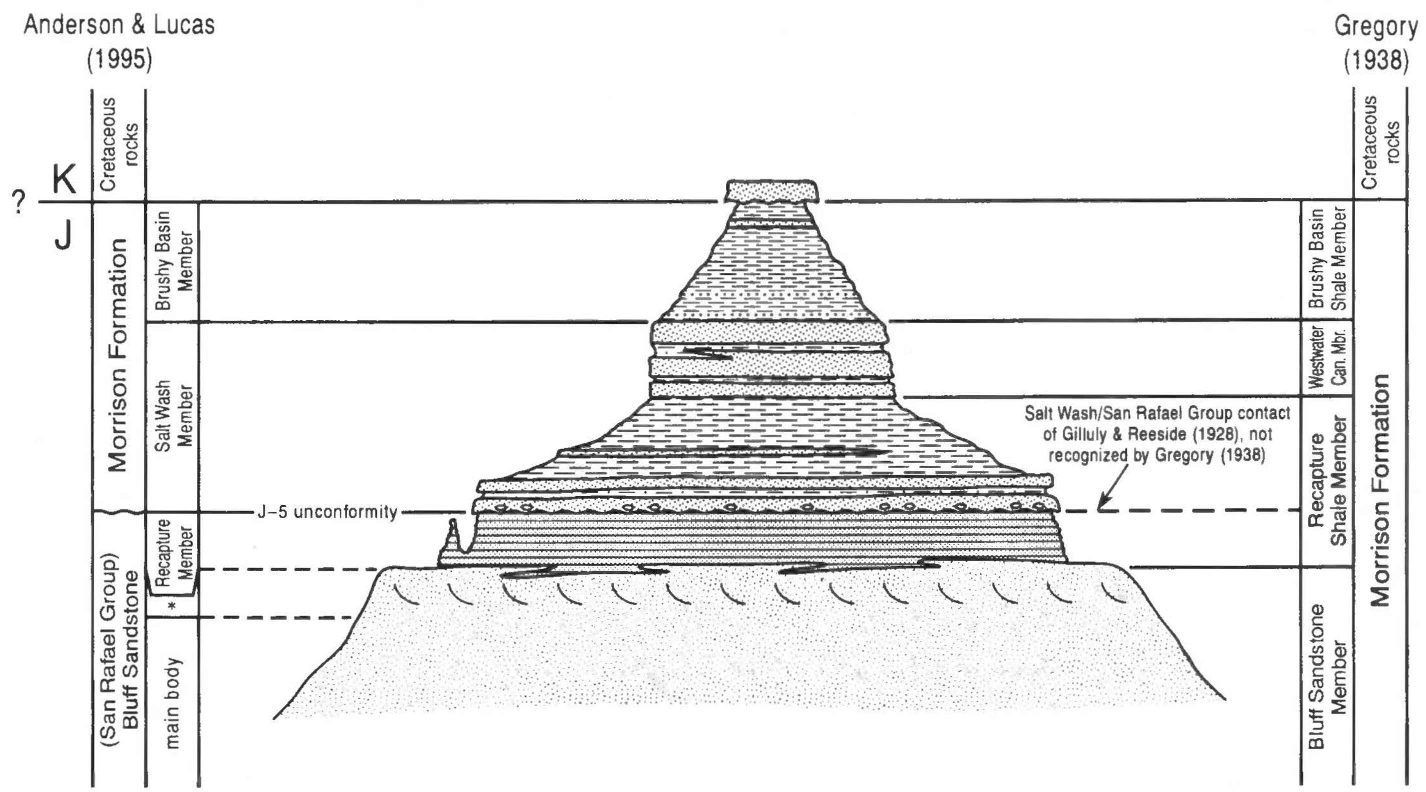

FIGURE 3. Diagram of stratigraphic sequence exposed at mouth of Recapture Creek, 8 km east of Bluff, Utah, contrasting the stratigraphic concepts of Gregory (1938) on right with concepts and nomenclature advocated in this paper on left. *Crossbedded unit correlates with Acoma Tongue of Zuni Sandstone.

over, they concurred with Craig et al. (1955) that the Bluff Sandstone is associated with San Rafael Group strata, and that a vertically restricted (compared to Gregory) Recapture Member of the Bluff forms a fine-grained unit at the top of the San Rafael Group (Fig. 3) across a broad area from Bluff, Utah to the southern San Juan Basin. The top of the Recapture Member was everywhere recognized as an unconformity (the J-5 unconformity of Pipiringos and O'Sullivan, 1978) commonly marked by pedogenic carbonate beds (Fig. 4), presenting a mappable contact between the San Rafael Group and the crossbedded, pebbly sandstones of the basal Morrison Formation.

BASE OF THE MORRISON FORMATION

Considerable uncertainty and difference of opinion exist with regard to the base of the Morrison Formation in the Four Corners region (Fig. 2). Much of this confusion reflects the fact that in this area the base of the Morrison was not determined by correlation with the formation type area (Eldridge in Emmons et al., 1896) or with the type section near Morrison, Colorado (Waldschmidt and LeRoy, 1944), but rather by correlation to the Morrison of southeastern Utah. Indeed, the longstanding subdivision of this western Morrison into four members lacks lithostratigraphic significance, contains overlapping units, employs duplicative nomenclature, and ignores a regionally traceable unconformity that is of great stratigraphic significance and mapping applicability. Extending this four-member subdivision into the San Juan Basin in the 1950s during the height of uranium exploration resulted in uncertain correlations and a Morrison basal contact that was not based on lithologic contrast. The resulting trivialization of the formation concept further resulted in the inclusion of some San Rafael Group strata in the overlying Morrison.

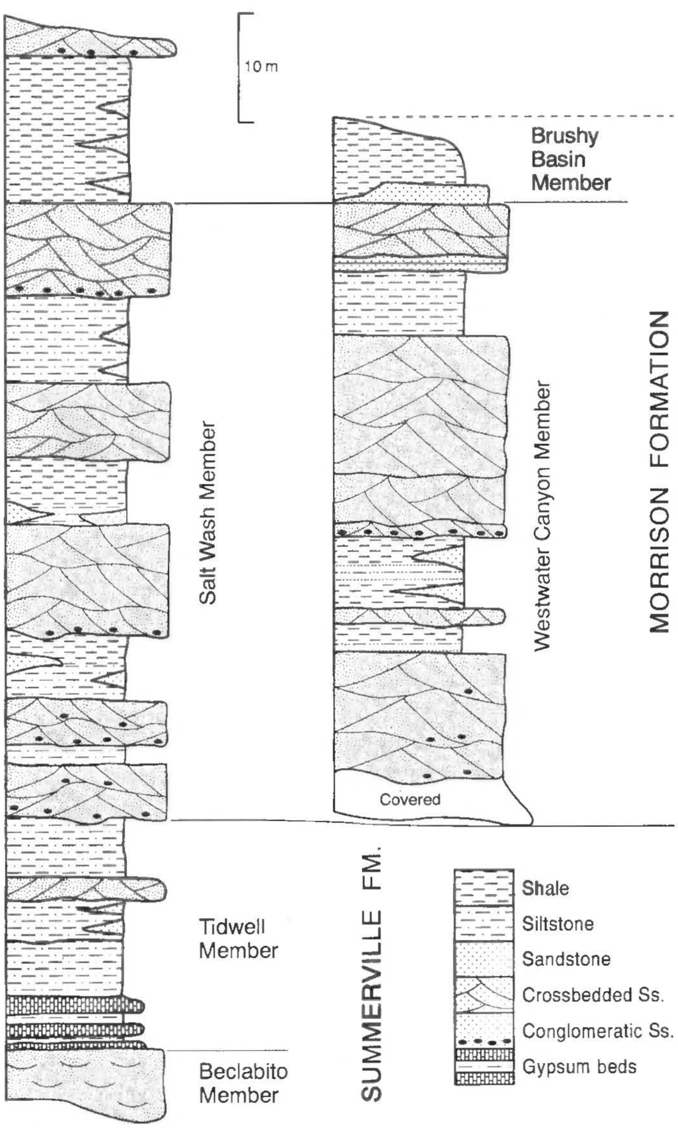

FIGURE 4. Type section of Salt Wash and Westwater Canyon Members of Morrison Formation. See Appendix for description of stratigraphic units.

As mentioned above, Gilluly and Reeside (1928) designated the strata overlying their San Rafael Group as Morrison Formation in eastern Utah. The basic lithologic distinction was that variegated shale, medium- to coarse-grained sandstones and mudstones of the Morrison tended to be slope formers above the brightly colored, thick, cliff-forming sandstones and fine-grained gypsiferous beds of the San Rafael Group. The lower of two members of the Morrison recognized by Gilluly and Reeside was a light gray to tan, crossbedded, coarse-grained, pebbly sandstone which exerts significant influence on topography in the areas of the San Rafael Swell, Green River, and north of Moab (Fig. 1). This lower unit was called the Salt Wash Sandstone Member, a name Lupton (1914) introduced for these beds in Salt Wash, 24 km southwest of Green River (Fig. 4).

In retrospect, Gilluly and Reeside's basal contact of the Morrison was a well justified stratigraphic decision. It provided a Morrison base that is an easily recognized lithologic break. The pebbly, trough-crossbedded Salt Wash Member contains rip-up clasts, clay galls and other sedimentary features that readily identify it as a fluvially deposited sandstone very different from underlying fine-grained San Rafael Group strata (Fig. 5). The channel scour at their Morrison base is a regionally traceable surface, which also is a major aid to geologic mapping. In modern terminology, the base of the Morrison, as picked by Gilluly and Reeside, is a sequence boundary, one which reflects climatic and base-level changes and records the onset of widespread braidplain deposition of Morrison strata during Late Jurassic time.

Perhaps the most significant attribute of this early-recognized Morrison-San Rafael Group contact is the lithogenetic contrast it represents. The uppermost San Rafael Group strata were assigned by Gilluly and Reeside to the Summerville Formation. The Summerville consists of thin, parallel beds of very fine-grained gypsiferous sandstone or siltstone, with subordinate mudstone and bedded gypsum or carbonate near the top. Summerville strata and related San Rafael Group eolianites form a sequence deposited in marginal marine, tidal flat, arid coastal plain or sabkha settings with persistent erg development (Entrada and Zuni Sandstones), around the southern margins of the Sundance seaway. This paleogeography was also recognized by Imlay (1954), Harshbarger et al. (1957), Kocurek and Dott (1983), Brenner (1983), Ridgley (1989), and Anderson and Lucas (1992, 1994), among others. With this paleogeographic and paleodepositional basin concept, the post-San Rafael Group sequence takes on added significance. The pebbly, coarse-grained, trough-crossbedded sandstones of the Salt Wash Member of the Morrison Formation represent fluvial (braidplain) deposition and higher energy systems, which in turn indicate higher gradient and an increase in sediment supply during Late Jurassic time. Paleoflow direction was generally eastward (Craig et al., 1955; Harshbarger et al., 1957; Saucier, 1967; Turner-Peterson, 1986). This delineates a source area to the west in an area of known Mid- to Late Jurassic back arc volcanism. Uplift preceding and associated with the volcanism provided the source area for the basal Morrison pebbly sandstone beds, which back-filled a moderately incised topography. Continued volcanism, dominated by latitic and rhyolitic ash (Kowallis et al., 1991), provided much of the source rock for the claystone-dominated (largely smectite) upper part of the Morrison Formation. The distinctive, smectitic claystone as well as authigenic chlorite (Hicks, 1981) may also be found in partings in the lower Morrison, thus providing further lithologic contrast with the underlying San Rafael Group.

