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Steven M. Cather, 2021, pp. 251-258

in:

Geology of the Mount Taylor area, Frey, Bonnie A.; Kelley, Shari A.; Zeigler, Kate E.; McLemore, Virginia T.; Goff, Fraser; Ulmer-Scholle, Dana S., New Mexico Geological Society 72nd Annual Fall Field Conference Guidebook, 310 p.

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New Mexico Geological Society Guidebook, 71st Field Conference, Geology of the Mount Taylor Area, 2021, p. 251-257.

JURASSIC STRATIGRAPHIC NOMENCLATURE FOR NORTHWESTERN NEW MEXICO

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Abstract—Nomenclatural debates concerning Jurassic strata of northwestern New Mexico are long-standing and contentious. I present arguments here that support the following: (1) The term Wanakah Formation has little utility in New Mexico, where its two constituent members are typically mapped as formations. The lower of these two formations is the Todilto Formation. The upper should be termed the Beclabito Formation, as these strata cannot be confidently correlated to the type Summerville Formation of central Utah. (2) The Bluff Sandstone should be a broadly inclusive unit that encompasses all prominent eolianites above the Beclabito and its equivalents, and should be regarded as a formation within the eolianite-bearing San Rafael Group. (3) The Recapture Member should remain part of the Morrison Formation because, despite containing eolianites and sabkha deposits, much of the unit is fluvial. The contact between eolianites and fluvial strata within it is commonly not well enough exposed to be mapped reproducibly. (4) The Westwater Canyon Member of the Morrison Formation is a valid term and should not be renamed the Salt Wash Member. (5) The Jackpile Sandstone Member should be removed from the Morrison Formation and instead should be mapped as the Lower Cretaceous Jackpile Sandstone or as Burro Canyon Formation.

In general, lithologic identity (depositional environment) provides the best basis for nomenclature. Lateral correlation and stratigraphic subdivision using unconformities in the Jurassic section have proven problematic, because many such unconformities are not regional in scope and are likely diachronous.

INTRODUCTION

The evolution of stratigraphic nomenclature for Jurassic beds in northwestern New Mexico has been problematic. Perhaps no other region of the state has generated more nomenclatural debates. Differences in nomenclature have arisen not only from arguments based on priority or the preoccupation of stratigraphic terms, but also from ambiguities in the physical correlation of strata and the significance of unconformities in the Colorado Plateau region. For example, Dickinson (2018) regarded most of the regionally recognized, intra-Jurassic unconformities to represent nothing more than diachronous, time-transgressive surfaces between prograding or laterally migrating depositional systems. As such, he questioned the utility of sequence-stratigraphic models that are based on the concept of synchronous, regional unconformities. The scarcity of paleontologic and radioisotopic age constraints for Jurassic strata has also contributed to correlation uncertainties.

Here, I modify and expand upon a discussion of stratigraphic nomenclature for the Jurassic San Rafael Group and Morrison Formation presented in an earlier paper by Cather et al. (2013), which outlines the current policy for Phanerozoic stratigraphic nomenclature in geologic maps produced by the New Mexico Bureau of Geology and Mineral Resources. The present paper is intended only as a synopsis. For additional discussion, see Condon and Peterson (1986), Condon (1989, 1993), Peterson (1994), Lucas and Anderson (1993, 1997), Anderson and Lucas (1997), Lucas and Heckert (2003), O'Sullivan (2003, 2010a, b), Lucas (2004), Turner and Peterson (2004, 2010), and Dickinson (2018).

ENTRADA SANDSTONE

The basal unit of the Jurassic section in most of northwestern New Mexico was originally termed the Wingate Sandstone by Dutton (1885). These same strata were subsequently renamed the Entrada Sandstone by Gilluly and Reeside (1928). The term Wingate was eventually applied to a stratigraphically lower, Upper Triassic–Lower Jurassic eolianite (see summary in Lucas and Heckert, 2003) present in extreme northwestern New Mexico (Craigg, 2001; Dickinson, 2018).

