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JURASSIC STRATIGRAPHY IN THE CHAMA BASIN, NORTHERN NEW MEXICO

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Abstract.—Jurassic strata have an extensive outcrop belt in the Chama Basin of Rio Arriba County, New Mexico, and are assigned to the Entrada, Todilto, Summerville and Morrison formations. Previous workers have identified the Morrison Formation in the Chama Basin as the strata between the Jurassic Todilto Formation and the Cretaceous Burro Canyon Formation, or they have identified a "Wanakah Formation" between the Todilto and Morrison base. However, recent restudy of the Jurassic section in the Chama Basin (especially at Ghost Ranch and at Mesa Alta) indicate the Jurassic section is: (1) Slick Rock Member of the Entrada Sandstone, 60 to 76 m of trough crossbedded and ripple laminated sandstone; (2) Todilto Formation, consisting of a lower limestone-dominated Luciano Mesa Member (2-8 m thick) and an upper, gypsum-dominated Tonque Arroyo Member (0-30 m thick); (3) Summerville Formation, 74 to 111 m of thinly and cyclically-bedded, grayish red and yellowish gray siltstone, sandy siltstone, fine gypsiferous sandstone and mudstone; (4) Bluff Sandstone (Junction Creek Member), 30 to 43 m of light gray, very fine grained, well sorted sandstone with crossbeds in thick sets; (5) Recapture Member of Bluff Sandstone, 6 to 14 m of grayish red gypsiferous siltstone, fine sandstone and minor mudstone; and (6) Brushy Basin Member of Morrison Formation, 41 to 68 m of variegated pale greenish gray and reddish brown, bentonitic mudstone and a few beds of trough-crossbedded, pebbly sandstone. This revised lithostratigraphy is consistent with regional lithostratigraphy that recognizes the Summerville Formation across northern New Mexico, and the Bluff Sandstone in the eastern San Juan Basin, adjacent to the Chama Basin. Only the Slick Rock Member of the Entrada Sandstone is present, and this suggests a depositional high in the Chama Basin area during the time of the Carmel transgression. The absence of a basal Salt Wash Member of the Morrison Formation in the Chama Basin is a striking departure from the regional stratigraphy. We interpret this absence as direct evidence of the J-5 unconformity, which separates the base of the Morrison (usually the Salt Wash Member, but in the Chama Basin the Brushy Basin Member) from underlying San Rafael Group strata.

INTRODUCTION

Jurassic strata in the Chama Basin of northern New Mexico (Fig. 1) are the basis for some of the region's striking scenery. Bold cliffs of Entrada Sandstone cap mesas and escarpments throughout the Arroyo Seco and Gallina River drainages in the southern part of the Chama Basin, and picturesque exposures of the Todilto, Summerville and/or Morrison formations locally cover higher slopes throughout the region. Although first recognized by Cope (1875), Jurassic rocks in the Chama Basin are much less studied than equivalent strata on other parts of the Colorado Plateau. Here, we review the lithostratigraphy, paleontology and correlation of the Jurassic strata in the Chama Basin.

PREVIOUS STUDIES

The first geologist to work in the Chama Basin, Newberry (1876), did not recognize rocks of Jurassic age; he assigned those strata a Triassic age. Cope (1875, p. 67, fig. 2, p. 81, figs. 5-6) first suggested that "Jurassic" strata are present in the Chama Basin, though he had no clear basis for assigning a Jurassic age to these strata. Nevertheless, Cope (1875) clearly identified strata now assigned to the Entrada and Todilto formations as Jurassic.

After Newberry and Cope, about half a century passed before further observations on the Jurassic strata in the Chama Basin were published. Darton (1928, pl. 37) assigned Jurassic strata in the Chama Basin to the Wingate Sandstone, Todilto Formation and Morrison Formation (though he assigned a Cretaceous age to the Morrison Formation), essentially establishing the Jurassic stratigraphy of the region (Fig. 2). Indeed, most subsequent workers (e.g., Muehlberger, 1967; Bingler, 1968; Woodward, 1987) used the Jurassic stratigraphy of Darton, though they replaced the term Wingate with Entrada. However, Craig (1959) referred to the post-Todilto Jurassic section in the Chama Basin as the Recapture, Westwater Canyon and Brushy Basin members of the Morrison Formation, though this usage was never repeated.

Smith et al. (1961) assigned the Jurassic section to essentially the same units as had Darton (1928). Thus, they recognized the Entrada (=Wingate), Todilto and Morrison formations in the Chama Basin. In the Todilto, Smith et al. (1961) discriminated a

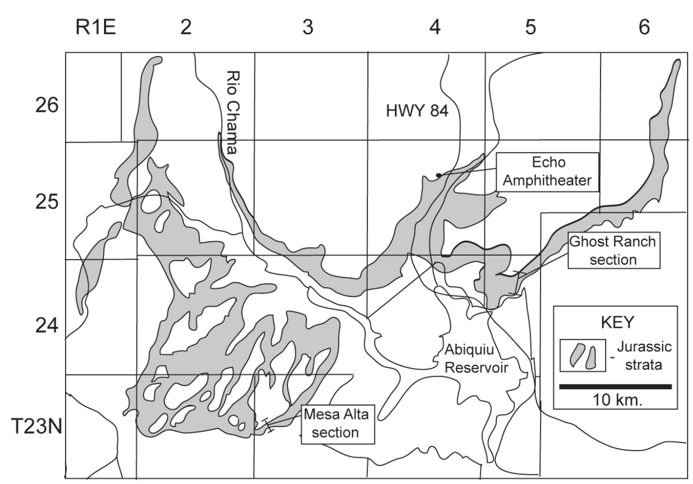

FIGURE 1. Distribution of Jurassic strata in the Chama Basin showing location of measured sections at Mesa Alta and Ghost Ranch and of Echo Amphitheater.