The sedimentary record also contains evidence that a climate change accompanied the transition from San Rafael Group to Morrison deposition. The arid conditions so obviously recorded in the eolianites of the Middle Jurassic San Rafael Group were moderated considerably by Late Jurassic time as the North American continent drifted northward into more temperate zones, and into the zone of prevailing westerlies (Kocurek and Dott, 1983; Dickinson, 1989). The uppermost strata of the San Rafael Group near Bluff, Utah, as well as southeastward in the San Juan Basin, consist of eolianites with well expressed, thick sets of eastward-dipping foresets. These foresets signal the arrival of the Four Corners area in the

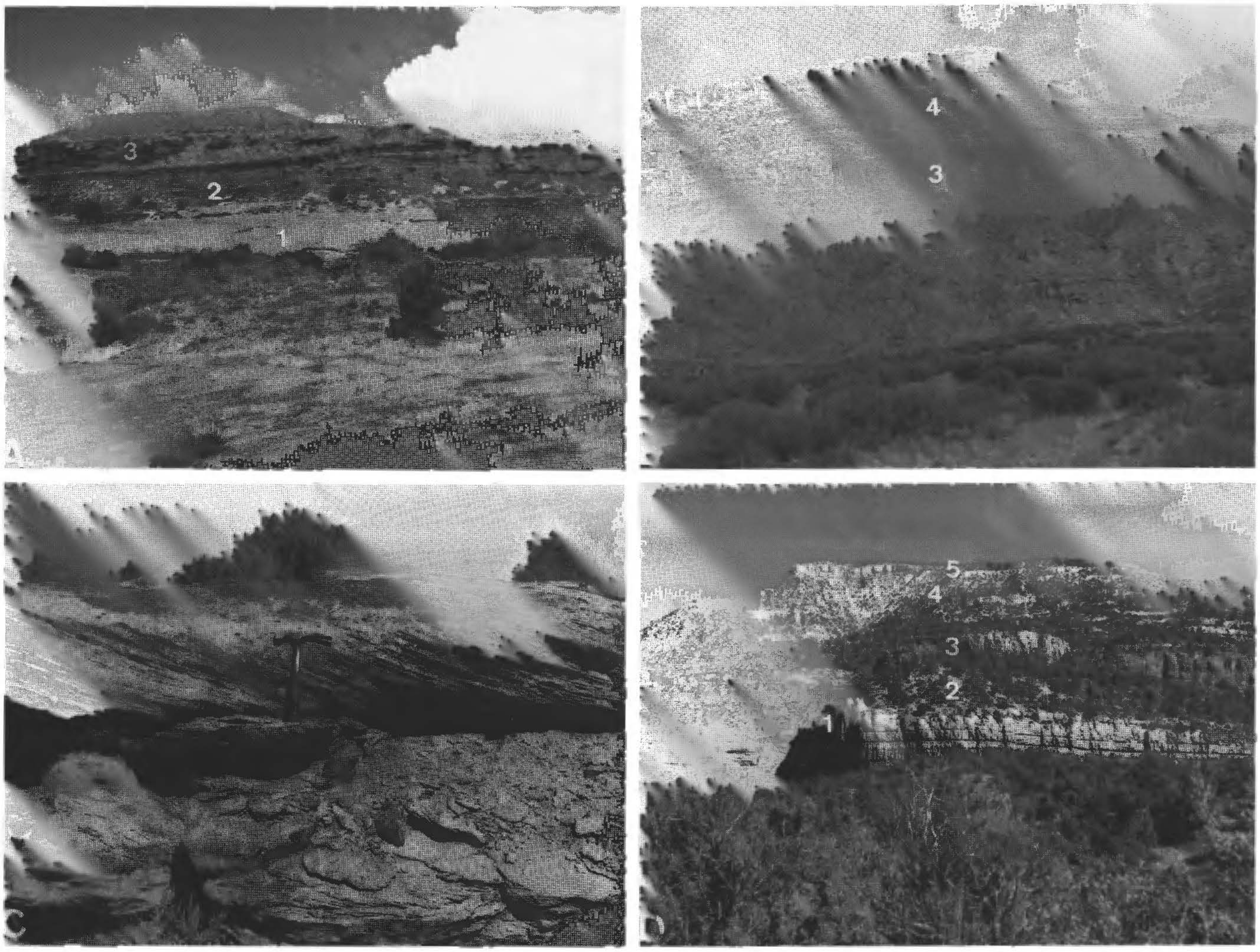

FIGURE 5. Selected Jurassic outcrops in the Four Corners region. A, Type section of Recapture Member of Bluff Formation in Recapture Creek, Utah. B, Section at McCracken Point, Utah on east flank of Recapture Creek. C, Typical pebbly fluvial sandstone of lower part of Salt Wash Member of Morrison Formation, Recapture Creek, Utah. D, Section of Jurassic strata in Sanostee Canyon, New Mexico. Lithostratigraphic units are 1=Main body of Bluff Sandstone; 2=Recapture Member of Bluff Sandstone; 3=Salt Wash Member of Morrison Formation; 4=Brushy Basin Member of Morrison Formation; 5=Cretaceous strata (Cedar Mountain Formation in B, Dakota Formation in D).

zone of prevailing westerlies during latest Callovian-early Oxfordian time (Dickinson, 1989). Fluvial deposits of the basal Morrison rest disconformably on these foresets at many localities, but in other areas, horizontally-bedded red siltstone and fine-grained sandstone (sabkha deposits) intervene to form the top of the San Rafael Group (Fig. 5C). In either case, the lithologic contrast between the Morrison and underlying strata is sharp, as is the quantitative aspect of the fossil record.

In summary, the regional aspects of Morrison stratigraphy and the basal contact with the San Rafael Group established by Gilluly and Reeside (1928) provide a widely applicable working model of Morrison depositional systems. Later work complicated this stratigraphy and inadvertently introduced an element of confusion, particularly with regard to regional correlations, which has existed for more than 50 years.

GREGORY'S WORK

The most significant work on the Morrison Formation of southeastern Utah was that of Gregory (1938). In his detailed report on the "San Juan Country," Gregory subdivided the Morrison into four members. In ascending order, these were the Bluff Sandstone Member, Recapture Shale Member, Westwater Canyon Sandstone Member and Brushy Basin Shale Member (see Figs. 2, 3).

The Bluff Sandstone is mostly an eolianite particularly well developed and exposed near Bluff, Utah (Fig. 1). At the type locality 8 km west of Bluff along Butler Wash, the unit is as much as 38 m thick and consists of very fine- to lower medium-grained, mostly crossbedded, sandstone. It does not constitute a facies or lithology that prior to Gregory (1938) was considered to be present northward or eastward in the Morrison Formation, nor does it occupy the same stratigraphic position as the basal Salt Wash Member of Gilluly and Reeside's stratigraphy. Moreover, Gregory did not offer an explanation for the inclusion of this sandstone unit in the Morrison.

Goldman and Spencer (1941) recognized the Bluff as a pre-Morrison lithology and correlated it with the Junction Creek Sandstone in southwestern Colorado. On a lithologic basis, Craig et al. (1955) removed the Bluff from the Morrison Formation and included it in the uppermost part of the San Rafael Group (Fig. 2). We concur with Craig et al. (1955) and regard the Bluff Sandstone and the closely associated, overlying, Acoma Tongue of the Zuni Sandstone of west-central New Mexico (Anderson, 1993) as part of the upper San Rafael Group throughout the Four Corners area and southeastward into the San Juan Basin.

Gregory defined the "Recapture Shale Member" from exposures near the mouth of Recapture Creek, 8 km east of Bluff (Fig. 6). He described it as a unit that encompassed a wide variety of lithologies as well as a very significant, regionally traceable scour surface. The total reported thickness of 88 m was described as consisting of a basal 12–17 m of red sandstone overlain by coarse-grained, pebbly sandstone, followed by a "shaly" sec-

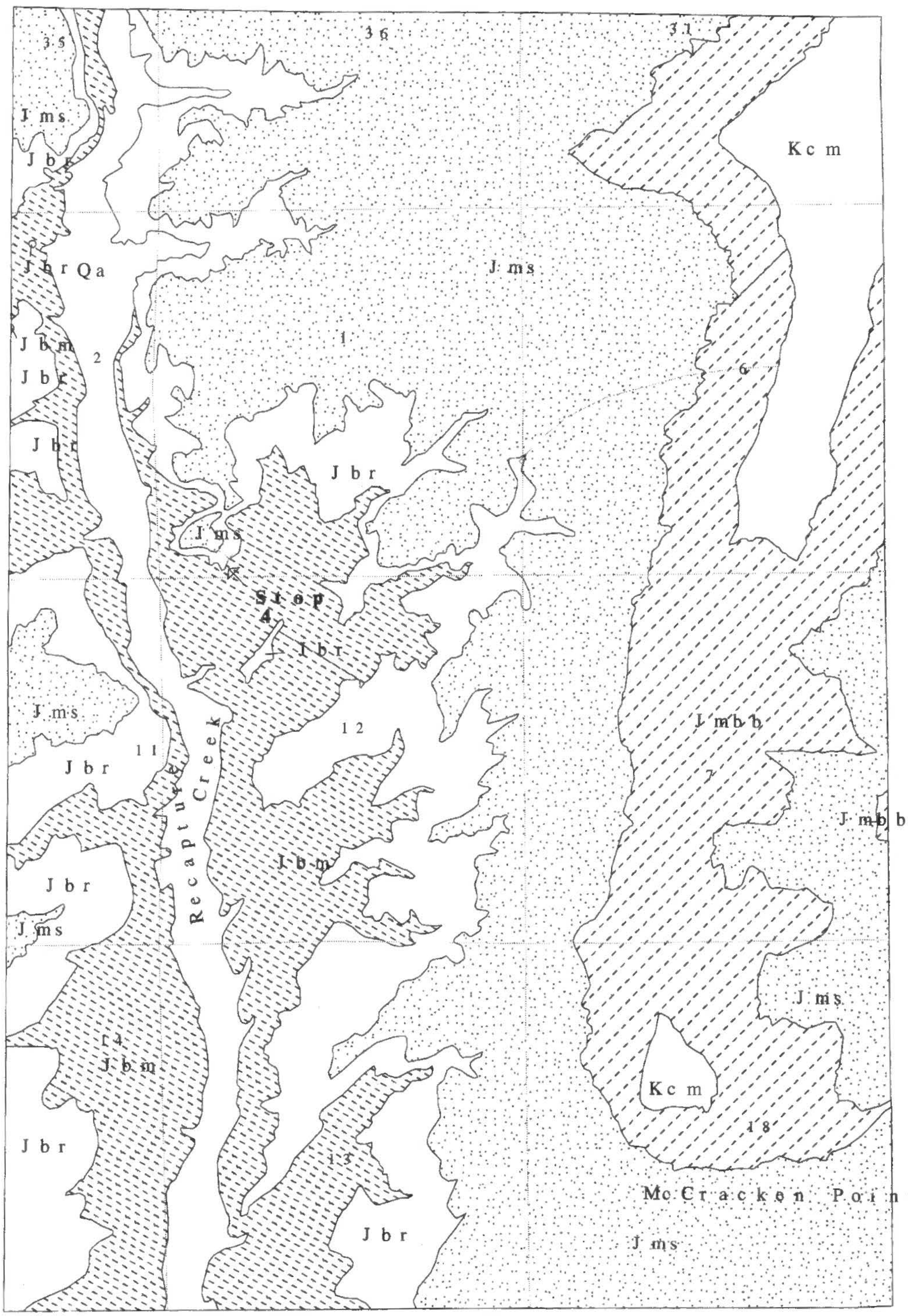

FIGURE 6. Reconnaissance geologic map of Recapture Creek, Utah. Jbm=Main body of Bluff Sandstone, Jbr=Recapture Member of Bluff Sandstone, Jms=Salt Wash Member of Morrison Formation, Jmbb=Brushy Basin Member of Morrison Formation; Kcm=Cedar Mountain Formation; Qa=Quaternary alluvials.

tion. The significance of Gregory's Recapture Shale Member is twofold. First, the lower 12–17 m of red sandstone are very fine grained, silty, parallel bedded and gypsiferous. These strata are very similar in lithology and sedimentary features to the Summerville Formation. The Summerville (which underlies the Bluff Sandstone) was deposited in arid coastal plain and sabkha type environments. Thus, the basal "Recapture Shale Member" of Gregory was associated with the brief return of sabkha conditions locally following deposition of the eolian Bluff. Gregory's basal "Recapture Shale" also intertongues with the Bluff Sandstone (Fig. 3), demonstrating its genetic and temporal association with that unit. This intertonguing, though not so stated, undoubtedly was the reason for his inclusion of the Bluff in the Morrison Formation.