The Entrada Sandstone *sensu* Gilluly and Reeside unconformably overlies Upper Triassic strata throughout most of northwestern New Mexico. Largely eolian, the Entrada is equivalent to the Exeter Sandstone (Lee, 1902) of northeastern New Mexico. The Entrada is Middle Jurassic and has been variously divided into two or three members (e.g., Lucas and Heckert, 2003; O'Sullivan, 2003; Dickinson, 2018). No consensus has yet emerged concerning the member-rank nomenclature for the Entrada Sandstone.

TODILTO FORMATION VS. TODILTO LIMESTONE MEMBER OF WANAKAH FORMATION

The Entrada Sandstone is overlain by Jurassic water-laid deposits in the San Juan Basin area. These deposits are termed the Todilto and Summerville formations by some workers and the Wanakah Formation by others. Near the Zuni Uplift these water-laid deposits pinch out. The stacked equivalents of the Entrada and Bluff eolianites south of the pinch out have been termed the Zuni Sandstone by Lucas and Heckert (2003). Although the term Zuni Sandstone has been redefined several

times since first introduced by Dutton in 1885, I find the Lucas and Heckert (2003) concept of the term to be useful where the Entrada and Bluff eolianites are not divisible by the presence of the "Todilto notch," which represents an unconformity corresponding to the Todilto/Wanakah pinch out.

The Todilto Formation (Gregory, 1917) is a mappable unit of limestone and gypsum throughout much of northwestern New Mexico and, thus, has long been considered a formation by most geologists in the state. The U.S. Geological Survey (USGS), however, regards the unit as the Todilto Limestone Member of the lower Wanakah Formation. The term Wanakah was first applied to Devonian strata in New York, but was subsequently applied to Middle Jurassic strata the Four Corners area as well (Burbank, 1930; see summaries in Condon, 1993, and O'Sullivan, 2010a). Despite this oft-mentioned duplication of names, there has been long usage of the term Wanakah in the Four Corners region by both the USGS and the Colorado Geological Survey that continues to the present day.

Lucas and Anderson (1993, p. 66) stated that duplication of stratigraphic names, such as Wanakah, "...is a recipe for nomenclatural chaos." There is, in fact, little potential for confusion between the two Wanakah units due to their wide geographic separation and differing ages. I know of no examples, either in print or in conversation, of nomenclatural misunderstanding of the two units. Given the common usage of the term Wanakah Formation in the Four Corners region since 1930, it seems unlikely that further objections to the term based on homonymy will result in its abandonment.

The term Wanakah Formation, however, has not been widely used as a map unit in New Mexico, largely because its constituent members are there mostly regarded as formations, and the utility of a "Wanakah Group" has not been demonstrated. I recommend mapping the Todilto as a formation in northwestern New Mexico, except possibly in the Defiance Uplift region, where it is thin (~1–3 m) and its inclusion as the lower member of the Wanakah Formation is justifiable.

SUMMERVILLE FORMATION VS. BECLABITO MEMBER OF THE WANAKAH FORMATION

The term Summerville Formation was coined for a marginal marine, thin-bedded, dominantly siltstone succession that overlies the marine Curtis Formation in the San Rafael Swell region of south-central Utah (Gilluly and Reeside, 1928). The Summerville consists of tidal flat, supratidal, and sabkha deposits (Wilcox, 2007; Zuchuat et al., 2019). The term Summerville was subsequently exported some 500 km to the southeast to New Mexico (Rapaport et al., 1952), where it was applied to salina-margin and sabkha sandstones and mudstones above the salina deposits of Todilto Formation. The importation of the term Summerville to New Mexico is based partly on the now-disputed correlation of the underlying, physically disjunct Todilto and Curtis Formations (they are divided laterally by the Moab Tongue of the Entrada Sandstone).

Lucas and Heckert (2003, p. 295) stated, "The Todilto Formation in west-central New Mexico occupies the same stratigraphic position as the Curtis Formation in east-central Utah (between the Entrada and Summerville formations). Both units are of Callovian age, but current biostratigraphic data are insufficient to document a precise correlation." They further asserted (p. 295), "The Summerville Formation in west-central New Mexico is *physically continuous* with the Summerville Formation in the type area of southeastern Utah."