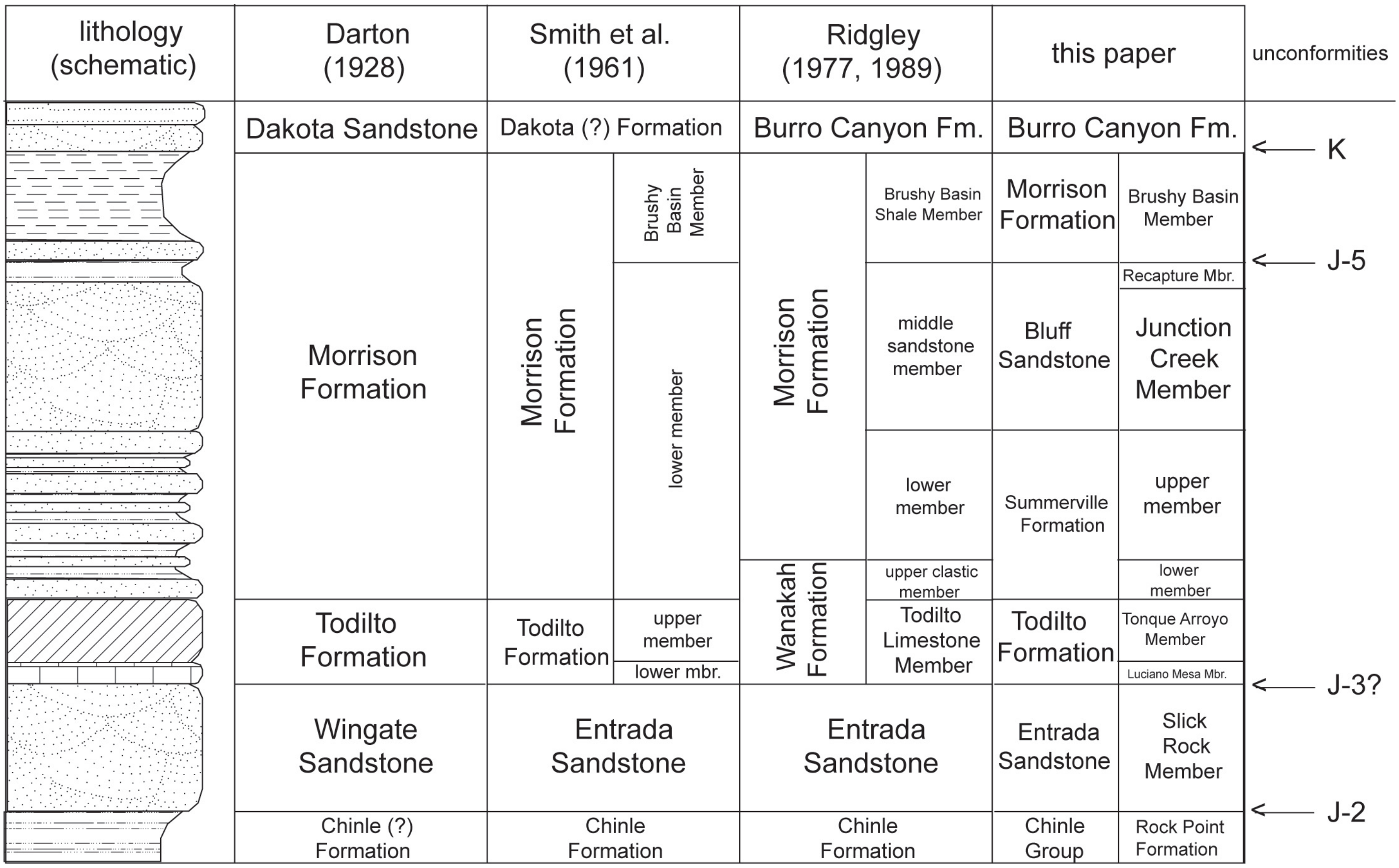

FIGURE 2. Development of Jurassic lithostratigraphic nomenclature in the Chama Basin.

lower member (limestone) and an upper member (gypsum). They also divided the Morrison Formation into a lower member (up to 400 ft thick), "an alternating sequence of pale brown, chocolate, or deep purple mudstones and white to pale gray siltstones" (p. 13), overlain by the Brushy Basin Member. Dane and Bachman (1965) similarly assigned Jurassic strata in the Chama Basin to the San Rafael Group (Entrada and Todilto formations) and Morrison Formation.

Ridgley (1977, 1986, 1989) revised the Jurassic stratigraphic nomenclature in the Chama Basin to meet then-current regional Jurassic nomenclature used by the U.S. Geological Survey (e.g., Condon and Peterson, 1986). Thus, she assigned the Jurassic strata to the Entrada, Wanakah, and Morrison formations (Fig. 2). The Wanakah was divided into a lower, Todilto Limestone Member and an upper clastic member. Ridgley also divided the Morrison Formation into a lower member, middle sandstone member and Brushy Basin Shale Member.

The preoccupied term Wanakah should be abandoned as a stratigraphic name for Jurassic rocks in the Southwest (e.g., Anderson and Lucas, 1992; Lucas and Anderson, 1997, 1998). Todilto has long been, and continues to be mapped as a formation rank unit, with two distinct members (Lucas et al., 1995; Anderson and Lucas, 1996; Lucas and Anderson, 1997, 1998). Furthermore, as discussed below (also see Anderson and Lucas, 1996), strata assigned by Ridgley (1977, 1989) and earlier workers to the lower part of the Morrison Formation are lithologically the same as strata of the Summerville Formation and Bluff Sandstone elsewhere.

Therefore, Lucas and Anderson (1998; also see Anderson and Lucas, 1996) revised the Jurassic stratigraphic nomenclature in the Chama Basin, and that nomenclature is used here (Fig. 2). The base of the Jurassic section is Entrada Sandstone (Slick Rock Member, see Lucas and Heckert, 2003). The overlying Todilto Formation can be divided into a lower, limestone-dominated Luciano Mesa Member and an upper, gypsum-dominated Tonque Arroyo Member. Summerville strata above the Todilto consist of lower and upper members. The Bluff Sandstone above that is mostly eolian sandstone of the Junction Creek Member overlain by thin gypsiferous sandstones and siltstones of the Recapture Member. The overlying Morrison Formation strata are assigned to the Brushy Basin Member.

LITHOSTRATIGRAPHY

Entrada Sandstone

The oldest Jurassic strata in the Chama Basin are assigned to the Slick Rock Member of the Entrada Sandstone. In the sections we measured (Figs. 3-6), the Entrada Sandstone is 60 to 76 m of very fine- to medium-grained, moderately well sorted sandstone