In contrast, the sandstones above the basal 12–17 m of Gregory's "Recapture Shale" are medium to coarse grained and conglomeratic with clay galls and rip-up clasts, and much more abundant sauropod dinosaur remains; they are clearly fluvial in origin. We contend that the abrupt change in lithology and sedimentary features at the top of the "red sandstone" unit reflects a change from sabkha conditions to fluvial braidplain deposition in the overlying unit. The contact is also marked by a regionally traceable scour surface that represents a diastem or unconformity, albeit with a poorly constrained time value, and as noted above, a sequence boundary. We further contend this unconformity is the San Rafael Group-Morrison Formation contact; as picked, this contact is consistent with the earlier lithologic descriptions of this contact offered by Gilluly and Reeside (1928), and most importantly, the contact is readily mappable. Thus, the basal 12–17 m of Gregory's "Recapture Shale" is reassigned to the San Rafael Group as the Recapture Member of the Bluff Sandstone (Fig. 3, left side). Lithologically (fine-grained, thinly bedded, gypsiferous sandstone and silty sandstone) and lithogenetically (sabkha, arid coastal plain) these strata belong in the San Rafael Group.

The second significant aspect of Gregory's "Recapture Shale" is that the base of the medium- to coarse-grained pebbly sandstone 12–17 m above the base at the type locality correlates with the unit that Lupton (1914) and Gilluly and Reeside (1928) recognized as the Salt Wash Member (Fig. 3). Gregory's description of these strata at the type locality is very similar to the description that Lupton as well as Gilluly and Reeside gave for their basal Salt Wash Member. The two units occupy the same stratigraphic position, although the Bluff Sandstone is not present to the north in the vicinity of Lupton's type Salt Wash, which is just southeast of Green River (Fig. 1). Distance between the two areas (southeast of Green River to Bluff) is approximately 160 km, however, the stratigraphic succession is similar. Failure to recognize the significant lithologic break and major change in depositional environments above the base of his "Recapture Shale Member" constituted a stratigraphic oversight by Gregory. He thus included parts of the San Rafael Group and the basal Morrison Formation in one member—his "Recapture Shale."

Gregory also recognized pebbly sandstone beds near Blanding, Utah, 32 km to the north of Bluff, as being in the same part of the section as the "Salt Wash Sandstone," but he hesitated to assert the correlation. Stokes (1944) did recognize a Salt Wash unit low in Gregory's "Recapture Shale," but this observation has been ignored for 50 years.

Gregory (1938) introduced another member name for these pebbly sandstone beds near Blanding. From the excellent outcrop near the confluence of Cottonwood Wash and Westwater Canyon, just south of Blanding, Gregory named a 53 m thick, dominantly sandstone section the "Westwater Canyon Sandstone Member" (Fig. 4). Significantly, he assigned the name only "tentatively," because "its exact equivalency to the typical Salt Wash sandstone has not been satisfactorily established." Anderson and Lucas (1995) recognized that the "Westwater Canyon Sandstone Member" is a synonym of Salt Wash Member and that the latter name has priority. The type sections of the two units occupy the same stratigraphic position, are of essentially identical lithology, and are of similar thickness (Fig. 4; Appendix). Correlation problems resulted not only from this duplicative nomenclature, but also because the type "Westwater Canyon Sandstone" was miscorrelated southward within a 32 km distance so that at the type locality of the "Recapture Shale" the newly named "Westwater Canyon Sandstone Member," was unknowingly included. The type "Westwater" was erroneously correlated by Gregory with a locally prominent, fine-grained sandstone much higher (54 to 76 m) in the section at Recapture Creek.

Further correlation problems resulting from this duplicative nomenclature manifested themselves on many maps (Hintze and Stokes, 1964; Hackman and Olson, 1977; O'Sullivan and Beikman, 1963; Moench, 1963, Thaden et al., 1967), and stratigraphic diagrams (Condon and Huffman, 1984; Peterson and Turner-Peterson, 1987; Peterson, 1988) that attempted to show the relationship among Gregory's "Westwater Canyon Sandstone," and "Recapture Shale," and the earlier recognized Salt Wash Member. A clear example of these efforts was one by Peterson and Turner-Peterson (1987) included here as Figure 7A. These attempts failed to acknowledge that Gregory named the "Westwater Canyon Sandstone" only tentatively and that Stokes had earlier recognized a Salt Wash–"Recapture Shale" correlation in part. Of great significance was his recognition of an unconformity at the base of his type "Westwater Canyon Sandstone Member" and that this "sandstone may prove to mark the beginning of a cycle of sedimentation that continued until interrupted by pre-Dakota erosion." This statement is true, and when the correct name Salt Wash is substituted for "Westwater Canyon Member" it carries even more significance. Gregory also stated that ultimately it may be found that the Morrison is composed of several formations. After remeasuring most of Gregory's Morrison sections, we have come to the conclusion that his intuition was good and his statement was prophetic—his lower "Recapture Shale" most surely is part of the San Rafael Group. The correlations of Anderson and Lucas (Fig. 7B) are based on original definitions and lithostratigraphy, plus recognition of sequence boundaries, and contrast sharply with those of Peterson and Turner-Peterson (Fig. 7A), which we contend are unapplicable in the field.

SALT WASH MEMBER

The Salt Wash Member of the Morrison Formation exhibits all the characteristics of a fluvially deposited unit. Crossbedded, pebbly-conglomeratic, quartzose sandstones in generally fining-upward sequences are the typical facies. Mud and clay clasts, impressions of woody trash, and locally trace fossils are common. The crossbedding ranges from trough, to low and medium angle compound cross laminations with truncation surfaces, to less common planar and planar-tangential forms. Interpretations of paleoflow directions and sediment transport are based on our own crossbed dip measurements in trough forms, the data of Craig et al. (1955), and the data of Saucier (1967). All the data indicate southeastward, eastward, and to a lesser degree, northeastward flowing stream systems. A statistical treatment of data collected from trough crossbed sets in northwestern New Mexico by Turner-Peterson (1986) indicated a northeasterly-flowing stream system in the lower part of the Salt Wash Member followed by easterly and southeasterly flowing systems in the middle and upper parts of that unit. Both Saucier and Turner-Peterson referred to this unit as the Westwater Canyon Member.

Source terrains lay mainly to the west. The quartzose sandstone with small but variable amounts of chert, feldspar (Craig et al., 1955; Turner-Peterson, 1986), and opaline tuff (Craig et al., 1955) suggest that Salt Wash streams drained areas in which sedimentary, metamorphic, plutonic, and volcanic rocks were exposed.

The basin of Salt Wash deposition was broad and shallow, extending from central Utah through northeastern Arizona and into north-central New Mexico. A thin but mappable Salt Wash is present at places along the southern Front Range of the Rocky Mountains in northeastern New Mexico, but it is not present in extreme northeastern New Mexico or in adjacent Oklahoma. This strongly suggests that clastic input to the basin was highly asymmetric with essentially all of it coming from the western side. The finer grained facies of the overlying Brushy Basin Member have greater eastward extent and represent deposition in shallow lacustrine and overbank environments on a vast, sediment-choked floodplain.

BRUSHY BASIN MEMBER

To complete the discussion of Gregory's four-part Morrison Formation, we must consider the upper, most widely recognized and most extensive unit, the Brushy Basin Member. It is a claystone-dominated (largely smectitic), slope-forming unit with lesser amounts of sandstone and nodular limestone. The typical greenish cast, common variegated color banding, and abundant free-swelling clays are characteristics that stratigraphers most associate with Morrison Formation strata. This unit may be recognized from Montana and South Dakota southward to Arizona and New Mexico, as well as eastward into Oklahoma (Fig. 1). Gregory named it for exposures approximately 14 km northwest of Monticello, Utah, in a topographic feature called Brushy Basin. At this locality the Brushy Basin Member is approximately 136 m thick with only 13 m described as sandstone. Our reconnaissance, however, indicates that the base of this member is not well exposed at the type locality. Elsewhere it is well exposed and commonly we see an interfingering relationship with the underlying Salt Wash Member (Figs. 5B, D). Thus, the upper member—the Brushy Basin—of the Morrison is generally a noncontroversial unit and the only one of the four proposed by Gregory (1938) that has any stratigraphic utility with respect to the Morrison Formation.

Lake T'oo'dichi'

Bell (1981) first suggested that deposition of the Brushy Basin Member of the Morrison Formation took place in a closed, lacustrine basin (also see Bell, 1983, 1986). The most comprehensive explanation of this idea was developed by Turner and Fishman (1991), who proposed a large alkaline, saline lake, which they named Lake T'oo'dichi,' as the site of Brushy Basin

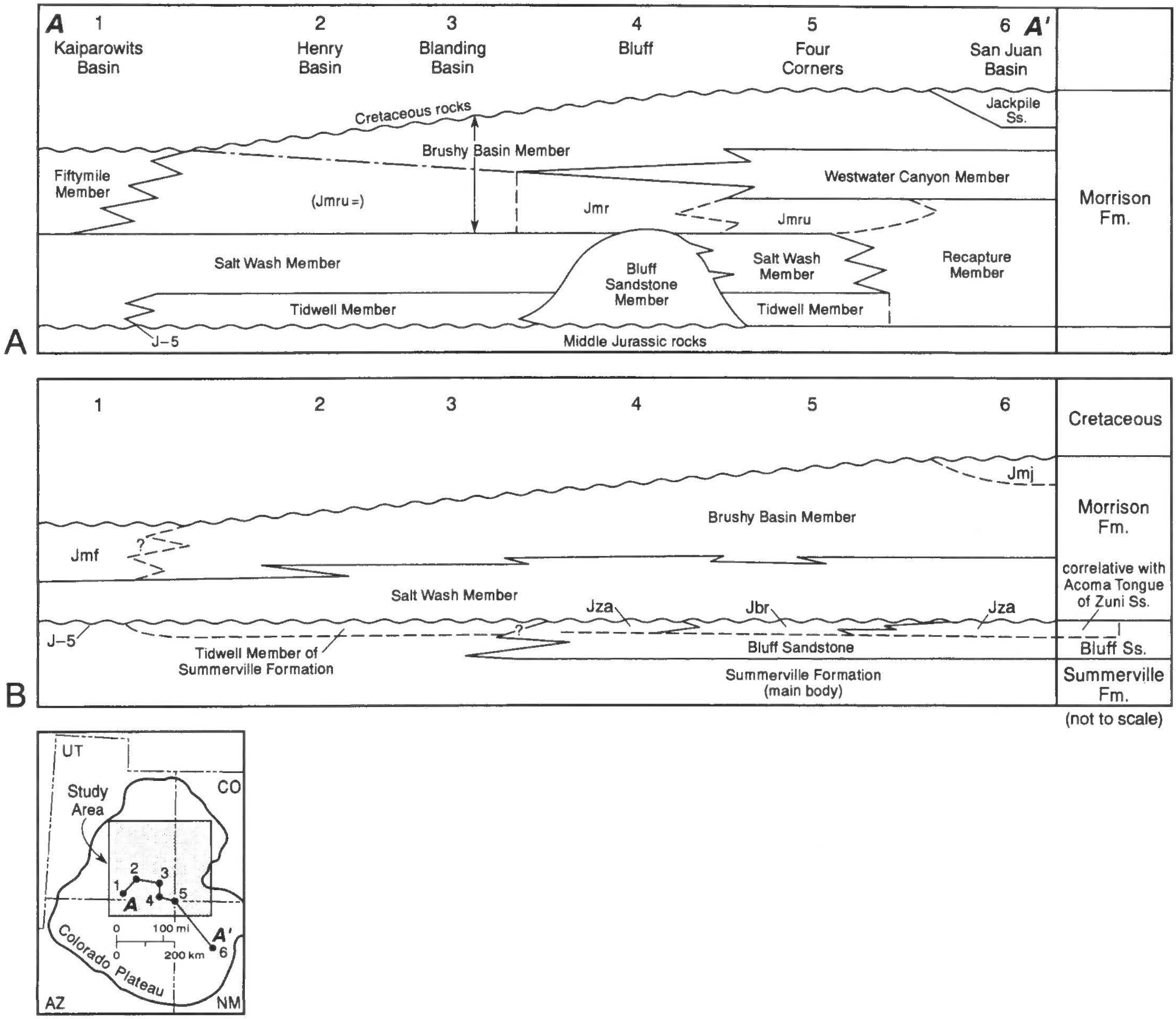

FIGURE 7. A, Stratigraphy and correlation of Middle and Upper Jurassic rocks in Four Corners region as envisioned by Peterson and Turner-Peterson (1987). Jmru, upper part of Recapture Member of Morrison Formation; Jmru upper Recapture equivalent. Line of section shown in inset at left. B, Stratigraphy and correlation of Middle and Upper Jurassic rocks, same area as A above, as proposed in this paper. Jmj, Jackpile Member of Morrison recognized in southeastern San Juan Basin; Jmf, Fifty mile Member of Morrison; Jza, Acoma Tongue of Zuni Sandstone; and Jbr, Recapture Member of Bluff Sandstone. Both A and B are diagrammatic.