In contrast, O'Sullivan (1980) stated, "Work in the area northwest of Moab shows that all of the Summerville is beveled out eastward by an unconformity at the base of the Morrison Formation and is absent in the Moab area." Members of the USGS (e.g., Pipiringos and O'Sullivan, 1978; Condon, 1989; Peterson, 1994; O'Sullivan, 2010a) regard the New Mexico strata as older than, and not laterally continuous with, the Summerville Formation of Utah. They applied the term Beclabito Member of the Wanakah Formation to the New Mexico beds.

Dickinson (2018) preferred use of the term Summerville Formation in New Mexico. He interpreted these strata to be laterally continuous with and "homotaxially equivalent" (i.e., lithologically similar but not necessarily the same age; Dickinson, 2018, p. 11 and 110) to the beds in Utah.

The Entrada Sandstone, Todilto Formation, and Summerville/Beclabito comprise an essentially conformable succession in the San Juan Basin area. None of these units have been directly dated in New Mexico. The Todilto Formation contains the fossil fishes *Hulettia americana* and *Caturus dartoni* that, although not themselves age-diagnostic, are also present in the Bathonian Stockade Beaver Shale Member and Canyon Springs Sandstone Member of the Sundance Formation of South Dakota–Wyoming (Fig. 1; Lucas et al., 1985; Lucas and Anderson, 1997). These fish fossils, together with regional inferences about the age of the underlying Entrada Sandstone, have led to tentative age assignments for the Todilto that range from early to middle Callovian (Schultze and Enciso, 1983; Schaeffer and Patterson, 1984; Lucas et al., 1985; Kirkland et al., 1995; Lucas and Anderson, 1997; Lucas, 2014).

Recent paleontologic dating of the Curtis Formation in Utah, however, indicates it is younger than the widely interpreted Callovian age of the Todilto Formation. Dinoflagellate cysts (*Wanea fimbriata*, *Stephanelytron redcliffense*) and the ammonite *Quenstedtoceras* (*Pavloviceras*), recovered from the lower Curtis Formation in the San Rafael Swell–Uinta Uplift area of Utah, indicate it is lower to middle Oxfordian (Fig. 1; Wilcox and Currie, 2006; Wilcox, 2007). The Summerville Formation of Utah must be Oxfordian as well, based on the presence of ~156.8 Ma ashes (lower Kimmeridgian) in the overlying Morrison Formation (Fig. 1). The age of the Curtis in Utah had previously been inferred to be late middle Callovian, based on lithologic similarities with the Pine Butte Member of the Sundance Formation (Imlay, 1980).

If correlation of the Curtis Formation of Utah with the Todilto Formation of New Mexico is viable, then the New Mexico strata must be significantly younger (Oxfordian) than previously thought. This requires that the Todilto/Sundance fishes ranged in age at least from the Bathonian to the Oxfordian and that the entire Todilto through Bluff succession in New Mexico was deposited in less than about 6 my (see age constraints in Fig. 1).