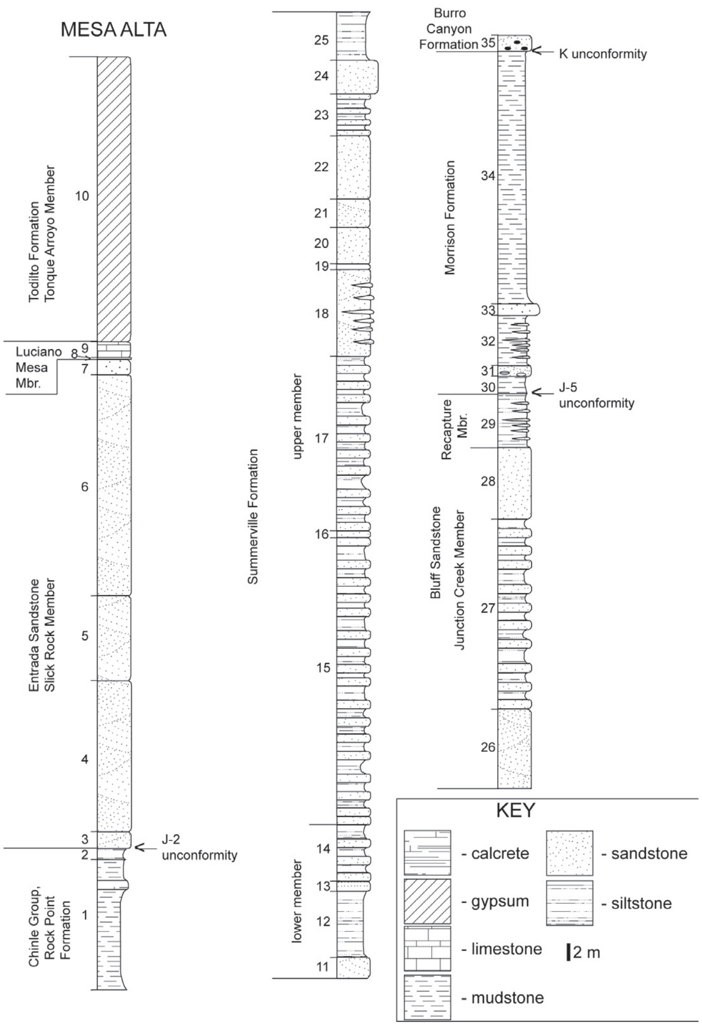

FIGURE 3. Measured section of Jurassic strata at Mesa Alta. See Appendix for description of numbered lithologic units.

that forms bold cliffs along escarpments and mesa tops. Trough crossbeds and ripple laminations are the dominant bedforms. Colors are shades of yellow, light brown and grayish orange.

The base of the Entrada Sandstone is a sharp surface above siltstone and fine sandstone of the Rock Point Formation of the Chinle Group (Lucas et al., 2003). This is the regional J-2 unconformity of Pipiringos and O'Sullivan (1978), and it separates the Middle Jurassic Entrada Sandstone from underlying Upper Triassic strata. The top of the Entrada Sandstone also is a sharp, apparently disconformable surface overlain by limestone at the base of the Luciano Mesa Member of the Todilto Formation (Ahmed Benan and Kocurek, 2000). This surface probably correlates to the J-3 unconformity of Pipiringos and O'Sullivan (1978).

Across west-central and parts of north-central New Mexico, the Entrada Sandstone is divided into two members, the lower Dewey Bridge Member and upper Slick Rock Member (Lucas and Anderson, 1998; Lucas et al., 1999; Lucas and Heckert, 2003). Only the Slick Rock Member, dominantly trough-cross-bedded eolian sandstone, is present in the Chama Basin.

Todilto Formation

In the Chama Basin, the Todilto Formation consists of a lower, limestone-dominated interval (Luciano Mesa Member) overlain locally by a gypsum interval (Tonque Arroyo Member), as it does across much of north-central New Mexico (Lucas et al., 1985, 1995; Kirkland et al., 1995) (Figs. 3-6). The Luciano Mesa Member is 2 to 8 m thick and consists mostly of thinly laminated, dark gray or yellowish gray, kerogenic limestone. Beds near the base of the member are usually sandy, and microfolding of the thin limestone laminae is common.

The overlying Tonque Arroyo Member is up to 30 m of white to light gray gypsum. Whereas the Luciano Mesa Member is continuous throughout the Chama Basin, the Tonque Arroyo Member has a sporadic distribution and thins to zero over short lateral distances. Where present, it consists of convex upward mounds or pods less than a km in lateral extent (e.g., Figs. 4D, 6D). The flanks of these mounds have slopes of 25-30 degrees, and the overlying Summerville strata are draped over them. The original extent of the gypsum was likely controlled by anhydrite deposition in shallow brine pools in interdunal lows of the Entrada paleotopography upon which the Todilto was deposited (e.g., Ahmend Benan and Kocurek, 2000). However, such deposits should have thinned laterally to a feather edge and would not exhibit the strong, convex-upward geometry of the gypsum mounds evident today (even given the volume increase that would accompany the hydration of original anhydrite to gypsum).

To explain this, we submit that the original extent of the gypsum (anhydrite) has been modified extensively by subsurface dissolution. To support our assertion, we further note that the current distribution of the gypsum is mutally exclusive with the limestone breccia zone of the underlying Luciano Mesa Member of the Todilto Formation. The breccia is only present where the gypsum is absent, which suggests it is a dissolution breccia associated with the removal of the evaporite above it. Thus, to map the original extent of the Todilto brine pools, one has to map the breccia facies together with the current gyspum distribution.

Summerville Formation

In the Chama Basin, strata of the Summerville Formation are 74 m to 111 m of thinly and cyclically bedded grayish red, yellowish gray, and grayish yellow green siltstone, fine-grained gypsiferous sandstone and mudstone (Figs. 3-6). The basal contact of the Summerville Formation is where ripple-laminated, gypsiferous sandstone rests with a sharp contact on gypsum or limestone of the underlying Todilto Formation. The top of the Summerville Formation is where sandstone of the Bluff Sandstone rests on siltstone or mudstone of the Summerville Formation.

In the Chama Basin, the Summerville Formation is readily divided into two informal members, lower and upper. The lower member is 12 to 15 m thick and is repetitively bedded gypsiferous sandstone and siltstone that forms a ribbed cliff or slope. It is the same unit that Goldman and Spencer (1941) termed the "Bilk Creek Sandstone Member" in southwestern Colorado. The