deposition on the eastern Colorado Plateau (Fig. 8). According to Turner and Fishman (1991), the closed lake basin was 500 km north-south and 300 km east-west and was the locus of formation of authigenic zeolites–analcime and clinoptilolite–and albite. Indeed, a putative concentric zonation of these zeolites was the principal evidence Turner and Fishman (1991) used to postulate the existence of Lake T'oo'dichi'.

We, however, view the existence of Lake T'oo'dichi' as highly improbable for the following reasons:

1. The Brushy Basin Member throughout the Colorado Plateau contains sandstone bodies characteristic of meander belt channels. This is particularly evident at the Four Corners National Monument, which supposedly sat near the center of Lake T'oo'dichi' (Turner and Fishman, 1991, fig. 12). Here, several lenticular sandstone bodies in the Brushy Basin have scoured bases, conglomeratic lags, lateral accretion foresets and bioturbated tops indicative of a meandering fluvial system, not a playa lake. Another of the numerous examples that could be cited, is along the eastern margin of the Colorado Plateau in the clinoptilolite zone of "Lake T'oo'dichi'." Here, as well, meander belt channel sandstones are common in the Brushy Basin Member (Flesch, 1974). The presence of such sandstones is inconsistent with a playa-lake setting for deposition of the Brushy Basin Member.

2. Turner and Fishman (1991) presented too few data to document a convincing concentric zonation of zeolites. Their two cross sections do suggest smectite-dominated mudrocks to the north (Grand Junction area) and south (Toadlena) with either clinoptilolite, analcime or K-spar dominated mudrocks at some points in between. Most albite-dominated mudrocks are in the Durango-Norwood Hill-Piedra River area of southwestern Colorado, sites on or near the edge of the Oligo-Miocene San Juan volcanic field (Fig. 8). That aside, the two cross sections presented by Turner and Fishman (1991, figs. 1, 4-5) are not adequate to support the concentric zonation of zeolite facies they (fig. 12) envision.

3. Brushy Basin facies extend well beyond the Colorado Plateau; indeed, virtually all of the Morrison away from the Plateau is Brushy Basin

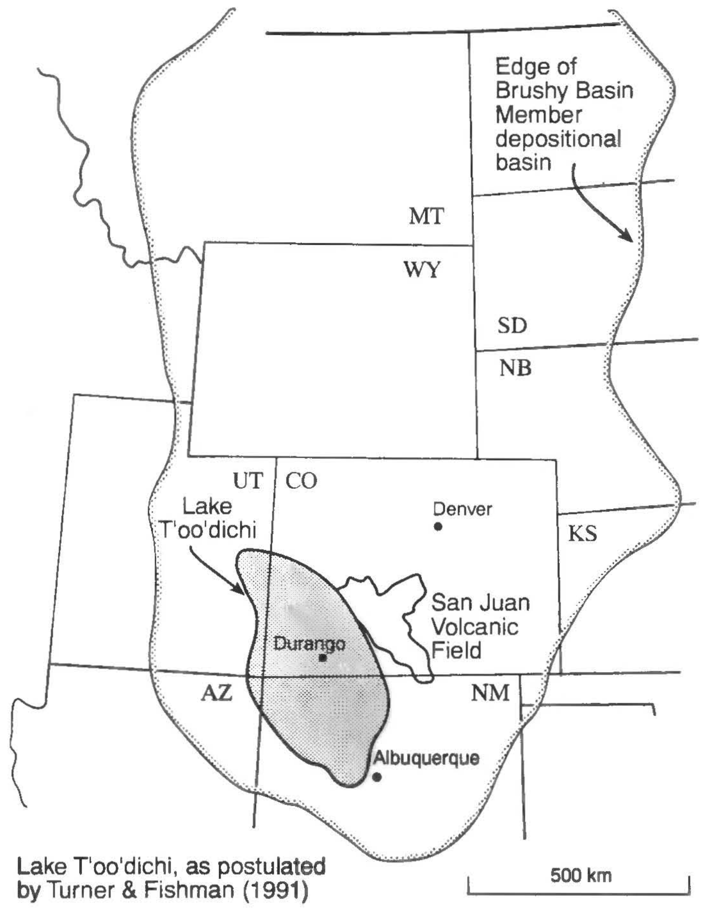

FIGURE 8. Hypothetical Lake T'oo'dichi' and outcrop edge of Brushy Basin Member of Morrison Formation.

Member (Lucas et al., 1985; Anderson and Lucas, 1995) (Fig. 8). This suggests the possibility that Lake T'oo'dichi' extended all the way to Montana and Oklahoma, but such extension is incompatible with concentric zonation of zeolite minerals confined to the eastern Colorado Plateau (Turner and Fishman, 1991, fig. 12). Obviously, the same facies Turner and Fishman identified as lacustrine extend well beyond the limits of their postulated Lake T'oo'dichi'.

4. Taphonomic and paleoecological studies of Brushy Basin fossil plants and vertebrates do not indicate the presence of a large lake. Morrison fossil plants suggest a humid subtropical climate during Morrison deposition (Tidwell, 1990), not the arid or seasonally arid climate consistent with the presence of Lake T'oo'dichi', a large saline alkaline playa. Mass death assemblages of dinosaur fossils in the Brushy Basin Member on the Colorado Plateau mostly show fluvial transport as a substantial concentrating mechanism of carcasses and bones (e.g., Morris et al., 1996; Richmond and Morris, 1996). Such fluvial transport is not consistent with a playa-lake setting.

Collectively these points weigh heavily against the existence of Lake T'oo'dichi'. Brushy Basin Member deposition instead took place on a vast, muddy floodplain characterized by a mosaic of meandering channels, small lakes or playas and stable, pedogenically-modified interfluves with an extensive, long-term infall and/or reworking of volcanic ash (Anderson and Lucas, 1997).

MORRISON FORMATION, SAN JUAN BASIN, NEW MEXICO

Early attempts (1950s) to correlate and recognize a four-member Morrison Formation in northwestern New Mexico were related to uranium exploration efforts. Some of this work was classified information, other efforts were completed as in-house reports, so they were not generally available to the scientific community (e.g., Rapaport et al., 1952), and some of the work was in the form of graduate student theses (e.g., Chenoweth, 1953). All, however, left some aspects of the correlations unclear; for example, no diagrams satisfactorily explained the Salt Wash–Recapture relationship (reportedly interfingered) in the Four Corners area and southward, nor how the Westwater Canyon Sandstone could be extended southward from Recapture Creek into the southern San Juan Basin (C. T. Smith, oral commun.; Smith, 1954). Most of what was called "Recapture Shale" in New Mexico was pre-Morrison interdunal and/or minor fluvial facies that interfingered with the upper part of the "Cow Springs Sandstone"; Cow Springs was a name that Harshbarger et al. (1951) suggested as a junior synonym for the Zuni Sandstone, a distinctive crossbedded eolianite in the southwestern San Juan Basin and associated Gallup-Zuni Basin (Anderson, 1993). Thus was born the erroneous concept that Morrison strata, specifically "Recapture Shale," intertongued with or graded southward into the eolian Zuni Sandstone (or to complete the confusion—into "Cow Springs Sandstone").

Formal adoption of Gregory's Morrison Formation members in New Mexico came with the work of Craig et al. (1955). They did not recognize the Bluff Sandstone as part of the Morrison Formation, advocating instead that the Bluff be included with the San Rafael Group. They failed to note, however, that the reddish, fine-grained facies at the top of the Bluff is, depending upon location, either interdunal or sabkha-related, and preferred to accept the interpretation that this fine-grained facies is part of the Salt Wash Member. Thus, Craig et al. stated, largely from the literature, that in the Four Corners area the Salt Wash and Bluff intertongue, detracting from the value of reassigning the Bluff to the San Rafael Group.

In the San Juan Basin the fine-grained reddish facies overlying and intertonguing with the Bluff Sandstone (or Acoma Tongue of the Zuni, where present) is locally thicker than its counterpart in Utah (herein named Recapture Member of the Bluff) and also exhibits much more fluvial influence. At some localities such as near Thoreau, New Mexico (Fig. 1), this fluvial influence is present at intervals throughout 36 m of section above the Bluff Sandstone, and thus the eolian Acoma Tongue of the Zuni is locally displaced by these unnamed water-laid and interdunal deposits. Importantly, all of the fluvially influenced facies near Thoreau lie below the regional scour surface and pedogenic carbonate that marks the base of the overlying Morrison Formation. Thus, the initial correlation of these fluvially influenced strata with Gregory's "Recapture Shale" (Craig et al., 1955, and subsequent USGS workers) was in error because most of the type "Recapture Shale" lies above the regional scour or sequence boundary. In contrast, all the strata called "Recapture" in the San Juan Basin by the USGS (Harshbarger et al., 1957; Condon and Huffman, 1984; Peterson and Turner-Peterson, 1987; Condon, 1988) demonstrably underlie the regional scour-sequence boundary or J-5 unconformity (Fig. 6B) that marks the base of the Morrison Formation.

New perspective on the correlation of rocks associated with the San Rafael Group-Morrison contact has come from observations regarding the distinctively crossbedded eolianite at the top of the Bluff Sandstone. Noted by Anderson and Lucas (1992) as the Acoma Tongue of the Zuni Sandstone and discussed in terms of regional significance, event stratigraphy and simplification of nomenclature by Anderson (1993), the Acoma Tongue is now recognized over a much broader area, based partly on observations by Condon (1985) in the Bluff, Utah area. Condon noted a distinctively crossbedded facies with eastward-dipping foresets very similar to the Acoma Tongue of the Zuni and in similar stratigraphic position. While a revelation in terms of regional correlation of eolian facies in uppermost San Rafael Group rocks, Condon unfortunately assigned the distinctively crossbedded facies to the Morrison Formation. This left him with the unenviable task of having to identify a group-rank boundary (top of San Rafael Group) in a continuous eolian sandstone sequence, based only on a change in bedform (the crossbedded facies). In addition, this approach ignored the lithologic basis of earlier descriptions of the Morrison, and is inconsistent with the North American Code of Stratigraphic Nomenclature, which recommends that boundaries of rock-stratigraphic units be placed at positions of greatest lithologic contrast.