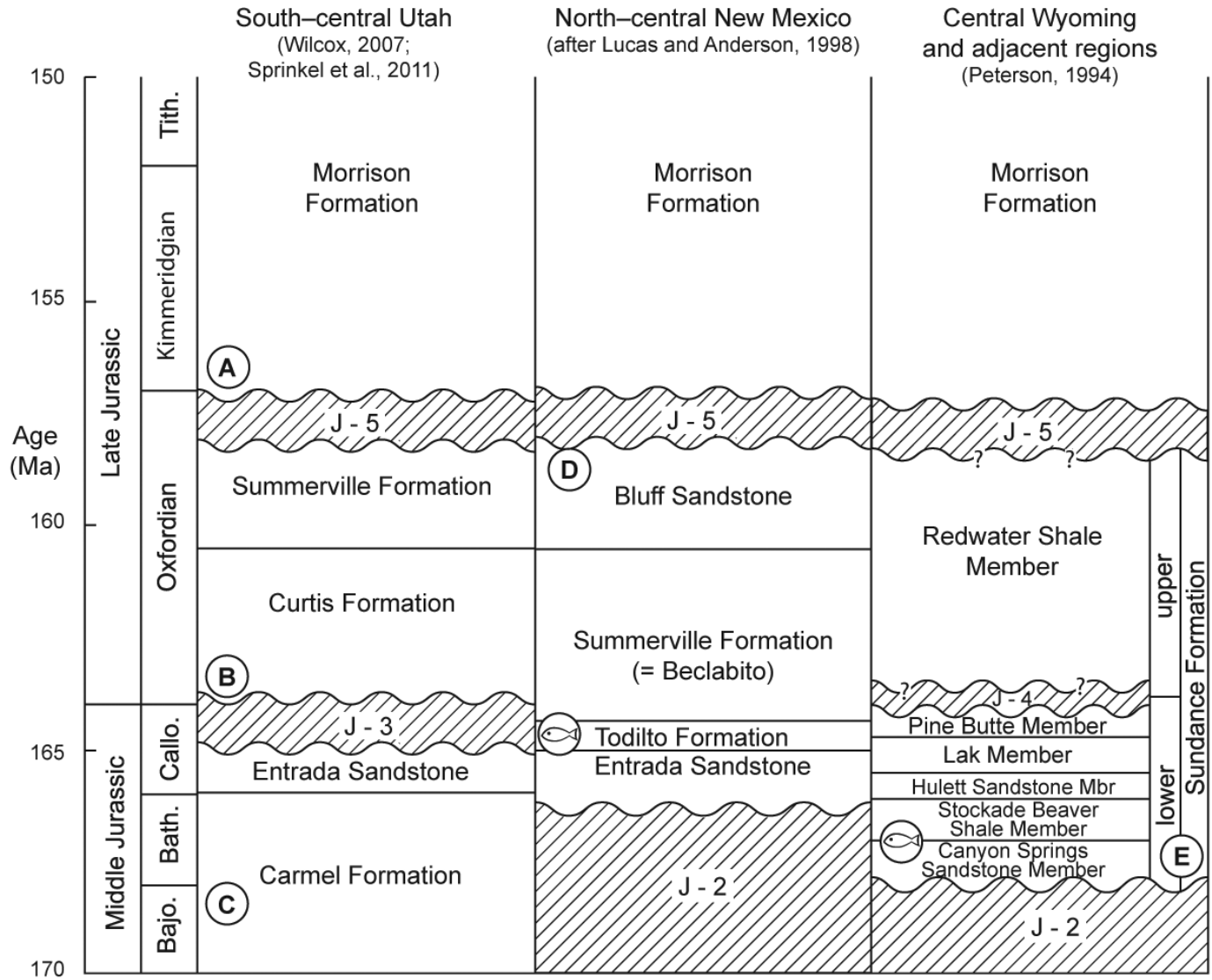

FIGURE 1. Chronostratigraphic correlation chart showing age constraints (circled letters), unconformities (hachured), and inferred temporal relationships between Middle to Upper Jurassic units in south-central Utah (San Rafael Swell region), north-central New Mexico, and the central Wyoming region. Modified from Cather et al. (2013). Note that Dickinson (2018) interpreted the depicted unconformities as diachronous, time-transgressive surfaces between prograding or laterally migrating depositional systems. Age constraints are: **A**– 156.84±0.59 Ma (northeastern Utah) and 156.77±0.55 (southeastern Utah) $^{40}Ar/^{39}Ar$ ash ages in basal Morrison Formation (Tidwell Member; Trujillo and Kowallis, 2015); **B**– early Oxfordian age of lower Curtis Formation based on dinoflagellate cysts (*Wanea fimbriata*, *Stephanelytron redcliffense*) and the ammonite *Quenstedtoceras* (Pavloviceras) (Wilcox and Currie, 2006; Wilcox, 2007); **C**– ash ages as young as 168.25±0.64 Ma in upper Carmel Formation (modified from Kowallis et al., 2001, using the 28.201 Ma standard for Fish Canyon sanidine of Kuiper et al., 2008 (B.J. Kowallis, written commun., 2013)); **D**– ca. 158 Ma maximum depositional age from detrital zircon analysis of Bluff Sandstone (Dickinson and Gehrels, 2009); **E**– biostratigraphic control of Bathonian ages of marine beds in Sundance Formation (Imlay, 1980). Fish symbols are non-age-diagnostic fossil fishes *Hulettia americana* and *Caturus dartoni*, which occur in both the Todilto Formation and the lower Sundance Formation. Timescale is GSA 2012 (Walker et al., 2012). Bajo. – Bajocian, Bath. – Bathonian, Callo. – Callovian, Tith. – Tithonian.