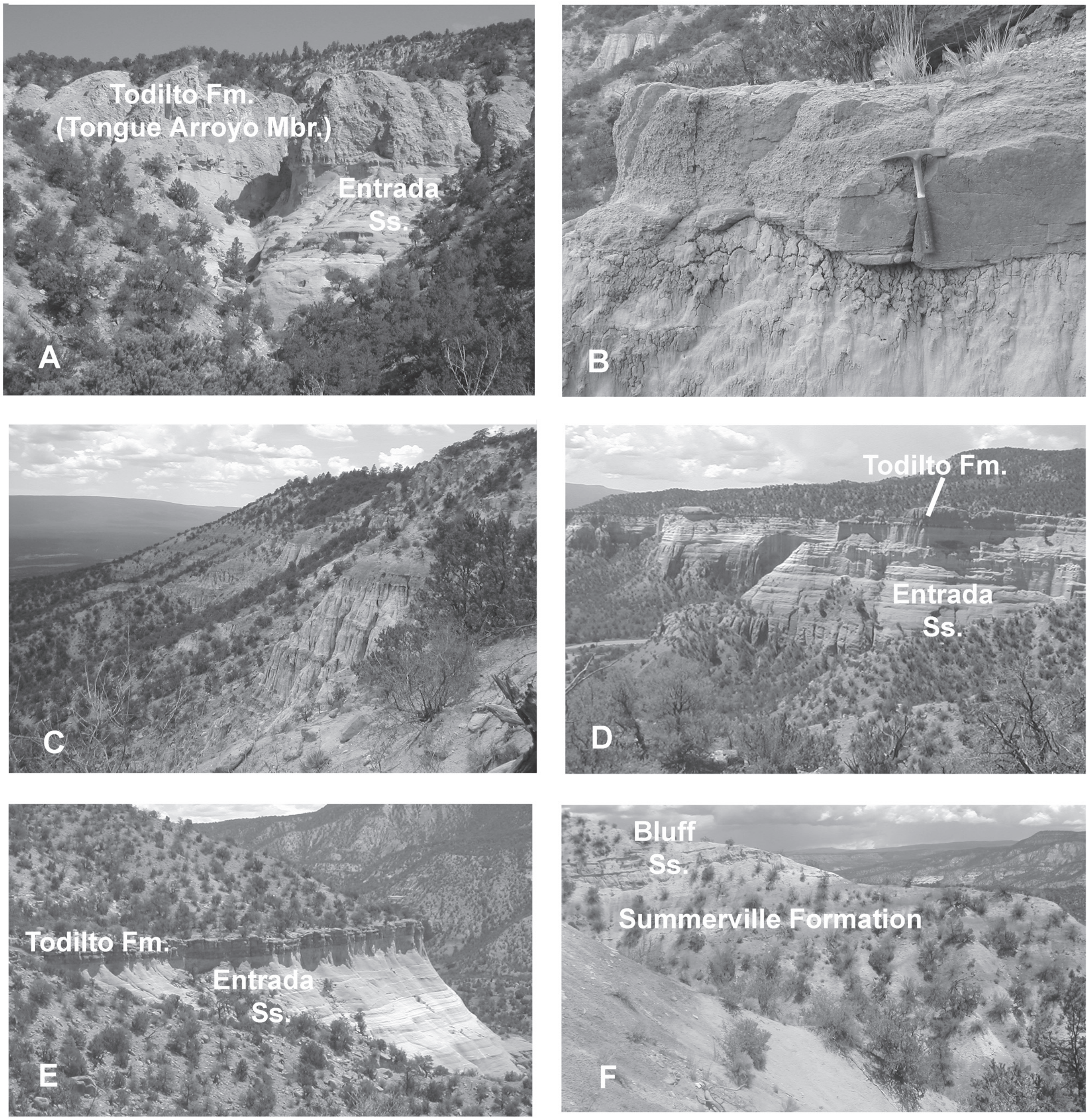

FIGURE 4. Selected outcrops of Jurassic strata at Mesa Alta (A-C) and Echo Amphitheater (D-F). A, Overview of Entrada Sandstone overlain by Todilto Formation at Mesa Alta. B, Characteristic gypsiferous sandstone of Summerville Formation at Mesa Alta. C, Overview of Summerville Formation at Mesa Alta. D, Entrada Sandstone overlain by relatively thick Todilto Formation (note gypsum-dominated Tonque Arroyo Member) at Echo Amphitheater. E, Entrada Sandstone overlain by relatively thin Todilto Formation (note absence of gypsum-dominated Tonque Arroyo Member) near Echo Amphitheather. F, Summerville Formation and Bluff Sandstone near Echo Amphitheater.

upper member is 61 to 96 m of siltstone and thinly-interbedded gypsiferous sandstone and mudstone that forms a thick, grayish red and white banded slope. Elsewhere on the Colorado Plateau, the Summerville Formation consists of two members, the lower Beclabito and upper Tidwell members (Lucas and Anderson, 1997), but these are not the same as the informal members present in the Chama Basin. Thus, the Tidwell Member is mostly the lateral equivalent of the Bluff Sandstone (e.g., Anderson and Lucas, 1994, 1995; Lucas and Anderson, 1997), so the Summerville Formation in the Chama Basin is essentially equivalent to the Beclabito Member.

Strata we term Summerville Formation in the Chama Basin were assigned to the Morrison Formation by most previous workers (Fig. 2), though Ridgely (1989) did assign what we term the lower member of Summerville Formation to the Wanakah Formation. Summerville strata in the Chama Basin resemble Summerville strata elsewhere on the southern Colorado Plateau – they are a repetitively bedded succession of fine-grained gypsiferous

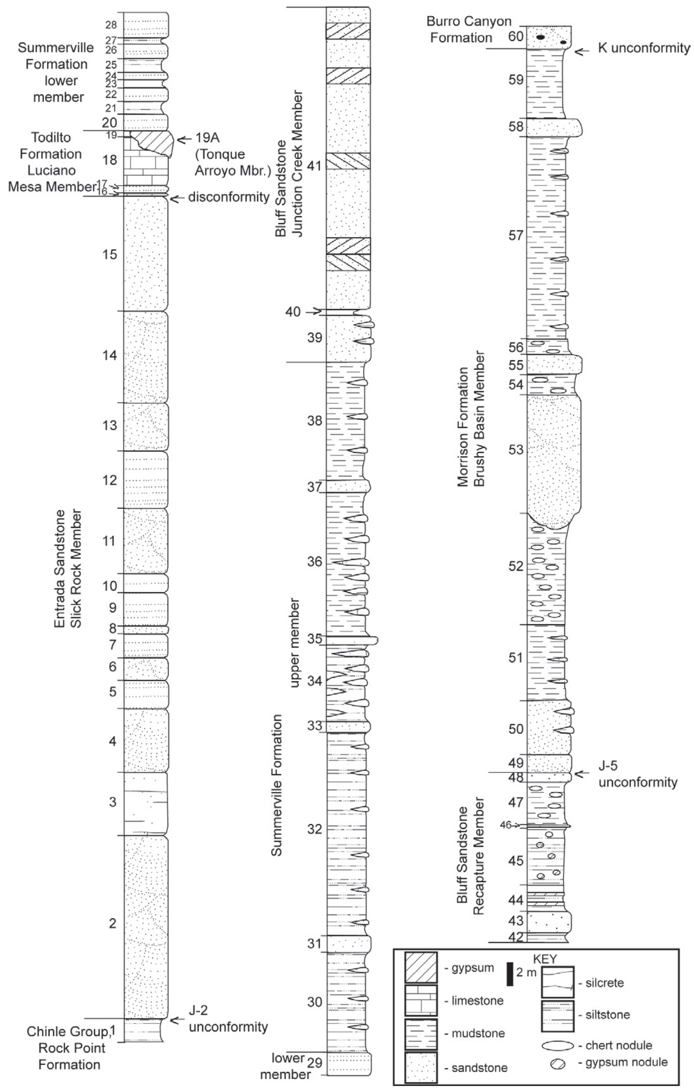

FIGURE 5. Measured section of Jurassic strata at Ghost Ranch. See Appendix for description of numbered lithologic units.

sandstone and siltstone with some beds of mudstone. They are also in the same stratigraphic position as Summerville strata elsewhere, between the Todilto and Morrison formations. Thus, recognition of the Summerville Formation across the Chama Basin is readily justified.

Bluff Sandstone

In the Chama Basin, the Bluff Sandstone is 44 to 47 m thick (Figs. 3-6). As elsewhere on the southern Colorado Plateau, the Bluff Sandstone consists of two members, a lower Junction Creek Member and an upper Recapture Member (Anderson and Lucas, 1996, 1997; Lucas and Anderson, 1997, 1998). The Junction Creek Member comprises most of the formation (30-40 m thick) and is mostly pale yellowish green and light olive gray, very fine grained, well sorted sandstone with crossbeds in thick sets. These are primarily eolian deposits similar to the type section of the Junction Creek Member near Durango, Colorado (Goldman and Spencer, 1941).