Condon and Peterson (1986), in an effort to defend their placement of the basal Morrison contact, referred to it as "an unrecognizable time boundary," presumably because there was no lithologic basis for their decision. The question inevitably arises, if it is unrecognizable to them, of what utility is it to physical stratigraphy or the geologic mapper? We contend that the distinctly crossbedded facies records the change in wind pattern as this part of the NorthAmerican continent drifted northward into the zone of prevailing westerlies. As such it is not a lithostratigraphic unit but rather a widely recognized facies, based primarily on bedform, with chronostratigraphic significance, i.e., the base of the crossbedded facies is an isochronous horizon. Thus the time boundary need no longer remain "unrecognizable" as it may now be associated with that most basic of all tectonic processes, continental drift, and be regarded as an example of event stratigraphy.

Anderson and Lucas (1995) rejected the concept of major eolianites in the basal Morrison Formation for the following reasons: (1) the Morrison type section in the Colorado Front Range contains no eolianites; (2) the original definition of the "western Morrison" by Gilluly and Reeside (1928) did not include any eolian strata; (3) the base of the Morrison as described by Gilluly and Reeside (1928) can be projected into the San Juan Basin of New Mexico (Fig. 9) and is clearly above the crossbedded eolian strata recognized by Condon (1985) and by Anderson and Lucas (1992); and (4) from a lithologic and a paleoclimatic perspective, the eolianites are clearly related to San Rafael Group arid depositional systems rather than to Morrison Formation fluvial systems. Thus, we recognize the distinctive crossbedded strata of the Acoma Tongue of the Zuni Sandstone as far northwestward as Bluff, Utah, where it is coeval and intertongues with the Recapture Member of the Bluff Sandstone (Fig. 9). We also recognize that at this locality, remote from the type area of the Acoma Tongue, it may be appropriate to assign a local name to the crossbedded facies which are herein correlated both chrono- and lithostratigraphically with the Acoma Tongue. Perhaps it should be regarded locally as a member of the Bluff Sandstone given the subtlety of the contrast between the units and the remoteness from the Zuni Sandstone. The base of the overlying Morrison is readily placed at the abrupt change in grain size and the presence of fluvial characteristics encountered at a scour surface cut and backfilled by the Salt Wash Member. This regionally traceable surface is the lower bounding surface of the Morrison fluvial sequence.

The area northwest of Bluff and into the San Rafael Swell (Fig. 1), while outside the main area of consideration in this report, is of interest because the pre-Morrison stratigraphy is somewhat different. The Bluff Sandstone is not present in that area, and in addition the upper part of the Summerville Formation contains distinctive grayish-green mudstone beds and bedded gypsum which Peterson (1988) referred to as the Tidwell Member of the Morrison Formation. Because these lithologies are common in the underlying main portion of the Summerville and bedding characteristics (parallel, thinly bedded strata) are similar, we see little utility in placing the Tidwell Member in the Morrison. The very local and thin, coarser-grained facies at the base of the Tidwell, noted by Peterson (1988), we interpret as wadi deposition (shallow desert arroyos active only during heavy rainstorms) during the latter part of Summerville time. At the type area of the Tidwell Member at Tidwell Bottom, Utah (sec. 24, T22S, R13E), we noted minor wadi-type channel deposits scattered throughout the upper part of the Tidwell in otherwise typically Summerville lithologies. Conversely, the scoured base of the immediately overlying Salt Wash Member defines the horizon above which no Summerville-like strata are present. Accordingly, we include Tidwell strata in the Summerville Formation (Fig. 6B).

The base of the Morrison in the San Juan Basin is similarly placed at the scoured base of a prominent, cliff-forming sandstone that since Craig et al. (1955) has been called "Westwater Canyon Sandstone Member." This scour surface also marks an abrupt change in grain size and sedimentary characteristics. Most diagnostic is the appearance of pebbly sandstones, clay clasts, rip-up clasts, fluvial crossbedding, and smectitic clay in the interbedded mudstone (overbank) deposits. As such the scour surface is everywhere recognizable, commonly has a thin, irregular pedogenic carbonate unit associated with it, and can be correlated with the base of the distinctive Salt Wash Member into the Four Corners area. Just south of Beclabito, New Mexico (Fig. 1), near the Four Corners, the so-called three-part Salt Wash Member (W. Chenoweth, oral commun. 1993) apparently includes a relatively fine-grained basal unit, up to 9 m thick and showing oxidized (red) colors. This unit correlates with the reddish, parallel-bedded unit that formed the base of Gregory's "Recapture Shale Mem-

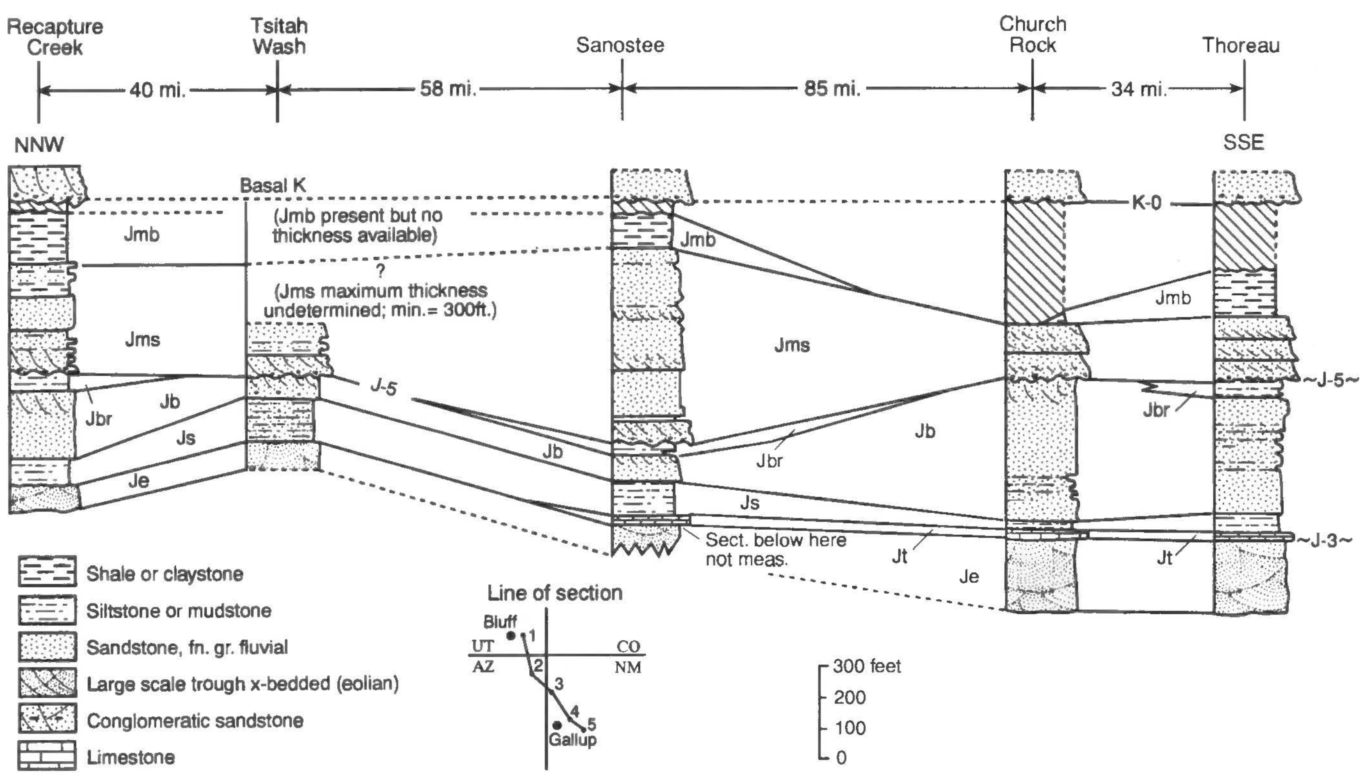

FIGURE 9. Regional stratigraphic cross section of Morrison Formation (Upper Jurassic) and San Rafael Group (Middle and Upper? Jurassic). Morrison Fm. units are Jmb=Brushy Basin Member, Jms=Salt Wash Member; San Rafael Group units are Jb=Bluff Sandstone (Jbr=Recapture Member), Js=Summerville Fm., Jt=Todilto Fm., Je=Entrada Sandstone. K=Middle or Upper Cretaceous rocks (Cedar Mountain or Dakota Fm.). Jurassic unconformities numbered, e. g., J-3. K–0=basal Cretaceous unconformity. Data from the authors and from Condon and Peterson (1986).

ber" and is here reassigned to the San Rafael Group. Thus, the middle part (crossbedded, pebbly sandstone) of the so-called three-part Salt Wash is the actual base of the Salt Wash Member, in the stratigraphy presented here, and it is that horizon or stratum which is correlated with the base of what has been called "Westwater Canyon Sandstone" in the San Juan Basin.

Although the name "Westwater Canyon Sandstone" was recommended for abandonment (Anderson and Lucas, 1995), we nonetheless point out that the unit referred to as "Westwater Canyon" in the San Juan Basin is coarser grained and does not correlate with the "Westwater Canyon" Member at Gregory's reference section in Recapture Creek. The two may be correlative in part, but the base of the San Juan Basin unit is stratigraphically lower and hence somewhat older than the base of the "Westwater Canyon" designated at the Recapture Creek section by Gregory. This is significant because most workers used the Recapture Creek section as the basis for correlations southward into the San Juan Basin as it was geographically closer and offered better exposures. Thus, most early correlations of the "Westwater Canyon Member" southward into the San Juan Basin were incorrect because they were not tied to the type section of that member, which as we now know is equivalent to Salt Wash strata.

The logical stratigraphic procedure would be to apply the name Salt Wash to the basal Morrison sandstone in the San Juan Basin. Anderson and Lucas (1995) adopted this nomenclature but did not ignore the fact that the basal Morrison in the San Juan Basin has a different source area than the type Salt Wash Member. Source area for the type Salt Wash was inferred to be to the west in south-central Utah (Craig et al., 1955). Source area for the "Westwater Canyon", considered to be an "alluviating distributary system of braided channels" (Craig et al., 1955) was inferred to be in west-central New Mexico and adjacent Arizona. The observations are supported in a general way by paleoflow interpretations of crossbedded strata and to a lesser extent by geometry of the sandbodies. However, our observations of basal Morrison sandstones suggest there is little evidence, if any, indicating source areas in New Mexico; they were farther to the west and southwest.

In addition to the different source area is the fact that the Salt Wash has a somewhat different topographic expression than the basal Morrison of the San Juan Basin. This is primarily due to a lower ratio of stream deposit thickness to floodplain deposit thickness in the type Salt Wash; in other words the basal Morrison sandstone in the San Juan Basin characteristically has thicker channel sandstone deposits than the Salt Wash.

For these reasons, a case could be made to recognize the basal Morrison sandstone of the San Juan Basin as a separate member much as Smith (1954) advocated, and correlate it with the Salt Wash Member. Smith, working on the Thoreau 7½' quadrangle in the southern San Juan basin, recognized 57 m of crossbedded, pebbly sandstone, with at least three significant finer-grained intervals (up to 5 m) in the lower part of the Morrison as the Prewitt Member. These lithologies are not dissimilar to those of the Salt Wash Member. We, accordingly, have chosen to simplify the nomenclature and here term the basal Morrison sandstones of the San Juan Basin the Salt Wash Member pending further study of their internal stratigraphy and lithology.

The Salt Wash is beveled off by pre-Dakota erosion south of Gallup at latitude 35°22', and from this latitude southward the Dakota rests on the Zuni Sandstone or older Mesozoic rocks. Eastward from the Thoreau-Grants area the Salt Wash depositionally thins, and at Mesa Gigante, 48 km west of Albuquerque, the Salt Wash is only locally present. In this eastward direction the fine-grained upper member of the Morrison Formation, the Brushy Basin, persists all the way to the southern High Plains. Thus, the east–west extent of the Brushy Basin Member approaches 800 km, greater than has heretofore been acknowledged in the literature. This is significant to any basin analysis study of the upper Morrison.

In those few areas of the southeastern San Juan Basin where the Salt Wash Member is not present, the mapping contact may be based on the lithologic contrast between the greenish, variegated smectitic claystones of the Morrison and the underlying reddish, silty sandstones of the San Rafael Group. In addition, dinosaur bone fragments are relatively abundant in the Morrison of this area, but few have been reported locally in the San Rafael Group.