Alternatively, the Curtis Formation of central Utah may be younger than the Todilto. If so, this presents problems for models (e.g., Lucas et al., 1985; Kirkland et al., 1995; Lucas and Anderson, 1997) that interpret Todilto deposition to have occurred *during* the Oxfordian Curtis maximum transgression, rather than before it. If the Curtis/Summerville contact of central Utah is indeed younger than the Todilto/Summerville contact of New Mexico, it would lend support to the age interpretations by stratigraphers of the USGS, who use the term Beclabito Member of the Wanakah Formation in lieu of the Summerville Formation.

Although the term Summerville Formation has been used in recent quadrangle mapping in New Mexico (e.g., Cather et al., 2002; Kelley et al., 2005; Cather, 2011), I suggest the term Beclabito, here raised to formation rank, is the preferable term for these beds. If the Todilto and the Curtis formations are not correlative (a distinct possibility), then use of the term Summerville in New Mexico is questionable. From a genetic perspective, it seems inadvisable to apply the name Summerville both to a siltstone-dominated, marginal marine succession in Utah and a sandier, marginal salina succession in New Mexico. If future research shows the Beclabito Formation is indeed equiv-

alent to the Summerville Formation of Utah, the correlation can simply be noted. But if the two units are not correlative, much confusion will be avoided if the term Summerville does not become further entrenched in New Mexico geologic maps and reports. It is always easier to correlate units retroactively than it is to uncorrelate them, especially when erroneous terms appear on geologic maps that typically have a decades-long shelf life. It thus seems prudent to employ the local stratigraphic term Beclabito Formation rather than to rely on the disputable regional correlation to the Summerville Formation.

MORRISON FORMATION
Bluff Sandstone and Recapture Members

The Morrison Formation in northwestern New Mexico has traditionally been divided into the Bluff Sandstone, Recapture, Westwater Canyon, and Brushy Basin Members (Gregory, 1938). Some workers (Rapaport et al., 1952; Craig et al., 1955; Anderson and Lucas, 1995 and 1997; Dickinson, 2018), however, have argued that the eolian Bluff Sandstone Member should be removed from the base of the Morrison and become a formation within the underlying, mostly eolianite San Rafael Group.

Removal of the Bluff Sandstone Member from the Morrison has not been accepted by some workers (e.g., Turner and Peterson, 2004; Hintze and Kowallis, 2009; O'Sullivan, 2010b; Kirkland et al., in press). The ongoing controversy about the affinity of the Bluff Sandstone, however, need not be a major issue for mappers. As long as it is mapped separately and contact relationships are adequately defined (placement of contacts varies significantly among workers; see summaries in Anderson and Lucas (1995, 1997) and O'Sullivan (2010b)), the Bluff Sandstone can be assigned to either the Morrison Formation or the San Rafael Group at a later date when consensus is achieved. For now, I tentatively consider the eolian Bluff Sandstone (=Junction Creek Sandstone in Colorado) as the upper formation in the mostly eolian San Rafael Group. An added benefit of considering the Bluff Sandstone a formation (rather than a member of the Morrison Formation) is that it allows the Bluff to be divided into members, should the need arise.

The eolianites above the Beclabito have been divided into various units: the Bluff Sandstone (*sensu* O'Sullivan, 2010b), the Cow Springs Sandstone, the Horse Mesa Member of Wanakah Formation, and the Sandstone at Mesita (Harshbarger et al., 1957; Condon and Peterson, 1986; Condon, 1989). I follow Lucas and Heckert (2003) and Dickinson (2018) in thinking these units should be subsumed within a broadly defined Bluff Sandstone (Fig. 2; see below). I agree with Dickinson (2018) that the various terms applied to the Bluff Sandstone (as here broadly defined) are based on expectable lithologic variations within an erg system, and that such variations should not be the basis for formal lithostratigraphy. Such lithologic variations are best accommodated *within* a formation, as members or sedimentary lithofacies.