The Recapture Member is 6 to 14 m thick and is mostly pale brown, grayish red, and light greenish gray gypsiferous siltstone, fine-grained sandstone and mudstone. Recapture strata lithologically resemble underlying Summerville strata. Their fine-grained gypsiferous lithotypes indicate that these strata do not belong to the Morrison Formation, but instead are correctly assigned to the Recapture Member of the Bluff Sandstone (Lucas and Anderson, 1997, 1998).

Morrison Formation

In the Chama Basin, the Morrison Formation is 41 to 68 m thick and is assigned to the Brushy Basin Member (Figs. 3-6). These strata are mostly variegated pale greenish gray, grayish yellow green, pale olive, yellowish brown, and pale reddish brown bentonitic mudstone with a few beds of trough-crossbedded pebbly sandstone. Locally, the base of the Morrison Formation is a thin (up to 8 m thick) interval of trough-crossbedded sandstone and interbedded mudstone. Above that interval, the formation is mostly mudstone. This basal interval is likely correlative to the Salt Wash Member of the Morrison Formation to the west and south. However, this interval is neither thick enough, persistent enough nor lithologically distinctive enough to separate from the Brushy Basin Member.

The upper contact of the Morrison Formation in the Chama Basin is a sharp unconformable surface where conglomeratic sandstone of the Burro Canyon Formation rests directly on mudstone of the Brushy Basin Member. This is the K unconformity of Pipiringos and O'Sullivan (1978).

PALEONTOLOGY

Very few fossils are known from Jurassic strata in the Chama Basin. This is mostly due to three factors: (1) some units, such as the Entrada Sandstone, are generally unfossiliferous; (2) access is difficult to much of the Jurassic section in the Chama Basin; for example the high mesa slopes of the Morrison Formation; and (3) little effort has been made to look for and collect Jurassic fossils in the Chama Basin.

Thus, no fossils are known from the Entrada Sandstone in the Chama Basin. Two fossil fishes assigned to *Todiltia schoewei* are the only Todilto Formation (Luciano Mesa Member) fossils from the Chama Basin (Hunt et al., 2005).

Anderson and Lucas (1996) reported theropod dinosaur footprints from the Summerville Formation along the Chama River west of Navajo Peak. Lockley et al. (1996) assigned these footprints to *Megalisauripus*, a widespread theropod dinosaur ichnogenus in the Summerville Formation of Utah, Arizona, New Mexico and Oklahoma. Ridgley (1989) reported the bivalve *Vetulonia* from the Summerville Formation near Echo Amphitheater. This locality is stratigraphically low in the Summerville Formation (UTM zone 13, 363057E, 4025430N, NAD 27). Trace fossils from the same general locality were identified by Ridgley (1989) as *Rhizocorallium, Arenicolites* and *Thalassinoides*, and she interpreted them to indicate a lake-margin environment. However, based on Ridgley's photographs and descriptions we cannot

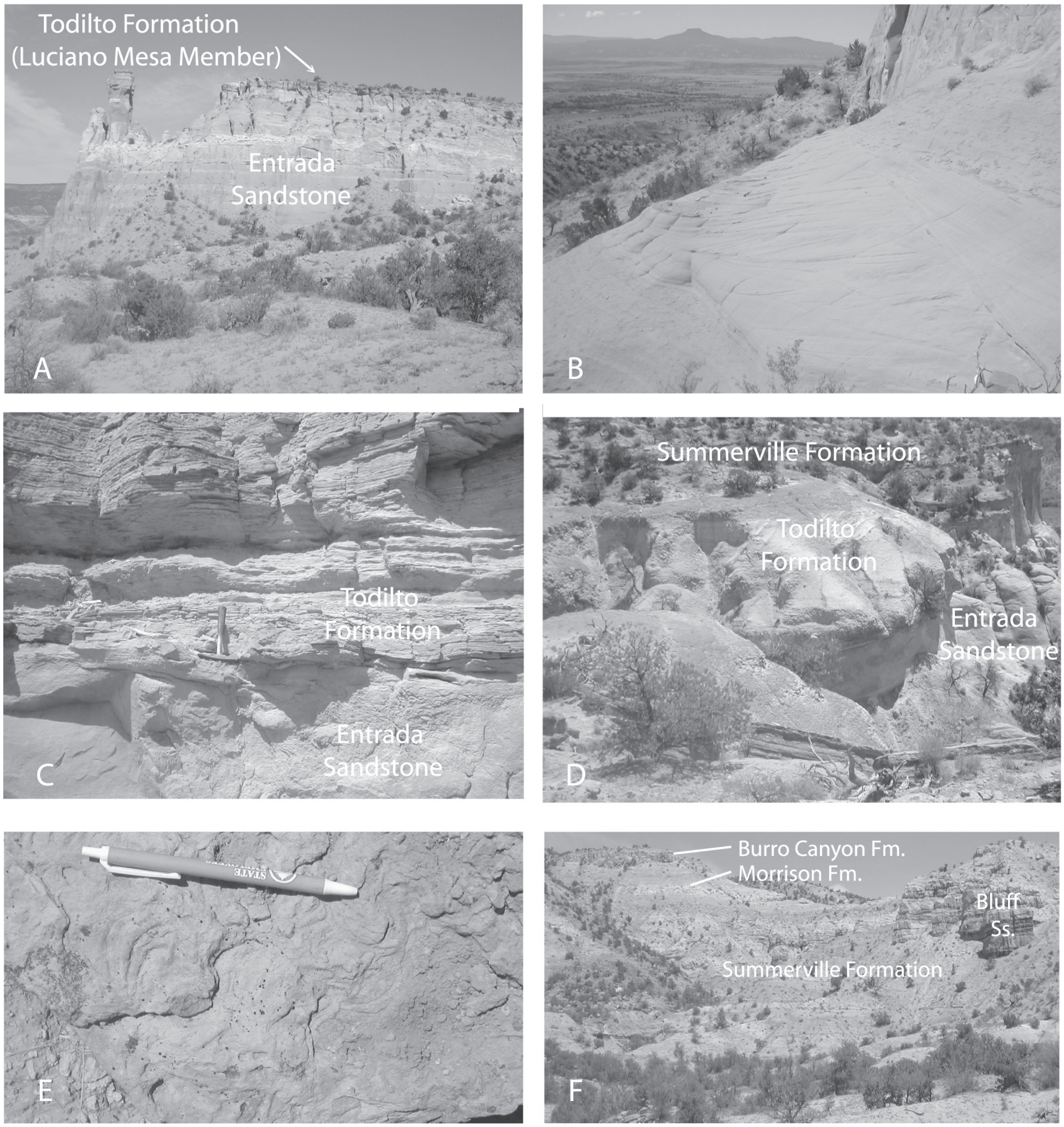

FIGURE 6. Selected outcrops of Jurassic strata at Ghost Ranch. A, Entrada Sandstone overlain by Luciano Mesa Member of Todilto Formation. B, Characteristic southwest-dipping, large-scale trough crossbeds in Entrada Sandstone. C, Close-up of contact at Luciano Mesa Member of Todilto Formation on Entrada Sandstone. D, Entrada, Todilto (Tonque Arroyo Member) and Summerville strata. E, Characteristic gypsiferous sandstone of Summerville Formation. F, Overview of upper part of section.

confirm her trace fossil identifications. Furthermore, if identified correctly, *Rhizocorallium*, *Arenicolites* and *Thalassinoides* are more likely indicative of a marine margin (coastal plain or tidal flat environment) than of a lake-margin environment.