PALEONTOLOGY AND AGE

The vertebrate fossils that have been collected throughout the Morrison depositional basin are extensive and diverse (e.g., Mook, 1916; Simpson, 1926; Ostrom and McIntosh, 1966; Clemens et al., 1979; Dodson et al., 1980; Lucas and Hunt, 1985; Hunt and Lucas, 1987). They characterize the Comobluffian land-vertebrate faunachron of Lucas (1993). The dinosaurs are dominated by the sauropods *Diplodocus, Camarasaurus, Apatosaurus,* and *Brachiosaurus* (*Ultrasaurus* is a junior synonym; Paul, 1988), the allosaurid *Allosaurus*, the stegosaurid *Stegosaurus* and the iguanodontid *Camptosaurus*. Smaller, and less common, dinosaurs include the coelurid *Ornitholestes*, the fabrosaurid *Nanosaurus* and the dryosaurid *Dryosaurus*. The Comobluffian turtle is *Glyptops*, and the crocodilian is *Goniopholis*. Two anurans, one urodele, two rhynchocephalians, three lizards, a pterosaur and at least 50 species of mammals complete the Comobluffian faunal list (Jensen and Ostrom, 1977; Clemens et al., 1979; Prothero and Estes, 1980; Dodson et al., 1980; Prothero, 1981; Callison, 1987). Typical mammals, best known from quarry 9 at Como Bluff, include amphilestids (*Phascolodon, Aploconodon*), triconodontids (*Trioracodon, Priacodon*), docodontids (*Docodon*), multituberculates (*Ctenacodon*, etc.), symmetrodonts (*Eurylambda, Tinodon,* etc.) and eupantotheres (*Paurodon, Dryolestes, Laolestes, Amblotherium,* etc.). Comobluffian vertebrate footprints are mostly of sauropods and theropods (e.g. Lockley et al., 1986; Lucas et al., 1990).

At present, it is impossible to do anything but treat the vertebrate fauna of the Morrison Formation as representative of a single land-vertebrate "age," despite the fact that the Morrison crops out from southern Alberta to central New Mexico as a complex array of fluvial and lacustine facies that average 100 to 200 m in thickness (Peterson, 1972; Peterson and Turner-Peterson, 1987). Fossil vertebrate localities cover essentially the entire stratigraphic range of the Morrison Formation from the basal Salt Wash Member through the Brushy Basin and locally the Jackpile Member (e.g., Dodson et al., 1980; Armstrong and McReynolds, 1987; Hunt and Lucas, 1987; Bartleson and Jensen, 1988). Yet systematic changes in the vertebrate fauna through the stratigraphic section seem to be due simply to taphonomic or facies differences (e.g., vertebrates are more abundant in the upper than the lower part of the Morrison). Bakker (1986, p. 400) claimed a succession of sauropod and stegosaur species in the Morrison Formation. Although the taxonomy upon which he based his claim has not been presented, biochronological subdivision of the Comobluffian is desirable and may be feasible, but not with the data currently available.

A long history of debate regarding the age of the Morrison Formation lies at the core of the problem of correlating the Comobluffian with marine stage ages and thus the Jurassic-Cretaceous boundary (Simpson, 1926). In short, nonmarine invertebrates (unionids and gastropods) and megafossil plants (mostly cycadeoids, conifers and ferns; Tidwell, 1990) are not particularly useful; they are either endemic, facies controlled and/or in dire need of restudy. Morrison ostracods (Peck, 1951; Anderson, 1973) from Oklahoma suggest an Early Cretaceous (=lower Purbeck) age, but to apply this age to the entire formation across its broad outcrop distribution seems questionable.

The age indicated by Morrison dinosaurs has long been considered to be Late Jurassic based on correlation with the Tendagaru Beds of Tanzania, Africa (Schuchert, 1918; Simpson, 1926). However, a closer examination of this correlation reveals that it does not provide conclusive evidence that the Morrison is contained within the Late Jurassic. Indeed, the Tendagaru-Morrison correlation leaves open the interpretation that the upper part of the Morrison is of Neocomian age.

The most compelling evidence that the Morrison may be in part Early Cretaceous in age come from radiometric dates that suggest the top of the Morrison is locally as young as 130 Ma. Fission-track ages of bentonite beds in the Brushy Basin Member of southeastern Utah indicate a Cretaceous age (younger than 144 Ma) (Kowallis and Heaton, 1987). Similar ages have been obtained from the Morrison in western Colorado (Kowallis, 1986). A K-Ar biotite age of 135.2 ± 5.5 Ma at Dinosaur National Monument in eastern Utah indicates an Early Cretaceous age for the upper part of the Brushy Basin in that area (Bowman et al., 1986). However, a recent argon-argon age on a sample from the same stratigraphic level and locality indicates a Jurassic age (153 Ma; Kowallis et al., 1991). Moreover, argon-argon ages from the Brushy Basin Member at Montezuma Creek, Utah, indicate that all but the upper 20 m, for which no radiometric ages are available, are older than 145 Ma and thus of Jurassic age (Kowallis et al., 1991). Magnetostratigraphy in the Bighorn Basin of Wyoming suggests that the upper part of the Morrison is younger than M17, and thus of Early Cretaceous age (Douglas and Johnson, 1984). In west-central New Mexico, Rb-Sr age data suggest a minimum age of deposition for the Jackpile Sandstone Member (a local sandstone unit at the top of the Brushy Basin Member) of 139 ± 5.5 Ma, consistent with an Early Cretaceous age (Lee and Brookins, 1978; Brookins, 1980). A poorly constrained Rb- Sr age on the Brushy Basin Member in west-central New Mexico of 124 ± 28 Ma also has been reported (Della Valle, 1980; Woldegabriel and Hagan, 1990). Radiometric age determinations and magnetic-polarity stratigraphy thus suggest that the upper part of the Morrison Formation, particularly on the Colorado Plateau, may be of Early Cretaceous age (Lucas, 1989; Mateer et al., 1992), although more recent magnetostratigraphy has been correlated to indicate a wholly Jurassic age (Steiner et al., 1994).

CONCLUSIONS

We recognize a two-part Morrison Formation throughout northwestern New Mexico and southeastern Utah. Previous attempts to recognize and correlate Gregory's (1938) fourfold division of the Morrison in Utah and New Mexico met with failure for the following reasons: (1) his basal Bluff Sandstone Member is basically a fine-grained eolianite with affinities to the San Rafael Group, and it demonstrably lies below a regional unconformity and/or pedogenic carbonate above which fluvial deposition in a more mesic climatic regime prevailed; (2) his type "Recapture Shale Member" included sabkha deposits at the top of the San Rafael Group, the unconformity at the base of the Salt Wash Member, and the entire Salt Wash Member; (3) his type "Westwater Canyon Sandstone Member" is demonstrably correlative with the Salt Wash Member, so the name "Westwater Canyon Member" is superfluous; and (4) most of the type "Recapture," by original definition, lies above the regional unconformity, whereas the Recapture unit that was correlated into the San Juan Basin lies demonstrably and entirely below this regional unconformity and hence is part of the San Rafael Group.

Recapture and Westwater Canyon are thus superfluous names as members of the Morrison Formation in northwestern New Mexico. The valid name Salt Wash Member pertains to the prominent pebbly sandstone at the base of the Morrison Formation throughout its area of western distribution, and it is overlain by and intertongues with the distinctive, claystone-dominated (smectitic) Brushy Basin Member. In the more distal areas, such as at Mesa Gigante in the southeastern San Juan Basin, the Salt Wash Member is not present, and the Brushy Basin Member rests on a more profound unconformity marked locally by a paleosol and a sharp lithologic contrast.

The name Recapture Member is retained as a subdivision of the Bluff Sandstone in southeastern Utah and in adjacent New Mexico to define a 12–17 m-thick, fine-grained, parallel-bedded silty sandstone. This silty sandstone represents local sabkha conditions at the close of San Rafael Group deposition. As so defined the Recapture Member represents a reappearance of the Summerville Formation facies. However, because these strata formed the base of Gregory's type Recapture Member, we have chosen to perpetuate the name and associate it with the Bluff Sandstone because it intertongues with the Bluff or with the highly crossbedded facies at the top of the Bluff.

The distinctively crossbedded upper part of the Bluff Sandstone contains thick sets of east-dipping foresets, and where present has an intertonguing relationship with the Recapture Member. The crossbedded unit is recognized in the southern San Juan Basin in similar stratigraphic position, where it is designated as the Acoma Tongue of the Zuni Sandstone. This unit is more significant in terms of event stratigraphy than as strictly a lithostratigraphic unit and thus we will leave the matter of nomenclature for this unit in Utah to local mappers or investigators. We do not accept the proposal by previous workers (Condon and Peterson, 1986) that the gradational base of this crossbedded sandstone represents an unrecognized time boundary that defines the base of the Morrison Formation because it lacks lithostratigraphic significance and lithologic contrast. The event stratigraphy alluded to above relates to the concept that this part of the North American continent drifted into the zone of prevailing westerlies at the close of San Rafael Group deposition (late Middle Jurassic or early late Jurassic), and eolianites of that age reflect this in the prominent east-dipping foresets.

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APPENDIX–MEASURED SECTIONS

Type section of Westwater Canyon Member, Morrison Formation

Section measured in the NW¼ sec. 31, T37S, R22E, San Juan County, Utah near the mouth of Westwater Canyon where it meets Cottonwood Canyon; section begins at UTM 12628460E, 4154718N and ends at UTM 12628433E, 4154722N. Strata are flat-lying.

Unit	Lithology	Thickness (m)
Brushy Basin Member: Not Measured		
Westwater Canyon Member:		
10.	Sandstone; yellowish gray (5Y7/2); fine to medium grained; quartzose; subrounded; well sorted; slightly calcareous; trough crossbedded; forms a cliff.	4.4
9.	Sandstone; dark greenish yellow (10Y6/6) and yellowish gray (5Y7/2); very fine grained; quartzose with some chlorite?; subangular; moderately sorted; not calcareous; laminae; forms a cliff.	1.1
8.	Silty mudstone and muddy siltstone; mudstone is grayish yellow green (5GY7/2); siltstone is reddish orange (10R6/6) to pale reddish brown (10R5/4); not calcareous; contains some nodules of calcareous siltstone that are yellowish gray (5Y7/2); forms a slope.	7.1
7.	Sandstone: yellowish gray (5Y7/2) and 5Y8/1); very fine to fine grained; quartzose; subrounded; well sorted; not calcareous; some medium-grained beds that are calcareous; trough crossbedded; forms a cliff; unit is multistoried channel bodies.	13.0
6.	Sandstone; yellowish gray (5Y7/2) and grayish yellow (5Y8/4); very fine to fine grained; quartzose with a few feldspars; subrounded; well sorted; calcareous; trough crossbedded; forms a cliff; unit is multistoried channel bodies that laterally thins to give way mostly to sandy mudstone like unit 4.	4.7
5.	Sandstone; very pale orange (10YR8/2); fine to medium grained; quartzose; subrounded; well sorted; calcareous; trough crossbedded; base of unit is matrix-supported conglomerate of chert, jasper and mudstone pebbles up to 12 mm in diameter; unit forms base of big cliff.	0.8
4.	Sandy mudstone; pale olive (10Y6/2) and light greenish gray (5G8/1); calcareous; contains 0.3–0.6-m-thick ledges of sandstone that are yellowish gray (5Y8/1); very fine grained, quartzose, subrounded, well sorted, calcareous and massive to bioturbated.	6.7
3.	Sandstone; yellowish gray (5Y7/2); very fine to fine grained; quartzose; subrounded; well sorted; trough crossbedded; forms a ledge.	0.9
2.	Sandy mudstone; same colors and lithology as unit 4.	1.9
1.	Sandstone; grayish yellow (5Y8/4) and very pale orange (10YR8/2); same lithology as unit 3; trough crossbedded; some mudstone pebbles; unit is multistoried channel bodies with scour bases and bioturbated topset beds.	11.4

Type Section of Salt Wash Member, Morrison Formation

Section measured in the NW¼ sec. 19, T23S, R18E, Grand County, Utah. Section starts at UTM 12590639E, 4295274N and ends at UTM 12587750E, 4295482N. Strata are flat-lying.