Anderson and Lucas (1995, 1997) argued that sabkha and eolian deposits in the basal 12–17 m of Gregory's (1938) Re-

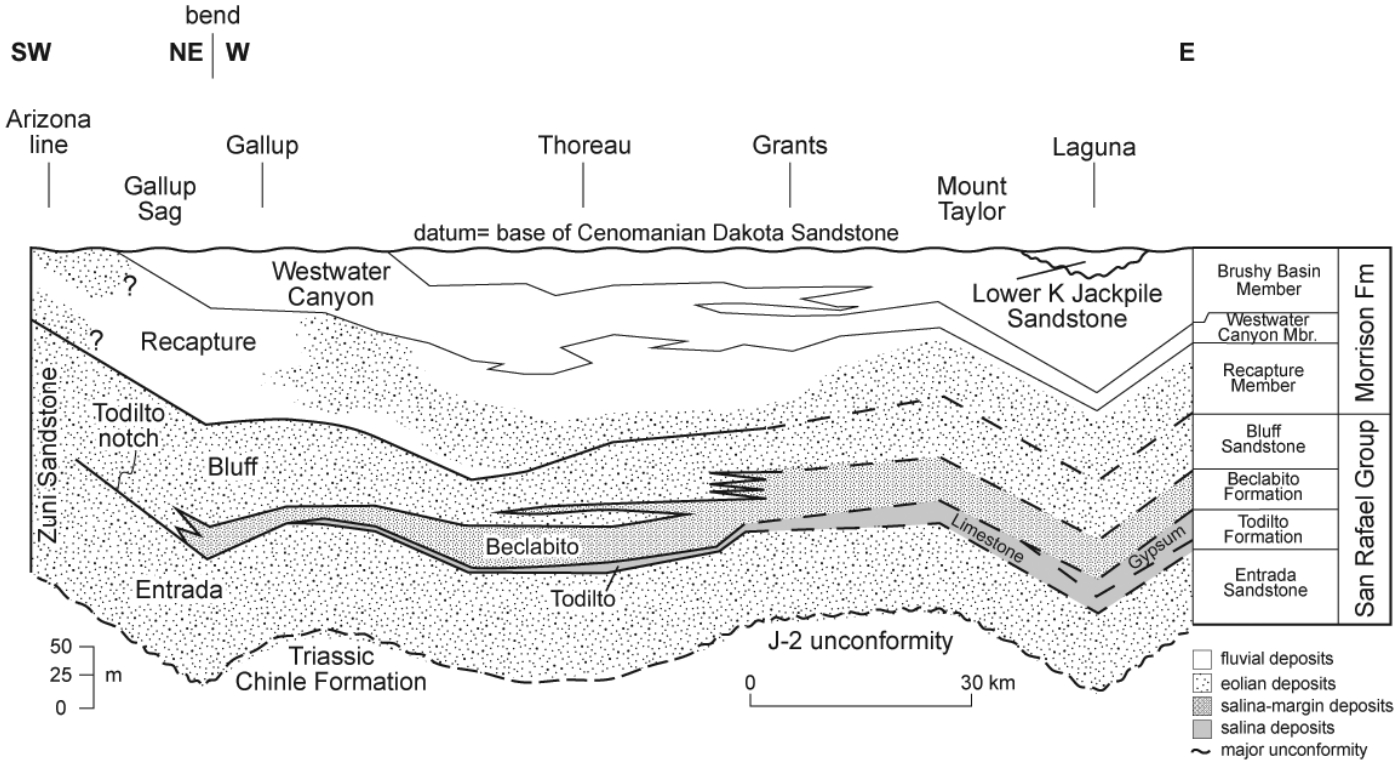

FIGURE 2. Correlation and suggested nomenclature for Jurassic strata in the southern San Juan Basin along the I–40 corridor from the Arizona line to near Laguna, New Mexico. Dashed lines indicate inferred subsurface contacts. Redrawn from Condon (1989, his fig. 2). See Condon (1989, his fig. 1) for locations of control points.

capture Member should also be included in the upper part of the San Rafael Group (this interval became their Recapture Member of the Bluff Sandstone of the San Rafael Group). The remainder of Gregory's Recapture Member, above their interpreted position of the J-5 unconformity, they assigned to the mostly fluvial Morrison Formation (the lower part of their revised Salt Wash Member; see below). The eolian component of the Gregory's Recapture Member, however, is not limited to its basal part, but interfingers with fluvial deposits at many stratigraphic levels within the Recapture (Fig. 2; Condon, 1989). Moreover, the proposed contact lies within a recessively weathering sedimentary succession and, thus, is of questionable mappability.