The only Morrison Formation fossil known from the Chama Basin is a sauropod dinosaur bone at the Ruth Hall Museum of Paleontology (Ghost Ranch) with imprecise locality data. These data suggest it was collected in the Brushy Basin Member north of Echo Amphitheater.

CORRELATION

Regional correlation of the Jurassic strata in the Chama Basin is made primarily on stratigraphic succession and lithology (Fig. 7). This correlation indicates the following:

1. Only the Slick Rock Member of the Entrada Sandstone is present in the Chama Basin. The Dewey Bridge Member, which represents the landward extent of the Carmel transgression, is absent. This suggests a depositional high in the Chama Basin area during the time of the Carmel transgression.

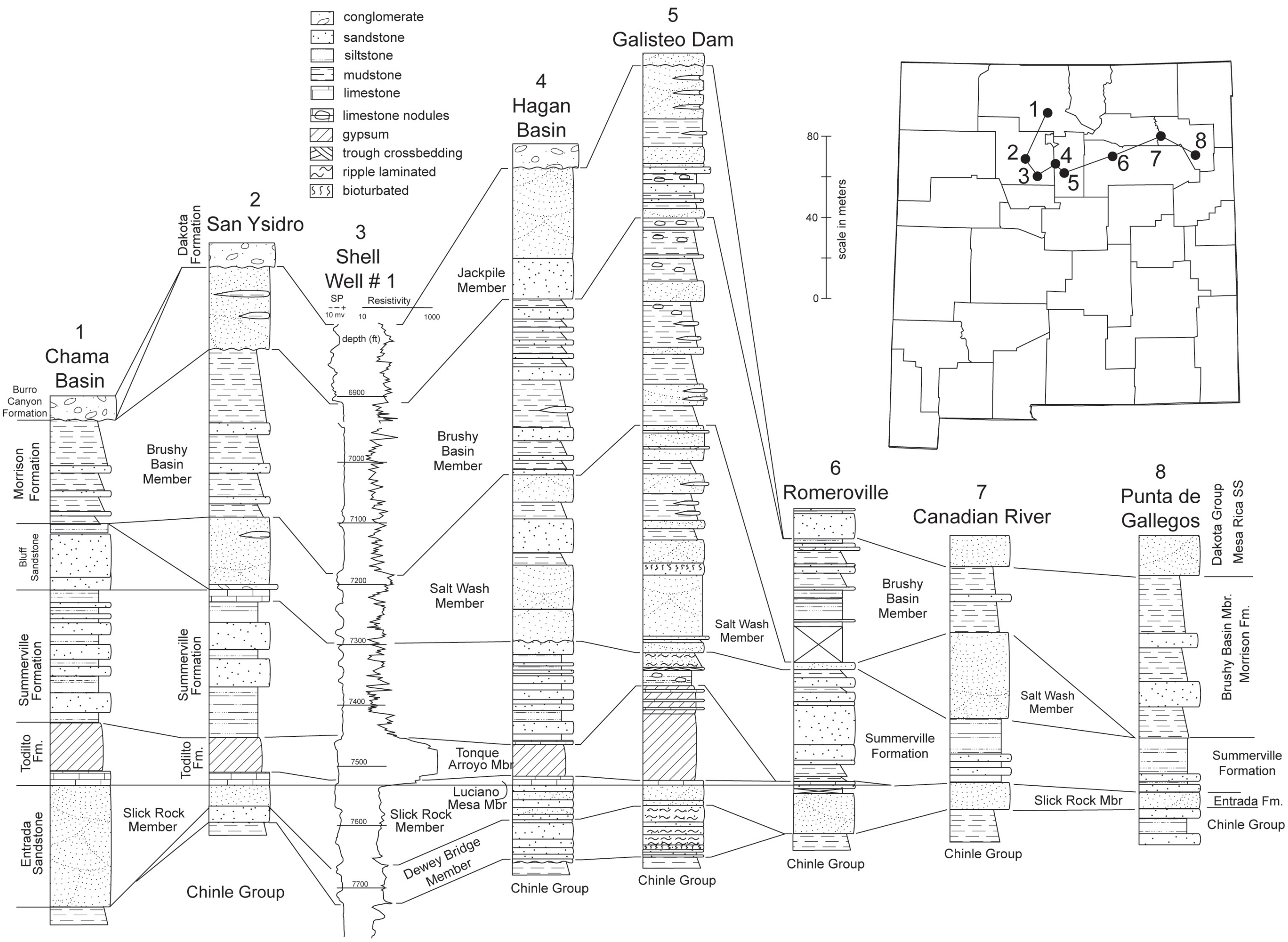

FIGURE 7. Regional correlation of Jurassic strata in the Chama Basin.

2. The Todilto Formation limestone and gypsum members are present in the Chama Basin, placing it well within the original Todilto depositional basin as well as the succeeding evaporitic basin (Lucas et al., 1985; Kirkland et al., 1995).

3. The Summerville Formation is a thick, persistent unit in the Chama Basin. This helps to establish the regional continuity of the Summerville lithosome, which extends from east-central Utah across the Four Corners and southward into the Gallup-Grants area, as well as eastward into western Oklahoma (Lucas and Anderson, 1997; Lucas and Woodward, 2001; Lucas and Heckert, 2003).

4. Identification of the Bluff Sandstone in the Chama Basin also is consistent with regional stratigraphy. Bluff outcrops are present to the northwest, south and southwest of the Chama Basin (Anderson and Lucas, 1996; Lucas and Anderson, 1997; Lucas and Heckert, 2003). Bluff stratigraphy at these outcrops is the same as in the Chama Basin—lower Junction Creek Member and upper Recapture Member, except where the Recapture Member is missing beneath the J-5 unconformity.

5. The absence of the basal Salt Wash Member of the Morrison Formation in the Chama Basin is striking, and we see this as clear evidence of the J-5 unconformity between Morrison and Bluff strata.