Unit	Lithology	Thickness (m)
Morrison Formation:		
Brushy Basin Member:		
11.	Sandstone and conglomeratic sandstone; sandstone is very pale orange (10YR8/2) with dark gray (N3) spots; weathers pale yellowish brown (10YR6/2); conglomeratic sandstone is very light gray (N8), weathers pale brown (5YR5/2); fine to medium grained; subarkosic; subangular; moderately sorted; cong lomerate clasts are mudstone pebbles up to 1 cm in diameter; trough crossbedded; forms a ledge.	Not measured
10.	Mudstone; greenish gray (5GY6/1); not calcareous; upper 5 m very bentonitic; has ledgy lenses of sandstone that is pinkish gray (5YR8/1), very fine grained, subarkosic, subrounded, moderately sorted and calcareous; forms a slope.	13.6
Salt Wash Member:		
9.	Sandstone; very light gray (N8); fine to medium grained; quartzose; subrounded; well sorted; calcareous; conglomeratic base of unit is matrix supported pebbles up to 1 cm in diameter of light greenish gray (5GY8/1) mudstone and chert and jasper pebbles up to 0.5 cm in diameter; trough crossbedded; forms a cliff; unit is multistoried channel bodies.	8.2
8.	Sandy siltstone; pale red (5R6/2) with mottles of greenish gray (5GY6/1) and pinkish gray (5YR8/1); bentonitic; calcareous; contains lenses of sandstone that are moderate brown (5YR8/1); well sorted and calcareous; forms a slope.	8.3
7.	Sandstone; very pale orange (10YR8/2); very fine to fine grained; quartzose; subrounded; well sorted; calcareous; trough crossbedded; forms a ledge; unit is multistoried channel bodies with prominent scoured base.	7.3
6.	Silty mudstone; same colors and lithology as unit 4; lower 1–2 m has ripple-laminated sandstones; forms a slope.	6.5
5.	Sandstone; pinkish gray (5YR8/1); very fine grained; quartzose with a few feldspars; subrounded; well sorted; calcareous; basal conglomerates of channel bodies are pale olive (10Y6/2) mudstone pebbles up to 15 mm in diameter in pale yellowish brown (10YR6/2) matrix; trough crossbedded; unit is multistoried channel bodies; forms a ledge.	9.3
4.	Silty mudstone; grayish red (10R4/2) and light greenish gray (5GY8/1); calcareous; has some ledgy beds of sandstone that are very pale orange (10YR8/1); calcareous; very fine grained, subarkosic, subrounded, well sorted and ripple laminated with much horizontal bioturbation on bedding planes; forms a slope.	5.1
3.	Sandstone; white (N9); very fine grained; quartzose; subrounded; well sorted; calcareous; some conglomerate	

Unit	Lithology	Thickness (m)
	as in unit 5 at channel bases; trough crossbedded; forms a ledge; multistoried channel bodies.	
2.	Silty mudstone; same colors and lithology as unit 4; forms a slope.	
1.	Sandstone, very light gray (N8); very fine to medium grained; subarkosic; subangular moderately sorted; calcareous; some coarse- to very coarse-grained parts have red and black chert pebbles; trough crossbedded; scour base with flute casts and tool marks; multistoried channel bodies that fine upward to bioturbated tops.	5.3

Sanostee Wash

Section measured in Blanco Canyon and Sanostee Wash. Section starts at UTM 12678717E, 4032606N, Stops at UTM 12678313E, 4034450 N. Strata dip 3° to 570°E.

Unit	Lithology	Thickness (m)
Dakota Formation:		
67.	Sandstone and siliceous conglomerate; sandstone is moderate reddish orange (10 R 616), very fine to medium grained, subangular, moderately sorted arkosic; not calcareous; trough crossbedded; caps ridge.	Not measured
Unconformity		
Morrison Formation:		
Brushy Basin Member:		
66.	Smectitic mudstone; greenish gray (5 G 611); forms a slope with a few thin (up to 20 cm thick) pale green (5 G 712) silcrete ledges.	19.8
65.	Silty shale; pale reddish brown (10 R 514); not calcareous; forms a slope	5.8
64.	Sandstone; pinkish gray (5 YR 811); fine grained; subrounded; well sorted; subarkose; not calcareous; trough crossbedded; scour base; forms a bench.	3.2
63.	Smectitic mudstone; moderate reddish brown (10 R 416) and yellowish gray (5 Y 811); slightly calcareous; slope.	10.9
Salt Wash Member:		
62.	Sandstone; some color and lithology as unit 60; locally scours down to unit 60 and thins so unit 61 is thicker than unit 62; trough crossbedded.	12.3
61.	Silty sandstone; same color and lithology as unit 59; forms a slope.	2.9
60.	Sandstone; very pale orange (10 YR 812); fine to medium grained; moderately sorted; subrounded; subarkose; not calcareous; multistoried; trough crossbedded; units 60–62 form a persistent yellow cliff.	7.0
59.	Silty sandstone; pale brown (5 YR 512); very fine to fine grained; subangular; moderately sorted; litharenite; not calcareous; with thin interbeds of green smectititic mudstone; some calcrete nodules; trough crossbedded; ledgy; some cover.	40.2
58.	Sandstone; yellowish gray (F 7 811), weathers pale grayish red (5 R 512); fine to medium grained; subangular; poorly sorted;volcanic litharenite; not calcareous; trough crossbedded; forms a bench	2.1
57.	Smectitic mudstone with sandstone lenses; mudstone is greenish gray (5 G 611) with pale red (10 R 612) calcrete nodules; sandstone is medium gray (N 5), very fine grained, well sorted, bioturbated volcanic litharenite; forms a slope.	6.7
56.	Sandstone; grayish orange pink (10 R 812); very fine to fine grained; subrounded; poorly sorted; arkosic; calcareous; trough crossbedded; a few thin lenses of red and green mottled siltstone; forms a cliff.	20.6
55.	Sandstone; some color and lithology as unit 51.	4.6
54.	Sandstone; same color and lithology as unit 52.	7.6
53.	Sandstone; same color and lithology as unit 51.	8.8
52.	Sandstone; pinkish gray (5 YR 811); very fine grained; well sorted; subangular; arkosic, not calcareous; trough crossbedded and laminated.	2.4
51.	Sandstone; pale reddish brown (10 R 514) and grayish orange pink (5 YR 712); very fine grained; well sorted; subangular; arkosic; very calcareous trough crossbedded; slope former.	11.3
50.	Sandstone; pale reddish brown (10 R 514); very fine grained; subangular; well sorted; arkosic; not calcareous; trough crossbedded; some clay-ball rip ups; top heavily pedoturbated; forms a bench.	8.8
49.	Sandy siltstone and sandstone; some color and lithology as unit 47.	4.3
48.	Sandstone; some color and lithology as unit 44; forms a bench.	2.1
47.	Sandy siltstone and sandstone; siltstone is pale reddish brown (10 R 514) and not calcareous; sandstone is pinkish gray (5 YR 811), very fine grained subangular, well sorted, arkosic, massive and not calcareous; sandstone occurs as lenses in the siltstone.	0.5
46.	Sandstone; same color and lithology as unit 44; forms a bench.	5.2
45.	Sandy siltstone; pale reddish brown (10 R 514); not calcareous; slope, some cover.	3.7
44.	Sandstone; pale reddish brown (10 R 514); fine to medium grained; subrounded; poorly sorted; litharenite; not calcareous; trough crossbedded; some clay-pebble lenses; forms a bench.	4.3
43.	Covered slope.	4.9
42.	Sandstone; moderate orange pink (10 R 714); subrounded; well sorted; arkosic; not calcareous; laminated; top bioturbated.	0.9
41.	Sandstone; pinkish gray (5 YR 811); very fine grained; subrounded; well sorted; arkosic; slightly calcareous; multistoried; trough crossbeds; some lenses of clay-pebble conglomerate; scour base; forms a cliff.	15.8
40.	Sandstone; pale reddish brown (10 R 514) and yellowish gray (5 Y 811); very fine grained; subangular; well sorted; arkosic; not calcareous; trough crossbedded; some clay ball rip ups and laminated beds.	2.7
39.	Shale and sandstone interbedded; shale is grayish red (5 R 412) and calcareous; sandstone is pale reddish brown (10 R 514), fine and medium grained, subrounded, moderately sorted litharenite; very calcareous; trough crossbedded.	5.8
38.	Sandstone and conglomeratic sandstone; pale reddish brown (10 R 514) and moderate reddish orange (10 R 616); very fine to medium grained; subangular; litharenite; conglomerate clasts are angular chert and quartzite pebbles up to 0.5 cm diameter; trough crossbedded; forms a slope.	9.3
37.	Sandstone and conglomeratic sandstone; yellowish gray (5 Y 712); very fine to medium grained; subarkosic; conglomerate clasts are pinkish gray (5 YR 811) clay pebbles; trough crossbedded; multistoried.	6.9
Bluff Sandstone:		
Recapture Member:		
36.	Sandstone; same color and lithology as unit 32.	0.3
35.	Silty sandstone; same color and lithology as unit 33.	0.5
34.	Sandstone; same color and lithology as unit 32.	0.8
33.	Silty sandstone; pinkish gray (5 YR 811); very fine grained; subrounded; well sorted; arkosic; very calcareous; ripple laminated; forms a ledge.	0.6
32.	Sandstone; light brownish gray (5 YR 511) and yellowish gray (5 Y 811); fine grained; subrounded; well sorted; litharenite; very calcareous; thin siltstone interbeds give this unit a "ribbed" appearance; bioturbated to massive.	3.1