The presence of eolian facies in the Recapture Member, a fine-grained, southern fan complex that is equivalent to the Salt Wash Member, is an expectable consequence of the northward Jurassic drift of Laurentia, as the southern part of the Morrison depositional system was the last to leave the desert latitudes (Dickinson, 2018). Dickinson (2018) kept the entire Recapture Member (*sensu* Gregory, 1938) within the Morrison Formation, a decision with which I concur. The basal contact of the Morrison Formation should be placed at the top of the uppermost ledge of the Bluff Sandstone. This contact is a disconformity that represents a short lacuna (at most ~ 2 my; Fig. 1), likely related to the diachronous progradation of the basal Morrison fluvial systems across the Bluff erg (Dickinson, 2018).

Westwater Canyon Member

The Westwater Canyon Member (Gregory, 1938) of the Morrison Formation overlies the Recapture Member and is overlain by, and grades northward into, the Brushy Basin Member (Dickinson, 2018). Anderson and Lucas (1995, 1997) argued that the term Westwater Canyon Member is a junior synonym for the Salt Wash Member (Lupton, 1912; Gilluly and Reeside, 1928) and should be abandoned because of priority. Studies of regional stratigraphy, paleocurrents, detrital zircon analysis, and petrology, however, have all demonstrated that the Salt Wash and Westwater Canyon members were deposited by overlapping megafans with differing source regions (e.g., Craig et al., 1955; Hurd et al., 2006; Dickinson and Gehrels, 2008; Dickinson and Gehrels, 2010; Dickinson, 2018; Kirkland, *in press*). Most workers restrict the Salt Wash Member to southeastern Utah and southwestern Colorado, where it interfingers southward with the Recapture Member. The term Westwater Canyon Member is thus valid and should be retained.

Jackpile Sandstone

The Jackpile Sandstone has been regarded by most workers as the uppermost member of the Morrison Formation in the Mount Taylor area of New Mexico (e.g., Freeman and Hilpert, 1956; Owen et al., 1984; Lucas, 2018). Aubrey (1992), however, argued that the Jackpile is probably equivalent to the Lower Cretaceous Burro Canyon Formation, a unit that occupies a stratigraphic position similar to the Jackpile but is Lower Cretaceous (Barremian?–Albian, based on palynomorphs and a zircon fission-track age of 125±10 Ma from a bentonite; Craig, 1982; Tschudy et al., 1984).

The interpretation that the Jackpile is part of the Morrison is partly based on the local gradational basal contact of sandstones of the Jackpile with underlying, fine-grained deposits. The basal contact of the Burro Canyon Formation, however, in places occurs *within* the fine-grained deposits beneath its basal prominent sandstone (Turner and Peterson, 2010, p.11). Thus, it seems possible that the basal disconformity of the Jackpile may locally also lie within the underlying, fine-grained deposits.

Unlike sublitharenitic sandstones of the underlying Brushy Basin Member (Dickinson, 2018), sandstones of the Burro Canyon and the Jackpile are quartzose and contain widespread kaolinite cement. Correlation of the Jackpile to the Burro Canyon is further supported by their nearly identical detrital-zircon age distributions and the dissimilarity of their zircon populations to the rest of the Morrison Formation (Dickinson and Gehrels, 2010). The Jackpile Sandstone should be removed from the Morrison Formation (Cather et al., 2013; Dickinson, 2018) and mapped separately as Lower Cretaceous Jackpile Sandstone, or simply as Burro Canyon Formation.