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APPENDIX – DESCRIPTION OF MEASURED STRATIGRAPHIC SECTIONS

Mesa Alta

Section measured in two segments. The upper part of the section (most of the Entrada Sandstone through the Burro Canyon Formation) was measured between UTM 351513E, 4009142N (zone 13) and 351370E, 4009567N in the NW 1/4 sec. 20 and NE ¼ sec. 19, T23N, R3E. The lower part of the section (Chinle through lower Entrada) was measured between UTM349122E, 4008724N and 349123E, 4008782N in the NW1/4 sec. 24, T23N, R2E. Strata dip 5˚ to N20˚W.

unit	lithology	thickness (m)
Cretaceous:		
Burro Canyon Formation:		
35	Sandstone and conglomerate; sandstone is light greenish gray (5GY8/1), quartzose, medium grained and not calcareous; conglomerate is light olive gray (5Y6/1) siliceous pebbles (mostly quartzite) in sandstone matrix; trough crossbedded.	**not measured**
unconformity		
Jurassic:		
Morrison Formation:		
34	Mudstone; greenish gray (5GY6/1); mostly covered by colluvium.	**30.1**
33	Sandstone; grayish yellow green (5GY7/2); arkosic; clayey; fine to medium grained; not calcareous; massive; ledge.	**1.4**
32	Mudstone; greenish gray (5GY6/1); with lenses of grayish yellow green (5GY7/2) very fine-grained, arkosic, muddy, calcareous sandstone.	**6.0**
31	Sandstone; very pale green (10G8/2); arkosic; very fine grained; calcareous; trough crossbedded; mud-chip rip-ups at base.	**1.3**

30 Sandy mudstone; pale yellowish green (10GY7/2); not calcareous. **2.0**

unconformity (J-5)

Bluff Sandstone:

Recapture Member:

29 Muddy siltstone; grayish red (10R4/2); not calcareous; some lenses of grayish yellow green (5GY7/2), gypsiferous, very fine grained sandstone. **6.5**

Junction Creek Member:

28 Sandstone; same as unit 15. **8.5**

27 Sandstone and siltstone; sandstone is pale yellowish green (10GY7/2), very fine grained, subarkosic; siltstone is grayish red (10R4/2); sandstone and siltstone in thin, banded interbeds. **22.7**

26 Sandstone; same as unit 23 sandstone; prominent white band, trough crossbeds. **9.5**

Summerville Formation:

25 Siltstone; grayish red (10R4/2). **5.8**

24 Sandstone; grayish red (10R4/2) and pale yellowish green (10GY7/2); gypsiferous; very fine grained; haloturbated; ledge. **4.0**

23 Sandstone and sandy mudstone; same as unit 14. **5.0**

22 Sandstone; same as unit 15. **7.5**

21 Sandstone; moderate red (5R5/4); gypsiferous; fine grained; haloturbated; calcareous; trough crossbedded. **3.3**

20 Sandstone; same as unit 15. **4.3**

19 Sandstone; same as unit 18; laminated; ledge. **0.6**

18 Sandstone; light greenish gray (5GY8/1); very fine to fine grained; subarkosic; very calcareous; some siltstone lenses; trough crossbeds. **10.5**

17 Sandstone and siltstone; sandstone is very pale green (10G8/2), fine grained, gypsiferous and not calcareous; siltstone is grayish red (5R4/2), muddy and not calcareous; thinly interbedded. **20.7**

16 Sandstone; grayish yellow green (5GY7/2); gypsiferous; very fine grained; slightly calcareous; prominent white band. **0.8**

15 Sandstone and siltstone; same as unit 14; partly covered by colluvium. **33.3**

lower member:

14 Sandstone and siltstone; sanstone is pale yellowish green (10GY7/2), gypsiferous and very fine grained; siltstone is mottled pale red (5R6/2) and pale yellowish brown (19YR6/2); forms a ribbed slope/cliff. **7.7**

13 Sandstone; grayish orange pink (5YR7/2); gypsiferous; very calcareous; very fine grained; ripple laminated. **1.1**

12 Sandy siltstone; pale grayish red (5R6/2); not calcareous; blocky. **3.8**

11 Sandstone; grayish yellow green (5GY7/2); very fine grained; trough crossbedded. **2.5**

Todilto Formation:

Tonque Arroyo Member:

10 Gypsum; white (N9); massive; top is hummocky with 3-5 m of relief. **34.0**

Luciano Mesa Member:

9 Limestone; yellowish gray (5Y7/2); thinly laminated; kerogenic; some sandy beds; sharp base with a few cm of relief. **1.9**

8 Sandstone; grayish yellow (5Y8/4); very fine grained; subarkosic; calcareous; thinly laminated. **0.2**

Entrada Sandstone:

Slick Rock Member:

7 Sandstone; yellowish gray (5Y7/2); subarkosic; medium grained; not calcareous; massive to tabular bedded. **1.8**

6 Sandstone; yellowish gray (5Y7/2); subarkosic; very fine grained; not calcareous; trough crossbeds in 1-2 meter thick sets. **26.3**

5 Sandstone; dusky yellow (5Y6/4); subarkosic; fine grained; hematitic; not calcareous; trough crossbeds. **14.1**

4 Sandstone; moderate reddish orange (10R6/6); subarkosic; very fine grained; slightly calcareous; trough crossbeds and eolian ripples. **18.0**

3 Sandstone; light greenish gray (5GY8/1); subarkosic; medium grained; calcareous; trough crossbeds. **2.0**

unconformity (J-2)

Chinle Group:

Rock Point Formation:

2 Sandy siltstone; moderate reddish orange (10R6/6) and pale greenish yellow (10Y8/2); litharenite; very fine grained; blocky. **1.3**

1 Silty mudstone; mottled pale reddish brown (10R5/4) and pale green (10G8/2); with calcrete ledge. **15.5**

Ghost Ranch

Section base at UTM 366956E, 4022218N (zone 13) below Chimney Rock; top at UTM 367275E, 4023832N in sec. 2, T24N, R4E. Strata are essentially flat lying.

unit lithology thickness (m)

Cretaceous:

Burro Canyon Formation:

60 Sandstone and conglomeratic sandstone; yellowish gray

(5Y7/2) matrix with pale greenish yellow (10Y8/2) chalcedony pebbles; matrix is fine- to coarse-grained quartzose sandstone; matrix supported; trough cross-bedded. **not measured**

unconformity (K-0)

Jurassic:
Morrison Formation:
Brushy Basin Member

59 Mudstone; yellowish gray (5Y7/2). **6.1**

58 Sandstone; moderate yellowish brown (10YR5/4) and yellowish gray (5Y7/2); very fine grained; arkosic; not calcareous; well indurated; finely-laminated to massive; ledge-former; Liesegang bands. **1.6**

57 Mudstone with some silcrete lenses; pale olive (10Y6/2), silcrete is yellowish gray (5Y7/2); calcareous; much covered by colluvium. **21.1**

56 Mudstone; same as unit 52. **1.2**

55 Sandstone; pale greenish yellow (10Y8/2); very fine- and fine-grained; arkosic; not calcareous; trough cross-bedded; units 53-55 form a bench. **1.8**