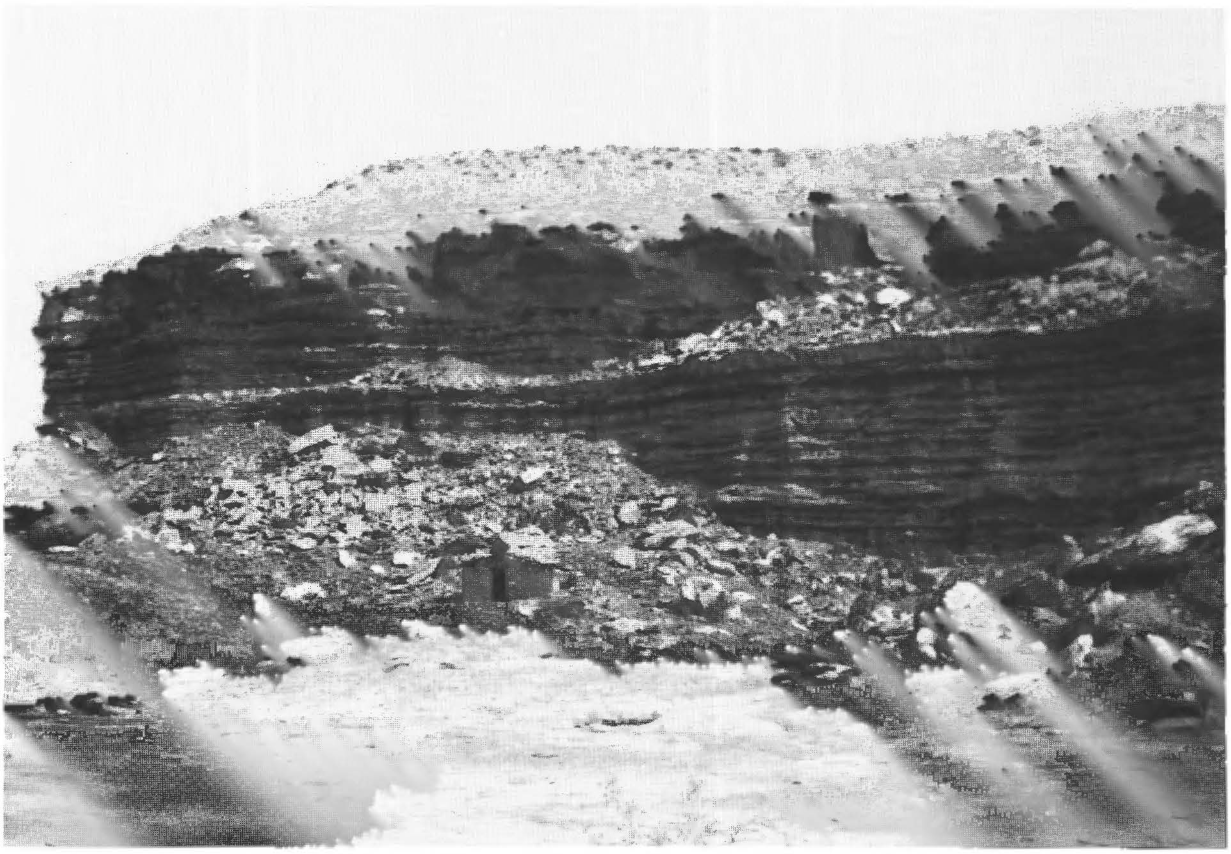
Unit	Lithology	Thickness (m)
Main body:		
31.	Sandstone; pinkish gray (5 YR 811); fine grained; subrounded; well sorted; arkosic; very calcareous; trough crossbeds dip to NE.	0.9
30.	Sandstone; moderate reddish brown (10 R 516); very fine grained; subrounded; well sorted; hematitic litharenite; not calcareous; laminated in thin, (0.3- m-thick) sets.	10.1
29.	Sandstone; same lithology as unit 30; laminated in thick (2 - m-thick) sets.	5.8
Summerville Formation:		
28.	Sandy siltstone; see unit 6.	0.3
27.	Sandstone; see unit 5.	2.9
26.	Sandy siltstone; see unit 6.	0.3
25.	Sandstone; see unit 5.	2.7
24.	Sandy siltstone; see unit 6.	0.1
23.	Sandstone; see unit 5.	3.1
22.	Sandy siltstone; see unit 6.	0.2
21.	Sandstone; see unit 5.	1.6
20.	Sandy siltstone; see unit 6.	0.2
19.	Sandstone; see unit 5.	2.4
18.	Sandy siltstone; see unit 6.	0.1
17.	Sandstone; see unit 5.	1.8
16.	Sandy siltstone; see unit 6.	0.2
15.	Sandstone; see unit 5.	2.0
14.	Sandy siltstone; see unit 6	0.2
13.	Sandstone; see unit 5.	1.6
12.	Sandy siltstone; see unit 6.	0.2
11.	Sandstone; see unit 5.	1.5
10.	Sandy siltstone; see unit 6.	0.2
9.	Sandstone; see unit 6.	0.2
8.	Sandy siltstone; see unit 6.	1.5
7.	Sandy siltstone; see unit 5.	1.5
6.	Sandy siltstone; grayish red (5 R 412); not calcareous; laminated and ripple laminated.	0.2
5.	Sandstone; light brown (5 YR 614); very fine grained; subangular; well sorted; litharenite;not calcareous; massive and blocky.	1.5
4.	Sandstone; light brown (5 YR 614); very fine grained; subrounded; well sorted; litharenite; not calcareous; trough crossbedded.	5.5
Todilto Formation:		
3.	Limestone; medium gray (N5); similar to unit 2 but more thickly bedded and hummocky.	1.5
2.	Limestone; medium gray (N5); laminated.	1.5
Entrada Sandstone:		
1.	Sandstone; pale red (5 R 612); very fine grained; subrounded; well sorted; litharenite; calcareous; large trough crossbeds and some lamination	Not measured

Recapture Creek

Measured stratigraphic section of Morrison Formation exposed in Recapture Creek, Utah. Section starts at UTM 12637871E, 4132774N and ends at UTM 12638878E, 4133409N. Strata are essentially flat lying.

Unit	Lithology	Thickness (m)
Cedar Mountain Formation (Cretaceous):		
44.	Sandstone and conglomerate; sandstone is grayish orange pink (5 YR 712), medium to coarse grained, moderately sorted, subrounded-subangular quartzose and not calcareous; conglomerate is chert and quartzite pebbles.	Not measured
Unconformity		
Morrison Formation:		
Brushy Basin Member:		
43.	Smectitic mudstone; green; mostly covered slope above prominent bench.	25.6
42.	Sandy smectitic mudstone; mostly pale yellowish green (10 GY 712) with much pale grayish red (5 R 512) banding; much covered on top of a bench formed by slumped sandstone of Cedar Mountain Formation.	13.2
41.	Sandstone; very light gray (N8); very fine and fine grained; moderately sorted; subangular; subarkose; clayey; calcareous, ripple laminated and hummocky; forms a ledge.	0.8
40.	Silty smectitic mudstone; pale grayish red (5 R 512); calcareous.	2.7
39.	Sandy smectitic mudstone; same color and lithology as unit 35; some thin nodular calcrete lenses.	14.5
38.	Sandstone and conglomeratic sandstone; sandstone is yellowish gray (5 Y 712), fine and coarse grained, poorly sorted, subangular, volcanic litharenite; conglomeratic sandstone is pale yellowish green (10 GY 712) clay pebbles in olive gray (5 Y 611) fine-grained, subangular litharenite; trough crossbedded; multistoried; forms a bench.	5.1
37.	Sandy smectitic mudstone; same color and lithology as unit 35; contains lenses of moderate reddish orange (10 R 616) agate.	3.2
36.	Sandstone; same color and lithology as unit 33.	0.2
35.	Sandy smectitic mudstone; pale yellowish green (10 GY 712); not calcareous.	3.9
Salt Wash Member:		
34.	Sandstone; yellowish gray (5 Y 712); fine and medium grained; poorly sorted; subrounded; subarkosic; not calcareous; trough crossbedded; basal 0.5 m has clay-ball rip-ups; multistoried; scour base.	4.7
33.	Sandstone; light olive gray (5 Y 611); fine-grained; subangular; litharenite; trough crossbedded; with green smectitic mudstone interbeds; lens of unionid bivalves at base at UTM 12639628E, 4132619N occuring as articulated steinkerns.	3.7
32.	Smectitic mudstone; grayish yellow green (5 GY 712); with pale yellowish brown (10 YR 612) siliceous nodules.	4.3
31.	Sandstone; same color and lithology as unit 29; forms a cliff.	5.7
30.	Interbedded sandstone (see unit 29) forming slope.	4.1
29.	Sandstone; same color and lithology as unit 22; forms a cliff.	6.7
28.	Sandstone; greenish gray (5 GY 611); fine grained; well sorted; subangular; litharenite; clayey; forms a slope.	1.2
27.	Sandstone; same colors as unit 22; fine and medium grained; subrounded; moderately sorted; subarkose; ferruginous; multistoried; trough crossbedded; each set fines upward to a bioturbated top; forms a cliff.	9.7
26.	Sandstone; light olive gray (5 Y 611) and pale yellowish brown (10 YR 612); fine grained; angular; well sorted; litharenite; not calcareous; friable with siltstone lenses.	5.3
25.	Sandstone; grayish orange (10 R 714), fine and medium grained; subangular; hematitic subarkose; trough crossbedded and extensively bioturbated.	2.7
24.	Sandstone; light greenish gray (5 GY 811); very fine and fine grained; subrounded; moderately sorted; arkosic; friable; trough crossbedded.	3.5
23.	Silty sandstone; same color and lithology as unit 21.	3.1
22.	Sandstone and conglomeratic sandstone; sandstone is very pale orange (10 YR 712), fine grained,	

Unit	Lithology	Thickness (m)
	subangular, moderately sorted arkose; conglomeratic sandstone is clay balls and quartzite clasts in moderate yellowish brown (10 YR 514), coarse-grained subarkosic sandstone matrix; slightly calcareous; trough crossbedded; multistoried; 1.5 m above base is prominent scour surface; forms a cliff.	6.7
21.	Silty sandstone; pale grayish red (10 R 512); very fine grained; subangular; well sorted;litharenite; slightly calcareous; bioturbated and ledgy.	3.4
20.	Sandstone; same color and lithology as unit 18; trough crossbedded; multistoried with 3 scour surfaces; forms a cliff.	6.4
19.	Conglomeratic sandstone; matrix is light olive gray (5 Y 611), fine and coarse grained, poorly sorted, subangular litharenite; clasts are pale red (10 R 612) mudstone; unit is lenticular.	0.8
18.	Sandstone; very pale orange (10 YR 812); fine and medium grained; subangular; moderately sorted; feldspathic quartzarenite; low angle planar crossbeds.	1.0
17.	Conglomeratic sandstone; clay pebbles in matrix of grayish orange pink (5 YR 712), fine and medium grained, subangular, poorly sorted, subarkosic sandstone; ferruginous ledge; this unit is base of Gregory's (1938) "Westwater Canyon Sandstone Member."	0.4
16.	Silty shale; same color and lithology as unit 7.	2.9
15.	Sandstone; grayish orange pink (10 R 814); very fine grained; subangular; well sorted; arkosic; not calcareous; trough crossbedded; bioturbated top; forms a cliff.	3.7
14.	Sandstone; grayish orange pink (5 YR 712) and grayish orange (10 YR 714); fine and medium grained; subangular; poorly sorted; lithic subarkose; calcareous; trough crossbedded; top bioturbated.	0.8
13.	Sandy mudstone; same color and lithology as unit 9.	3.6
12.	Sandstone; same color and lithology as unit 10.	0.6
11.	Sandy mudstone; same color and lithology as unit 9.	3.3
10.	Sandstone; pinkish gray (5 YR 811); fine grained; subrounded; well sorted; arkosic; not calcareous; lenticular; ledge.	0.8–1.5
9.	Sandy mudstone; pale reddish brown (10 R 514); calcareous; numerous grayish orange pink (5 YR 712) calcrete nodules; some green mottling; forms a slope.	6.6
8.	Sandstone; same color and lithology as unit 6; forms three closely spaced ledges; trough crossbedded; extensive bioturbation.	0.8
7.	Silty shale; grayish red (10 R 412) with grayish yellow green (5 GY 712) mottles; slightly calcareous.	2.3
6.	Sandstone; grayish orange pink (5 YR 712); fine grained; subrounded; well sorted; lithic quartzarenite; calcareous; some clay-pebble lenses; locally unit scours through unit 5 to lie on unit 4; multistoried; trough crossbedded; forms a bench.	1–5.2
5.	Sandy siltstone; moderate brown (5 YR 414); calcareous; forms a slope.	3.1
4.	Sandstone and conglomeratic sandstone; sandstone is pinkish gray (5 YR 811), medium grained, subrounded, well sorted lithic arkose; conglomerate clasts are green clay pellets; multistoried; trough crossbedded.	1.4–2.5
3.	Sandy mudstone; pale reddish brown (10 R 514); calcareous; slope.	2.1
2.	Sandstone; grayish orange pink (5 YR 712); fine to very coarse grained; poorly sorted; subangular; arkosic litharenite; very calcareous; planar crossbedded; top extensively bioturbated.	0.8–1.2
1.	Sandstone; pinkish gray (5 YR 811); very fine to medium grained; subrounded; poorly sorted; quartzose; calcareous; trough crossbedded; forms a ledge.	0.8–1.3



The type section of the Recapture Member of the Bluff Sandstone is in Recapture Creek, near Bluff, Utah. The lower, flat surface of sandstone upon which the stone building sits is the main body of the Bluff Sandstone, which interfingers with the Recapture Member. The rhythmically bedded sandstones and siltstones of the Recapture Member form a cliff above it, and they are capped by a thick ledge of trough-crossbedded, fluvial sandstone and conglomeratic sandstone of the Salt Wash Member of the Morrison Formation. The Salt Wash-Recapture contact is the J-5 unconformity