SUMMARY

Of the stratigraphic terms discussed in this report, it is interesting to note that only the Brushy Basin Member of the Morrison Formation has escaped nomenclatural controversy. It is perhaps expectable that subdivision of vast Jurassic depositional systems of the southwestern United States into named units is not straightforward. Some of this controversy derives from differing concepts of how formations should be named. Should a formation be defined primarily on its lithologic characteristics (which reflect its depositional environment)? Or should nomenclature hinge more upon factors such as lateral correlation of bounding unconformities that serve to divide similar lithofacies or bound ones that are lithologically dissimilar? I suggest the former approach is better.

Since the 1980s, some workers have emphasized the role of unconformities and lateral correlations in naming formations. This can be problematic because regional correlations of Jurassic units are seldom unambiguous (the Summerville/Beclabito controversy is a good example of this) and, as noted by Dickinson (2018), unconformities are not everywhere traceable and are likely time-transgressive. Moreover, the stratigraphic position of some unconformities is disputed. For example, Anderson and Lucas (1995) placed the J-5 unconformity within Gregory's (1938) Recapture Member, but O'Sullivan (2010b) placed the J-5 within the underlying eolianites, at the base of his Bluff Sandstone Member of the Morrison Formation.

An example of the disadvantage of relying upon unconformities to define formations is the Bluff Sandstone. In southeastern Utah, geologists of the USGS consider the eolian Bluff Sandstone Member to overlie an unconformity (their J-5), which is developed on another eolianite, the Horse Mesa Member of the Wanakah Formation (e.g., O'Sullivan, 2010a; Turner and Peterson, 2010, p. 16). It seems possible to me that

this unconformity is simply a major intra-erg erosion surface (an eolian super-surface; Kocurek, 1988) within a fundamentally eolian succession. A similar intra-eolianite unconformity, however, is not present in the San Juan Basin region. Because of this, the USGS regards the entire eolianite above the Beclabito in the southeastern San Juan Basin as Horse Mesa Member (e.g., Condon, 1989). I agree with Anderson and Lucas (1996) and Dickinson (2018) that the whole eolianite above the Beclabito (their Summerville) should be regarded as Bluff Sandstone, the uppermost formation of the San Rafael Group.

Another example of overemphasis on unconformities (in this case, to broaden the content of a formation) is the eolian Moab Member of Utah, formerly part of the Entrada Sandstone, but now considered part of the Curtis Formation (e.g., Doelling, 2002). This reassignment was based on the presence beneath both the Curtis and the Moab of the J-3 unconformity, which serves to divide them from the underlying Entrada Sandstone.

Inclusion of the Moab as a member of the Curtis, however, creates a formation that ranges in its genesis from shallow marine to eolian, which is contrary to the definition of a formation, "A formation should possess some degree of internal lithic homogeneity..." [North American Stratigraphic Code (NASC), North American Commission on Stratigraphic Nomenclature, 2005, p. 1567]. Because the Stratigraphic Code allows unconformities within formations ("a formation...may include breaks in deposition"; NASC, p. 1567), it would be best to regard the Moab Member as part of the mostly eolian Entrada Sandstone [see Dickinson (2018, his Table 10) for a similar opinion], or to map it separately as a formation.

Formation-rank stratigraphic nomenclature based on depositional environments (i.e., dominantly erg, salina, salina-margin, or fluvial; Fig. 2) offers more reproducibility than does a nomenclature based on lateral correlation or interpretive subdivision of depositional systems using unconformities. A similar approach was advocated by Dickinson (2018). Within a nomenclatural scheme based on depositional environment, unconformities and facies characteristics can be used to subdivide formations into members or lithofacies.

The synthesis presented above will not resolve all issues concerning the Jurassic stratigraphic nomenclature of the San Juan Basin region. My intent is to propose a workable nomenclature for field mapping that may begin to heal some of the major schisms in the stratigraphic nomenclature of New Mexico.

ACKNOWLEDGMENTS

Field work was supported by the New Mexico Bureau of Geology and Mineral Resources and the STATEMAP program (Mike Timmons, Associate Director). I benefited from discussions with Spencer Lucas, Doug Sprinkel, and the late Bill Dickinson. Stephanie Chavez drafted the figures. The manuscript was improved by reviews from Jim Kirkland and Kate Zeigler.

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