54 Mudstone; same as unit 52. **1.9**

53 Sandstone; pale olive (10Y6/2); fine- to medium-grained; arkosic; not calcareous; trough crossbedded; base 1-2 m of stratigraphic (scour) relief). **10.5**

52 Mudstone; pale reddish brown (10R5/4); silty; not calcareous; chert (chalcedony) nodules. **10**

51 Mudstone; pale olive (10Y6/2); calcareous; some sandy lenses. **6.9**

50 Sandstone with sandy mudstone lenses; sandstone is grayish yellow green (5GY7/2); fine- to medium-grained; arkosic; not calcareous; trough crossbedded; mudstone is moderate yellowish green (10GY6/4); sandy and calcareous. **4.9**

49 Sandstone; same as unit 50 but without mudstone lenses. **1.6**

unconformity (J-5)

Bluff Sandstone:
Recapture Member:

48 Gypsiferous sandstone; light greenish gray (5GY8/1); massive. **0.9**

47 Silty mudstone; grayish yellow green (5GY7/2); with gypsiferous limestone nodules that are light greenish gray (5GY8/1); some red chert nodules. **3.8**

46 Sandstone; grayish green (10GY5/2); very fine grained; quartzose; not calcareous; ledge. **0.1**

45 Muddy siltstone; pale brown (5YR5/2); mottled yellowish gray (5Y7/2); some gypsum nodules. **5.2**

44 Sandy siltstone; grayish red (10R4/2); some yellowish gray (5Y7/2) gypsiferous bands. **2.3**

43 Gypsiferous sandstone; pale yellowish brown (10YR6/2); not calcareous; massive. **1.9**

42 Muddy siltstone; grayish red (10R4/2); calcareous. **0.9**

Junction Creek Member:

41 Sandstone; light olive gray (5Y6/1); very fine grained; hematitic; not calcareous; low angle crossbeds in 1-2-m-thick sets; friable. **27.1**

40 Mudstone; grayish red (10R4/2); calcareous; notch. **0.5**

39 Sandstone; same as unit 41, with some grayish red mudstone lenses. **4.2**

Summerville Formation:
upper member:

38 Mudstone; grayish red (10R4/2); with ledges of pale red (10R6/2), very fine grained, gypsiferous, calcareous sandstone. **10.5**

37 Sandstone; pale red (10R6/2); very fine grained; gypsiferous; calcareous; ledge. **1.0**

36 Silty mudstone; with thin sandstone ledges as in unit 34. **12.9**

35 Sandstone; yellowish gray (5Y7/2); gypsiferous; very calcareous; some trough crossbeds; prominent ledges. **0.7**

34 Muddy siltstone; pale red (10R6/2) with pale olive (10Y6/2) mottles; not calcareous; with 0.1 m. thick ledges and lenses of gypsiferous, pale red (10R6/2), very fine grained, calcareous, sandstone. **6.9**

33 Sandstone; yellowish gray (5Y7/2); gypsiferous; fine to medium grained; massive; friable. **1.0**

32 Muddy siltstone; grayish red (10R4/2) and yellowish gray (5Y7/2); with sandstone lenses as in unit 30. **18.2**

31 Muddy sandstone; pale olive (10Y6/2); very fine grained; calcareous. **1.5**

30 Sandy siltstone; yellowish gray (5Y7/2) and grayish red (10R4/2); with lenses of yellowish gray (5Y7/2), gypsiferous, very fine grained sandstone. **8.9**

lower member:

29 Sandstone; yellowish gray (5Y7/2); very gypsiferous; ripple laminated; some grayish red (10R4/2) banding. **2.0**

28 Sandstone; moderate yellow (5Y7/6) to grayish yellow (5Y8/4); ripple laminations and small crossbeds. **2.3**

27 Sandy siltstone; yellowish gray (5Y7/2); calcareous. **0.5**

26 Sandstone; light brown (5YR6/4) and yellowish gray (5Y7/2); gypsiferous; very fine grained; hematitic; calcareous; ripple laminated. **1.3**

25 Sandy siltstone; same as unit 21. **1.2**

24 Sandstone; same as unit 22. **0.6**

23 Sandy siltstone; same as unit 21. **0.7**

22 Sandstone; dusky yellow (5Y6/4); gypsiferous; very fined grained; calcareous; ripple laminated. **1.2**

21 Sandy siltstone; light brown (5YR6/4); gypsiferous; calcareous; some lenses of ripple laminated sandstone like unit 22. **1.0**

20 Sandstone; yellowish gray (5Y6/2); gypsiferous; not calcareous; ripple laminated. **1.5**

Todilto Formation:

Tonque Arroyo Member:

19A Gypsum; white (N9); massive, locally present between base of Summerville Formation and top of Luciano Mesa Member. **≤ 1.0**

Luciano Mesa Member:

19 Limestone; medium gray (N5); kerogenic; brecciated. **0.5**

18 Limestone; greenish gray (5GY6/1); very thinly laminated; kerogenic. **4.3**

17 Limey sandstone; yellowish gray (5Y7/2); very thinly laminated. **0.6**

16 Sandy limestone; yellowish gray (5Y7/2); more thickly laminated than units 17 and 18. **0.3**

disconformity

Entrada Sandstone:

Slick Rock Member:

15 Sandstone; moderate yellow (5Y7/6); fine grained; hematitic; not calcareous. **10.3**

14 Sandstone; moderate yellow (5Y7/6); fine to medium grained; hematitic; not calcareous; large scale trough crossbeds. **8.3**

13 Sandstone; same as unit 14 but with smaller scale crossbeds; joint fracture with gypsum. **4.3**

12 Sandstone; pale greenish yellow (10Y8/2); very fine grained; quartzose; slightly calcareous; ripple laminated. **5.2**

11 Sandstone; dark yellowish orange (10YR6/6); very fine grained; quartzose; slightly calcareous; large scale crossbeds. **5.9**

10 Silty sandstone; light brown (5YR6/4); very fine grained; hematitic; calcareous; ripple laminated. **1.7**

9 Silty sandstone; same as unit 10. **3.0**

8 Sandstone; grayish orange (10YR7/4); very fine grained; quartzose; not calcareous; crossbedded. **0.7**

7 Sandstone; same as unit 3. **2.1**

6 Sandstone; same as unit 2. **2.0**

5 Sandstone; same as unit 3. **2.5**

4 Sandstone; same as unit 2. **5.7**

3 Sandstone; light brown (5YR6/4); very fine grained; hematitic; silty; calcareous; flat bedded and ripple laminated. **5.6**

2 Sandstone; light brown (5YR6/4); fine to medium grained; not calcareous; hematitic; large scale trough crossbeds. **16.5**

unconformity (J-2)

Chinle Group:

Rock Point Formation:

1 Siltstone; pale reddish brown (10R5/4); not calcareous. **not measured**